NZ Battery Project Technical Reference Group Meeting

12 July 2022

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Today’s programme

No	Time	Item	Lead
1.	09.00am – 09.10am	Welcome / Karakia and Agenda overview	Adrian Macey and Hoani Langsbury
2.	09.10am – 10.00am	Workstream updates and achievements	NZB Team
3.	10.00am – 10.45am	Ecology at Lake Onslow	NIWA
4.	**10.45am – 11.15am**	**Tea/Coffee break - 30 mins**	
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Workstream update and Achievements

Workstream 1 – Lake Onslow – Progress update

- Phase 1A design deliverables landing
    - Preliminary feasibility design
    - Draft Consenting Strategy
- Phase 1B in progress, final draft due for review 02/09
    - Baseline assessments in progress (including DOC, NIWA and Aukaha)
    - Further design refinement on narrower option set
    - Incorporation of findings to date from geotechnical investigations

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Workstream 1 – Lake Onslow – Progress update

- s 9(2)(f)(iv) [redacted]
- Like the fieldwork near Lake Onslow, this work includes drilling boreholes, digging surface-level test pits and geophysical surveys.
- The work will occur on public land over approximately the next 2 months at sites selected to minimise disruption to the community and surrounding environment, with one bore hole on private land under discussion.
- This work is to understand what's happening underground and investigate where on the Clutha River/Mata-Au water could be stored (if required) before being pumped to Lake Onslow.

Workstream 2 - Other Hydro & Other Pumped Hydro

Recap

- Problem 1. Study carried out to determine likely benefits of hypothetical generic “Battery” options, initiated before NZ Battery project commenced.
- GIS scan. Automated scan for elevated basins that have the physical attributes required for potential pumped hydro storage schemes.
- Desktop assessment. Desktop engineering assessment of pumped hydro sites and possible storage expansion of an existing hydro lake. Includes assessment of cultural, environmental, social effects to inform meaningful engagement should any further work be deemed appropriate.
- Findings so far (see next slide).

Next Steps

- Confirm approval for engagement approach from steering group.
- Execute engagement plan ahead of any further work.
- Compare WS2 options based on information acquired so far with Lake Onslow and other technologies through Indicative Business Case process.

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Workstream 3 - Non hydro options – Progress update

- WSP is investigating the feasibility of three options:
    - Biomass production and storage, with potential import/export
    - Controlled schedulable geothermal generation
    - Hydrogen and ammonia production and storage, with potential import/export.

- Their recent focus has been on understanding the key uncertainties and risks to feasibility.

- These uncertainties/risks will materially shape what a solution looks like (eg, how big it *could* be and how big it *should* be), and hence need to be 'baked-in' early

- They will also be essential to our advice in December

- We expect a draft report in early August, which will give a broad feasibility assessment of each technology

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NIWA Update - Ecology at Lake Onslow

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Assessment of Lake Onslow climate, hydrology and ecology

s 9(2)(a) [redacted]

12 July 2022

Draft version

NIWA
Taihoro Nukurangi

Outline

- Hydrology
- Morphometry and residence time
- Hydrodynamic observations
- Fine sediment, light, trophic state
- Lake hydrodynamic model
- Implications of water level fluctuations on ecology
- Trophic basis of fish production
- Macrophytes and biosecurity
- Greenhouse gas emissions

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Tea and Coffee Break

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Taking stock, and process to the end of the year

- Mid-year Cabinet report back has just taken place

- We are focussed on what we need to deliver by end of year:
    - Finalise feasibility studies and economic analysis
    - Indicative Business Case (with cost benefit analysis) – EY engaged
    - Providing advice to Minister Woods to inform end of year Cabinet paper
    - Iwi, agency and landowner engagement

- Key driver of this afternoon's session is to identify priority areas for TRG engagement and TRG members' sense of gaps

Mid-Year Cabinet update

- The Minister gave an oral update to Cabinet on 30 May, followed by a formal update to DEV (22 June) and Cabinet (27 June).
- The paper:
    - Outlined the dry year problem
    - Reported that emerging findings indicate Lake Onslow is technically feasible
    - Noted that, should Onslow advance, there will be environmental challenges and private interests to manage
    - Updated Cabinet on Workstreams 2, 3 and 4
    - Noted that next steps are to continue our work in order to inform end of year decisions and to develop an indicative business case
- Cabinet agreed to work continuing on feasibility assessments into pumped hydro at Lake Onslow, other hydro options and the potential of biomass, hydrogen, geothermal and demand response options to address the dry year problem.

- Feedback from DEV.

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EY Presents – NZ Battery Indicative Business Case

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2. Placing NZ Battery in an IBC context

While the NZ Battery IBC will need to be Better Business Case compliant, the detail provided in the cases will need to be tailored to address the key questions for the project, and reflect the level of information available.

A typical IBC has a clear focus on the Strategic and Economic Cases. The NZ Battery IBC will follow this approach, s 9(2)(f)(iv) [redacted]

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2. What questions each case will likely answer

Strategic Case

1. Describes the origin of the mandate provided and sets out the key objectives as directed in the Dec 2020 Cabinet paper
2. Establishes ‘dry year’ as the key problem the investment is seeking to address – pending confirmation through an ILM
3. Provides the context of how NZ Battery fits into the broader National Energy Strategy, wider Government objectives, and market context

Economic Case

1. Describes the process to narrow all possible options → feasible options
2. Establishes the counterfactual and shortlist of options
3. Outlines the magnitude of benefits, costs and expenses of each shortlist option
4. Sets out a preferred option. May identify 1-2 options to consider in further detail at the DBC stage

Does not – provide an investment ready option to solve the dry year problem

Commercial Case

1. Explores the potential commercial options that could be implemented over the lifecycle of the asset
2. Establishes a framework for evaluating the pros, cons, and implications of each commercial model (using a risk allocation based approach)
3. Outlines the likely procurement models that could be implemented to achieve at least the D&C of the preferred option(s)
4. Provides confidence that there are acceptable commercial options available

Does not - outline a preferred commercial, operating, or procurement model. This will be done at the DBC stage

Financial Case

1. Outlines indicative potential costs (whole of life)
2. Outlines potential funding sources and magnitudes under different commercial models
3. Outlines the funding envelop to explore options further through the DBC stage

Does not - seek all funding for the project at this stage

Management Case:

1. Outlines the governance and project management options over the lifecycle of the asset
2. Outlines proposed delivery model post DBC (e.g. is a new agency required)
3. Provides a detailed project plan up to Implementation Business Case
4. Outlines stakeholder management approach – both up to and including the DBC, but also beyond.

3. Economic Case – Heading by heading considerations

The next section provides a heading by heading walk-through of the Economic Case. For each heading, a traffic light rating has been used to provide an early indication of where further work may be required to achieve the purpose of each heading e.g. whether work needs to be done to land contentious questions or to flesh out work done to date in specific areas. **All traffic light positions are indicative and represent our current understanding based on the work done to date and the information on hand at the time of writing this.**

What each colour denotes in this context is outlined below:

🟩 **Green** – The purpose of this section does not appear to raise any highly contentious issues or require significant additional work to deliver the purpose of each heading.

🟧 **Orange** – Some work is required to provide further detail on existing work done or achieve a consensus view on a contentious issue to achieve the purpose of this section. However, the work is in-train or the level of effort required is expected to be manageable.

🟥 **Red** – Addressing the purpose of this section may need additional work than is currently underway, or where reaching a consensus may be difficult to achieve.

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Lunch Break

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Purpose

Purpose of this session – Gap analysis

- To take you through the Project plan for the remainder of the year and ensure we have identified the questions that will need to be answered at the end of the year.

What we want from you

- We are keen to get your feedback and views on where you see any gaps in our thinking and recommendations to consider.

Next steps from here

- This session will help us identify gaps but also prioritise and plan for future TRG input

Covering our bases

- Identify the questions that we might receive at the end of the year?
- Where are there gaps in our understanding/explanation?
- Which gaps do we prioritise filling?

Chopping it up a bit

The next slides contain high-level questions that we have identified – and MBIE's assessment on our current understanding and thinking

Buckets:

Problem	**Costs**
Solutions	**Benefits**
Counterfactuals	**Market impacts**
Options	**Technical aspects of Onslow**

MBIE's assessment:

Good	Confident in our understanding and explanation of the issues is sufficient for this stage of the investigation
Coming	More analysis has been procured or planned, to support our understanding and explanation.
Gap	Insufficient understanding or ability to explain, and no work on the immediate horizon to fill the gap

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Forward agenda for MBIE/TRG engagement

- The next step is to prioritise, based on discussions today, the items for MBIE/TRG engagement in the coming weeks and months.
- We will hold a feedback session on the economic analysis already circulated + assumptions in the near future – pencilled in for 19 July.
- For summary and discussion – how do we best spend the next monthly sessions, and do we need any additional?
- MBIE will circulate forward agenda following this meeting.

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NZ Battery Project - Technical Reference Group Summary Notes – 1 March 2022

Date:	Tuesday 01 March 2022
Time:	10.00am – 3.30pm
Location:	Online via Teams
TRG members present:	Adrian Macey (Chair) Cristiano Marantes, George Hooper, Isla Day, Allan Miller, Amanda Larsson, Raymond Gunn, Hoani Langsbury, Stephen Batstone, Mike Howatt
MBIE staff & contractors:	Andrew Millar, Adrian Tweeddale, Conrad Edwards, Malcolm Schenkel, John Hancock, Eleanor Bell, Samuel Treceno, Bridget Moon, Jodi Percy
Apologies:	Carl Walrond

Agenda items

1. Project update – Progress and next upcoming decisions
2. Workstream 1 – TRM update on key findings
3. Environment update from DOC and s 9(2)(a) from Wildlands will join the discussion.
4. Aukaha – Discuss findings from the desktop assessment report into the cultural, archaeological and heritage values for the Lake Onslow option.
5. John Culy to present his recent historical inflow analysis work.
6. Workstream 3 – (non hydro options) Discuss recommendations from WSP report

Item	Update/Actions	Lead
1.	**Project update**	**Andrew M**
	• Andrew Millar provided a project status update on previous work completed since November 2021 and milestones achieved. Andrew then covered the importance of the work underway, and the Cabinet paper process/timeline as we work towards May/June to build the Cab paper. • Land access remains a challenge in some key areas, and we are working on alternative ways to gather data/information as part of the feasibility study for Phase 1. • Members of the TRG noted the timing issue for delayed Geo tech work for local landowners has been an issue and raised some concerns about future work.	
2.	**TRM update on key findings**	**Adrian T and** s 9(2)(a)
	• s 9(2)(a) – TRM lead Project Manager presented the various dam scenarios and key information that has been discovered in recent months as part of the investigation work underway. TRG asked the question on low carbon Concrete and if this will be looked at or included in TRM's investigation as part of the global carbon emissions reduction	

	plan.	
3.	**DOC and Wildlands Presentation**	s 9(2)(a) [redacted]
	• DOC team presented findings from the conservation values, non-conservation land, recreational and landscape values assessment completed. DOC is compiling all the information into a report which will be sent next week to the NZ Battery team.	
4.	**Aukaha Presentation**	s 9(2)(a) [redacted]
	• Kate presented some interesting findings from the cultural values assessment and there are some significant areas that would require further investigation.	
5.	**John Culy – historical inflow analysis work**	s 9(2)(a) [redacted] **John Culy**
	• John presented interesting historical flow and wind/solar/hydro correlations data. TRG raised some questions the modelling assumption work and what further work is being done.	
	Action: Jodi to organise a follow up session with the TRG covering off the workstream 4 work plan over the coming months and questions raised from John Culy's inflow analysis work. **Completed on 8 March and summary notes sent to you all.**	
6.	**Non-hydro storage options**	**Bridget Moon**
	• Bridget led a follow up (post email feedback) discussion on the 3 option recommendations from the WSP draft report. TRG agreed with these 3 options and provided further suggested feedback on Biomass and Geothermal downsides/challenges especially in supply and cost.	
	Action: • Bridget has noted the TRG feedback on the narrowed down 3 options and will be including this in Task 1 WSP report review. • Bridget will circulate a copy of the final report to the TRG once available.	

NZ Battery Technical Reference Group – addition session on Work stream 4 (8 March 2022)

Inflow data

- A lot of effort has gone into inflow assumptions (hydro, wind and solar), given inflow variability can have significant impact on security of supply, historically from hydro, in future from wind and solar too.
- The hydro data is based on the last 89 years of hydro inflows and is adjusted to the existing hydro fleet
- The solar and wind data is the best available
- We've also done work to look at the correlations between solar, wind and hydro inflows to understand where there might be overlaps and gaps in the future 100% renewable system with balancing intermittent and controllable generation.
- All the historic inflow data is being complemented by adjustments to account for the potential changes to weather patterns as a result of climate change. Dr. Jen Purdie did this work based on NIWA observations. Confidence in the quantum of the results is low given the level of uncertainty around climate change projections, so we will be conducting sensitivity analysis. Confidence in the direction of the projections is higher.
- The AR6 report was released to late for its conclusions to influence this work, [Post-meeting note: Jen Purdie's report, which she is just revising to better reflect uncertainties, is heavily referenced with relevant academic papers]

Purpose of the modelling

- Several purposes but most important one is to indicate gross economic benefit of the NZ Battery options
- Secondary objectives include understanding how an NZ Batter would integrate with the market and supporting work on resilience and power system integration.
- Currently looking at gross benefits of each option, once we get the costs of the options, we'll be able to do the net benefits, in the next month or so we'll have revised high level cost estimates for the different options, their accuracy won't be perfect, but they will give decision makers a sense of the different options
- Onslow will be +/- 50%, the others will be less certain than that, by the end of the year this will improve
- Deliberately and openly looking at gross benefits, once we get the costs, we can look at net benefit. Solar and wind overbuild is the base case. Lake Onslow and potentially other NZ Battery options will require overbuild to, but less, hence one benefit.

Discussion of models and what they do/don't do

- The NZ Battery Project is using two complementary economic modelling approaches - the John Culy model and the SDDP model (see Conrad's slides for more detail on comparisons). We are also conducting power system analysis through Transpower.
- The issue and hence the models are complex. To gain insight into the complexity, and hence into the modelling, an 'energy balance' demonstrator tool has been developed (and was demonstrated at this meeting). Energy balance modelling is good and tells you a lot about the problem, but you need the economic overlay, it's a simplistic illustrative model and helps us understand what kind of questions we need to ask, it gives you a good eyeball of the problem but we need more detail to inform decisions.
- Models can show how much generation would be required if you didn't have an NZ Battery and how much extra generation you could avoid building if you had an NZ Battery. There are other important benefits too, including reduced demand curtailment.
- Models show storage plays an important role in managing inflow variability: additional storage is always good, but we also know it might be expensive.

- John Culy and SDDP models both use water values – the major determinant of water values is risk of spill (lost opportunity) and risk of going dry. In the market, traders in hydro generators are constantly balancing this: the economic models reflect such considerations
- The models assume perfect competition and no use of market power which affects how you interpret the results, particularly in relation to price.
- We are running the SDDP model on a weekly basis and then focusing in on three years (2035, 2050, 2060) to provide some extra detail, particularly important for looking at dunkelflaute events (calm, cloudy periods which affect wind and solar generation, something we will have more of in the future)
- Looking at the actual historical inflow sequences in order allows you to fully take into account observed correlations between hydro, wind and solar inflows, and allow for the risk of consecutive dry years.

Market design questions

- We're not looking at market design per se, s 9(2)(a) work gets into it a little, which we will flag to Ministers (e.g. negative pricing) but progressing market design changes is out of scope of the project.
- One market design change we have included in models is to force fossil fuels off, all models would otherwise keep fossil thermals in till the late 2030s
- s 9(2)(f)(iv)

Discussion around solar and wind

- Important to get costs right for solar and wind projections. The TRG was involved in a major review of our 'non-Inflow' assumptions in late 2021.
- Input assumptions capture the expected rates of residential rooftop solar and batteries etc. but do not explicitly consider the impact on these of peer-to-peer trading.
- How does one account for non-price related incentives on companies to invest in solar? E.g. to improve their green credentials. Need to do sensitivity analysis on these.
- MBIE are engaging a consultant specifically to look at the accuracy of assumed future wind and solar costs.
- **MBIE Action**
    - share Jen Purdie report and Conrad's slides from the session (see attached)
    - estimate accuracy of future wind and solar costs,
- **Allan Miller Action**
    - contact Conrad re his ideas on improving the mapping of solar and wind to hydro inflow sequences, asap,
- **Amanda Larsson Action**
    - revisit agreed input assumptions (noting inputs are now frozen for this production round)

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chapman tripp

Energy Link

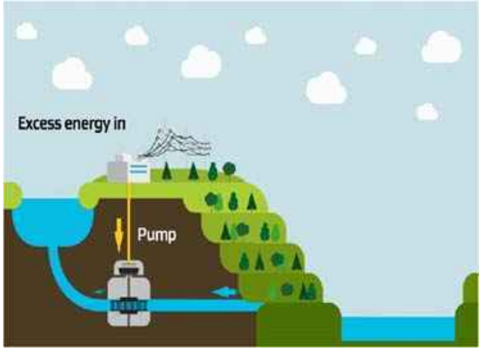
sapere

NZ Battery – electricity market study

Problem 2: Market Interaction

Toby Stevenson, Greg Sise, David Reeve and Andy Nicholls

Date 3 May 2021



Contents

Appendices

Glossary

Abbreviation or term	Stands for
CCC	Climate Change Commission
CE	Contingent event
CFD	Contracts for differences
Code	Electricity Industry Participation Code
DSR	Demand side response
ECE	Extended contingent event
ETS	Emissions Trading Scheme
GIP	Grid injection point
GW, GWh	Gigawatt, gigawatt hours
GWAP	Generation weighted average price
HHI	Herfindahl-Hirschman Index
HVDC	High voltage direct current transmission interconnector AKA the Cook Strait Cable. It is made up of three links known as Pole 1, Pole 2 and Pole 3.
ICCC	Interim Climate Change Committee
ILR	Interruptible load reserve
kV	Kilovolts
LCOE	Levelised Cost of Energy, defined as the constant average annual electricity price attained by the plant over its lifetime that just achieves target return on investment after covering all cash costs
LRMC	Long Run Marginal Cost, defined as the minimum increase in total cost associated with an increase of one unit of output when all inputs are variable
MW, MWh	Megawatts, megawatt hours
n-1	Operating security standard where the power system is run to allow for the tripping of the largest risk (plant) without activating automatic load shedding
NI WCM	North Island Winter Capacity Margin
Nodes	Points on the grid where electricity is either exported (generation) or imported (consumption)
O&M	Operations and maintenance
OCC	Official conservation campaign

ORDC	Operating Reserve Demand Curve
PLSR	Partially loaded spinning reserve
ROI	Return on Investment
SFT	Simultaneous feasibility constraints. These protect one line from overloading post the loss of another line
SLR	Supplier of last resort
SOE	State-owned enterprise
SOS	Security of Supply
SRMC	Short Run Marginal Cost, defined as the change in short run total cost for a change of one unit in output
TWAP	Time weighted average price
TWD	Tail water depressed
VoLL	Value of Lost Load

Executive summary

Our brief and the problem definition

Our brief is to address how any large-scale dry year storage mechanism (NZ Battery) would interact with and affect New Zealand's current electricity market. We have interpreted the current market in this context as the operation of the existing market design and institutions after the 100 per cent renewable electricity policy in 2030 has come into effect.

The dry year risk problem the NZ Battery Project is considering arises as the consequence of removing fossil-fuelled thermal generation from the market. Historically, fossil-fuelled thermal generation has provided dry year cover and peaking duties. The question is whether the market will provide dry year cover after that transformation to 100 per cent renewable electricity has taken place or whether there is a case for a further intervention in the market.

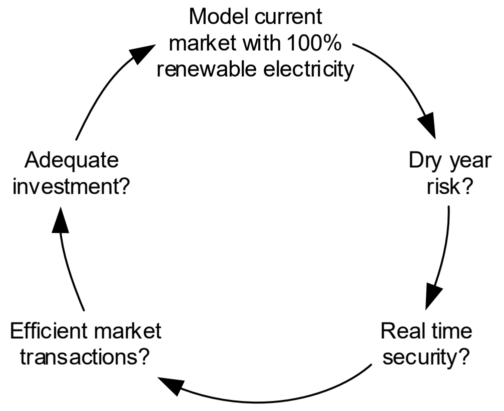
The case for an NZ Battery solution would be made if, in a 100 per cent renewable electricity world, security of supply would not be assured by the market at an overall cost less than the cost of the market with NZ Battery. If the proposed solution that comes out of the NZ Battery project is the Lake Onslow Pumped Hydro Scheme (Onslow), other effects resulting from Onslow's location would also have to be taken into account before proceeding.

Any assessment of the workings of the market also has to take into account whether the market will continue to perform its core roles once the 100 per cent renewable policy was introduced and again if Onslow is added into the market. The core policy objectives for the market are to deliver efficient market transactions and providing adequate investment in generation, all the while providing security of supply. The challenge to deliver adequate investment is heightened by the combined need to replace the fossil-fuelled generation in the move to 100 per cent renewables and then the reliance on electrification for decarbonisation under the net zero carbon 2050 legislation.

Our analytic approach

The analytic logic we applied is shown in Figure 1 below. First, we carried out the modelling with the current market design and fossil-fuelled thermal removed as at 2030, which is, for this purpose, the current market. We applied the tests as shown. We then reran the model with an Onslow pumped hydro scheme in operation and repeated the tests.

Figure 1: Illustrative analytic approach to the "current market" with and without Onlsow



The thinking behind this approach and the outputs from the modelling provide an initial look at the decisions that have to be made and the impacts of those decisions in an integrated way, which will, in turn, inform the development of the case to construct Onslow and/or any other required scheme.

s 9(2)(f)(iv) [redacted]

An important issue we have taken into account, and an important issue for the whole market, is that price formation in a 100 per cent renewable electricity world will be quite different than it is today. After the shift to 100 per cent renewable electricity, the offer curve – and, as a consequence, cleared prices – will have a greater incidence of low SRMC based prices and potentially a higher incidence of prices that reflect scarcity. In lay terms, compared to a market with thermal generation, it will be a market with lower prices most of the time, but with an increased chance of occasional very high prices. We consider the shift in prices resulting from that new price formation dynamic in the 100 per cent renewable case to price formation after Onslow is added into the 100 per cent renewables market.

We have focused our analysis on a pumped hydro scheme at Lake Onslow because this scheme is documented and has the potential scale to address the problem the NZ Battery project is looking at. However, s 9(2)(f)(iv) [redacted]

Modelling results

The modelling reflects the iterative approach shown above. The modelling tests for the level of prices that would encourage enough generation investment to meet dry year risk for the given set of circumstances. For the first step to 100 per cent renewable electricity supply, the level of generation required is referred to as "overbuild" because much of the available renewable generation uses fuel supply that cannot be stored. That is to say it is the amount of generation required in a dry year and, by implication, some of it would not run to commercial level of capacity utilisation in other conditions. The concept of overbuild carries through when Onslow is introduced, but the amount of required overbuild is reduced.

s 9(2)(f)(iv) [redacted]

s 9(2)(f)(iv)

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[redacted]

Table 1: Diversity and reliance on key assets

	Reliance on Key Assets for Security										
Scenario	SI hydro	NI hydro	Wind	Solar	Coal	Gas	Other	Storage excl Hydro	HVDC Link	AC Grids	Diversity Score
Present day	High	Low	Medium	Zero	Medium	High	Low	Zero	Medium	High	High
95% renewables	High	Low	Medium	Medium	Zero	Medium	Medium	Zero	Medium	High	High
100% renewables - ICCC 100%	High	Low	High	High	Zero	Zero	Medium	High	Very High	Very High	Low

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

Implication for the next phase as MBIE develops the scope for the business case for NZ Battery

We have:

- considered the policy context in which the NZ Battery study is being conducted
- developed a default operational model and pricing approach for an Onslow project for the purpose of testing how an NZ Battery solution would interact with the market
- analysed the likely security of supply and security settings in the current market with fossil-fuelled thermal removed in line with the 100 per cent renewable electricity in 2030 policy. s 9(2)(f)(iv)
- projected the security of supply and security settings in 2050 with Onslow in the market and the market design otherwise unchanged
- taken into account advice from MBIE and the team working on problem 1 on the method of intervention to meet government objectives
- demonstrated the market impacts of the intervention based on the Onslow scheme, s 9(2)(f)(iv)

This work provides the NZ Battery project a framework for thinking about the operation of a state-owned intervention in the market and sets out a full range of matters we recommend should be taken into account. The implication for the next phase of the project is that all of these matters should be resolved when the business case for a project is developed.

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s 9(2)(f)(iv)

Introduction

New Zealand has operated an energy-only wholesale electricity market since 1996. The market has been tested a number of times, governance arrangements have been changed twice, the Crown briefly re-entered the market, new participants have entered, existing participants have departed, consumers have been increasingly included in decision making, behaviours have been investigated, and outcomes have been challenged. The Crown's expectations of the market have evolved, most notably with the recent requirement of Government that electricity supply should come 100 per cent from renewable sources by 2030.

To date, thermal has filled several roles in the market, including peaking duties (security) and management of dry year risk (security of supply). With fossil-fuelled thermal gone, the market may struggle to fill those two roles. In addition, the Government's GHG emission agenda relies heavily on electrification of transport and process heat. As a result, demand may increase in the order of 50 per cent by 2050. The combination of removing fossil-fuelled thermal and increasing demand will test the market.

The move to 100 per cent renewables leads Government to ask the question whether the market will deliver an acceptable level of security of supply at least cost to New Zealand. Governments have asked this question before the market was conceived and at a number of points through its history, so this is not novel. The corollary is if Government cannot be confident that security of supply will be maintained without fossil-fuelled thermal in the market, it must consider what forms of policy intervention are available to it. The Government's focus is a storage option such as a pumped hydro storage scheme. Given the scale required, this could lead to two new pressures on the market: the Crown may re-enter the market, and the operation of the scheme could change market dynamics. We have been asked to consider the impact of an NZ Battery option, s 9(2)(f)(iv) [redacted], entering the market.

First, we consider what the wholesale price distribution might be without fossil-fuelled thermal in the market and the implications for investment and security of supply. Then we consider how an NZ Battery solution might functionally interact with the market in 2030 and 2050.

The issue around what wholesale price distribution looks like without fossil-fuelled thermal in the market is significant. Fossil fuelled thermal generation has performed a substantial role, directly and indirectly, in price formation since the inception of the market and price formation will be very different without it.

s 9(2)(f)(iv)

[redacted]

Our engagement

MBIE has engaged Sapere to assist with the development of the initial scope and assumptions for the business case evaluation for the NZ Battery project, specifically how any NZ Battery project will interact with and affect New Zealand's current electricity market. Sapere has teamed up with Energy Link and Chapman Tripp for this assignment.

MBIE is the primary government department responsible for advice to the Government on energy issues and associated legislation and regulation. The NZ Battery is a project being administered in its initial phases by MBIE.

The NZ Battery project is a government initiative to develop the business case for a solution or solutions to New Zealand's dry year risk problem, whereby in years with low hydro inflow, electricity generation can face a shortfall on average of around 5,000 GWh.

The Government has allocated a multi-year appropriation of $100 million to fund the project. The project is divided into phases. The first phase is the business case evaluations ($30 million), and the second phase is the engineering design of the selected options ($70 million). The project is being managed by a core project team, supplemented through services procured through a number of consultancies.

The NZ Battery project is established in conjunction with the Government's goals of 100 per cent renewable electricity by 2030 and net zero carbon by 2050. The central issue is how to best meet these goals while maintaining security of supply. This requires an examination of potential energy storage solutions and the consideration of the costs and benefits of each and what trade-off may need to be considered. In order to commence this work, MBIE identified two interrelated problems that should be addressed at the outset:

- Problem 1: Dry Year Size
- Problem 2: Market Interaction.

This report focuses on Problem 2: Market Interaction. The work has been conducted in parallel with work that focuses on Problem 1: Dry Year Size.

Problem 2: Market Interaction

The NZ battery project provided the following background to our assignment:

> The second problem MBIE is looking to address is how any dry year storage mechanism will interact with and affect New Zealand's current electricity market.
>
> Currently New Zealand operates an energy-only electricity market; that is, no separate capacity payment or similar mechanism exists. Experience from the government operation of the Whirinaki diesel power station a decade ago was that it was thought to have deferred private investment in generation. A dry year solution may have a similar effect, particularly if its operational rules permit it to operate at times of high prices, as well as low water storage.

Conversely, a dry year solution, such as a pumped hydro that purchases energy at low prices, may act to stabilise income streams for intermittent renewables, by removing very low to zero prices.

Accordingly, our deliverable is an assessment of how the currently configured electricity market would be affected for given levels of dry year storage invested in by the Crown under a range of operating arrangements.

The insights and information provided in the deliverable will inform the identification of an NZ Battery solution. It should include inputs into the initial scope and assumptions for the business case evaluation for the NZ Battery project. We understand it will help establish the framework for subsequent analysis.

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Moving to 100 per cent renewables

Policy objective

The broadest context for this task is the role of the electricity market. Liberalisation of state ownership of electricity generation and the introduction of wholesale markets was intended to address a number of roles which, in turn, would satisfy public policy objectives. The overarching question now facing the sector is whether the market in New Zealand will still be able to carry out all of those roles and meet the accompanying public policy objectives without fossil-fuelled thermal generation. Implicitly, if the answer is no, the need for an NZ Battery solution is made, and then the question is whether the market in New Zealand will still be able to carry out those roles and meet the remaining public policy objectives without fossil-fuelled thermal and with the NZ Battery project in place. In order to address those questions we have to also understand the likely operating model for any such project.

To recap, after more than two decades of retail competition and a wholesale market for electricity, the New Zealand electricity sector is performing reasonably well. Governance has changed along the way, issues have been debated, many improvements to the Code have been made, retail competition has demonstrably improved, dry years managed, and renewable generation built. For the most part, the sector has delivered the outcomes expected of it. There are areas where the industry hasn't done itself any favours. For example, increases in retail prices have not been well explained to consumers, and as a result consumers remain unconvinced that electricity prices are fair and reflect reasonable costs. Another example is the current trading environment where a constrained gas system on top of low hydro levels is leading to unprecedented and sustained high wholesale electricity prices.

One way to assess outcomes from the electricity sector is to analyse those outcomes against the following five public policy objectives—objectives that are enduring for policy makers across countries and time:

- security of supply – in the sense of supply meeting demand continuously without involuntary cutting of supply, or a heightened threat of cuts to supply
- efficient operation of the wholesale and retail sectors, with competition a primary tool for achieving efficiency
- efficient use of, and investment in, long-life assets (including transmission and distribution), guided by economic regulation
- meeting community or social minimums, including universal access to electricity and support for those who can't pay
- integrating environmental objectives while mitigating the impact on the industry of achieving these objectives, with a current focus on climate change.

From time to time, outcomes under one or other of these public policy objectives come to the fore, leading to heightened interest from – and potentially intervention by – government. In this report we take account of the sector's outcomes against each public policy objective, first with the implementation of the 100 per cent renewable electricity policy in 2030 and then the addition of an

NZ Battery solution based on an assessment of a full range of operating models. This is the same framework we used in our 2009,[6] 2014[7] and 2018[8] reports.

Underlying this framework is the idea that the wholesale market design we have supports and does not undermine all of the policy objectives. This was questioned in 2006 and 2009:[9]

> December 2006: Electricity Market Review A review of the electricity market, prompted by ongoing concerns about security of supply and price increases, was completed. The review concluded that the performance of electricity market arrangements had been mixed, and that while the current regulated market should be retained, a range of enhancements should be pursued to improve performance, particularly regarding security of supply.
>
> April 2009: Ministerial review of electricity market A Ministerial review of the electricity market was announced, with the review team being supported by a technical advisory group of six independent experts. The review was to examine market design and regulation and governance issues, drawing on work done by the Electricity and Commerce Commissions as input to the review.

Changes to market design were contemplated in 2014 although no action followed. Outcomes from the market were tested again in the 2018 Ministerial Review, and changes arising from that review continue to be implemented. Security of supply wasn't at the centre of this 2018 review. However, the 2018 review reinforced the needs for market solutions to be equitable:[10]

> In April 2018, the Minister of Energy and Resources commissioned an independent review into New Zealand's electricity market. The 2018-19 review was unique as it addressed the need for electricity prices to be fair and affordable, not just efficient or competitive. Another novel element was the review's focus on the consumers' point of view and their say in the direction of the sector.

Using this framework to describe the context for this paper, Government has introduced a policy targeted at environmental goals (100 percent renewable) that may impact on the electricity market's ability to deliver on the security of supply objective. The NZ Battery project is a response to the possible implications for security of supply. To answer the question that is the subject of this work, we need to assess whether the other ever-present policy goals (efficiency, investment, and equity of access to energy) would still be met with the renewable electricity supply target and an NZ Battery solution in place. Critically, the question is whether there will be sufficient investment in renewable generation and whether the wholesale market can still deliver efficient market transactions with the renewable electricity supply target and an NZ Battery solution in place.

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[6] Dr Graham Scott, Kieran Murray, Toby Stevenson (2009) *Determining outcomes or facilitating effective market processes: a review of regulation and governance of the electricity sector.*

[7] Kieran Murray, Toby Stevenson, Joanna Smith (2014) *Achieving policy objectives for the electricity industry.*

[8] Kieran Murray, Toby Stevenson, David Reeve, Corina Comendant, Ashley Milkop, Dean Yarrall (2018) *Electricity Sector Review 2018.*

[9] MBIE Energy Markets Policy Energy & Resources Branch, Chronology of Market design in New Zealand reform 2015.

[10] MBIE website https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-consultations-and-reviews/electricity-price-2018-19/

Can we anticipate a problem?

If there is a problem, it emerges from the answer to the question: why wouldn't the current electricity market deliver 100 per cent renewable by 2030, and security of supply with equity, transaction efficiency and investment adequacy? Some background into our electricity market will be useful here.

The concept of the spot market for electricity was driven by a need to encourage efficient investment in, and to seek private capital input into, grid-supplied electricity generation. The driver overseas, and particularly in the USA, was ageing fossil-fuelled thermal plants that were highly inefficient. In New Zealand, increasing inefficiencies within the New Zealand Electricity Department were a concern, but so was the fact that 30 per cent of the Government's fixed budget was being spent on electricity projects. The solution was an observable, independent central spot pricing mechanism with prices based on the marginal cost of generation, combined with low barriers to entry for new investment.

When an electricity market is highly competitive, generators seek to gain whatever volume they can from the spot market, providing they recover at least their variable (SRMC) costs. Clearing prices are set at the offer price of the most expensive generator and so prices tend to be the SRMC of those plants under effective competition.

In the early days of an electricity spot market, this was all that was needed as the LRMC of new plant was less than the SRMC of old inefficient plant and was able to displace the end-of-life assets. However, markets soon rationalised, and the SRMC of the marginal plant was no longer sufficient to necessarily attract new investment, especially for security of supply.

Many overseas markets, especially in North America, addressed this by having capacity markets. In a capacity market, generally, purchasers are given the obligation to secure enough capacity for their peak demand with a reserve margin. The purchasing of this capacity is intended to recover the fixed costs of generation, and the spot market is expected to clear at variable cost.

The capacity market mechanism couldn't work in New Zealand as, especially in the 1990s, New Zealand had plenty of hydroelectric peaking capacity. New Zealand's problem was dry periods and a need for firm energy to replace hydro for a period of up to many months. New Zealand's high proportion of hydroelectricity compared to overseas jurisdictions was also a factor. Hydro doesn't have significant variable costs in the sense of costs that are avoidable in the short run, but hydro must be priced in a market to ration storage and allocate it to periods where it is most valued. Instead, hydro plants offer on the basis of short run opportunity costs,[11] which easily adapt to the cost of scarcity. New Zealand needed a different mechanism.

The mechanism chosen had at its core an 'energy-only' market, which simply means no capacity market and prices are expected, at times, to rise above SRMC during times of scarcity to enable the recovery of fixed costs and enable revenue adequacy for new investment (see Figure 8).

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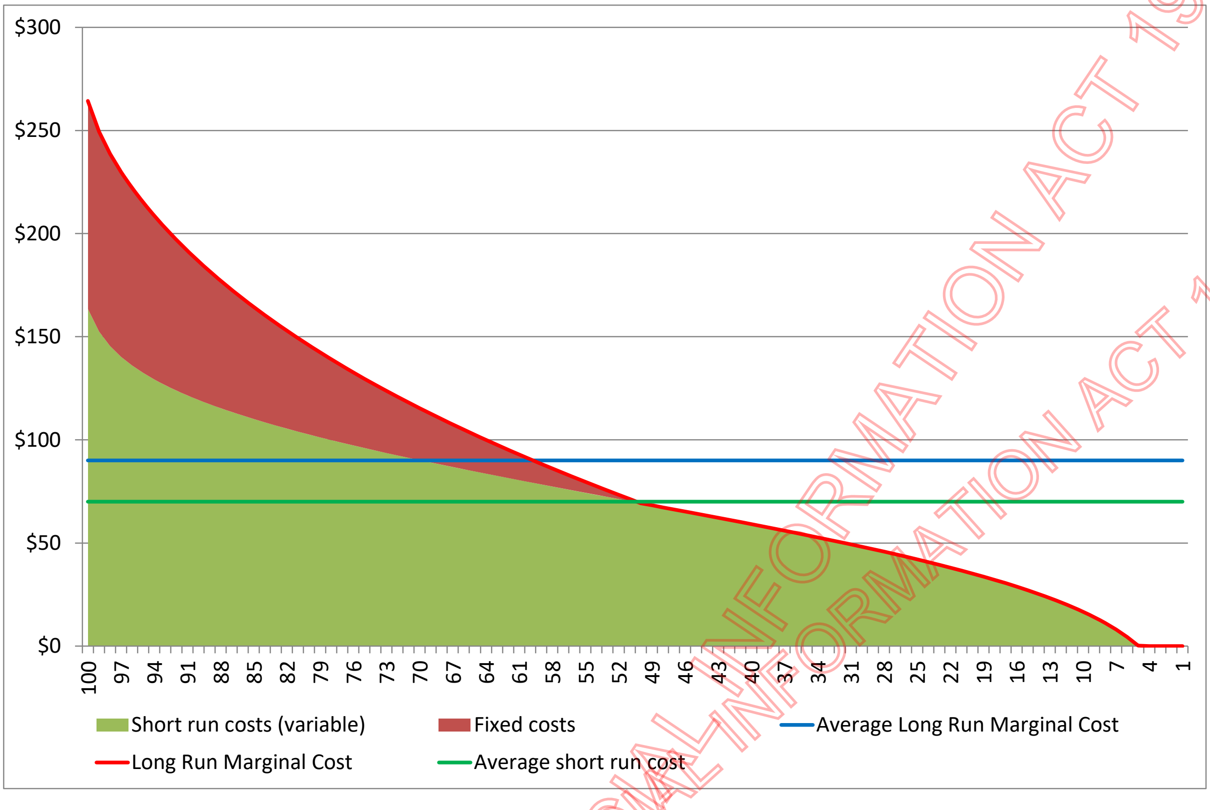
[11] See explanation of water values in Appendix B.

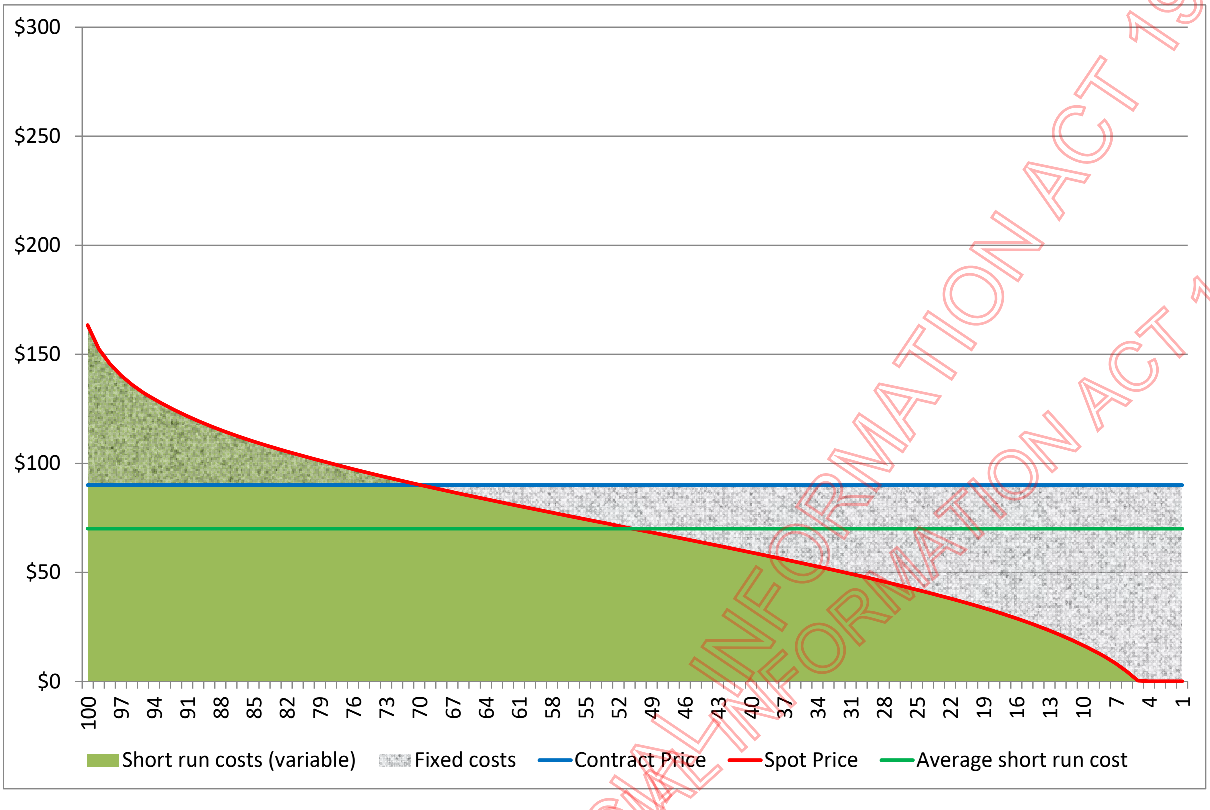
Figure 8: Illustration of how the energy-only market contributes to fixed and variable costs



However, an energy-only spot market also needs working contracts markets. Without financial arrangements to smooth cashflows, retailers could go bankrupt in one dry year and generators ensuring security of supply could go years before they stand a chance of making an economic profit. Contract prices should strike above the current average electricity spot price. This wedge between contract prices and the average electricity spot price is the risk premium for retailers to transfer their purchase volatility to a generator, and this risk premium pays for generator fixed costs (see Figure 15).

This might suggest that efficient contracts should be of long duration so that generators are sure of recovering fixed costs and purchasers are sure of managing risk. Theoretically, in a perfect contracts market where every party has the same information, understands the risk and there is no market power, then contract duration doesn't matter. Counterparties will be able to determine the efficient price. However, contract markets are never perfect and, in electricity, access to relevant information and understanding risk are particular problems. In this context, longer duration contracts don't help. The efficient price agreed between the parties is still a forecast and information asymmetry, hidden or misunderstood risks, and market power can still disrupt an efficient transaction.

Figure 9: Illustration of how contracts contribute to fixed and variable costs



As the generator now has the risk, through its contract obligations, and is recovering fixed costs, then the generator will run when it needs to at its SRMC. In other words, in theory and with effective competition, an energy-only spot market with a well-functioning contracts market achieves the same thing as a capacity market but with no regulatory intervention. However, how well functioning either the spot market and/or contracts markets are is often a matter of debate.

So the substantive question is: can the New Zealand energy-only spot market and accompanying contracts market function well – i.e. deliver a secure market, cover dry year risk, discover prices through a competitive process, incentivise sufficient investment, at prices consistent with equity of access – while moving to 100 per cent renewable electricity by 2030?

Can the current market deliver?

The distinction between New Zealand's electricity generation when the market started in 1996 compared to the market that would exist in a 100 per cent renewable 2030 is key to assessing the problem.

In 1996 there was sufficient fossil-fuelled thermal generation, with hydro operators' shadow pricing to fossil-fuelled thermal, that low prices weren't particularly low.[12] Fossil-fuelled thermal generation has high variable costs and relatively low fixed costs. Therefore, when hydro inflows were high, average prices were often still relatively high, and contract premiums, similarly, didn't need to be very high.

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[12] See further discussion in Appendix B on water values

Even the low prices, at the time, were sufficient to make a significant contribution to the high fixed costs of hydroelectricity.

s 9(2)(f)(iv)

[redacted]

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s 9(2)(f)(iv) [redacted]

The Ministerial Inquiry of 2009 made recommendations on this that were given effect under section 42(2)(b) of the Electricity Industry Act 2010. This addressed the issue by recommending a scarcity pricing regime whereby, in a situation where the lack of peak generating resources might constrain the market price model and lead to lower prices, a scarcity price should be administered.[14] As the market solution required a relaxation of security standards, increasing the chances that load would be interrupted, the recommendation was that the scarcity price should be equal to the Value of Lost Load (VoLL). It was determined that the administered scarcity price should be no less than $10,000/MWh and no more than $20,000/MWh. In the latter case of $20,000/MWh it was determined that, for any solution that cost more than $20,000/MWh, that it would be more economic to reduce load, preferably the most price-sensitive load.

The scarcity pricing regime is, in effect, performing some of the role of a capacity market. By ensuring prices don't go too low during periods of scarcity, the scarcity pricing regime:

- provides incentives for short-term peaking solutions
- lifts the average generation price, helping the recovery of fixed costs
- increases the cost of shortage for hydroelectric operators, affecting water value calculations.

Evidence

After around 2007 New Zealand's national electricity demand growth rate changed significantly. It went from steady linear growth to not growing on average. As the market had continued to anticipate demand growth, and because power station projects were already underway, a significant surplus of generation was available from 2009 until 2015. As a result, prices stayed soft for a few years, though 2012 was a dry year. As would be expected, low electricity prices lead to rationalisation, and the Southdown and Ōtāhuhu power stations were decommissioned at the end of 2015.

With the removal of the fossil-fuelled thermal capacity in 2015 and a dry period in 2017, prices started to firm and remained higher than they had done over the earlier period. Then the tightening of the gas market from 2018 strongly affected prices, which have been at record levels since.

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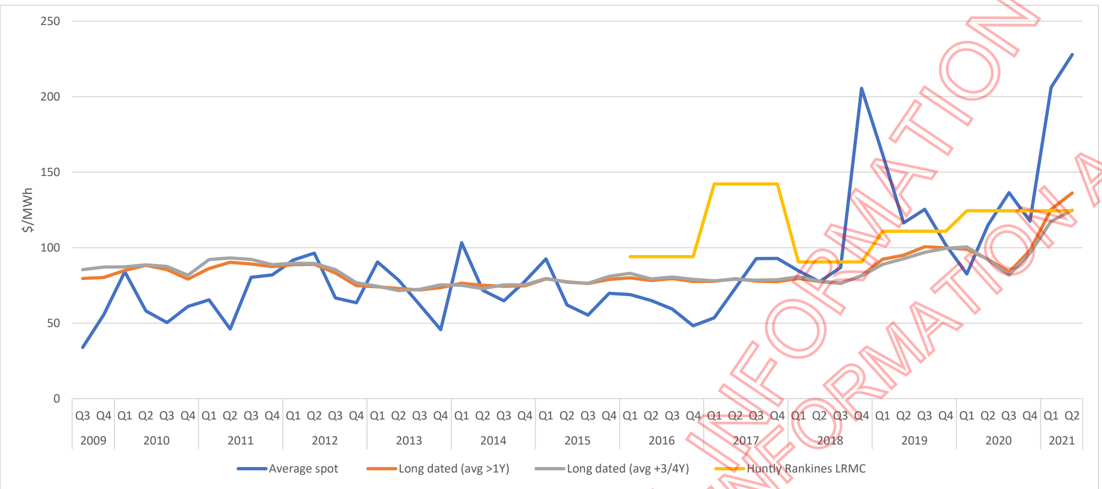
[14] Described in the Act as "imposing a floor or floors on spot prices for electricity in the wholesale market during supply emergencies (including public conservation campaigns)".

The spot price series is shown in Figure 10. Also shown is the Huntly forward-looking total cost of energy (LRMC), which we have assessed from 2016. This is forward looking because it includes no sunk costs, but does include fuel costs, variable O&M, and the fixed cash costs required to retain the units. Also shown are prices of future contracts entered in to well ahead of the contract maturity, i.e. they should reflect the efficient contract price of forecast spot plus a risk margin.

Figure 10: Long dated futures vs spot vs HLY LRMC



From 2009 to 2012 contract prices were higher than average spot prices and were almost equal to our lower assessment of Huntly LRMC, i.e. contracts were recovering fixed costs and encouraged the retention of security of supply capacity. From 2012, when:

- the market easily weathered a significant dry period,
- participants recognised that demand was not going to grow again immediately, and
- the Electricity Authority strongly supported retail competition

there was a perception that prices would continue to be flat and risks would be lower, leading to contract prices moving closer to variable spot prices. Now there was no risk premium and no contribution to fixed costs from contract prices. Under this regime, fossil-fuelled thermal generation exited the market. This is not the first time this has occurred. Competition and the perception of a benign market also led to low contract prices and under-contracting in 2000, then a dry year in 2001 stressed the market and lead to the exit of On Energy, which had been New Zealand's largest retailer.

Once the market tightened from 2017, contract prices lagged spot prices, i.e. they were not reflecting the actual risk, and retailers weren't contracting so much ahead for multi-year risk, e.g. dry period risk. Tellingly, the total cost of energy of the Huntly Rankine machines increased as the two-for-one carbon credit policy rolled off and then ETS reforms pushed up carbon prices. Of course, a lift in the total cost of energy of Huntly Rankines wouldn't lead retailers to believe that risks had also increased. However, as can be seen, the futures contracts weren't pricing in risk. However, few parties, if any, anticipated the level of price increase that occurred from 2018 on.

s 9(2)(f)(iv) [redacted]

- [redacted]

s 9(2)(f)(iv) [redacted]

Conclusion

s 9(2)(f)(iv) [redacted]

Can we rely on market-based interventions?

The market-based intervention that can be applied is some form of mandatory security of supply insurance for all retailers. As the mandated requirement would be on all retailers, this would preserve retail competition but at higher prices than will clear in the spot market – equivalent to the LRMC of new security of supply, given set reserve capacity requirements.

s 9(2)(f)(iv) [redacted]

s 9(2)(f)(iv) [redacted]

s 9(2)(f)(iv) [redacted]

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Will a market intervention work?

Despite the possibility of above interventions, the market could still fail as a result of two possibilities:

1. The economic options for security of supply convey too much dominance to one or more market participants.
2. Despite the interventions, no party would invest in the most economic security of supply option.

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s 9(2)(f)(iv)

Market power

Market power is a term that means that a party to a market is able to influence price without losing sales, or where the price uplift compared to the loss of sales is more profitable than committing their full volume. Some market power is accepted in energy only electricity markets during periods of scarcity so that prices lift to the level for recovery of long run fixed costs, which encourages investment in security of supply as described above. Ideally markets should have no market power, so that consumers are paying the least cost for their purchases. However, most markets are not perfect and the term 'workably competitive' is often used to describe markets where there may be market power but the exercise of it is not excessive. This is context-specific; for example, a 100 per cent renewable energy only electricity market that was perfectly competitive in the short run would fail in the long run as prices would never lift high enough to encourage new investment when needed.

There are two key attributes to market power that are equally important from an effective competition perspective: the existence of market power, and the incentive to exercise it. Markets are still considered workably competitive where there is potential for market power to be exercised but it is not exercised. The Electricity Authority has spent a great deal of time trying to ensure that mechanism in the Code disincentivise generators from exercising market power for example.

For this paper the issue is whether the existence, or potential exercise, of market power might be changed with the introduction of a single storage facility into the market. We have not addressed the issue directly but have factored the issue into the default operating model we used for the modelling. This model has, we consider, the least risk of exercising market power mainly because it would prioritise meeting dry year needs over any other objectives and its earnings would be regulated thereby reducing the incentive to manipulate the market.

Best option cannot meet private investment criteria

It could also be the case that the best security of supply option cannot meet investor criteria. For example, the potential Lake Onslow scheme is very large and involves significant tunnelling and civil works. At a nominal cost in the order of billions of dollars, geotechnical risk could make it look too big and too risky to private investors. Similarly, private investors may conclude that the resource consenting issues are too significant for a private investor.

Evidence

The assessment of whether security of supply options would need to be in public ownership is a function of what option looks to have the best business case. An option where security of supply was highly distributed – e.g. overbuild of wind farms, if this can be encouraged using market interventions – could probably be left to private investments, whereby Onslow probably could not.

As a rough guide to the level of distribution of security of supply that might be required for private investment, we use the Herfindahl-Hirschman Index (HHI) to assess the potential for market power in the provision of security of supply. HHI is a measure of market concentration which can be used as a qualified guide for the potential for market power. Generally, a HHI of 2,500 or less is required for a market to be considered moderately competitive.

Assessing a couple of possible and illustrative options, the results are shown in Table 2.

Table 2: HHI assessment of market power in security of supply

Security suppliers	**Current**		s 9(2)(f)(iv) [redacted]
	GWh	%	[redacted]
Pukaki	1,600	34.8	[redacted]
Tekapo	290	6.3	[redacted]
Waikato	560	12.2	[redacted]
Huntly	1,100	24.4	[redacted]
Stratford	1,000	22.2	[redacted]
Supplier 1			[redacted]
Supplier 2			[redacted]
Supplier 3			[redacted]
HHI	2,500		[redacted]

s 9(2)(f)(iv) [redacted]

[redacted]

Conclusion

In this section we have highlighted two questions that the NZ Battery project has to consider as context for the business case:

- Will there be sufficient investment in renewable generation, and can the wholesale market still deliver efficient market transactions with the 100 percent renewable electricity supply target and an NZ Battery solution in place?
- Why wouldn't the current electricity market deliver 100 per cent renewable by 2030, and security of supply with equity, transaction efficiency and investment adequacy?

s 9(2)(f)(iv) [redacted]

[redacted]

NZ Battery – a discussion case

Getting started

We have modelled scenarios as per our brief. We have found it necessary to zoom out and clarify the context that the market would operate in. s 9(2)(f)(iv) [redacted] The modelling outputs provide quantitative answers to some of the questions, but the analytic framework also provides MBIE a way to think about the problems holistically.

Overview of the analytic framework

Figure 11 and Figure 12 tease out the analytic framework for the current market without fossil-fuelled thermal (the counterfactual) and for the market where a Crown-owned NZ Battery solution is created. We base the modelling on the potential Lake Onslow pumped hydro storage scheme, as the early evidence is that this is the most accessible solution if the 100 per cent renewable market fails to deliver security of supply at least cost. We revisited this framework once we saw the early results from modelling because the risk of failure to supply in the North Island came through clearly in the modelling.

Figure 11: Analytic approach to understanding the “current market” i.e. in 2030

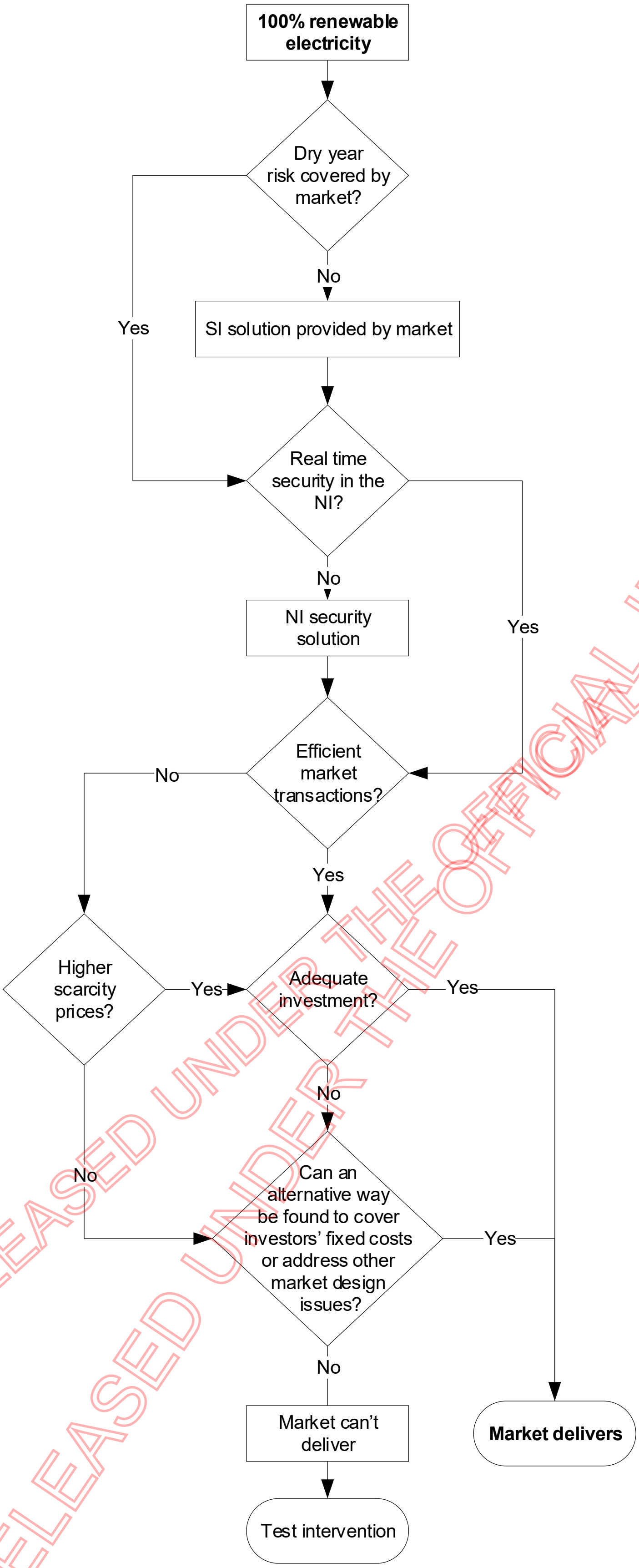
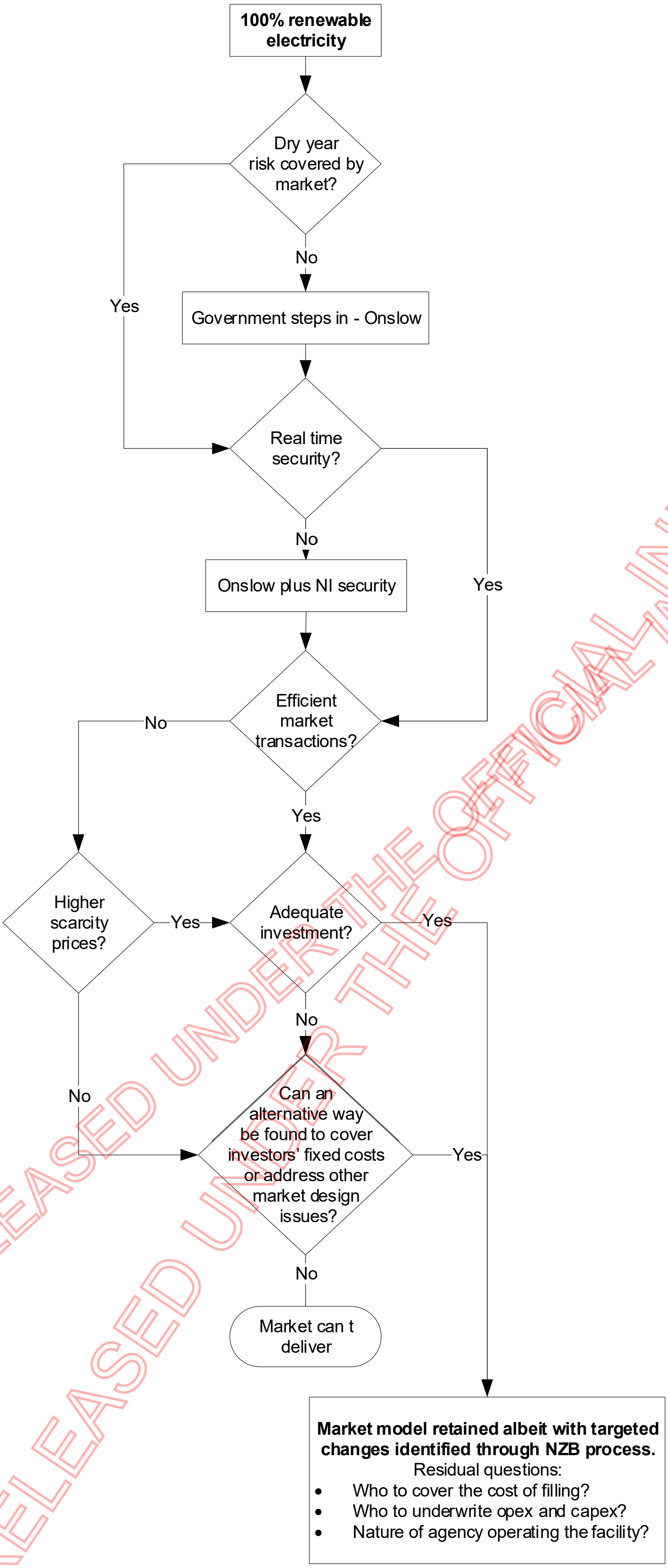


Figure 12: The analytic approach to understanding the current market with Onslow added in using our assumptions for the operational model



Dry year risk

We use the terms 'security of supply' and 'dry year risk' interchangeably. This is the requirement for large volumes of energy to make up a deficit of hydro generation which may last several months. It is not time-of-day specific; it is sufficient to provide volume day by day to firm other generation sources.

Real time security

In this paper, real time security is the risk of non-supply at a particular time. That might be a cold, dark calm winter peak or when a generator fails or the HVDC is constrained.

Efficient market transactions

Efficient market transactions include price formation in the spot market reflecting scarcity of supply when it should and stimulating investment where prices exceed the LRMC over time on average. There is a presumption that market power is dealt with by the market regulator. W we chose an independent entity, regulated for cost recovery only, operating continuously on the basis of a water value approach for our modelling because we think this model will have the least risk of a market power problem.

Efficient market transactions include a thriving forward market. It is possible that the NZ Battery operator offers dry year contracts as part of its activity, but obviously this could not be at the expense of its preeminent operating objective.

Higher scarcity prices

With no fossil-fuelled thermal setting prices in the dry year role and the peaking role, the supply curve may be much steeper than is the case currently. In the absence of interventions or changes in market design, scarcity prices would become a bigger feature of wholesale prices, and some thought may have to go into what is acceptable for the level of prices that signals scarcity. If those high prices are suppressed, that would raise the risk of underinvestment.

Adequate investments

Adequate investment is critical for the success of the market. Investment is required to replace fossil-fuelled thermal generation, meet increased demand from decarbonisation, contribute to security of supply and contribute to real time security.. If a scheme at Lake Onslow went ahead there would also be the need for gernation to fill the dam initially and after events.

Alternative ways for investors to cover fixed costs or address other market design issues

If the workings of the market do not yield spot prices or forward prices that encourage investments or if other issues arise from the 100 per cent renewable policy, there may be ways the market design can be advanced to create incentives or deal with other problems. This paper is not intended to address the problems. It is to provide a first look at a context for understanding how all of these issues fit together.

Residual questions

These are the questions our analysis does not address but which will have to be addressed if the case for an intervention is made.

Operating models

In order to understand *the potential market interactions or effects which MBIE will need to consider when completing the evaluation of options to address the dry year problem or issue* we have to understand:

- the mandate the organisation interacting with the market has, and
- the objective function the organisation's traders apply when they are interacting with the market.

When thinking about the possible operating model for NZ Battery, there will be a number of characteristics to work through, including:

- level of independence from the Crown
- operational settings
- revenue or profit objective
- price setting.

For each of these there will be a range or spectrum of possibilities.

For example, the possible independence settings could include a spectrum from Crown control, to Crown entity, to SOE, to bespoke statutory framework guaranteeing independence (such as the Reserve Bank), to private ownership.

s 9(2)(f)(iv) [redacted]

s 9(2)(f)(iv) [redacted]

- [redacted]
- [redacted]

Resolving the revenue or profit settings will still leave choices to be made on how NZ Battery should set prices.

We assume, given the scale and potential market power of NZ Battery, that revenue or profit settings will be at the cost recovery or regulated end of the spectrum of choices rather than unconstrained pursuit of profit. But even where revenue or profit is regulated, on say a one-year or five-year basis, that still leaves considerable room for choices to be made about how to set prices.

s 9(2)(f)(iv) [redacted]

s 9(2)(f)(iv)

[redacted]

Given the potential scale of NZ Battery in the electricity system and the fact that it would be set up to exercise judgment to advance the public policy objective of security of the system, there is the potential for the analogy of the Reserve Bank to illuminate some of the choices to be made in establishing NZ Battery, in its independence, articulation of a primary objective of security of the system, and potential for secondary objectives where they don't detract from the main mission.

The final model would have to be tested against some criteria. For example, for a given model, does the market:

- meet security of supply requirements?
- meet real time security requirements?
- support efficient market transactions?
- encourage sufficient investment?
- achieve an equity policy objective?

We have not modelled Onslow's financials because we don't know what the capital cost or operating costs would be. As a result we can't assess whether its revenue will be sufficient or whether there would be a net cost that requires underwriting. If there is a net cost, those could be met from taxes, levies, or a charge set against generators along the lines of the current HVDC charge. We haven't needed to address the level of costs or the approach to cost recovery for the modelling. For this report the only point we have to make is that a levy approach to cost recovery would alter the distribution of price outcomes from the modelling.

How continuous operation would work

s 9(2)(f)(iv)

[redacted]

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[redacted]

s 9(2)(f)(iv)

[redacted]

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[redacted]

The operating model we have used in our analysis

In Figure 16 below we set out a matrix of possible entity styles and active regime approaches. We suggest five criteria for assessing each combination and permutation of operating entity and operating modes.

s 9(2)(f)(iv)

[redacted]

The modelling

Introduction

Modelling of the electricity market was undertaken to test the impact of Onslow on the electricity market as it is likely to be in both 2030 and 2050, on the assumption that generation is 100 per cent renewable by 2030, i.e. that there are none of the current fleet of fossil-fuelled thermal generators remaining in service by 2030.

s 9(2)(f)(iv)

[redacted]

Our approach

In both 2030 and 2050, the market was modelled initially without Onslow, with only enough new plant built so that each achieves its target return on investment (RoI),[17] more or less, in the year of interest. To build more new plant than this would depress prices, causing new generation to fall short of its target RoI, and to build less would see new plant recovering greater than target RoI, neither of which is likely, on average, in a competitive market.[18]

But this test for new plant building is not an exact test. In the real market, prices might turn out higher or lower than expected. In the modelled market, it is simply not possible for all new plant to simultaneously achieve its exact target RoI, so the test for a 'balanced build' is that new plant is, on average, close to achieving target RoI in the year of interest. An additional complication is that new grid-scale projects are large, and there can be periods when adding one new project reduces RoI below target for all new plant, but without that one project, target RoIs are exceeded for all new plant: hence some judgement is required as to when sufficient new plant is built.

Geothermal plant tends to outperform wind and solar farms because it runs baseload, so it gets the advantage of price spikes that occur when wind and solar output is low, e.g. on cold, calm winter evenings. But there is a relatively small supply of new geothermal plant, whereas wind and solar farms have a much greater supply and will be required in significant number to satisfy demand in 2050.

There are two models involved: I-Gen[19] and *EMarket*. I-Gen works out which plant to build and when, with the list of new plant known as a 'build schedule', whereas *EMarket* models the market including the new and existing plant. This configuration is ideal for this exercise where the question of adequate

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s [redacted]

[17] The test is actually performed on target EBITDAF, which includes cash RoI.

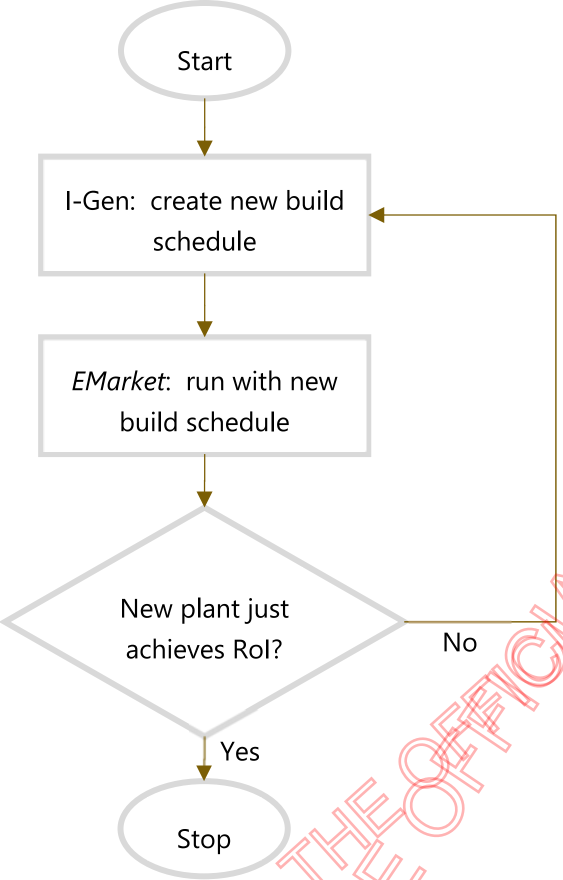
[18] After 2008 we saw a period of years when demand was expected to follow its long-term growth path, and a lot of new capacity was added through to 2014. However, the growth rate of demand fell dramatically after 2008, and the end result was a surplus of capacity.

[19] It is planned to integrate I-Gen into *EMarket*, but currently the two models are separate.

generation investment is critical to Government's policy objectives for the sector. It allows us to calibrate the generation build then test to see if security of supply and security is achieved.

There is an iteration between I-Gen and *EMarket* as shown below.

Figure 17: Creating a final scenario



I-Gen has inputs which allow it to calculate the levelised cost of energy (LCOE) of each potential new project. LCOE is equal to the constant average annual electricity price attained by the plant over its lifetime that just achieves target RoI after covering all cash costs. In simple terms, if a project reaches a point where its forecast GWAP[20] exceeds its LCOE, then it becomes a committed project and starts construction.

The emphasis in the modelling was on exploring market impacts, rather than on creating, to the extent possible, models of 'perfectly built' markets, because achieving these could hide potential negative impacts on the market or hide the potential for instability. For this reason, the iterations shown above were not taken to the point where a perfect solution was attained. It was also observed that in 2050 the high frequency of occurrence of DSR and SLR dispatch caused prices to become highly sensitive to small changes in the build schedule, and also to assumptions around how much

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[20] Generation-weighted average price.

short-term battery storage and capacity was available; on the latter point, for example, a key uncertainty is how much EV battery capacity will be available to supply the market, and at what cost.

The forecast GWAP must be calculated carefully because it is a function of a project's location on the grid and its output profile. For example, the output of windfarms in New Zealand, on average, correlates negatively with price, so the ratio of a wind farm's GWAP to the TWAP at its GIP is less than 1. There is no standard definition for this effect, and it goes by the name of 'GWAP/TWAP', peaking factor or market premium, with the latter defined as GWAP/TWAP -1. For wind farms, the market premium is less than zero and currently averages about -10 per cent, though over time it is expected to fall further as more windfarms are added.

The solar market premium is currently greater than zero, but will fall over time as more solar depresses summer prices.

Geothermal generation is baseload, so its market premium is close to zero.

The Supplier of Last Resort (SLR), which partly takes the place of fossil-fuelled thermal peaking generation, has a large positive market premium.

The final run in *EMarket* uses existing generation, less (forced) retirements, but with new plant commissioned according to the final build schedule from I-Gen. A run for 2030 or 2050 consists of 89 runs of this year but with a different historical inflow sequence each time, starting with inflows from 1931 and ending with inflows from 2019: 89 inflow years in total.[21]

To obtain a realistic spread of storage outcomes, the final *EMarket* run was also iterated a couple of times, taking final storage for each inflow year and using this as the starting storage for the immediately following inflow year in the next *EMarket* run. This gives a spread of starting storage values, thus we capture the impact of, for example, consecutive dry years or consecutive wet years. There is a limit to this approach, however, as it will not fully capture the impact of more than two consecutive dry years, and it cannot be used to stress-test the market using multiple dry years. But the spread of storage trajectories actually used was sufficient to allow market impacts to be assessed without skewing results.

EMarket was run in three-hour mode, giving a total of 2,920 steps in each inflow year. *EMarket* can run down to the half-hourly level, which matches the granularity of the spot market, but this would require run times of around nine hours. Three-hour mode achieves a good balance between model run times and the need to model the ability of the market to meet peak demand.

The core elements of *EMarket* are listed below.

1. A grid consisting of 220 nodes and around 290 transmission lines: this provides enough detail to allow accurate calculation of power flows and losses on the grid including the high voltage DC (HVDC) link that connects the two main islands, along with accurate nodal spot prices.

2. Detailed modelling of major hydro systems including large storage reservoirs, head ponds, individual generating stations, minimum flows and water values.

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[21] Mean inflows is also run as a scenario, so each run actually has 90 inflow scenarios.

3. Detailed modelled of wind and solar farms, including use of historical wind speed data for wind generators back to 1980.

4. Detailed modelling of geothermal generation.

5. Full modelling of the process of generators submitting offers to the System Operator.

6. Full modelling of the dispatch process and the process of calculating the final spot price used for settlement.

7. An internal programming language that is used for a variety of purposes including modelling scheduled maintenance of large generating plant.

EMarket can run with the thermal rating limit constraints active on all lines, thus capturing the pricing and dispatch effects of network congestion, but this can slow runs down significantly for little value. We used our usual approach, which is to enforce the HVDC limits and, since Tiwai is not included in either year, the post-upgrade limits between the Clutha and Waitaki valleys.

What the modelling is not

The focus of this report is the impact on the market of Onslow, or a similar large battery, intended to ensure that SoS is preserved with once it is added to the market after the move to 100 per cent renewables supply. We undertook enough modelling to allow us to understand these impacts, but this did not require the modelling of a fully developed 100 per cent renewables market. For example, and as noted above, the build schedules were not iterated to a fully converged solution. That being said the market models a lightly dystopic market for the purpose of highlighting potential negative impacts.

Since the modelling is market modelling, it reflects the dynamic processes inherent in the electricity market; it is not a technical optimisation of SoS or security.[22]

Furthermore, we did not systematically seek to determine which, if any, aspects of the current market design might need to change, and how, to sustain a market of 100 per cent renewables. However, where the modelling showed that the current market design may struggle or fail, then we have noted this in the discussion and conclusion.

How do we know that Onslow solves the dry-period problem?

It is not a given that a large storage battery such as Onslow is required to maintain electricity supply during dry periods. From a purely technical perspective, if enough renewable generation capacity were to be built, then there could be sufficient capacity to always meet demand. But to achieve this would require a substantial ‘over-build’ because renewable generators such as windfarms and solar farms cannot be relied on to produce energy; they rely on wind and sun.

During a dry period, when hydroelectric generation is reduced, the additional capacity would provide the additional energy.

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[22] By this we mean that dispatch is based on prices as per the market design and not on the physical capability of plants.

But there is a particular problem that occurs on cold, calm winter evenings when the sun has set and demand peaks: in these cases, solar generation is zero and total wind generation may be very low indeed. Something is required to fill the gap, and that 'something' is generation that can be relied on to produce energy, including geothermal generation, biomass-fuelled generation, other forms of renewable generation, batteries, demand-side response (DSR) and supply of last resort (SLR).

Batteries in this context means any source of stored electrical energy provided into the market for reserve duties. They have high capacity but low overall storage, so they charge during off-peak periods when prices are low, and discharge (generate) during peak periods when prices are high, with the charge-discharge cycle being quite short-term, typically between one and several days. The battery capacity could be supplied by grid-scale batteries or by small-scale batteries that sell power back to the grid, and these could be in EVs, houses, businesses, or they could be attached to generators such as wind and solar farms.

DSR represents demand that is contracted to turn off when the price reaches certain thresholds, and it is modelled by DSR generators that offer at between $2,000/MWh and $8,000/MWh, with total of 100 MW in 2030 and 150 MW in 2050. To qualify as DSR, the response must be firm, in the sense that it has contracted out of any discretion as to whether it can be dispatched off at any time.

SLR is priced at $10,000/MWh which is the value that is currently specified in the Code as the lower end[23] of the price that will be set when there is a shortage of generation offered into the market relative to actual demand. The assumption here is that SLR would be offered at or just below $10,000/MWh and it could represent very expensive generating capacity that operates infrequently, or ultimately it could be non-supply.

Without a large battery such as Onslow, which has seasonal storage, the over-build is required to ensure SoS and security, to the extent possible. But with Onslow in the market, even though it may solve the SoS problem, some over-build may be required to ensure security. If Onslow contributes to SoS and to security, then the over-build might reduce even further once Onslow is added to the market.

Nevertheless, the basic test that Onslow makes a substantial contribution to the dry-period problem is that its presence in the market reduces the over-build to the extent possible, while still preserving SoS.[24]

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[23] In a scarcity pricing situation, prices are scaled so that the GWAP in the affected island sits between $10,000/MWh and $20,000/MWh. If the GWAP is initially less than $10,000, then all prices are scaled up until the GAWP equals $10,000. If the GWAP is initially greater than $20,000, then all prices are scaled down until the GAWP equals $20,000. There is a 'safety valve' that operates if the average price remains above $1,000/MWh for a week.

[24] The full list of assumptions is contained in Appendix A.

Results

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[26] See Appendix B for a full discussion on water values and reference to the role of a buffer in that context.

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[redacted]

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Price distribution

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

Diversity and the HVDC link

s 9(2)(f)(iv)

[redacted]

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[redacted]

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In Table 5 these criteria are assessed on the following scale:

- Zero – zero impact
- Low – impact is under the level required for Code compliance (i.e. 30MW)
- Medium – impact is significant (i.e. greater than 30MW) but less than the current plant that most influences the criteria (generally a Manapouri unit (120MW) in the South Island and Huntly unit 5 (400MW) in the North Island)
- High – equal to the current plant that most influences the criteria as above
- Very high – significantly higher than the current plant influences so that the NI WCM will need to be redefined.

Table 5: Diversity and reliance on key assets

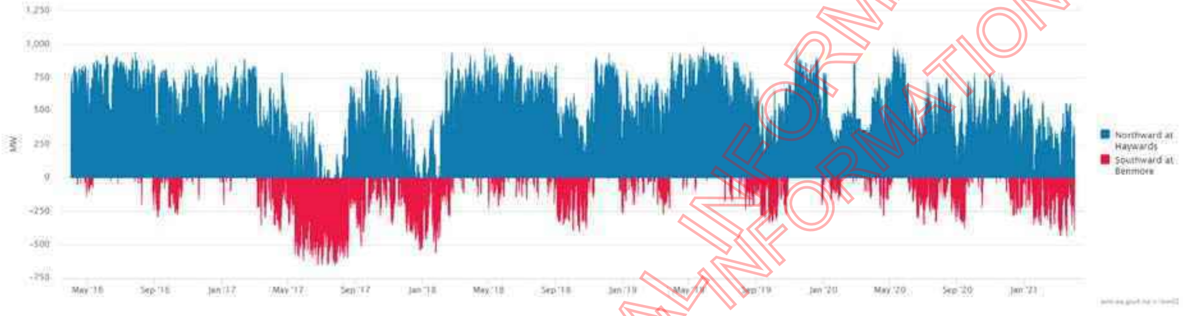
	Reliance on Key Assets for Security									
Scenario	SI hydro	NI hydro	Wind	Solar	Coal	Gas	Other	Storage excl Hydro	HVDC Link	AC Grids	Diversity Score
Present day	High	Low	Medium	Zero	Medium	High	Low	Zero	Medium	High	High
95% renewables	High	Low	Medium	Medium	Zero	Medium	Medium	Zero	Medium	High	High
100% renewables - ICCC 100%	High	Low	High	High	Zero	Zero	Medium	High	Very High	Very High	Low

s 9(2)(f)(iv)

[redacted]

As shown in Figure 34, HVDC north flows have not exceeded 985MW over the last five years. With either pole capable of 700MW[30] when operating by itself (single pole mode), then the extended loss of a pole reduces North Island supply by no more than 285MW, less than Huntly unit 5 (the largest unit in the North Island, with maximum output of just over 400 MW depending on ambient conditions). Even though Pole 3 of the HVDC would be transferring 565MW when both poles are peaking at 985MW, because Pole 2 can instantly pick up Pole 3's load when it trips and overload for a short period, it is a lower CE risk than Huntly unit 5. The risk of both poles tripping at the same time is managed as an ECE risk; however, this generally hasn't required more reserves than Huntly unit 5 at the levels it has been operating at. Therefore, the risk for the HVDC currently is assessed as greater than 30MW and less than 400MW, and is medium.

Figure 34: HVDC flows April 2016 to March 2021



Source: Electricity Authority

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s 9(2)(f)(iv)

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Transmission

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Modelling key takeaways

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Implication for the next phase as MBIE develops the scope for the business case for NZ Battery

We have:

- considered the policy context in which the NZ Battery study is being conducted
- developed a default operational model and pricing approach for an Onslow project for the purpose of testing how an NZ Battery solution would interact with the market
- analysed the likely security of supply and security settings in the current market with fossil-fuelled thermal removed in line with the 100 per cent renewable electricity in 2030 policy. s 9(2)(f)(iv) [redacted]
- projected the security of supply and security settings in 2050 with Onslow in the market and the market design otherwise unchanged
- taken into account advice from MBIE and the team working on problem 1 on the method of intervention to meet government objectives
- demonstrated the market impacts of the intervention based on the Onslow scheme, s 9(2)(f)(iv) [redacted]

This work provides the NZ Battery project a framework for thinking about the operation of a state-owned intervention in the market and sets out a full range of matters we recommend should be taken into account. The implication for the next phase of the project is that all of these matters should be resolved when the business case for a project is developed.

Appendix A. Assumptions

We have a made a number of assumptions in order to provide a first cut of how Onslow would interact with the market and what market outcomes would look like. The exercise is made more challenging by the fact that we had to make some assumptions to model, the starting point being the market without fossil-fuelled thermal generation performing the roles we are familiar with today and contributing to price formation as it does today. Individually, some of these assumptions could be debated at length, and for future modelling there may well be some changes.

Assumptions common to 2030 and 2050

The modelling was undertaken assuming inflation is zero, so all costs, prices and revenues are expressed in real terms.

At the outset we determined:

s 9(2)(f)(iv)

[redacted]

The common key assumptions are listed below.

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[redacted]

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s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv) [redacted]

The offer price for wind generation

To be clear, the \$12/MWh offer price of windfarms creates a hierarchy for spill in which wind is ‘spilled’ before water and solar, the latter offered at \$0.01/MWh. It may or may not be the case that windfarms offer at this price in future, because their maintenance contracts may have both fixed and variable pricing elements. Currently, the risk of being dispatched off[41] is low for windfarms, so there is typically no need to offer at SRMC and hence to bear the costs associated with frequent dispatch instructions. But in future, there will be long periods when prices are close to or below windfarm SRMCs, and their owners may well consider it worth the cost and effort required to be dispatched off when prices reach or fall below \$12.

In terms of the modelling, the primary benefit of pricing windfarms at \$12 is that windfarms become the prime indicator of over-build; this leads to longer periods when windfarms are dispatched down, and hence to a fall in their average capacity factor and GWAP.

The carbon price

A modest carbon price of \$46 per tonne CO_2 was assumed, although it plays no role in the detailed modelling. Geothermal generation is the only renewable generation modelled that has any emissions, and if the carbon price were to get to very high values, this could change the order in which new plant is built, potentially favouring wind and solar before geothermal. However, it was important to include some geothermal plant amongst the new plant built in 2030 and 2050, to contrast to the other renewable technologies and, especially in 2050, new geothermal plant gains a much better financial return than wind and solar, so would still be built even with much higher carbon prices.

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s 9(2)(f)(iv) [redacted]

[41] Instructed by the system operator to generate less than indicated by generation offers

DSR

Four DSR suppliers are modelled, with two located in each island. The DSR offers are the same of each location with five offer bands of $2,000, $4,000, $5,000, $6,000 and $8,000/MWh. The offer band size is 20 MW in 2030 and 30 MW in 2050. By 2030, and certainly by 2050, DSR could take many forms including, but not limited to, contracted load-reduction in response to price, and voltage-to-grid power transfer from EVs and batteries installed in residential dwellings and businesses.

Standalone privately owned batteries

The 2030 modelling has five batteries modelled varying in size. There is a single South Island battery which has 1,200 MWh storage with a 150 MW generation rate. The North Island has four batteries, with a total of 3690 MWh storage and 540 MW combined generation.

The 2050 modelling has six batteries varying in size. There is a single South Island battery which has 2,400 MWh storage with a 150MW generation rate. The North Island has five batteries, with a total of 11,090 MWh storage and 1,040 MW combined generation.

The batteries are generic in the sense that they do not assume any particular technology, so they could be lithium-ion, sodium-ion, flow batteries, and potentially other technologies that will be cost-effective in the future. However, these batteries are assumed to be installed primarily for the purpose of managing grid security, either at the transmission level, or at the distribution level. Each battery can contribute to meeting peak demand, but they could also simultaneously provide other services such instantaneous reserves and voltage support.

SLR

In order to derive meaningful outputs we have arrived at four SLR suppliers, with two located in each island. The SLR offer is the same for each location at $10,000/MWh. The offer band size is 500 MW in 2030 and 1,000 MW in 2050.

Onslow

In runs that include Onslow, it is configured with 5,000 GWh of storage capability, 1,000 MW of generating and pumping capacity, pumping efficiency of 75 per cent, generator characteristic of 5.41 MW/cumec,[42] injecting at ROX2201. It is also assumed that Onslow can change from pumping to generating within the three-hour time step used in the modelling.

It is assumed that the tunnel connects Onslow to a point below the Roxburgh dam, which minimises the tunnel length and hence, all else equal, construction costs. There are other pros and cons to connecting below the dam, or above the Roxburgh dam: below the dam does not take water from Roxburgh generation, but then it does not add water for generation at Lake Roxburgh. Connection

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[42] *Evaluating the potential for a multi-use seasonal pumped storage scheme in New Zealand's South Island*, PhD thesis, M K Majeed, 2019.

below Roxburgh also offers an independent Onslow operator the least interaction with Contact Energy.[43]

There are no penalty prices applied when Onslow storage approaches full or empty levels.

The HVDC

The HVDC link's 1,000 MW overload capacity, along with net free reserves for FIR, means that quite small amounts of instantaneous reserves would be required to cover HVDC risk. This could be provided by PLSR, TWD, ILR and also from batteries that are included in the plant mix.

The transition to 100 per cent renewables

An assumption which is implicit in all modelling runs is that Onslow reaches a stable operating state at the end of 2029. Although beyond the scope of this report, it does raise the question of how this will this occur.

Onslow is a large reservoir with a tunnel connecting it to the Clutha River. Under the assumptions of 5.41 MW/cumec and 75 per cent pumping efficiency, the maximum charge rate is only 139 cumecs, which would be required for 9.1 months to fill the lake. This assumes that it would be filled entirely before entering its normal operating mode, which is unlikely if, for example, there is a dry period while filling.

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[redacted]

Other assumptions for 2030

The 2030 run is based on the ICCC's 100 per cent Base Case.

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[43] There is a minimum flow requirement below Roxburgh, but when this is likely to be binding, Onslow is more likely to be generating.

- Demand: Tiwai gone, 0.5 per cent p.a. growth, plus 100 MW South Island data centre, plus 600 GWh of process heat conversion to electricity;
- Medium-term demand elasticity as per ICCC – response to high prices and OCCs;
- Contingent storage total of 668 GWh.

Other Assumptions for 2050

- Demand for 2050 is matched to the 2050 demand value used by Concept Consulting for Problem 1, i.e. 56 TWh per annum;
- Contingent storage total of 668 GWh;
- Medium-term demand elasticity as per ICCC – response to high prices and OCCs;
- 4 x 150 MW hydrogen powered batteries, one located in the South Island and three in the North Island. Each offers 5 offer bands at 20MW, 40 MW, 35MW, 35 MW and 20 MW. The offer prices are $400, $500, $600, $700 and $800/MWh.

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The term ‘water value’ is used extensively in this report, and this section provides a basic introduction to the concept. A full description of water values is quite mathematical and beyond the scope of this report.

To assist with the explanation, we will step through:

- water values in a market with fossil-fuelled thermal (i.e. the current market)
- water values in a 100 per cent renewables market (i.e. the position in 2030)
- water values as a way of maximising security of supply (in both kinds of markets)
- water values and security.

Water values in a market with fossil-fuelled thermal

The modelling assumes that the current market structure remains intact through to 2050 notwithstanding the absence of fossil-fuelled thermal, which means that generators over 10 MW have to offer into the market in order to be dispatched.

The modelling also assumes that the operator pricing the water for dispatch will adopt the now conventional approach to valuing releases from stored hydro used in some form or another by hydro operators in New Zealand. The derivation of the implicit value of water at a given generation offer in $/MWh is explained numerically in the box below.

Suppose that the operator of a hydro generator with storage offers to generate up to 100 MW at a price of $100/MWh, and that its generators convert water to energy at the rate of 2 MW per cumec. This means that the energy content of water stored in the hydro lake is 2/3,600 MWh per m^3 (0.00056 MWh/m^3) or 2/3.6 kWh per m^3 (0.56 kWh/m^3).
If the generator is dispatched at 100 MW and it is marginal,[44] then revenue will be earned at the rate of $10,000 per hour on water releases of 50 cumecs or 180,000 m^3 in total: this gives the value of the water released as $0.056/$m^3$.
This places a value of $0.056/$m^3$ on the water released during the period. But not all of the water in the lake is released, so it is in fact the marginal value of water in storage.

What this tells us is that no matter how one might choose to value water in storage, the price attained at the time of release determines the actual value of the water released. This applies to all existing lakes and would apply to Onslow.

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[44] Which means that the generator’s offer is marginal and hence sets the price.

The concept typically used in the electricity context is that of the water value, which is short for marginal water value for the reason noted above. The techniques and algorithms used to calculate water values originated in electricity markets featuring a mix of hydro and fossil-fuelled thermal generation, in which it was highly desirable to value stored water in a way which maximised a specified objective for the management of hydroelectric storage lakes, e.g. minimising fuel burn.

The variable costs of fossil-fuelled thermal generators are primarily set by the cost of fuel and carbon and they are typically substantial, whereas the variable costs of hydro generation are close to zero or, if not, then relatively small. For example, the fuel cost of operating a fossil-fuelled thermal station such as a gas-fired peaker with heat rate of 10,000 GJ/GWh[45] and with gas priced at $10/GJ and a carbon price of $40 per tonne is $121/MWh. On the other hand, the variable cost of running a large hydro system is a few dollars per MWh at most, plus, if the generator is in the South Island, the HVDC charge of $5.35/MWh.[46]

If hydro generators offered to generate at less than $10/MWh while fossil-fuelled thermal generators offered at prices reflecting their variable costs, then prices would initially be low, but only until all the lakes emptied out, after which they would have to rely on run-of-river inflows to generate; at which point prices would be very high, reflecting a shortage situation and the cost of generating a lot of power from fossil-fuelled thermal generators.

Exactly the opposite would happen if hydro generators over-valued their water relative to fossil-fuelled thermal generators; prices would be high until all the lakes filled up and started spilling.

Neither of the above scenarios is desirable, and they illustrate why it is important to get water values right. It also points to the importance of how water values would apply if the market has no fossil-fuelled thermal.

The approach used is to calculate the optimum water value in each period, typically weekly, which establishes the opportunity cost of water in storage, where opportunity cost is the value of the next best alternative to generating today. Since the vast majority of stored water is used for electricity generation,[47] the only alternative to generating today is to generate tomorrow, or the day after tomorrow, or the day after the day after tomorrow, and so on.

Tipping[48] draws on the literature to expand on this:

> "On any given day, the hydro generator holds a portfolio of real options,[49] such as the option to generate today, the option not to generate today, and the options to generate or not on any day in the future. As storage is limited and inflows stochastic,[50] generating today can compromise the ability to generate in the future. Therefore, the marginal cost

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[45] Based on HHV efficiency of 36%.

[46] This charge is due to be abolished when the new TPM comes into force in 2023.

[47] In large hydro lakes, a small portion might also be used for irrigation.

[48] *The Analysis of Spot Price Stochasticity on Deregulated Wholesale Electricity Markets*, PhD thesis, James Tipping, 2007.

[49] Investopedia defines a real option as "an economically valuable right to make or else abandon some choice that is available to the managers of a company, often concerning business projects or investment opportunities."

[50] Uncertain.

> of hydro generation includes not only the physical cost of passing water through the turbines, but also the value of options both created and destroyed by generating today."

A hydro generator typically has the objective of maximising profit when calculating water values, taking into account highly uncertain inflows, and subject to constraints including the size of the hydro lake, the maximum rate of release, and MW per cumec ratio of the generator, reducing the risks of shortage, and other variables.

A large profit-maximising hydro generator may also take advantage of its market power when calculating water values, but when market power is ignored then the use of water values should, in theory, achieve the same market outcome as would a central utility seeking to minimise the total cost of generation over a period. In a hydro-fossil-fuelled thermal electricity market, minimising the cost of generation comes down to minimising the cost of the total fuel burn: this also maximises the value of water over the period.

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For the modelling in this report, Energy Link used its *EMarket* model which simulates the operation of the electricity at a high level of detail, and a key part of this is to calculate water values for each major hydro reservoir.

EMarket's water values are produced from an optimisation with the objective of maximising the revenue from a hydro lake with uncertain inflows, over a specified period of at least one year in length, at weekly time steps, assuming that market power is not used. As a result, the water values maximise the value of water and hence also minimise the value of the fuel burned by fossil-fuelled thermal generators.

For a particular lake, the water value changes with the lake's own storage, with the storage in other lakes, with the (expected) offers from fossil-fuelled thermal generators, with demand, with expected renewable generation, and also taking into account the cost of DSR and the possibility that SLR will be dispatched (which could include non-supply). At any point in time, the water value for a storage lake provides its operator with a starting point for the price that it offers its generation into the market.

Water values are often calculated on grids of storage (for the lake in question), storage in all other lakes, and time. But this multidimensional grid view is not intuitive, and so *EMarket* converts its grids into water value contours, which were inspired by the operating guidelines produced by the SPECTRA model developed by ECNZ back in the 1980s.

Figure 42: Simplified water value contours

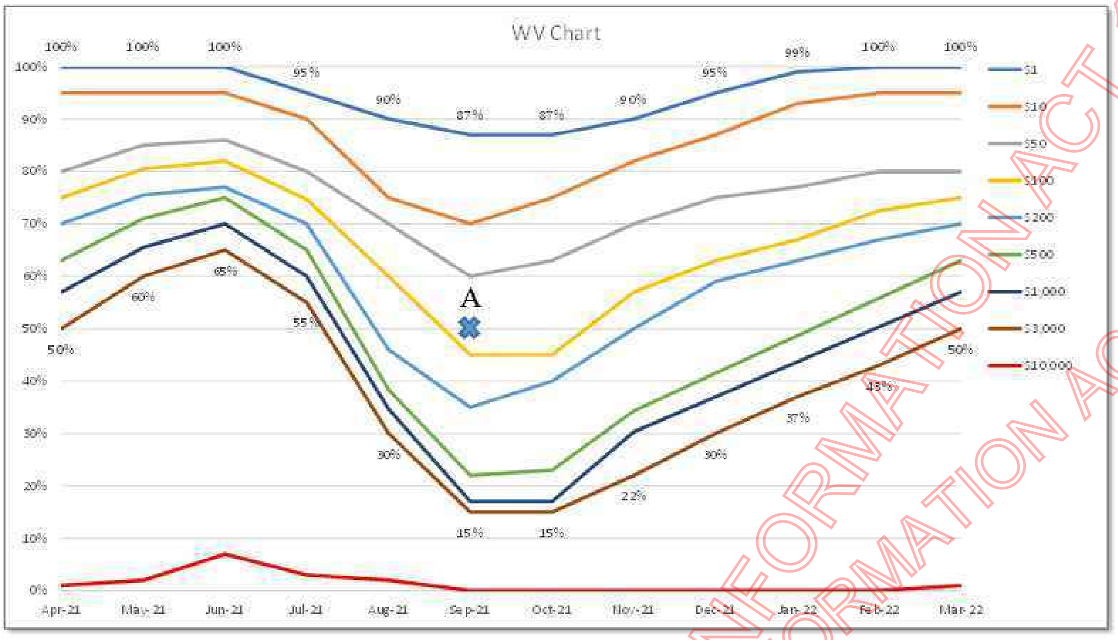


Figure 42 shows some simplified water value contours for a generic lake, with storage marked on the vertical axis in terms of percentage full. Each line is a water value contour at a constant price, which is a more convenient expression of value than using dollars per m^3.

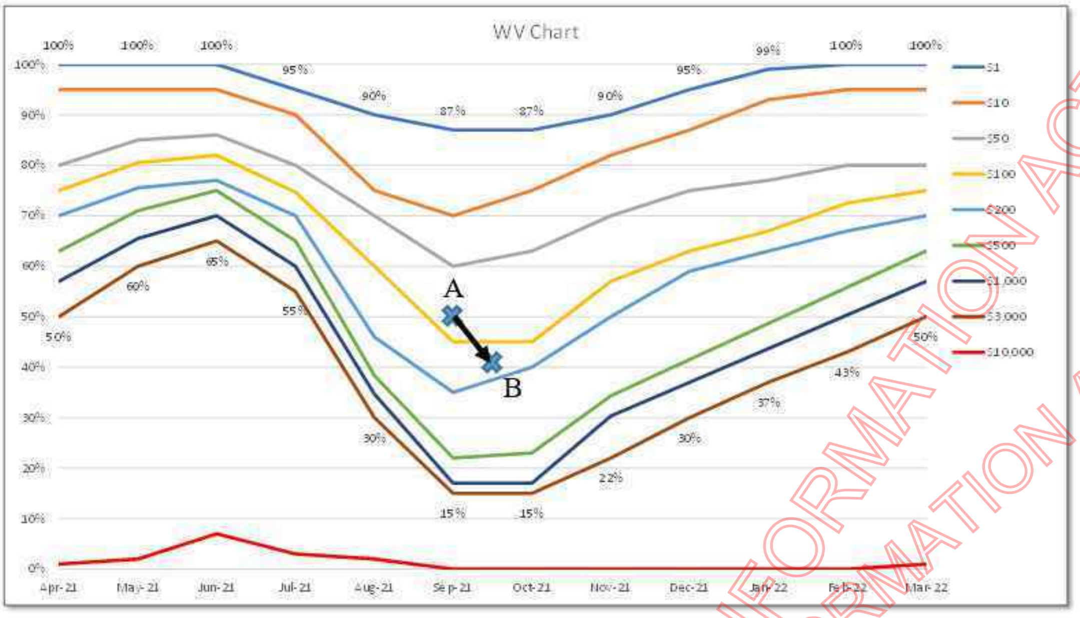
For example, at point A, which is at the 50 per cent storage level in September, the water value is part-way between the yellow ($100) and grey ($50) contours. Using simple linear interpolation between the two prices, the water value at A is about $83/MWh.

Water values are calculated using many possible inflow scenarios, usually based on historical data, which are projected into the future. As storage falls below A, for example, more projections fall into lower storage zones, and hence the WV increases.

Suppose there is a significant fossil-fuelled thermal sector, as there is today. Then the water values can be constructed so that each one is priced at one of the offers of a fossil-fuelled thermal generator. In theory then, as storage crosses one of these contours, the relevant fossil-fuelled thermal offer should be dispatched into the market. The contours with prices of $500 and above are more likely to represent demand-side response (DSR), supply of last resort (SLR) and, ultimately, non-supply at prices above $10,000.

For example, suppose storage falls from A to B, as shown in Figure 43, in the first half of September. If the yellow contour at $100 represents an offer from a fossil-fuelled thermal generator, then this offer should be dispatched into the market as the contour is crossed. In this way, as storage falls, more fossil-fuelled thermal generation comes on, and this acts to slow the rate at which storage falls (for if it falls too far, then shortages could occur).

Figure 43: Fossil-fuelled thermal dispatch



If the fossil-fuelled thermal sector is sufficiently large and competitive, then any market power possessed by a large hydro generator is highly constrained. If capacity is withheld or offer prices increased, then more fossil-fuelled thermal will run and storage will tend to increase again.

Currently, the fossil-fuelled thermal sector has three significant players – Contact Energy, Genesis Energy and Todd Generation – so there is no shortage of competition in this sector.

Of course, if gas prices generally rise, then the prices on the fossil-fuelled thermal-based WV contours will rise accordingly, and water values will also rise, which is why gas prices are a key driver of electricity spot prices, even though we have far more hydro generation than fossil-fuelled thermal generation.

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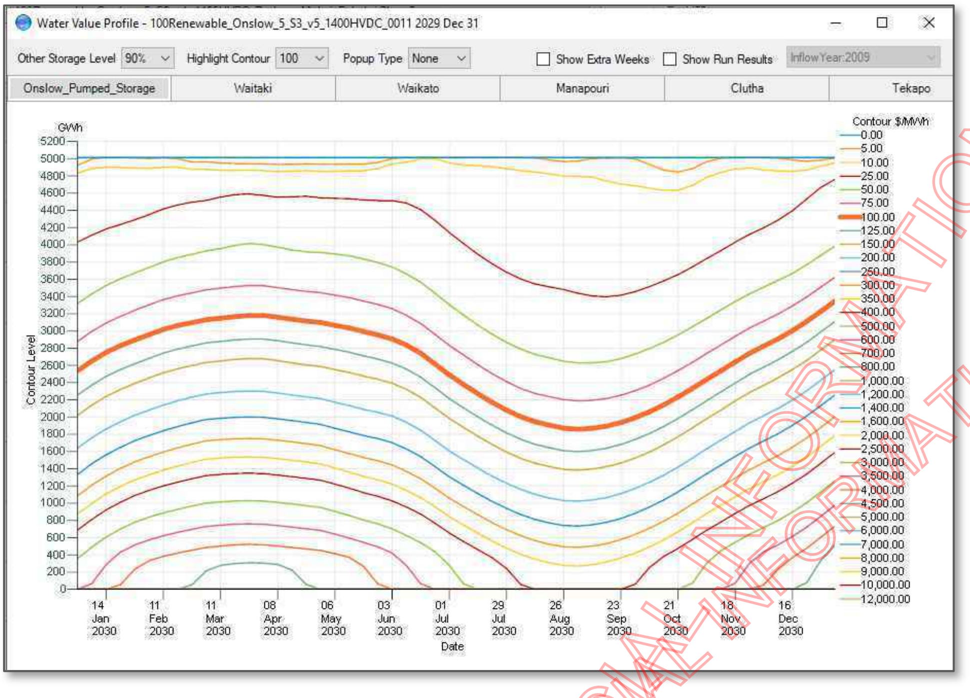

Water Value Profile - 100Renewable_Onslow_5_S3_v5_1400HVDC_0011 2029 Dec 31

Other Storage Level: 90%
Highlight Contour: 100
Popup Type: None
☐ Show Extra Weeks
☐ Show Run Results
InflowYear:2009

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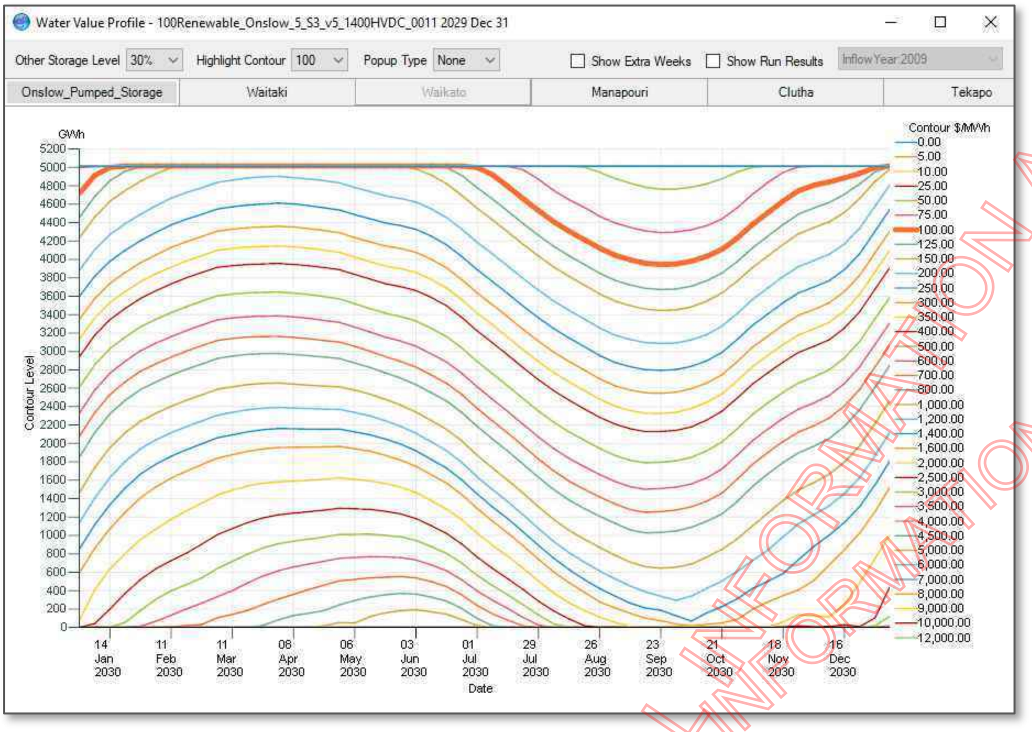
Figure 45: Onslow water values with other storage at 30% full



Water Value Profile - 100Renewable_Onslow_5_S3_v5_1400HVDC_0011 2029 Dec 31

Other Storage Level 30%
Highlight Contour 100
Popup Type None
☐ Show Extra Weeks
☐ Show Run Results
Inflow Year:2009

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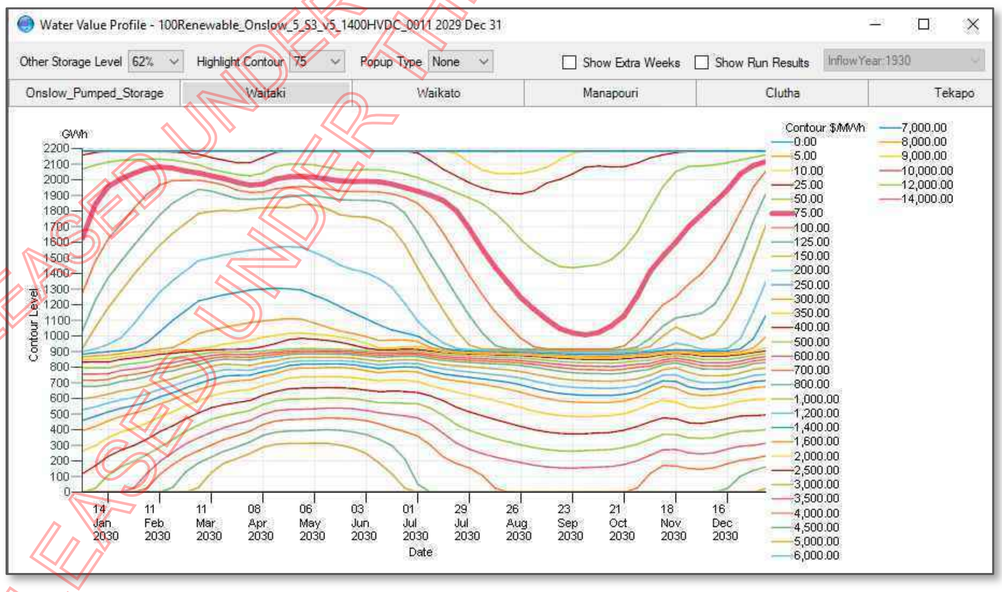
[redacted]

Figure 46: Waitaki water values with other storage at 62% full



Water Value Profile - 100Renewable_Onslow_5_S3_v5_1400HVDC_0011 2029 Dec 31

Other Storage Level 62%
Highlight Contour 75
Popup Type None
☐ Show Extra Weeks
☐ Show Run Results
Inflow Year:1930

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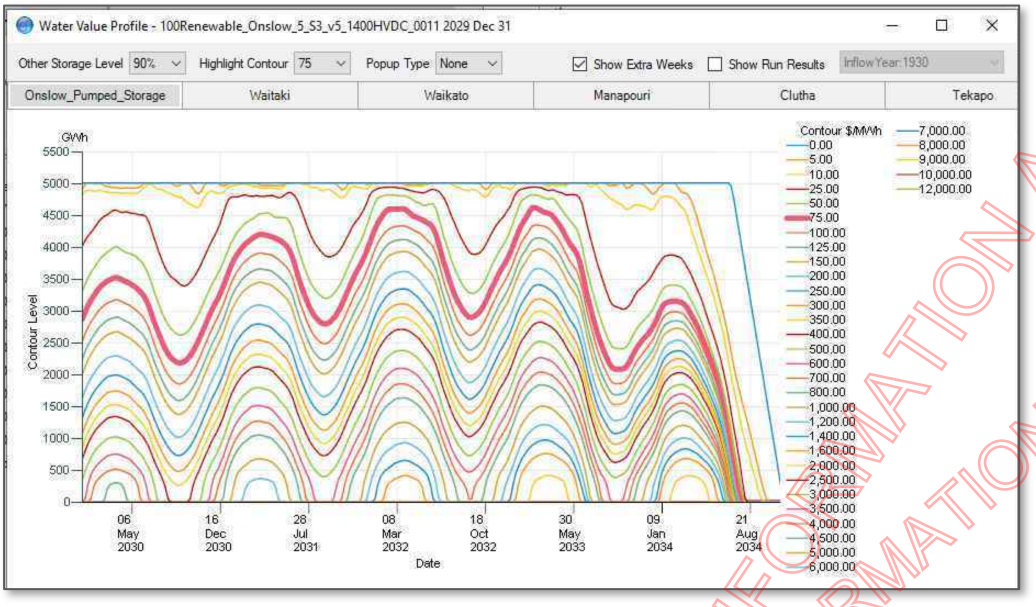
Figure 47: Multi-year water values for Onslow



Water Value Profile - 100Renewable_Onslow_5_S3_v5_1400HVDC_0011 2029 Dec 31

Other Storage Level 90%
Highlight Contour 75
Popup Type None
☑ Show Extra Weeks
☐ Show Run Results
Inflow Year: 1930

The following case study illustrates how Onslow's water values work to preserve SoS. Again, it is easier to first illustrate the operation of the market to first consider a market with fossil-fuelled thermal, and then consider a 100 per cent renewables market.

it is based on the market without enough renewable capacity to be 100 per cent renewable, so fossil-fuelled thermal remains, but it is informative because it is easier at first glance to understand the interactions between Onslow and the fossil-fuelled thermal fleet, and then to extend the understanding to the market with 100 per cent renewable generation.

The case study was run by Energy Link in October 2020, using a base case without Onslow, and the following charts compare the with-Onslow results to the without-Onslow results.

Figure 48: Change in fossil-fuelled thermal generation with Onslow added to the market

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[redacted]

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[redacted]

Figure 49: Onslow with fossil-fuelled thermal in the market

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What Onslow does is to charge during summer, which uses more of the cheaper fossil-fuelled thermal generation, but then Onslow has water stored to generate with in winter, displacing the more expensive fossil-fuelled thermal generation.

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[redacted]

It is not quite so obvious how Onslow works with 100 per cent renewable generation, but it is again illustrated in simple terms in Figure 50.

Figure 50: Onslow with 100% renewable generation

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[redacted]

To complete the picture, however, we need to ask the question: what is the economic factor that drives this behaviour?

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Water values and security

The discussion of Onslow tends to focus on how it can achieve SoS, but it is now clear that there is another element to water values which is highly relevant to the assessment of the impact of Onslow on the market.

The water values establish the expected future value of water – the opportunity cost – but water values are typically indifferent as to whether generation occurs solely to preserve SoS or to ensure security.[54] In fact, the operator of Onslow could reasonably take the view that any time the price received in the market exceeds the water value, Onslow should generate. This will obviously occur during dry periods but also during demand peaks when capacity is in short supply.

This makes perfect sense when one considers that fossil-fuelled thermal generation currently in the market plays two roles: one is to generate during dry periods, but the other is to fill the gap during peaks periods when hydro and any other peaking plant is fully dispatched. The fossil-fuelled thermal generation performs two key roles, one for SoS and one for security.

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Water value key takeaways

- Water values are a particular case of ‘energy-in-storage’ values, but the generic concept of energy-in-storage values as an opportunity cost would apply to any battery with long-term (seasonal) storage.
- Water values as the basis for market offers are proven in New Zealand, and work for Onslow.
- Water values optimisation adjusts to the market, and would typically be undertaken weekly to capture on-going changes such as demand, plant outages and plant commissioning.
- Water value is the opportunity cost of generation and (after efficiency loss) charging.
- Water values will tend, on average, to charge Onslow in summer and discharge it winter, thus minimising the overall cost of preserving SoS and security.
- Onslow’s operator would offer and bid to the market, while at least returning water value.
- Onslow’s operator would develop its own water value optimisation program that would be based on the overriding objective of achieving a specified level of SoS, subject to a range of constraints.

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[54] Onslow’s operator could instead decide to determine water values based only on generating to preserve SoS and to ignore the need to preserve security. But this would require additional capacity to be retained in the market in order to preserve security, increasing the overall cost of electricity supply.

About Sapere

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concept consulting JC²

Estimated gross benefits of NZ Battery options

21 May 2021

Version 4.0

Disclaimer

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- However, Concept and its staff and associates shall not, and do not, accept any liability for errors or omissions in this presentation or for any consequences of reliance on its content, conclusions or any material, correspondence of any form or discussions arising out of or associated with its preparation.

Executive summary

Purpose

- This report sets out estimates of gross benefits for generic energy storage schemes (referred to as ‘NZ Battery’ options) defined in terms of their storage size (‘tank’), maximum output (‘tap’), location in the North or South Island, and round-trip efficiency (% of input energy which is returned to the grid)

Approach

- Gross benefits are measured at the national level based on the change in total system cost enabled by each NZ Battery option
- System costs include the capital costs for new generation and smaller-scale batteries, fuel and carbon costs, and the costs of demand response
- Gross benefits are formally estimated for three representative years: ‘2035’ (early in project life but after any ‘fill’ period), ‘2050’ (when decarbonisation has lifted non-Tiwai electricity demand by around 50%) and ‘2065’ (when electricity demand has almost doubled)
- We use these representative years to estimate gross benefits for the NZ Battery schemes with assumed 60-year economic lives. Gross benefit estimates for years between 2035, 2050 and 2065 are based on interpolations. Gross benefits beyond 2065 are assumed to be constant in real terms.
- s 9(2)(f)(iv) [redacted]
- We do not calculate any estimates of net benefits because we do not have information on the costs of different NZ Battery options

Executive Summary - NZ Battery Options Assessed

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Executive summary - results

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[redacted]

Executive summary - results

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[redacted]

Executive summary – NZ’s storage needs change over time

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[redacted]

Executive summary - results

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- We have varied key inputs to test their effect on estimated gross benefits
- The inputs with greatest effects:
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  -
  -
- s 9(2)(f)(iv) [redacted]

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Contents

Analytical question and methodology

Analytical question and how we address it

The analytical question

- We have been asked to identify the preferred target configuration for the 'NZ Battery' to achieve reliable power supply in a system with 100% renewable electricity
- The target configuration characteristics to be considered include:
  - Storage capability (GWh)
  - Discharge/recharge capacity (MW)
  - Location (South or North Island or both)

How we address the question

- The preferred target configuration will be the NZ Battery option with the greatest net benefits (i.e. gross benefits minus costs)
- However, we have no detailed information on costs of building and operating different NZ Battery options
- For this reason, we are unable to identify an optimal NZ Battery configuration
- Rather, we estimate the gross benefits of different NZ Battery options
- These gross benefit results can be used in future business case analysis for NZ Battery once cost information is available
- The gross benefit results also provide useful information to help target future effort

What do we mean by gross benefits of NZ Battery?

- Gross benefits are defined as the savings in total electricity system costs arising from a given NZ Battery option
- These savings are estimated by considering the difference in total electricity system costs between in two scenarios:
  1. NZ Battery is already built, filled and available
  2. NZ Battery option is not built
- In both scenarios we identify the least cost mix of generation and demand response – i.e. we take the role of a cost minimising system planner
- Our total system cost estimates:
  - include capital costs for construction of new generation and small-scale batteries (i.e. not NZ Battery)
  - include cash operating costs for new generation and smaller scale batteries and carbon charges (e.g. for geothermal)
  - include demand response costs – both voluntary and involuntary
  - exclude capital costs for existing generation which is likely to continue in operation (since capex for these is already sunk)
  - exclude transmission costs because the grid is assumed to be the same in the scenarios with and without NZ Battery
  - exclude the cost of building and initially filling ('charging') NZ Battery as both are currently unknown
  - include the cost of refilling NZ Battery once it is operating – noting this cost is embedded in the capital cost for new generation (some of whose energy is used to fill NZ Battery and cover its recharge/transfer losses)
- The resulting differences in estimates represent the national economic benefits of NZ Battery

Note: Capital costs are annualised costs using a capital recovery factor based on a 7% post tax nominal weighted average cost of capital, and economic life and construction cost profile. This capital recovery factor is close to an annuity based on a 6% pre tax real rate. Carbon prices in 2021 $ terms follow the CCC assumptions of $160/t, $250/t and $390/t in 2035, 2050 and 2065. We assume some additional within-island transmission will be built to enable new renewables to connect, but these costs are not quantified.

We model the system in three representative future years

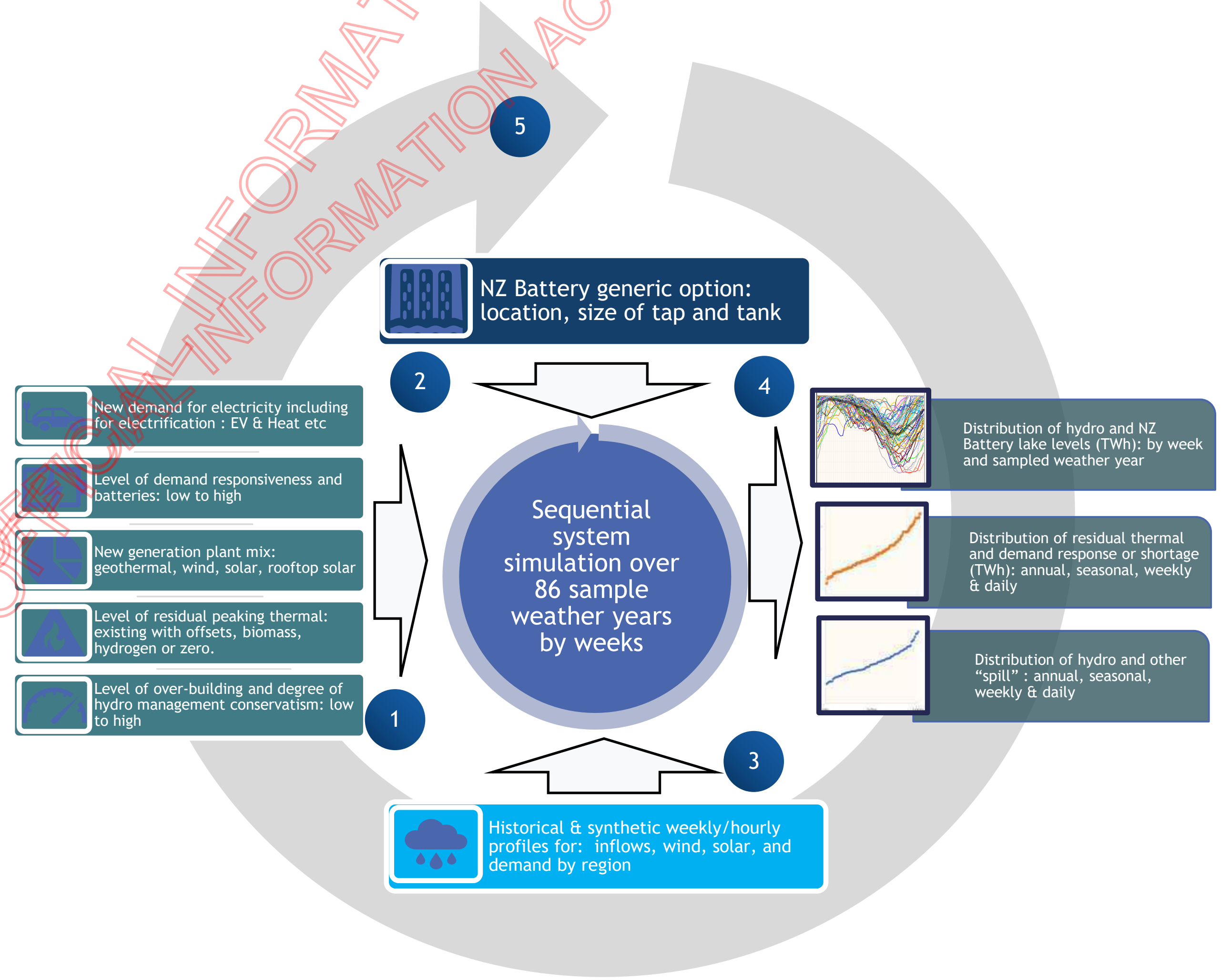
- The analysis needs to look well into the future because:
  - NZ Battery solution could be an asset with a long life (50+ years)
  - NZ’s storage needs will change as the economy progressively electrifies to achieve net zero carbon

- To address these factors, we model three representative future years
  - 2035 – an early year in asset life. This year should be sufficiently far into the future to avoid transition issues (such as building and filling a large pumped storage facility) but soon enough to represent the initial benefits
  - “2050” – an intermediate year on the transition path in which electricity demand (ex Tiwai) is 50% higher than 2020
  - “2065” – a year in which electricity demand (ex Tiwai) is almost 100% higher than 2020 and represents a decarbonised economy
  - In all years we assume the Tiwai Aluminium smelter is closed

- Using these representative years, we can look far into the future but avoid the computational overhead associated with modelling every consecutive year (i.e. keep the modelling power to explore other matters)

High level modelling approach

- **Step 1** – Set input assumptions for future demand growth, new generation options available to be developed etc.
- **Step 2** – Set NZ Battery assumptions
- **Step 3** – Apply the sources of variation – rainfall, wind, solar, demand etc
- **Step 4** – Run model simulations to identify least cost mix of plant etc to maintain reliable supply for given set of input assumptions
- **Step 5** – Iterate model to identify preferred target characteristics for NZ Battery under varying assumptions for future demand, etc



5

NZ Battery generic option: location, size of tap and tank

2

4

New demand for electricity including for electrification : EV & Heat etc

Level of demand responsiveness and batteries: low to high

New generation plant mix: geothermal, wind, solar, rooftop solar

Level of residual peaking thermal: existing with offsets, biomass, hydrogen or zero.

Level of over-building and degree of hydro management conservatism: low to high

1

Sequential system simulation over 86 sample weather years by weeks

Distribution of hydro and NZ Battery lake levels (TWh): by week and sampled weather year

Distribution of residual thermal and demand response or shortage (TWh): annual, seasonal, weekly & daily

Distribution of hydro and other “spill” : annual, seasonal, weekly & daily

3

Historical & synthetic weekly/hourly profiles for: inflows, wind, solar, and demand by region

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[redacted]

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Seasonal shape of demand - expressed in terms of average GW per month

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[redacted]

Transmission and new supply – key assumptions

- We model HVDC losses/constraints explicitly - HVDC capacity assumed to be 1400 MW (north) and 950 MW (south) and we assume no reserve-related transfer limits on basis that NI batteries should be able to support full reserves requirements
- Average HVAC losses are included in demand and AC grid is assumed to be unconstrained
- The model has a menu of new supply and demand response options available for development/use at different costs:
  - s 9(2)(f)(iv) [redacted] hydro is available
  - s 9(2)(f)(iv) [redacted]

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Variability in supply - key assumptions

- We have modelled variability in supply and demand as follows:

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[redacted]

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[redacted]

Modelling of new investment in generation and small scale batteries

Approach

- In essence, for a given level of future demand and assumed existing supply the model calculates the “revenue[1]” available from incremental investments in different new supply resources (wind, geothermal, LiON batteries etc)
- These revenue sums are compared to the annualised costs of the different options (noting costs decline over time)
- When revenue for a resource type exceeds its cost, we add more of a resource
- An iterative process of adding resource is followed until the point where further investment is no longer revenue adequate
- s 9(2)(f)(iv) [redacted]

North/South

- s 9(2)(f)(iv) [redacted]

Regional wind/solar

- The model places wind/solar investments in different locations to reflect effect of correlation issues GWAP/TWAP[2] factors (see later slide for more info)

---

1. The “revenue” measure is derived from prices which depend on assumed water value curves, the SRMC of plant, and demand response and shortage cost tranches.
2. Generation weighted average price / time weighted average price. This provides a measure of how much of the average market price that a particular project can ‘capture’.

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[redacted]

Scenario ‘worlds’

- We estimate the benefits of NZ Battery options in three alternative ‘worlds’:

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What are ‘green’ peakers?

○ Green peakers are combustion turbines which use a zero carbon fuel – such as biodiesel or green hydrogen

○ The capital cost for such turbines is well understood but there is some uncertainty over the fuel cost. Having said that, research by Scion[1] indicates biodiesel from pulp logs using an *existing technology* would cost roughly $25t-$45/GJ to produce depending on log costs

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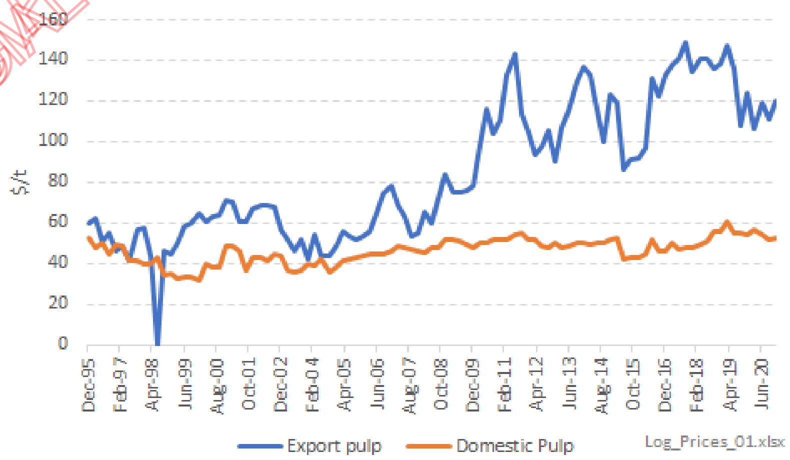
Historical pulp log prices



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1. Scion, February 2018 report: *“New Zealand Biofuels Roadmap Technical Report”*, and MfE’s *“Marginal abatement cost curves analysis for New Zealand”*
2. See https://www.transport.govt.nz/area-of-interest/environment-and-climate-change/biofuels/

Gross benefit estimates for different NZ Battery options

This section sets out the estimated gross benefits for various NZ Battery options

- This section sets out gross benefit estimates for various NZ Battery options

- In particular it presents analysis on:
  - How gross benefits vary with different storage capacities ('tank sizes')
  - How gross benefits vary with different maximum output levels ('tap sizes')
  - How gross benefits vary with location of a NZ Battery in the North Island or South Island, or both islands

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[redacted]

Gross benefit for alternative South Island “tank and tap sizes”

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[redacted]

Gross benefit for alternative North Island “tank sizes”

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[redacted]

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[redacted]

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[redacted]

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[redacted]

Total system costs and incremental system benefits for various Battery options

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[redacted]

Total system benefits - summary of results

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[redacted]

Related results

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Qualitative discussion on effect of modelling assumptions

- In addition to the effects quantified above, we briefly discuss how some modelling assumptions and approaches might have affected results

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[redacted]

Results from the shadow model

We have also run a shadow model alongside the main model

- Why a shadow model?
  - Allows us to cross-check key results from the main model
  - Developed independently from main model
  - It has strengths and weaknesses relative to the main model
- Similarities with main model
  - A “stack” model that dispatches plant according to offers derived from SRMC or water values
  - Two island transmission system with HVDC losses and constraints
  - Uses historical hydrological inflows as indicator of future inflows
  - Uses demand response (and shortage) as ultimate/most expensive dispatch resource
- Differences from main model
  - Models each hour in year in chronological order (main model is chronological by week)
  - Models HVDC reserve requirement and co-optimizes energy and reserve dispatch (main model uses a simplified approach)
  - Optimizes generation planting based on economic cost (main model uses revenue adequacy, based on water values and SRMC, test to determine planting)
  - Implements “fuzzy” battery scheduling using inaccurate wind, solar and demand forecasting (main model has perfect foresight within week)
  - Independently derived inputs, such as new generation build costs and new wind build profiles
  - Takes longer to run!!!

Key results from shadow model

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THE CHANGING NATURE OF DRY YEAR AND CAPACITY BACKUP ISSUES

NZ’s storage needs are expected to change over time

NZ’s storage requirements will progressively change as s 9(2)(f)(iv) [redacted]

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Detailed results for a 5 TWh,1 GW option in the South Island

This section takes a deeper dive into a South Island option with 5 TWh of storage and 1 GW max output

- This section takes a more in-depth look at a single South Island option (to avoid being overwhelmed by the detail of many alternative options
- The choice of option is somewhat arbitrary because we have no information on NZ Battery costs, and therefore cannot focus on the option which appears to have greatest net benefits
- Given the absence of any preferred option at this stage and no information about the technical opportunities in the North Island, we have chosen to examine a South Island option with 5 TWh of storage and 1 GW of capacity (noting this may be somewhat oversized unless there are marked economies of scale)
- Looking at the detailed results allows us to examine the underlying drivers – which is useful in its own right but also tests the robustness of the modelling approach

We start by decomposing the benefits for a 5TWh/1GW Battery in South Island in 2050 - the chart shows the way we decompose benefits…

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[redacted]

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[redacted]

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[redacted]

Charts show how the sources of benefit for 5TWh/1GW Battery in South Island change over time and between the two different worlds

- Analysis shows how sources of benefit change over time – and alter between the two different ‘worlds’
- s 9(2)(f)(iv) [redacted]
-

2035

2050

2065

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[redacted]

- As discussed earlier, the gross benefits are sensitive to assumption about the availability of any alternatives to pumped storage which are also zero carbon

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[redacted]

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[redacted]

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[redacted]

s 9(2)(f)(iv) [redacted]

Limited thermal	100% renewable	Comments

s 9(2)(f)(iv) [redacted]

s 9(2)(f)(iv)

[redacted]

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[redacted]

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[redacted]

With 5TWh/1.0 GW Battery in South Island

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[redacted]

s 9(2)(f)(iv)

[redacted]

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[redacted]

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With NZ Battery 5.0TWh/1.0GW - s 9(2)(f)(iv)

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Outcomes are similar with different South Island pumped hydro guidelines

Shared water value - scheduled by time zone

SI Pumped Hydro Flat seasonal guidelines

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[redacted]

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[redacted]

Detailed results for options in the North Island

This section takes a deeper dive on North Island options

- This section takes a more in-depth look at North Island options
- The choice of options is somewhat arbitrary because we have no information on technical feasibility or costs
- s 9(2)(f)(iv) [redacted]

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[redacted]

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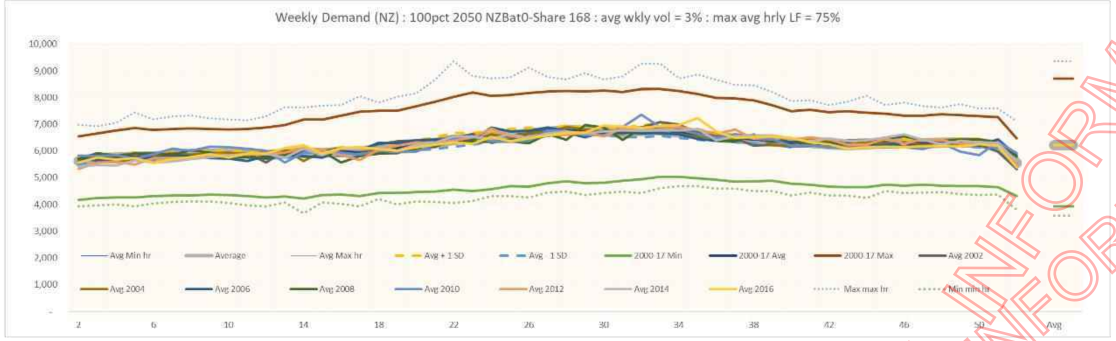
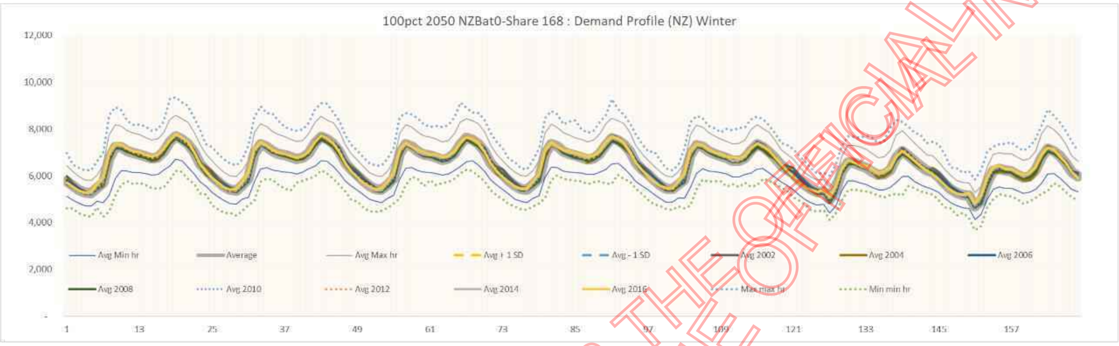
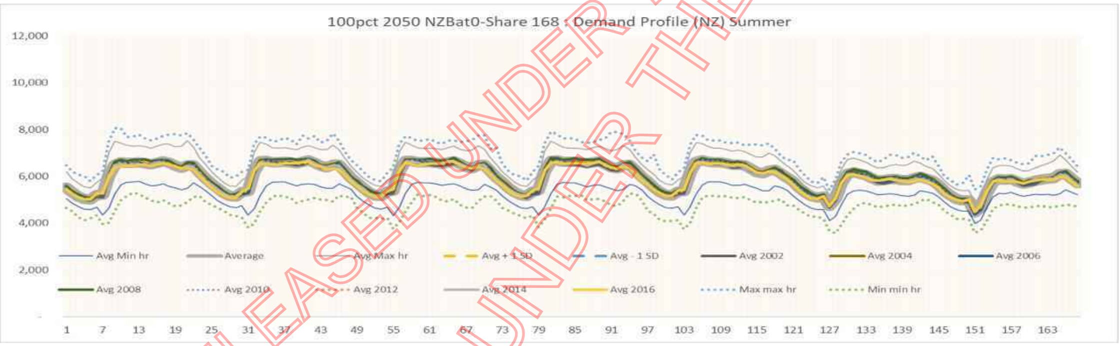
APPENDIX 1: DETAILED INPUTS :
DEMAND, HYDRO, WIND, AND SOLAR SUPPLY PROFILES AND STATISTICS

Demand Inputs

The demand has significant seasonal and within day shape


Weekly Demand (NZ) : 100pct 2050 NZBat0-Share 168 : avg wkly vol = 3% : max avg hrly LF = 75%

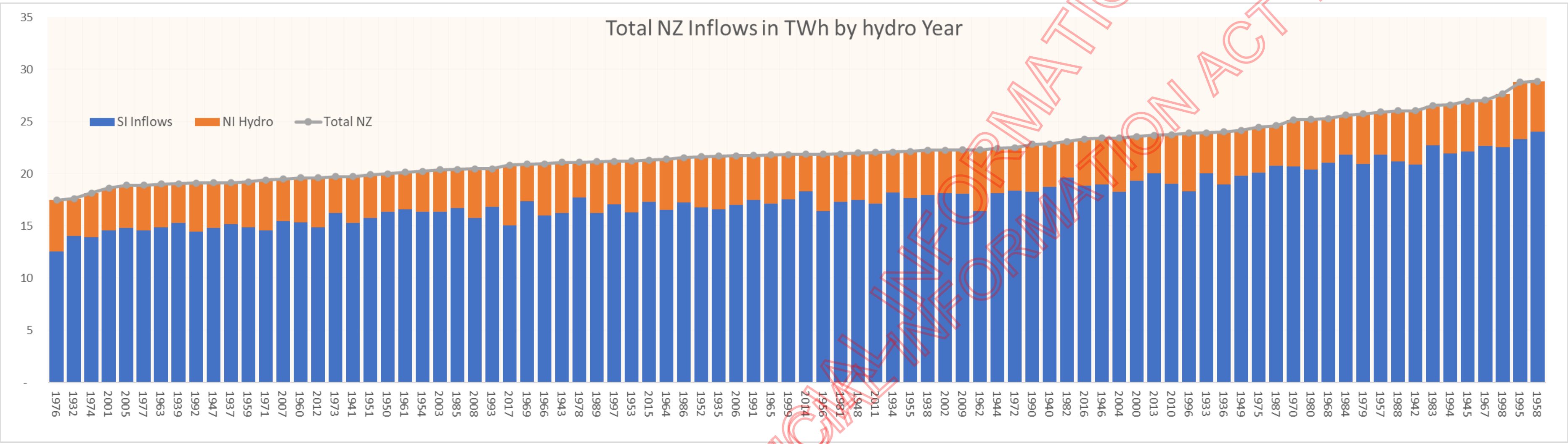

100pct 2050 NZBat0-Share 168 : Demand Profile (NZ) Winter

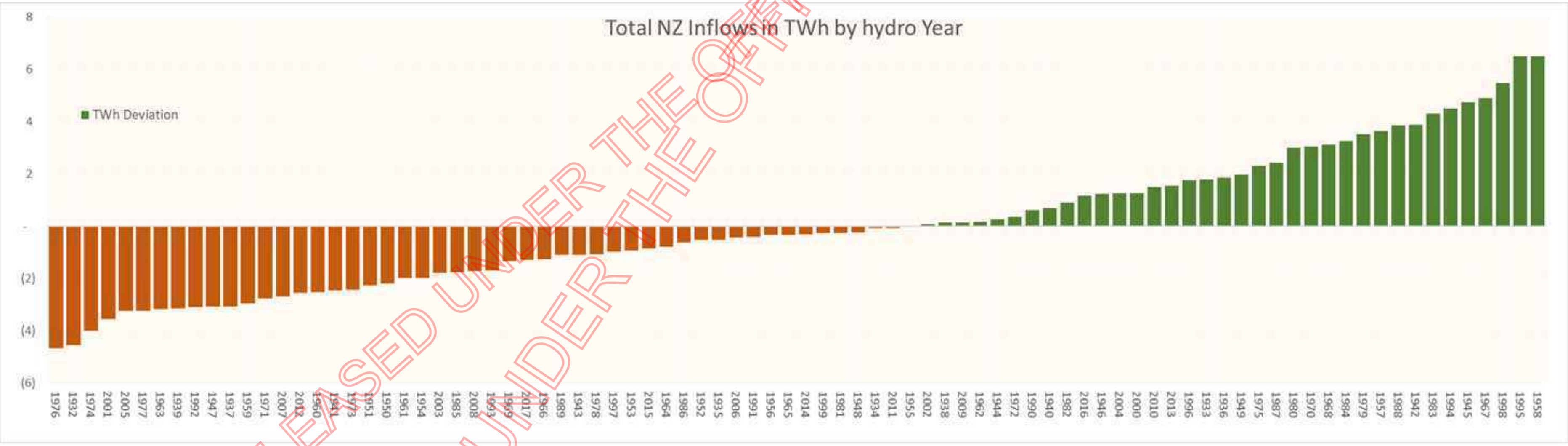

100pct 2050 NZBat0-Share 168 : Demand Profile (NZ) Summer

Comments

- These charts show the ranges of variation and patterns of demand, solar and wind used in the modelling.
- A full set of 18 years of hourly matched demand, wind and solar data is used in the modelling.
- This ensures that corelations between intermittent supply and demand are preserved and are accounted for in the modelling, along with weekly hydro tributary and controllable inflow variations. This becomes very important once the system has much higher levels of wind and solar a less flexible thermal back up.

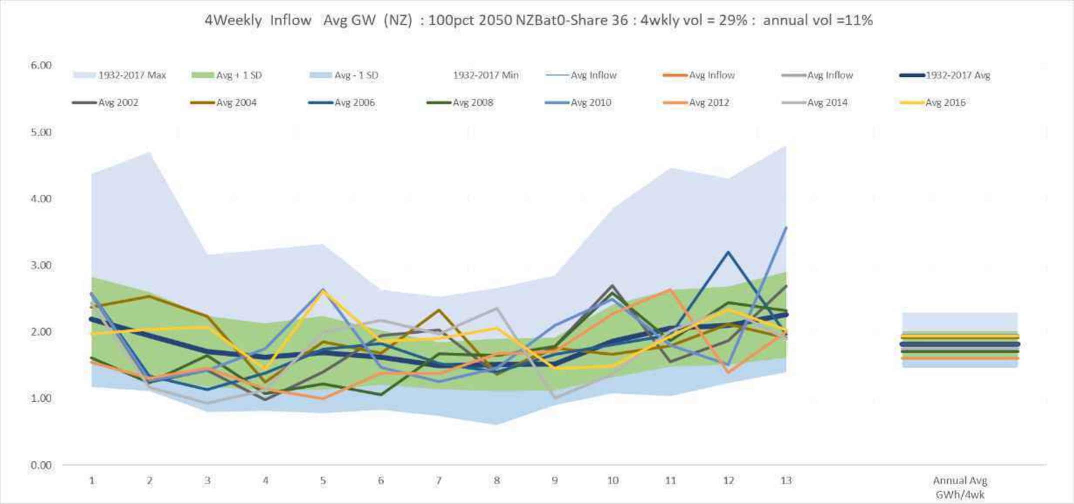
Annual distribution of hydro inflows by island

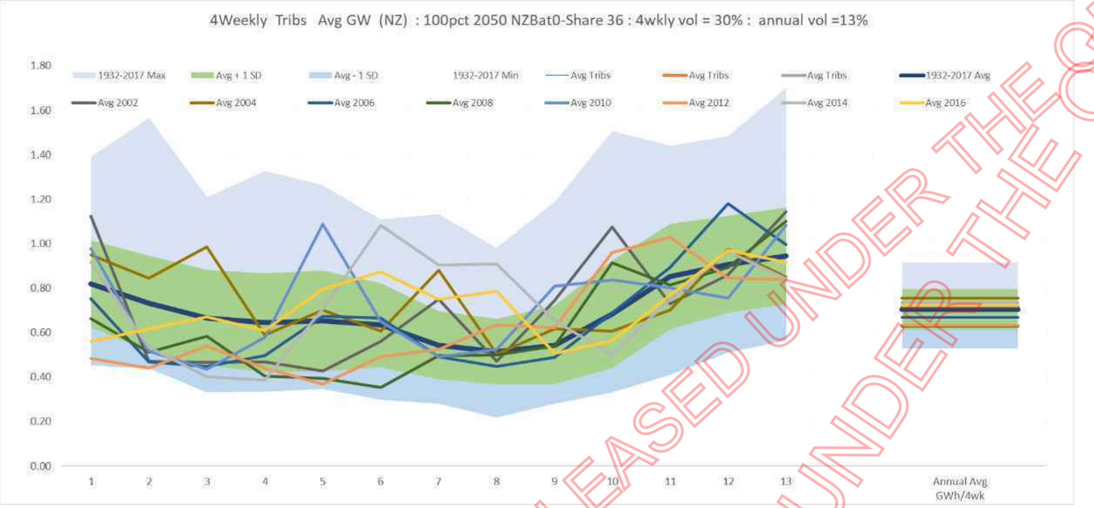




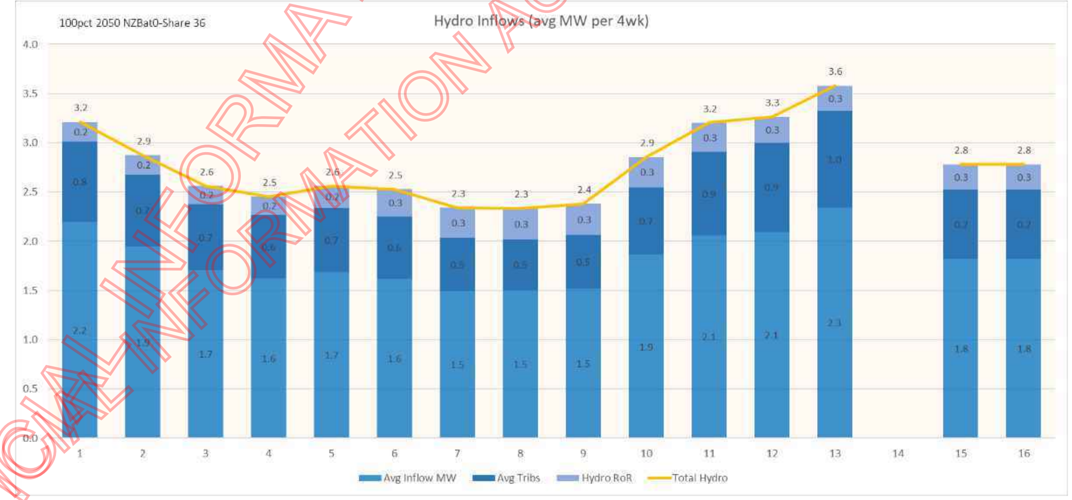
The seasonal patterns of hydro and other renewables in 2050

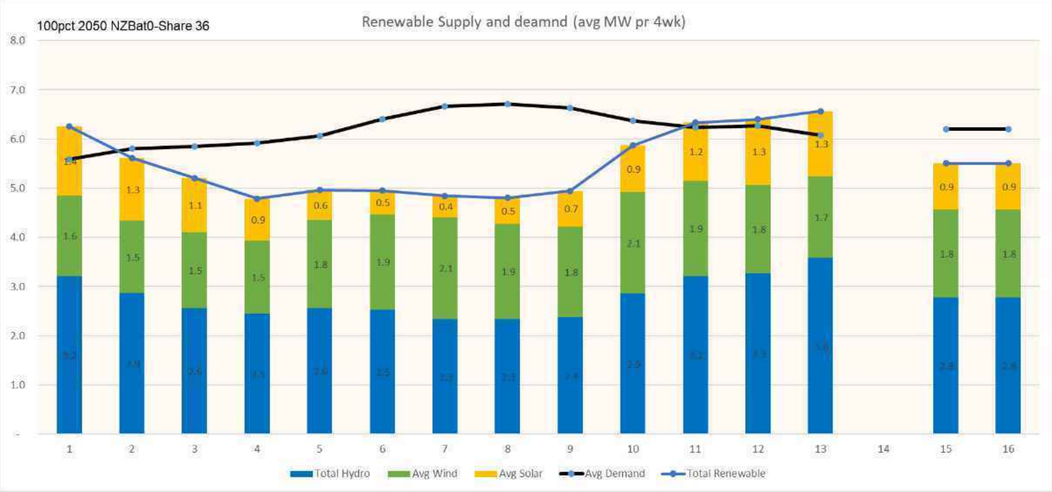
There is a high volatility in hydro inflows per month





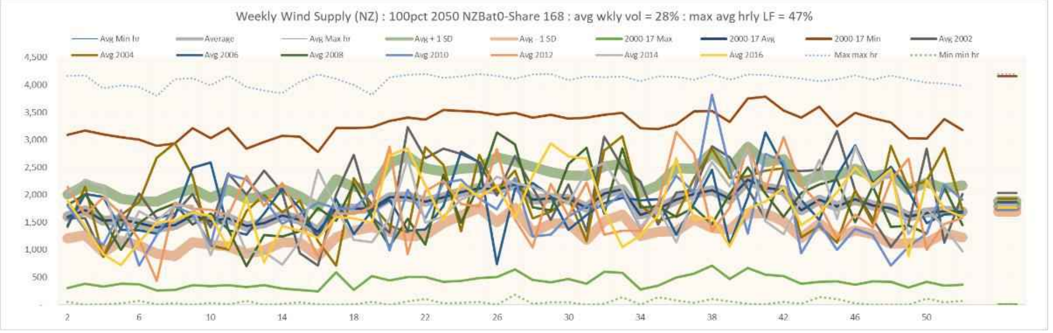
Hydro Inflows and solar supply are lowest during winter

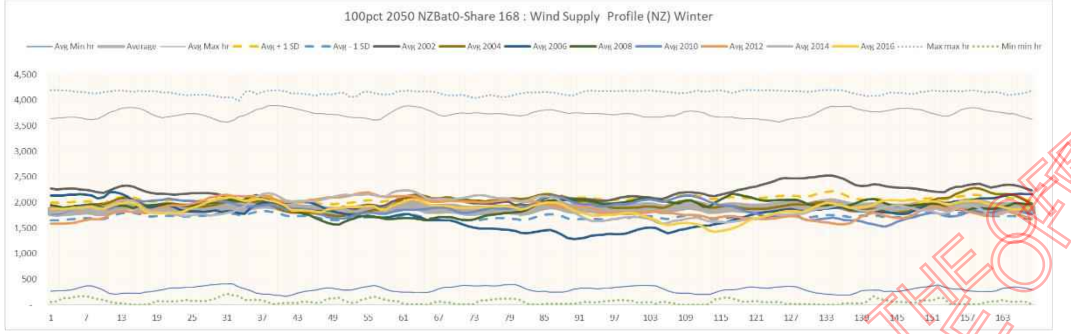


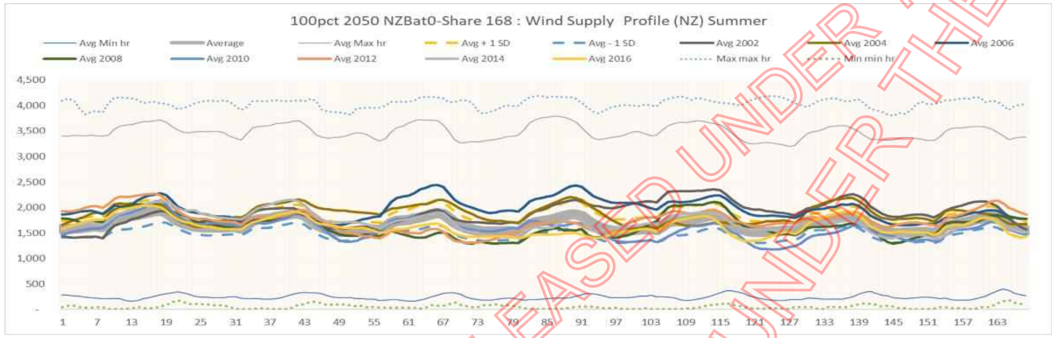


Solar and Wind Supply Data

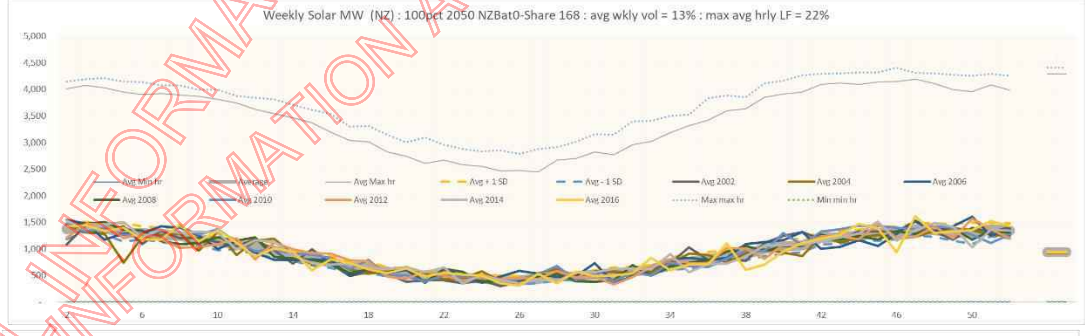
Wind

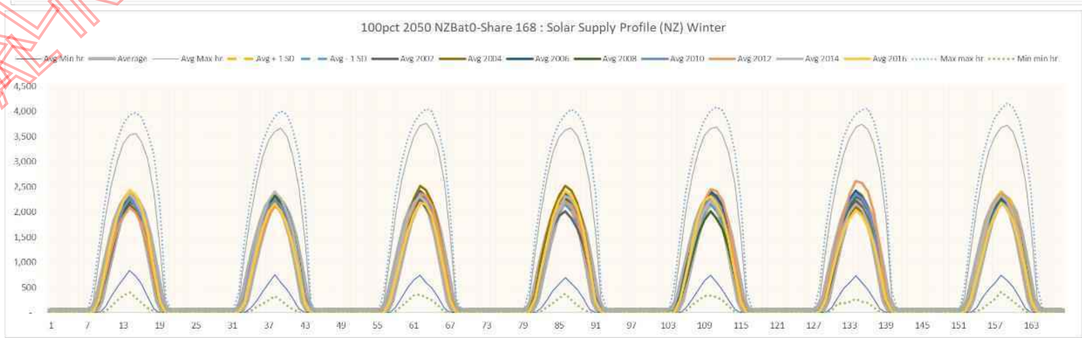

Weekly Wind Supply (NZ) : 100pct 2050 NZBat0-Share 168 : avg wkly vol = 28% : max avg hrly LF = 47%

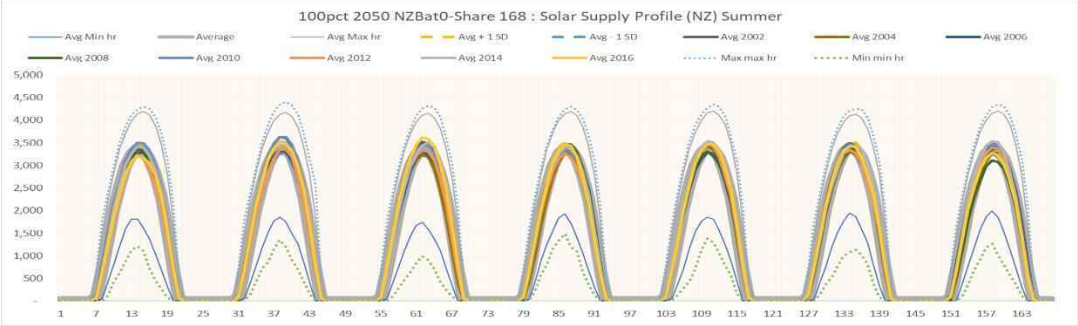

100pct 2050 NZBat0-Share 168 : Wind Supply Profile (NZ) Winter


100pct 2050 NZBat0-Share 168 : Wind Supply Profile (NZ) Summer

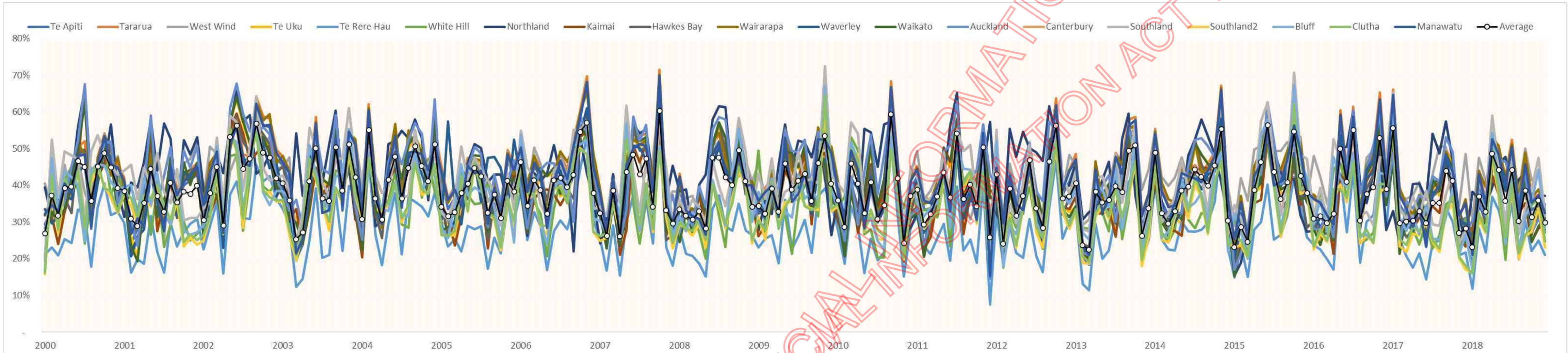
Solar


Weekly Solar MW (NZ) : 100pct 2050 NZBat0-Share 168 : avg wkly vol = 13% : max avg hrly LF = 22%


100pct 2050 NZBat0-Share 168 : Solar Supply Profile (NZ) Winter


100pct 2050 NZBat0-Share 168 : Solar Supply Profile (NZ) Summer

There is high monthly variation in wind supply by region as shown by the monthly chart over 18 years. Statistical measures of variation on other time frames are provided below.



Daily Statistics

	Average Capacity factor	P5	P10	P90	P95	Volatility	Cross Correl Tararua	Serial Correl
Te Apiti	40%	90%	83%	15%	5%	70%	100%	51%
Tararua	43%	91%	84%	18%	8%	65%	100%	50%
West Wind	43%	90%	83%	18%	7%	65%	77%	37%
Te Uku	39%	86%	79%	14%	5%	70%	59%	54%
Te Rere Hau	28%	74%	65%	8%	2%	84%	98%	51%
White Hill	36%	85%	78%	10%	4%	77%	43%	55%
Northland	42%	91%	84%	16%	5%	68%	23%	55%
Kaimai	37%	84%	76%	14%	6%	70%	58%	54%
Hawkes Bay	39%	90%	81%	15%	9%	69%	81%	52%
Wairarapa	43%	90%	83%	19%	8%	64%	97%	47%
Waverley	39%	85%	77%	16%	6%	67%	85%	48%
Waikato	39%	88%	80%	13%	5%	71%	61%	53%
Auckland	42%	90%	84%	15%	5%	69%	52%	55%
Canterbury	41%	90%	83%	16%	7%	67%	47%	57%
Southland	41%	90%	83%	16%	7%	67%	47%	57%
Southland2	34%	83%	74%	11%	4%	76%	52%	55%
Bluff	37%	85%	76%	13%	4%	73%	45%	58%
Clutha	35%	83%	74%	13%	5%	73%	50%	56%
Average	39%	87%	79%	15%	6%	**70%**	65%	52%

70% daily volatility

Monthly Statistics

	Max	P10	P90	Min	Volatility	Cross Correl Tararua	Serial Correl
Te Apiti	70%	53%	28%	15%	26%	100%	13%
Tararua	72%	55%	31%	17%	23%	100%	12%
West Wind	64%	53%	33%	22%	19%	86%	6%
Te Uku	63%	53%	26%	17%	26%	77%	30%
Te Rere Hau	57%	40%	18%	8%	31%	99%	10%
White Hill	62%	49%	24%	17%	27%	64%	8%
Northland	66%	57%	28%	15%	24%	41%	42%
Kaimai	66%	51%	26%	16%	25%	78%	25%
Hawkes Bay	67%	52%	26%	16%	25%	89%	20%
Wairarapa	70%	55%	31%	20%	23%	99%	12%
Waverley	66%	51%	28%	19%	24%	90%	13%
Waikato	64%	53%	27%	15%	26%	77%	31%
Auckland	68%	56%	28%	17%	25%	73%	33%
Canterbury	72%	55%	30%	19%	23%	67%	9%
Southland	72%	55%	30%	19%	23%	67%	9%
Southland2	62%	47%	23%	16%	27%	72%	14%
Bluff	67%	51%	26%	17%	26%	64%	8%
Clutha	65%	47%	25%	16%	25%	70%	13%
Average	66%	52%	27%	17%	**25%**	78%	17%

25% monthly volatility

Annual Statistics

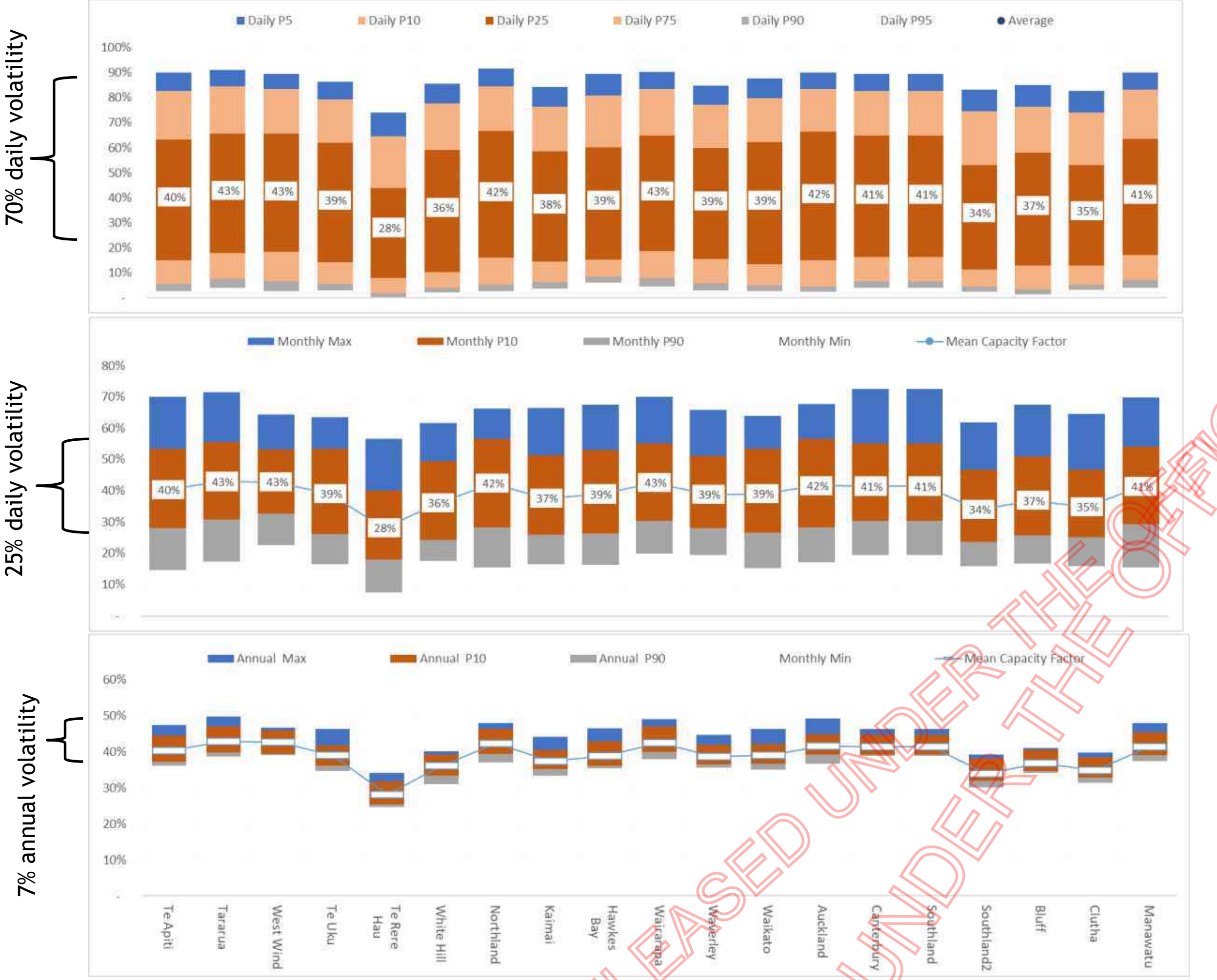
	Max	P10	P90	Min	Volatility	Cross Correl Tararua
Te Apiti	47%	44%	37%	36%	7%	100%
Tararua	50%	47%	40%	39%	7%	100%
West Wind	47%	46%	39%	39%	6%	83%
Te Uku	46%	41%	35%	35%	8%	79%
Te Rere Hau	34%	32%	25%	25%	9%	99%
White Hill	40%	39%	33%	31%	7%	78%
Northland	48%	46%	39%	37%	7%	22%
Kaimai	44%	40%	34%	33%	7%	73%
Hawkes Bay	46%	43%	36%	35%	8%	89%
Wairarapa	49%	47%	40%	38%	7%	99%
Waverley	45%	42%	36%	35%	7%	87%
Waikato	46%	42%	35%	35%	7%	81%
Auckland	49%	44%	38%	37%	7%	72%
Canterbury	46%	45%	39%	36%	7%	76%
Southland	46%	45%	39%	36%	7%	76%
Southland2	39%	38%	30%	28%	9%	75%
Bluff	41%	41%	34%	32%	7%	74%
Clutha	40%	38%	31%	29%	8%	74%
Average	45%	42%	36%	34%	**7%**	80%

7% annual volatility

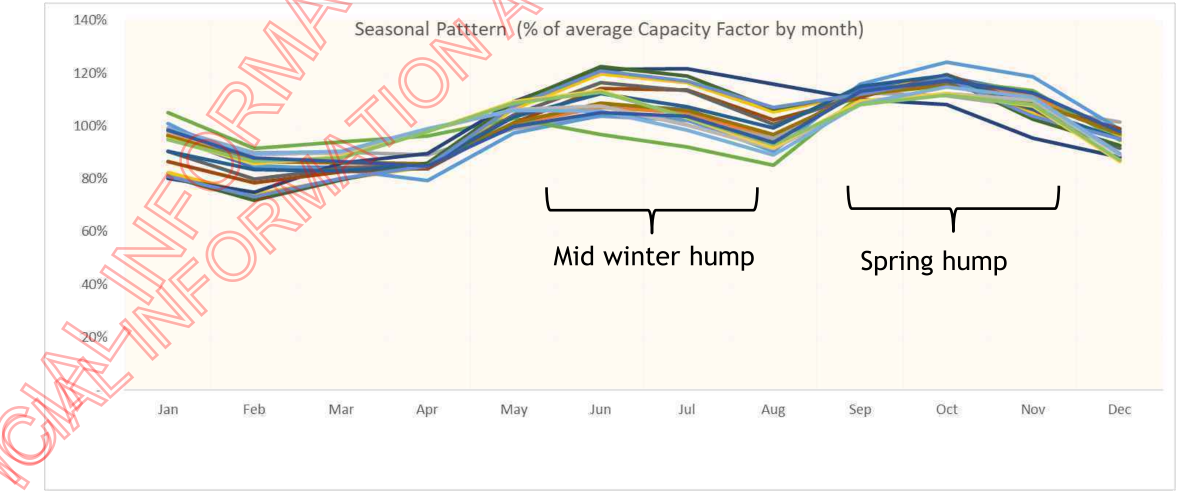
Note: Volatility = standard deviation/mean

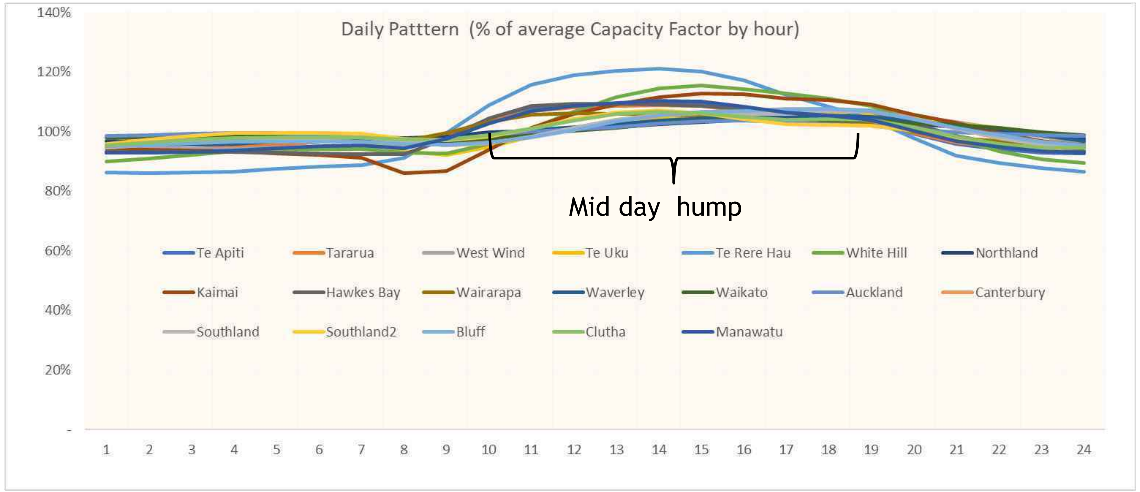
There is a modest winter and spring bias in the seasonal pattern and a small time-time bias in the daily pattern on average

There is a very high daily variation in the wind profiles. The greatest volatility is around is between days. This falls to 25% between months and 7% between years.



The average seasonal and daily patterns of supply show slight mid-winter,spring and mid-day humps.





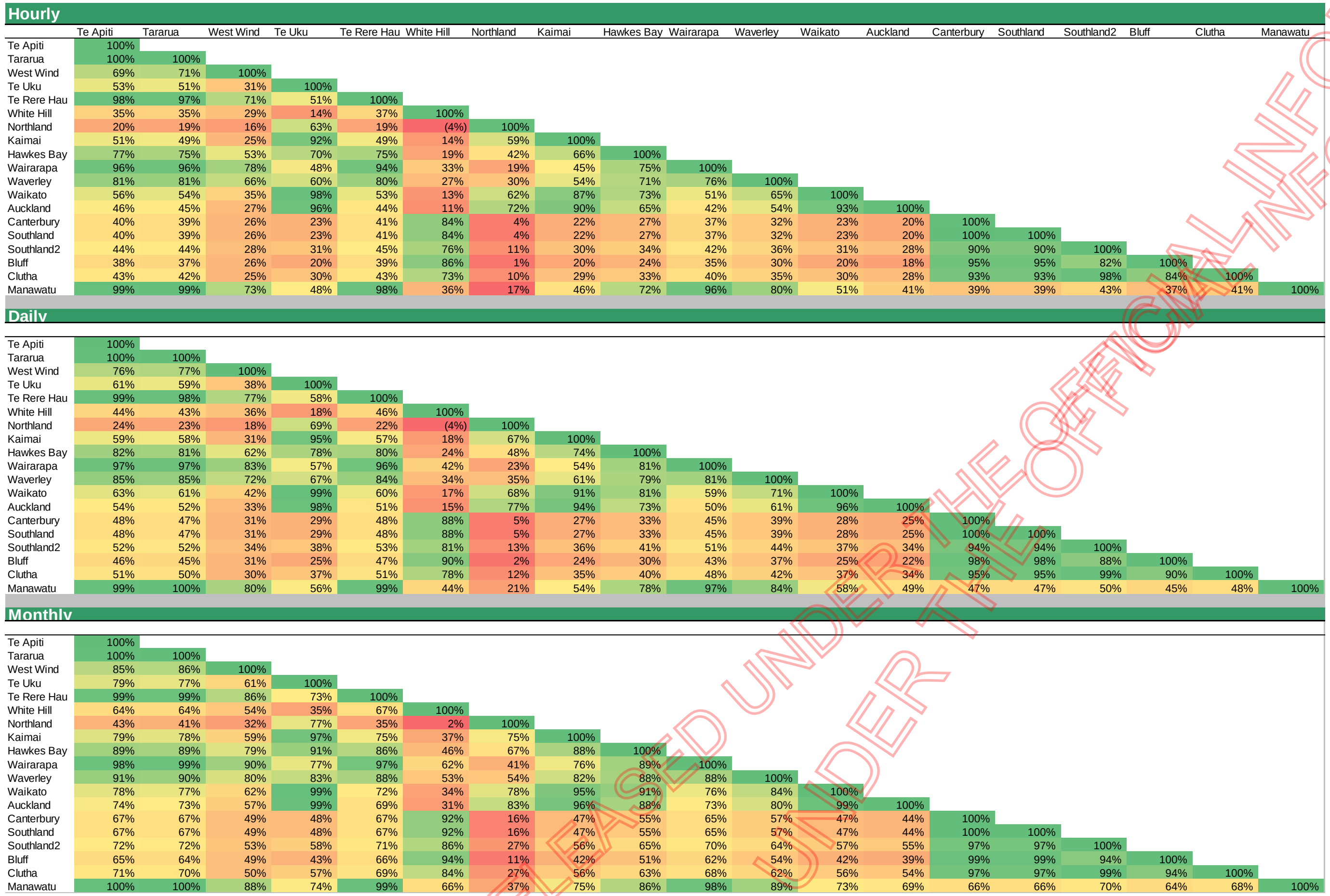
There is a high correlation between wind profiles within the Manawatu. The correlation falls off with distance, but is still is reasonably high at 35-45% in the South Island.

The cross corelation matrix shows the relationship between variation between all pairs of wind profiles. The highest cross correlations are shown in green and the lowest in red.

The correlations are greatest on a monthly basis, lower on a daily basis and also lower again on an hourly basis.

There is a 90% + corelation between profiles within the Manawatu, this falls towards 50% for other NI regions, and down to 40% for South Island sites and Northland.

The benefits from regional diversification of wind are significant, but not overwhelming.



Hourly

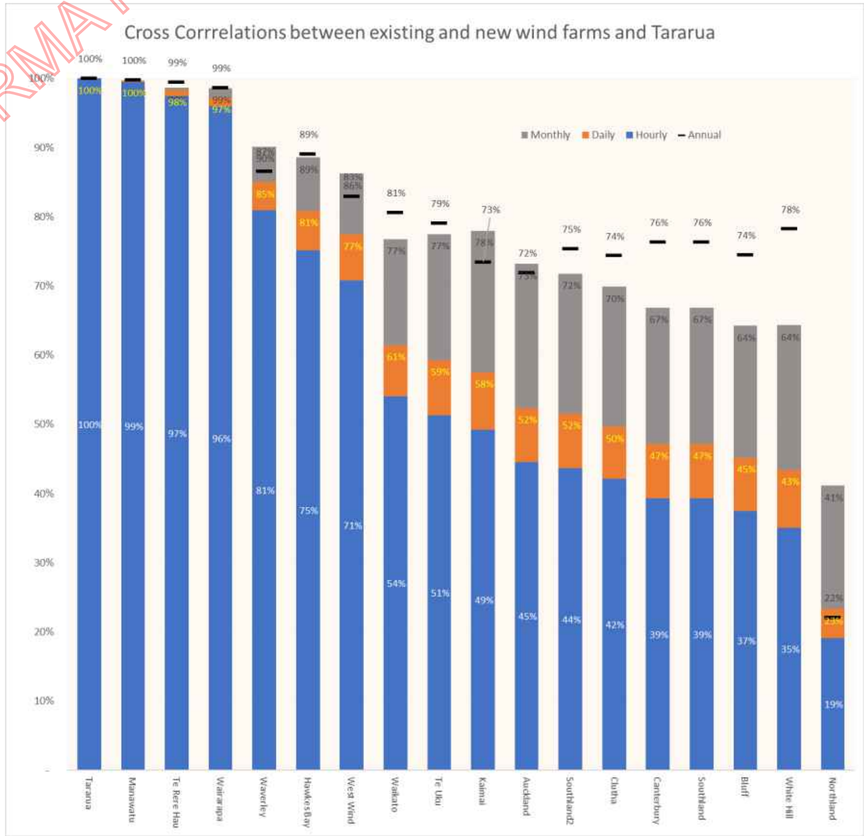
	Te Apiti	Tararua	West Wind	Te Uku	Te Rere Hau	White Hill	Northland	Kaimai	Hawkes Bay	Wairarapa	Waverley	Waikato	Auckland	Canterbury	Southland	Southland2	Bluff	Clutha	Manawatu
Te Apiti	100%																		
Tararua	100%	100%																	
West Wind	69%	71%	100%																
Te Uku	53%	51%	31%	100%															
Te Rere Hau	98%	97%	71%	51%	100%														
White Hill	35%	35%	29%	14%	37%	100%													
Northland	20%	19%	16%	63%	19%	(4%)	100%												
Kaimai	51%	49%	25%	92%	49%	14%	59%	100%											
Hawkes Bay	77%	75%	53%	70%	75%	19%	42%	66%	100%										
Wairarapa	96%	96%	78%	48%	94%	33%	19%	45%	75%	100%									
Waverley	81%	81%	66%	60%	80%	27%	30%	54%	71%	76%	100%								
Waikato	56%	54%	35%	98%	53%	13%	62%	87%	73%	51%	65%	100%							
Auckland	46%	45%	27%	96%	44%	11%	72%	90%	65%	42%	54%	93%	100%						
Canterbury	40%	39%	26%	23%	41%	84%	4%	22%	27%	37%	32%	23%	20%	100%					
Southland	40%	39%	26%	23%	41%	84%	4%	22%	27%	37%	32%	23%	20%	100%	100%				
Southland2	44%	44%	28%	31%	45%	76%	11%	30%	34%	42%	36%	31%	28%	90%	90%	100%			
Bluff	38%	37%	26%	20%	39%	86%	1%	20%	24%	35%	30%	20%	18%	95%	95%	82%	100%		
Clutha	43%	42%	25%	30%	43%	73%	10%	29%	33%	40%	35%	30%	28%	93%	93%	98%	84%	100%	
Manawatu	99%	99%	73%	48%	98%	36%	17%	46%	72%	96%	80%	51%	41%	39%	39%	43%	37%	41%	100%

Daily

Te Apiti	100%																		
Tararua	100%	100%																	
West Wind	76%	77%	100%																
Te Uku	61%	59%	38%	100%															
Te Rere Hau	99%	98%	77%	58%	100%														
White Hill	44%	43%	36%	18%	46%	100%													
Northland	24%	23%	18%	69%	22%	(4%)	100%												
Kaimai	59%	58%	31%	95%	57%	18%	67%	100%											
Hawkes Bay	82%	81%	62%	78%	80%	24%	48%	74%	100%										
Wairarapa	97%	97%	83%	57%	96%	42%	23%	54%	81%	100%									
Waverley	85%	85%	72%	67%	84%	34%	35%	61%	79%	81%	100%								
Waikato	63%	61%	42%	99%	60%	17%	68%	91%	81%	59%	71%	100%							
Auckland	54%	52%	33%	98%	51%	15%	77%	94%	73%	50%	61%	96%	100%						
Canterbury	48%	47%	31%	29%	48%	88%	5%	27%	33%	45%	39%	28%	25%	100%					
Southland	48%	47%	31%	29%	48%	88%	5%	27%	33%	45%	39%	28%	25%	100%	100%				
Southland2	52%	52%	34%	38%	53%	81%	13%	36%	41%	51%	44%	37%	34%	94%	94%	100%			
Bluff	46%	45%	31%	25%	47%	90%	2%	24%	30%	43%	37%	25%	22%	98%	98%	88%	100%		
Clutha	51%	50%	30%	37%	51%	78%	12%	35%	40%	48%	42%	37%	34%	95%	95%	99%	90%	100%	
Manawatu	99%	100%	80%	56%	99%	44%	21%	54%	78%	97%	84%	58%	49%	47%	47%	50%	45%	48%	100%

Monthly

Te Apiti	100%																		
Tararua	100%	100%																	
West Wind	85%	86%	100%																
Te Uku	79%	77%	61%	100%															
Te Rere Hau	99%	99%	86%	73%	100%														
White Hill	64%	64%	54%	35%	67%	100%													
Northland	43%	41%	32%	77%	35%	2%	100%												
Kaimai	79%	78%	59%	97%	75%	37%	75%	100%											
Hawkes Bay	89%	89%	79%	91%	86%	46%	67%	88%	100%										
Wairarapa	98%	99%	90%	77%	97%	62%	41%	76%	89%	100%									
Waverley	91%	90%	80%	83%	88%	53%	54%	82%	88%	88%	100%								
Waikato	78%	77%	62%	99%	72%	34%	78%	95%	91%	76%	84%	100%							
Auckland	74%	73%	57%	99%	69%	31%	83%	96%	88%	73%	80%	99%	100%						
Canterbury	67%	67%	49%	48%	67%	92%	16%	47%	55%	65%	57%	47%	44%	100%					
Southland	67%	67%	49%	48%	67%	92%	16%	47%	55%	65%	57%	47%	44%	100%	100%				
Southland2	72%	72%	53%	58%	71%	86%	27%	56%	65%	70%	64%	57%	55%	97%	97%	100%			
Bluff	65%	64%	49%	43%	66%	94%	11%	42%	51%	62%	54%	42%	39%	99%	99%	94%	100%		
Clutha	71%	70%	50%	57%	69%	84%	27%	56%	63%	68%	62%	56%	54%	97%	97%	99%	94%	100%	
Manawatu	100%	100%	88%	74%	99%	66%	37%	75%	86%	98%	89%	73%	69%	66%	66%	70%	64%	68%	100%



Note: the correlation is measured using the Pearson Product-Moment Correlation. The Northland result is derived from renewable ninja website, but appears to be an outlier. This profile is not used in the modelling.

The changing regional mix of wind supply – 100% renewable worlds with no NZ Battery

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[redacted]

APPENDIX 2: CHANGES IN THE DAILY GENERATION PATTERNS DURING TYPICAL WEEKS IN WINTER AND SUMMER

Averaged daily patterns of supply in 2035 with modest levels of solar and EVs

Limited Thermal	100% Renewable without NZ Battery	100% Renewable with NZ Battery - SI 5TWh/1.0GW

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[redacted]

Averaged daily patterns of supply in 2050 with significant electrification and solar

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[redacted]

The charts show the contribution of each source of supply and flexibility in GW in each hour of a typical working day in winter and in summer. The results are averaged over all 86 weather years.

Averaged daily patterns of supply in 2065 with full transport electrification and high solar

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[redacted]

The charts show the contribution of each source of supply and flexibility in GW in each hour of a typical working day in winter and in summer. The results are averaged over all 86 weather years.

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Examples of supply by hour over sample weeks - in 2065 - limited thermal without NZ Battery

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[redacted]

Examples of supply by hour over sample weeks - in 2065 - 100% renewable with a NZ Battery (SI 5TWh/1GW)

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[redacted]

APPENDIX 3: ANALYSIS OF GENERATION CONTRIBUTION TO PERIODS OF SCARCITY AND SURPLUS

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[redacted]

Contribution of renewables to periods of surplus and scarcity in 2065 : without NZ Battery

Limited Thermal

100% renewable World

100% renewable World with NZ Battery

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[redacted]

Notes: The horizontal axis is a set of “bins” of modelled periods ranked from periods of highest “spill” risk to highest scarcity/shortage risk. The vertical axis is average GW contribution to meeting demand in each “bin”.

GW contribution to periods of surplus/scarcity in 2065: with SI Battery 0.5 to 1.0GW

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[redacted]

APPENDIX 4: THE FREQUENCY AND NATURE OF DEMAND RESPONSE AND SHORTAGE

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[redacted]

APPENDIX 5: A TABLE OF KEY SIMULATION RESULTS

Table of key results in the 2 worlds without and with a SI 5TWh/1GW pumped hydro

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[redacted]

APPENDIX 6: AN ALTERNATIVE ANALYSIS OF THE CHANGING NEED FOR FLEXIBLE BACK UP – FOCUSING ON RESIDUAL DEMAND AFTER INTERMITTENT SUPPLY

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[redacted]

Residual demand variability

- We repeated the steps in the previous slide for a wide range of different time periods, and across our three modelled years
- The results are shown alongside and some things are apparent:

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[redacted]

Residual demand variability

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[redacted]

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[redacted]

APPENDIX 7: A TABLE OF KEY ASSUMPTIONS

Summary Table of Key Assumptions for each of the Worlds

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[redacted]