New Zealand Battery Project

Cost of Shortage Study

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This report was prepared on your instructions solely for the purpose of supporting the Ministry of Business, Innovation and Employment (MBIE) to conduct research on the issues and considerations relating to the financial and economic cost of electricity shortages should a viable NZ Battery solution be pursued in the future. The report should not be relied upon for any other purpose. In carrying out our work and preparing our report, we have worked solely on the instructions of MBIE and for MBIE’s purposes. This report was developed from information from modelling and studies completed to date by the NZ Battery project team, other reports provided by MBIE and some limited publicly available information. However, this is not intended to be a comprehensive review of all publicly available information.

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In preparing this report we have considered and relied upon information from a range of sources believed to be reliable and accurate. We have not been informed that any information obtained from public sources was false. Responsibility for its accuracy and completeness does not rest with Ernst & Young Limited.

Our work has been limited in scope and time and we stress that a more detailed report may reveal material issues that this report has not.

Contents

1. Executive Summary

Understanding the 'cost of shortage' is a key pillar in the investment case for an NZ Battery solution as it helps provide an indication of the economic and financial costs that are avoided should a viable NZ Battery solution be pursued.[1]

Using an insurance analogy, the 'cost of shortage' represents the size of potential economic loss to the New Zealand economy from shortage events in dry years, the scope and nature of the NZ Battery solution represents the level of coverage, and the cost of an NZ Battery solution represents the up-front equivalent of insurance premiums. While there are other benefits that accrue from NZ Battery, avoiding the cost of shortage resulting from dry years is the key driver for the NZ Battery project.

Simplistically, the cost of shortage is a function of:

- **The expected 'shape' of outage**: A composite of characteristics that include depth of outage, duration of outage, frequency and/or probability with which outages occur, the time of year an outage occurs, amount of forewarning that electricity customers receive, and consumer type.[2]
- **The cost of outage**: Influenced by the breadth of parties that are impacted, the expected responses to outage events, and ultimately the level of utility/wellbeing that would be lost.

An initial indication of the costs of shortage was considered as part of the Indicative Business Case. Electricity market modelling determined the average annual amount of shortage (as well as demand response) that occurred in each IBC option, including the Counterfactual, with an exogenous $10,000/MWh cost applied to the worst case of shortage (described in the assumptions book as 'deep rolling outages').

This analysis was a reasonable, and important contributor to the economic analysis completed in the IBC, but was limited by several factors, primarily related to the 'average annual' nature of the analysis. These limitations very likely had the effect of underestimating the size and cost of shortage. In particular, the analysis:

1. Did not provide an indication of how bad the 'worst case' in a given year looks, nor the probability of outage occurring in any given year.
2. Did not provide an indication of how shortage would be managed in practice, including which sectors of the economy would be impacted and in what ways, and how this might materially change over time.
3. Used price as a proxy for expected impacts – so did not pick up the flow-on implications of shortage on other parts of the economy including investment attraction. In this sense, $10,000/MWh can be seen as an artificial ceiling on impacts.

Furthermore, as the NZ Battery economic analysis was primarily comparative (scenarios with and without an NZ Battery), looked to maximise economic efficiency, and assumed shortage costs are high relative to other system marginal costs, all scenarios tended to have similar amounts of shortage. Taking average values of such scenarios provides little insight in of itself to the shortage cost risks inherent in each scenario.

To gain a better understanding of this and issues 1 and 2 above, supplementary analysis was commissioned that helped identify the shape of outage as well as to provide an overview of those economic sectors affected.

Key findings from this analysis are:

- **Cost of shortage is highly dependent on the shape of shortage, which has high uncertainty** – Trying to understand the shape and duration of shortage events in a dynamic and transformational electricity market is challenging. Each shortage event will be unique, and the interpretation of impacts is dependent on the supply and demand assumptions that go into the electricity market modelling.

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[1] Environmental, social and cultural costs are also important but are generally outside of the scope of this analysis.

[2] Note: consumer type is something that might warrant further attention in a DBC. The current classification suggests industrial, commercial, agricultural, residential as the right distinctions. With greater electrification there might be a requirement for new classifications including the introduction of prosumers, those highly dependent on electricity, those which have diverse fuel dependency, etc.

- **The economic costs of shortage differ markedly depending on the characteristics of the event**. By considering the results from a range of studies, alongside appropriately chosen international examples of shortage and published numbers on economic output and electricity consumption, an estimate for the order of magnitude of the cost of shortage can be derived.

  This is shown in Figure Figure 1 where the red (gradient) bar on the bottom shows extended shortage events on a spectrum of mild to severe. Overlayed on this are a set of slightly overlapping green bars which show different types of response from the industry. As the shortage increases in severity, the response becomes more and more costly. In addition, the uncertainty in the cost also increases. Ultimately, predicting the cost of shortage comes down to several key assumptions: "*who is turned off?*", "*when are they turned off?*", "*for how long they are turned off?*", and "*how much warning are they given?*".

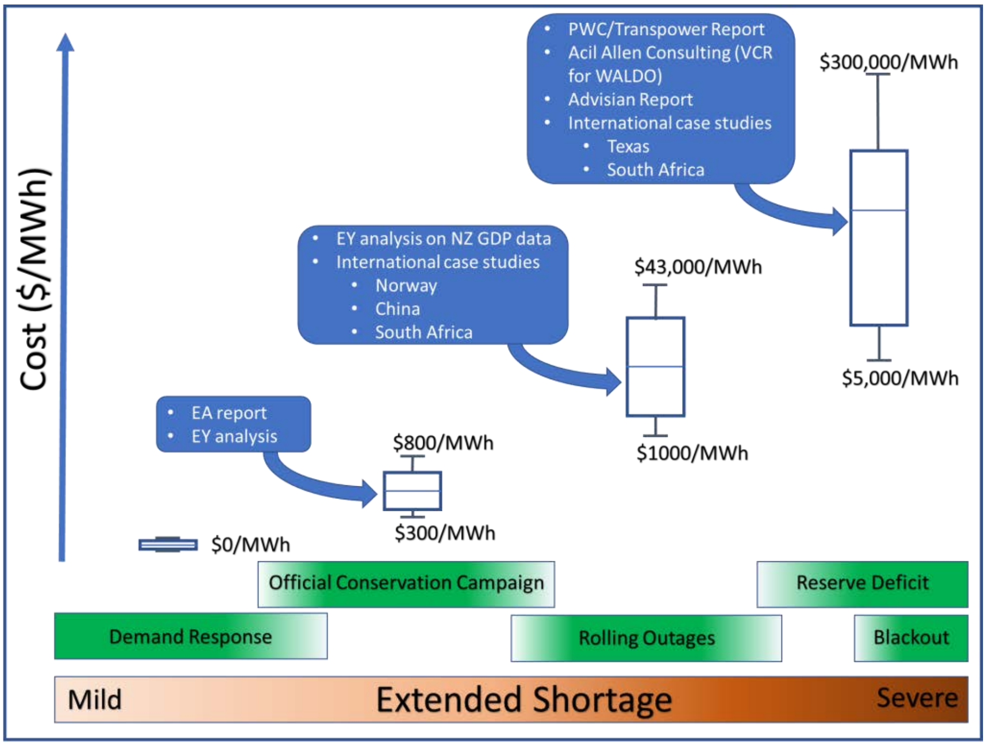


Figure 1 Summary of cost of shortage figures identified from various sources.

Looking forward on the supply side, the future trajectory of the electricity market necessitates additional consideration around unsupplied energy in the dry year. As a result of increased penetration of both (or either) wind and solar generation, the dispatch of hydro generation will evolve from its current role of providing baseload and mid-merit peaking to a role of firming intermittent generation. For this reason, a dry year event in the future may not require a reduction in energy consumption but rather expect an increase in the likelihood of an un-signalled power outage due to a lack of generation.

Additionally, on the demand side, trends in electrification suggest that a much greater proportion of the economy will be reliant on electricity, including high value use cases such as transport and industrial process heat. This has the potential to exacerbate the cost of shortage described above.

This analysis therefore reinforces the original Case for Change in the IBC – shortage from dry years in a 100% renewable electricity system has the potential to generate material economic costs. However, this issue is complex and material knowledge gaps remain. While this work does not fully address these gaps, it aims to provide a basis to inform more detailed investigations to better quantify the cost of shortage. This future analysis is expected to focus on:

- Continued refinements to the 'Base Case' assumptions that go into electricity modelling – as there are a range of assumptions that will continue to be improved and which can materially influence outcomes.
- Better understandings of dynamic and downstream economic implications of shortage to provide a truer picture of shortage events.

Scope of work

MBIE commissioned EY in March 2023 to complete a cost of shortage study that sought to build on known knowledge gaps identified in the NZ Battery IBC. This study was conceived with four phases:

1. **Phase one: An international literature review of comparable electricity outages.** The purpose of this review is to describe real world examples of the scale and potential magnitude of shortage impacts across an economy. This includes reviews of available economic impact studies for international shortage events, news and journal articles which may help understand wider socio-economic impacts of shortage, and interpretation of these results in a NZ context.
2. **Phase two: A description of the 'shape' of shortage in a dry year**. This includes interrogation of SDDP market modelling results to help better describe the quantum of shortage and demand response expected in highly renewable world, interrogation of historical data to build on previous work findings describing dry years, and interrogation of existing industry documents that provide guidance about how shortage events would be managed. This is then used to describe scenarios to help understand the potential impact of shortage in dry years. The full merits of SDDP modelling are provided in Section 3 but the primary rationale is that it enabled time of year impacts, as well as probability of shortage, to be understood.
3. **Phase three: A description of a highly electrified New Zealand economy.** This includes identifying and describing electrification assumptions which underpin the electricity market modelling and supplementing this with information (including quantitative and qualitative information) from additional sources where appropriate.
4. **Phase four: A qualitative desktop assessment of how outage could affect economic sectors.** This work is intended to provide a contextual starting point for the detailed shortage study expected to be conducted as part of the DBC. The output of this phase is to develop a table which describes:
   - A breakdown of impacted sectors
   - The concentration of economic players in those sectors
   - Qualitative descriptions of expected impacts of shortage on each sector

This work is also intended to be a first step in a longer-term piece of work to better understand the costs of shortage which would likely include economic modelling such as Computable General Equilibrium (CGE) modelling to account for downstream economic impacts beyond those easily attributable to the event itself.

Upon completing the analysis, it became clear that there was significant overlap between many of these elements. So, the structure of this report differs slightly from this conception, although all components have fed into the report.

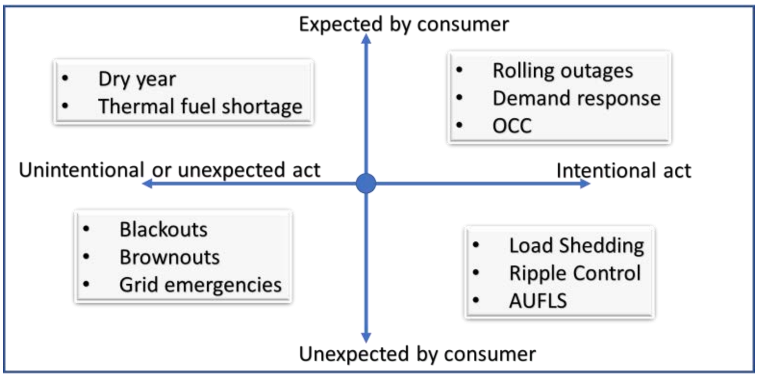
Definitions

There are a range of distinct and overlapping concepts related to the cost of shortage. Some of these concepts are more directly related to the NZ Battery project while others are more peripheral. Some of these terms are used differently by different parts of the energy industry, and others have specific meanings in the context of the NZ Battery electricity market modelling assumptions. Clarity of technical and economic concepts will enhance the reader's understanding and to transmit the content effectively. For the purpose of clarity, the way in which these terms have been defined and used throughout this report is described in Appendix A.

In addition to the clarification of technical terms used in this report, it is important to clarify the scope of the 'concept' being considered.

Shortage can manifest in a number of different ways, with different drivers and impacts. Figure 2 is a summary of some of the key forms of shortage, whose definitions for the purpose of this report are provided in Appendix A. While these events all have depressive effects on electricity supply and demand, **the primary focus of this paper is on extended shortage events that lead to extended periods of unserved energy, as occurs during a dry year**.

Figure 2 Different forms of shortage events



The cost of extended shortage events is distinct from that of acute shortage events because they are preceded by a period of forewarning, where the electricity risk curves gradually show a higher chance of an outage occurring as the dry period extends. The forewarning enables mitigating measures to be set in motion which help reduce (but certainly not eliminate) the overall cost of the event such as the System Operator (SO) calling for an Official Conservation Campaign (OCC).

2. Background

What is the 'cost of shortage'?

Electricity shortage is defined in this report as insufficient available electricity supply to meet all demand, including both inelastic (price insensitive) and elastic (price sensitive) components. When this shortage goes beyond what's economically viable, the market is no longer in a state of allocative efficiency, and this unsupplied demand has a true economic cost.

Defining this cost is complex as the cost of unsupplied energy is highly dependent on a range of factors. These can broadly be grouped into those that describe the 'shape' of outage (depth and duration) and those that describe the 'cost' of outage ($/MWh).

Factors that influence cost of shortage	Classification
Depth – the amount of electricity that is unserved	Shape
Duration – the amount of time that unserved electricity exists in the market	
Season/time-of-year	
Probability of occurrence	Shape and cost
Degree of forewarning	
Consumer type and expected response	Cost

What do we know now?

The existing understanding of the cost of shortage is understandably piecemeal and not comprehensive. While there are several valuable contributions, they often address different shortage situations which prevents the direct comparison of results across the studies.

The literature provides a broad range of costs (typically reflected a $MWh impacts) arising from different shortage events. A summary of findings includes:

- The cost of an outage event ranges from $2,920/MWh (large, industrial, 8 hours long outage) to $290,000/MWh (small, primary industries,10-minute-long outage).
- The average cost of a Widespread and Long Duration Outages (WALDO) event which includes residential, commercial and social costs is $43,780/MWh (over a 7.16-hour period).
- Preventative outage measures such as the OCC have a total cost which is close to $0/MWh by design, but are limited in how much total load is decreased

A consistency throughout the literature is that the cost of shortage is directly related to the shape of the outage.

Despite noted evidential limitations, conventional thinking around NZ's dry year problem, and the assumptions that went into the NZ Battery IBC, tells us that the unsupplied energy would broadly be expected to occur with the following parameters:

- Depth of up to 5TWh (maximum)
- Duration of 1 to 3 months where unsupplied demand is possible
- Most likely occurs during late winter when demand is at its peak
- Considerable degree of forewarning (at least a few weeks)
- Impacts most consumers – albeit to varying extents – given the likelihood of rolling outages.

This paper will test and challenge these parameters using known information sources. By doing so, this should improve our understanding of cost of shortage to confirm whether the case for change remains valid (in the short term) and to highlight those gaps in our knowledge to better inform the NZ Battery Project (in the longer term).

A summary of studies that canvases elements of the cost of shortage spectrum is noted in Table 1.

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Table 1 Existing studies relating to impacts of shortage

Document title	Key info	Limitations

NZ Battery team – Indicative Business Case[3]	• The fundamental problem statement in the IBC is that a dry year will present costs to New Zealand – and therefore avoiding these costs represents a material benefit of the investment.
	• The IBC explored several options to resolve the dry-year problem including the development of a 100% renewable scenario which was the counterfactual for all other options.
	• A core input to the options assessment process was the completion of electricity market modelling – whereby (inter alia) shortage was modelled using increasingly high-price tranches of demand response.
	• Three tranches of shortage correspond to increasingly deep and prolonged shortages were stated.
	  o Conservation campaign **$800/MWh**
	  o Shallow rolling outages **$3,000/MWh**
	  o Deep rolling outages **$10,000/MWh**
	• The third and last shortage tranche effectively represents unsupplied demand at a price of $10,000/MWh. This tranche was only reached after 10% of demand response from lower cost sources had been exhausted.
		This analysis was limited by a number of factors, primarily related to the 'average annual' nature of the analysis.
		These limitations very likely had the effect of underestimating the size and cost of shortage. In particular, the analysis:
		• Did not provide an indication of how bad the 'worst case' in a given year looks, nor the probability of outage occurring in any given year.
		• Did not provide an indication of how shortage would be managed in practice, including which sectors of the economy would be impacted and in what ways, and how this might materially change over time.
		• Used price as a proxy for expected impacts – so did not pick up the flow-on implications of shortage on other parts of the economy including investment attraction.
		Additionally, because of the way the modelling is completed, the $10,000/MWh acts as an artificial ceiling on impacts. For example, there are customers who would be willing to pay more than $10,000/MWh to avoid outage, but that 'surplus' is not captured.

Electricity Authority - 2022 review of the Minimum Weekly Amount payable by retailers during an Official Conservation Campaign[4]	• This study was a review of the Official Conservation Campaign (OCC) which is a type of demand response used to reduce the chance of an outage occurring in the future
	• In the event of an OCC, eligible participants will receive the minimum weekly amount (MWA) now set at $12.00 per ICP.[5]
	  o The MWA is derived from the average estimated rates of electricity consumption and savings and is designed to be cost-neutral to retailers.
	  o This means that the payment to participants should be roughly equal to the cost of utilising the more expensive marginal generator that would have been necessary to meet the additional demand.
	  o By aligning the compensation with the cost of the pricier generation, retailers can encourage participants to actively
		This study is not directly relevant to this Cost of Shortage study in that:
		• It focussed on conservation campaigns, which will have a limit to their efficacy.
		• The 'ceiling' of the analysis was **~$600/MWh** which does not correlate with shortage.
		• The figure is expected to be 'cost neutral' (in general) and so does not represent a true economic cost.
		This study highlights a fundamental issue related to the effectiveness and unpredictability of OCCs as a form of demand response. While previous OCCs have achieved an average demand reduction of 7.8%, there is no guarantee of achieving similar outcomes in the future as demonstrated by the 2008 incident. This may be due to consumers feeling inadequately compensated, or

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[3] NZ Battery Project Team. Indicative Business Case (2023) URL: www.mbie.govt.nz/dmsdocument/26295-new-zealand-battery-project-indicative-business-case-and-appendices-february-2023.

[4] Electricity Authority. Te Mana Hiko (2022) URL: www.ea.govt.nz/documents/3025/2022_review_of_weekly_amount_payable_under_an_official_conservation_campaign.pdf.

[5] We derived retailers could potentially bear the cost $400-900 per MWh in figure X below. The new data inputs in Electricity Authority's decision paper are used to validate this range. Retailers would receive a difference of $621 per MWH in 2022. This is derived from $724.59-$103.70=$620.89. 7.8% savings rate means consumers (2.24 million ICPs) would effectively lower their demand by 43,505 MWh. This is calculated by 0.078*557.76=43.5053 GWH. We can multiply retailer's difference with 43,505 MWh to find the estimated avoided cost of supplying the electricity during an OCC. $621*43,505=$27,016,605.00 Finally, this $27 million matches our prediction that retailers would have to pay out $26.8 million to 2.24 million ICPs under the newly reviewed $12 MWA.

Document title	Key info	Limitations
	contribute to load shifting and demand response measures, helping to prevent a shortage from occurring with minimal costs. • The study states that OCCs called in 2001 and 2003 were able to reduce demand by 7.8% on average. o With winter weekly demand currently being around 900GWh, this suggests around 70 GWh per week of demand reduction can be achieved via an OCC. • The study also states that an OCC was called in 2008 but was largely ignored. This was because, at the time “there was general dissatisfaction amongst electricity consumers with frequent calls for uncompensated electricity savings efforts”.	even just forgetting to reduce demand. This is different from other forms of demand response that are likely to be available in future such as smart appliances, where an EV charger or dryer could self-regulate during an economic shortage to ensure savings and peak demand reduction. In the event of a dry year, an OCC would be expected to get called quite early on as soon as the lake levels fall to a stated threshold. The efficacy of an OCC in this scenario is unknown. The OCC would likely become less effective the longer it goes on as the minor impacts to wellbeing build up. People will be more willing to turn off their heaters in the first week of an OCC, than the fourth week. If an OCC proved insufficient to address the shortage problem, rolling outages would be utilised.
Transpower - Estimating the Value of Lost Load (VoLL) in New Zealand[6]	• The VoLL from this study represents the dollar cost of shortage due to un-signalled blackouts for a range of outage durations. The VoLL is calculated as the ratio between the value of an outage and the unserved energy that wasn’t consumed during the outage. • The value of an outage can be measured from two perspectives: o Willingness to accept (WTA): how much compensation would be required to experience an outage o Willingness to pay (WTP): how much one would be willing to pay to avoid experiencing the outage • This framing can cause drastically different results. Results from this study showed that for a 1-hour winter outage, commercial respondents were willing to accept eight times the amount they were willing to pay. • WTP was chosen to estimate baseline values for this study. WTP framing is more sensitive to the characteristics of an outage and better suited for the purposes of this study. • The results of this study suggest that the VoLL is higher when the duration of the outage is shorter, and the size of the sector is smaller. • The average $ / MWh per outage duration is: o **10-minutes: $142,632; 1-hour: $28,338; 5-hours: $ 8,477; 8-hours: $5,677** • The average $/ MWh per sector is: o **Commercial: $50,711; Industrial: $39,528; Primary: $68,160; Residential: $7,169**	This analysis did a reasonable job of addressing the shape of an outage, i.e. • Length of outage • Season • Day of week • Time of day • Customer type • Consumption level However, it was focused on unplanned/un-signalled outages. Outages due to dry year and extended shortage events are likely to be signalled well in advance. When an outage is signalled well in advance, the $/MWh cost of that outage will be less than if the outage is un-signalled.

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[6] PriceWaterhouseCooper (2018). Estimating the Value of Lost Load in New Zealand. URL: tpow-corp-production.s3.ap-southeast-2.amazonaws.com/public/publications/resources/PWC_Estimating%20the%20Value%20of%20Lost%20Load.pdf?VersionId=7_XSa809EQ8Ehf6oNbC.wVGoUHnqhCBD.

Document title	Key info	Limitations

Australian Energy Regulator - Value of Customer Reliability (VCR) – for Widespread and Long Duration Outages (WALDO) [7]	- This study focused on the impacts of blackout events which covered a wide area and lasted for a long time (minimum 3 hours) in Australia.
	- This involved building upon a model previously built to calculate the Value of Customer Reliability (VCR) for a 'standard' outage scenario made up of three components:
	  - Residential: represents the total amount that individual households are willing to pay to avoid an outage
	  - Commercial: represents the total loss to businesses after factoring in the value lost, amount recovered, and restart costs
	  - Social costs: represents the total additional costs not captured by the other 2 components. This can include emergency and essential services, animal welfare, and communication & transport disruptions.
	- The average cost of WALDO is: **$43,780 / MWh (NZD)**
	  - Average duration: 7.16 hours
		The resulting outage costs from this study appear high compared to outage costs from other studies with similar durations, this may be due to:
		- The lack of literature on WALDO. Two adjustment factors were used in this study to account for the outage characteristics:
		  o A "Wideness" multiplier of 1 – 1.3 was applied to the residential component depending on the radius of the impacted area
		  o A "Social Cost" weighting of 1.3 was applied to both the residential and business component to account for the additional indirect costs incurred.
		- It could also be that WALDO situations are much costlier, and the total cost of such an event would be much more than the sum of what everyone is willing to pay to avoid that outage. For example, social costs aren't considered in most WTP calculations.
		- An extended shortage or a dry year scenario increases the probability of WALDO occurring, so a method to estimate social costs in a NZ context should be considered.

Electricity Industry Participation Code (The Code), 2010[8]	- Unsupplied Demand Situations are a specific example of Shortage regulated the Code. Assigned values include:
	  o **$10,000/MWh for the first 5% of demand**
	  o **$15,000/MWh for the next 15% of demand**
	  o **$20,000/MWh for the remaining 80% of demand.**
	- Further details are included in Appendix A titled Glossary.
		The price-quantity bands were set by the Electricity Authority as part of the real-time pricing changes to the market. They were not intended as an authoritative estimate of the cost of shortage, and we are not aware of any published supporting evidence for these numbers.

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[7] Acil Allen Consulting. (2020). Value of Customer Reliability: For Widespread and Long Duration Outages. URL: www.aer.gov.au/system/files/WALDO%20VCR%20final%20report%28202759.1%29.pdf.

[8] Electricity Industry Participation Code. (2010).

How does New Zealand manage shortage events today?

There are several important policies and publications, listed below, which set out how New Zealand manages shortage events:

- Security of Supply Forecasting and Information Policy
- Emergency Management Policy
- Security of Supply Annual Assessment
- Electricity Risk Curves
- System Operator Rolling Outage Plan
- Participant Rolling Outage Plans.

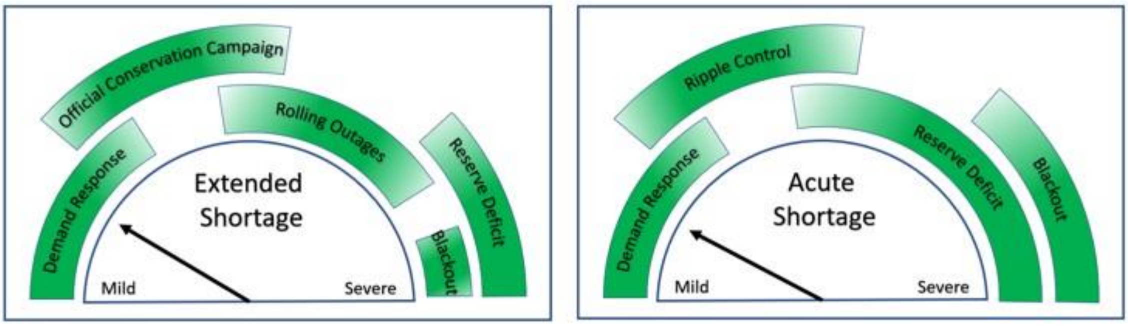
How a shortage event plays out in practice depends on whether the shortage is acute or extended, and the severity of the event. This is illustrated in Figure Figure **3**. As discussed earlier, dry year shortage is an example of extended shortage. In the case of an extended shortage, which is most directly relevant to this report, the escalation in response would typically play out as follows:

1. Demand Response (during this phase electricity risk curves are monitored and published daily and Customer Advice Notifications are issued to encourage generators to defer planned outages)
2. Official Conservation Campaign
3. Rolling Outages
4. Reserve Deficit
5. Blackout.

In the case of an acute shortage, the situation is different in that the industry has little or no time to prepare and respond[9]. This means the opportunity to mitigate costs through Customer Advice Notifications, Conservation Campaigns, and Rolling Outages will not exist and the situation can very rapidly escalate into reserve deficit and even blackouts.

Figure 3 shows how New Zealand currently manages and responds to shortage events. The process depends crucially on whether the shortage is extended (left hand figure) or acute (right hand figure). An extended shortage offers more time to prepare and coordinate a response. However, in the most severe cases, when/if all mitigation measures have been exhausted, the electricity system can still reach its breaking point which means reserve deficit and/or blackouts just as in the case for an acute shortage. The dial represents the severity of the shortage event. During the Demand Response period, the system operator issues Customer Advice Notices to encourage generators to defer any planned outages and provides daily updates to the Electricity Risk Curves.

Figure 3 Shortage responses



Figures 4-7 below give a brief description of how each response escalates/de-escalates as the dial shifts from one type of response to another.

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[9] *Notices for Insufficient Generation*, Transpower. https://tpow-corp-production.s3.ap-southeast-2.amazonaws.com/public/bulk-upload/documents/Overview%20of%20notices%20for%20insufficient%20generation.pdf?VersionId=BLeGfw351ws5T5ophnE5xQf8ZCZHIq6K

Figure 4 Description of demand response

Demand Response

- Demand Response, as defined in this report, is a normal and healthy response of a well-functioning market
- It does not have any cost because it is simply consumers responding to price signals in a way that reflects the value they place on using electricity for a particular purpose or function.
- The shortage experienced when only demand response is in play is Economic Shortage.
- Some may consider this Economic Shortage to be a precursor to true Shortage (which has a cost).

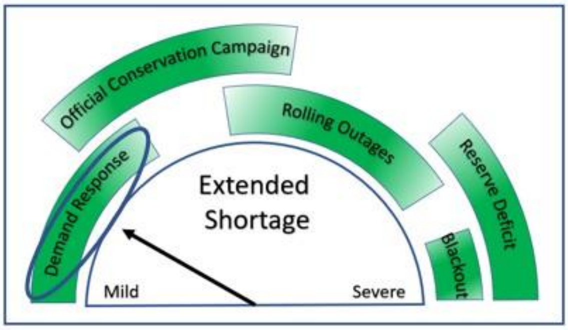


Figure 5 Description of Official Conservation Campaign

Official Conservation Campaign

- When the ERC exceeds 10% and its forecast to continue to do so for at least one week
- SO calls for people to voluntarily reduce their consumption using advertisement on TV, print, and radio
- Retailers pay qualifying customers $12 per week during an OCC.
- During an OCC people may feel compelled to switch off rather than fairly compensated for switching off

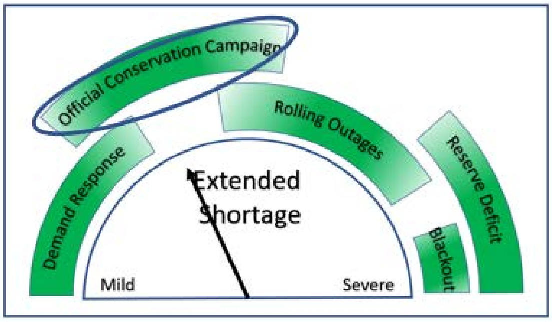
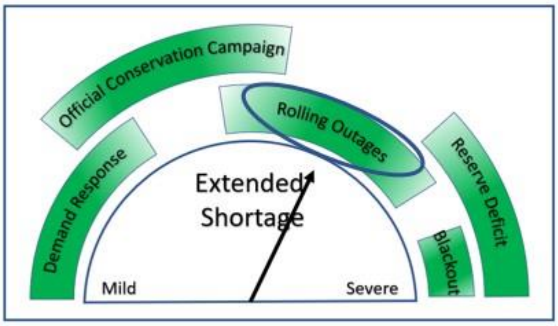


Figure 6 Description of rolling outages



Rolling Outages

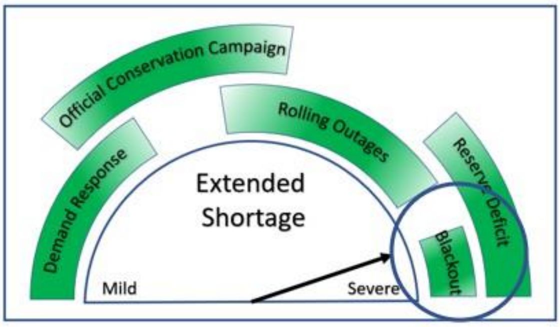
System Operator

- Publishes SO Rolling Outage Plan
- Monitors ERCs
- Issues 14 day notice if ERC likely to hit 50%
- Sets trigger
- Sets savings target
- May also request timing (day vs night)

Distributors and direct connects

- Publishes participant rolling outage plan
- Determines who is disconnected (which feeder)
- Responsible for health and safety issues (alongside retailer)
- Considers the prioritisation of load shedding

Figure 7 Description of blackout



Blackouts

- In the most severe extended shortage events, reserve deficit and even blackouts may occur
- Blackouts differ from Rolling Outages in that there is no forewarning for a blackout
- A range of studies exist on the cost of blackouts (VoLL studies)
  - Estimating the Value of Lost Load in New Zealand, (PWC, March 2018)
  - Advisian report
  - VDR for WALDO report (Acil Allen Consultants)

How rolling outage occurs in practice

Once an OCC has begun the SO will start monitoring for rolling outage triggers[10]. On a best endeavour's basis, there will be 14 days' notice before implementing rolling outages. The SO sets the energy and capacity targets for each rolling outage and sets the timing. The distributor or direct connect is responsible for implementing the outage.

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[10] Triggers are: Sustained unplanned outages are forecast to occur in next 21 days due to low hydro storage and/or hydro storage is likely to fall to 50% electricity risk curve within 21 days.

Although the distributor must have regard for the load-shedding prioritisation (shown in Table Table 2), the current way in which outages are implemented is to switch off network feeders at the substation.[11] This is very much a broad-brush approach, and the impact will be felt across entire neighbourhoods or regions. This approach makes selective load-shedding, as implied by the prioritisation table, near impossible to achieve to the level of precision implied.

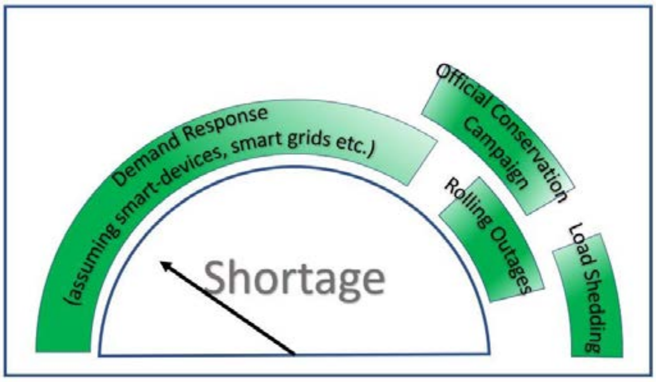
Table 2 Priority of load shedding in rolling outages

Priority	Priority Concern	Maintain supply to:
1	Public health and safety	Critical health and disability services e.g., major hospitals, air traffic control centres, emergency operation centres
2	Maintaining important public services	Lifelines infrastructure e.g., energy control centres, communication networks, water and sewage pumping, fuel delivery systems, major ports, public passenger transport, major supermarkets
3	Public health and safety	Vulnerable sectors e.g., rest homes, prisons, medical centres, schools, street lighting
4	Animal health and food production / storage	Dairy farms, milk production facilities, chicken sheds, cool stores
5	Maintaining production	Central business districts, commercial and industrial premises
6	Avoiding disruption to households	Residential premises

How might New Zealand manage shortage events in the future?

In the future, the high-level principles for managing shortage are likely to remain (e.g., lower cost/impact demand reduction is used first, followed by increasingly higher cost/impact demand until rolling outage and/or load shedding is required). However, the expected increases in smart-grid technologies, potentially supported by market/regulatory changes such as creation of a flexibility market, would potentially increase both the amount and specificity with which demand response can be drawn on.

Figure 8: Hypothetical way in which shortage would be managed in a future with high penetration of internet-connected devices and highly automated controls



This demand response is most likely to predominantly help address capacity (as opposed to energy shortage) constraints by reducing peak load through load shifting. However, this may also provide some support for managing energy shortage through genuine demand reduction (e.g., turning off appliances and not turning them on at a later time, or at least not for as long) and through incentivising greater uptake of distributed generation (e.g., rooftop solar coupled with home battery storage, or vehicle to grid (V2G) enabled EVs).

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[11] Load shedding refers to an intentional and sudden reduction in load as defined in Appendix A.

In the IBC modelling, demand response was broken into three categories:

- **Load shifting** – Includes 'classic' short-term demand response from space or water heating or cooling, and emerging forms of load shifting through the use of batteries, including residential/commercial batteries (possibly as part of a solar system), utility-scale batteries, and smart EV-charging. This also assumes existing levels of load shifting continues and is incorporated into the base demand shapes.
- **Load curtailment** – Where load, such as industry, voluntarily reduces consumption in response to high prices. Load curtailment is modelled in three chances of increasing price ($700/MWh, $1,000/MWh and $1,500/MWh). Total available load curtailment is assumed to double from 0.5GW in 2021 to 1GW in 2065.
- '**Shortage'**[12] – Where load is forced off resulting from insufficient load curtailment available to balance supply with demand. This includes both conservation campaigns (modelled at $800/MWh for first 5% of shortage) and rolling outage (modelled at $3,000/MWh for next 5% of demand though 'shallow' rolling outages, and $10,000/MWh for the remaining 90% of demand through 'deep' rolling outages).

As described in the previous sections, rolling outages are largely delivered by turning off a feeder within the distribution network. However, in future it is likely that a more targeted method of delivering outage could be achieved. The introduction of smart grid technology, that makes use of internet connected sensors embedded within the grid, could allow EDBs to gather and process data on geographical energy supply, and use, in real-time. This real-time bi-directional information flow could allow EDBs and, in turn, the SO to better identify, and separate out, specific users based on their energy use[13]. This could allow for more targeted and efficient rolling outage to avoid industries and users that have particular characteristics that make them more affected by electricity shortage. Further, when combined with smart appliances, smart grids may also have the ability to connect into houses and businesses to identify electricity savings in real time and shut off non-essential appliances and plant. Smart grids are currently in use in a range of different countries, and MBIE anticipates that this technology will be widely adopted within New Zealand by 2050.[14]

However, the ability for demand response to contribute to supporting energy shortage events will likely primarily be useful for managing short-term energy shortage. This involves shifting demand to non-peak periods, but this has no impact to the net energy as the same amount of demand will be consumed but just at a later time. Where shortage is particularly deep or prolonged, once less necessary / impactful interruptible load is shed and battery capacity is exhausted, it would be expected that the hierarchy of deep rolling outage as it is currently conceived (i.e., effectively a similar result of turning of a feeder) and load shedding would apply. This is assumed on the basis that the current hierarchy is already arranged around general principles of societal necessity.

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[12] The NZ Battery IBC modelling assumptions uses a different definition of shortage to this report, as described here.

[13] *Introduction of smart grid,* Korea smart grid association. *Digital Demand-Driven Electricity Networks Initiative,* International Energy Association.

[14] MBIE, *How Smart Grid Developments Can Support Emission Reductions*, NZ Smart Grid Forum, 2016, www.mbie.govt.nz/dmsdocument/4297-how-smart-grid-developments-can-support-emission-reductions.

3. The ‘shape’ of shortage in a 100% renewable world

As noted above, determining the ‘shape’ of shortage in a 100% renewable world is one of two critical inputs to determining the cost of shortage.

As part of the New Zealand Battery Indicative Business Case[15], electricity market modelling was deployed (‘Culy’ optimisation model) and validated against Optgen and SDDP[16]. The SDDP model calculates how market operations (generation dispatch, in particular) occur in the presence of hydrological uncertainty. The essential point of difference for SDDP is that it dispatches hydro generation according to water-values that are calculated according to the stochastic nature of inflows (i.e., at the time a decision to dispatch is made, the decision-maker does not know what inflows will be in the future). This is unlike alternative models which use heuristics and/or assume the decision-maker has perfect foresight of future inflows[17] when deciding whether to dispatch. For this reason, SDDP provides valuable insights into what shortage looks like in a dry year.

Before delving into these insights, we highlight some key limitations, as well as some assumptions that went into the modelling.

As with any kind of long-term (10+ horizon years) modelling, Optgen and SDDP have some significant limitations and shortfalls. These limitations are important context to keep in mind as we consider the outputs. Although this is not an exhaustive list, two such limitations worthy of mention are given below:

1. In the real-world, decisions are made by many independent agents each acting on their own information, having their own capabilities (financial, engineering, legal, etc.), and their own objectives (profit, risk, portfolio management, etc). Within the modelling however, all these agents are replaced by a single agent whose sole objective is to minimize cost in the system. From this perspective, we would expect that the modelling is likely to understate the cost of extended shortage events, relative to what might occur in reality.
2. In the real-world, decisions have social, environmental, and political consequences, as well as economic costs. These additional consequences can be extraordinarily difficult to quantify and convert to a dollar figure[18], which is a necessary requirement if they are to be included within SDDP. From this perspective, we expect the modelling to perform poorly in the estimation of social, environmental, and political costs. These costs are likely to be significant during extended shortage events.

The value of this modelling is that it can provide a view into the future – particularly a future wherein the supply of electricity comes 100% from renewable resources. It is clear that a 100% renewable electricity system would be highly vulnerable to dry year shortage if today’s generation from gas and coal was simply replaced on an annual-GWh-by-annual-GWh basis by wind and solar (alongside common[19] battery energy storage systems for the management of daily peaks). The Optgen-SDDP model has two main options to mitigate this vulnerability:

1. The model can choose to build additional wind and solar (over and above what is required to replace the average-annual-GWh output of today’s gas and coal generation). This is often referred to as renewables overbuild.
2. The model has the option to build green-peaking plant (or green peakers). These provide more of a like-for-like replacement of existing thermal plants, particularly in terms of their operational capability and the role they play within the overall system. In the modelling, green peakers have been assumed to be low capital cost, high operating cost generation plant, running on a zero-carbon fuel. With their high operating costs, driven by assumed high bio-fuel prices ($45 / GJ) green peakers would be expected to operate at low-capacity factors only to cover periods of low intermittent renewables and/or very dry periods

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[15] https://www.mbie.govt.nz/dmsdocument/26295-new-zealand-battery-project-indicative-business-case-and-appendices-february-2023

[16] PSR software. We note that the SDDP modelling was used only as assurance for an alternative modelling approach. The SDDP modelling did not provide the quantitative estimates of benefits used in the IBC.

[17] Heuristic and deterministic approximations to the hydro dispatch problem provide enormous benefits in that they require significantly less computational time and resource for the calculations.

[18] Indeed, this forms part of the motivation for further work on the cost of shortage.

[19] By common, we mean MWh (storage) to MW (power) ratios less than 10.

Finally, it's important to note that modelling for the IBC already has an assumed cost of shortage. These are given by a series of price-quantity pairs[20] which represent the quantity of demand reduction that occurs (either voluntarily or forced) when prices reach a given point. These assumptions will have impacted the results – i.e., if the cost of shortage were assumed to be lower, the outputs would show higher levels of shortage (and the inverse holds true). The price-quantity pairs used within the IBC are given in Table Table 3. These numbers dictate that a certain percentage of demand will go unserved if it cannot be supplied at a certain cost.

Table 3 Cost of shortage used in the SDDP modelling for the IBC.

Quantity (Per cent of total demand)	Price/Cost ($/MWh)
2.99%	700
2.24%	1,000
2.24%	1,500
5%	3,000
87.63%	10,000

With a clear understanding of the limitations and assumptions that went into the modelling, it is instructive to understand what this modelling is telling us. The SDDP model makes use of 89 historical years of hydro inflow data, including all of NZ's major hydro schemes plus many of the smaller schemes. This historical inflow data quantifies the seasonal patterns, including fluctuations about the mean. It is used in conjunction with the generation fleet (including the assumed renewable overbuild and green-peakers), and the fuel/carbon/shortage costs, to determine an optimal hydro dispatch policy. This policy is then used to perform 89 distinct simulations[21] (one for each year of hydro inflow data) of the electricity system.

The insights from this analysis are visualised in Figures 9 and 10 below. In Figure Figure 9, the contours (shown as boundaries between different colours, with the colour-scale shown to the right) within these figures show, across all 89 simulations, for each week of the year, what was the highest level of shortage, the second highest level, the third, etc. These contours represent the probability of exceeding that level of shortage in a given week. Note that each contour does not represent a single simulation. The contours are a statistic derived from all 89 simulations.

In Figure Figure 10 we show the shortage that is actually occurring in the 5 most extreme simulations.

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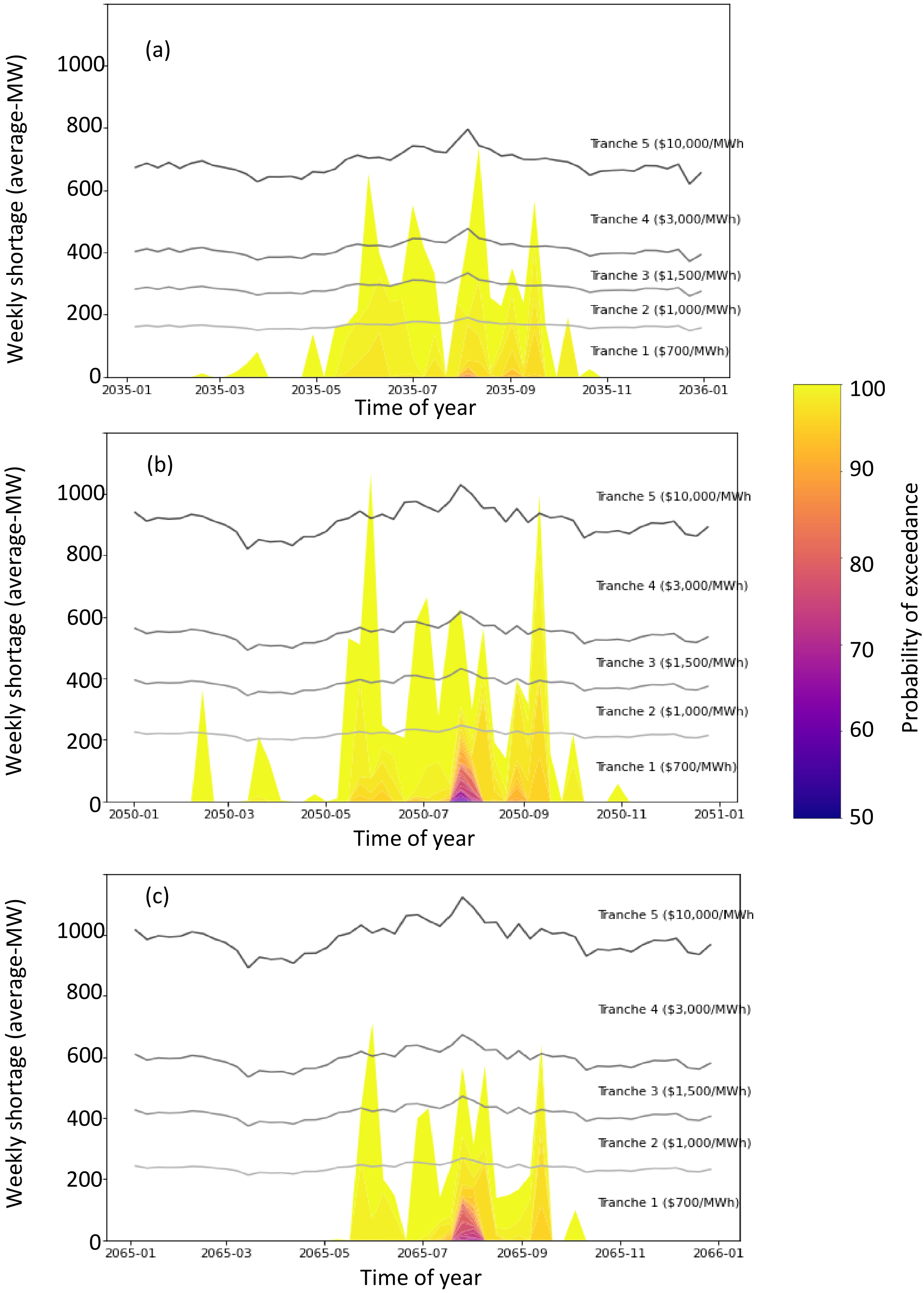
[20] Note that prices in SDDP are set by the change in the objective function (total cost) per infinitesimal change in demand. Generation is dispatched according to short-run-marginal cost. So, there is no distinction between cost and price of shortage within SDDP.

[21] It is possible to perform any number of simulations. 89 is the most reasonable choice as it covers the range of historical data for each horizon year.

Figure 9 Probability (per week) of exceeding a particular level of shortage in (a) 2035, (b) 2050, and (c) 2065[22].



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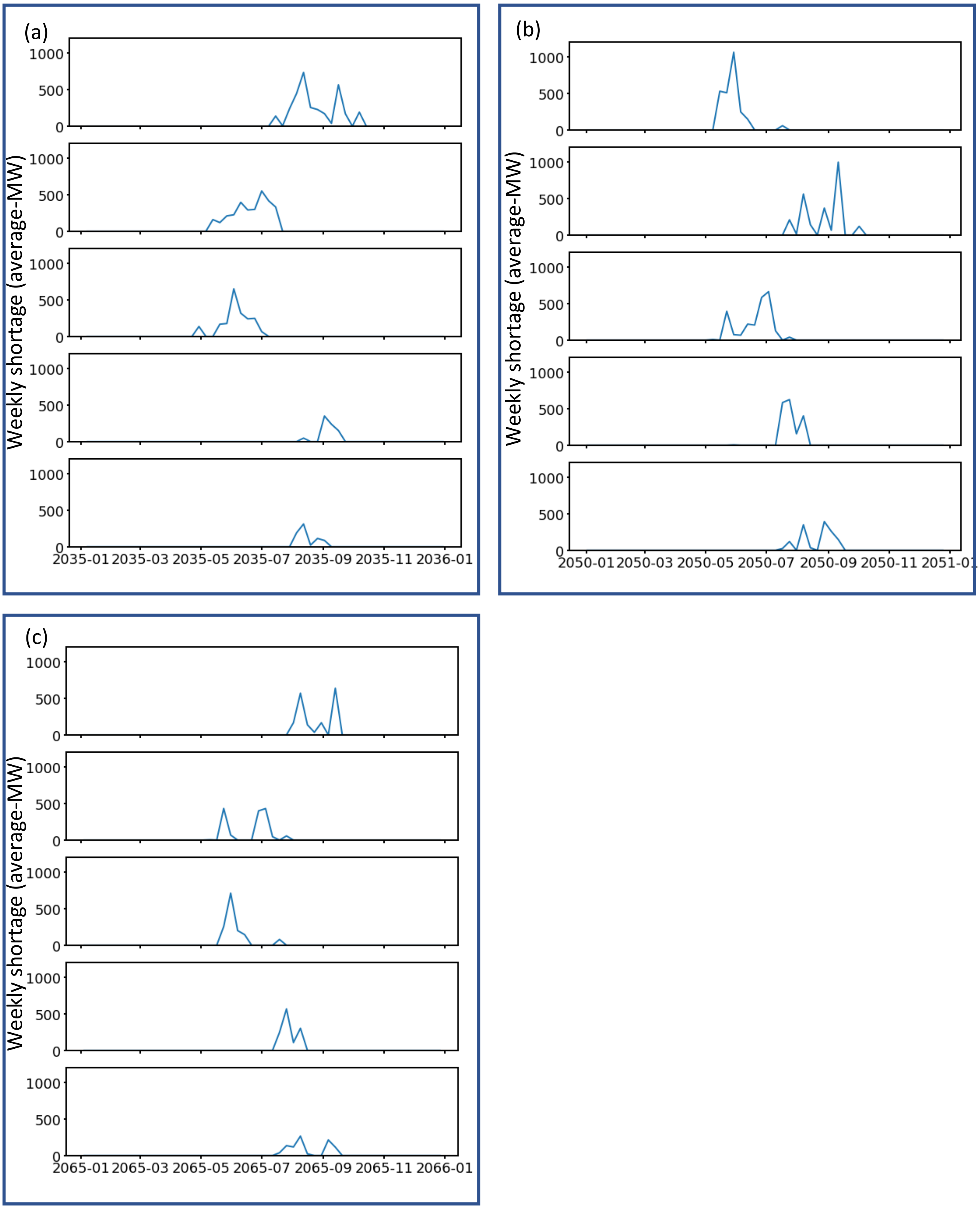
[22] Note: On the vertical axis, shortage for that week shown in average-MW (1 average-MW for the week is equal to 24*7 MWh).

Figure 10 - Five most severe cases of shortage among the 89 simulated scenarios. The three boxes group them into years: (a) is 2035, (b) is 2050, and (c) is 2065.



Both Figures 9 and 10 indicate that, even with renewable overbuild, green-peaking plant, and an assumed cost of shortage, periods of shortage (both extended and acute) are likely to persist in the future and potentially become even more probable than they are today[23]. We also note that shortage is

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[23] We note that the present-day system was not modelled and therefore we cannot say with confidence how probable shortage is today.

concentrated in the winter months between June and October. This corresponds to when demand is high, hydro inflows tend to be low (due to precipitation landing as snow rather than rain), and consequently lake levels tend to be low. At this stage however, we have not quantified the extent to which these shortage events are due to calm and cloudy conditions as opposed to low lake levels. We hypothesise that it is a combination of these two conditions that causes the shortage we observe.

Further insights from these charts are as follows:

- The threat of shortage worsens between 2035 and 2050 but improves between 2050 and 2065
- Shortages can be of a significant size (above a 400 MW-average or 67GWh per week) in all time periods considered. The probability of large-scale shortage approximately occurs at around the 90th+ percentile of years. That's a 1-in-10 probability.
- In the worst-case scenario there was a shortage of 1000 MW (168 GWh per week) occurring once in the 90 scenarios
- Small levels of shortage appear to occur more frequently with as many as 1 in every 2 years in 2050 and 2065 resulting in around two 50-100 MW weeks.

Key conclusions and further investigation

With the assumptions used in the IBC, the SDDP model has identified significant shortage is still likely to occur. This is interesting as the model has used both renewable overbuild and green-peaking plant to mitigate the risk of shortage. The fact that these two approaches fail to prevent shortage tells us that it is not straight-forward to entirely remove the risk of shortage in the future.

The modelling also tells us that the risk is highest during winter months when demand is at its highest and hydro inflows are at their lowest. In some scenarios the shortage is seen to persist for 8 weeks at a time.

Energy market modelling is capable of providing significant insights into the problem. It provides a quantitative assessment of the following crucial concepts:

- The probability of shortage
- The severity of shortage
- The timing of shortage.

However, it is imperfect in many respects and ultimately driven by input assumptions which are largely impossible to foresee. Particularly, it is unclear to what extent the assumptions relating to renewable overbuild, green peaking plant, and cost of shortage have masked the true scale of the problem.

Continued refinements to the 'Base Case' assumptions that go into electricity modelling is seen as a critical next step.

4. The ‘cost of shortage’ in a 100% renewable world

Understanding the ‘cost of shortage’ is the essence of this study – what are those economic costs related to electricity shortage that can be avoided through the presence of an NZ Battery.

While there is no definitive measure of the cost of shortage, or indeed a full suite of information that enables this to be calculated, there are several bespoke studies, as well as official data sets that enable an order of magnitude understanding to be derived.

As a proxy, the economic impacts due to a lack of electricity supply in this section are described quantitively, qualitatively and benchmarked against international evidence of economic impacts. This exercise is a preliminary step in building comprehensive groundwork to assess economic impacts and can be used:

- As a starting point for any Computable General Equilibrium (CGE) work commissioned to understand dynamic and downstream implications of shortage. Current economic impacts are limited to industries that are directly affected and does not capture flow-on effects or take into account constraints in the economy. CGE would provide more detail and identifies the flow-on effects on households and businesses, capturing the additional effects not felt in the initial economic shock.
- To refine input assumptions into electricity modelling into the cost of shortage ($MWh).

The modelled depth and duration from SDDP, as described in Section 3 above, has been used as the basis for the quantitative assessment. The time of year that this shortage is likely to be felt in (winter) has also been used to colour some of the qualitative findings.

Economic composition – Current state

To frame the qualitative and quantitative analysis, current statistical definitions provided by Statistics New Zealand have been used. Specifically, the New Zealand economy is split into five headline sectors (and their key sub-sectors) as per the table below. Key considerations in determining a current state economic composition include:

- **Sector Groups**. Sector classifications derived from Statistics NZ, specifically using ANZSIC level 2 classifications.[24] See Appendix B for a description of the constituent parts of each group.
- **Electricity Consumption**. Consumption of electricity by sector has been sourced from the Energy End Use Database (EEUD).[25]
- **GDP (Total Production)**. While several GDP figures exist – total production, intermediate consumption, and value add – total production is used for this exercise as it is the most widely understood. Total production essentially captures the entire value chain of raw products and value add to produce outputs. In practice, this will not be applicable for all sectors as the impacts may be more muted but is useful as an indicator of size of shortage.
- **Electricity contribution**. Electricity contribution is calculated by dividing the figure under contribution to GDP by sector (NZD $m) over electricity consumed (MWh). This is useful for understanding an indicative amount of economic output that is foregone per MWh lost. This calculation is indicative only and is no substitute for a survey-based approach to understanding the cost of shortage, or the completion of CGE type modelling.

The current state composition figures below (which have been rounded to 0DP) are used as the basis for calculating a high-level cost of shortage figure in the next section.

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[24] The data points adopted in this paper have been calibrated based on ANZSIC level 2 classifications to follow the methodology of sector aggregation described in Appendix B.

[25] This paper adopts EECA’s proxy of electricity consumed per sector. The energy use estimates in (EEUD) are derived using ‘top down’ approach based on MBIE’s annual high-level sector/fuel energy demand data and proportioned into further disaggregated sectors using ‘bottom up’ data held by EECA. The MBIE data used is supplied directly to EECA and not publicly available. EECA. (2023). Energy End Use Database. URL: www.eeca.govt.nz/assets/EECA-Resources/Research-papers-guides/EEUD-Key-insights-and-methodology-March-2023.pdf.

Table 4: Economic output per sector (annual)

Sector groups	Sectors	Total production, current prices, 2020 (NZD $m)[26]	Total electricity consumed (GWh)[27]	Electricity contribution (NZD$/MWh)
Residential	Aggregated	N/A [1]	12,877	NA
Industrial	General industrial services	$130,528.00 21.04%	3,672	35,545
	Food product manufacturing[1]	$29,192.00 4.70%	1,648	17,713
	Dairy product manufacturing[1]	$23,892.00 3.85%	1,225	19,503
	Primary metal and metal product manufacturing	$3,569.00 0.85%	6,240	572
	Pulp, paper, and converted paper product manufacturing	$3,354.00 0.54%	687	4,884
	Electricity generation, distribution, gas and water supply and waste services[28]	$23,092.00 3.72%	564	40,946
Commercial	Aggregated commercial services	$303,550.00 48.92%	8,419	36,057
Agriculture, fishery, and forestry	Non-diary agriculture (incl. horticulture and fruit growing and livestock farming)	$23,117.00 3.73%	651	35,489
	Forestry and logging	$5,427.00 0.86%	66	82,691
	Dairy cattle farming	$13,844.00 2.23%	1,970	7,026
Transport	Aggregated transport services	$29,696.00 4.79%	857	34,647

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[26] Stats NZ. (2020). National accounts (industry production and investment): Year ended March 2020. Table 3.

[27] Energy Efficiency & Conservation Authority. (2023. Energy End Use Database. URL: www.eeca.govt.nz/insights/data-tools/energy-end-use-database/.

[28] This sector group produces electricity but also consumes electricity to operate its equipment (i.e., pumps for water supply and wastewater).

Cost of shortage – Quantified current state

Given the lack of a prescriptive methodology to calculate a cost of shortage, this study has applied the following methodology (which should be considered indicative):

- Identify the expected depth and duration of outage as described in Section 3.
- Identify those customers that would be subject to rolling outage as per the Transpower load hierarchy as described in Section 2
- Present the expected economic costs associated with those customers experiencing lost output in line with the equivalent information in Table Table 5.

As noted in Section 2, while the load shedding hierarchy provides a conceptual way of prioritising loads, the current tools are not sophisticated enough to be precise in how this is applied. Moreover, the type of shortage contemplated in a dry year is likely to take a political tone and this introduces the potential for alternative ways of managing this risk, and this would likely reflect an efficiency / equity trade-off. For example, spreading outages across a large number of parties might be more 'equitable' but we know that there are certain users that have a higher 'cost of shortage' than others, and therefore, this decision would be economically inefficient. The inverse also holds true.

Detailed testing of these different management approaches has not taken place – although an indication of the spread of impacts has been noted between sectors and within sectors as described below.

Analysis

As noted above in section 2, the most severe shortage outcome generated by the SDDP modelling was a 1000 MW (168 GWh) shortage. This suggests that a shortage of this magnitude has an occurrence probability of 1 in 90 (1.11%) each year without an NZ Battery solution. This does not represent the full suite of outage events that are possible and is subject to the limitations in the modelling process. However, it does enable some high-level calculations to be derived.

Residential sector

If the management approach was to focus exclusively on the residential sector (noting this sector alone is prioritised as level 6 of Transpower's load shedding hierarchy), then this level of unserved energy would equate to:

- 500k houses experience a single interruption of duration 1 week
- All NZ houses experience a single interruption of 43.5 hrs.
- All NZ houses experience two interruptions of 21.75 hrs.

Commercial and industrial sectors

If commercial and industrial users were the focus of an outage, then Table Table 2 displays all subsectors likely to be categorised as priority level 5 on Transpower's load shedding hierarchy.

The cost of imposing the 168 GWh load on level 5 subsectors of the economy could equate to a cost of shortage of $352m – $7,180m **($2,095 – 42,738 NZD/MWh**), depending on the approach taken to prioritising load shedding. This equates to between **0.1% and 1.9% of annual GDP** (assuming a NZ average GDP figure of $382.5b).[29]

- The most economically efficient approach would be to target those customers with the lower cost of shortage figure (expressed by the electricity contribution column). These customers would bear a collective economic cost of $352m (0.1% of GDP).
- If the most economically inefficient approach to target customers with the highest cost of shortage. These customers would bear a collective economic cost of $7,180m (1.9% of GDP).
- If the 168GWh shortage was to be spread evenly throughout the level 5 sectors, ~54% of each sector will experience the shortage giving rise to a total economic cost of $3,977m (1% of GDP).

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[29] Stats NZ reports full year GDP figures for FY 22 as between $385b and $380b depending on whether it is income or expenditure method and seasonally adjusted or not. $382.5b is taken as an average of these methods. View table - Infoshare - Statistics New Zealand (stats.govt.nz)

It is notable that a dry year conservation campaign in New Zealand in 1992 was estimated to have reduced total GDP for the June quarter of that year by approximately 0.6%. If this impact was applied to in the context of 2022, this would equate to NZD $575 million of lost GDP.[30]

While directionally helpful, the above analysis is indicative in nature and is subject to a number of limitations. For example, it does not take into account the seasonality of some sectors, nor does it consider the specific implications of electricity shortage where some sectors might lose output entirely (if product spoils) whereas other sectors might simply displace economic activity into the future. The following sector on qualitative impacts provides some additional colour to these conclusions.

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[30] How we learned the lessons from 1992 - NZ Herald and The power surge - Business News - NZ Herald

Cost of shortage – Qualitative current state

The section above has provided a very high-level indication of the potential economic costs associated with shortage. However, the specific nature of impacts on each sector will always be unique, and corresponds with the characteristics of the sector, its use and reliance of electricity, as well as the extent to which it can continue to operate effectively in prolonged periods of outage.

A detailed survey of impacts on sectors would be required to validate the following, but high-level indications of qualitative impacts have been assessed based on desktop research. Given that the duration of an outage is a critical influencer of the size of the impact on an industry, high-level impacts over short- and longer-term horizons have been described.

Table 5: Qualitative Impacts

Sector groups	Sectors	Expected Impacts
Residential	N/A	• **Frequency of shortage:** The occurrence of shortage is expected to be frequent given that residential customers are at Level 6 of the load shedding hierarchy. • **Impacts of short-term shortage:** When load shifting and non-essential demand response measures are used to compensate for times of shortage, the impacts of such shortages should result in a minor decrease in well-being due to the reduced utilisation of non-essential household appliances. • **Medium-longer term-shortage:** In cases where the shortage persists for an extended period and load shifting proves insufficient to resolve the scarcity issue, the economic impacts on the residential sector are expected to escalate. This impact encompasses various aspects, such as food spoilage due to the interruption of refrigeration, and a significant decrease to welfare as households endure prolonged periods without heating, cooling, cooking and access to hot water. As electricity consumption and reliance is expected to increase for the residential sector in the future, these prolonged outages will only become costlier, as extended periods of shortage will prevent people from performing vital tasks such as charging their EVs and working from home which will have costly follow-on effects.
Industrial	General industrial services	• **Frequency of shortage:** the occurrence of shortages is expected to be less frequent than the residential sector due to general industrial services sitting at level 4 and level 5 in the load shedding hierarchy. • **Short-term shortage:** in the case of short-term shortages, brief interruptions can result in minor costs due to temporary disruptions in production and productivity, leading to wages being paid without corresponding utilisation. As the electrification of processes is projected to increase in the future, these costs are expected to rise, as the reliance on electricity for various industrial operations becomes more prevalent. • **Medium – longer term shortage:** in the event of a prolonged shortage or reoccurring shortages lasting multiple consecutive days within a week, the risk of permanent production losses rather than temporary deferrals increases. Therefore, the overall output of the economy and productivity are expected to decline. This effect is compounded due to the ripple effect caused by the lost productivity in one industry negatively impacting other sectors, leading to broader economic consequences.
	Food product manufacturing[31]	• **Frequency of shortage:** the food product manufacturing sector is anticipated to experience a relatively low frequency of interruptions due to its place within the load shedding hierarchy at level 4. This sector along with dairy product manufacturing is placed higher than some other industries as the potential cost of an interruption is expected to be high. • **Short-term shortage:** sign-posted and short-term outages (below 2 hours) are expected to have minimal costs arising from deferred production and the loss of wages paid. However certain food production processes may be unable to be turned off abruptly, leading to potential losses when processing plants are shut down mid process. • **Medium – long term shortage:** an extended outage can lead to substantial losses, primarily due to the disposal of spoilt food caused by the lack of

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[31] Specifically, the sector of meat & meat product manufacturing approximately exports $9,430 mil and contributes to 11.10% of New Zealand's total exports in 2020. These values are taken from Infometrics's database which utilises a similar but not exact taxonomy of sectors. https://ecoprofile.infometrics.co.nz/auckland/gdp/exports

Sector groups	Sectors	Expected Impacts
		refrigeration. These losses are ultimately passed down to the consumers and a potential indirect impact could include erosion of competitive advantage for NZ produced food as costs increase.
	Dairy product manufacturing	• **Frequency of shortage:** the dairy product manufacturing sector is anticipated to experience a low frequency of interruptions due to its place within the load shedding hierarchy at level 4. • **Short-term shortage:** expect to cause a temporary loss of production and loss of productivity from wages being paid without corresponding utility. There is also expected to be some degree of food spoilage due to the lack of refrigeration. • **Medium – long term shortage:** significant losses are expected due to the dumping of milk and other dairy products caused by the lack of refrigeration or interruptions in the processing chain. However certain high temperature process heat, such as boilers and milk powder drying units, may not be fully electrified. Being able to run on alternative fuels such as biomass and potentially hydrogen can help limit production losses and provide a means to utilize products that might otherwise be wasted.
	Primary metal and metal product manufacturing	• **Frequency of shortage:** Low – medium interruption is expected given this sectors position within the hierarchy of load shedding. However, contracts between Tiwai point (the largest single user of electricity in the country) and Meridian energy included demand response as a means to reduce peak demand. • **Short-term shortage:** unexpected outages of electricity to this sector (of almost any duration) will pose significant costs to this sector if a plant shut down occurs mid-processing. • **Medium – long term shortage:** Where the shortage is particularly deep, the costs are expected to be significant if large producers have to shut down entire potlines to reduce load (this causes hardening of material in the pots and requires remediation to get them back online). Further, steel and aluminium are commodities which can be readily substituted from other producers – lost production may lead to permanent loss of market share to competitors
	Pulp, paper, and converted paper product manufacturing	• **Frequency of shortage:** After the residential sector, the pulp and paper sector are expected to be the next likely sector (along with aggregated commercial services, forestry and logging, and general industrial services) to be interrupted in a dry year given this sector's position in the hierarchy and the expected limited impact of a shortage. Due to the price responsive nature of this sector, they are however unlikely to be producing during times of shortage and high electricity prices. • **Short-term shortage:** Expected temporary loss of production and loss of productivity from wages paid without corresponding utility. However, currently a significant portion of process heat in this sector comes from natural gas with an outlook to substitute the gas with biomass and geothermal steam. The economic loss associated with outages may be limited where the use of natural gas persists or alternative fuels such as biomass or geothermal steam are used to provide high-process heat. • **Medium – long term shortage:** Where outage is prolonged, there would be a permanent loss of production, higher costs to produce goods, and the substitution of New Zealand pulp and paper products leading to reduced market share and lower national exports and GDP.
Commercial	Aggregated commercial services	• **Frequency of shortage:** After the residential sector, this sector is expected to be the next likely sector (along with pulp and paper, forestry and logging, and general industrial services) to be interrupted in a dry year given this sector's position in the hierarchy. The expected impact of shortage may escalate for commercial services that are reliant on electricity for their core business services such as an electronic payment system. • **Costs of shortage:** Significant costs are anticipated as this sector sees significant electrification of processes leading to greater reliance on electricity, which will in turn induce significant costs associated with lost production and wages paid. This is expected to manifest both over the short-term and long-term (with long-run shortage creating dynamic impacts such as reduction in market share from substitution, higher input costs for other industries etc.). While short term disruption may lead to displacement of economic activity, longer term shortage will inevitably lead to lost output.

Sector groups	Sectors	Expected Impacts
Agriculture, fishery, and forestry	Non-dairy agriculture (incl. horticulture and fruit growing and livestock farming)	• **Frequency of shortage:** non-dairy agricultural services are expected to sit either under 5th or 4th priority in the hierarchy of load shedding. Animal health related services are expected to be higher priority and less interrupted relative to other services. Horticulture farming anticipates low interruption due to its relatively high position within the hierarchy of load shedding and the expected high cost of interruption. • **Short-term shortage:** It is anticipated that the cost of short-term interruption to this sector is relatively low as it does not have high amounts of product loss associated with spoiling due to a loss of refrigeration as there might be with other sectors. Therefore, loss will be centred around wages paid but production lost. Horticulture will face an expected temporary loss of production and loss of productivity from wages paid without corresponding utility. • **Medium – long term shortage:** However, given the value of agricultural exports, where services are interrupted for significant periods, it is expected that the economic loss increases significantly as reduced agricultural services will likely lead to a reduction in the productive capacity of the agricultural sector in general. This is expected to also have dynamic impacts such as reduced market share, substitution effects, higher costs of production, etc. Prolonged outages in horticulture would incur additional losses associated with the dumping of food due to the lack of refrigeration and processing capabilities. Leading to a reduction in GDP from reduced sales of products, although that may be able to be mitigated through a delayed harvest or by transporting goods to markets faster.
	Forestry and logging	• **Frequency of shortage:** After the residential sector, this sector is expected to be the next likely sector (along with pulp and paper, aggregated commercial services, and general industrial services) to be interrupted in a dry year given this sector is positioned 5th on the hierarchy and the expected limited impact of shortage. • **Impacts:** Forestry and logging is expected to be minimally disrupted in even a prolonged shortage event given it relies predominately on heavy industry (large commercial machinery and transport – e.g., trains, ships and road freight) which is expected to either have alternative fuel sources (e.g., hydrogen or biofuels) that can provide a substitute for electricity.[32]
	Dairy Cattle Farming	• **Frequency of shortage:** Low interruption is anticipated as this sector is ranked 4th on the hierarchy of load shedding given the expected high cost of interruption and seasonally low levels of milk production during the winter period.[33] • **Short term shortage:** It is anticipated that the cost of short-term interruption to this sector is modest given product loss associated with spoiling through loss of refrigeration will be moderate depending on the length of the outage. • **Medium – long term shortage:** Where extended shortage causes delayed or extended periods without milking (although milking is expected to be shiftable in most instances to take place outside of peak periods), it is expected that there might be significant animal welfare issues, and over time, a loss of milk production within herds. A reduction in the level of milk production (on a per cow basis) is expected to also increase overall costs associated with New Zealand dairy production and erode New Zealand's competitive advantage which potentially can lead to a reduction in market share and a commensurate reduction in GDP.
Transport	Aggregated transport services	• **Frequency of shortage:** Low interruption is anticipated as this sector is ranked 4th on the hierarchy of load shedding • **Short term shortage:** The increasing uptake of EVs within the light and heavy vehicle fleet are expected to allow the transport sector to avoid significant costs for short interruptions while the vehicles have charge. • **Long term shortage**: Where shortage is prolonged (beyond one charge cycle) and as electric vehicles cannot be used, the economic loss in the transport industry will have additional spill-over effects such as reduction of public transport services and costly disruptions to commercial operations.

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[32] https://www.mpi.govt.nz/dmsdocument/55684-Final-Forestry-and-Wood-Processing-Industry-Transformation-Plan-Report

[33] https://dcanz.com/wp-content/uploads/2022/12/2022_09-New-Zealand-Milk-Production-Sep2022.pdf

Cost of shortage – International comparison

The types of economic shocks described in the section above predominately consider direct loss (e.g., loss of production and sales and loss of productivity from wages). However, there are wider flow on implications from this outage which are not canvassed above (but could be understood through CGE modelling).

In lieu of this modelling, international examples of shortage highlight the dynamism of national economies and the importance of the flow on effects of shortage across all sectors. When these impacts are considered the true economic costs of shortage are much more pronounced.[34] Table Table 6 provides an overview of high-level impacts and costs associated with four different international shortage events in Texas, China, Norway and South Africa.

Whilst the circumstances surrounding these international examples are often not directly applicable to a New Zealand dry year scenario, they still provide an indication of possible costs if New Zealand were to face a shortage with similar depth and durations.

Table 6: International examples of shortage

<table>
<tr><th>Country</th><th>Event and relevance to NZ</th><th>Event and economic Impacts</th></tr>
<tr><td>Texas</td><td>

The 2021 winter storm caused an electricity outage event that left 4.5 million customers without electricity and the deficit of power was ~49% of total grid capacity. The total duration of load shed during the mid-February freeze was 70.5 hours, with an average load shed close to 14,000MW.
Texas’s economic composition is unlike NZ and the lack of ability to forecast severity of this event with sufficient forewarning likely increased the impact when compared with what might be expected from dry-year shortage.
The estimated economic impacts of the electricity outage have been calculated separately from the other major consequences such as the fuel of supply and (e.g., natural gas) and physical damages to properties and infrastructure.

</td><td>
Total value of economic impact due to the storm:
<table>
<tr><th>USD</th><th>Pro-rata NZD</th></tr>
<tr><td>$130 b (USD) at the state level [35]</td><td>~ $29.5 b (NZD)[36]</td></tr>
</table>
Total value of cost of outage:
<table>
<tr><th>USD</th><th>Pro-rata NZD</th></tr>
<tr><td>$4.3 b (USD) based on power lost along with VOLL estimates[37]</td><td>$0.59 b (NZD)[38]</td></tr>
<tr><td>$9000 USD/MWh which was the system cap set by ERCOT</td><td>$5,487 NZD/MWh</td></tr>
</table>
</td></tr>
<tr><td>China</td><td>

The Sichuan province saw 70 days of drought with a 50% drop in Sichuan’s hydro reservoirs. Around 84 million[39] people in Sichuan suffered suspended or limited power supply with some households going without electricity for more than 10 hours a day[40]. In addition, the heat associated with the drought led to a >25% increase in peak load demand compared to the prior year.
The Sichuan province’s advantageous hydropower production accounted for 77.39% of the province’s capacity in 2021 and 30% of China’s total hydroelectric generation in 2022. NZ shares a similar generation mix. However, Sichuan province also has interconnections with other regions which NZ does not.

</td><td>
Total value of direct economic loss due to the power outage:
<table>
<tr><th>RMB</th><th>Pro-rata NZD</th></tr>
<tr><td>¥ 2.73 b (Yuan) [41]</td><td>~$197 mil (NZD)[42]</td></tr>
</table>
</td></tr>
</table>

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[34] A study conducted by the Congressional Research Service show estimated that the inflation-adjusted cost of weather-related electricity outages in the United States cost $25 to $70 billion annually. The costs of outages take various forms but broadly cover lost output and wages, spoiled inventory, delayed production, inconvenience, and damage to the electric grid. Economic benefits of increasing electric grid resilience to weather outages, U.S. Department of Energy, 2013.

[35] https://www.dallasfed.org/research/economics/2021/0415

[36] This is a prorated figure based on relative GDP (Texas:NZ) ratio of 7.26 given Texas' GDP was $1815b USD and NZ's GDP was $250b USD in 2021. This was calculated by dividing the economic cost of $130 b USD over 7.262 and the NZ prorated economic cost was $18 b USD (~$29.5 b NZD).

[37] https://www.dallasfed.org/research/economics/2021/0415

[38] This is a prorated figured based on relative GDP (Texas:NZ) ratio of 7.26.

[39] https://edition.cnn.com/2022/08/19/china/china-drought-alert-climate-intl/index.html

[40] https://www.nytimes.com/2022/08/26/business/economy/china-drought-economy-climate.html

[41] https://think.ing.com/articles/impact-of-chinas-drought-is-small-compared-to-its-real-estate-crisis
https://www.theguardian.com/world/2022/aug/22/china-drought-causes-yangtze-river-to-dry-up-sparking-shortage-of-hydropower

[42] This is a prorated figure based on relative GDP (Sichuan province:NZ) ratio of 3.18 given Sichuan's GDP was $795 b USD and NZ's GDP was $250b USD in 2021. This was calculated by dividing the economic cost of ¥2.73 b (Yuan) over 70.94 and the NZ prorated economic cost was ¥0.86 b Yuan (~$197 mil NZD). This indicative figure intuitively appears lower than what would be expected given the scale of impacts. Also note that no definitive GWh figure lost provided – therefore $/MWh figure is not able to be presented.

<table>
<tr><th>Country</th><th>Event and relevance to NZ</th><th>Event and economic Impacts</th></tr>
<tr><td></td><td>• However, the way outage is managed, the size of the economy, and China's significant advanced manufacturing economy must be noted in considering the estimated economic loss due to the power outage.</td><td></td></tr>
<tr><td>Norway</td><td>• A 6-month long drought in 2022 reduced the water level of Lake Marídal from its usual level of 88% to 69%, edging close to the predetermined electricity crisis threshold of 61%.[43]
• Electricity exports were halted, and the Norwegian government approved applications from operators to boost production from several gas fields to increase supply and some local municipalities implemented conservation campaigns. Widespread power rationing was avoided, nonetheless the industry experienced record-breaking increases to the price of electricity.[44]
• 90% of Norway's total power is produced through hydropower plants. The electricity outage due to the drought has relevance given NZ has a high percentage of electricity produced by hydropower plants.
• NZ does not share Norway's unique trading power in electricity and geographic advantages. Norway is notable for its ability to draw on other Scandinavian countries' electricity systems when required, which allows them to minimise the impact of electricity shortage as it diversifies the electricity supply source. In times of hydro scarcity, the Norwegian government also limits electricity exports and rations domestic power use (businesses are first to be rationed).</td><td>The impact on spot prices
<table>
<tr><th>Euro/MWh</th><th>Pro-rata NZ $MWh</th></tr>
<tr><td>€532.52[45]
This highest recorded daily spot price is 7.31 times the average monthly electricity wholesale price in Norway of €64 Euro/MWh in the prior comparable period.</td><td>~$1,098[46] NZD/MWh
$602.3 NZD/MWh is the NZ equivalent of 7.31 times of the average generation-weighted average price of $82.4 NZD/MWh (Jun 22 - Jun 23).</td></tr>
</table></td></tr>
<tr><td>South Africa</td><td>• A range of operational deficiencies meant that operations and maintenance work were significantly hampered. Moreover, new power stations built by Eskom (South African utility company and the largest producer of electricity in Africa) faced cost overruns, design flaws, and delays, resulting in less generation than expected.[47]
• To prevent a total grid collapse, Eskom cut power from residents first and many experienced six hours of outage. Recently, Eskom entered stage six of rolling outage and cut 6,000 megawatt hours to prevent a nationwide blackout.
• The cause of power outages in South Africa is unlikely to happen in New Zealand. As of 2023, the Reserve Bank of South Africa expects the prolonged and mandatory rolling outages to deduct 2% of GDP.[48] An equivalent impact to NZ would equate to NZD $7.65 billion. While the causes of South Africa's issues are deep-seated, severe and may be unlikely to occur in New Zealand, rolling outages are a response we would potentially need to draw on in a dry year for which we did not have adequate back-up.</td><td>Total value of economic impacts due to the outage:
<table>
<tr><th>Rand[49]</th><th>NZD</th></tr>
<tr><td>2021: R500 b (Rand)</td><td>2021[50]: ~ $23.2 b (NZD)</td></tr>
<tr><td>2022: R2 trillion (Rand)</td><td>2022: ~ $92.9 b (NZD)</td></tr>
<tr><td>2023 (Jan-May): R2.25 trillion (Rand)</td><td>2023 (Jan-May) ~ $105 b (NZD)</td></tr>
</table>
Total value of cost of outage:
<table>
<tr><th>Rand</th><th>NZD</th></tr>
<tr><td>R250,000[51] Rand/MWh</td><td>~$21,750[52] NZD/MWh</td></tr>
</table></td></tr>
</table>

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[43] https://www.courthousenews.com/drought-has-oslo-on-edge-of-critical-water-shortage/

[44] https://balkangreenenergynews.com/norway-to-impose-power-export-controls/
https://www.courthousenews.com/drought-has-oslo-on-edge-of-critical-water-shortage/
https://oilprice.com/Latest-Energy-News/World-News/Norways-Hydropower-Reserves-Hit-Hard-By-Drought.html

[45] https://energynews.pro/en/norwegian-hydroelectricity-in-trouble/

[46] The amount in pounds was converted to NZD based on the exchange of 1 GBP = 2.06 NZD

[47] https://www.news24.com/fin24/economy/eskom-south-africas-fallen-energy-giant-20230302; https://www.bbc.com/news/world-africa-62053991

[48] South African Reserve Bank. (2023). Statement of the monetary policy committee. URL: www.resbank.co.za/content/dam/sarb/publications/statements/monetary-policy-statements/2023/may/Statement%20of%20the%20Monetary%20Policy%20Committee%20May%202023%20.pdf

[49] https://www.bbc.com/news/world-africa-62053991

[50] The figures in Rand are prorated to on the relative GDP ratio (South Africa:NZ) of 1.872 given South Africa's GDP is $419 b USD and NZ's GDP is $249.9 b USD. For example, the 2021 economic cost of R500 b ZAR was divided by 1.872 which derives R267 b ZAR. These figures in rands are then converted to NZD based on the currency rate of 1 ZAR = 0.087 NZD.

[51] https://www.bbc.com/news/world-africa-62053991

[52] Assuming 1 ZAR = 0.087NZD

Cost of shortage – Limitations and other considerations:

This paper acknowledges that the above analysis is suitably high level and there are a number of limitations with the calculation methodology as documented throughout this section. Two large areas not covered above include:

- **Economic composition:** Even minor changes in the composition of New Zealand's economy can have a significant impact on the expected economic impacts of shortage – for example, a move away from manufacturing, agricultural, and industrial industries to a more service-based economy (that is heavily reliant on communications and electricity) will increase overall reliance / exposure of the New Zealand economy to electricity and shortage.
- **Intangible loss of value:** Where electricity shortage and industrial or productive load shedding is a regular feature of New Zealand's future economy, there are a range of other dynamic impacts that may reasonably occur that go beyond immediate productive loss. A sample of these is provided below.

It is expected that CGE modelling would be able to pick up many of these intangible effects described above and should be the focus of any future investigations.

1. Loss of investor confidence leading to a reduction in Foreign Direct Investment (FDI)

Where New Zealand's electricity system becomes known for reliability issues / known to rely heavily on demand response and outage (in a way that materially impacts productivity and production), it is anticipated that it will reduce the attractiveness of New Zealand as an investment destination. This potentially has a two-fold impact:

- Reduction in access to capital: a reduction in FDI can come in the form of shallower capital markets. This makes it harder for domestic companies to raise capital for expansion or capital upgrades reducing the competitiveness and productivity of New Zealand domiciled companies.
- Reduction in information sharing: as well as shallower markets a lack of FDI could lead to fewer foreign companies opening subsidiaries in New Zealand. As well as reducing dynamic competition in the market, and a direct loss of potential industry, it also reduces the opportunity for domestic companies to share information and learn from other companies. Over the long run this could lead to lower overall productivity rates.

2. Loss of confidence in the electricity system by domestic producers

Where New Zealand's electricity system becomes known for reliability issues / known to rely heavily on demand response and outage (in a way that materially impacts productivity and production), it is anticipated that it will reduce domestic producer's reliance on the electricity system. This is expected to manifest in slower electrification rates (and slower decarbonisation) as producers rely on alternative fuel sources to run production. This is expected to materially impact New Zealand's ability to meet international climate obligations and could cause preserve incentives to invest in expensive and inefficient alternatives such as self-sustained electricity generators. This could lead to more purchases of international offsets under current agreements and damage to New Zealand's environmental reputation.

3. Reduction in exports during outage leading to a loss of market share

An outage or demand response has a double impact on economic production of immediate reduction or shift in time of production and long-term loss of market share.

- Immediate reduction or shifting in time of production leads to either absolute loss of GDP (and in some instances export value) or the loss of the opportunity cost of income received earlier.
- Where production is lost on a regular basis or for a prolonged period, an industry may lose market share to more suppliers who are not constrained by their domestic electricity system.

Cost of shortage – Future electrified economy

The previous sections provide an overview of the potential costs of shortage based on known, current state information. Growth in base demand, taking into account assumed improvements in energy efficiency, is expected to increase over time, from 37.3TWh in 2021 to 49.3TWh in 2065[53]. However, in the future the role of electricity in the economy is likely to evolve which will likely change both the amount and way in which electricity is consumed, as well as the way shortage and its associated impacts are managed (as described in the previous sections).

Three electricity system super trends have been identified that are anticipated to significantly increase total electricity demand as well as the way in which shortage might impact the economy (and translate into economic loss). These are:

1. **Electrification:** New Zealand's energy system contributes 44% of the country's total greenhouse gas (GHG) emissions and nearly 90% of total carbon dioxide emissions. Electrifying parts of the energy system, specifically transport and process heat, is considered one of the most effective ways to reduce these emissions[54].
    a. **Process heat:** Approximately 60% of process heat is supplied by fossil fuels. It is anticipated that both biomass and electricity will play a role in decarbonising this sector with numerous projects and pilots being undertaken nationally[55]. In total, process heat electrification is anticipated to contribute an additional 8TWh of demand by 2050[56].
    b. The uptake of Electric Vehicles (EVs): EV growth is currently 1,700 vehicles per month and Government targets have been set to reach 30% penetration among light passenger vehicles by 2035 (however recent data indicates that EV uptake is accelerating faster than previous expectations as incentive schemes have brought forward cost equivalence with internal combustion engines) – expected to add 8.2TWh to total electricity demand by 2050. In addition, commercial and heavy transport options are also expected to electrify, however, electrification in these parts of the transport fleet is expected to grow at a slower rate (anticipated to make up 4.2TWh of total demand by 2050).

2. **The uptake of Distributed Energy Resources (DER) and smart technology:**
    a. **DERs:** DERs describe smaller residential and community scale controllable energy resources. DERs can include both generation and storage assets located either within the distribution network or within consumer's homes. Some studies have suggested that small scale battery storage could provide as much as 1,150MW by 2035 with potential to grow to 3,200MW by 2050.[57]
    b. **Smart technology:** Similar to smart grid technology (described in section 2 above), smart meters and internet connected appliances are anticipated to be able to collect, process, communicate, and reduce electricity use in real time. This is expected to allow individual households and businesses to separate and target electricity reduction in non-essential appliances, lighting, heating, and processing plant in times of peak load.

The impact of these super trends is highly uncertain, and assumptions need to be made based on information available. The potential impacts of each super trend on each of the five headline sectors (and key sub-sectors) as modelled for NZ Battery, as well as other examples which highlight the uncertainty of how this could vary, are outlined below in Table 1Table **7**.

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[53] NZ Battery modelling assumptions for growth in base demand for generation, assuming NZAS retires by 2035

[54] Decarbonising process heat is a large opportunity for New Zealand as it contributes 10% of gross emissions and 27% of energy-related emissions. As technology evolves and improves, and carbon prices rise, the economics will increasingly favour electrification for many process heat users in New Zealand. *Taking the climate heat out of process heat*, Transpower, 2019.

[55] Fonterra is currently completing a 30MW biomass project to replace coal boilers in Te Awamutu. In addition, Fonterra are also trialing high temperature heat pumps for steam generation - https://www.fonterra.com/nz/en/our-stories/media/fonterra-and-man-energy-solutions-enter-into-major-partnership.html . Synlait also commissioned its first electric boiler in its South Island plant in 2019.

[56] *NZ Battery Indicative Business Case,* Ministry of Business, Innovation, and Employment, 2022.

[57] Sapere (2019). *Distributed Energy Resources – Understanding the potential.* Microsoft PowerPoint - EA presentation - final - Read-Only and CBA model (excel form)

Table 7 Summary of impacts arising from super trends

Sectors	Impacts of super trends 2020 – 2050
Total generation	Total electricity consumption is anticipated to increase from 42.3TWh in 2020 to 65.5TWh in 2050[58].
Residential	**DERs and smart appliances:** • **DER penetration:** o **Generation:** Over the past decade, the total number of solar installations have grown by an average of 40% per year, to 42,793 ICPs in 2022 – this equates to approximately 2.3% of all households[59]. This trend is anticipated to continue as the levelized cost of electricity for residential solar continues to decline. Current installed rooftop solar generation is **170MW,** but this is anticipated to increase to **1,375MW** by 2050[60]**.** However, as the price of solar falls and the economics of residential solar improve (particularly for households with an EV or if subsidies were to be introduced) the future installed capacity of residential solar could be much higher. In countries where solar penetration is high (where one in three houses have solar, equating to 20GW) this shows up as a reduction in residential electricity demand during sunny periods, creating a 'duck curve' effect. However, without accompanying storage which is capable of operating in isolation of the grid, increased rooftop solar does not itself provide additional resilience in the event of shortage. o **Storage:** Storage is anticipated to increase the residential sector's resilience to short-term outages as home and community electricity storage systems may be able to maintain power to users (and effectively shift load) for short periods of time, noting that this will be less effective at managing longer-term shortage. Alongside EV storage (described below), community and household storage are also anticipated to grow materially. For the NZ Battery IBC modelling, it has been assumed that by 2050 there is 600MW of distributed battery capacity, excluding any potential storage available from EVs with V2G capabilities (see EV section below). However, some studies have suggested this could be as high as 2,268 MW of standalone residential battery capacity installed and 680MW of standalone commercial battery capacity[61]. • **Smart appliances:** As outlined in section 2, smart appliances may allow for significant intelligent aggregated demand response within the residential sector as non-essential appliances or EV charging in the home could be turned off or shifted to off peak times. This could have two beneficial impacts: • Reduce peak demand and improve the resilience of the system (as more demand response could be delivered from residential customers). Current ripple control = 15% of total peak load (~1.05GW of demand based on peak winter demand of ~7GW). In 2050, with a greater ability to impact / turn off non-essential residential appliances this demand shifting capability could be significantly higher[62], and o Reduce the blunt impacts of electricity shortage to households. Where non-essential appliances can be delayed or turned off for

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[58] *NZ Battery Indicative Business Case,* Ministry of Business, Innovation, and Employment, 2022.

[59] Transpower (2022). Monitoring Report 2022. PowerPoint Presentation (amazonaws.com)

[60] *NZ Battery Indicative Business Case,* Ministry of Business, Innovation, and Employment, 2022.

[61] Sapere (2021). *Explaining the Cost Benefit Analysis performed on the potential of Distributed Energy Resources,* Microsoft PowerPoint - EA presentation - final - Read-Only

[62] Poletti (2023) *Notes on the NZ Electricity Market*. Note: Average household energy demand, as of 2022, is ~7,146KWh per annum or ~19.58KWh per day (where total demand is prorated over the year). Current residential load is growing at around 2.1% per annum. However, this growth also incorporates new connections. At a household level, total electricity consumption is declining, the average household consumption per ICP has fallen 6.0% between 2021 and 2022. WiTMH report March 2023, Transpower.

Sectors	Impacts of super trends 2020 – 2050
	short periods (e.g., refrigeration, external lights, hot water systems etc.) demand may be able to be shifted without a commensurate reduction in wellbeing that might typically accrue from completely shutting off power to residential consumers. For both of the benefits listed above, much of this will result in load shifting from peak to non-peak periods. This will be important in reducing peak demand, but during periods of genuine energy shortage (i.e., not just during peak but also off-peak periods) the ability to mitigate the impacts of shortage is expected be less significant. **EV adoption:** • EVs may increase the residential sector's resilience to short-term outages as EVs provide a significant source of electricity storage (average EV battery storage is currently between 40 – 65kWh and growing at 5.3% per annum[63]). Where capability exists to use EV's to release power back to homes in times of scarcity, this capability may help shift demand while maintaining power to users for short periods[64]. In addition, depending on manufacturer appetite, vehicle to grid (V2G) services could also offer a significant resource to provide short-term power back to the grid in times of high demand. Where this service was aggregated this could be a significant source of system firming[65]. While this has the potential to help mitigate some impacts of shortage, this will depend on how V2G capabilities, and the supporting system and regulatory changes evolve over the coming years. Further, where shortage is more pronounced or for longer periods, owners of EVs may be unable to charge their vehicle for extended periods. In this instance, EV ownership may increase the economic cost of shortage as it reduces transport options for people.
Industrial	Electrification of these three sectors is anticipated to be largely centred around process heat and other boilers (e.g., large-scale HVAC[66]). Process heat is defined as energy used in the form of heat, specifically in industrial and manufacturing processes. Currently, a significant portion of New Zealand's overall energy use is for process heat and over half of this is supplied by burning fossil fuels such as coal or natural gas[67]. By 2050 electrification of process heat is expected to create an additional 8TWh of annual demand. Specific types of process heat (lower temperature and water heating applications) are likely to be electrified quickly with some types of process heat unlikely to be electrified by 2050 (e.g., high temperature process heats)[68]. For lower temperature industrial process heat applications, highly efficient electric heat pumps already present a compelling economic alternative to fossil fuel solutions[69]. ***Major/notable subsectors:*** • **Food processing** is currently a major user of coal and fossil fuel powered process heat. Much of their processing requires intermittent temperature process heat which is more expensive to electrify[70]. As a result, it is anticipated that electrification of this sector is likely to take longer and may switch to alternative fuels sources such as biomass[71]. This is largely
Commercial	
Agriculture, fishery, and forestry	

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[63] WiTMH report March 2023, Transpower.

[64] Average household energy demand, as of 2022, is ~7,146KWh per annum or ~19.58KWh per day (where total demand is prorated over the year).

[65] As of February 2023, total EV battery storage in New Zealand is around 2,450 MWh. EV penetration currently is ~1% of the total light vehicle fleet. Where this makes up 30% of the total light vehicle fleet expected capacity could be in excess of 51,300MWh.

[66] Coal boilers used for this purpose are expected to be phased outby 2037.

[67] EECA (2021) Accelerating the decarbonisation of Process Heat.

[68] Food-product-manufacturing-energy-insights-report.pdf (eeca.govt.nz)

[69] EECA (2021) Accelerating the decarbonisation of Process Heat.

[70] Food-product-manufacturing-energy-insights-report.pdf (eeca.govt.nz)

[71] https://www.fonterra.com/nz/en/our-stories/media/major-step-low-carbon-transition.html

Sectors	Impacts of super trends 2020 – 2050
	consistent with the climate change commissions reference case which sees these sectors as major users of fossil fuels out to 2040[72]. • **Dairy product manufacturing:** This sector is the single largest producer of process heat emissions in New Zealand. It is expected that this sector might be one of the first sectors to move from fossil fuels, through a combination of electrification and biomass[73]. It is assumed that 35% of process heat load will come from the dairy industry. • **Wood, pulp and paper, mining and quarrying** are currently large users of natural gas, this is expected to continue out until 2040[74]. Further, once phased out it is anticipated that the significant portion of this process heat may move to alternatives such as biomass or geothermal steam. • **General Industrial and services and Primary metal and metal product manufacturing** are currently major users of electricity and fossil fuels. International demand for low-carbon manufacturing is expected to push manufacturers away from fossil fuels to lower carbon alternatives, such as electrification or biomass. Further, the Government is actively incentivising decarbonisation, including via electrification, through GIDI fund. As a result of electrification, these sectors are expected to become more exposed to the impacts of electricity shortage, which could lead to significant costs due to lost productivity. **Smart technology:** • Similar to how connected devices are expected to be able to distinguish between essential and non-essential home appliances in the residential sector, it is anticipated that similar technology could provide commercial producers with the same ability. E.g., provide the capability to isolate and shut off non-essential or lower interruption-cost equipment. This could both reduce the economic cost of shortage but also increase the amount of demand response available from commercial users to be able to draw on in scarcity events.
Transport	**Electrification** – greater electrification is expected to reduce overall sector resilience and increase the economic impact of electricity loss: • Passenger fleet electrification will reduce resilience to longer-term outages (beyond one charge cycle of use) / rolling outages where electricity use may be conserved i.e., where shortage prevents the charging of EVs outside of peak demand. • Heavy industry is anticipated to have a slower electrification uptake and many commentators assume other fuel technologies such as hydrogen (produced by electricity) and biofuel may play a role in this sector. This could mean less reliance on electricity potentially muting the impact of shortage on this sector relative to passenger vehicles.

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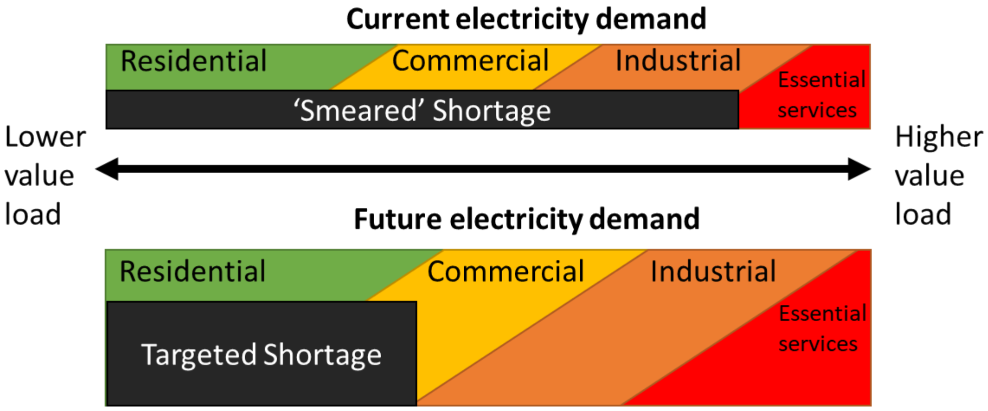
[72] EECA (2021) Accelerating the decarbonisation of Process Heat.
[73] Transpower (2022) Transpower Monitoring Report 2022. PowerPoint Presentation (amazonaws.com)
[74] EECA (2021) Accelerating the decarbonisation of Process Heat.

Summary of cost of shortage in a highly electrified economy

Decarbonisation through electrification is expected to lead to significant demand growth. However, increased electrification does not necessarily translate to increase costs of shortage resulting from dry years. As dry-year shortage is a function of weather, it remains constant (i.e., the 3-5TWh of potential shortage does not increase with demand). Therefore, as demand increases, the amount of shortage from a dry year becomes a smaller proportion of total demand. However, the value of the new demand to the economy can affect the cost of shortage (i.e., if new demand comes from a sector which is a significant contributor to the economy, then the VOLL of this new load will be high, increasing the cost of shortage).

This assumes that shortage is distributed across all users. As described earlier, the hierarchy of load shedding aims to prioritise important or high value load (such as emergency services, or high value industry) over lower value load (e.g., residential). However, the ability to target these loads is currently limited, meaning realistically, shortage is often ‘smeared’ across all users. In the future, an increased ability to target which users are impacted by shortage would help to reduce the cost of shortage. This would also need to take into account the broader impacts (e.g., equity and social implications if residential load were to be identified as the ‘lowest value’ load).

Figure 11: Cost of shortage impacts (current vs future with increased load from electrification, combined with better ability to target which loads are impacted by shortage)



As described above, much of the anticipated demand growth is expected to come from transport and industrial heat. This electrification will mean that these sectors are more vulnerable to shortage events. Given that these sectors represent relatively high value sectors in the economy, this suggests that the cost of shortage in future could be higher than it is currently. However, just as it is today, the cost of shortage will be highly dependent on the nature of the shortage and the industry and customers’ needs.

At the same time, super trends in the sector have the potential to create new capabilities for better balancing supply and demand, which may help to both prevent and mitigate the impacts of shortage. While these new capabilities are most likely to manage capacity constraints and shorter-term shortage through load shifting, there is also potential for these to play some role in managing energy shortage - e.g., through genuine demand response (excluding simple exercises of load shifting) or management of shorter-term shortage. However, these new capabilities are expected to be less capable of managing prolonged periods of energy shortage (e.g., weeks to months) on their own.

The modelling conducted for the NZ Battery IBC considered both the increased load from electrification, and the super trends described. However, there remains significant uncertainty as to how these trends will play out, which has the potential to influence the cost of shortage. Through the future steps of the NZ Battery project, it is expected that further modelling is required to explore these scenarios in further detail. This modelling will then provide some of the additional detail required to understand the wider economic impacts of shortage in a highly electrified economy.

5. Conclusion

Key findings from this analysis are:

- **Defining the cost of shortage is dependent on the shape of shortage, which has high levels of uncertainty** – Trying to understand the shape and duration of shortage events in a dynamic and transformational electricity market is challenging. Each shortage event will be unique and is significantly impacted by the supply and demand assumptions that go into the electricity market modelling.
- **The economic costs of shortage differ markedly depending on the characteristics of the event**. By considering the results from a range of studies, alongside appropriately chosen international examples of shortage and published numbers on economic output and electricity consumption, an estimate for the order of magnitude of the cost of shortage can be derived.

  This is shown in Figure Figure 12 where the red (gradient) bar on the bottom shows extended shortage events on a spectrum of mild to severe. Overlayed on this are a set of slightly overlapping green bars which show different types of response from the industry. As the shortage increases in severity, the response becomes more and more costly. In addition, the uncertainty in the cost also increases. Ultimately, predicting the cost of shortage comes down to several key assumptions: "*who is turned off?*", "*when are they turned off?*", "*for how long they are turned off?*", and "*how much warning are they given?*".

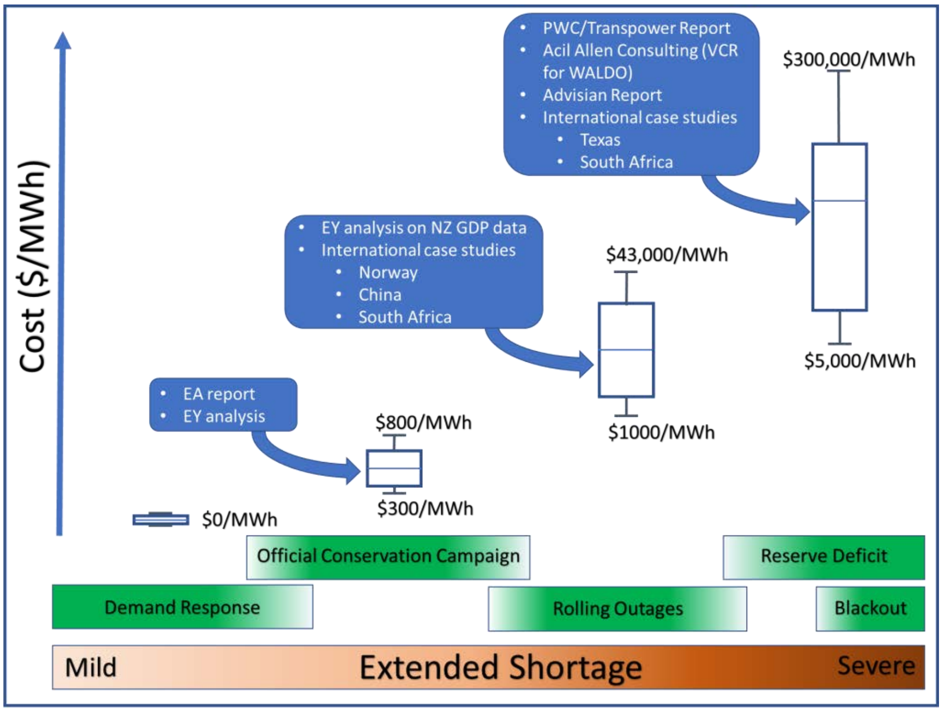


Figure 12 Summary of cost of shortage figures identified from various sources

Looking forward on the supply side, the future trajectory of the electricity market necessitates additional consideration around unsupplied energy in the dry year. As a result of increased penetration of both (or either) wind and solar generation, the dispatch of hydro generation will evolve from its current role of providing baseload and mid-merit peaking to a role of firming intermittent generation. For this reason, a dry year event in the future will not only require a reduction in energy consumption but may also increase the likelihood of an un-signalled power outage due to a lack of generation.

Additionally, on the demand side, trends in electrification suggest that a much greater proportion of the economy will be reliant on electricity, including high value use cases such as transport and industrial process heat. This has the potential to exacerbate the cost of shortage described above.

This analysis therefore reinforces the original Case for Change in the IBC – shortage from dry years in a 100% renewable electricity system has the potential to generate material costs. However, this issue is complex and material knowledge gaps remain.

6. Areas for further investigation

Further work is needed to better understand the costs of shortage. Five areas of potential focus include:

1. **Load block analysis** – Current electricity market modelling uses load block analysis which averages supply and demand over a week. This technique gives a less granular picture of outage. Using a more granular SDDP modelling technique that models supply and demand in 30-min increments may provide a sharper picture of when shortage is occurring and for how long.
2. **Large user group outage report** – In determining the value of lost load in a previous study, a survey was created that asked large consumers to indicate what the impact of shortage would be on their business. Having access to this information or conducting a similar survey would help ensure that the expected economic impacts as described above are accurate.
3. **Willingness to pay (WTP) survey** – a WTP method is a form of contingent valuation – a method used in economics to value goods and services not bought or sold in a marketplace. A WTP survey that understood the residential sector's willingness to pay to avoid outage over longer outage periods would be helpful to quantify the welfare loss from consumers for turning power off in a shortage event.
4. **CGE modelling** – A longer form study that makes use of CGE modelling is required to better understand the dynamic economic loss across the economy from shortage beyond direct production loss
5. **Updating the counterfactual** – Given economic loss in this paper is driven off an analysis of the type of shortage expected in the counterfactual scenario as articulated in the NZ Battery IBC, continuing to develop and update that counterfactual based on new trends etc. is vital to ensure it remains valid. Refining base case assumptions will be a key piece of that work.

Appendix A: Glossary

Acute Shortage: Refers to a shortage event that is resolved within hours. An acute shortage is always a potential threat as it generally results from an unexpected or unpredictable event. The probability is not quantified through the electricity risk curves. However, as the Electricity Risk Curves (ERC) increase, so too does the risk of acute shortage.

Blackouts: A blackout is a total loss of electricity supply in a specific area. Blackouts are unintentional and caused by either a sudden and significant reduction in electricity supply (from generation / transmission equipment failure, severe weather conditions etc.), or a sudden increase in demand that exceeds the available capacity of the electricity system. In a blackout, all power to the impacted area is lost, causing significant disruptions to homes, businesses, and critical infrastructure. Blackouts tend to occur in response to Grid Emergencies. They are a more colloquial version of an Unsupplied Demand Situation.

Brownouts: A brownout is defined as a drop in voltage of the electricity supply. They can be either intentional or unintentional. Brownouts are not intentionally used in New Zealand because they would put the system operator in breach of regulation (their Principal Performance Obligations as defined in the code). Brownouts are used in some other jurisdictions where PPOs are not as stringent. Brownouts can have very serious consequences on equipment, particularly anything with a digital control system.

Demand Response: Like Load Shedding, Demand Response refers to an intentional reduction in electricity demand or load. However, unlike Load Shedding, the reduction is initiated by consumers in response to either market price signals (spot price), or a signal from an organisation (such as the grid-owner) to reduce demand in exchange for a payment. Currently, most electricity consumers are not exposed to spot prices and do not provide Demand Response. However, this is likely to change as smart devices become more commonplace. Demand Response is related to an OCC, with the overarching goal of an OCC being to elicit as much Demand Response as is necessary to reduce risk back to the 8% level (at which point the OCC ends). However, an OCC is distinct from Demand Response because during an OCC consumers may feel *"compelled to reduce demand"* whereas, in the case of Demand Response consumers feel *"sufficiently compensated to reduce demand".*

Economic Shortage: When the elastic (price sensitive) component of demand is unsupplied because market prices were such that it was uneconomic to supply the load. Economic Shortage can be thought of as a subset of Shortage, wherein the market stays in a state of allocative efficiency. This does occur because of Demand Response and may occur in certain cases of Load Shedding.

Electricity Risk Curves: Transpower reports the risk curves for the purposes of reflecting the risk of extended energy shortages, using a standardised set of assumptions.

Emergency Management Policy: A requirement of the System Operator to set out the steps they must take during an extended security of supply emergency.

Extended Shortage: Refers to a shortage event that takes days, weeks or possibly even months to resolve. The Security of Supply Forecasting and Information Policy (SOSFIP) establishes the Electricity Risk Curves which are used to forecast these events. Such events can occur due to dry year conditions and/or thermal fuel unavailability. Extended shortage resulting from dry years is the focus of the NZ Battery project, and therefore this report. However other types of shortage (e.g., acute shortage) are also considered in the report, as a dry year can increase the risk of these events.

Grid Emergency: A grid emergency is triggered by the system operator in any event (typically unexpected) that; leads to an Unsupplied Demand Situation; compromises the system operator's ability to deliver on their principal performance obligations (power quality obligations); puts public safety at risk; puts grid assets at risk.

Load Shedding: Load shedding refers to an intentional and sudden reduction in load. The reduction is initiated by the SO (or, in some circumstances, a distribution company) to prevent a more catastrophic or cascade failure from occurring. This is like a Blackout, however Blackouts are unintentional, whereas

Load Shedding is intentional and even possibly automated. It is also like Rolling Outages, however during Rolling Outages the consumer has been forewarned, whereas with Load Shedding there is unlikely to be forewarning. Load Shedding can be an automated response, for example all assets connected to the grid are required to automatically respond when frequency drops below a certain threshold. This is commonly known as AUFLS or Automatic Under Frequency Load Shedding. Another common form of Load Shedding is Ripple Control.

Official Conservation Campaign: If storage in the hydroelectricity lakes fall to very low levels[75], the system operator is required to call an OCC. This may be in the South Island alone or it may be across all New Zealand. Two weeks' notice is expected before commencing an OCC. During an OCC, the system operator appeals to New Zealanders to use less electricity, thereby reducing the risk of rolling outages in the future. Qualifying consumers are compensated for their efforts. The current minimum compensation is $12 per week per qualifying ICP[76].

Participant Rolling Outage Plans: Each electricity industry participant is required to publish their rolling outage plans in compliance with the Electricity Industry Participation Code 2010.

Principal Performance Obligations: A minimum set of power quality requirements that the SO must maintain. These requirements are mainly related to balancing supply and demand in a way that maintains frequency, voltage and avoids any cascade failure of assets. They are also obliged to schedule enough instantaneous reserve.

Reserve Deficit: Reserve Deficit is where the system operator is forced to forgo the instantaneous reserve requirement to instead meet the energy requirement. Instantaneous reserve is generating capacity, or interruptible load, that is procured in the market to cover sudden, unexpected equipment failure. In normal operation, the reserve requirement is set by the system state (largest contingent event) and the procurement of energy and reserve is co-optimised. This response can help with certain acute shortage situations but cannot help as a mitigation measure during extended shortage.

Ripple Control: Ripple control is a limited form of Load Shedding that involves distributors turning off consumers' electric hot water systems at times of peak demand. Ripple control has been New Zealand's most common demand management tool since the 1950s and all 29 distributors in New Zealand operate ripple control plant.[77] It is estimated that the total load connected to ripple control equates to approximately 15% of New Zealand's annual peak demand[78]. Ripple control can only be used up to 4 hours consecutively for residential's hot water heating in any 8 hour period, and no more than 8 hours per day; while businesses' hot water heating is turned off 2 hours in any 5 hour period and no more than 6 hours per day.[79] It is effective at shifting load from one hour to the next but does very little to reduce the total energy required over the longer term (beyond 6-12 hours). In addition, the removal of the Regional Coincident Peak Demand (RCPD) charge from the Transmission Pricing Methodology has added to the general lack of incentive for distributors to maintain ripple control systems.

Rolling Outages: A series of intentional power outages that affect different parts of the network at different times. The outages are designed to achieve both an energy and a capacity savings target during a supply shortage. The system operator, in conjunction with distribution companies and directly connected consumers, publishes a rolling outage plan. This plan includes guidance on how distribution companies should prioritise different types of demand. Rolling Outages are used as a measure of last resort in the system operator's response to Shortage.

Security of Supply Annual Assessment: Transpower's view of the balance between supply and demand in the electricity system over the coming decade and this is publicly disclosed information to aid decision-making for generators, other market participants, investors and stakeholders.

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[75] Officially, the hydro lake levels must be such that there is a 10% chance of shortage both now and 1 week into the future. Alternatively, an OCC may be called by the system operator if they can agree with the Authority that reasons necessitate such action. The OCC ends when hydro lake levels reach an 8% chance of shortage.

[76] This minimum compensation is reviewed at least every 3 years. Qualifying ICPs are meter categories 1 and 2.

[77] PSC Consulting, The future of ripple control and peak demand management in New Zealand, retrieved from www.pscconsulting.com/the-future-of-ripple-control-and-peak-demand-management-in-new-zealand/.

[78] EECA (2020) *Ripple Control of Hot Water in New Zealand,* EECA 2020.

[79] Orion Ripple Control Summary document, retrieved from https://www.oriongroup.co.nz/assets/Customers/Orion-Ripple-Control-summary.pdf

Security of Supply Forecasting and Information Policy: A required document to be produced by the System Operator to specify the regular oversight over managing security of supply and annual reporting of assessing whether security of supply standards is likely to be met for at least the next five years.

Shortage: Electricity shortage is defined in this report as insufficient available electricity supply to meet all demand, including both inelastic (price insensitive) and elastic (price sensitive) components. Although the inability to meet elastic demand may reasonably occur with some frequency in a well-functioning market, it is still considered shortage in the context of this report. Shortage can be a forecasted event (for example as set out by the system operator's security of supply forecasting.

System Operator Rolling Outage Plan: A requirement of the System Operator to set out the thresholds at which they will implement rolling outages and the actions that they and other industry participants must take in the event of rolling outages.

Unsupplied Demand Situation: A situation that occurs in real-time when there is insufficient generation offers in the market to supply demand at a grid-exit point. During these situations, current regulation places an obligation for the system operator to assign price and quantity values as $10,000/MWh for the first 5% of demand, $15,000/MWh for the next 15% of demand, and $20,000/MWh for the remaining 80% of demand. Unsupplied Demand Situations are a specific example of Shortage that is written into the Electricity Industry Participation Code 2010.

Value of Lost Load: VoLL represents the economic value, in dollars per MWh, that a consumer places on electricity they plan to consume but do not receive because of a power interruption. It is very different (conceptually and numerically) to the price consumers pay in the wholesale and retail markets for electricity. Both the wholesale and retail prices reflect the marginal cost of production (assuming the market is in a state of allocative efficiency) whereas VoLL reflects consumers' demand to avoid power interruptions (for which there is no market).

Appendix B: EEUD Total output, intermediate consumption, value added, and electricity consumed per sector groups and per sectors

Internal Sector Category	National Accounts Sector Groups (ANSIZ level 1)	National Accounts Sectors	ANZSIZ level 2	Transpower Load Shedding Hierarchy Priority Positior	EEUD Sector Group	EEUD Sector	ANZSIC	Electricity Consumed (GWh, 2020)	Total industry output (NZD mil as per EEUD secto	Total Industry Output (NZD mil as per national accounts secto	Intermediate Consumption (NZD mil as per EEUD sector)	Intermediate Consumption	Value Added (NZD mil as per EEUD sector)	Value Added
Aggregated commercial services	Retail trade	Other store-based retailing and non-store retailing	G42, G43	5	Commercial	Wholesale and Retail Trade - Food and Non Food	F33, F34, F35,F36, F37, F38, G39, G40, G42, G43	833	48,247	13,838	23,443	5,863	24,804	7,975
	Retail trade	Motor-vehicle and motor-vehicle parts, and fuel retailing	G39, G40	5						3,583		1,303		2,280
	Wholesale trade	Wholesale trade	F	5						30,826		16,277		14,549
	Accommodation and food services	Accommodation and food services	H	5		Accommodation and Food Services	H	1,272	15,042	15,042	15,042	7,981	15,042	7,061
	Retail trade	Supermarket, grocery stores, and specialised food retailing	G41	2		Retail Trade - Food	G41	1,421	19,996	5,892	9,160	2,043	10,836	3,849
	Information media and telecommunications	Information media services	J54, J55, J56, J57	2		Information Media and Telecommunications	J	614		5,041		3,123		1,918
		Telecommunications, internet, and library services	J58, J59, J60	2						9,063		3,994		5,069
	Financial and insurance services	Finance	K62	5		Financing, Insurance, Real Estate and Business Services	K, L, M, N72	1,382	115,027	15,299	46,602	5,815	68,425	9,484
	Financial and insurance services	Insurance and superannuation funds	K63	5						10,065		5,549		4,516
	Financial and insurance services	Auxiliary finance and insurance services	K64	5						6,799		3,002		3,797
	Rental, hiring, and real estate services	Rental and hiring services (except real estate)	L66	5						6,558		3,003		3,555
	Rental, hiring, and real estate services	Property operators and real estate services	L67	5						32,677		12,583		20,094
	Professional, scientific, and technical services	Professional, scientific, and technical services	M	5						43,629		16,650		26,979
	Administrative and support services	Administrative and support services	N	5		Building Cleaning, Pest Control and Other Support Services	N73	15	12,732	12,732	6,554	6,554	6,178	6,178
	Local government administration	Local government administration	O75	1		Local Government Administration	O753	403	23,149	2,560	9,602	932	13,547	1,628
	Central government administration, defence, and public safety	Central government administration, defence, and public safety	O76, O77	1		Public Administration and Safety	O751, O752, O754, O755, O77	283		20,589		8,670		11,919
						Defence	O76	153						-
	Education and training	Education and training	P	3		Education and Training: Pre-School, Primary and Secondary, Tertiary Education and Other Education	P80-P82	652	19,161	19,161	5,203	5,203	13,958	13,958
	Health care and social assistance	Health care and social assistance	Q	3		Health Care and Social Assistance	Q	819	31,004	31,004	11,491	11,491	19,513	19,513
	Arts and recreation services	Arts and recreation services	R	5		Arts, Recreational and Other Services	R, S	572	19,192	8,085	8,843	3,777	10,349	4,308
	Other services	Other services	S	5						11,107		5,066		6,041

Internal Sector Category	National Accounts Sector Groups (ANSIZ level 1)	National Accounts Sectors	ANZSIZ level 2	Transpower Load Shedding Hierarchy Priority Position	EEUD Sector Group	EEUD Sector	ANZSIC	Electricity Consumed (GWh, 2020)	Total industry output (NZD mil as per EEUD sector)	Total Industry Output (NZD mil as per national accounts sector)	Intermediate Consumption (NZD mil as per EEUD sector)	Intermediate Consumption	Value Added (NZD mil as per EEUD sector)	Value Added
Aggregated Transport services	Transport, postal, and warehousing	Road transport	I46	2	Transport	Road Transport	Z002	34	10,351	10,351	5,660	5,660	4,691	4,691
		Rail, water, air, and other transport	I47, I48, I49, I50	2		Rail Transport	Z002	63	8,678	8,678	5,908	5,908	2,770	2,770
		Postal, courier transport support, and warehousing services	I51, I52, I53	5		Transport, Postal and Warehousing (Commercial - Non-Transport)	I52,I53	757	10,667	10,667	4,152	4,152	6,515	6,515
Dairy product manufacturing	Food, beverage and tobacco product manufacturing	Dairy product manufacturing	C113	4	Industrial	Dairy Product Manufacturing	C113	1,225	23,892	23,892	20,128	20,128	3,764	3,764
Electricity generation, distribution, gas and water supply and waste services	Electricity, gas, water and waste services	Electricity and gas supply	D26, D27	2		Electricity, Gas, Water and Waste Services	D	564	23,092	18,186	14,199	11,674	8,893	6,512
		Water, sewerage, drainage, and waste services	D28, D29	2						4,906		2,525		2,381
Food product manufacturing	Food, beverage and tobacco product manufacturing	Meat and meat product manufacturing	C111	4		Meat and Meat Product Manufacturing and Seafood	C111-C112	853	14,353	12,626	11,410	10,275	2,943	2,351
		Seafood processing	C112	4						1,727		1,135		592
		Fruit, oil, cereal and other food product manufacturing	C114, C115, C116, C117, C118, 119	5		Food and Beverage Product Manufacturing (excluding Dairy, Meat, Seafood)	C114-C119, C12	795	14,839	8,217	9,410	5,542	5,429	2,675
		Beverage and tobacco product manufacturing	C12	5						6,622		3,868		2,754
General industrial services	Mining	Mining	B	5	Industrial	Mining	B	416	5,556	5,556	2,715	2,715	2,841	2,841
	Textile, leather, clothing and footwear manufacturing	Textile, leather, clothing and footwear manufacturing	C13	5		Textile, Leather, Clothing and Footwear Manufacturing	C13	96	1,865	1,865	1,245	1,245	620	620
	Printing	Printing	C16	5		missing in EEUD dataset	missing in EEUD dataset	missing in EEUD dataset	1,472	1,472	811	811	661	661
	Non-metallic mineral product manufacturing	Non-metallic mineral product manufacturing	C20	5		Non-Metallic Mineral Product Manufacturing	C20	262	3,230	3,230	2,085	2,085	1,145	1,145
	Furniture and other manufacturing	Furniture and other manufacturing	C25	5		Furniture and Other Manufacturing	C25	207	2,121	2,121	1,280	1,280	841	841
	Wood and paper products manufacturing	Wood product manufacturing	C14	5		Wood Product Manufacturing	C14	1,306	5,588	5,588	3,934	3,934	1,654	1,654
	Petroleum, chemical, polymer and rubber product manufacturing	Petroleum and coal product manufacturing	C17	5		Petroleum, Basic Chemical and Rubber Product Manufacturing	C17-C19	764	24,184	8,620	16,100	5,954	8,084	2,666
		Basic chemical and chemical product manufacturing	C18	5						4,970		3,552		1,418
		Polymer product and rubber product manufacturing	C19	5						3,740		2,212		1,528
	Metal product manufacturing	Fabricated metal product manufacturing	C22	5						6,854		4,382		2,472
	Transport equipment, machinery and equipment manufacturing	Transport equipment manufacturing	C23	5		Fabricated Metal Product, Transport Equipment, Machinery and Equipment Manufacturing	C22-C24	140	12,942	4,273	7,472	2,917	5,470	1,356
		Machinery and other equipment manufacturing	C24	5						8,669		4,555		4,114
	Construction	Building construction	E30	5		Construction	E	391	73,570	30,303	51,071	24,389	22,499	5,914
		Heavy and civil engineering construction	E31	5						14,535		9,737		4,798
		Construction services	E32	5						28,732		16,945		11,787

Internal Sector Category	National Accounts Sector Groups (ANSIZ level 1)	National Accounts Sectors	ANZSIZ level 2	Transpower Load Shedding Hierarchy Priority Positior	EEUD Sector Group	EEUD Sector	ANZSIC	Electricity Consumed (GWh, 2020)	Total industry output (NZD mil as per EEUD secto	Total Industry Output (NZD mil as per national accounts secto	Intermediate Consumption (NZD mil as per EEUD sector)	Intermediate Consumption	Value Added (NZD mil as per EEUD sector)	Value Added
Non-dairy agriculture	Agriculture	Horticulture and fruit growing	A011, A012, A013, A015	4	Agriculture, Forestry and Fishing	Non-Dairy Agriculture	A0112-A0113, A0115, A0121, A0123, A013-A015, A017-A019, A02, A05	651	23,117	5,508	13,363	3,150	9,754	2,358
		Sheep, beef cattle and grain farming	A014	4						9,220		5,299		3,921
		Poultry, deer and other livestock farming	A017, A018, A019	4						1,798		1,202		596
	Fishing, aquaculture and agriculture, forestry and fishing support services	Fishing and aquaculture	A02, A04	4		Fishing, Hunting and Trapping	A04			1,535		988		547
		Agriculture, forestry and fishing support services and hunting	A05	5		Indoor Cropping	A0111, A0114, A0122			5,056		2,724		2,332
Dairy cattle farming	Agriculture	Dairy cattle farming	A016	4	Agriculture, Forestry and Fishing	Dairy cattle farming	A016	1,970	13,844	13,844	6,914	6,914	6,930	6,930
Forestry and logging	Forestry and Logging	Forestry and logging	A04	5	Agriculture, Forestry and Fishing	Forestry and logging	A03	66	5,427	5,427	3,797	3,797	1,630	1,630
Primary metal and metal product manufacturing	Metal product manufacturing	Primary metal and metal product manufacturing	C21	5	Industrial	Primary Metal and Metal Product Manufacturing	C21	6,240	3,569	3,569	2,976	2,976	593	593
Pulp, paper and converted paper product manufacturing	Wood and paper products manufacturing	Pulp, paper and converted paper product manufacturing	C15	5		Pulp, Paper and Converted Paper Product Manufacturing	C15	687	3,354	3,354	2,712	2,712	642	642
Residential	Owner-occupied property operation (residential)	residential		6	Residential	Residential	Z001	12,877	Not Applicable	31,239	Not Applicable	7,451	Not Applicable	23,788
Total										**620,500**		**323,672**		**296,828**