Court File Reference: ENV-2018-CHC-38

BEFORE THE ENVIRONMENT COURT

I MUA I TE KOOTI TAIAO O AOTEAROA

UNDER	The Resource Management Act 1991 (RMA)
IN THE MATTER	Appeals under clause 14(1) of the First Schedule of the Act in relation to the Proposed Southland Water and Land Plan
BETWEEN	**MERIDIAN ENERGY LIMITED** **Appellants**
AND	**SOUTHLAND REGIONAL COUNCIL** **Respondent**

STATEMENT OF EVIDENCE OF GUY MEREDITH TE PUKA WAIPARA

FOR

MERIDIAN ENERGY LIMITED

15 February 2019

Judicial Officers: Judge Borthwick and Judge Hassan

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(ENV-2018-CHC-27)

HORTICULTURE NEW ZEALAND
(ENV-2018-CHC-28)

ARATIATIA LIVESTOCK LTD
(ENV-2018-CHC-29)

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(ENV-2018-CHC-30)

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(ENV-2018-CHC-31)

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(ENV-2018-CHC-32)

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(ENV-2018-CHC-33)

BEEF + LAMB NEW ZEALAND
(ENV-2018-CHC-34 AND 35)

DIRECTOR-GENERAL OF CONSERVATION
(ENV-2018-CHC-36)

SOUTHLAND FISH & GAME COUNCIL
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SOUTHWOOD EXPORT LTD, SOUTHLAND PLANTATION FOREST COMPANY OF NZ
(ENV-2018-CHC-46)

TE RUNANGA O NGAI TAHU, HOKONUI RUNAKA, WAIHOPAI RUNAKA, TE RUNANGA O AWARUA AND TE RUNANGA O ORAKA APARIMA
(ENV-2018-CHC-47)

PETER CHARTRES
(ENV-2018-CHC-48)

RAYONIER NEW ZEALAND LTD
(ENV-2018-CHC-49)

ROYAL FOREST AND BIRD PROTECTION SOCIETY OF NZ INC
(ENV-2018-CHC-50)

Appellants

AND **SOUTHLAND REGIONAL COUNCIL**

Respondent

QUALIFICATIONS AND EXPERIENCE

1 My full name is Guy Meredith Te Puka Waipara.

2 I am the General Manager of Generation & Natural Resources for Meridian Energy Limited (Meridian) based in Wellington. I have held this position since November 2017. My management responsibilities include:

(a) operation, maintenance and enhancement of Meridian's renewable generation assets (hydro and wind);

(b) maintaining a health and safety framework for Meridian's people;

(c) developing a pipeline of new renewable generation options;

(d) managing the procurement and construction new renewable projects; and

(e) maintaining ongoing relationships with the communities in which Meridian operates.

3 Overall, I oversee the management of Meridian's generation assets including the Manapōuri Power Scheme (MPS). Before my current role, from April 2016 I was the General Manager of Markets and Production at Meridian. From 2010 until taking up the General Manager of Markets and Production role I was General Manager External Relations at Meridian. I have been part of Meridian's Executive management team since 2010.

4 Prior to the above positions I held a variety of roles in offshore business development and developing company strategy which included managing our electricity system modelling team. I have nearly 30 years' experience in the electricity sector and previously worked at Transpower New Zealand Limited in roles responsible for transmission planning and network development.

5 I hold a BE (Hons) in electrical engineering and Masters in Business Administration.

6 This statement is not made as an expert but rather it is a statement in the context of my position with Meridian. The primary purpose of my statement is to assist the Court in understanding the context of the MPS as part of the wider electricity system in New Zealand and its importance with respect to the contribution to the same, particularly in the context of increasing demand scenarios as New Zealand moves towards a lower-carbon

economy. I am authorised to present this evidence as a representative of Meridian and on behalf of the Company.

7 I have also read and am familiar with the statements of evidence of Dr Jennifer Purdie (Fuel Advisor) and Andrew Feierabend (Statutory and Compliance Strategy Manager).

SCOPE OF THIS EVIDENCE

8 In my statement I:

(a) Provide an overview of Meridian;

(b) Provide an overview of the New Zealand Electricity Market and how this operates;

(c) Outline the role and importance of the hydroelectric power generation within the New Zealand electricity system compared to the use of other generation fuel types and how Meridian's generation portfolio fits within this;

(d) Describe how the MPS contributes to national and regional demand, the supply of energy to the Tiwai Smelter and the importance of this in the context of the Southland Regional economy;

(e) Discuss the ancillary functions the MPS plays in supporting the national grid with respect to spinning reserve, frequency keeping and voltage control;

(f) Discuss New Zealand demand projections and the likely effects of this on New Zealand's future generation mix; and

(g) Discuss the future importance of the MPS operation in meeting New Zealand's national objectives with respect to climate change and renewable energy targets.

MERIDIAN ENERGY LIMITED – AN OVERVIEW

9 In this section of my statement I provide an overview of Meridian. The purpose of this is to give context to Meridian as the operator of the MPS.

10 Meridian is listed on the New Zealand and Australian stock exchanges and is 51% owned by the New Zealand Government.

11 Meridian is a renewable energy generator and electricity retailer. Meridian is committed to generating electricity from 100% renewable sources – water and wind. The company generates around 30% of New Zealand's current electricity production.

12 Meridian's core business is the generation, marketing, trading and retailing of electricity and the management of associated assets and ancillary structures in New Zealand. Meridian's asset base in the Southland region consists of the MPS and the White Hill Wind Farm.

13 Meridian owns and manages two hydro power schemes in New Zealand: the Waitaki Power Scheme (from Lake Pūkaki down and comprising 6 power stations), and the MPS. Meridian owns five wind farms in New Zealand: Te Uku (Raglan), Te Apiti (Manawatu), Mill Creek (Wellington), West Wind (Wellington) and White Hill (Southland). Meridian's hydro stations generate enough electricity to power the equivalent of around 1.7 million homes each year and its wind farms generate enough electricity to power the equivalent of around 190,000 homes each year.

14 In Australia, Meridian owns and operates two wind farms: Mt Mercer in Victoria and Mt Millar in South Australia; and three hydro stations in New South Wales: Hume, Burrinjuck and Keepit.

15 Meridian retails electricity across New Zealand with around 290,000 customers supplied through its Meridian and Powershop brands. Powershop has an additional 100,000 customers in Australia. In the UK, the Powershop platform retails to customers via a franchise agreement.

16 Meridian's largest customer is the New Zealand Aluminium Smelter at Tiwai Point in Bluff. The smelter consumes around 13% of New Zealand's national demand, equivalent to around 37% of Meridian's annual average generation production.

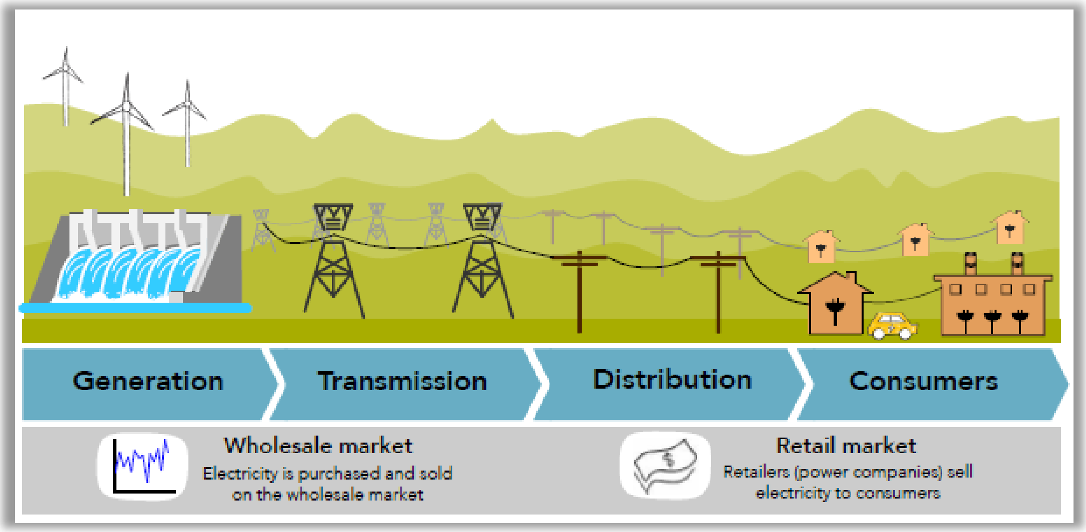
THE NEW ZEALAND ELECTRICITY SYSTEM AND HOW IT OPERATES

17 The New Zealand Electricity System as it operates today is an outcome of Government reform prior to and during the 1990s. This culminated in the establishment of a wholesale market place for the generation and sale of electricity in 1996.

18 The government reforms split the sector into: generation, transmission, distribution, retail and consumers and established a regulatory regime to

oversee the competitive and monopoly elements of the industry. This is diagrammatically represented in Figure 1 below.

Figure 1 – The New Zealand electricity system[1]



19 The New Zealand Electricity Authority was established as an independent Crown entity responsible for the efficient operation of the New Zealand electricity market. The Authority is strictly an electricity market regulator. Its purpose is to promote competition and ensure a reliable supply by the efficient operation of the electricity industry for the benefit of consumers. The Commerce Commission regulates the monopoly aspects of the industry, transmission and distribution.

20 Transpower performs two functions within the electricity system. Its first function is as the owner and operator of the National Grid. Its second function is as the System Operator. As System Operator Transpower is responsible for managing the real-time power system and operating the wholesale electricity market. This ensures generation matches demand at all times and that electricity is dispatched to meet demand securely and at lowest cost.

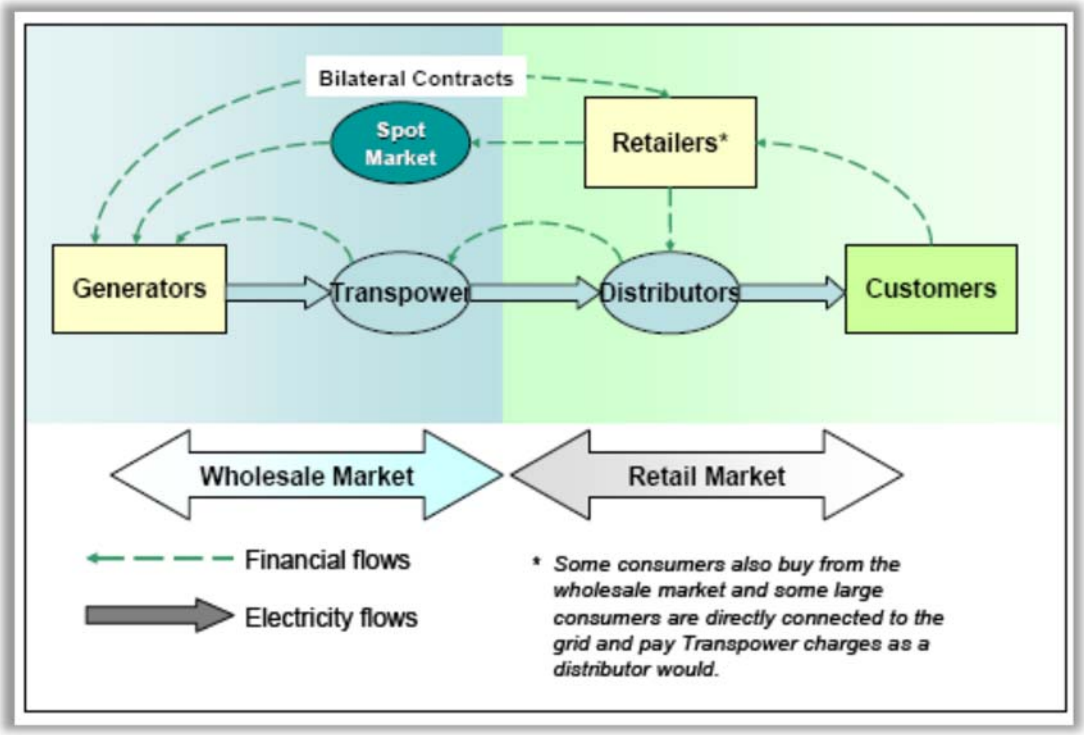
21 The electricity market in New Zealand is an energy only market place. Generators compete with each other for the opportunity to generate electricity and only get paid for what they supply at the marginal market price for each half hourly trading period. The marginal market price is the highest price at which electricity is supplied to the National Grid in each half hour. There is generally mandatory separation between lines and retail

[1] *New Zealand Productivity Commission – Low-emissions economy – Final report August 2018*

electricity businesses and there is open and equal access to transmission and distribution networks. Finally, there is full retail contestability between providers.

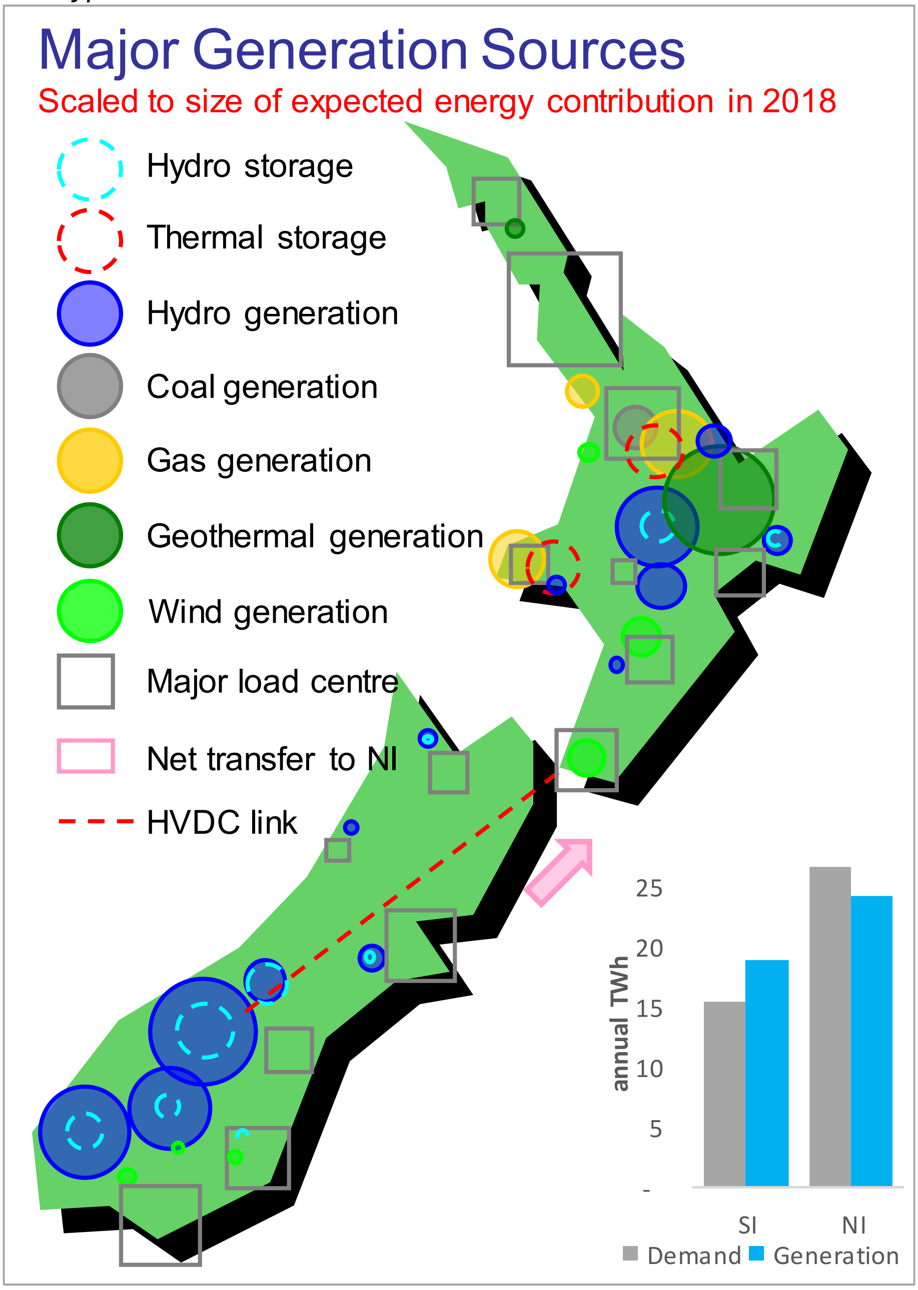
22 The New Zealand electricity market includes competitive wholesale and retail markets. As depicted in Figure 2. Electricity markets have relatively unique characteristics in that, once generated, electricity cannot be stored in the system and generation must be continuously matched with consumption on a moment-to-moment basis to ensure that the entire system is maintained in a stable and secure state. As discussed above it is the role of the System Operator to coordinate the matching of supply and demand in real time.

Figure 2 – The commercial structure of New Zealand's Electricity Market



23 The nature of New Zealand's power system is determined by its geography, population base and natural resource (see Figure 3). The network by its nature is isolated, long and drawn out across the length of the country. Demand is dominated by the North Island with energy being exported or imported between both islands via the High Voltage Direct Current (HVDC) link. The majority of time there is a positive flow of electricity energy to the North Island via this link, although sometimes the flow of electricity is in the opposite direction, depending on the state of hydro generation and storage in the South Island and relative levels of demand.

Figure 3 – The New Zealand power system – key generation sources by fuel type



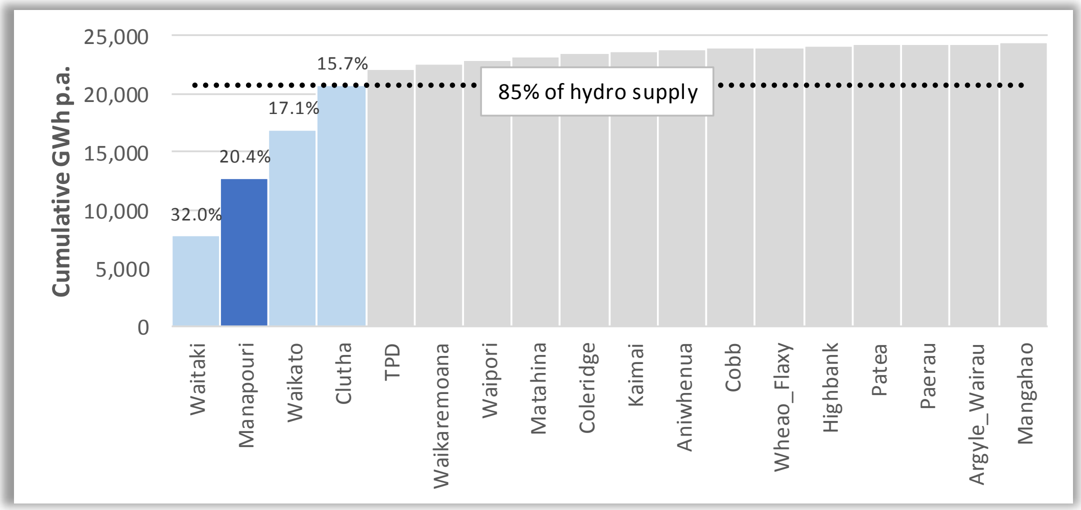
THE SIGNIFICANCE OF HYDROELECTRIC POWER GENERATION TO THE NEW ZEALAND ELECTRICITY SYSTEM

24 The New Zealand power system has historically been characterised by the dominance of hydro generation of electricity. Such generation is produced from both run of river systems and systems based on water stored in reservoirs, both natural and man-made.

25 Approximately 85% of New Zealand's grid connected hydro supply is currently from four schemes, as shown in Figure 4. While small scale renewable developments will contribute to future energy supply needs, the

importance of preserving and enhancing the capability of these existing large-scale developments is critical for New Zealand to meet its renewable energy targets and climate change commitments. The importance of this is further discussed in my evidence below.

Figure 4 – Cumulative supply from grid connected hydro schemes (average 2014 to 2018)[2]



26 Rainfall patterns are highly variable and unpredictable with the resulting hydro generation subject to year-on-year volatility. Seventy five percent of the hydro resources are in the South Island with inflows driven by seasonal snowfall and rainfall in the Southern Alps.

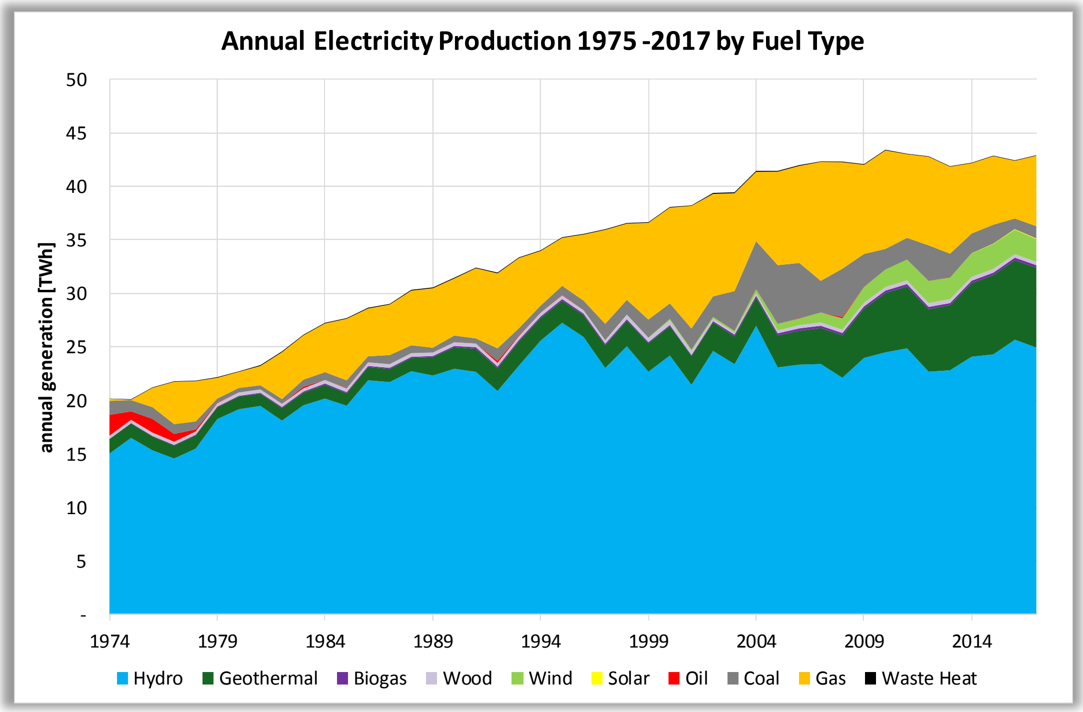
27 The hydro proportion of total generation has declined from a high of 80% in the 1970s to between 50–60% in recent years. This was initially due to increased thermal generation being added and then latterly by new geothermal and wind generation. This proportion will likely reduce further over time as total demand and supply grow with only a modest amount of remaining economic and realistically consentable hydro development likely.

28 However, hydro generation is still the largest single source of generation at approximately 24TWh per annum in a typical year. Geothermal contributes around 17% (7TWh), wind contributes 5% (2.2TWh), and coal, gas and thermal plant together contribute 12–21% (5–9TWh) depending on rainfall conditions[3].

[2] https://www.emi.ea.govt.nz/Wholesale/Datasets/Generation/Generation_MD/
[3] https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/

29 Figure 5 provides a diagrammatic represention of annual electricity generation by fuel type from 1975 to 2017. An important note with respect to fuel type and use is the diminishing use of coal as it is replaced by gas and new geothermal production. Hydro generation, as previously stated, has plateaued.

Figure 5 – Annual electricity producton 1975-2017 by fuel type[4]



30 The operating capacity and generation associated with each fuel type in New Zealand is shown in Table 1 and visually represented in Figure 6. The information is derived from Ministry of Business, Innovation and Employment (MBIE) generation and generating plant data for the 2017 year. Table 1 and Figure 6 below provide a snapshot in time of the range of fuel types used for generation, the relative importance and contribution of each to the total sector and the spread of generation between the North Island and South Island.

[4] https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/

Table 1 – Operating Capacity and Generation by Fuel Type in New Zealand

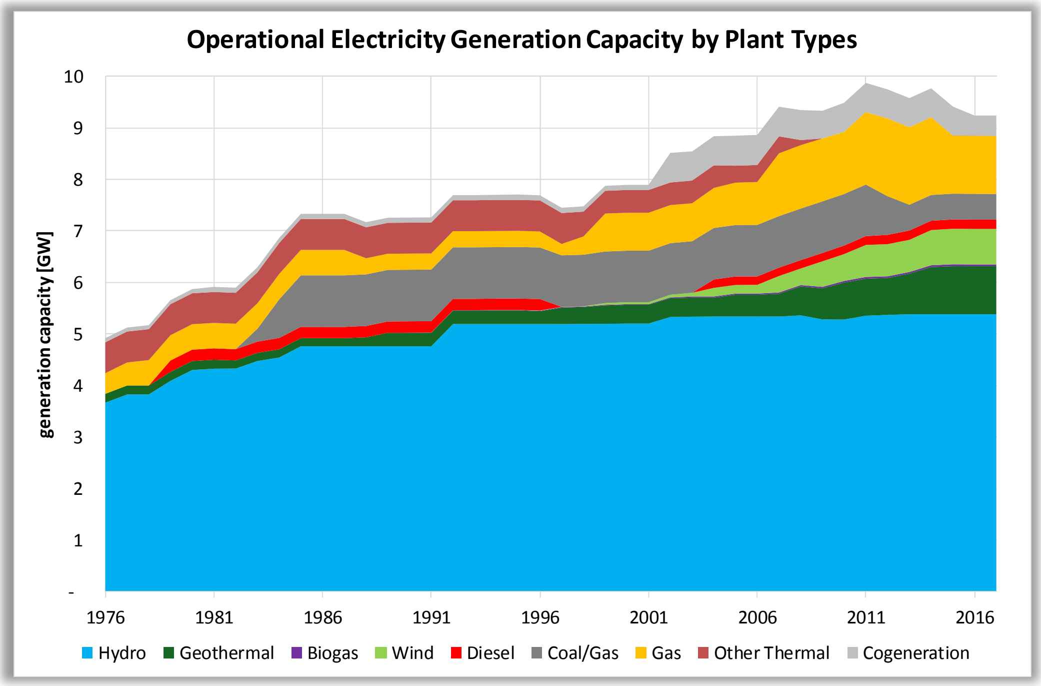
Installed Capacity (MW) in New Zealand, 31 Dec 2017

Fuel	New Zealand	NZ %	North Island	NI %	South Island	SI %
Hydro	5,381	58%	1,804	33%	3,577	96%
Geothermal	933	10%	933	17%	-	0%
Biogas	33	0%	23	0%	10	0%
Wind	689	7%	577	10%	112	3%
Diesel	180	2%	165	3%	15	0%
Coal/Gas	500	5%	500	9%	-	0%
Gas	1,127	12%	1,127	20%	-	0%
Other Thermal	-	0%	-	0%	-	0%
Cogeneration	394	4%	394	7%	-	0%
TOTAL	**9,237**	**100%**	**5,522**	**100%**	**3,714**	**100%**

Generation (GWh) in New Zealand in 2017

Fuel	New Zealand	NZ %	North Island	NI %	South Island	SI %
Hydro	24,934	58%	6,634	27%	18,300	98%
Geothermal	7,392	17%	7,392	31%	-	0%
Biogas	176	0%	122	1%	54	0%
Wind	2,120	5%	1,774	7%	346	2%
Solar PV	74	0%	48	0%	26	0%
Oil	5	0%	5	0%	0.4	0%
Coal	517	1%	517	2%	-	0%
Gas	5,581	13%	5,581	23%	-	0%
Cogeneration	2,112	5%	2,112	9%	-	0%
TOTAL	**42,911**	**100%**	**24,185**	**100%**	**18,726**	**100%**

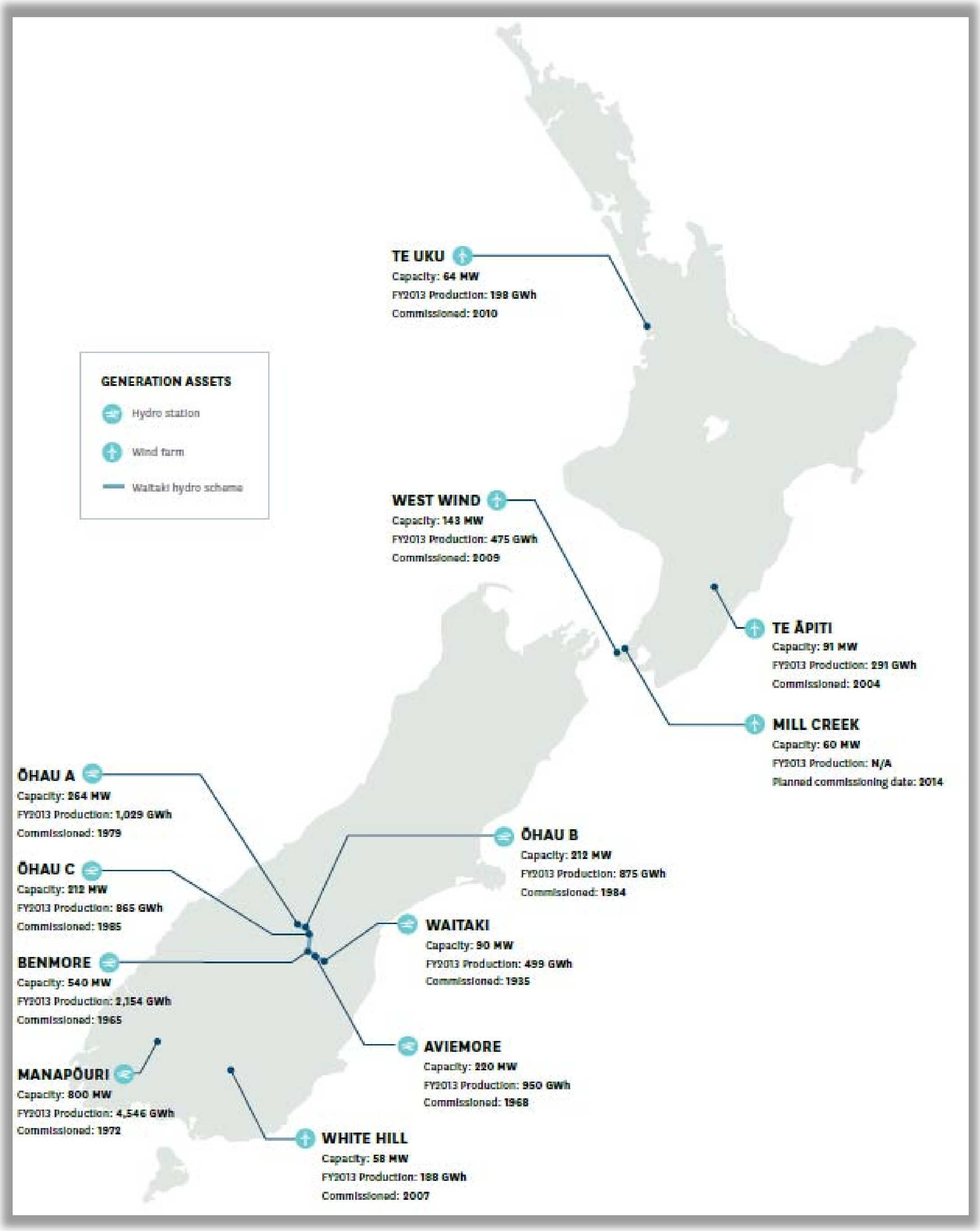
Figure 6 – New Zealand generating capacity 2017[5]



31 Within this system Meridian operates its generation portfolio which is diagrammatically represented in Figure 7 below. As previously indicated this is based on 100% renewable energy generation. Production from Meridian's portfolio is dominated by the contribution of the Waitaki Hydroelectric Power Scheme (WHEPS) which has 1538MW installed capacity, (exclusive of the Tekapo A & B Power Stations which are owned and operated by Genesis Energy Limited).

[5] https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/

Figure 7 – Meridian's generation portfolio



32 In addition to the energy that hydro generation contributes to the New Zealand electricity market, its flexibility provides a significant benefit in integrating or firming other intermittent sources of renewable energy, in particular wind and in the future solar power as this continues to grow.

33 In 2006–2008, in depth analysis was undertaken by Professor Goran Strbac to assess the economic impact on the incumbent power system of

integrating significant quantities of new wind generation[6]. This economic impact was described as the “system cost” or cost to the existing system to accommodate more wind generation. In these studies, scenarios of up to 20% wind generation (by total energy) were developed and analysed. A copy of the summary of findings from the New Zealand Wind Integration Study is attached as Appendix 1.

34 The system costs relate to the cost of building new generation supply to act as reserve plant for periods where there is low wind, as well as the operational costs of running this plant. The key findings from this analysis was that New Zealand’s hydro generation flexibility means that this can be operated to firm wind power without significant new investment. The cost of running hydro power (compared to burning fuel for a gas or coal power station) is also very low. As such, Professor Strbac concluded that New Zealand could accommodate at least 20% of wind power without incurring significant additional system costs. The reason for this was the presence of significant and flexible hydro generation resources.

35 Given the time frame for system firming is short term, i.e. seconds to hours up to potentially a day, hydro generation can provide this flexibility even during dry periods. This is due to the fact that the objective is to shift or move energy across a day between low and high wind generation periods but without consuming more energy overall, for example over the course of a week.

36 Professor Strbac concluded that largely due to the presence in New Zealand of flexible hydro schemes the ability to integrate significant additional intermittent renewables (solar, wind, marine, etc) into the New Zealand power system was significantly easier and the cost of doing so much lower than had been assessed for predominantly thermally dominated international powers systems.

THE MANAPOURI POWER SCHEME NATIONAL – REGIONAL DEMAND – THE TIWAI ALUMINIUM SMELTER

37 The MPS is operated as part of Meridian’s wider generation portfolio and as part of New Zealand’s electricity system. Every day decisions are made as to how Meridian will generate electricity in a way that meets its current

[6] *New Zealand Wind Integration Study – Goran Strbac, Danny Pudjianto, Anser Shakoor, Manuel J Castro, Guy Waipara, Grant Telfar, April 2008*

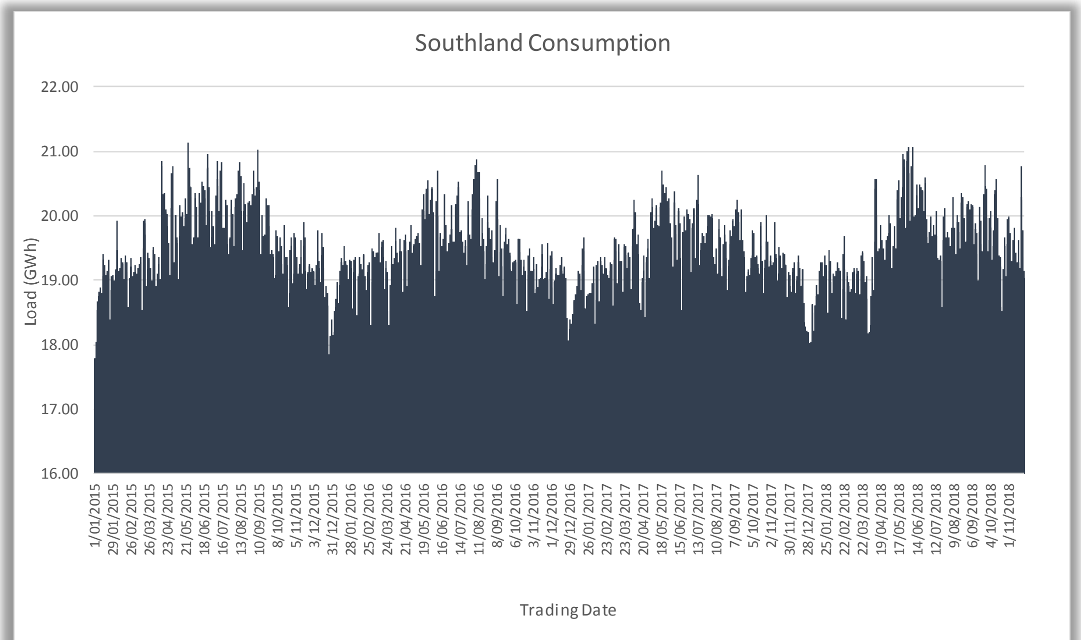
and future electricity supply commitments and market demands while complying with its authorisations and consents to operate.

38 At the same time Meridian must also manage its storage and fuel use so as to avoid risks associated with discontinuity of supply or meeting its above commitments. This means generation opportunities at the MPS need to be carefully managed, given the nature of its relative short-run storage as discussed in Mr Feierabend's evidence. Generation from the MPS is balanced with other generation opportunities, principally from the WHEPS but also from Meridian's wind farm interests.

39 Southland average daily demand for electricity as measured from 1 January 2015 to 22 November 2018 was 19.34 Gigawatt Hours (GWh) as represented in Figure 8 below. For the same period the average daily export of generation from Southland into the national grid equated to 5.52 GWh as represented in Figure 9. Figure 9 also shows those periods when energy is imported into Southland to cover shortfalls in regional generation.

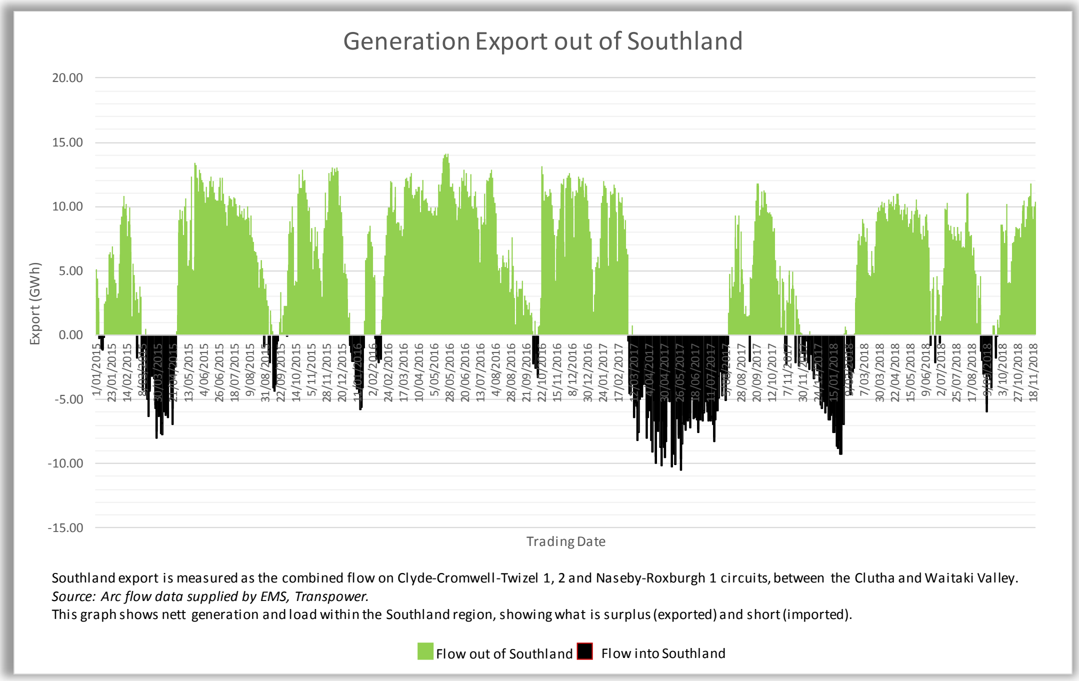
40 Actual import and export volumes vary according to real time levels of generation and real time levels of demand. Demand changes instantaneously and the flexibility of hydro storage to match instantaneous changes in demand is a crucial benefit of the MPS to the Southland and New Zealand electricity system.

Figure 8 – Average daily generation demand Southland – 1 January 2015–1 November 2018



Source: 30min Average SCADA load data, Transpower

Figure 9 – Average daily Southland generation export 1 January 2015–18 November 2018



41 In essence, the MPS is critical in meeting the electricity needs of Southland and contributes significantly to its social and economic wellbeing. This includes providing electricity to the aluminium smelter operated at Tiwai Point by Pacific Aluminium Limited. This company utilises approximately 12% of the national production of electricity at around 5TWh per annum).

42 The smelter is Meridian's largest customer consuming the equivalent of approximately 37% of Meridian's total electricity production. As recorded on the Pacific Aluminium Limited website the smelter contributes $525 million to Southland's economy or 10.5% of the Southland Region's economy. It also employs 900 full time equivalent employees and contractors on the site.

43 In December 2018 Pacific Aluminium Limited officially recommissioned potline four as metal prices have warranted this. This will allow the company to increase its production by a further 9.2%. Likewise, other Southland industry including primary production in the form of dairying, milk processing plants, horticulture, and meat processing are also heavily reliant on electricity.

44 While the MPS exports its electricity into the national grid, total annual demand from the Tiwai Point smelter is well matched to the total annual generation from the MPS. This allows the smelter to be supplied with

electricity relatively efficiently from a transmission and electrical losses perspective.

45 In the event that the Tiwai smelter ever closes, the current transmission system operated by Transpower has the capacity, with upgrading, to allow the majority of the MPS's output to be exported to the national grid and the wholesale market.

THE MANAPOURI POWER SCHEME – ANCILLARY SERVICES

46 The MPS is a large and critical component of the New Zealand electricity system and national transmission network. The MPS provides integrity and redundancy to this nationally essential physical resource in the event of planned or unplanned outages. In addition to generating electricity, the MPS provides the following essential ancillary services to maintaining the current electricity system as set out below.

(a) **Frequency keeping:** The MPS generators are fitted with governor systems which respond automatically to small system frequency deviations. This is an essential part of maintaining the balance between supply and demand as it varies second by second across the day. The frequency keeping service enables this balancing service to be allocated to specific plant designed for the task. This allows the entire power system to operate at a stable frequency which minimises wear and tear on all other generation plant.

(b) **Instantaneous reserves:** The scheme has the flexibility to respond automatically to a rapid fall in South Island system frequency due to a sudden loss of a large generating unit. This service is essential to maintaining the system frequency within acceptable limits, preventing other generators disconnecting automatically and risking South Island blackouts.

(c) **Over-frequency reserves:** The scheme has the flexibility to respond automatically to a rapid rise in system frequency due to a sudden loss of a large electricity load (for example, at the Tiwai Aluminium smelter) or failure of HVDC transmission capacity when sending electricity to the North Island. This service is essential to maintaining the system frequency within acceptable limits, preventing generators disconnecting automatically and risking South Island blackouts.

(d) **Voltage support:** Generators within the MPS are fitted with control systems which enable them to absorb or produce reactive power, as instructed by the System Operator, to enable the System Operator to maintain grid voltage levels within acceptable levels and maintain the quality and security of supply. This service has an impact on voltage levels over large areas of the grid.

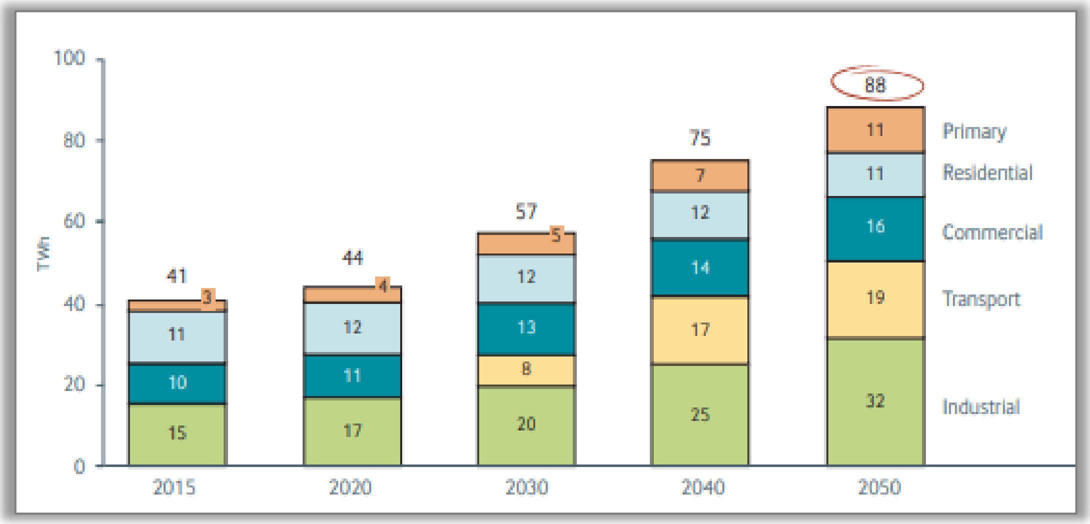
ELECTRICITY DEMAND PROJECTIONS

47 Electricity demand in New Zealand has been relatively flat for the past decade as energy efficiency (LEDs, insulation, appliances, domestic heat pumps, industrial process improvements) has lowered the level of demand growth for electricity[7].

48 This is expected to change as population and the economy are forecast to grow in coming decades. Electricity demand is projected to increase over the next 30 years[7]. However, while all forecasts agree that demand will increase, there is uncertainty about how great the increase will be due to variable factors such as future efficiency measures, technology changes, population increases, and changes in GDP.

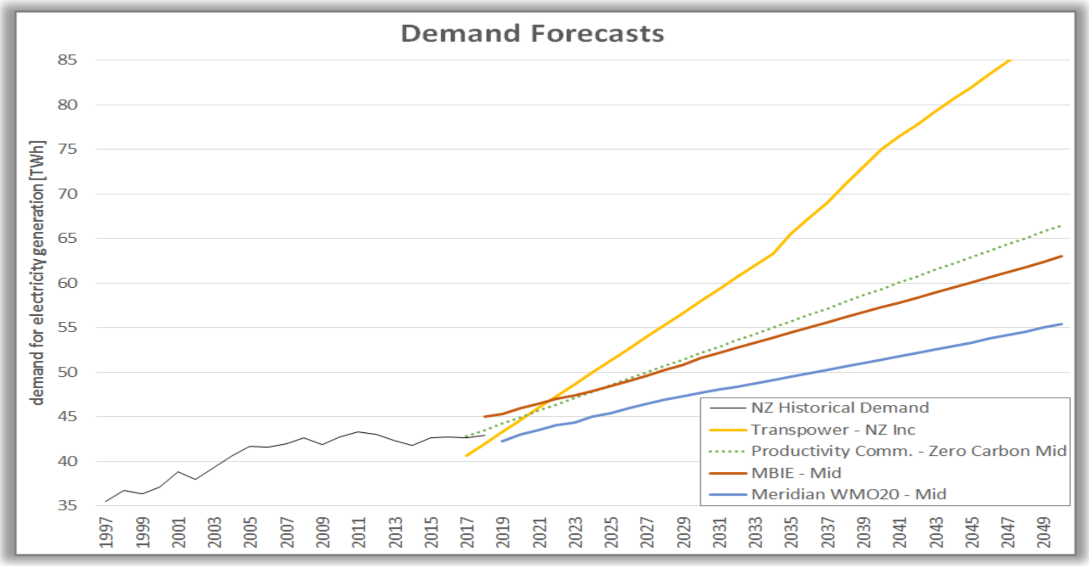
49 Transpower expects that all forms of energy demand will grow over the next 30 years at least. They estimate a doubling of electricity demand by 2050[7] (see Figure 10). Although the spread of projections from other government agencies is wide, all agree there will be an increasing demand for electricity (see Figure 11).

Figure 10 – Estimated New Zealand electricity demand by sector[7]



[7] *Transpower 2018: Te Mauri Hiko – Energy Futures white paper*

Figure 11 – Historical and forecast electricity demand in New Zealand 1997 to 2050, from Transpower[7], Productivity Commission[8], MBIE[9], and Meridian Energy



50 Transpower projects significant electrification – the shift from energy sources such as coal, gas and oil to renewable electricity[7], while the rate at which transport and stationary energy (process heat, industrial boilers, etc) will convert to electricity is uncertain.

51 There is broad consensus that taken together these features describe a larger role for electricity in the future NZ economy, and create a need for additional generation, the bulk of which must be renewable in nature if international climate obligations and current domestic government policy goals are to be met. The construction of new renewable generation and the move away from non-renewables will happen over time as asset life-cycles naturally require replacement and generators respond to demand growth and the market opportunities this presents for commissioning new generation projects.

Historical Generation Mix

52 The electricity market has delivered secure power to meet the varied needs of New Zealanders over the last 23 years with over $11.5B of investment (*source: Meridian Energy*) in new generation and lines over this period.

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[8] *NZ Productivity Commission 2018: Low-emissions economy: Final report 620 pp. www.productivity.govt.nz*

[9] *MBIE 2016: Electricity demand and generation scenarios, 26 pp, ISBN: 978-0-947524-28-9*

53 New Zealand's high proportion of renewable generation is built upon a strong hydro generation base. Coal generation peaked in the mid-2000s and is now used mainly only during dry periods[10]. Geothermal generation (now 17%), followed by wind generation (now 5%), have seen the greatest growth areas over the past 15 years (see Figure 5).

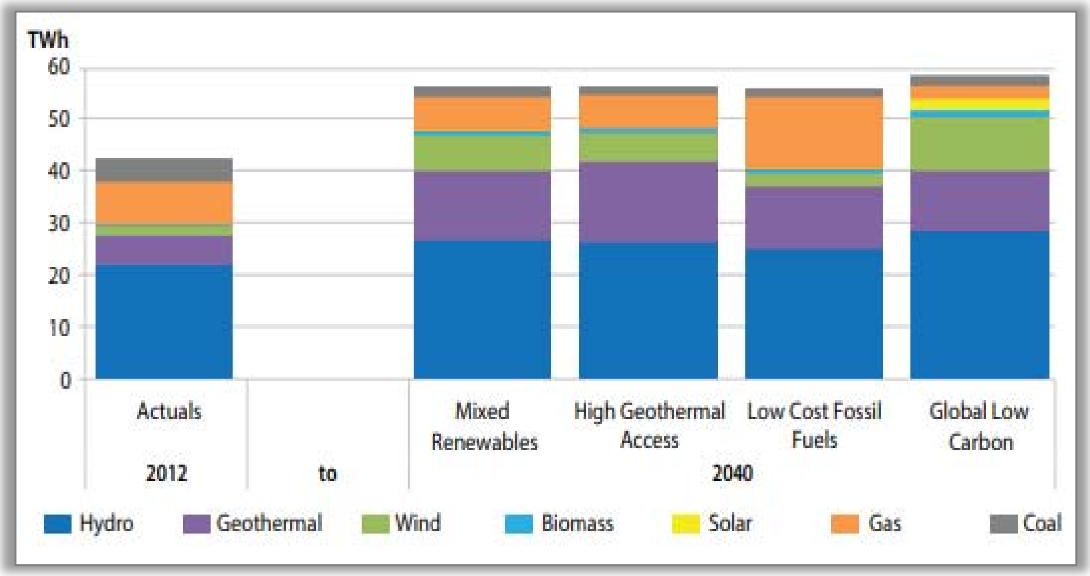
54 NZ's renewable generation hit a low point in 2008 (66%) and has trended up since then (2017 = 82%)[8].

Future Generation Mix – Supplying Demand in a Renewable Electricity System

55 Demand growth and retirement of existing generation plant necessitate a significant ongoing role for new generation build. Wind, geothermal and solar are expected to dominate new options. New, small, clean, gas-fired turbines are likely required to support system stability until at least 2035[8].

56 Strong international imperatives to reduce greenhouse gas emissions, as evidenced in New Zealand by the Zero Carbon Act, Powering Past Coal Alliance, and 100% Renewable electricity policy, mean that a significant increase in renewable generation share over time is expected, especially as thermal plant is retired and new, cheap supply technologies come to market (see Figure 12).

Figure 12 – Electricity generation fuel source in 2012 and 2040 by scenario[11]



[10] *MBIE 2018: Energy in New Zealand*
[11] *MBIE 2015: New Zealand's Energy Outlook: Electricity Insight*

57 Existing hydro (and transmission) flexibility are key to unlocking a smooth transition to a greener New Zealand power system.

58 New renewable options (solar, wind) have no ability to store potential energy like large hydroelectricity systems (MPS, Waitaki, Clutha and Waikato) do (in the form of stored water); therefore, these new options introduce significant intermittency to the electricity system. This creates an ever-stronger need for reliable hydro generation (and demand response) to be the "battery bank" to support increasing proportions of renewable generation, especially over peak demand periods. No significant hydro generation has been built in decades, and none is forecast in the near future.

59 MBIE reports that "Beyond 2035, existing hydro flexibility, batteries and new demand-side options will be needed to drive a transition towards a low carbon power system"[9].

60 In my opinion, the retention of the solid existing hydroelectricity baseload and flexibility in the operation of NZ's major existing hydro catchments, including the MPS in the Waiau catchment, is an essential part of the stability of the New Zealand electricity system in the future. It will underpin New Zealand's ability to meet expected demand growth while also meeting climate change obligations. Significant reductions in the overall output from, or significant reductions in the operating flexibility of major existing hydro generation assets will compound the challenges NZ faces in meeting both electricity demand and climate change imperatives.

THE IMPORTANCE OF THE MPS IN CONTRIBUTIING TO NATIONAL TARGETS ON CLIMATE CHANGE AND RENEWABLE ENERGY GENERATION

61 Irrespective of the Tiwai Aluminum Smelter and its future in Southland, the Government has a target of reaching 100% of New Zealand's electricity requirements from renewable sources by 2035 and a zero-carbon commitment for the economy by 2050 in the context of its international climate change obligations. Legislation is passing through Parliament in 2019 to enshrine this in statute. The pre-existing Government target for the electricity system is to achieve 90% of renewables by 2025.

62 These matters are extensively described in Dr Jennifer Purdie's evidence. In order to meet these obligations, the operations of the MPS and the retention of its base load and flexibility of existing generation will provide a

significant contribution to meeting these targets. The MPS alone meets around 11% of the country's current total demand for generation.

63 As discussed in my evidence, the flexibility that hydro generation with storage provides to the overall system means that its retention is critical to allow additional renewable resources (in particular wind and solar power) to be accommodated into the system in a way that results in low additional system costs.

64 With the storage capability and flexibility provided by Lakes Manapouri and Te Anau, the MPS is one of the key schemes (alongside the Waitaki, Waikato and Clutha systems) that will enable more wind and solar generation to be economically integrated into the New Zealand power system. While gas peaking plant could also operate in this flexible generation mode, it would impose significantly larger capital and operating costs, and would contribute new carbon emissions.

65 The other point covered in Dr Jennifer Purdie's evidence is the projection for annual inflows into the Waiau catchment to increase by around 4% by 2050, along with rainfall likely to occur in larger individual storm events. To maximise the potential of these inflows for the production of renewable energy, the retention of operating flexibility of the MPS and opportunities to undertake scheme enhancements will be important.

66 Finally, it is worth considering the cost to New Zealand in replacing any potential lost generation from the MPS with new generation. The traditional approach to calculate this is to multiply lost generation by the unit cost of replacement generation. This unit cost approach combines the total capital and operating costs of new generation over its expected life time into an equivalent cost per unit generated figure. A reasonable estimate for the unit cost of new generation is $80/MWh. This figure is consistent with historic project costs as well as Meridian's estimates of future costs. Based on this sum, the cost to the country of a loss of 1% or 50 GWh from the MPS would equate to $4 million per annum. A 5% or 250 GWh loss of generation would equate to $20 million per annum.

CONCLUSIONS

67 The MPS is a critical contributor of electricity to both the Southland region and the nation. It has an important function in providing redundancy and resilience within the existing national transmission network for both planned and unplanned outages and it delivers important ancillary services that help keep the power system secure, including frequency keeping, instantaneous reserves and voltage support.

68 As identified within the evidence of Jennifer Purdie there is a government desire to move New Zealand's electricity system to 100% renewable generation by 2035 and to move to a zero-carbon economy by 2050. This will require the development of a substantial amount of new renewable electricity generation over the next 10–30 years to meet expected demand.

69 The MPS provides on average around 11% of New Zealand's electricity generation from a 100% renewable resource. It is the second largest renewable energy power scheme in the country.

70 New Zealand's proportion of electricity generation that comes from renewables is increasing and was 82% in 2017. About 60% of New Zealand's renewable generation comes from hydro generation.

71 All forms of energy demand are expected to grow over the next 30 years at least. Transpower forecasts a doubling of electricity demand by 2050. This is as a result of increasing population and economy size, but also inflated by electrification of transport and industrial processes (currently based on the consumption of oil, gas, and coal).

72 A significant increase in new renewable generation plant build is expected over the next 30 years at least, as demand increases and New Zealand phases out coal and moves towards the 100% renewable government target. The most likely new renewable generation forms will be a combination of wind, geothermal and solar.

73 No significant hydro generation has been built in decades, and none is forecast in the near future.

74 Retaining the flexible way in which the MPS can be operated would enable it to be a significant contributor (along with the Waitaki, Waikato and Clutha schemes) to economically integrate new renewable energy resources, in particular wind and solar power into the New Zealand power system.

75 Any reduction in renewable generation from the MPS would need to be replaced by new generation if demand is to be met across the country with the current levels of security. Any replacement generation would have a national cost of approximately $80/MWh. A 1–5% loss of generation would cost the country $4–$20 million per annum in replacement generation costs.

Guy Waipara

General Manager Generation and Natural Resources, Meridian Energy

15 February 2019

Summary of Findings

New Zealand Wind Integration Study

Goran Strbac, Danny Pudjianto, Anser Shakoor, Manuel J Castro

Imperial College London

Guy Waipara, Grant Telfar

Meridian Energy Limited

April 2008

Challenges of integrating wind generation

- Generation capacity adequacy
  - How "reliable" is wind generation as a source? How much conventional capacity can it displace? What are the system integration capacity costs and benefits?
- Real time system balancing
  - What are the needs for flexibility and reserve? What are the costs? What is the role of storage, demand side participation and interconnectors?
- Transmission network requirements
  - How much new transmission capacity is required to efficiently transport wind power?
- System stability
  - What is stability performance of the system with new forms of generation? Can this technology contribute to improving stability?
- Role of enabling technologies
  - Can storage and responsive demand have a role in facilitating integration of wind generation? Are these solutions competitive? What are the drivers of value? What new tools are required to support system management with wind generation?
- Technical, commercial and regulatory framework
  - Are the technical, commercial and regulatory arrangements appropriate for a system with significant contribution of wind? Are the Grid Codes and Standards appropriate? Are the arrangements for access to transmission networks appropriate? Are non-network solutions to network problems competitive? Does the market reward flexibility adequately?

Wind Integration in NZ: Background

- Widespread expectation that wind power generation will become an increasingly significant proportion of overall generation mix in the future of NZ electricity system
- Wind Integration questions addressed include
  - Capacity value of wind (ability of wind power to displace thermal generation)
  - Increased reserves and flexibility requirements to deal with uncertain and variable nature of the outputs of wind generation
  - Location and remoteness of this generation relative to centres of demand
- Key objective of this work was to develop methodologies for providing detailed quantitative assessments of the system costs of integrating various levels of wind power into the NZ electricity system
  - The analysis shows that wind variability increases the need for operating reserve and associated generation capacity to manage balance of demand supply

System Cost Components of Wind Integration

1. Additional system reserve cost
   - Additional requirements for instantaneous and frequency keeping reserves
   - Additional requirements for scheduling reserve
2. Additional system generation capacity cost
   - Wind generation is primarily an energy source with limited ability to provide reliable generation capacity at times of peak demand
3. Transmission constraints and reinforcement cost driven by wind power*

*Reactive power reserves, voltage control and stability performance are not considered, as the cost of mitigation options are an order of magnitude lower.

Summary of Key Findings - 1

- Unlike thermal generation based power systems in which capacity value of wind is determined by the availability of wind during peak demand conditions, the capacity value of wind in New Zealand is:
  - High due to high load factors of wind resource
  - Enhanced by the presence of hydro generation
  - Reduced by the large variations in relatively small period of time that need increased amounts of reserves
- Additional capacity costs attributed to wind generation:
  - 2010 costs (1.7 to 2.7 $/MWh) are higher than the 2020 costs (1.3 to 2.2 $/MWh) due to the different NI-SI interconnector (2010 – 1000MW and 2020 1500MW) which increases the sharing of reserve capacity and diversity of wind generation.
  - 2020 – 2030 rise in wind capacity cost (to 6.2 -9 $/MWh) is primarily driven by larger capacity reserve requirements to accommodate larger wind forecasting errors at higher penetration levels

Summary of Key Findings - 2

- Hydro increases capacity credit of wind. However, at higher penetrations the contribution of hydro to firm up wind power reduces
- Capacity credit of wind generation in the NZ’s hydro dominated system is higher than in the other thermal based systems, however, it also declines with rise in wind penetration level
- Capacity values for wind are not effected by hydro (dry) conditions although the overall capacity requirements increase with low availability of hydro energy
- The low production of wind for days is found not to effect the capacity value of wind as this can be compensated by the flexible hydro energy with presence of large hydro reservoirs
- The role of the interconnector changes. Over time, interconnector will become critical for maintaining security of supply in the South Island.

Summary of Key Findings - 3

- Additional reserves are needed to cover the unpredictability of wind power
  - Instantaneous reserve, up to 30 min provided by synchronised generators
  - Frequency keeping reserve to cover 1 hour of wind variability is assumed to be provided by synchronised reserve
  - Scheduling reserve to cover 4-6 hours of wind variability is assumed to be provided by synchronised + standing reserve
- The quantity of wind reserve component increases with rise in wind penetration
- Provision of scheduling reserve up to 4-6 h time horizon
  - For low wind penetration (2010), hydro will be the primary source of scheduling reserve
  - For high wind penetration (2020 &2030), it is desirable to use flexible standing power plants for dealing with scheduling time horizons

Summary of Key Findings - 4

- The cost of additional reserve to deal with forecasting error of wind for several scenarios have been quantified
  - Instantaneous reserve, up to 30 min provided by synchronised generators
  - For low penetration (4.9% in 2010) , the cost of additional reserves is around 0.19 $/MWh of wind energy
  - The cost of additional reserves increases to 2.42 $/MWh of wind energy by 2030 under a high wind penetration scenario (17.9%)
- The primary source of synchronized reserve remains to be hydro but in future the contribution from interruptible load and thermal plants will increase
- Some curtailment of wind and hydro energy is observed in high wind penetration scenarios. This occurs during a combination of low demand, wet hydro conditions and high wind conditions

Summary of Key Results

	2010	2020	2030
Installed wind power capacity (MW)	634	2,066	3,412
Wind power (GWh)	2,285	6,724	10,797
Capacity credit of wind (%)	32	29	15
Max. Instantaneous Reserve (MW)	565	691	912
Max. Frequency Keeping (MW)	309	540	866
Max. Standing Reserve (MW)	46	377	566
Capacity cost ($/MWh of wind)	1.7 - 2.5	1.3 - 2.0	6.2 - 9.3
Reserve cost ($/MWh of wind)	0.19	0.76	2.42
Total cost attributed to wind ($/MWh of wind)	**1.89 - 2.69**	**2.06 - 2.76**	**8.62 - 11.72**

NZ Electricity System:
Future Scenarios Under Study

Scenarios

- Three scenarios correspond to future generation in 2010,2020 and 2030 were constructed to represent increasing levels of wind penetration up to 18% of electricity consumption in 2030
- Demand growth was assumed to be about 1.25%-1.5% p.a.
- Hydro inflows profiles were developed using SPECTRA
  - Daily run of river profiles
  - Weekly reservoir release profiles
- 2005 and 2006 wind profiles were assessed. 2005 wind profiles were used in the main studies as they represent a lower wind year

Future Wind Scenarios

High Wind 2010
NI:432 MW
SI:203 MW
NZ:634 MW

Location	Island	MW	GWh PA	Avg LF
Otago	SI	144.0	492	39.0%
Manawatu	NI	7.0	28	45.0%
Manawatu	NI	19.5	77	45.0%
Wellington	NI	142.6	573	45.9%

Very High Wind 2020
NI:1434 MW
SI:632 MW
NZ:2066 MW

Location	Island	MW	GWh PA	Avg LF
Otago	SI	144.0	492	39.0%
Manawatu	NI	7.0	28	45.0%
Manawatu	NI	19.5	77	45.0%
Wellington	NI	142.6	573	45.9%
Wellington	NI	94.3	363	44.0%
Hawke's Bay	NI	48.0	179	42.5%
Hawke's Bay	NI	150.0	484	36.9%
Central	NI	100.0	350	40.0%
Manawatu	NI	150.0	565	43.0%
Wairarapa	NI	90.0	323	41.0%
Northland	NI	102.5	359	40.0%
Taranaki	NI	99.0	361	41.7%
Northland	NI	68.8	241	40.0%
Wellington	NI	100.0	365	41.7%
Otago	SI	261.0	892	39.0%
Southland	SI	168.0	589	40.0%

Very High Wind 2030
NI:2215 MW
SI:1197 MW
NZ:3412 MW

Location	Island	MW	GWh PA	Avg LF
Otago	SI	144.0	492	39.0%
Manawatu	NI	7.0	28	45.0%
Manawatu	NI	19.5	77	45.0%
Wellington	NI	142.6	573	45.9%
Waikato	NI	44.0	135	35.0%
Manawatu	NI	150.0	526	40.0%
Wellington	NI	94.3	363	44.0%
Hawke's Bay	NI	48.0	179	42.5%
Hawke's Bay	NI	150.0	484	36.9%
Central	NI	100.0	350	40.0%
Manawatu	NI	150.0	565	43.0%
Wairarapa	NI	90.0	323	41.0%
Northland	NI	102.5	359	40.0%
Hawke's Bay	NI	111.0	389	40.0%
Otago	SI	100.0	377	43.0%
Otago	SI	261.0	892	39.0%
Taranaki	NI	99.0	361	41.7%
Northland	NI	250.7	878	40.0%
Auckland	NI	225.0	788	40.0%
Northland	NI	68.8	241	40.0%
Otago	SI	100.0	359	41.0%
Wellington	NI	100.0	365	41.7%
Otago	SI	150.0	512	39.0%
Canterbury	SI	215.0	659	35.0%
Southland	SI	168.0	589	40.0%

Source: www.nzwindfarms.co.nz

Capacity Value and Additional Capacity Costs of Wind Generation

NZ Generation Capacity Analysis

1. Assessment of optimal overall generation capacity requirements in each future wind scenario
2. Capacity credit evaluation of wind generation
3. Evaluation of additional capacity cost of wind generation
4. Sensitivity studies include*
   - A. Wind forecasting errors
   - B. Impact of hydro conditions (Dry/Average/Wet)
   - C. Impact of interconnector size and its reliability
   - D. Impact of wind diversity

* sensitivity analysis are not included in this executive summary but will be included in the final report

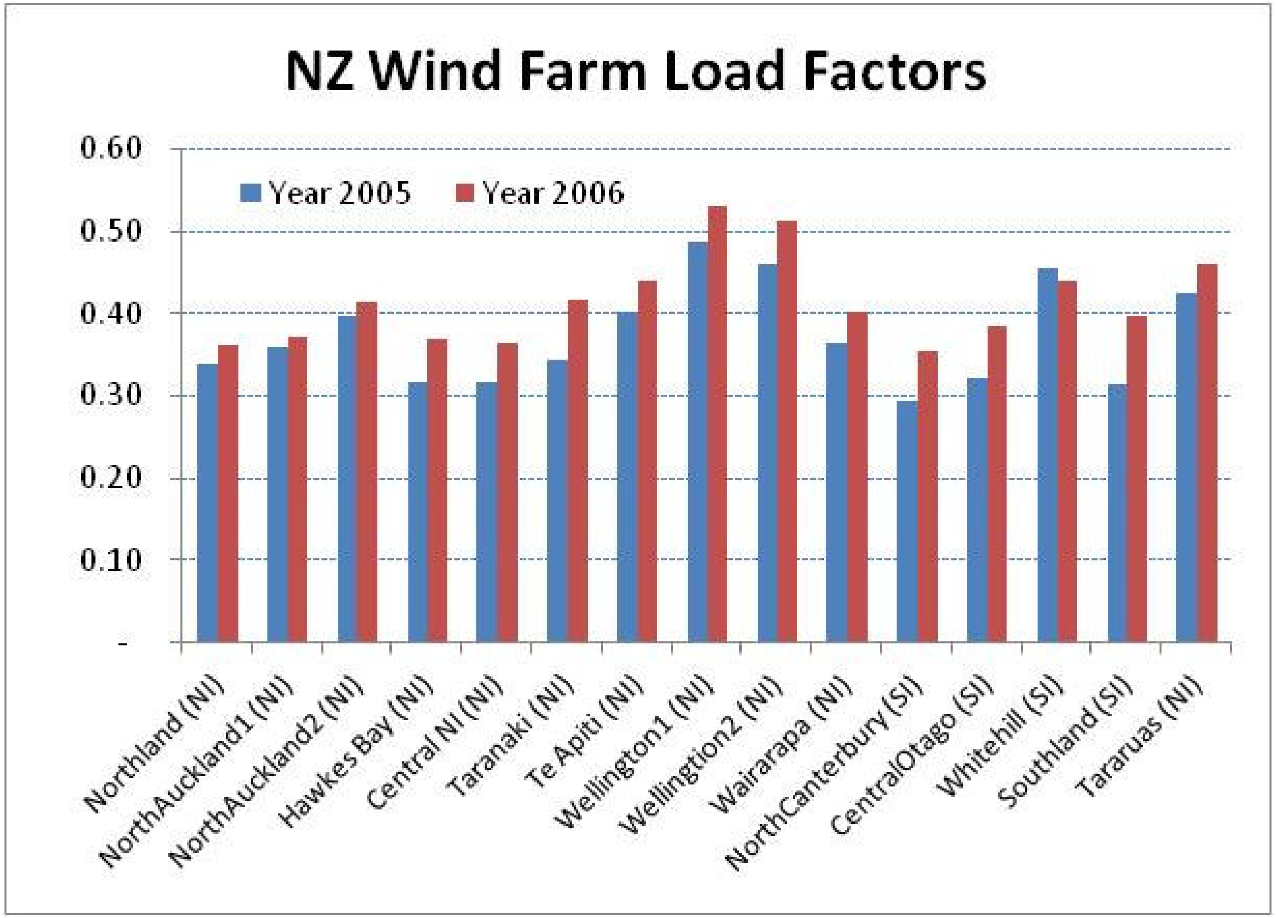
Capacity Modelling Approach – 1

- The system reliability criterion for capacity adequacy applied in this study is Loss of Load Expectation (LOLE) with a conservative target of 8 hours/year
- Hydro plants are represented as Island aggregated units. Island aggregated profiles of each of run-of-river and reservoir type hydro energy are used
- Hydro is modelled as a fully reliable generation
- The dispatch of hydro power is obtained optimally to minimize the overall thermal capacity requirements of the system - this serves as the objective function of the capacity assessment model
- Weekly reservoir releases (from the SPECTRA model) are used in the dispatch programme - water is used within each week and cannot be shared between weeks

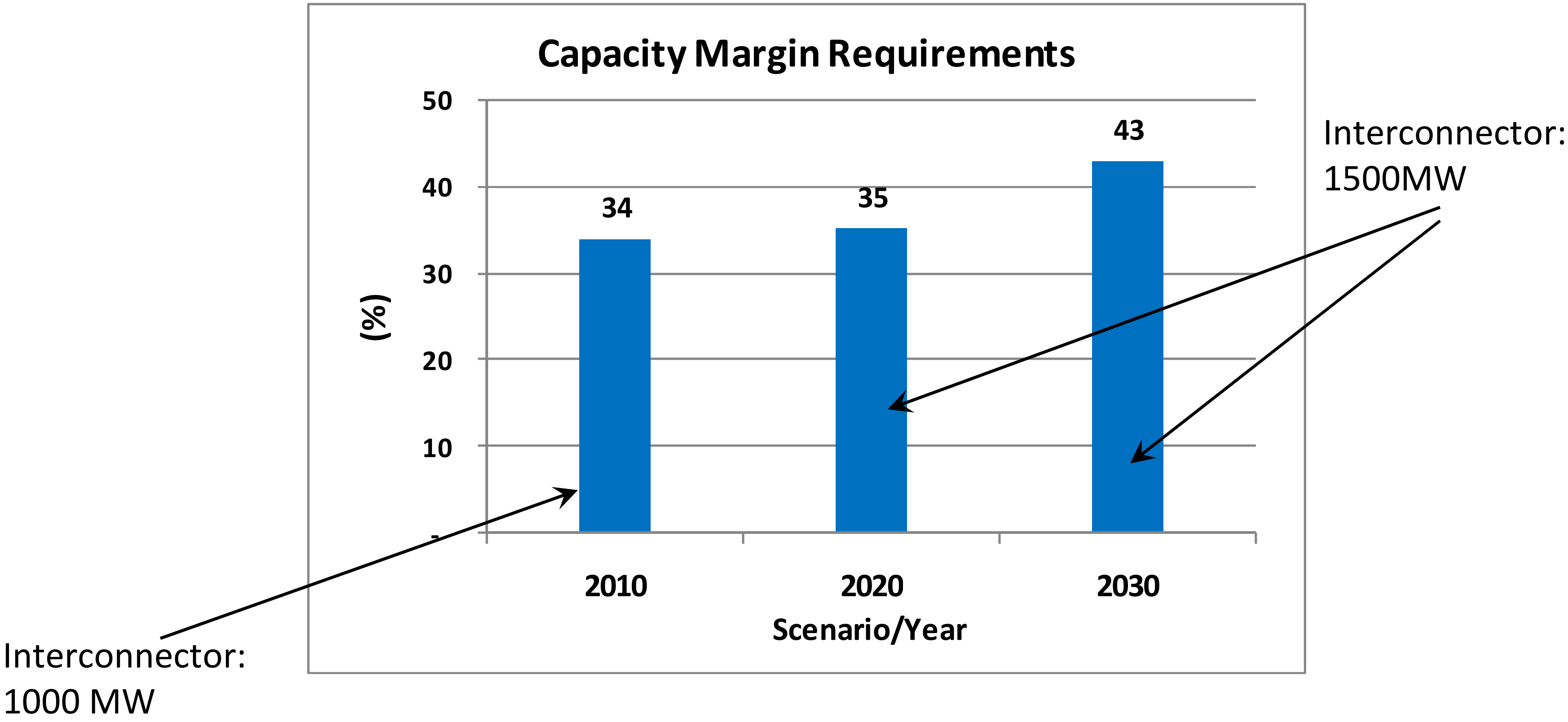
Capacity Modelling Approach – 2

- The unused capacity of the hydro reservoir type plant (i.e. the difference between installed capacity and dispatched power) during each simulation period (1/2-hour) is modelled as hydro capacity reserve to contribute to system reliability subject to reservoir energy constraints
- Main constraints include:
  - Aggregated (wind + Hydro + Thermal) production must meet demand in each time period
  - Minimization of wind and hydro energy curtailment
  - The aggregated reservoir size of each island for hydro energy storage
  - Minimum reservoir levels (10% of reservoir size)
  - 99% reliability of the interconnector (DC link between islands)

NZ Wind Farm (sites) Load Factors



System Capacity Margin Requirements



Key assumptions:

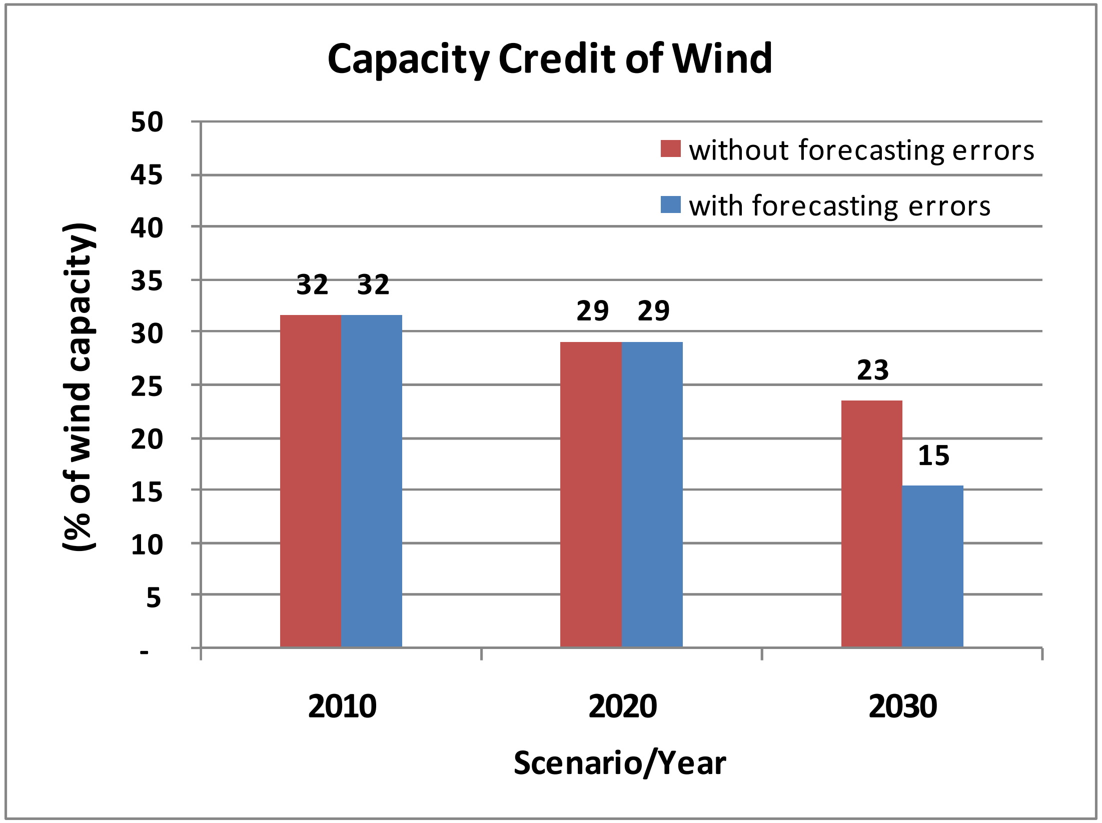
Conservative system reliability criterion: LOLE < 8 hours/year

Availability of conventional generation: 85% (consistent with planning time horizons)

NI-SI Interconnector reliability: 99%

Capacity Credit of Wind

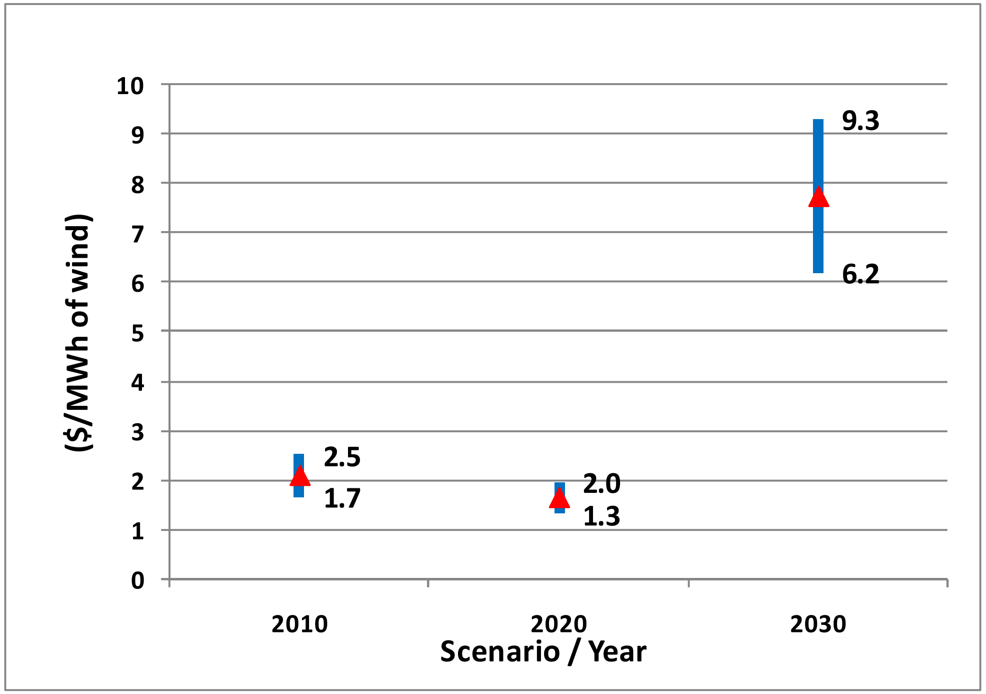
(Average hydro conditions)



Capacity credit with wind forecasting is based on a conservative approach to accommodate 99% of the wind variations across a 4 to 6 hour time horizon.

Additional Capacity Cost of Wind

(Average hydro conditions)



The source of additional capacity cost of wind generation is due to the difference between the quantites of energy versus capacity displaced when comparing wind power to a CCGT. The costs are driven by:

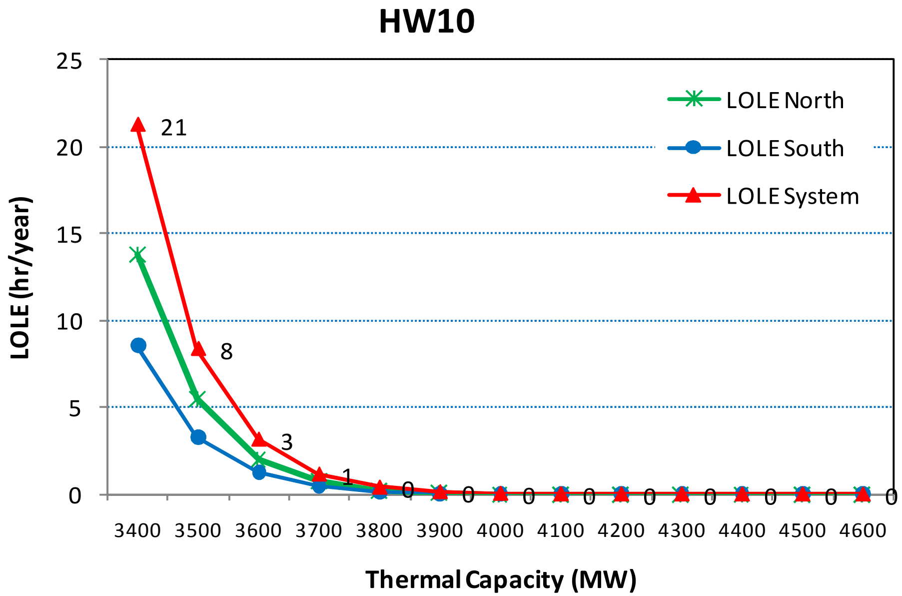
- Wind forecasting errors
- The utilisation of plant within the incumbent generation system
- The capacity of thermal plant required to be retained to maintain system reliability i.e., increased capacity margin

Assumptions:

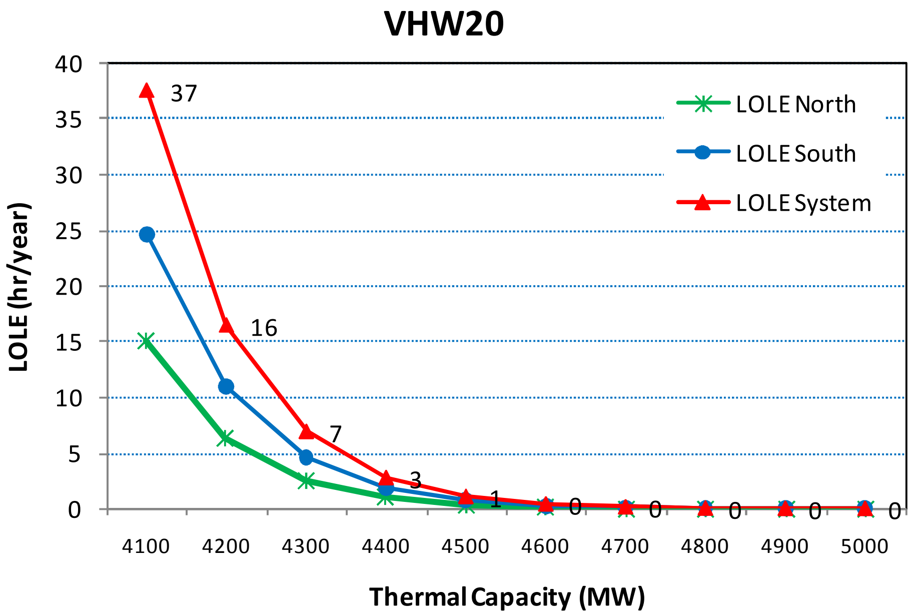
Capacity cost of conventional plant = 100 $/kW/yr to 150 $/kW/yr
Average load factor of thermal plant in the system = 58%
The additional costs of wind are relative to a base load thermal plant

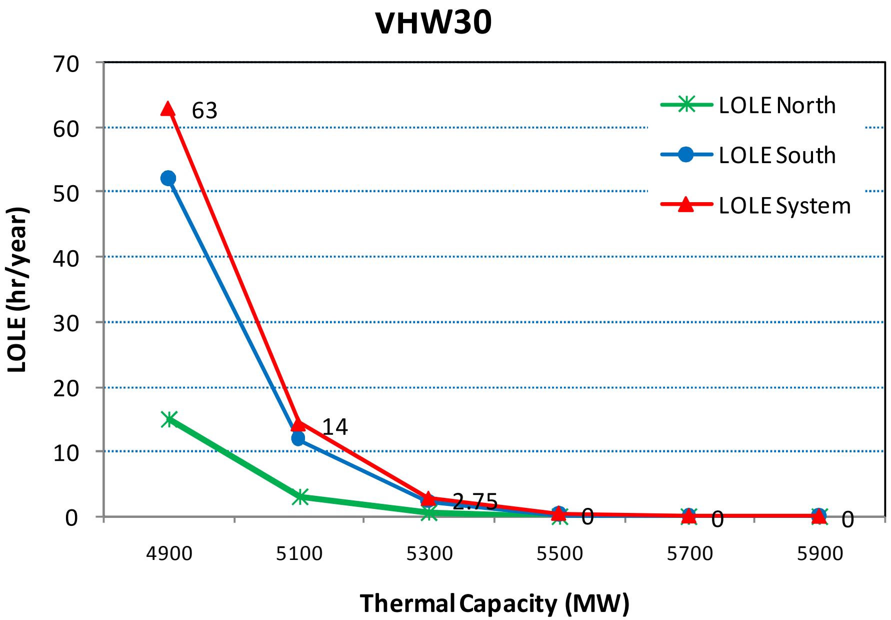
Changing role of the Interconnector

Interconnector:
520 MW



Thermal capacity is gradually added into the Island with higher LOLE or risk of non supply





Summary of Capacity Results - 1

- Unlike thermal generation based power systems in which capacity value of wind is determined by the availability of wind during peak demand conditions, the capacity value of wind in New Zealand is driven by its higher load factor as well as by the large variation in relatively small period of time
- Additional capacity costs attributed to wind generation:
  - 2010 costs (1.7 to 2.7 $/MWh) are higher than the 2020 costs (1.3 to 2.2 $/MWh) due to the different NI-SI interconnector (2010 – 1000MW and 2020 1500MW) which increases the sharing of reserve capacity and diversity of wind generation.
  - 2020 – 2030 rise in wind capacity cost (to 6.2 -9 $/MWh) is primarily driven by larger capacity reserve requirements to accommodate larger wind forecasting errors at higher penetration levels

Summary of Capacity Results - 2

- Hydro increases capacity credit of wind - however at higher penetrations its contribution to firming up the wind power reduces
- Capacity credit of wind generation in the NZ’s hydro dominated system is higher than in the other thermal based systems, however, it also declines with rise in wind penetration level
- Capacity values for wind are not effected by hydro (dry) conditions although the overall capacity requirements increase with low availability of hydro energy
- The low production of wind for days is found not to effect the capacity value of wind as this is compensated by the flexible hydro energy with presence of large hydro reservoirs
- The role of the interconnector changes over time – in 2010 South Island generation provides security of supply to the North Island – in 2020 and 2030 North Island generation provides security of supply to the South Island

Additional Costs of Reserve due to Wind Generation

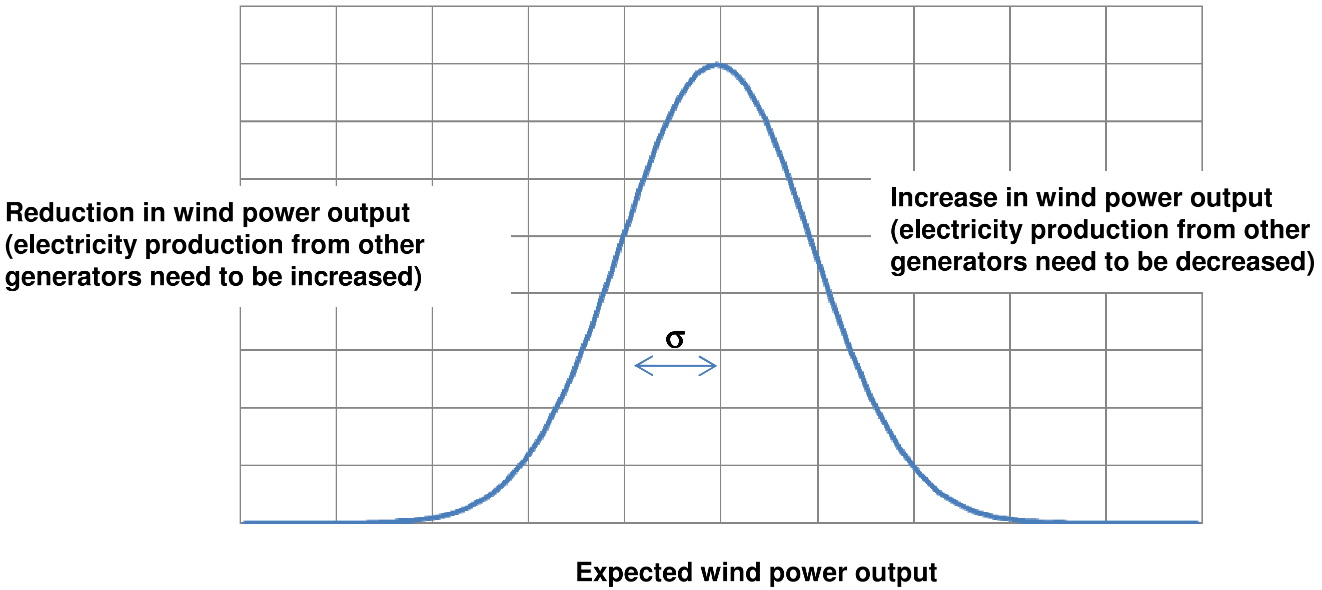
Methodology to Assess Additional Reserve Costs

1. Quantification of the additional operating reserve needed to deal with the forecasting errors of wind power
   - A. Instantaneous reserve (up to 30 mins) provided by synchronised generators
   - B. Frequency keeping reserve (up to 1 hour) provided by synchronised generators
   - C. Scheduling reserve (for 4-6 hours) provided by synchronised and standing generators
2. Analysing the impact of increased reserve requirement on system operating costs
   - A. Fuel cost, generation start up cost and no-load cost
   - B. Cost of interruptible load
3. Evaluation of the cost of increased operating reserve requirements
4. Sensitivity analysis*
   - A. Hydro conditions (Dry/Average/Wet)
   - B. Increased wind power (scenario 2010,2020,2030)
   - C. Interconnector capacity
   - D. Location of future wind power (North and Southland scenarios)
   - E. Different wind profiles (year 2005 and 2006 data based)

* **Sensitivity analysis are excluded from this executive summary**

Additional Reserve Assessment- Methodology

- Wind intermittency increases demand for operating reserve. Three types of reserves are modelled
  - Instantaneous reserve includes reserve to cover 30 minutes ahead wind unpredictability
  - Frequency keeping (1 hour ahead)
  - Scheduling reserve (4-6 hours ahead)
- The additional reserves due to wind are determined using a statistical analysis based on the distribution of wind forecasting errors



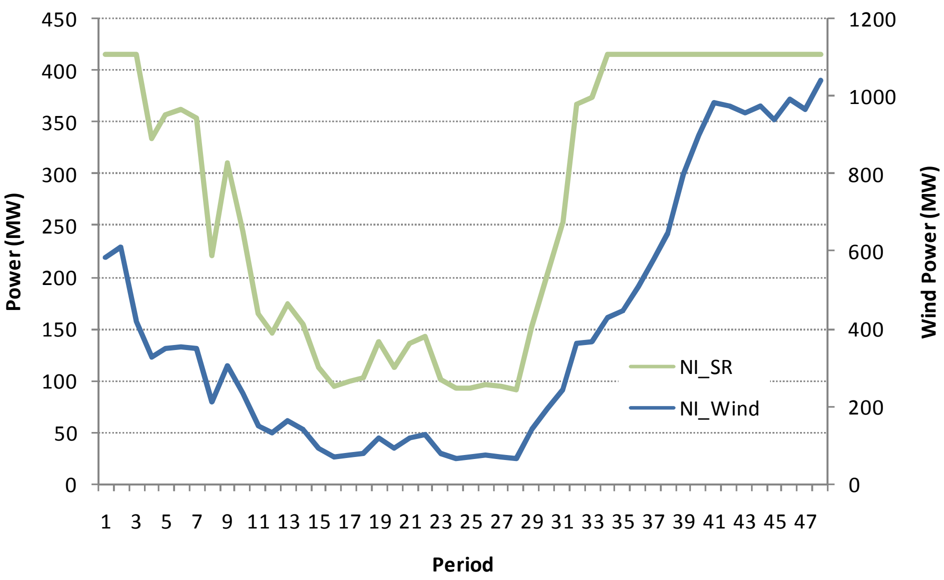
Note:
Sigma (σ) denotes the standard deviation. It is a measure of the spread of the values of wind power output from its mean μ (forecasted or expected value).
To cover 73% wind variability requires additional reserve (1σ).
96% → 2σ
99% → **3σ**
99.5% → **4σ**

Impact of Wind Variability on Reserves

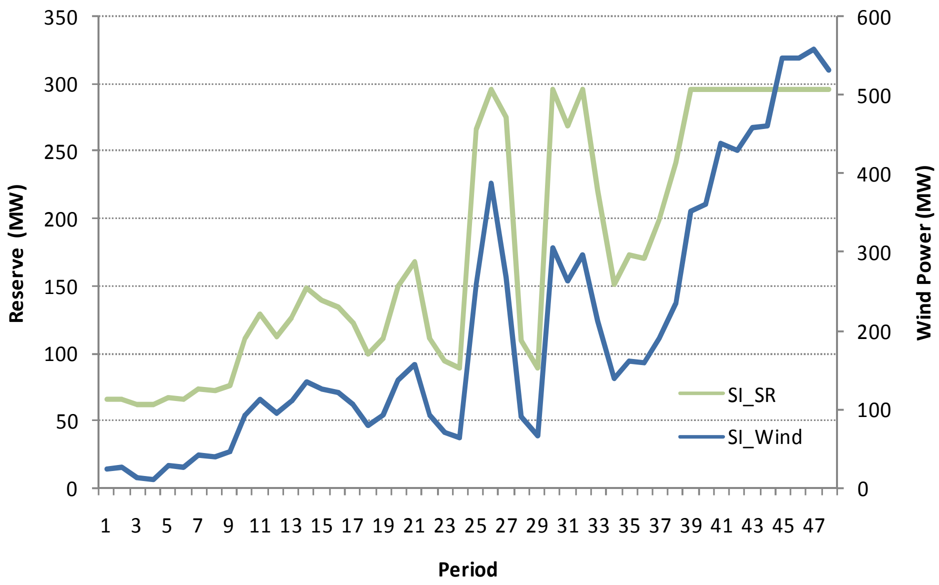
(Illustration)

(An illustrative winter peak demand day in 2020)

North Island



South Island



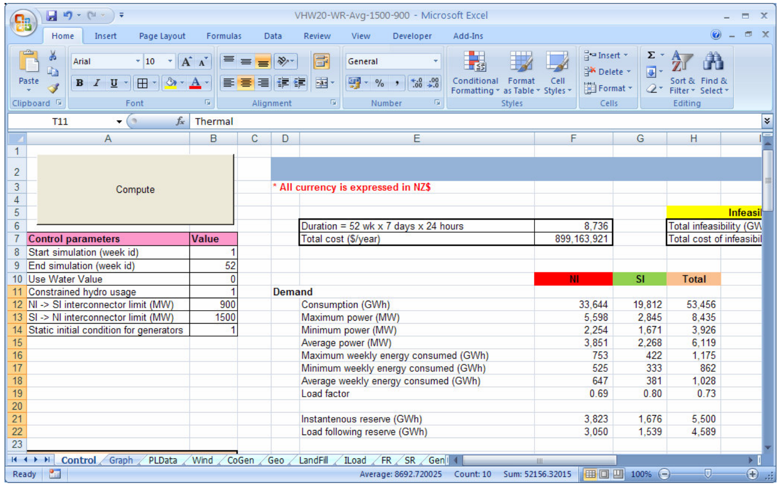
Amount of reserve required increases with increased wind output

Evaluation of Additional Reserve Costs

- Additional reserve will increase operating costs as wind power will demand
  - More on-line capacity
    - Use of low merit (expensive) generation
    - Lower efficiency- part loaded plants
  - Increased frequency of start ups of generators
  - Increased demand of Interruptible load (IL)
  - Increased standing reserve
- Cost of additional operating reserve attributed to wind is determined as the difference between the operating cost of the system with and without the wind reserve component
- Operating cost is determined using a generation scheduling optimisation model which optimises energy production and allocation of reserves among synchronised units
- Cost of standing reserve is determined by calculating the expected energy of standing reserve that would be exercised

The Optimisation Problem

- Objective
  - Minimise the overall generation cost including no load, start up cost and IL cost subject to operational constraints



- Include operational constraints
  - Power balance constraints
  - Generation constraints
    - Minimum stable generation
    - Power rating
    - Maximum Instantaneous Reserve limits
    - Ramp up/down constraints
    - Minimum up/down time constraints
    - Load factor constraints for CCGT (minimum 75%)
  - 0.5 hourly auxiliary and wind power energy constraints
  - Hydro power constraints
    - Daily ROR energy constraints
    - Weekly hydro inflows constraints
    - Reservoir constraints
  - Reserve constraints
    - Minimum instantaneous and frequency keeping reserve provision for each island
  - Flow constraints at interconnector
- Use of mixed integer linear programming

Reserve Modelling Assumptions - 1

- Additional operating reserves in each Island is analysed separately, i.e. no operating reserve transfers across the HVDC link are modelled
- The magnitude of power transfers across HVDC link is constrained by power transfer capability constraint. The maximum of NI to SI transfer is set to 60% of SI to NI power transfer
- All operating spinning reserve quantities for instantaneous reserve and frequency keeping are assumed to be unable to contribute to meeting demand requirements
- Operating reserve is assumed to be mainly provided by part loaded plant along with a contribution from demand side (interruptible load) during critical periods, consistent with existing practices
- Standing reserve is assumed to be provided by off-line thermal plants which can synchronise and produce electricity quickly to maintain balance between supply and demand
- Levels of operating reserve required are targeted to cover about 99.5% of all operating conditions

Reserve Modelling Assumptions - 2

- Reserve requirements from synchronised plant are assessed at 30 minutes and 1 hour. Standing reserve are allocated for dealing with the forecasting errors beyond 1 hours
- Reserve requirements are computed for each half hour time slot of the overall system simulation.
- The additional reserve requirement to deal with wind variability never exceeds expected wind power output.
- In the daily load cycles, the impact of different loading conditions during day and night periods on the operating reserve requirements is modelled.
- CCGT was assumed to operate with minimum load factor of 75% irrespective of hydro and wind conditions.

Required Quantities of Operating Reserves

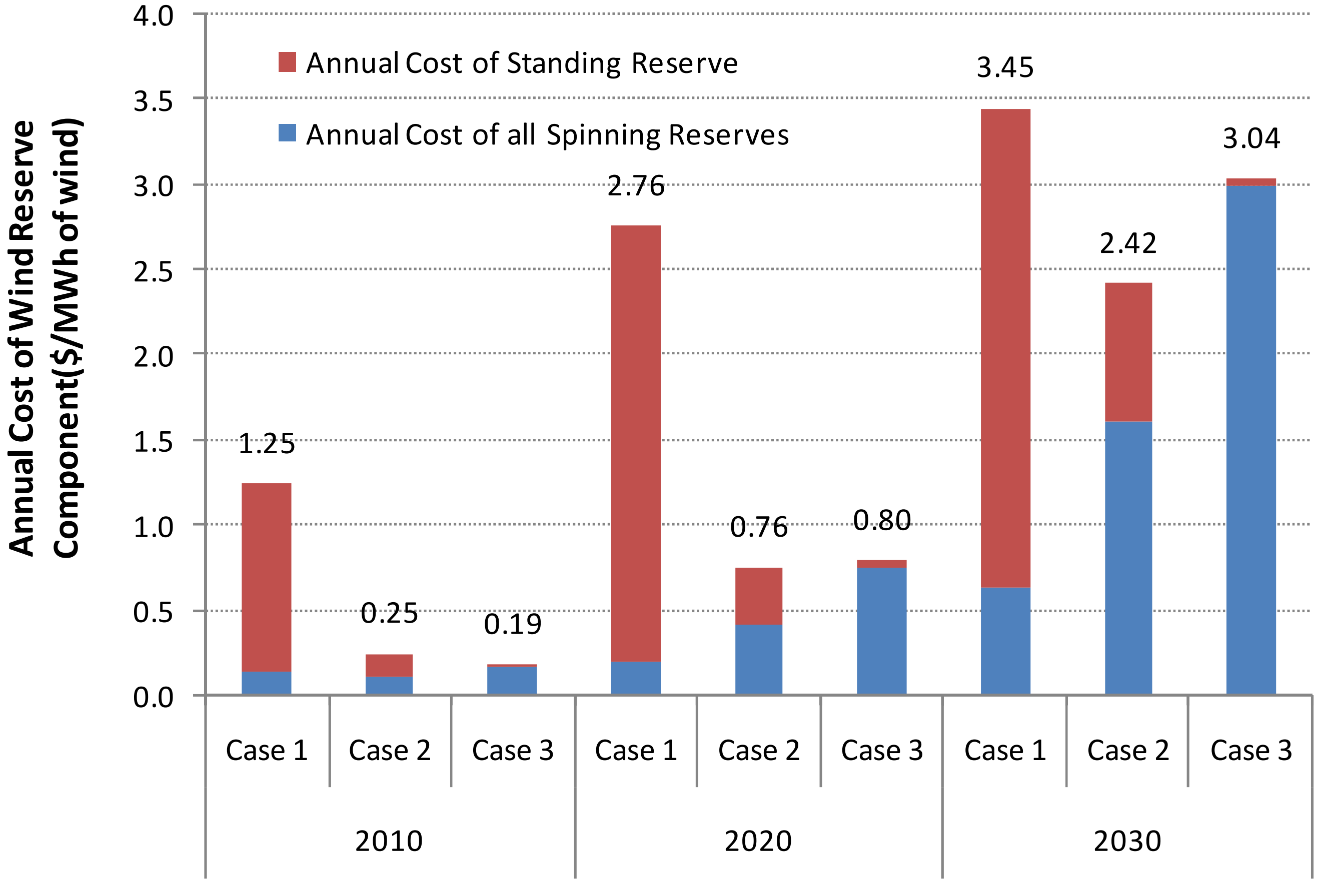
		2010			2020			2030		
		IR	FK	Standing	IR	FK	Standing	IR	FK	Standing
Case 1	NI	398	107	124	446	215	312	533	315	503
	SI	167	73	65	245	157	174	379	271	326
	NZ	565	180	189	691	372	486	912	586	829
Case 2	NI	398	150	81	446	314	272	533	466	352
	SI	167	93	31	245	226	105	379	400	214
	NZ	565	243	112	691	540	377	912	866	566
Case 3	NI	398	194	37	446	416	170	533	618	200
	SI	167	115	9	245	296	35	379	530	67
	NZ	565	309	46	691	712	205	912	1148	267

Note: all units are expressed in MW

IR = Instantaneous Reserve

FK = Frequency Keeping

Optimal Allocation of Standing and Spinning Reserves



Case1: dominated by standing reserve

Case2: balanced allocation

Case3: dominated by spinning reserve

Summary of the Reserves Results

- Additional reserves are needed to cover the unpredictability of wind power
  - Instantaneous reserve provided by synchronised generators
  - Frequency keeping reserve to cover 1 h wind variability provided by synchronised reserve
  - Scheduled reserve to cover 4-6 h wind variability provided by synchronised + standing reserve
- The quantity of wind reserve component increases with rise in wind penetration
- Provision of scheduling reserve up to 4-6 h time horizon
  - For low wind penetration (2010), hydro will be the primary source
  - For high wind penetration (2020 &2030), it is desirable to use flexible standing power plants
- The cost of additional reserve to deal with forecasting error of wind for several scenarios have been quantified
  - For low penetration (4.9% in 2010) , it is around 0.19 $/MWh of wind energy
  - It increases to 2.42 $/MWh of wind energy in 2030 with high wind penetration (17.9%)
- The primary source of synchronized reserve remains to be hydro but in future, it will require higher contribution from IL and other thermal plants

Summary of Key Results

	2010	2020	2030
Installed wind power capacity (MW)	634	2,066	3,412
Wind power (GWh)	2,285	6,724	10,797
Capacity credit of wind (%)	32	29	15
Max. Instantaneous Reserve (MW)	565	691	912
Max. Frequency Keeping (MW)	309	540	866
Max. Standing Reserve (MW)	46	377	566
Capacity cost ($/MWh of wind)	1.7 - 2.5	1.3 - 2.0	6.2 - 9.3
Reserve cost ($/MWh of wind)	0.19	0.76	2.42
Total cost attributed to wind ($/MWh of wind)	**1.89 - 2.69**	**2.06 - 2.76**	**8.62 - 11.72**

Summary of Findings

New Zealand Wind Integration Study

Goran Strbac, Danny Pudjianto, Anser Shakoor, Manuel J Castro

Imperial College London

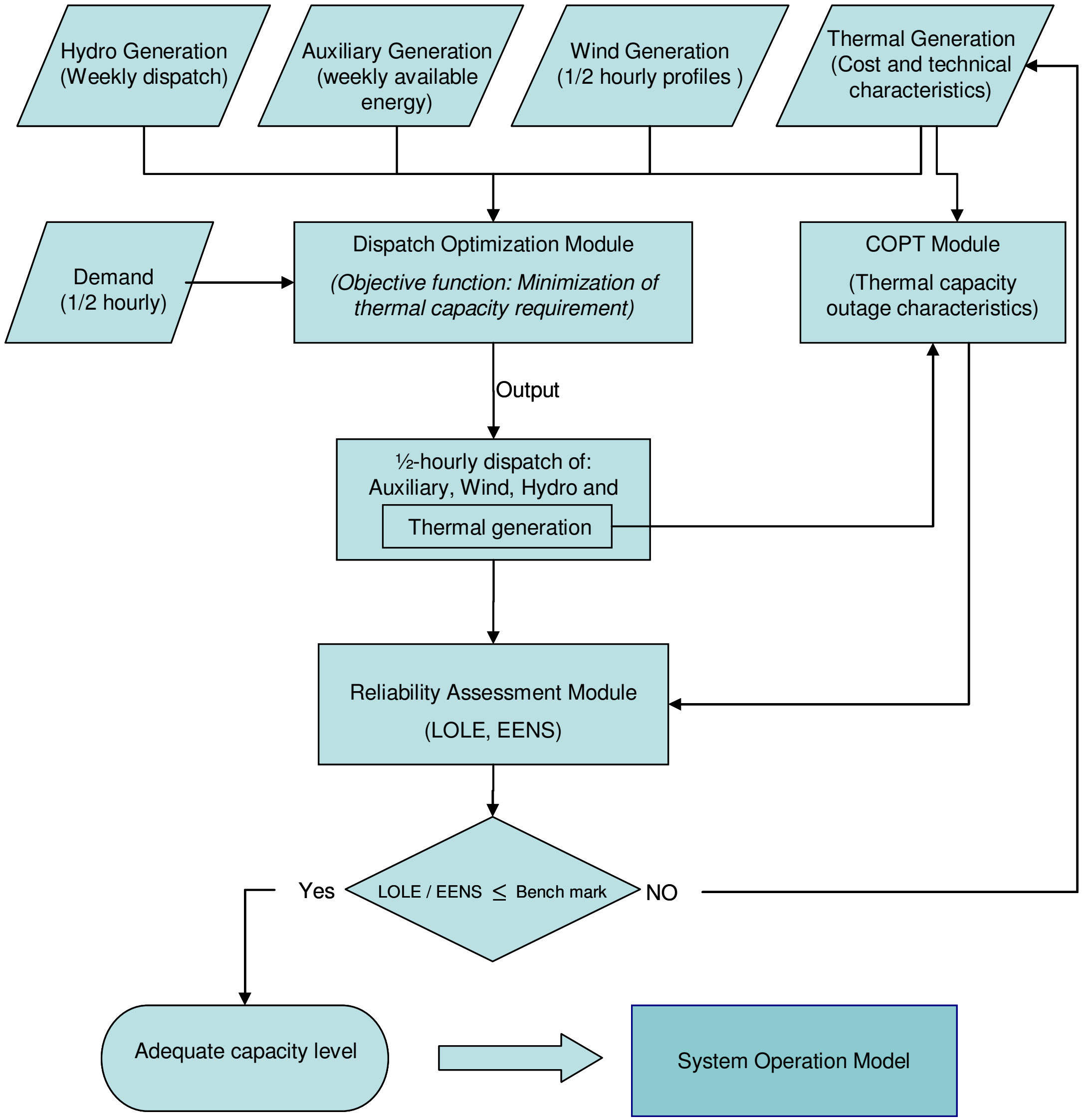
Guy Waipara, Grant Telfar

Meridian Energy Limited

April 2008

Appendix

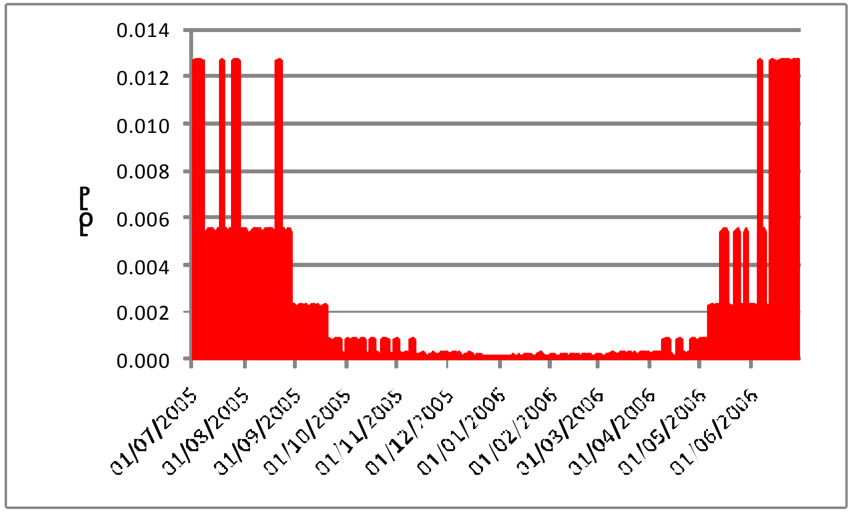
Simplified Representation of the Capacity Adequacy Assessment Model

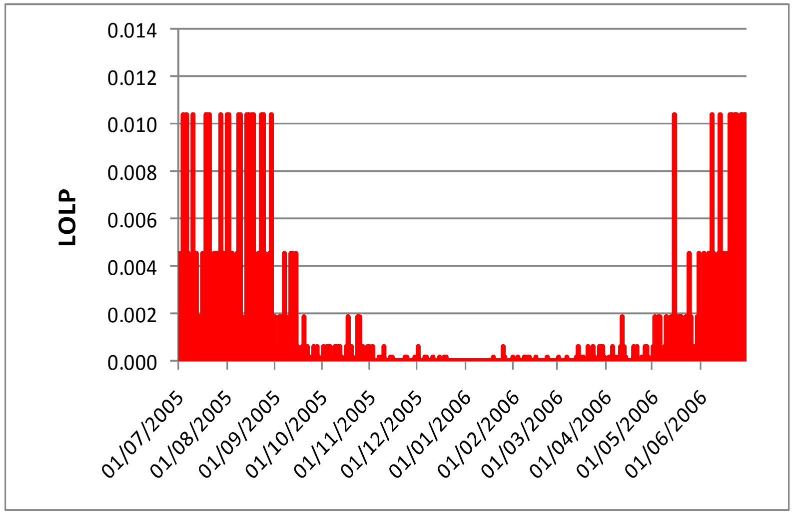


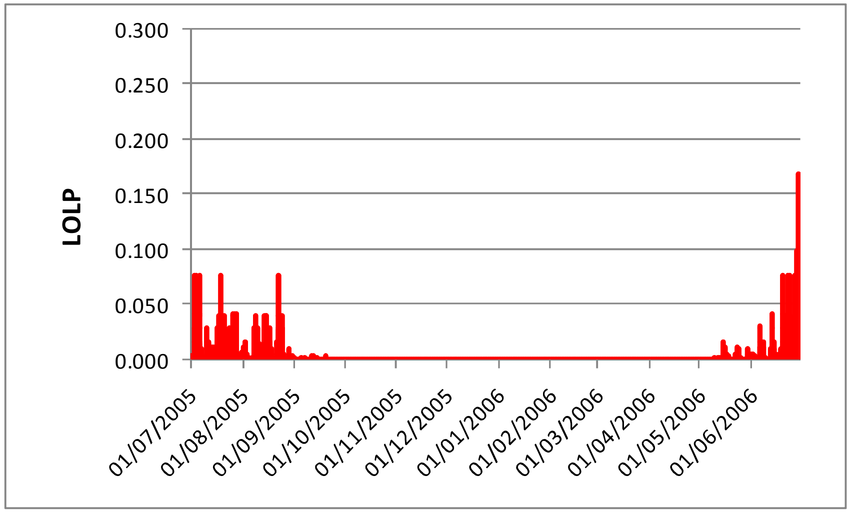
Yearly Distribution of Loss of Load Probability

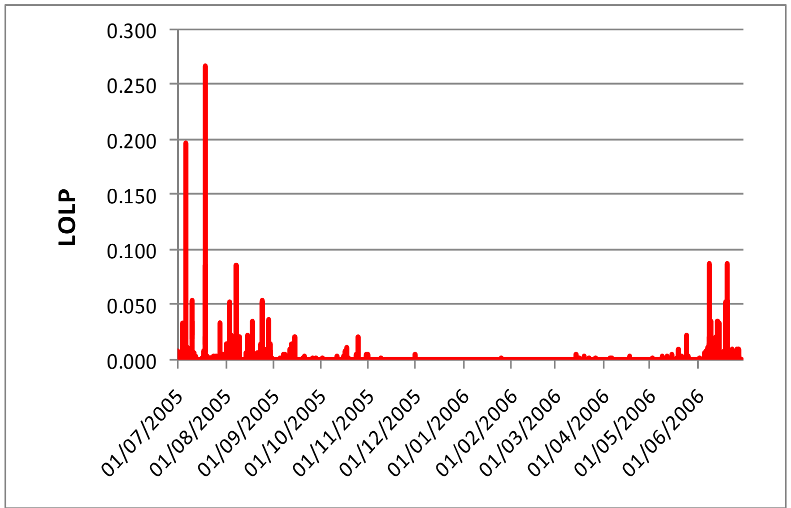
Without Wind | With Wind

2010 | 2030







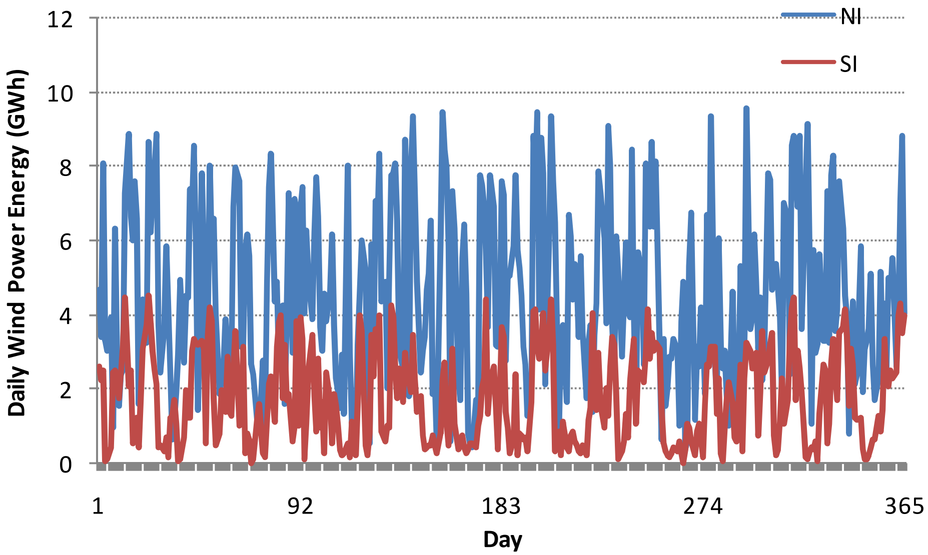


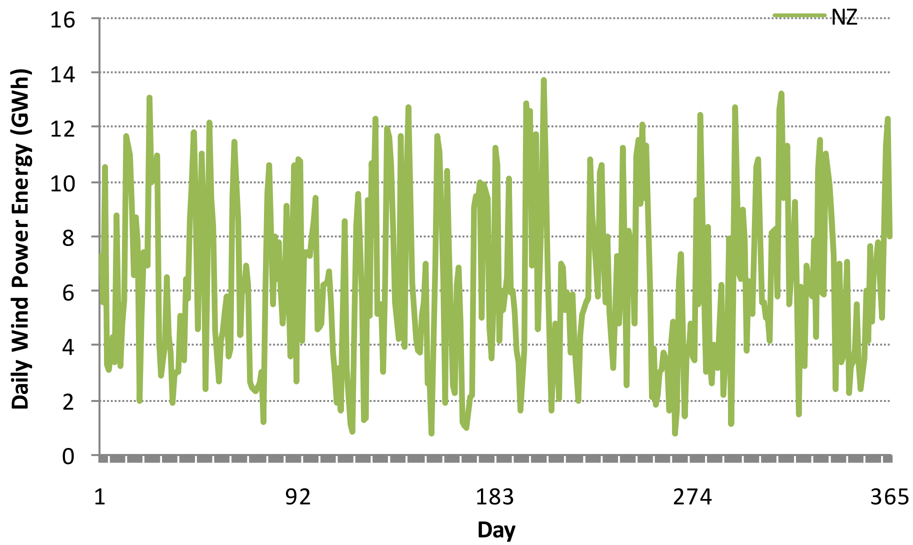
Initial Electricity Generation & Demand Scenarios

Scenario	High Wind 2010(4.9%)			Very High Wind 2020 (12.5%)			Very High Wind 2030 (17.9%)		
Region >>	NI	SI	NZ	NI	SI	NZ	NI	SI	NZ
Auxiliary	1,017	37	1,054	1,166	37	1,203	1,205	37	1,242
Wind	432	203	634	1,434	632	2,066	2,215	1,197	3,412
Hydro	1,873	3,557	5,430	1,873	3,557	5,430	1,873	3,557	5,430
Coal	972	-	972	972	-	972	972	-	972
Gas	1,500	-	1,500	1,570	-	1,570	1,810	-	1,810
Oil	-	-	-	-	-	-	-	-	-
Distillate	156	-	156	156	-	156	156	-	156
Total installed generation capacity (MW)	5,949	3,797	9,747	7,171	4,226	11,397	8,230	4,791	13,022
Hydro energy (GWh)	6,919	17,929	24,848	6,919	17,929	24,848	6,919	17,929	24,848
Wind energy (GWh)	1,653	631	2,285	4,906	1,819	6,724	7,442	3,354	10,797
Peak demand (MW)	4,842	2,455	7,297	5,598	2,845	8,443	6,273	3,197	9,469
Energy demand (GWh)	28,952	17,041	45,993	33,644	19,812	53,456	37,907	22,351	60,258

Wind Profiles

Based on 2005 wind profiles for 2010 scenario



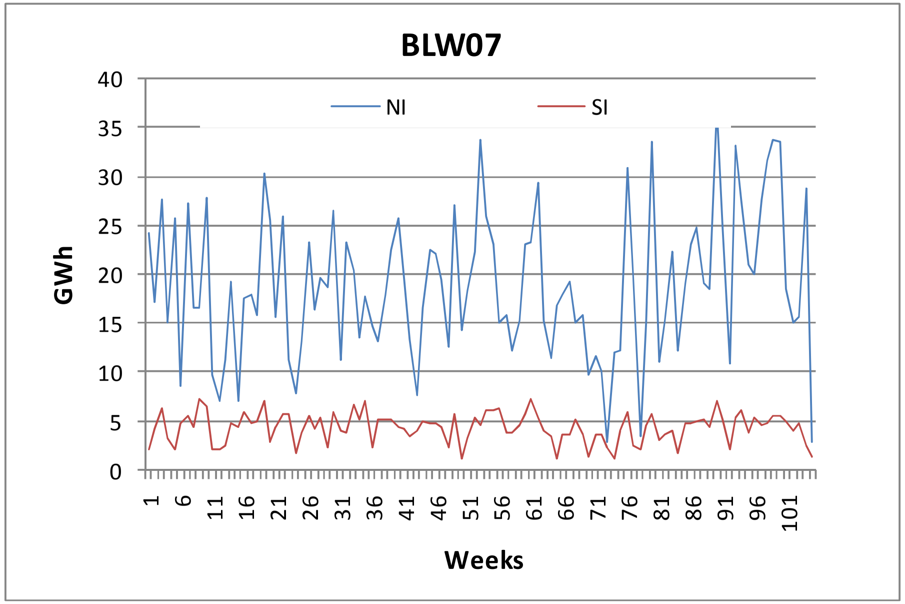


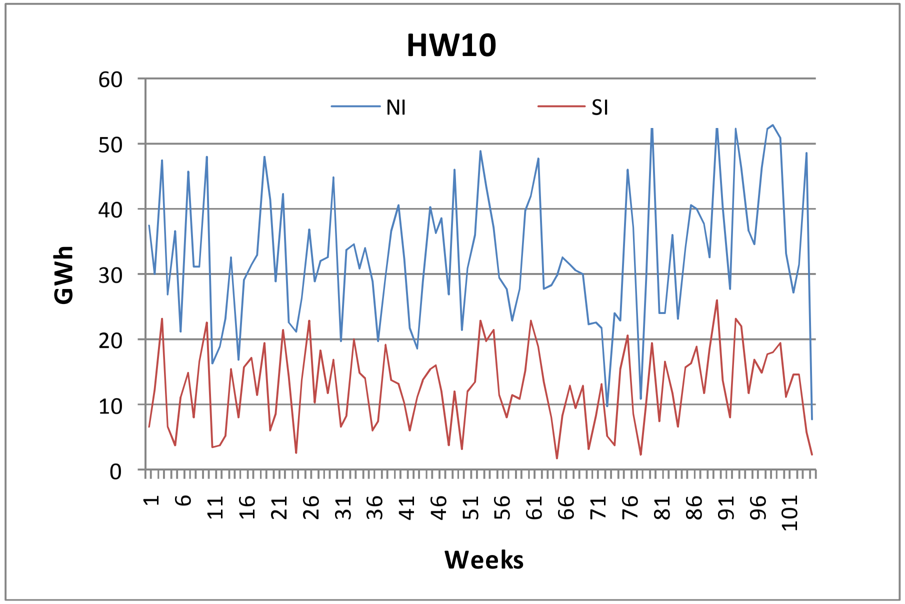
Wind energy (GWh)	NI	SI	Total
Annual	1,653	631	2,285
Weekly maximum	49	24	72
Weekly minimum	15	2	20
Weekly average	32	12	44

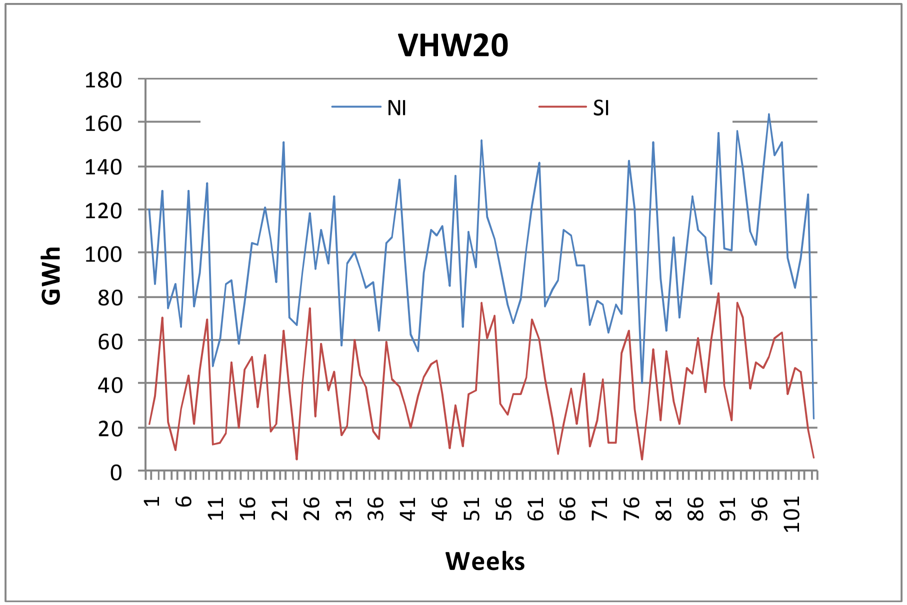
Wind energy (GWh)	NI	SI	Total
Annual	4,906	1,819	6,724
Weekly maximum	145	72	199
Weekly minimum	47	5	57
Weekly average	94	35	129

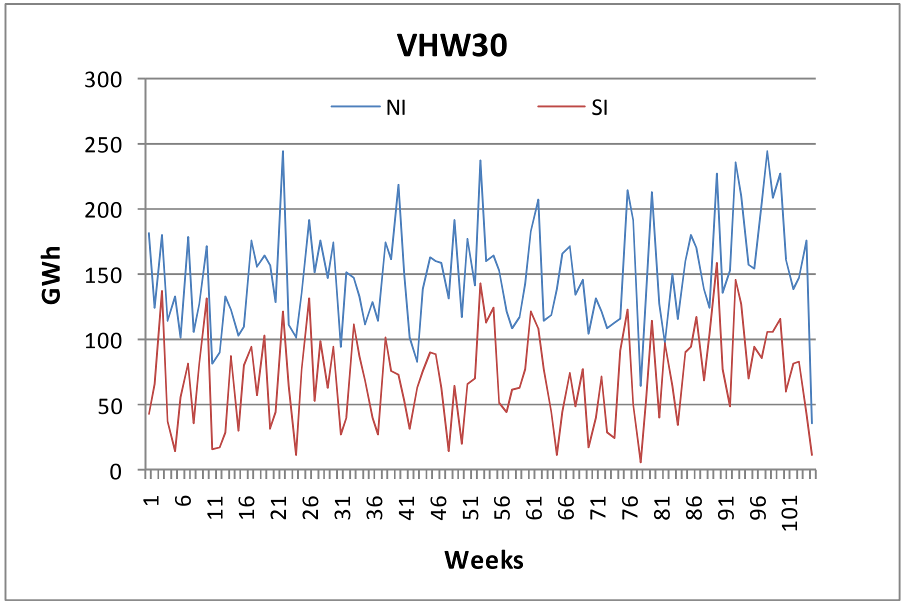
Wind energy (GWh)	NI	SI	Total
Annual	7,442	3,354	10,797
Weekly maximum	228	140	320
Weekly minimum	77	8	94
Weekly average	143	65	208

Weekly Wind Production

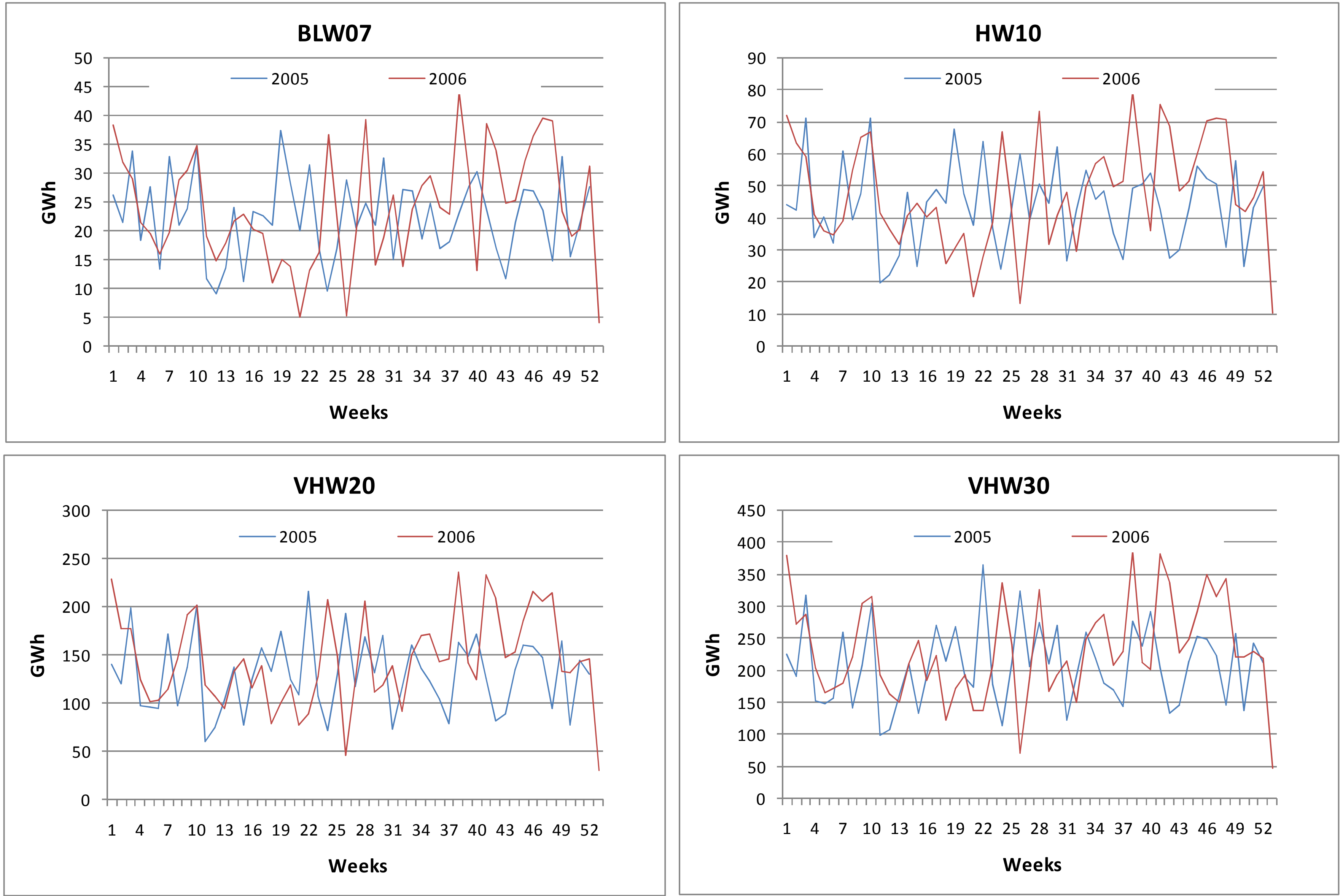








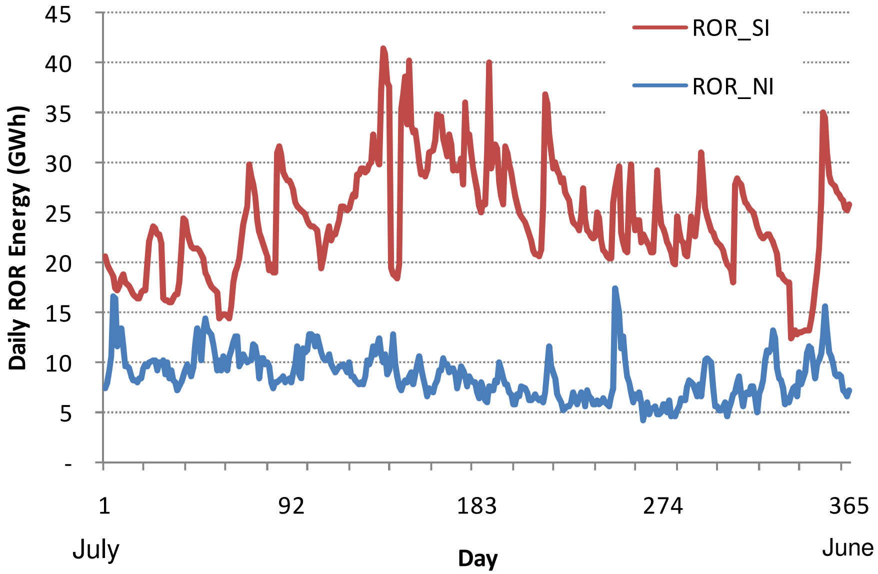
Weekly Wind Production (across years)

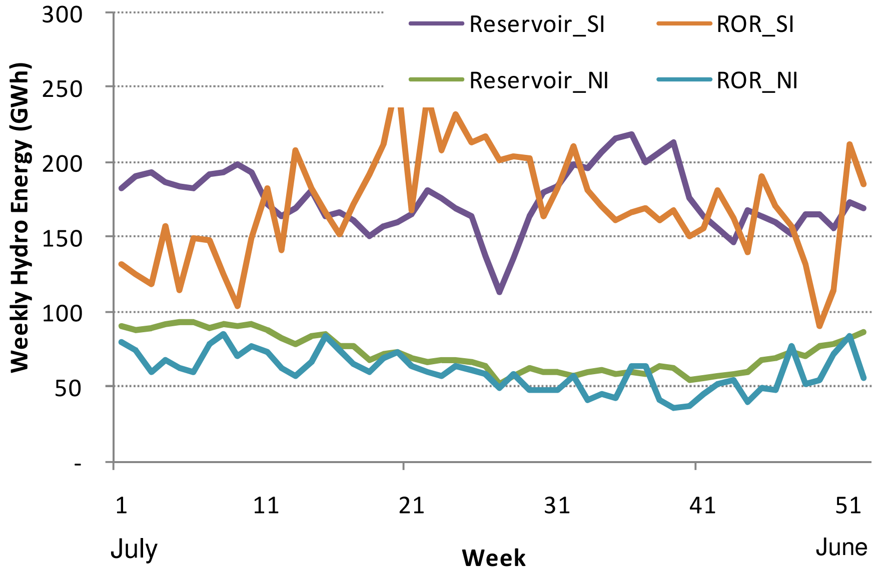


Data starts from first week of January

Hydro Profiles

Based on average hydro condition



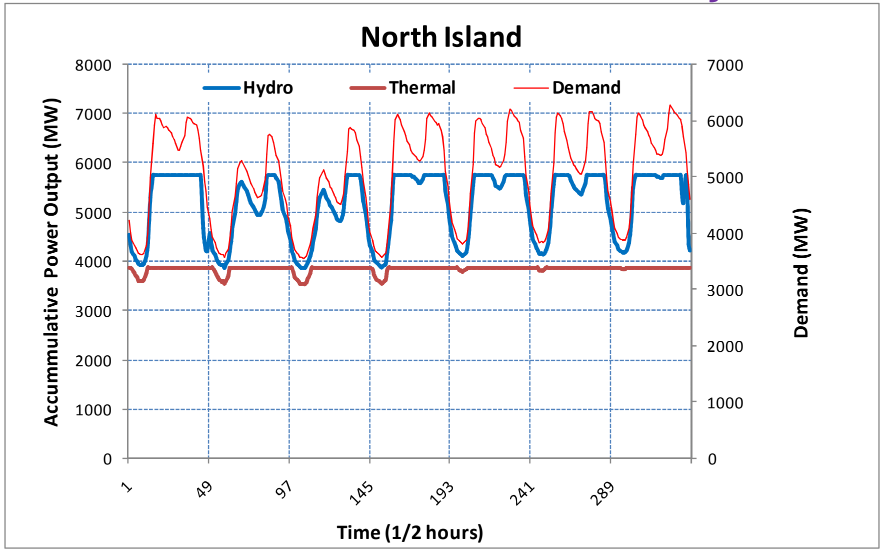


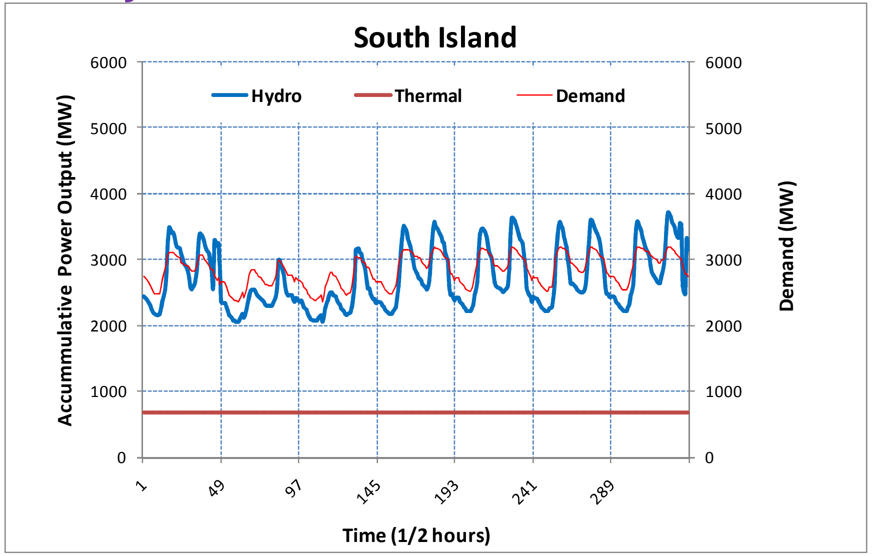
	Reservoir			Run of River			Total		
	NI	SI	NZ	NI	SI	NZ	NI	SI	NZ
Total energy (GWh)	3,760	9,080	12,840	3,159	8,849	12,008	6,919	17,929	24,848
Weekly maximum (GWh)	93	219	289.0	86	256	330	178	474	619
Weekly minimum (GWh)	52	113	165.3	36	90	145	89	203	310
Weekly average (GWh)	72	175	246.9	61	170	231	133	345	478

Appendix 1

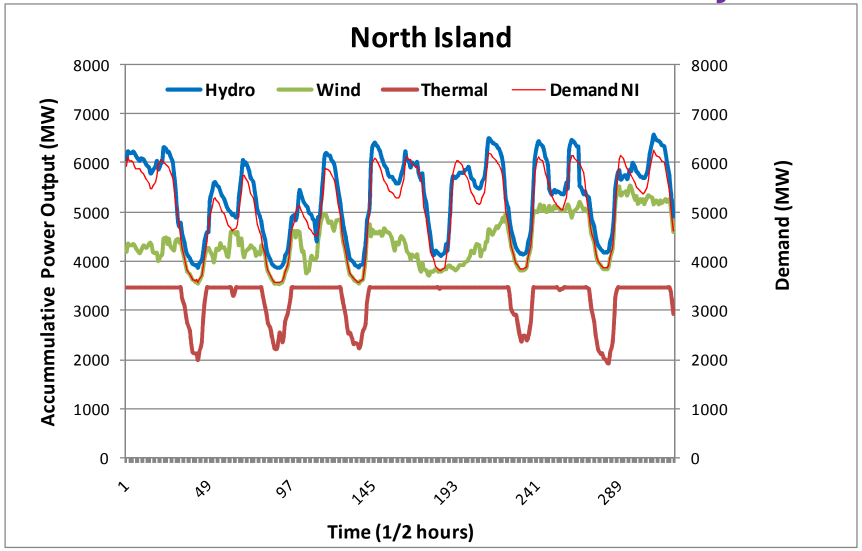
Illustrative one week dispatch -2030 Scenario
Hydro tends to flatten output of thermal generation

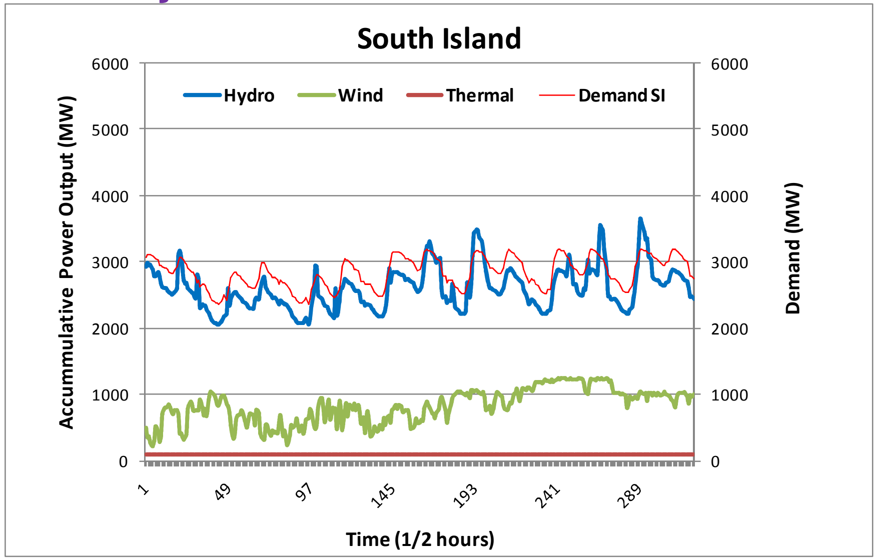
Hydro-Thermal System





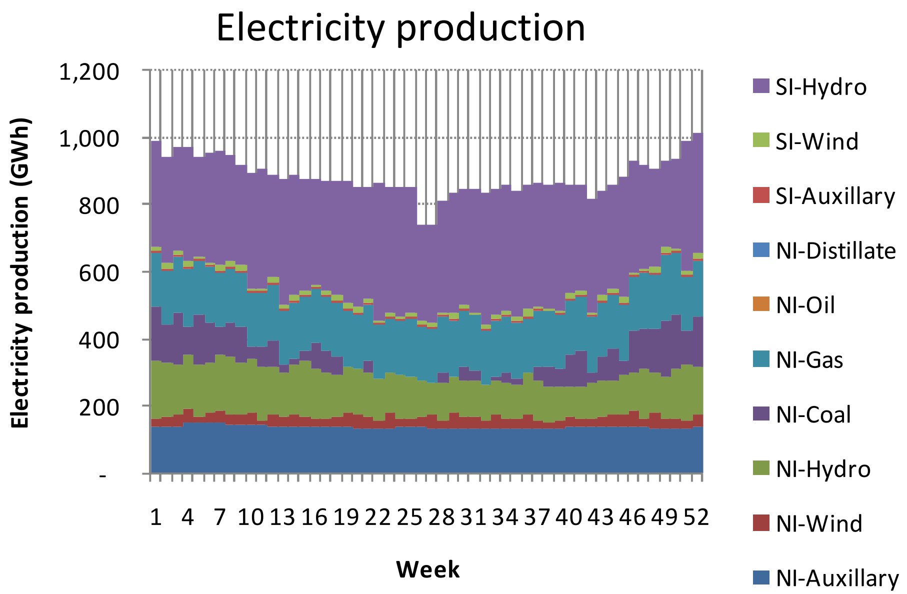
Wind-Hydro-Thermal System





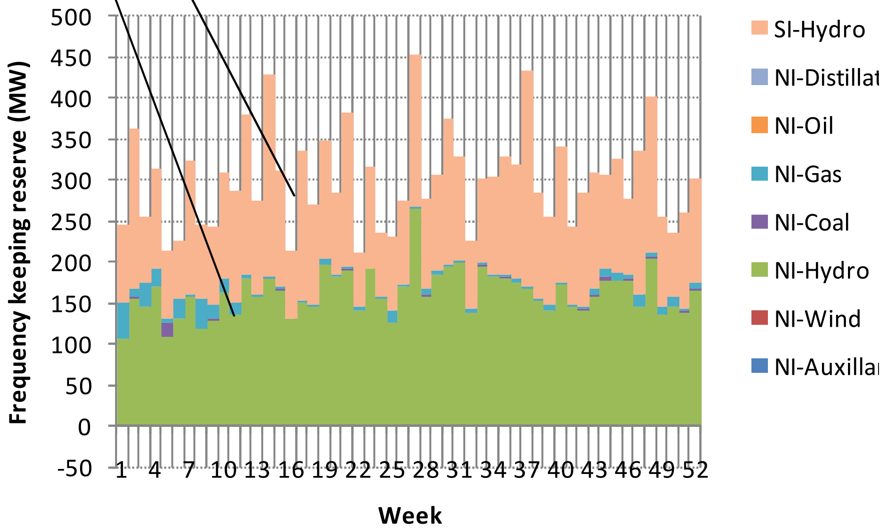
Providers of Reserves - Low Wind Penetration

High Wind Scenario 2010

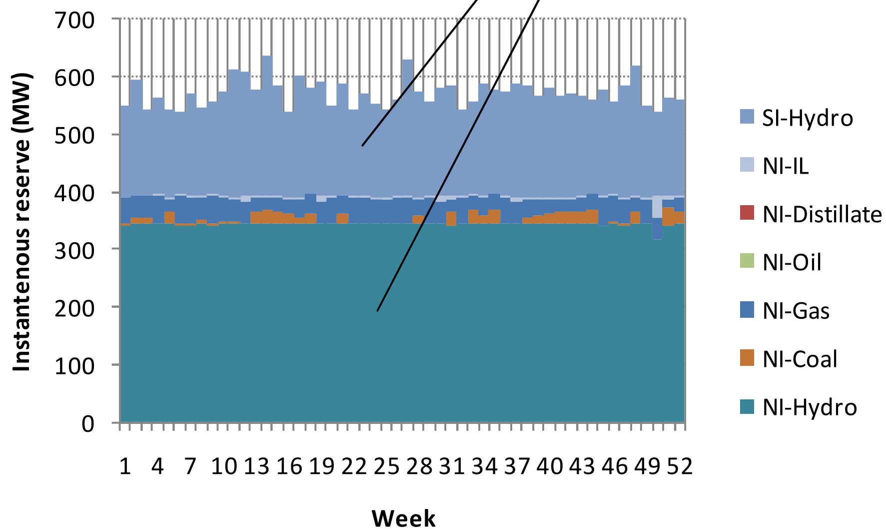


Throughout the year, hydro is primary source for FK

Primary source of Primary source for instantaneous reserve is Hydro (not affected by demand)



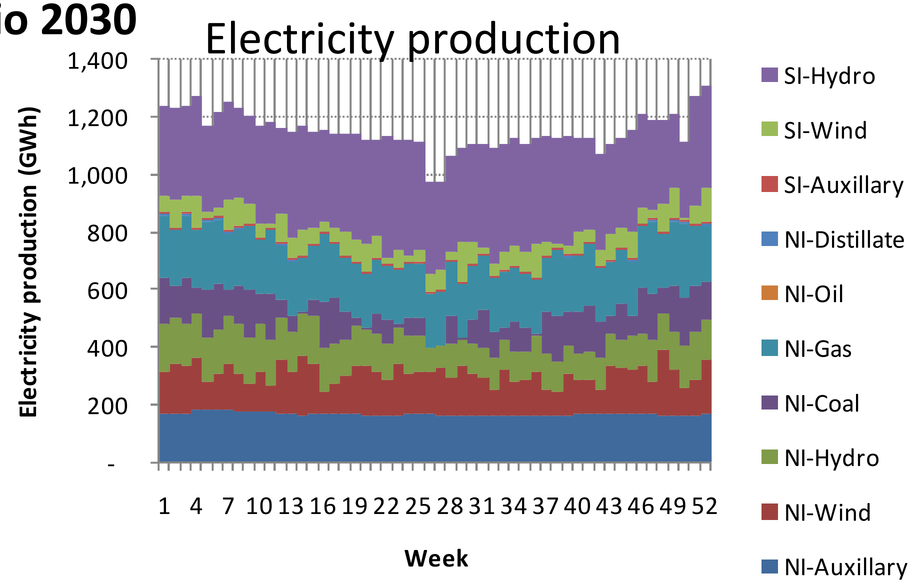
Frequency Keeping Reserve



Instantaneous Reserve

Providers of Reserves - High Wind Penetration

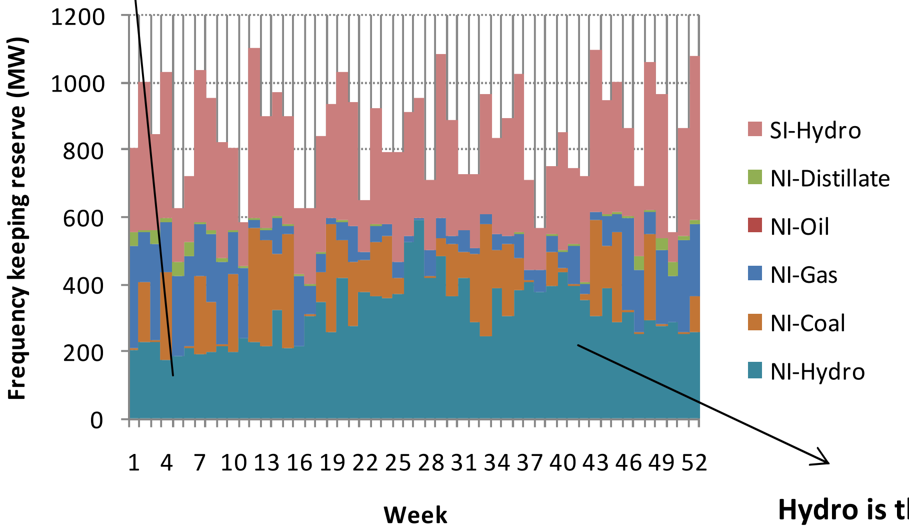
Very High Wind Scenario 2030



Primary source of instantaneous reserve is Hydro (not affected by demand)

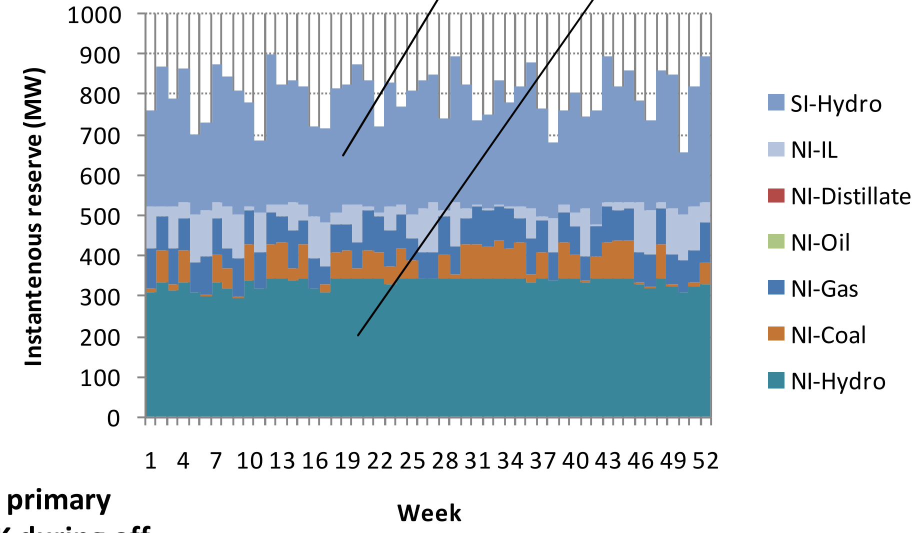
FK reserve from Hydro is less during peak demand (hydro provides more energy)

Coal, Gas and IL contribute to the provision of IR



Frequency Keeping Reserve

Hydro is the primary source for FK during off peak demand



Instantaneous Reserve