Case Study on

The Development of the wind industry in New Zealand

Report for APEC

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Structure of this report

This report outlines the development of the wind industry in New Zealand. The structure of this report is as follows:

- A timeline of the development of the wind industry in New Zealand.
- An outline of the characteristics of New Zealand's electricity system. Wind needs to be integrated into an electricity system. When considering how wind developed in New Zealand and the issues that have been addressed it is important to have a broad understanding of the electricity system.
- Understanding how wind became recognised as being an effective source of generation in New Zealand.
- Grid integration. The issue of integrating wind has been a focus of considerable study in New Zealand because of the electrically weak nature of the power system.
- Consenting[1] issues, such as managing noise, impacts on wildlife etc.
- Operations and maintenance. New Zealand's wind resource is extreme potentially placing significant stress on turbines.
- The important role of the New Zealand Wind Energy Association (NZWEA) in helping the industry develop.

[1] The term "consenting" means all aspects of environmental planning for windfarms.

Timeline of the wind industry in New Zealand

- 1970s: University researchers explore New Zealand's wind resources, including details such as understanding turbulence.
- 1970s: Research programme is established in response to the oil crises under the overview of a wind energy task force. Alternatives are sought for oil-fired generation and work starts on understanding the wind resource, with the work being done mainly by researchers.
- Early 1980s: Researchers recognise that New Zealand has a world class wind resource and that turbine developments internationally will lead to a commercial wind sector.
- 1985: Key report is published on the wind resource of New Zealand, power generation possibilities, power system integration issues etc. This report forms the basis for an informed debate about wind generation in New Zealand.
- Late 1980s: New Zealand's domestic electricity utility (ECNZ) plans a trial turbine on the hills overlooking Wellington, New Zealand's capital city.
- Early 1990s: Commercial wind prospecting begins.
- 1992: First wind conference held at a university, attended by a mix of enthusiasts and academics.
- 1993: A Vestas V27 225kW turbine is installed by ECNZ and quickly sets world records for wind generation for that type of turbine – capacity factor is above 50%.
- 1994: A 40 turbine windfarm – New Zealand's first large windfarm proposal – at the entrance to Wellington Harbour (New Zealand's capital city) is denied planning permission because of impacts on landscape values.
- 1996: A community-owned lines company establishes NZ's first multi-turbine wind farm using seven Enercon turbines (500kW). These turbines are still operating in 2016 with some maintenance/refurbishment.
- 1996: Annual wind energy conferences are organised by the Energy Efficiency and Conservation Authority, a government agency with responsibility for promoting renewable energy.
- 1997: New Zealand Wind Energy Association (NZWEA) is established with considerable support of the Energy Efficiency and Conservation Authority (a government agency). NZWEA begins to take over running the annual conference.
- 1998: Completion of first large windfarm (Tartarus 1), using forty-eight 660kW V47 turbines (31.7MW). the windfarm is built by a community-owned lines company,
- 1998: Major electricity reforms creates uncertainty for the electricity sector and wind development stalls.

- 1998: First domestic standard developed for windfarm noise.
- Early 2000s: Investigations and monitoring regains momentum all over New Zealand to identify potential windfarm locations funded by a mix of generation companies and independent companies on a commercial and confidential basis.
- 2003: New Zealand designed and built turbine (Windflow 500) commissioned at Gebbies Pass.
- 2004: Tararua 2 wind farm completed – fifty-five V47 660kW turbines. A government initiative to reduce carbon emissions (Projects to Reduce Emissions (PRE)) assists with project economics of this windfarm and a number of others.
- 2004: First grid connected wind farm (Te Apiti) which comprised multi-MW turbines (fifty-five 1.65MW). New electricity market rules developed to accommodate wind. Wind bids into the electricity market at 1 cent and achieves the clearance price but does not have to accurately determine the amount of generation. PRE assists with project economics.
- 2006: Planning permission sought for a 630 MW windfarm. In 2009 planning permission for this windfarm is declined on the basis of impact on landscape values.
- 2006: Transmission System Operator commences a major study looking at Wind Integration.
- 2006: Developers announce plans for 1+ GW of wind generation in a number of locations around New Zealand.
- 2007: Tararua III (3MW V90 90MW) and White Hill (2 MW V80 58MW) windfarms commissioned.
- 2008: Public concern about wind turbines increase and local groups form to oppose a number of the wind farm proposals. Planning permission becomes contested and it can take years to work through the planning process.
- 2009: A 142 MW windfarm completed 20 minutes drive from the centre of Wellington using Siemens 2.3MW turbines. The windfarm has some unexpected noise issues that take some months to resolve.
- 2010: In excess of 2GW of wind generation is being scoped or planning permission sought.
- 2010: The New Zealand wind turbine noise standard is revised and a revised standard is published.
- 2011: The largest wind conference with 250 registrations.
- 2011: The Mahinerangi windfarm is commissioned (3 MW V90 36 MW).
- 2011: The Te Uku windfarm is commissioned (2.3 MW SWT 101 64 MW).
- 2011: The government prepares domestic policy to assist consenting in response to highly contested resource consents resulting in considerable costs to all participants in the process.

- 2012: Flat electricity demand and an oversupply of electricity generation results in companies putting many wind development projects on hold.

- 2013: 500MW of coal generation mothballed and then retired. The thermal generation is uneconomic compared to renewable generation.

- 2014: Mill Creek windfarm commissioned near Wellington (SWT80, 2.3MW, 60MW).

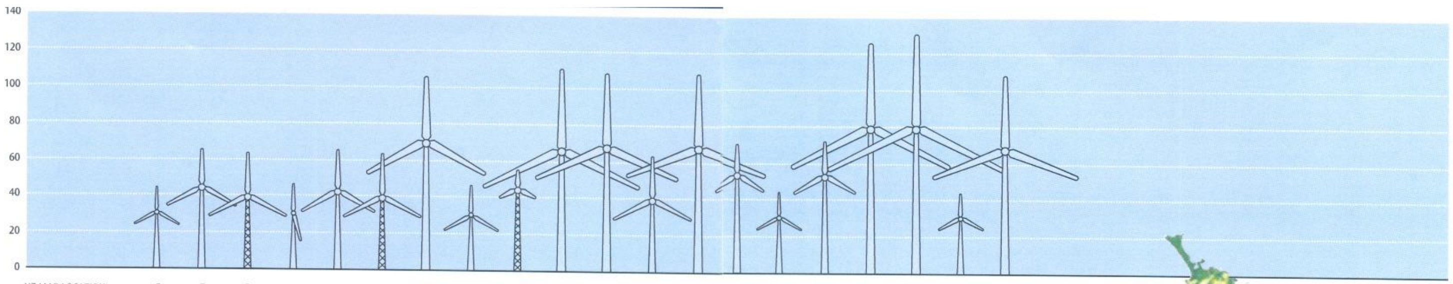
- 2015: Flat Hill windfarm (6.8 MW, Gamesa 850kW turbines) is commissioned at an estimated LRMC of NZ$70/MWh, demonstrating wind is now the cheapest form of new generation in New Zealand.

- 2015: Generators in New Zealand announce the closure of 1.5GW of thermal plant (gas and coal) on the basis of economics over the next 3-6 years. These retirements will result in a shortfall of generation creating a significant opportunity for wind development.

- 2016: The electricity regulator seeks views on how wind should be able to be offered into the market like any other form of generation.

Recommendations:

In the early stages of the wind industry having a research strand is important to help understand the details of the wind regime in an economy. The early research needs to be very applied and should focus on characterising the wind resource ideally at hub height (e.g. 80+ meters) and linking that characterisation to the operation of the electricity system. Various wind development scenarios should be modelled and electricity system integration issues assessed. Funding a research programme is an action that a government can take to support the development of an industry.



NZ MAP LOCATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
YEAR OF INSTALLATION	1993	1996	1999	2003	2004	2004	2004	2005	2005	2007	2007	2009	2009	2010	2010	2011	2011	2011	2011	UNDER CONSTRUCTION
TURBINE CAPACITY (MW)	0.225	0.55	0.66	0.5	0.6	0.66	1.65	0.5	0.1	3	2	0.75	2.3	0.225	0.25	0.85	3	2.3	0.25	XX
TOWER HEIGHT (M)	31	46	40	30	43	40	70	30	45	65	67	40	67	55	30	54	80	80	30	67
TIP HEIGHT (M)	43.5	66	63.5	47	66	63.5	106	47	55	110	107	62	111	70	43	72	125	130	43	111

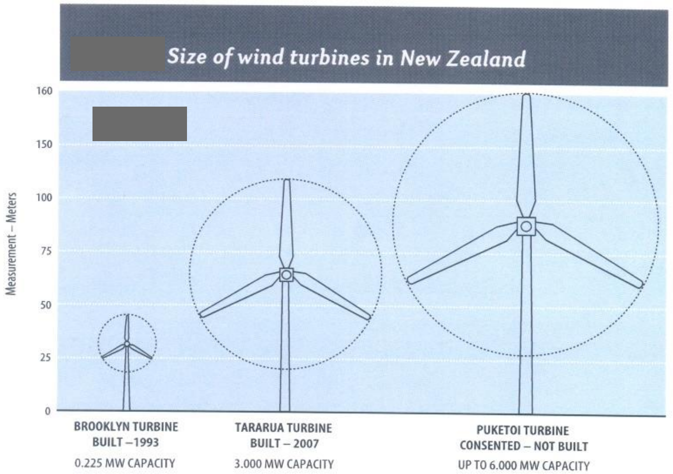


Figure 1: Locations of windfarms in New Zealand, growth in turbine size and heights/rotor diameters of built windfarms and windfarms with planning permission.

The New Zealand electricity sector

To understand the development of wind generation in the New Zealand electricity system it is first necessary to understand the development of the whole electricity system. This section outlines the development of the electricity sector in New Zealand, covering both the physical aspects and the institutional aspects.

Basic information 2015

• Total installed generation capacity:	10,539 MW
• Peak load	6,414 MW
• Electricity production (2014)	39.7 TWh
• Thermal plant (gas and coal)[2]	20%
• Wind generation	6%
• Hydro generation	59%
• Geothermal generation	15%

New Zealand is a long (1500 km), narrow (200km) economy with rugged terrain and extreme weather. The economy lies in the Southern Ocean between 35 and 47 degrees latitude and has two main islands separated by some 50km of ocean. New Zealand is isolated with the nearest neighbour being Australia some 2000 km distant.

New Zealand has plentiful rainfall and steep rivers amenable to hydro development. Geothermal resources are plentiful. In addition New Zealand discovered a significant quantity of natural gas in the 1970s and 80s. Located in the "Roaring Forties[3]" New Zealand has one of the best wind resources in the world for electricity generation.

Up until the 1950s New Zealand's electricity system comprised a number of disconnected grid systems built to meet local needs and supplied by local generation, mostly hydro. Over time these were connected using high voltage transmission. New Zealand's electricity system is characterised by a long, "stringy" grid system. In technical terms the grid is considered to be "electrically weak".

Electricity demand grew in New Zealand steadily over many decades. The electricity industry frequently struggled to supply enough electricity. From the 1950s to 1980s the New Zealand government focused strongly on building sufficient generation to meet demand.

Hydro is the mainstay of New Zealand's electricity system. But herein lay a problem. The best hydro development sites are in the South Island but the majority of the load and population are located in the North Island.

In the 1950s and 60 the government embarked on an ambitious electricity development plan that now shapes the electricity system in New Zealand. Hydro resources in the South Island were developed. A world leading 500km overland and undersea high voltage direct current (HVDC) link[4]

[2] By generation – the figures below are all by generation rather than installed capacity.
[3] The Roaring Forties, Furious Fifties and Screaming Sixties are terms used by sailors to describes the winds in the Southern Ocean. The terms have been adopted into New Zealand language.
[4] At the time (1960s) the HVDC link was the longest in the world, the previous longest HVDC link was approximately 50km.

was established to transport electricity from the large South Island hydro developments to the load centres in the North Island. A large aluminium smelter representing some 20+% of load (at the time) was built in the lower South Island. In 2015 the aluminium smelter represented some 15% of load.

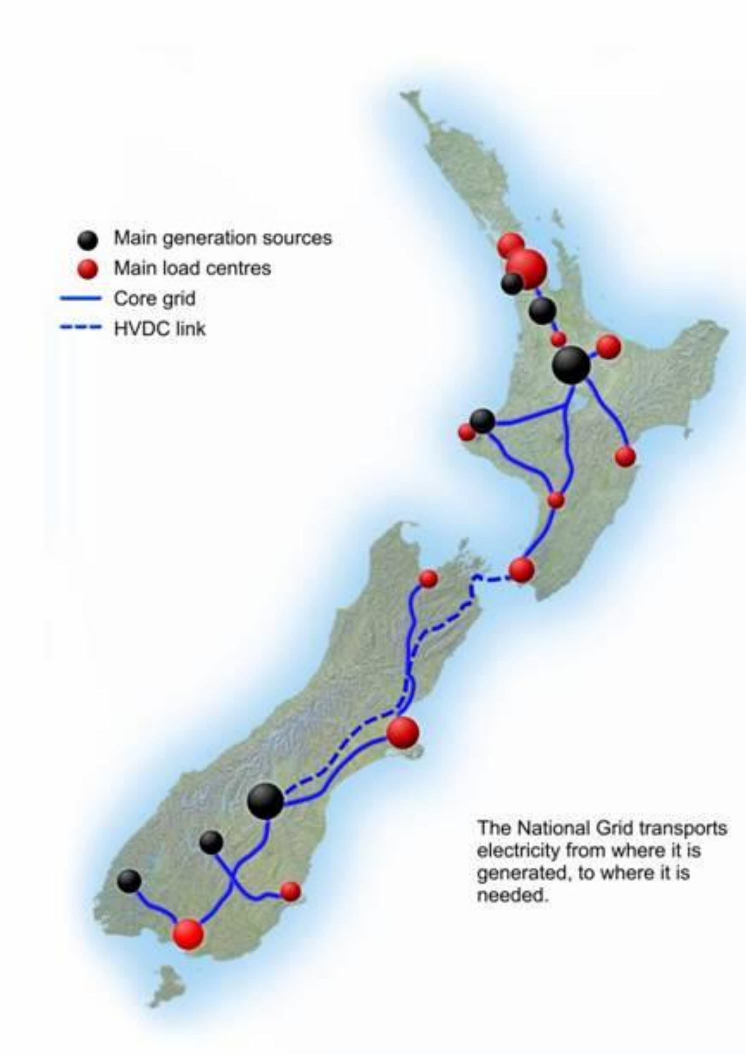


Figure 2: Map of the New Zealand Electricity System showing the main load centre and main generation sources

Prior to the HVDC link being developed New Zealand pioneered geothermal development. In the 1950s the world's largest geothermal power plant was developed and it used wet steam. This power station set the scene for a vibrant geothermal industry that today produces around 15% of New Zealand's electricity.

In the 1970s New Zealanders became concerned about the loss of rivers and raising of lakes for hydro generation purposes. After widespread opposition a number of lakes and rivers were protected in New Zealand. Hydro engineers needed to work harder to find suitable sites, resulting in increased costs. The last large hydro scheme was the Clyde Dam (464MW) completed in 1992.

In the 1970s New Zealand discovered a large gas field. The government signed a "take or pay" gas agreement that required it to pay for gas even if it did not use it. In the late 1980s industries based on gas failed to be established in New Zealand. The government, worried about paying for gas it did not use, sought to use gas to generate electricity. In the 1990s New Zealand commissioned two 400 MW combined cycle gas plants, converted a 1000MW coal power station to run on natural gas and in 2004 the government underwrote a third 400MW combined cycle gas plant. In the late 2000s New Zealand had some 2.4GW of thermal plant.

In the 1980s New Zealand embarked on a major transmission upgrade and improvements to the way the grid was operated[5]. The major programme involved physical infrastructure, such as transmission lines, communications systems, SCADA, and training. Over the course of a decade New Zealand evolved its grid system into a reliable and modern electricity system with highly skilled and well trained personal. This period of upgrade laid a solid foundation for future developments, such as the development of the wholesale market and the development of wind generation.

In the 1980s the government became concerned about costs in the electricity sector spiralling out of control, particularly hydro development. True costs of development were not clearly visible and the government together with industry leaders explored the idea of a wholesale electricity market where market participants would decide which power stations would be built. A market would enable the true costs of electricity production and supply to be visible.

With the market the government's role in the electricity sector changed. It went from the developer and operator of the power system to the regulator. Development of generation was no longer an area that the government was strongly involved in.

The government created four State Owned Enterprises by splitting up the state-owned electricity generator. These Enterprises were set up as autonomous entities to compete in the electricity market.

An electrically weak power system

The New Zealand power system is considered by electrical engineers to be "electrically weak". Compared with strongly meshed continental grids, the NZ power system experiences very large frequency and voltage excursions. Frequencies as low as 47 Hz occur a few times per year. The long stringy New Zealand grid means that the electrical characteristics of the grid vary across the economy.

A number of windfarms in New Zealand have been built in the distribution network. These networks can be very weak electrically. Windfarms in New Zealand have been carefully designed to help provide grid or distribution level services and on occasions both.

At the domestic level a significant project in the mid 2000s explored how wind could be effectively integrated into the power sector. This key study gave the System Operator comfort that significant amounts of wind generation could be accommodated on New Zealand' electrically weak power system. The Wind Grid Integration Project is outlined in a subsequent chapter.

[5] Reilly H; 2014; Keeping the Lights on – the history of System Operation in New Zealand; Transpower.

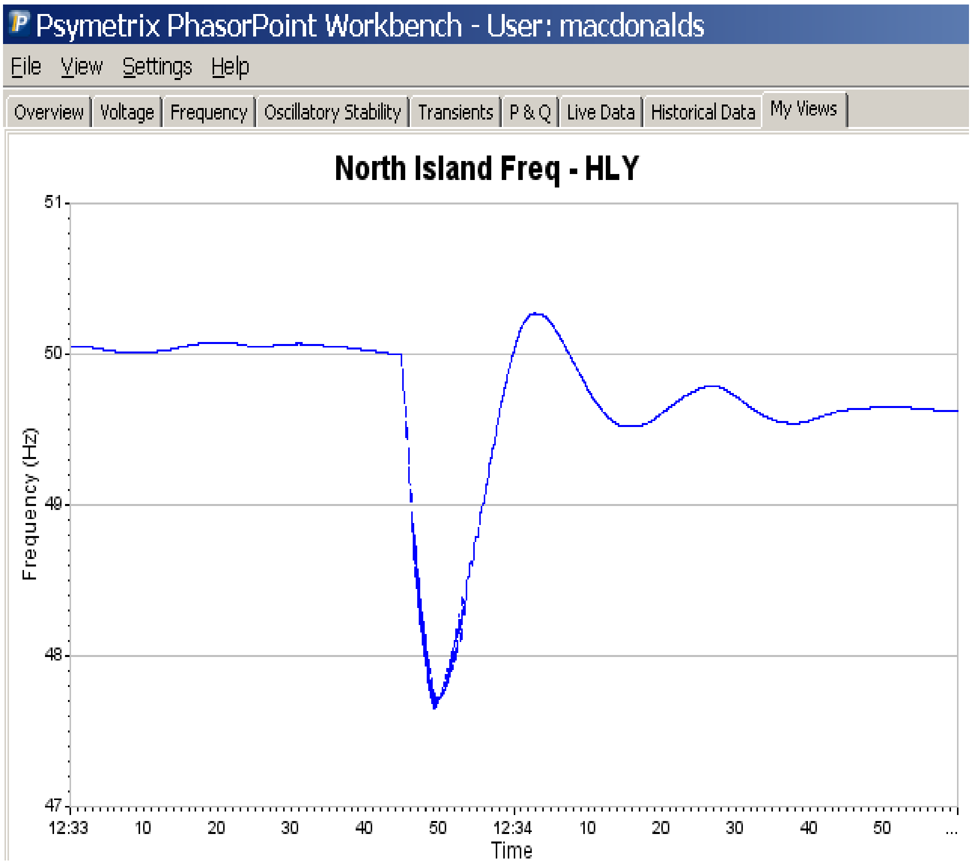


Figure 3: A dip in frequency caused by an event on the grid. Note that the frequency dips below 48 Hz.[6]

The wholesale electricity market

In the 1990s the world first locational marginal pricing electricity market was established in New Zealand. Wind developers in New Zealand have worked with the market since its inception – in effect the wind industry in New Zealand knows nothing other than the wholesale electricity market. It has operated with a high level of satisfaction across the electricity[7].

The dispatch system in the New Zealand electricity market operates on two principles:

- Security of the system, such as reserves etc.
- Most economic dispatch at any time.

The electricity market covers both the demand-supply balance and the provision of ancillary services. Key points of the New Zealand electricity market:

- 220 nodes (grid exit point) where prices are set.
- 30 minute trading periods.
- Dispatch every 5 minutes.
- Generation over 10 MW that is grid connected must offer into the market.

[6] Sourced: Transpower.

[7] The market model was adopted by PJM Interconnection some two years after it was established in New Zealand. PJM Interconnection generally regarded as the largest electricity system in the world.

- Embedded generation (in the distribution network behind a grid exit point) over 10 MW may be required by the SO to offer into the electricity market.
- Rules of intermittent generation are similar to must-run generation.
- Clearing price can drop to zero but not go negative.
- Markets exist for ancillary services such as; instantaneous reserve, spinning reserve, frequency keeping, voltage support, black start.

The forecasting timeframe for the electricity market is as follows:

- 6 months -1 year: Long term outlook such as weather patterns (e.g. droughts), planned major plant or transmission outages.
- 1 week – 6 months: Planned outages etc.
- 24 hours to 1 week: Short outage planning.
- 12-24 hours: Market scheduling.
- 6-12 hours: Slow start plant scheduling.
- 2-6 hours: Intermediate start plant.
- 2 hours: Gate closure and firm offers.

In 2004 the first wind farm in New Zealand (Te Apiti) was connected directly to the main electricity grid. The Te Apiti windfarm was required to participate in the electricity market. Prior to this the windfarms in New Zealand were located in distribution networks. This meant that they cannot be dispatched, however, there is a requirement that the SO understands how much generation will be coming from power plants in the distribution system that are over 30 MW.

The locational aspect of the New Zealand electricity market influences decisions on where to build new generation. The figure below shows areas of the economy where electricity prices are higher than average (red) and lower than average (blue). In the North Island geothermal generation east of Lake Taupo results in lower prices (dues to geothermal generation) and prices are lower near the area of main hydro generation in the South Island. Developers do consider the variation in nodal prices when considering where to build windfarms. For example, in recent years companies have focused on gaining planning permission for wind farms in the “red” parts of the economy.

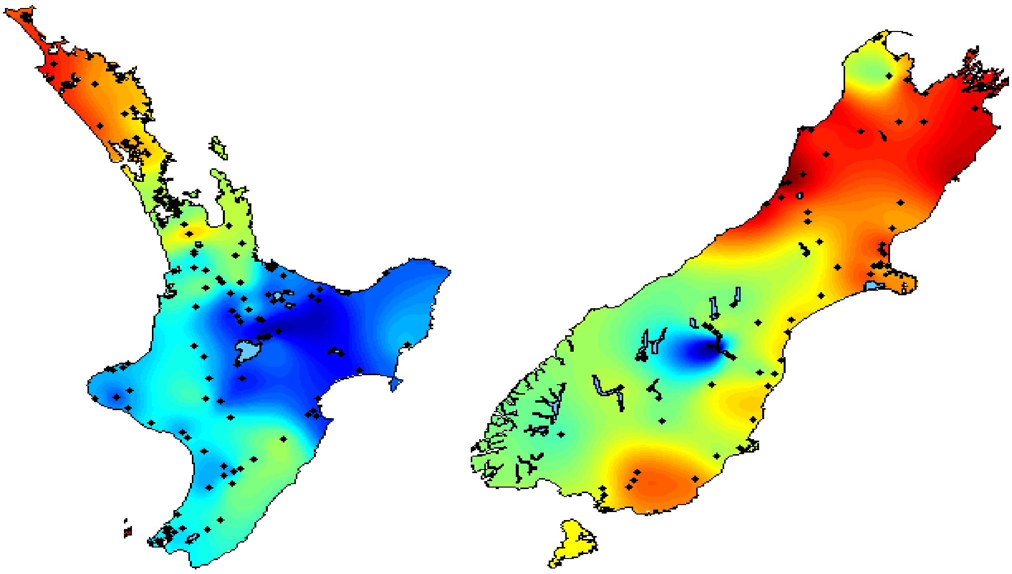


Figure 4: Higher(red) and lower (blue) prices across grid exit points in New Zealand[8].

The policy and institutional setting

The institutional setting has been an important influence on the development of windfarms in New Zealand, as it is in any economy. When the wind industry started in New Zealand in the mid 1990s the pioneers were the lines companies not the main generators. While the first commercial-scale turbine was installed (1993) by the state owned domestic electricity generator (ECNZ), it was lines companies who built the first wind farms in 1996 (Haunui) and 1998 (Tararua 1).

Further, it was lines companies who commissioned most of the monitoring of the windfarms in New Zealand. Almost all the current windfarms in New Zealand were first investigated by lines companies and other developers. For example, all of Meridian Energy's[9] windfarm sites were first monitored by other entities, often by the local lines.

The key point is that the centralised generation agency in New Zealand was slow to embrace wind and recognise wind as a new form of viable generation technology. It was the organisations that were looking for new opportunities and keen to innovate that explored wind and started to develop the first projects.

[8] Presentation to the NZ Wind Energy Conference by Dr James Tipping, Trustpower, 2012.

[9] New Zealand's largest wind farm operator by MW of wind capacity.

The 1980s and 1990s

In the 1980s and early 1990s New Zealand had a centralised generation system. The New Zealand Electricity Department was responsible for large scale generation and the transmission system. Electricity was sold to consumers by lines companies. The lines companies were natural monopolies (and still are) and were owned by municipalities or community trusts, i.e. they were seen as part of the community's infrastructure.

The lines companies, which were also the electricity retailers, charged consumers for:

- The cost of the distribution infrastructure that the lines company ran.
- The cost of domestic transmission that the NZ Electricity Department charged the lines companies.
- The cost of energy, which the NZ Electricity Department charged the lines companies.

Lines companies encouraged by the Government to develop local generation in the 1970s. But after some financially disastrous outcomes the government put in place barriers to lines companies developing generation. These barriers were lifted in 1992 and the lines companies began focusing on generation again.

Wind was seen by some in the lines companies as an ideal form of generation[10]:

- New Zealand has good wind resources.
- Wind generation is scaleable.
- The technology is straight forward to install, as compared for example, to hydro schemes which in New Zealand's diverse and earthquake-prone landscape can have significant geotechnical issues.
- Wind was profitable for lines companies because it meant they did not have to buy electricity from the domestic generator and they could pay less for domestic transmission.

The result of the policy settings coupled with an ability to innovate quickly wind meant that it was the lines companies who did much of the early investigation and development of wind farms in New Zealand. Unfortunately these developments came to a shuddering halt later in the 1990s due to central government reforming the electricity sector.

In 1996 the New Zealand electricity market was established. The lines companies responded quickly and started developing entities to bulk buy electricity from the State Owned Enterprises that the government established out of the old electricity department. Some in the electricity sector had concerns about the potential ability of lines companies to use their monopoly income position to finance new generation development, i.e. to in effect subsidise new development such as wind.

In 1998 the government passed a new law that required lines companies to either:

- Run the distribution network only or
- Become a retailer and or/generator.

[10] Allan Jenkins pers comm. Allan has recently retired as the CEO of the Electricity Networks Association, which represents all the lines companies in New Zealand.

Lines companies were not allowed to own generation or be a retailer. Some lines companies chose to become generators. But most chose to remain with the lines business.

As a consequence of this policy and institutional turbulence, wind generation development ceased in 1998 and did not get underway again until the early-mid 2000s, a period of 6 or so years.

The late 1990s onwards

The pattern of institutions in the NZ electricity system was largely set through the 1998 reform, which saw lines companies being constrained operating only the distribution network and have to sell off their retail and generation operations.

Four large generators had been created from the former NZ Electricity Department. These entities had to learn about the characteristics of wind generation and how to integrate the generation into their portfolio system which delayed the growth of the wind industry in New Zealand.

Only one of the large generators, Meridian Energy, developed significant wind generation capacity. All of Meridian Energy's windfarms were first explored by lines companies. The work by the pioneers in the wind industry in the early-mid 1990s and the institutional settings of that time have shaped the wind industry today.

In the 1990s and 2000s demand for electricity continued to grow and sources other than large hydro were sought. Potentially the wind industry could have grown rapidly over this time but three key factors constrained the growth of the wind industry:

- Restructuring of the lines companies (discussed in the previous section) that were the organisations most actively involved in wind generation development.
- Geothermal development grew rapidly from 5% of generation to 15%. New Zealand invested significantly in geothermal development as a consequence of a long history of development, considerable depth of expertise and a subsidy from the government in the form of research funding to help define geothermal fields. During electricity restructuring the geothermal teams were transferred largely intact from the government electricity department to the new smaller generation companies.
- Gas fired generation. In 2004 New Zealand suffered an electricity shortage caused by drought. The government was concerned that the electricity market would not deliver sufficient generation in time. It underwrote one of the state-owned generators to develop a new combined cycle plant. That plant (400MW) was commissioned in 2007. The development of this power plant had the added benefit for providing a large customer for the gas industry that enabled a new offshore gas field to be developed. Ironically in 2008 electricity demand growth in New Zealand ceased. This decision to in effect subsidise a gas-fired power plant resulted in a lost opportunity for the wind industry amounting to some 800MW-1000MW.

Institutional and policy settings summary

The wind sector would have grown more quickly in New Zealand if:

- The lines companies had been allowed to develop generation. These companies realised the opportunity related to wind and that wind could be developed locally and was scalable. The large domestic generator could not realise or access these opportunities as quickly as the more locally focused lines companies.

- Institutional reform meant that knowledge and capacity to develop wind was lost and had to be re-built. The reforms of 1998 set the wind industry back by some 5+ years, just at a critical stage of development.
- Government intervention – underwriting a large thermal power station – meant that wind was not given the opportunity to develop. Without this one intervention the New Zealand wind industry could be twice the size that it now is.

Recommendations relating to the overall electricity sector:

- Large generators will be slow to learn about wind generation. Ensure policy settings support the small, innovative players – they are the organisations who will explore and understand the opportunities around wind.
- Electricity sector restructuring needs to be very carefully worked through to ensure that unintended consequences do not occur, for example, constraining innovation.
- Governments should not pick and subsidise particular generation projects. If the government does wish to develop generation market-type mechanisms should be developed, such as tenders.

Getting the industry started

Throughout the interviews for this study, a common theme is that a good understanding of the resource is absolutely critical to developing a wind farm.

1970s and 80s – the early years

In the 1970s and 1980s a small number of academic staff at universities in New Zealand explored the idea of generating electricity from wind[11]. These academics recognised that New Zealand was windy and that research programmes in the US were exploring the development of wind turbines. As part of a broad R&D effort by the government to develop new sources of energy following the oil shock in 1973[12] a wind research programme was established.

The research work was important from a number of perspectives:

- Collecting accurate data on the wind regime. Up until this time there were no high quality wind datasets in New Zealand. Wind data were generally collected at airports etc but these data were of varying quality, for example, collected relatively low to the ground.
- Understanding how to collect good quality data and how important good quality data is. At this time few people in New Zealand knew how to collect good quality wind data, nor did they realise how important good quality data is.
- Characterising the wind resource. The early researchers explored issues such as wind shear, extremes, such as gustiness and calm periods.

The wind researchers inspired a small number of students and generally raised the profile of the possibility of wind generation in New Zealand. They were able to demonstrate, using world comparable methods, that New Zealand had a wind regime that was well suited for wind generation.

Two academic researchers were pivotal to the development of understanding of the wind industry in New Zealand. Neil Cherry (Lincoln College, Canterbury University, Christchurch) and Keith Dawber (Otago University, Dunedin). These visionary individuals were critical to the establishment of the wind industry.

Dawber led monitoring efforts in the South Island of New Zealand and was the first to collect sufficiently accurate wind data to be useful to develop windfarms. He also explored wind resource issues that could impact wind farm development, such as turbulence[13]. Dawber was active internationally, keeping abreast of the development of the wind industry and imparting knowledge about the wind industry to New Zealanders.

Cherry led the first domestic survey of the wind resource in New Zealand in the 1970s[14]. This study used data from existing meteorological stations. The wind industry made extensive use of this

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[11] Professor Richard Flay, Auckland University, interviewed 23rd February 2016.
[12] A number of economies around the world developed energy R&D programmes at this time.
[13] http://www.energywatch.org.nz/issues/EW7_8_1997.pdf accessed 15th February 2016.
http://www.windpowermonthly.com/article/956239/keith-dawber-dies
[14] http://www.nzine.co.nz/views/windflow.html

original report. It provided very useful information on where the windy sites were. More detailed monitoring campaigns were developed using the information in that early study.

An important ingredient was a report published in 1985[15] by Cherry on the wind resource in New Zealand and potential generation characteristics of windfarms. The report identified potential wind farming regions based on wind resource and proximity to load. Some 12 windfarms in New Zealand were modelled assuming 2.5MW turbines[16] generating around 20% of total electricity production[17]. This modelling enabled wind generation characteristics to be explored in relation to the electricity system. The wind data in the report were from meteorological stations upscaled to a 50m hub height and atmospheric wind speed data (from tracking weather balloons) downscaled to 50m. Cherry's 1985 report provided a solid foundation for an informed debate about the wind industry in New Zealand.

Cherry was also involved in international work. For example, he worked with the Battelle Laboratories, reviewing the US wind resource assessment programme. Cherry also had a sabbatical in the US, working on the wind programme in California. Through these sabbaticals and international interactions Cherry brought knowledge back to New Zealand.

As well as the academic researchers, two or three experts helped drive interest in wind generation. These experts had worked overseas and had practical experience in developing windfarms. These experts linked with the work of Cherry and Dawber and were able to put a compelling case for investigating wind generation in New Zealand. The experts were pivotal to the development of the industry.

The key ingredients

So, what convinced the electricity sector in New Zealand to start investing in wind? The following elements were important:

- A very small number of academic researchers (Dawber, Cherry) had collected some good quality wind data that demonstrated New Zealand had a world class wind resource. Further, the researchers had begun the process of characterising the wind resource, exploring turbulence, shear, the windiest locations etc.
- An effective report on the potential of wind generation in New Zealand and how wind may interact with the electricity system (published in 1985 by Neil Cherry).
- A small number of experts (2-3) with international experience who linked with the academic research and convinced the electricity industry that wind generation was worth investigating.
- Distribution companies[18] were keen to develop generation in their local areas. They recognised that wind generation could be built at different scales and was a significant change in thinking about generation from large centralised power plants.

[15] Cherry N; (1985); Wind Energy Resource Survey of New Zealand; New Zealand Energy Research and Development Committee.
[16] The largest turbines at the time were around 100kW.
[17] In 2012 the New Zealand Wind Energy Association produced a vision document for the wind industry in 2030. The target is for 20% wind generation by 2030, i.e. the identical target to the 1985 report.
[18] Companies that run the distribution-level networks.

- The domestic generation organisation (before being split into a number of companies) focused on wind generation, recognising wind to be a potential future form of generation.

Collecting the data – detailed understanding of the wind resource in New Zealand

The work of Chery, Dawber and colleagues provided very useful broad information. The industry recognised that to successfully develop windfarms accurate local datasets were needed. In the early 1990s the industry, mainly lines companies, started monitoring the wind resource around New Zealand. Existing wind data sets in New Zealand were not adequate to support the development of the wind industry. For example, the existing data was collected to the nearest knot, which is not sufficiently accurate to design a windfarm.

Importantly, the people returning from overseas understood the importance of measurement standards and well-designed measurement campaigns. These practitioners assisted New Zealand start well up the learning curve in terms of wind resource assessment techniques; they could explain why the existing wind datasets in the economy, for example, from the Meteorological Service, were not adequate for wind resource assessments and why site-specific data are essential.

30m towers were the common measuring platform reflecting the hub heights of the early 1990s. Later these measurements had to be supplemented by measurements at 70-80m reflecting the growth in wind turbine heights. A lesson is that monitoring campaigns should be designed for future turbine technology rather than current.

Modelling now provides some of the information that the wind resource study provides. However, practitioners in New Zealand consider that the broad-scale monitoring or modelling helps paint a broad picture of the resource. Detailed information is still needed and can only be provided through site-specific monitoring programmes, ideally measuring wind speed at the likely hub height of the wind turbine.

Recommendations: Starting the industry

- Encourage a research programme focused on wind resources.
- Support the key researchers who are leading wind research efforts.
- Ensure that monitoring is done to internationally accepted standards to ensure high quality data collection.
- Develop and publish robust information on the wind resource and make this information widely available.
- Collect site-specific data to characterise the wind at a particular location.
- Collect wind speed data at the potential hub height of future turbines, not just existing turbines. This height is likely to be a minimum of 80m, possibly as high as 140m.

Getting the first few projects underway; successes and some learnings

The wind industry in New Zealand grew slowly until 2004 when the first large (>1MW) turbines were installed to create the 90MW Te Apiti windfarm. This section outlines how the first few windfarm projects were developed. These first few projects were instrumental in establishing the industry.

Figure 5: Windfarms in New Zealand.

The Brooklyn wind turbine - The first commercial scale wind turbine in New Zealand; 1993

In 1993 a 225kW 27m rotor diameter Vestas turbine was installed on a prominent hill overlooking Wellington, New Zealand's capital city. The Brooklyn Turbine (named after the local suburb) was replaced in 2016 after some 23 years in service. The wind regime at the turbine site is Class 1A with high levels of gustiness and turbulence.

The turbine was installed by the Electricity Corporation[19] to gain experience and understanding of wind generation and to answer questions such as[20]:

- Would the turbine work effectively in the New Zealand wind conditions?
- What were the maintenance issues?
- Would the public accept the turbine from a visual perspective?
- What are the issues associated with wildlife, such as birds?

In terms of industry learning and public education this turbine was an outstanding success. In the first 6 months, the turbine set a world record for output from a 225kW turbine. The turbine proved that in New Zealand's tough wind conditions pitch controlled turbines can survive and not have significant maintenance issues. The gearbox has been replaced once but other than that the turbine has worked well at a capacity factor of around 50% and availability of around 97+%.

The turbine is next to an urban area. There are houses (i.e. suburban dwellings) within 500m of the turbine. There have been no noise complaints since the turbine was installed.

The turbine is also a great success from a public relations perspective. Stunning views of Wellington City can be had from the turbine site and it is one of the most popular tourist destinations in Wellington. A manager of the wind turbine commented that in its first year or two it was time consuming to run – because so many school groups wanted to visit and have someone talk to them about the wind turbine! In response to public demand a comprehensive interpretation display was developed.

In 1999, 6 years after the turbine was installed, a wildlife sanctuary was established with a boundary only meters from the turbine. The sanctuary, a world first, is enclosed by a predator proof fence[21]. In the absence of predators a number of rare and critically endangered bird species have been introduced into the sanctuary.

[19] A government agency that ran nearly all generation in New Zealand.
[20] Peter Browne pers comm. Peter Browne led the turbine project for the Electricity Corporation of New Zealand.
[21] The fence is designed to ensure that cats, rats, mice, stoats, ferrets, weasels etc do not enter the Karori Wildlife Sanctuary.

Figure 6: The new Brooklyn Turbine under construction in 2016. Note the predator proof fence in the left of the left-hand photo and on the right of the right-hand photo. The Brooklyn Turbine is right next to the most significant bird sanctuary in New Zealand.

To date no rare and endangered birds, which have now breed to large numbers in the absence of predators, have been killed by the turbine. Given the large numbers of visitors to the turbine, if it had killed birds these deaths would be been widely reported in the media. The Brooklyn turbine's location on the boundary of what is now New Zealand's premier bird sanctuary, has demonstrated that wind turbines can have minimal impact on New Zealand's rare and endangered bird species, provided they are in the right place.

In 2013 Meridian Energy, the company that owns the turbine, sought the views of the people of Wellington on whether they wanted the turbine removed or replaced as the turbine was coming to the end of its useful life. In a poll run by the local Wellington newspaper some 84% of people voted to replace the turbine. Local residents established a Facebook page focused on promoting the replacement of the turbine. In April 2016 the 27m rotor diameter Vestas turbine was replaced with a 44m (rotor diameter) 900kW Enercon turbine.

Learning from a failure – Baring Head and Te Uku

In the early 1990s a 40 turbine wind farm was proposed for Baring Head at the entrance to Wellington Harbour[22]. The project was proposed by the local lines company.

Wellington Harbour is a stunning landscape and the heads are largely free of large scale human development. A small number of suburbs in Wellington have views across the harbour of the heads and these people became very concerned that the heads would, over time, be covered in wind turbines like some of the images of early windfarms in California.

The local community became organised and launched a campaign against the windfarm. The consenting authority turned down the application for the windfarm based on landscape impacts.

[22] Based on an interview with Mike Underhill, Chief Executive of the Energy Efficiency and Conservation Authority and former Chief Executive of the lines companies involved in the Baring Head and Te Uku Windfarm proposals.

The decline of this application highlighted that the wind industry needed to be very careful about how it designed windfarms and worked with local communities.

Those involved in the project considered that they made some significant mistakes in the design and consultation process. For example, the company sought planning permission for 40 turbines, even though it was not planning to build all 40 in the near future. It is plausible that a windfarm with five or six turbines would have been granted planning approval.

Figure 7: The site of the proposed 40 turbine windfarm at Baring Head, Wellington Harbour. Strong local opposition meant the windfarm did not receive planning permission.

In the mid-2000s the Waikato Electric Lines Company was investigating a windfarm in a coastal environment that was a similar stunning landscape. A local town was nearby the proposed windfarm and residents would be able to see the windfarm from the town. Many of the ingredients were similar to the Baring Head windfarm. The number of wind turbines was less, but not much so, at around 30. But the turbines were bigger with 100m rotors vs the 37m rotors proposed for Baring Head.

The developers of the Te Uku wind farm had been involved in the Baring Head proposal and had learned from that experience. They worked very closely with the local community and sought to allay their concerns. Further, the windfarm was designed to deliver benefits to the local community. Examples of the approach including:

- Taking residents who had concerns about wind turbines to other windfarms in New Zealand so they could experience what the wind farm would look like, what the noise issues might be etc.
- Strengthening the local distribution system so that power outages would be reduced. The local town suffered regular power outages and the strengthened distribution system would result in significantly improved reliability.
- Assuring the community that environmental impacts associated with construction could be managed. The wind farm is in a harbour catchment and sediment run off from the roading was a significant concern in relation to potential impact on the fishery in the harbour.

The windfarm proposal easily gained planning permission. During the construction phase the windfarm won an environmental award for its innovative and effective ways of minimising sediment runoff from road construction. The Te Uku windfarm comprises twenty eight 2.3MW turbines, 80m towers and 101m rotors. It was constructed in 2011.

Figure 8: The Te Uku windfarm – the largest rotors in New Zealand at 101m.

Haunui – the first multi-turbine windfarm; 1996

The Haunui windfarm – seven 500kW turbines – was built by one of New Zealand's smallest electric lines companies in 1996[23]. Wairarapa Electricity saw a future in small generation that was distributed around the district. The company knew that there were a number of windy areas in the region and monitoring confirmed that it was indeed very windy and precisely characterised the wind resource.

Wairarapa Electricity relied on the very small number of experts New Zealand had in wind generation. These experts advised Wairarapa Electricity and guided the company through the various stages, such as monitoring the wind.

At this time New Zealand only had one commercial wind turbine. Wairarapa Electricity pioneered the industry and through this windfarm introduced a number of companies to the wind industry. For example, transport and crane issues needed to be worked through, from logistics through to financial aspects such as insurance.

The windfarm is embedded in the local network and connects directly to a 33kV feeder. Some electrical engineering design work was needed but this was of limited extent and well within the existing capability of New Zealand expertise.

The windfarm has operated successfully. Wairarapa Electricity had planned to develop more small windfarms, but policy changes meant that lines companies could no longer develop generation. Further the government policy changes required lines companies to sell their generation assets along with their customer base in 1998.

In 2004 the company that bought Haunui added a further 8 turbines – an indication of this early project's success.

[23] Interview with Dave Paton, former development manager at Wairarapa Electricity.

Figure 9: Haunui windfarm. Haunui is a Maori word meaning “big wind”.

Tararua 1 – the first large wind farm (48 turbines); 1999

In the 1990s Central Power operated the electricity distribution system in the Manawatu Area[24]. The company saw wind as something that the company could develop both from a technical and financial perspective.

Central Power started investigating wind generation in 1992. There was a sense that the Manawatu area was windy, but no-one knew quite how windy. The company sought advice from local experts[25] and internationally.

Staff from Central Power visited California to better understand the wind industry. This visit greatly helped with understanding the technology and the issues associated with it, such as economics, monitoring the wind resource, the types of turbines available etc. During this visit connections were made with wind experts in the US who continued to act as advisors as the project developed.

Subsequently the Manawatu became the wind farming capital of New Zealand. The Vestas V90 turbines in the Manawatu, installed in 2007, have produced more kWh than any other wind turbine in the world, i.e. the V90s are the most productive land-based wind turbines in the world[26].

[24] Based on an interview with Derek Walker, former General Manager Development for Central Lines Company. Like all lines companies Central Power also had a retail base
[25] As discussed previously a small number of experts with overseas experience were pivotal to the development of the wind industry.
[26] Presentation to the NZ Wind Energy Conference, 2015 by Vestas.

Figure 10: V47 turbines at Tararua Windfarm – one of the most productive sites in the world.

Te Apiti – the first wind farm using large turbines; signalling the market-driven switch from hydro to wind

The Te Apiti wind farm – 90 MW, 1.65 MW turbines – marked a step change in the wind industry in New Zealand. The project, commissioned in 2004, was notable because it used large turbines (>1MW) and was much larger than any other wind farm developed in New Zealand. Further, it was the first wind farm that connected to the domestic grid and therefore had to operate in the electricity market.

Te Apiti signalled the point that wind started to take over from large hydro as a major form of electricity generation. For a number of decades hydro planners had been exploring a large hydro scheme in the South Island's Waitaki catchment. The Waitaki catchment has eight hydro stations of 1700MW installed capacity – nearly 20% of New Zealand's generation fleet. The project, titled "Project Aqua" would complete the development of hydro in the catchment, at least in the minds of hydro planners.

In the 1990s Meridian Energy[27], a government company that operated the power stations in the Waitaki catchment commenced a detailed planning exercise to scope and cost "Project Aqua". After many detailed studies Meridian Energy concluded that Project Aqua would not be economic. A key

[27] Meridian Energy was formed from the break up of the New Zealand Electricity Department.

reason was uncertainty around the geotechnical aspects. At the time Meridian Energy was also exploring wind and wind stacked up economically compared to hydro.

This demise of Project Aqua and the rise wind highlights the value of electricity markets in choosing the most cost-effective form of generation. Before the market was developed it was highly likely that Project Aqua would have been built by the government. Any cost over runs would be met by the tax payer. The discipline of the market forced Meridian Energy to focus on the least cost form of generation and that proved to be wind generation.

The market also assisted the development of wind generation in two other key ways. First Meridian Energy realised that wind energy could be built in small increments as demand required it, i.e. moving closer to “just in time” electricity development. This thinking was crucially different to large hydro.

The second aspect of wind that the market assisted was the location of wind farms. New Zealand has good wind resources in many parts of the economy. With a location-based pricing system the market sends signals for where in the economy there are generation shortages.

The ability to scale wind and locate it in different place around the economy in response to market signals was a radical transformation in the electricity sector. The traditional approach of building large power stations and significant transmission (i.e. the Project Aqua model) was replaced by more nimble thinking about small wind farms distributed across the countryside.

The key point is that wind can thrive in a modern electricity market when the true costs of alternatives are clearly visible.

Figure 11: Te Apiti Windfarm.

Gebbies Pass - The Windflow 500 turbine

In 2003 the first New Zealand designed and built wind turbine was commissioned. The 500kW "Windflow" 500 turbine was installed near Christchurch. The turbine is a 2 bladed design, with a "teetering action" to reduce stress on the drive train. It is certified as an IEC Class 1 turbine and is designed for New Zealand's tough wind conditions. A class II turbine is under development.

To date over 100 turbines have been built with the vast majority installed in New Zealand. A small number have been installed on the Scottish Isles.

Figure 12: The first Windflow 500 turbine at Gebbies Pass.

Three phases; small, large and medium-scale development

The wind industry in New Zealand started small. Initially a single commercial turbine was installed. A few years after this single turbine a seven turbine windfarm (Haunui) was developed, followed by Tararua 1 with forty-eight turbines. A decade after the first turbine was installed turbines more than 1 MW were installed in the 90MW Te Apiti development.

But once companies saw that wind was viable in New Zealand some very large projects were proposed. Wind farm projects as big as 800MW were on the drawing boards and some received consent, whereas some others did not for a range of reasons, such as landscape.

The industry has now settled on medium scale development – windfarms in the 8MW-70MW range. The last four windfarms built in New Zealand were; 64MW, 36MW, 69MW and 8MW. This small-medium size of wind farm suits the electricity system of New Zealand and is manageable from a range of perspectives, such as logistics, landscape impacts and public perception.

A plan for the industry

In the mid 2000s the public were becoming alarmed at the prospect of vast wind farms being developed over significant areas of New Zealand. Consenting started to become difficult and the public started asking what the overall plan was and where were the limits.

In response in 2012 the wind industry published its vision for 2030[28]. The vision document proposed that 20% of New Zealand's electricity could be met by wind in 2030. The document outlined where the windfarms would most likely be built to help provide certainty and the sense of a "plan" for the public.

Helping the industry learn and reducing costs

In New Zealand data on cost reductions are hard to obtain due to competition and confidentiality in the industry. Data for the cost of developing wind generation from other economies indicates that as the industry learns costs reduce. For example, in South Africa the cost of wind in auctions has reduced as from USD 143/MWh to USD 52/MWh[29] over four auctions rounds.

New Zealand had one scheme to encourage renewable energy development. The Programme to Reduce Emissions (PRE) offered carbon credits to projects that could demonstrate would reduce CO_2 emissions. These credits could then be sold in carbon markets generating revenue for the project. This scheme was developed under the Kyoto protocol[30]. The government invited tenders for projects that would reduce emissions.

A number of windfarms received PRE funding totalling 320+MW – nearly 50% of the total developed. The PRE scheme finished in the mid 2000s and was to be replaced by a carbon tax, which was not implemented.

In hindsight the PRE scheme was complicated. It did assist the wind industry develop projects and it not interfere directly with the wholesale electricity market. Little evidence exits to suggest that

[28] NZ Wind Energy Association 2012: Vision 2030.
[29] http://www.gsb.uct.ac.za/files/PPIAFReport.pdf
[30] https://www.beehive.govt.nz/speech/projects-reduce-emissions-key-climate-change-policy

PRE's focus was to bring costs down for projects, for example, through increasing industry learning. It appears at the time there was a perception that renewable energy projects were expensive and would always be expensive. PRE was designed to get projects over the line rather than assist the wind and other industries move more quickly down the cost reduction curve.

Many economies have trialled approaches to assisting the wind industry in its early stages to help the industry move down the cost reduction curve. Electricity auctions currently seem to be best practice. The International Renewable Energy Agency (IRENA) has published a summary of these and has looked at the pros and cons[31].

Recommendations from the first few projects and the evolution of the wind industry in New Zealand

According to people interviewed for this study and who were involved in the early stages of the industry the following aspects are important to developing a wind industry:

- Focus on collecting accurate wind data. Accurate wind data is very important, at hub height. For many economies that means at 80-100m. Broad studies and manipulation of existing datasets, such as from meteorological stations, are not sufficient for detailed wind farm design. A well designed wind farm that performs as expected requires good data.
- Bring in experienced people. In New Zealand a couple of experts with overseas experience and who were effective communicators played a key role in advising, promoting and designing windfarms. These experts helped build confidence in wind generation.
- Support companies that are prepared to innovate. In the case of New Zealand it was the smaller companies who were prepared to take a risk and could quickly move a project through the design and financial closure process. This process can be easier for smaller companies.
- Visit operating windfarms to gain an understanding of windfarms. An important part of developing the industry in New Zealand was visiting operating windfarms in other economies and learning about issues in developing and operating windfarms.
- Encourage cooperation between companies. A windfarm requires a diverse set of companies that need to learn to work together to deliver the project. For example, in the first few projects construction disciplines such as road construction and cable laying had to work together. In some cases it took time for the different disciplines to understand each other's needs.
- Understand community concerns and be prepared to modify or even withdraw a project. In some cases it may be better to withdraw a project than continue against intense public opposition. Where possible work to bring the community on board by listening to and allaying concerns the community may have.
- Build the "right size" of project. Wind farms can be built in a range of sizes. Large may not necessarily be more economical and the size of the windfarm needs to recognise a number of factors, such as grid stability, landscape aspects, community concerns etc.
- Develop a vision for the wind industry as the industry starts to grow. The community may ask questions like "will wind turbines be everywhere". A strategy can help the industry

[31] http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Auctions_Guide_2015_1_summary.pdf

communicate its vision and assist with dialogue between the wind industry and the community.

- Provide assistance to the wind industry in its early stages to help move the industry along the learning curve more quickly. New Zealand used an approach of granting carbon emissions units[32]. Auctions are used in many economies where the electricity market is not fully liberalised.

Many of these points are remain relevant today even for a relatively mature wind industry like New Zealand. For example; accurate wind monitoring is still critical, wind developers still need to stay abreast of latest developments and gain experience in the latest developments, companies being able to work together well remains a very important part of a successful project.

[32] It is not clear whether the New Zealand initiative was designed in relation to industry learning or whether it was viewed as a means for getting projects “over the line” financially.

Grid and market integration

In the early 2000s grid connected windfarms were being planned in New Zealand. Wind posed a number of challenges to the electricity market and dispatch system, which is based on the premise of firm generation offers and penalties for not complying with the offers. Wind is a variable form of generation and it became apparent that wind could not comply with the existing electricity market and dispatch rules, but the government was keen to promote wind generation as a renewable and modern technology. So a way was needed to enable wind generation to participate in the electricity market.

New Zealand's electricity dispatch system has two key principles[33]:

- System security, i.e. ensuring that there is enough electricity being generated to meet demand.
- Economic dispatch. Making sure that the most economically efficient set of generators run at any time.

To provide certainty to all participants and the System Operator, the market has a final gate closure of two hours[34]. What this means is that 2 hours out from real time generation offers were confirmed and there are significant penalties for non-performance. The difficulty with wind generation in New Zealand is that output from windfarms can vary significantly within two hours[35] (discussed later).

In 2004 the 90MW Te Apiti windfarm was connected to the grid. Up until this time windfarms were embedded in local distribution networks and not subject to domestic dispatch rules. The development of this windfarm triggered the following programme covering:

- Temporary changes to the electricity market rules to enable wind to participate in the electricity market.
- Tactical studies to collect data on the issues that were being experienced with around 170MW of installed wind generation, 160 MW of which was in one location from a grid management perspective.
- A long term study called the Wind Grid Integration Project (WGIP) jointly run by the System Operator and the electricity regulator.

The focus of the studies was related to the two key principles of the electricity dispatch system:

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[33] Doug Goodwin pers comm. Doug is a former senior manager at the System Operator.

[34] Gate closure will be reduced in 1 hour in 2017. Some wind generators are promoting having a half hour gate closure.

[35] A two-hour gate closure, as compared to 1 hour or 3, was chosen because it was the shortest time that a "solve" could be computed using standard existing computers in the mid-1990s. At the time it was acknowledged that having gate closure as close to real time as possible was best practice, but computing power at the time was a limited factor.

- System security: Understanding the nuances of wind generation to develop ways to ensure that wind did not increase system security risk and ideally reduced system security risk.
- Economic dispatch: The studies aimed to develop rules for the electricity market to enable wind to operate in the market. Under the existing rules wind would be deemed non compliant and would either not be allowed to operate or would face the prospect of significant fines.

This chapter outlines the various studies and initiatives related to grid integration; temporary rules, tactical studies and the WGIP.

Wind and the electricity market – new market rules to accommodate wind generation

In order to be paid for the electricity they produced wind farm owners needed to participate in the electricity market. In order to participate wind farms needed to comply with the electricity market rules. Therein lay a problem: The electricity market rules were not designed to cover variable generation. The paradigm under which the market rules were developed was certainty of generation offers and penalties for not meeting the generation offer.

A working group comprising the wind industry, System Operator and Transpower[36] was established in the early 2000s. It was tasked with developing temporary rules that allowed wind to participate in the market.

The closest form of generation to wind was "must run" generation. This is generation that is offered into the market at $0.01/MWh which means that it is always at the bottom of the generation stack and is therefore always dispatched. This type of generation receives the settlement price – the price of generation offered to meet the demand. The working group decided that wind should also offer in at $0.01/MWh and would therefore be dispatched alongside must run generation.

The wind working group had to report to three different formal groups in the electricity system:

- The dispatch working group.
- The market rules working group.
- The pricing-liabilities working group.

In practice participants in these groups were a tight knit community and often sat on more than one group. The various groups worked well to focus on the aspects of wind generation.

Wind generators are required to forecast their potential generation at gate closure, i.e. 2 hours out from real time. In practice it was found that persistence forecasting is most reliable at this time frame. Persistence means that the amount of wind in the last time period will be similar to the amount of wind in the next time period, i.e. the windfarm would continue to run at its current output.

Since the early 2000s various attempts have been made to improve forecasting. To date none have proven to be more reliable than persistence forecasting over the 2 hour period, i.e. current wind generation provides a good estimate of wind generation in the immediate future. New Zealand is

[36] Transpower is the domestic grid operator.

possibly unusual compared to other economies in accuracy of forecasting. New Zealand's weather is very dynamic and there are no offshore weather stations with which to verify computer-generated forecasts[37]. In practice this means that the timing of weather events cannot be forecast to the level of accuracy needed for a 2 hour gate closure. Hence the agreement that persistence forecasting is the best approach.

The market arrangements for wind generation have largely proved satisfactory and remain in place in 2016, although the electricity regulator has indicated that it will review these. In addition some in the wind industry wish to see a reduced gate closure and the ability for wind to bid into the market rather than receiving the settlement price.

The tactical wind project

In 2004 150MW of wind had been built in the same area from a grid management perspective. Generation data were collected from these windfarms using meters installed on the windfarms. The metering results caused the SO some concerns:

- Ramp rates for 150MW of windfarms exceeded the frequency keeping generation ramping in the North Island, which was 10MW/minute[38].
- Variations in output from the 150MW of windfarms was greater than 50MW/5 minutes, which is the limit for frequency keeping plant under the market rules.

The study identified roughly 1 event per month that exceeded the market rules for changing output - 10MW/minute and 50MW/5 minutes. Some of these events pushed frequency in the North Island outside the normal frequency band of 49.8Hz to 50.2. In addition the tactical study also identified that transmission lines could be overloaded before the System Operator could re-dispatch generation. There was no requirement for windfarms to control their ramp rates which is generally possible when windfarm output increases. It is more difficult to achieve when the output decreases in a falling wind.

The tactical wind integration study resulted in:

- Recognition that there were some potentially significant issues associated with wind generation which needed to be investigated, clarified and impacts quantified.
- A solid justification for a much larger study – the Wind Grid Integration Project (WGIP).
- Greater clarity as to the scope for WGIP and the kinds of issues that needed investigation.
- Recognition that while wind generation introduces new challenges, these challenges are manageable, i.e. the study gave the SO a level of comfort in relation to wind farms.

Wind and system security – the wind grid integration project

In the mid 2000s it seemed plausible that some 2GW of wind could be constructed, which is significant in a 10GW system[39]. The electricity industry in New Zealand had little understanding of

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[37] Presentation by Andy Zeigler NZ MetService to an NZWEA "Wind and Forecasting workshop" 2014.
[38] SO (2005) Manawatu wind generation Observed impacts on the scheduling and dispatch processes
[39] Some results have been published in international journals:

- Integration of large scale wind generation in the New Zealand power system and electricity market, Ancell, G.B. ; Transpower New Zealand Ltd., Wellington ; Clarke, J.W. . http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4596442 exactly how wind generation would be integrated into the grid. The kinds of questions that were be asked across the electricity industry were:

- Would there be long periods when there would be no wind generation in New Zealand?
- Would the wind blow everywhere in NZ at once?
- Could all the wind farms start up and once and create huge ramps?
- What was the correlation between wind generation and hydro inflows?

There were two main drivers for the study:

- The variable nature of wind. The System Operator was comfortable with dispatchable generation, but considered that wind was not dispatchable and could arrive at any time in relatively unknown quantities.
- The nature of the generation equipment in a wind turbine. Most modern wind turbines use inverter technology and have an AC-DC-AC configuration. This arrangement has a number of implications for the grid system, both positive and negative. A positive is that a wind turbine can provide reactive power and can act as a static compensator. A negative is that a wind turbine can reduce inertia on the system.

The objectives of the WGIP were to:

- identify and quantify the technical and market impacts of increased wind generation on the New Zealand power system over the next ten years;
- recommend any amendments to the Electricity Governance Rules (EGRs) and other relevant processes required, to ensure future power system security and market outcomes are consistent with the Government Policy Statement on Electricity Governance (GPS) and the Electricity Commission's Principal Objectives and Outcomes;
- recommend an implementation plan for proposed changes (to the extent that this is required).

The issues that the WGIP focused on were[40]:

- Impacts arising from large sudden changes in wind generation output.
- Impacts arising from the variability and unpredictability of wind generation output.
- Asset capability of wind generation turbines and related equipment, e.g. can wind generators help support the grid, for example, assist with frequency and voltage stability?

- Where the wind blows, Power and Energy Magazine, IEEE (Volume:7 , Issue: 6), http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5233739
- Effect of wind generation on small-signal stability — A New Zealand Example, Vowles, D.J. ; Sch. of Electr. & Electron. Eng., Univ. of Adelaide, Adelaide, SA ; Samarasinghe, C. ; Gibbard, M.J. ; Ancell, G. , http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=4596444
- Effects of large scale wind generation on transient stability of the New Zealand power system, Samarasinghe, C. ; Transpower New Zealand Ltd., Wellington ; Ancell, G., http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=4596110

[40] https://www.systemoperator.co.nz/sites/default/files/bulk-upload/documents/wind-gen-project-so-rationale.pdf SO (2005); Tactical Wind Generation Project - Rationale for proposed rule changes to accommodate the connection of further wind generation until the Wind Generation Investigation Project is complete.

- Rule drafting – issues needing specific consideration and specific recognition of intermittent generation in the rules.

WGIP which used the following approach:

- Scenarios for wind development, i.e. how much wind generation might be developed in what locations around New Zealand.
- Implications of the scenarios in terms of operating the electricity system.
- Options for ensuring the electricity system could operate effectively.
- Preferred options.

An important context for the WGIP is that New Zealand has an electrically weak grid system. The frequency variation in the New Zealand system is much larger than overseas and that advanced protection systems are needed to ensure against a cascading failure that could have catastrophic consequences leading to a blackout. System security is paramount in the New Zealand, as it is in all electricity systems. But an electrically weak system has a number of nuances that are significantly different to strongly meshed systems.

The System Operator worked with the electricity regulator to identify the issues and work through them. An independent chairman for the process was appointed. Representatives from key stakeholders, including the New Zealand Wind Energy Association (NZWEA) were appointed as a group to overview the process. The System Operator and Electricity Commission[41] jointly funded the work. A brainstorming approach was used to identify the key issues to focus on. NZWEA played the important role of obtaining accurate information from members on the technical aspects of wind turbines including their generation characteristics[42].

The issues were grouped into three main categories with a number of sub-projects in each of these, as set out in the table below.

WGIP used two main sources of data:

- Actual operating data from New Zealand's windfarms, such as generation output on a 10 minute basis. At the time of the study New Zealand had around 200MW of wind farms with the turbines in two main locations some 1000km apart.
- Synthetic data for wind farm output derived from wind monitoring data.

In addition, information was sought from turbine manufacturers on the technical aspects of wind turbines. NZWEA played a key role in working with the manufacturers.

An important aspect of the study was communication with the industry. All reports were made publicly available. The results of the studies were outlined in NZWEA's newsletters to its members. The issue of wind integration was discussed at the annual NZ wind energy conferences.

[41] The Electricity Commission (now Electricity Authority) was the electricity system regulator.
[42] Graham Ancell pers comm. Graham led the Wind Grid Integration Project when working for the System Operator.

The WGIP agreed on four scenarios for wind farm development in New Zealand. These covered both the total amount of wind generation installed and also potential locations of windfarms. Location is important because of the differences in wind regimes and the level of correlation between windfarms, which was one of the issues the WGIP focused on.

The WGIP took into account specific characteristics of the New Zealand electricity system. For example, a particularly issue confronting the wind industry in New Zealand is that wind farms were being developed near to the terminal of the HVDC link. At times the link can carry 1000MW and the North Island load could be less than 3GW. When the HVDC "trips" voltage and frequency can vary significantly in the lower North Island – exactly the area where a substantial windfarm was being planned. The System Operator wanted wind generators to stay connected during grid disturbances and contribute to grid stability rather than contributing to grid unreliability.

Areas of concern	**Specific studies to address the concerns**
Pre-dispatch processes	• Effect of unpredictability of wind generation output on pre-dispatch processes.
Dispatch process	• Effect of variability on wind generation output on dispatch processes. • Effect of variability of wind generation output on asset loading.
Power system security	• Impact of wind generation on steady state voltage. • Effect of wind generation capability on management of frequency excursions. • Effect of wind generation on voltage stability. • Effect of wind generation capability on power system transient stability. • Effect of wind generation capability on oscillatory stability. • Effect of wind generation on dynamic voltage stability.

Table: Areas of concern covered in the Wind Integration Project.

An example of the process the WGIP to explore issues is set out in the Figure 13 below. In this example, variability was the focus of the investigation:

- Actual data from a wind farm was used to assess variability.
- Variability across all windfarms was explored using the four scenarios for wind farm development.

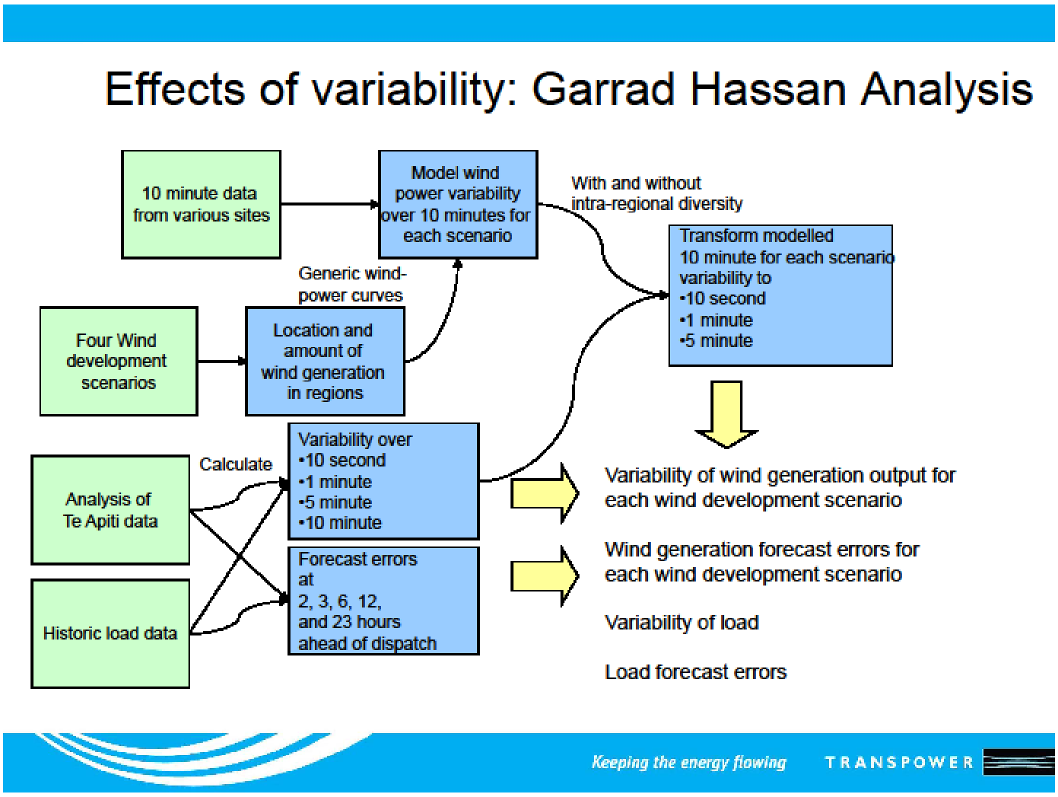

Figure 13: Model of the effects of variability in generation on the power system and the modelling needed to understand the impact of that variability for safe electricity system operation[43].

Results from WGIP

WGIP greatly assisted in developing a good knowledge base about how wind could operate in the New Zealand electricity system. The main outcome from WGIP was a much greater confidence as to what the issues were with wind integration and how to address them. WGIP also built understanding and confidence in the performance of wind turbines on the grid.

In particular staff in the System Operator came to understand what services wind turbines could offer and how they could offer these. The knowledge gained about the behaviour of wind turbines led to some very innovative power system designs in New Zealand, particularly at the distribution level. These are outlined in a case study below. At this time wind turbine manufacturers were continually enhancing the electrical capability of wind turbines to meet grid codes. Some of the enhancements addressed issues raised in the WGIP.

In addition to increased understanding and confidence the wind grid integration project resulted in:

- Confirmation of the interim rules for wind generation in the electricity market.
- Rules for wind turbines in terms of fault ride through, frequency support requirements etc.

Using information and experience developed through WGIP in 2007 the SO published an updated document covering the connection and dispatch of new generation. The new document has a chapter specifically on wind generation[44]. Issues the document focuses on includes:

[43] Presentation to a meeting of the Wind Grid Integration Project Team Meeting in 2005.

- Voltage control relating to connection to weaker parts of the grid.
- Connection issues, particularly where there are line limits and line protection systems, such as run back schemes, might be needed.
- Fault ride through requirements – down to 47Hz in the South Island and 47.5Hz in the North Island.
- Wind farm modelling requirements on the basis that each wind farm is different as is each brand of wind turbine.
- Power quality studies to ensure that wind farms do not negatively impact on power in the area.
- Commissioning studies. These are developed in relation to the specific characteristics of the wind farm.

The key point is that WGIP assisted the System Operator to identify the kinds of issues to explore. A clear theme has emerged of impacts on an electrically weak system – the WGIP identified that wind farms will tend to be built in the more remote and therefore electrically weaker parts of the power system, i.e. the weakest parts of an electrically weak grid system. New Zealand has developed considerable expertise in designing windfarms to functions effectively in electrically weak situations.

Case study: Inertia

A primary concern associated with an increasing proportion of wind generation is a loss of "inertia". In New Zealand's electrically weak power system the System Operator relies on the inertia of generators to ride through voltage and frequency variations. With the AC-DC-AC configuration and sophisticated electronics wind turbines would disconnect from the grid during a grid event. This disconnection aspect concerned the System Operator because it could lead to a cascading failure and blackout. Part of the issue was that wind turbines were developed for strongly meshed grid systems where voltage and frequency vary by a comparatively small amount. In New Zealand generators are expected to stay connected over a frequency of 47-52Hz, well outside the range wind turbines were set to operate in other grid systems. Turbine manufacturers and owners responded by exploring "virtual inertia" – using the software in the wind turbine to create what would look like "inertia" to the grid[45].

[44] https://www.transpower.co.nz/sites/default/files/publications/resources/connecting-dispatching-new-generation-nz.pdf

[45] Pellieter M; 2012; Inertia in the New Zealand Power System and its effect on the System; Presentation to the NZ Wind Energy Association Conference, Transpower NZ.

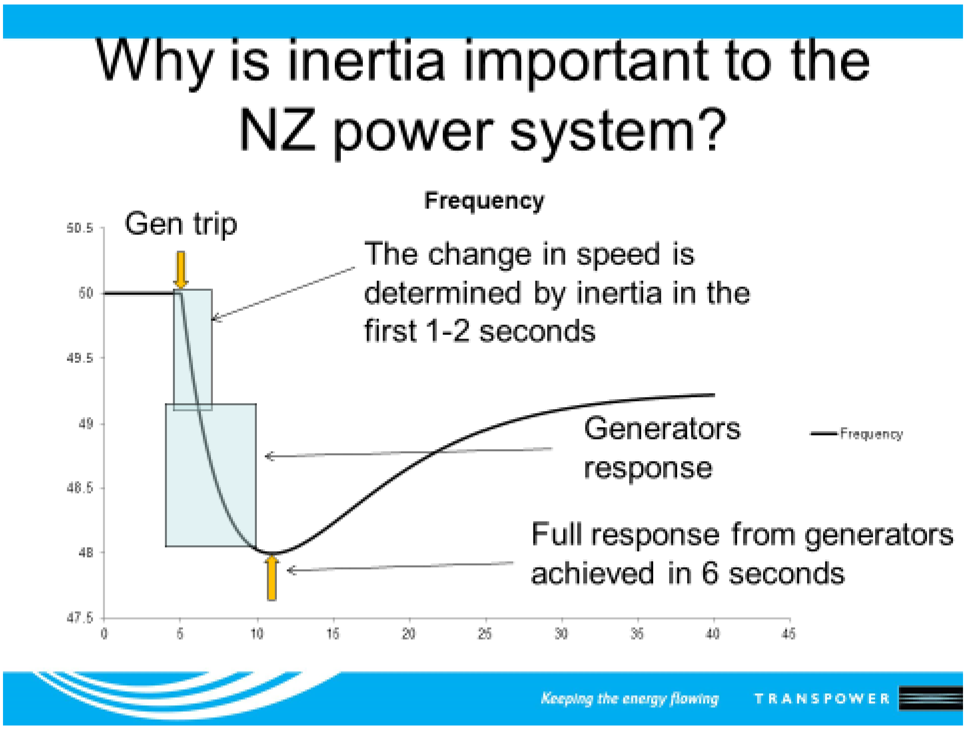

Figure 14: Inertia is important for ensuring the power system stays stable during a grid event. Inertia is critical for providing grid support in the first few seconds after a grid event.

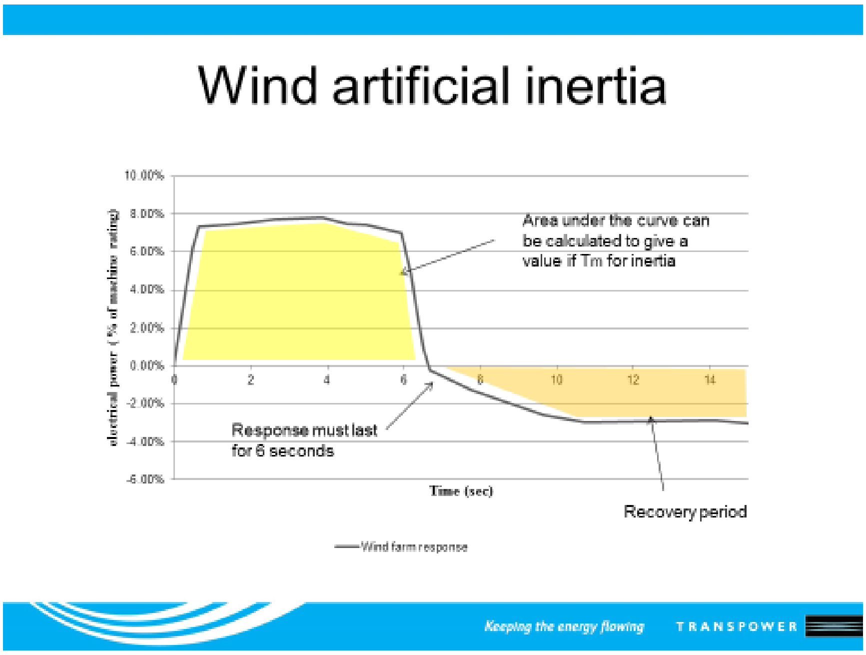

Figure 15: The amount of inertia a wind turbine needs to supply to play a role in supporting the New Zealand grid system during a grid event.

Case study: How correlated are the outputs from windfarms?

The WGIP explored just how variable wind would be. The System Operator gained some important "comfort" around wind. For example, through the WGIP it became clear that high rates of wind ramping were statistically unlikely to occur simultaneously across much of New Zealand. Understanding of how weather systems moved across New Zealand confirmed the statistics. As wind became established in more locations across New Zealand the kinds of issues seen at the grid level from the first few wind farms would not be amplified and if anything reduced.

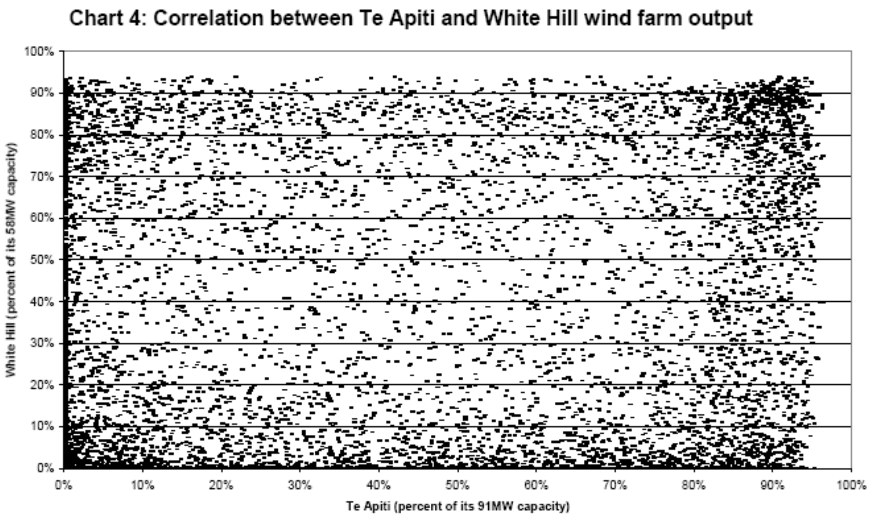

Figure 16: Correlation between two windfarms 1000km apart in New Zealand. Te Apiti in the lower North Island and White Hill in the lower South Island. Data is for half hour intervals.

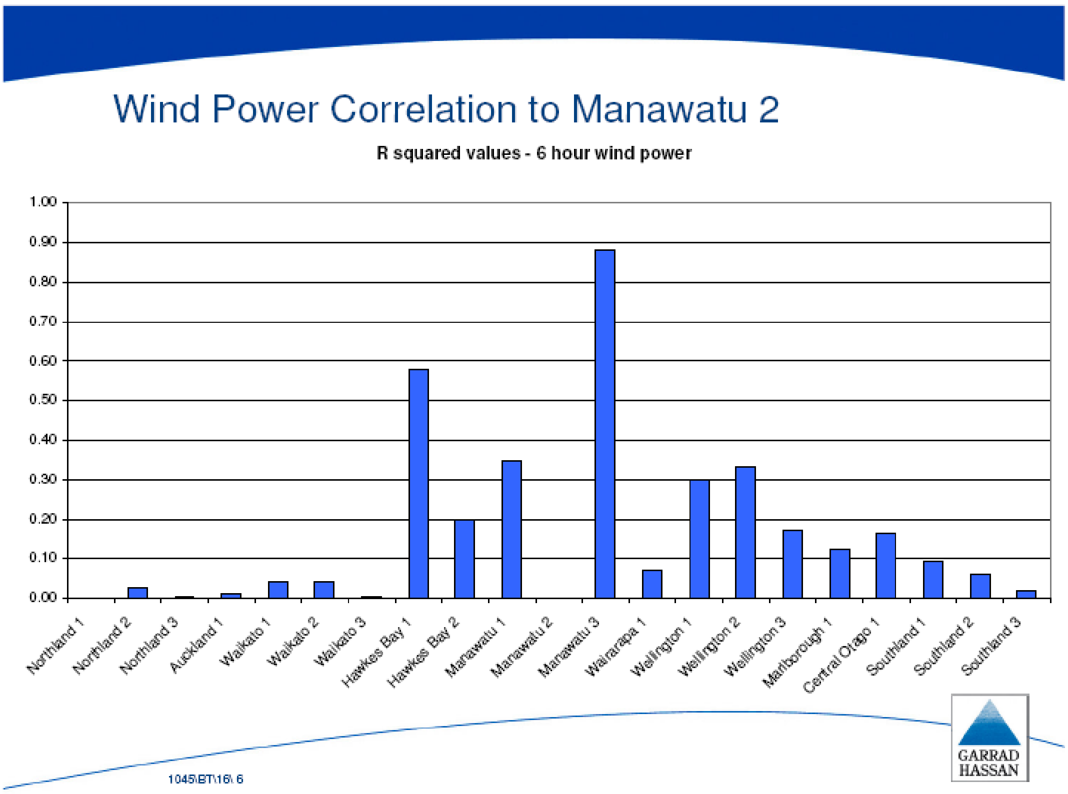

Figure 17: Correlation between a theoretical windfarm in the Manawatu (lower North Island in New Zealand) and other windfarm sites around New Zealand. The correlations were developed using wind data rather than actual output from windfarms.

The predicted results of the study have been shown to be largely correct as more windfarms were developed. For example, the two graphs below show the results of more windfarms added to the grid. The first graph of the West Wind windfarm shows a significant variation in output (10 minute data) – the output from the windfarm can vary from maximum to zero to close to maximum over a 24 hour period. But when a number of other windfarms are added in (second graph) the variations in one wind farm tend to be balanced out be the variation in the others.

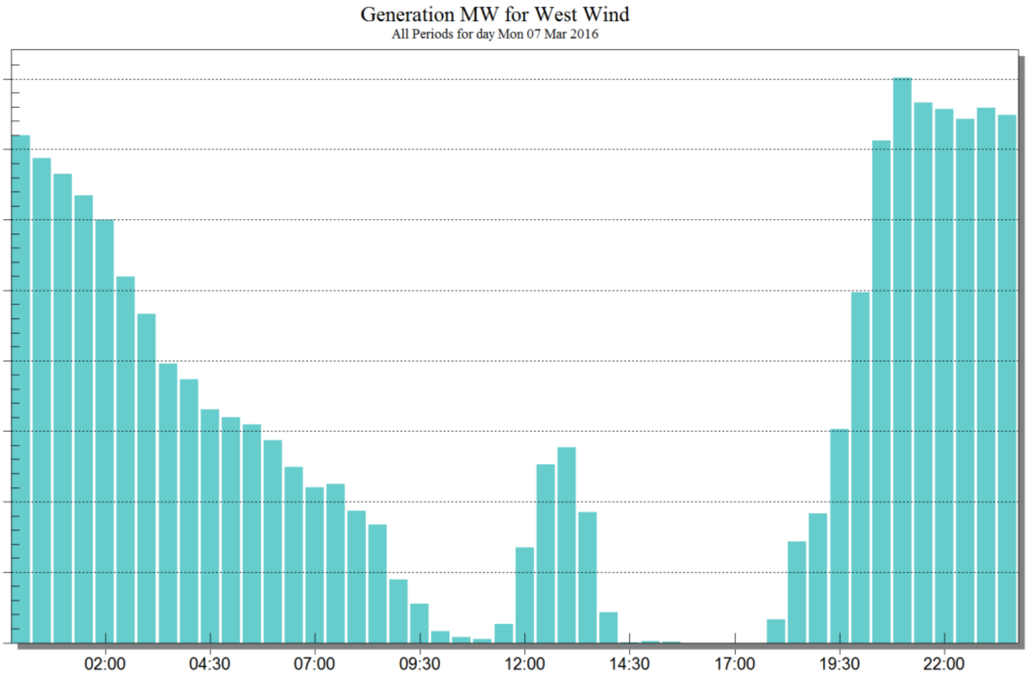

Figure 18: Electricity output from West Wind (142 MW), on a day with extreme variability.

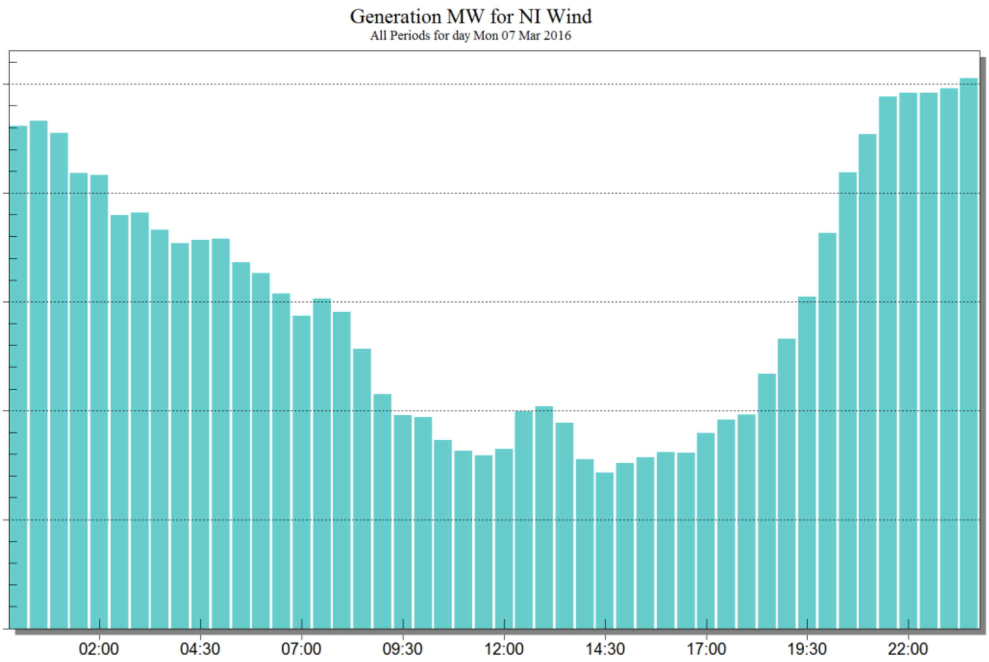

Figure 19: Electricity Generation from 3 North Island wind farms[46] showing the smoothing effect of multiple windfarms compared to a single windfarm (Figure 18). These three windfarms are spread across 350km.

[46] Presentation to the NZ Wind Energy Conference, 2016, Mike Roan, Meridian Energy.

The WGIP also enabled some of the issues associated with wind, such as ramp rates were able to be understood from a whole of electricity system perspective. In practice ramp rates for wind are little different to ramp rates in electricity demand, something the SO is very used to dealing with. When framed in this way wind was not seen as “scary” and while creating challenges wind could be integrated into the electricity system.

Wind spread geographically can lead to wind becoming, in effect, baseload generation, with wind generation. A single windfarm does have variability (Figure 18). Many windfarms spread across New Zealand results in a much steadier amount of electricity generated (Figure 19). Hydro can “fill” the gaps in wind generation and help ensure that electricity demand is met (Figure 20). In effect geographically distributed wind can be considered “baseload” generation and a good annual energy source, while controllable generation can provide power as and when required.

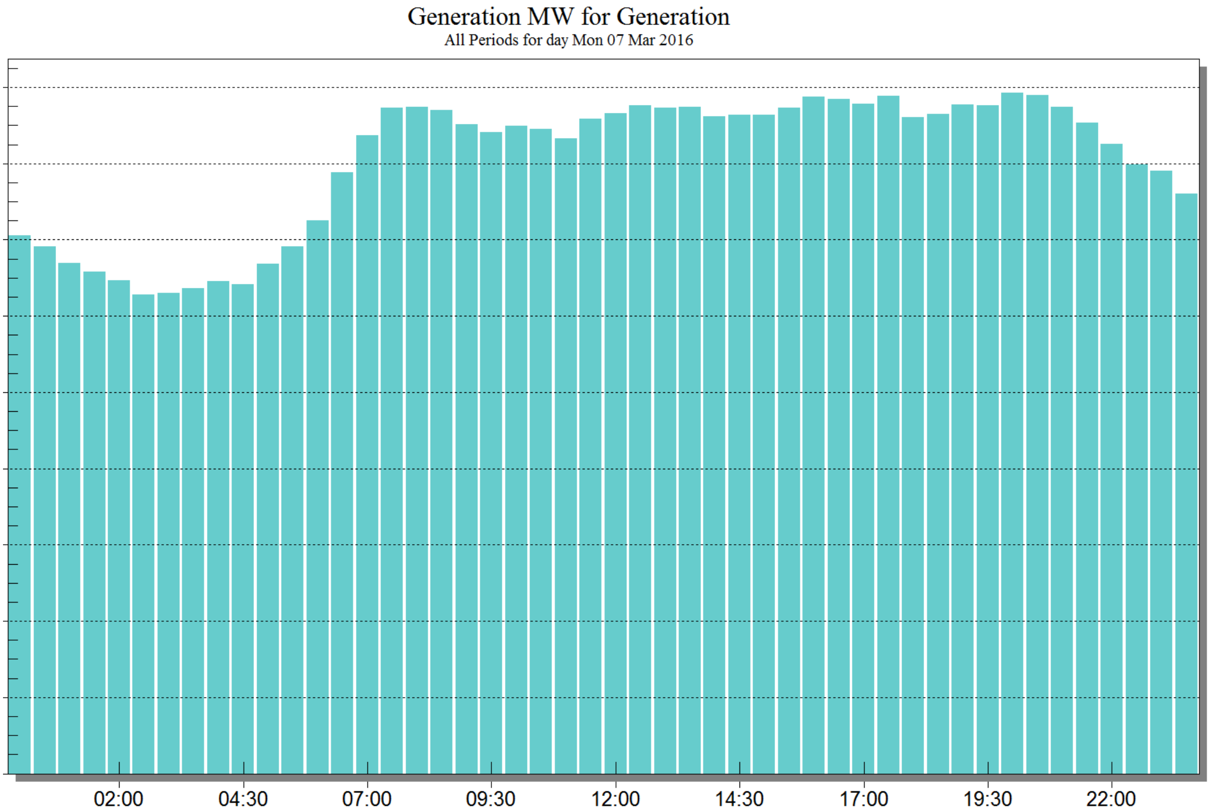

Figure 20: Wind combined with hydro generation provides an excellent electricity supply in terms of meeting the demand profile.

WGIP – outcomes and next steps

An interesting aspect following the study is that no significant changes have been made to the electricity system rules, despite wind growing from 170MW to 700MW and contributing up to 40% of generation in the North Island grid system at times. Some proposals are being worked on, such as requiring wind turbines to have fault ride through characteristics that vary in different parts of the economy, but this has not been seen as an urgent priority. The lack of changes confirms that one of the most important aspects of the study was building understanding and confidence.

Understanding the opportunities associated with wind generation is particularly important. Windfarms can be designed in such a way that they can improve grid characteristics, such as voltage stability (see case study on Te Uku windfarm next chapter). Discussions on innovative designs were made easier via the relationships and knowledge built up through the WGIP.

In a nutshell, the industry learnings and relationships, which are difficult to quantity, are probably the most important aspects of the WGIP.

Fault ride through

As wind generation in New Zealand has grown the System Operator has become increasingly concerned about the ability of wind generators to ride through faults in the electricity system. Wind turbines have generally been designed for large strongly meshed grid systems. The fault ride through characteristics of wind turbines generally do not meet the expectations of the New Zealand regulator (Electricity Authority) and the System Operator.

The Electricity Authority and the System Operator are working on new rules for fault ride through[47]. The proposed rules vary regionally because the requirements to stay grid connected vary around the economy. For example, close to the HVDC connection variations in voltages and frequency are larger than elsewhere and it is important that generators stay connected during an HVDC-caused disturbance, otherwise a cascading failure may result. The proposed rules for fault-ride through are still being developed.

Wind bidding into the electricity market.

With a two-hour gate closure wind cannot bid into the electricity market with certainty. The difference between forecast generation and actual generation is too high. In 2015 the Electricity Authority agreed that gate closure would be reduced to 1 hour – the wind industry would prefer half an hour (Figure 21). In 2016 the EA plans to explore how wind can offer into the electricity market[48]. The "interim" rules that have been in place since the early 2000s[49]. The work is not complete but one option being considered is treating wind like any other form of generation, i.e. wind being able to offer at a price the generator decides with the possibility of wind not being dispatched if the price is too high.

[47] https://www.ea.govt.nz/development/work-programme/wholesale/fault-ride-through-project/

[48] https://www.ea.govt.nz/development/work-programme/wholesale/bid-and-offer-provisions-of-the-code/consultations/

[49] Wind offering at \$0.01/MWh and being paid the clearance price.

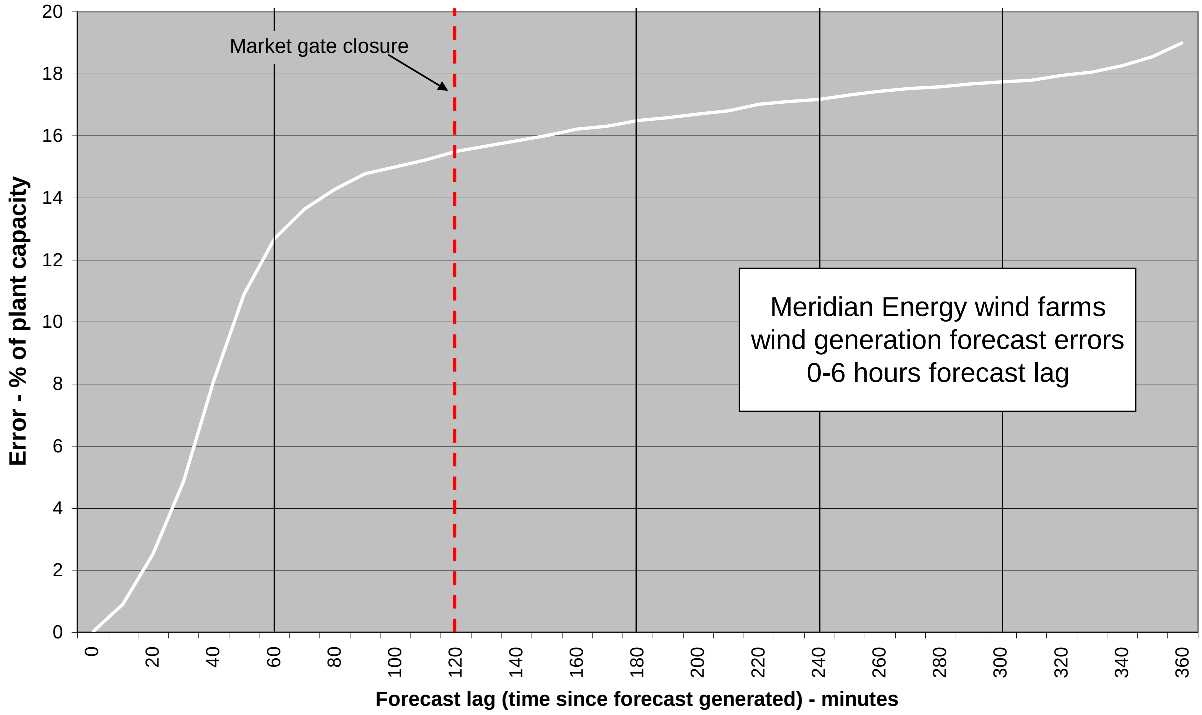

Figure 21: Accuracy of wind farm generation prediction versus the time of the forecast. A half hour market gate closure would result in comparatively high accuracy predictions for windfarm output.

Recommendations – Market and grid integration

To help build understanding of the characteristics of wind generation establish a wind-grid integration project that:

- Develops a range of scenarios for wind generation.
- Explores issues associated with wind generation, such as correlation between windfarms in different parts of the grid, ramping etc.
- Identifies how windfarms can be designed and operated to contribute to grid and distribution network stability.
- Involves all stakeholders in a collaborative and open process so that all the stakeholders learn together and have the same understanding.
- Proposes amendments to rules governing electricity system operation.

Performance of windfarms

How have windfarms in NZ performed? Data from Vestas shows that in early 2015 V90s at the Tararua 3 windfarm had produced more kWh than any other wind turbine in the world. For the Vestas V90 global fleet, New Zealand wind turbines rank; 1st, 2nd, 4th, 6th and 9th in terms of the amount of electricity produced. Clearly windfarms in New Zealand are among the most productive in the world[50].

Wind turbines have performed well in New Zealand's turbulent and high wind speed sites:

- The Brooklyn Wind Turbine, a 225kW turbine, was replaced in April 2016 after some 23 years of operation.
- The Hau Nui Windfarm celebrates its 20th birthday in 2016. This site is regarded as very turbulent by international standards.
- Vestas reports that turbines at New Zealand windfarms achieve a lost production factor (based on MWh) of less than 1.8% for modern turbines (V80, V90).

In addition windfarms provide grid services and, in some instances, have helped keep the lights on.

Case study: Wind keeps the lights on in New Zealand's capital city

On 18 February 2010 in the middle of the day the HVDC link tripped. This trip had the potential to cut power to Wellington, New Zealand's capital city, during a busy week day. At the time of the trip the West Wind windfarm (142MW) had a high level of production (Figure 22) as did windfarms some 200km north of Wellington. Together these windfarms supplied sufficient power to "keep the lights on" in New Zealand's capital city.

This was not the first time that wind generation has helped "keep the lights on". On 22nd September 2009 a fault reduced power flows through the HVDC link. The West Wind Windfarm was producing some 100MW which helped keep the lights on in Wellington. Electricity demand in Wellington was 250-390MW and the reduced HVDC could provide 130MW. Without West Wind Wellington would have faced a shortage of electricity resulting in a potential black out.

While wind generation can't always be guaranteed to be available when needed, wind farms generate for around 95% of the time. So the chances that a windfarm will be generating some power to help with an outage is very high.

[50] Presentation by Vestas to the New Zealand Wind Energy Conference 2015.

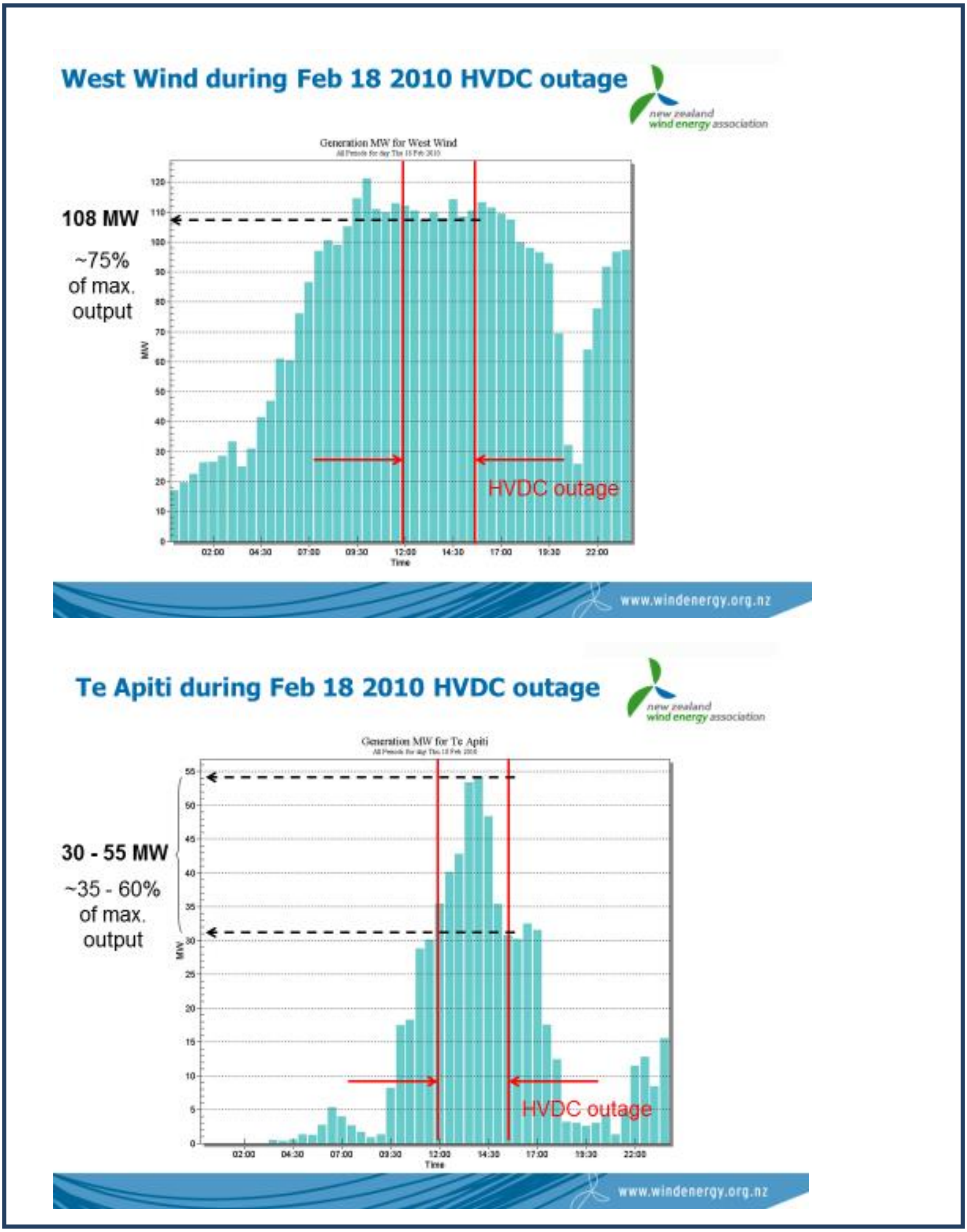

Figure 22: The output of West Wind and Te Apiti Windfarms (10 km and 200km from Wellington) when the HVDC link tripped.[51] Together West Wind and Te Apiti helped keep the lights on in Wellington, New Zealand's capital city.

[51] Presentation to the NZ Wind Energy Conference, 2011, Fraser Clark CEO, NZ Wind Energy Association.

Case study: Wind farms strengthening the grid at the distribution level

A number of wind farms in New Zealand have been embedded in local distribution grids, usually at the 33kV level. Embedded generation has its own challenges but installing wind farms can provide a range of opportunities.

The Te Uku windfarm (64MW, commissioned in 2011) is embedded in a local distribution grid. The windfarm can supply over 100% of the distribution grid's electricity needs and at times exports through the grid exit point to the Domestic Grid (220kV).

Te Uku is connected to two distribution substations, one close by, the other some 25km away, by a 33kV line that was doubled in capacity to handle the load. This doubling had the benefit of added system security for the local network which served a town of some 3000 people. Strengthening the local network was promoted to the community as a benefit of the windfarm – the windfarm is clearly visible from the town.

A network protection system, including a runback system, with reliable communications was installed to ensure that in the event of a failure the windfarm would not damage the system. For example, if one of the 33kV lines fails the windfarm reduces production automatically.

The windfarm was designed to also help address a domestic grid issue. The 220kV line that provided the grid exit point for the local network suffered voltage stability issues under certain circumstances. The inverters in the windfarm provide voltage support via the 25km 33kV line through the grid exit point and to the domestic 220kV line. The windfarm continues to provide this service even when there is no wind and the turbines are not generating.

In a second example, a windfarm (58MW) was designed to substantially improve voltage stability in the local distribution network. The result was that voltages in the nearby town (population 2000), some 60 km away, stabilized and remained within normal ranges, which had not been the case for decades.

Recommendations – strengthening the grid and distribution systems

Design windfarms to take advantage of the power electronics in wind turbines and provide services to both the grid and distribution networks. The power electronics in wind turbines can be programmed to help provide grid services such as inertia but these features need to be considered at the early design stages of a wind project.

Operations and maintenance – creating local jobs

As the number of wind turbines in New Zealand grew so too did operations and maintenance activities. NZWEA commissioned a survey in 2012 to determine the number of people involved in the wind industry[52]. The data were collected via interviews of companies that were involved in the wind industry.

It was estimated that there are 0.17 jobs created for each MW of installed capacity. For 700 MW that equates to approximately 100 jobs. Many of these jobs are in remote locations of the economy where there are few well-paying jobs for technically trained people. Windfarms therefore create employment opportunities in rural areas.

New Zealand has found that wind technicians sit "between" mechanics and electricians in terms of their skill sets. Wind technicians' work is so specialised their training does meet traditional training course requirements for either mechanics or electricians. Although highly skilled it is possible that wind technicians may not be able to claim a recognised qualification.

In recent years there have been moves to provide more formal training for wind technicians. The training aims to combine electrical and mechanical skills into a wind or more broadly energy-specific training qualification.

An important part of highly skilled staff is health and safety training. New Zealand companies are part of the Global Wind Organisation training programme. New Zealand has a GWO-accredited training provider who provides training and refresher courses.

Case study: Ashurst Engineering

A small, specialist engineering firm near the Te Apiti and Tararua windfarms became involved with the wind industry via a $25 job for the Te Apiti windfarm[53]. According to the owner of the company that one job led to further work and over the years the business has grown and grown. Windfarm work now represents at least 20% of the company's turnover, supporting up to eight families.

Ashhurst Engineering's work in and around wind farms has taken them all over the world. They have built specialist equipment for use at wind farms and create innovative solutions to new challenges. The company finds that it is important to be on-site because to see what the real problems are and generate practical ideas to fix them. Some of Ashhurst Engineering's solutions have been applied overseas, such as the US, providing opportunities for staff to travel to implement the engineering solutions.

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[52] BERL (2012); Economic Benefits of windfarms in New Zealand. Report prepared for the NZ Wind Energy Association.

[53] http://www.windenergy.org.nz/store/doc/Wind_Energy_Case_Study_You_Never_Know_Where_Wind_Will_Take_You.pdf

Staff are highly motivated to work on wind turbines – they enjoy the working with state of the art technology. The company ensures its staff are trained to operate in the turbine, for example, staff receive health and safety training and ensure that their training is kept up to date.

The engineering company is now one of the largest employers in Ashurst.

Recommendations: Operations and maintenance

- Encourage and support local businesses to provide operations and maintenance solutions.
- Develop a formal training programme involving local trainers.
- Establish an industry-wide health and safety programme and link this with the Global Wind Organisation.

Natural resource management and consenting (environmental planning)

The main natural resource management issues for wind farm development issues in New Zealand are:

- Noise: New Zealand has developed a robust science-based framework for managing noise issues.
- Birds: Some effective approaches have been developed for designing windfarms to ensure they have minimum impacts on birds.
- Landscape/visual: The potential impacts of windfarms on landscape values has been a fraught area in New Zealand and continues to be so.

The New Zealand experience is that a small section of society will always be strongly opposed to windfarms.

Noise issues

Noise from wind farms has been raised at a number of wind farm proposals in New Zealand. Noise issues were reported from Hau Nui, New Zealand's first multi-turbine windfarm. Corrective measures were put in place and the tonal noise ceased. However, in terms of public perception damage was done and noise became and remains an issue to this day.

One of the learnings from the Hau Nui experience was that New Zealand lacked a framework for assessing and managing sound from wind turbines. The Energy Efficiency and Conservation Authority promoted and funded the development of a domestic standard[54] for assessing and managing noise from windfarms that drew on best international practice[55].

A domestic standard is developed by an expert committee. The noise community in New Zealand is small and key members were invited to be on the committee. In this way "buy in" to the domestic standard was gained from the key members of the noise management community.

The noise standard was used in a number of consents. But increasingly it was seen to have limitations particularly in terms of the monitoring regime. Councils were setting more and more complicated monitoring conditions for each successive windfarm consent. In the late 2000s the standards committee on windfarm noise reconvened and revised the domestic standard to take account of learnings around monitoring. The revised standard was published in 2010[56].

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[54] A domestic standard is developed by the New Zealand standards organisation, which is affiliated to the international standards body.

[55] Fiona Weightman, former General Manager Renewable Energy at the Energy Efficiency and Conversation Authority.

[56] Chiles S; (2010); A new windfarm noise standard for New Zealand: NZS6808(2010); Proceedings of 20th International Congress on Acoustics, ICA 2010, Sydney, Australia.
http://www.acoustics.asn.au/conference_proceedings/ICA2010/cdrom-ICA2010/papers/p33.pdf

The flash point for revising the first noise standard was the consent conditions set for the West Wind windfarm, approximately 20 minute's drive from the centre of Wellington, New Zealand's capital city. Residents living near to the windfarm were very concerned about noise. In response to these concerns the consenting authority set very specific and unusual noise conditions. The conditions were complicated and were difficult to monitor against.

Unfortunately the turbines at West Wind produced tonal noise. The problem was identified as a new model gearbox. The turbines produced two tones; one at low speed and one at high speed. A successful solution was developed involving both software and hardware.

During the development of the wind industry a number of lessons have been learned and shared at the wind energy conference and workshops. Key lessons include:

- Wind turbines can, unexpectedly, create noise.
- Systems need to be in place to enable communities to easily report noise issues.
- The owner of the windfarm needs to engage with the community and respond to complaints about wind farms.
- A system for assessing and managing windfarm noise needs to be developed that has wide buy-in from noise experts.

A difficulty with windfarm noise is that once a community becomes sensitive to wind farm noise the issue can escalate. In the West Wind example above noise complaints were received even when the entire windfarm was shut down (grid fault). In this example, it took many months and considerable effort responding to community concerns for the noise issue to be satisfactorily resolved (Figure 23).

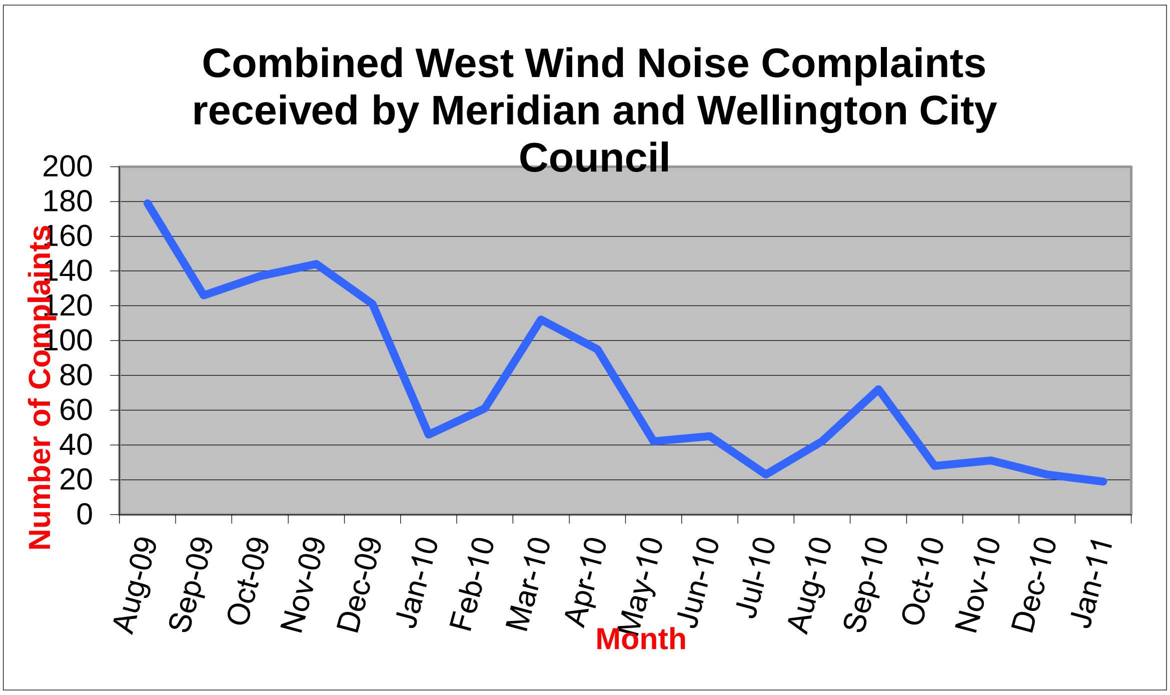

Figure 23: Noise complaints from the West Wind Windfarm[57].

[57] Presentation from Wellington City Council, NZWEA Conference, 2011, Wellington.

Recommendations: Noise

- Develop a robust noise management framework that draws on best international practice but is adapted for local conditions.
- Ensure that local noise experts are engaged in the development of the noise management framework so that they understand it and can successfully apply it.
- Encourage developers to put in place effective procedures for managing and addressing noise complaints and noise issues.

Wildlife issues – birds a key issue

New Zealand is a global biodiversity hotspot particularly for its native birds. Many of New Zealand's bird species are threatened with extinction due to introduced predators such as cats and rats. New Zealand has a strong conservation movement and concerns have been raised about the impact of wind turbines in native birds[58], particularly given reports of bird deaths from wind turbines in other economies.

Impacts of birds have been raised at many wind farm consenting processes in New Zealand. At some sites there has been considerable investigation into potential bird impacts. Developers have made the call early in the investigation stage that bird impacts might be significant and have decided to not continue with some sites[59].

Issues around impacts of windfarm roads on waterbodies (runoff) and clearance of native vegetation have been raised as issues. But unquestionably a key issue is potential impacts on birds.

In the early days of the wind industry in New Zealand impacts on birds did not feature. The reason largely was that the farms were built in areas of the economies where there are no significant native bird populations.

As windfarms were proposed in more areas of the economies the key bird issues that emerged were potential impacts on:

- Raptors, particularly the New Zealand falcon which listed as "endangered".
- Birds that migrate within New Zealand and international migratory species.
- Local bird populations that could be impacted by wind turbines.

General principles

The first step in assessing possible bird impacts is to understand that patterns of bird behaviour. Many bird species tend to follow certain flight paths that can be identified and mapped. For example, at one potential windfarm site in New Zealand, shags took a defined route each day from their nesting site to the ocean and a windfarm built in the shag's flightpath could have resulted in significant mortalities.

The second step is to make a broad assessment as to likely impacts. Some ecologists in New Zealand use a framework as follows:

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58 New Zealand has limited bat populations and only 2 bat species, one of which is extremely rare. To date few bat issues have been raised, but this is more a function of the limited populations in New Zealand.

59 This information is commercial and confidential and cannot be released in this report.

- The windfarm has the potential to have significant impact on birds and there is little that can be done to avoid significant bird mortalities. It is likely another site would be investigated.
- The site may result in significant mortalities, but more work is needed to confirm either way.
- The site will work but turbines may have to be sited carefully or some areas avoided. In the shag example above a decision was made to avoid the corridor used by shags.
- There are unlikely to be any problems with birds.

Monitoring is very important to both identify issues and to assure the public that there are no issues.

Raptors

Raptors have been identified as a potential issue at some wind farms. The New Zealand falcon, listed as a vulnerable species, is found around some windfarms. To date monitoring shows no falcon mortality association with windfarms.

Hawks, a common New Zealand species, have been associated with some mortality at New Zealand windfarms. It seems that juvenile hawks enjoy playing on the lift and turbulence created by turbine blades. Unfortunately at times they collide with the blades. Monitoring of the hawk populations show no reduction in the overall population around the windfarms.

The point with both of these issues is to be able to demonstrate to the public, through effective monitoring, what the impacts on bird species actually are.

Migratory bird species

New Zealand has a number of bird species that each year migrate from the braided rivers of the South Island to the large estuaries in the north of the economy and back. Like most native bird species in New Zealand these species are declining in numbers and threatened with extinction due to predation.

In the mid 2000s some 600MW of wind farms were proposed in the area that the migratory birds were thought to fly. Conservationists raised concerns about the potential impact of the windfarms on the migratory birds.

Very little was known about the details of the flight path of the birds. A data collection programme was established to understand the bird’s behaviour.

The first issue was where exactly did the birds fly, at what height, under what weather conditions etc? In order to gain planning permission the wind farm developers established a detailed bird monitoring programme. Radar was used to track the bird species and identify the height, direction, numbers etc of birds travelling through the area.

Some 40,000 birds were tracked using the radar[60]. This was an extensive exercise involving up to 85 people and the costs became significant in relation to project costs.

Overseas mortality estimates were used to assess the impacts on the New Zealand bird populations. Because the bird species are under threat in any case (due to predation), an offsetting programme was agreed. Under this innovative approach predators would be controlled where the birds breed.

[60] Presentation by Stephen Fuller to the NZ Wind Energy Conference 2011.

Recommendations: Birds

- At the early stages of considering a windfarm development, determine whether bird issues are likely to be significant.
- If birds are likely to be a significant issue, determine the pattern of bird activities.
- Avoid placing turbines in bird corridors. While designing a windfarm around bird issues may slightly reduce the productivity of the windfarm, that is likely to be a better outcome than having to deal with ongoing public concern about bird impacts.
- Be prepared to abandon a potential project if bird issues could be significant.
- Design a monitoring programme, including statistical procedures, as part of the windfarm design.
- Ensure monitoring takes place to the appropriate standards and review results from the monitoring programme.

Landscape issues

New Zealand has stunning landscapes. Wind is the first large technology that can impact on the New Zealand landscape significantly. Planning laws were largely silent on windfarms, which did not mean that communities were prepared to accept windfarms in their landscapes. Planning documents simply failed to cater for windfarm development and provided little, if any guidance. Some windfarms in New Zealand faced protracted opposition in terms of landscape. One 500+MW windfarm failed to gain planning permission due to impacts on the landscape.

A key issue is what comprises landscape values? The Environment Court in New Zealand has found that the landscape[61]:

- Is a biophysical entity, encompassing the shape of the land and its vegetation.
- Is valued, used and modified by people; and
- It is also perceived and experienced by people.

Landscape architects in New Zealand use a framework of "zones of visual influence" for assessing visual impacts in relation to viewing distance:

- Less than 1 km the impacts of turbines can be significant.
- At 1-3 km turbines are prominent and the potential for effects is significant.
- At 3-6km while still prominent, the potential for visual effects is moderate.
- At 10km the turbines are not prominent and impacts are slight.
- At 20km the turbines are distinguishable but impacts negligible.
- At 25km the wind turbines are difficult to distinguish.

The process for assessing landscape used by many landscape architects is as follows:

- Preliminary assessment of the landscape character at and near the proposed windfarm.
- Identify the values associated with the landscape to help with shaping the windfarm proposal.
- Assess the sensitivities of the landscape to the proposed windfarm development.

[61] Quoted in Bray S (2011); Review of best practice landscape assessment of wind farms. Unpublished report for NZ Wind Energy Association.

- Input to the design of the windfarm, location of turbines etc.
- Prepare visual simulations for communication with the public.
- Engage with the community and review potential impacts on houses etc.
- Prepare a landscape impact report covering; a description of the windfarm site and landscape setting, analysis of landscape change, assessment of effects of the change.

Recommendations: Landscape

Landscape issues have proven to be very difficult in New Zealand and have been a key source of debate about windfarms:

- Develop clear guidelines for the landscape assessment process.
- The wind industry should work with the landscape community to help ensure that the landscape community understands and can effectively assess windfarm proposals.
- Visual simulations are important for understanding landscape impacts.
- Ultimately decisions have to be made – wind turbines are large structures that cannot be "hidden". Effective decision-making processes are needed to make judgements on landscape issues.

The New Zealand Wind Energy Association

NZWEA has proved to be an important part of helping the wind industry grow in New Zealand. It has helped with coordination and cooperation across companies that are competitive, such as turbine manufacturers. It has enabled the industry to present a united view on contentious issues. And it has provided an authoritative voice on behalf of the whole industry. Importantly the association has also helped build connections and relationships across the industry. In short the wind industry association has helped the industry to grow and develop.

At a wind meeting/conference held in 1992[62] attended by some 40 people a proposal to form a wind energy association was unanimously approved by attendees. But progress setting up the new association was slow and by 1996 the association had not been formally set up.

Government support proved to be critical to establishing NZWEA - the Energy Efficiency and Conservation Authority played a key role in helping establish NZWEA. This agency organised meetings, provided secretarial services, ran an annual conference etc. Over the industry stepped up and ran the organisation. The NZ Wind Energy Association was established in 1997. Its mission, objectives etc are set out in the box below.

1. The Association promotes the responsible, sustainable and significant uptake of New Zealand's abundant wind resource as a reliable, renewable, clean and commercially viable energy source. The Association considers that wind energy has a substantial role to play in New Zealand's power generation portfolio, and strives to ensure that New Zealand's world-class wind resource is harnessed in a responsible and sustainable manner.
2. The Association is a non-Governmental, non-profit organisation. Our activities are funded by our members and by industry events such as our annual conference.
3. The Association's Mission and Objectives are:

Mission

The mission of the Association is to promote the uptake of New Zealand's abundant wind resource as a reliable, sustainable, clean and commercially viable energy source.

Objectives

The objectives of the Association are to achieve its mission ... by means of:

(a) policy advocacy with local and central government officials and elected representatives, regulatory bodies, industry groups and other interested organisations to raise the awareness of, and develop the concept of wind energy in New Zealand;

(b) organising seminars, conferences and other promotional and educational events, and to distribute information, relating to wind energy in New Zealand;

(c) providing a forum for external and internal networking, discussion and co-operation amongst persons with an interest in wind energy in New Zealand;

(d) promoting the economic, environmental, social and other benefits of wind energy in New Zealand; and

(e) *promoting research and development of wind energy technology in New Zealand.*

[62] Sims EH; (1992); Wind farming in New Zealand – Potential and Prospects. Proceedings of a Seminar 11th December 1992, Massey University.

Evolution of the association

A critical stage in the evolution of the NZWEA was developing the constitution for the organisation. This was developed through full consultation with interested organisations. It sets out the purpose of the organisation, how it will operate etc. The constitution has remained largely unchanged to this day.

NZWEA has an elected board. It has three levels of membership:

- Corporate: Companies that have a very strong wind focus.
- Associate: Companies that have an interest in wind, but wind is not a core business.
- Individuals.

Initially academics and enthusiasts were the main members of the New Zealand wind industry. Over time more companies become involved. Currently the board of NZWEA comprises industry representatives.

As the association developed its role became well established and has changed little over the years. Categories of activities include:

- Communications – raising the profile of wind generation and communications around the "myths" of wind generation.
- Policy, such as energy, climate change and environmental policy. Included under this category is developing a standard for wind turbine noise.
- Electricity system issues, such as fault ride through for wind turbines. Under this category NZWEA participated in the Wind Grid Integration Project.
- Supporting the industry. This area includes running the annual conference and specific initiatives, such as the Health and Safety initiative.

Case Study: The annual wind energy conference

A key role of NZWEA is organising the annual conference. The conference is the "family gathering" where all the key players in the wind industry meet. An important role of the conference is to help participants in the industry meet, maintain and build relationships. Building and operating a wind farm requires many companies and organisations to work together and the conference is an important place for people to meet and build relationships.

A significant conference was held in 1992. Generators, the domestic transmission system operator, academics industry representatives and government officials attended the conference. At that time there were no operating commercial wind turbines in New Zealand, although one turbine was planned to be installed in 1993. Experts from Denmark presented on the development of the wind industry there.

In 1996 the "inaugural" wind industry conference was held, which was organised by the Energy Efficiency and Conservation Authority. Some 90 people attended the conference. Topics covered included:

- Projects underway.
- Understanding the wind resource, including wind prediction, turbulence etc.

- Consenting.
- Electricity system issues.
- Operations and maintenance.
- Government policy.

In 1997 the second conference was held, again organised by the Energy Efficiency and Conservation Authority. This conference celebrated the work of one of New Zealand's leading wind generation researchers, Keith Dawber. Keith's work focused on the wind regime in New Zealand at the local scale, such as turbulence.

From 1998 onwards the wind industry conference has been an annual event organised by NZWEA. It provides a forum for debate discussion, sharing knowledge and building social capital.

The topic areas have changed little from the first conference. What has changed is the discussion of those topics. For example, while the grid continues to be a focus, the emphasis has changed from wind integration to new technologies, such as the role batteries can play.

The conference presentations provide very valuable information about the development of the industry and a record of the growth and development of the industry. Conference presentations are available on the NZWEA website.

Case study: Health and safety programme

In 2011 a wind farm employee who had worked in the United Kingdom suggested that NZWEA should establish a health and safety programme. The NZ Wind Industry considered that safety was a key issue and NZWEA established a H&S initiative. The initiative connects globally including with the Global Wind Organisation (GWO)[63], which is the umbrella organisation for health and safety in wind farms.

The H&S programme runs 4 all-day meetings a year. A key aim is to share learnings across the industry based on the principles that:

- "my accident is your accident" and
- There is no competitive advantage in health and safety.

Learnings are shared from incidents, construction of new wind farms, development of improved procedures etc. The programme takes the view that H&S is an integral part of work place productivity; a safe working environment and a productive working environment go hand in hand.

The quarterly meetings are attended by a mixture of wind turbine owners, manufacturers and contractors. The terms of reference for the H&S programme are set out in the box below.

[63] For example, in 2013 the Chairman of the GWO, Clause Rose, presented at the NZWEA annual conference.

Background – the need for a whole of industry approach

- Health and safety is an industry good
- The industry needs to work together on H&S for the good of the industry (while competing in the market)
- In the public's mind the industry is as good as the last incident
- The public sees an industry not individual companies, including contractors.

Aims

- To develop, maintain and update a common set of relevant guidelines for wind farm health and safety.
- To develop shared training resources/system and gain global recognition of these with the US, Australia, Europe etc, i.e. internationally consistent training systems that are relevant to the NZ situation (e.g. legal arrangements).
- To share best practice.
- To connect the wind industry H&S work with relevant H&S work in related industries, for example, the electricity industry.

Scope

The focus should be on operations and include public access. This initiative should cover suppliers and contractors, i.e. not just windfarm operators. It should cover:

- Operations
- Maintenance
- Construction
- Public visitation.

Measures of success

- Development of resources that are used by the industry and are updated as needed.
- A forum where views can be aired, information exchanged, learnings discussed etc.
- A skills training system that is actively used by industry players.
- Consistent reporting systems and sharing of data (using appropriate confidentiality systems).

Case Study: A report on the cost of wind energy versus other forms of generation

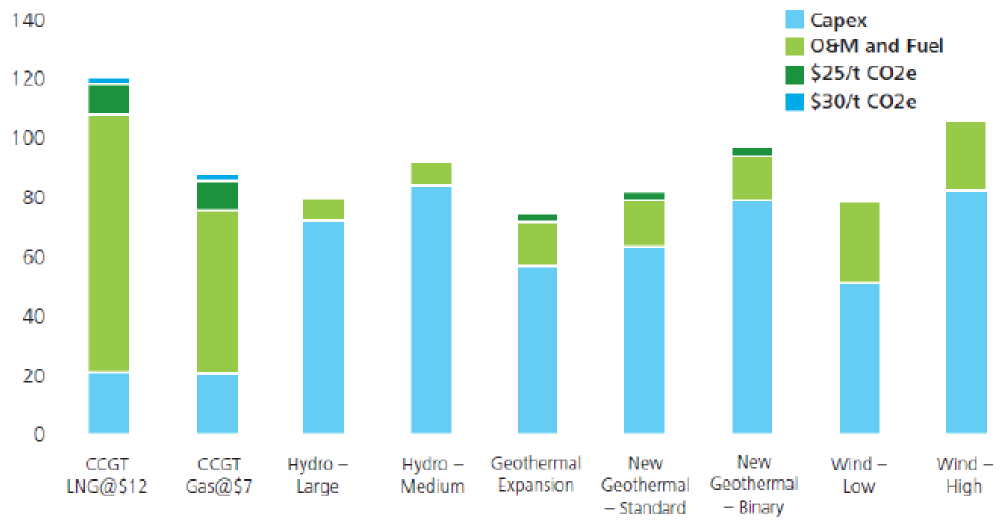
In the late 2000s commentators, government officials and the media were quoting figures for wind which were significantly higher (>30%) than was actually the case. A general perception had been created that wind was expensive and could only be cost effective with subsidies.

A problem in exposing the "true" numbers is that in New Zealand these are commercially sensitive. A further problem is that authoritative information was needed.

NZWEA contracted Deloitte to prepare that compared the costs of wind generation with other forms of generation. Members of the industry were interviewed by Deloitte and Deloitte were given access to confidential information on individual projects. Deloitte aggregated the data which meant the data on individual sites could not be identified, which got around the confidentiality problem.

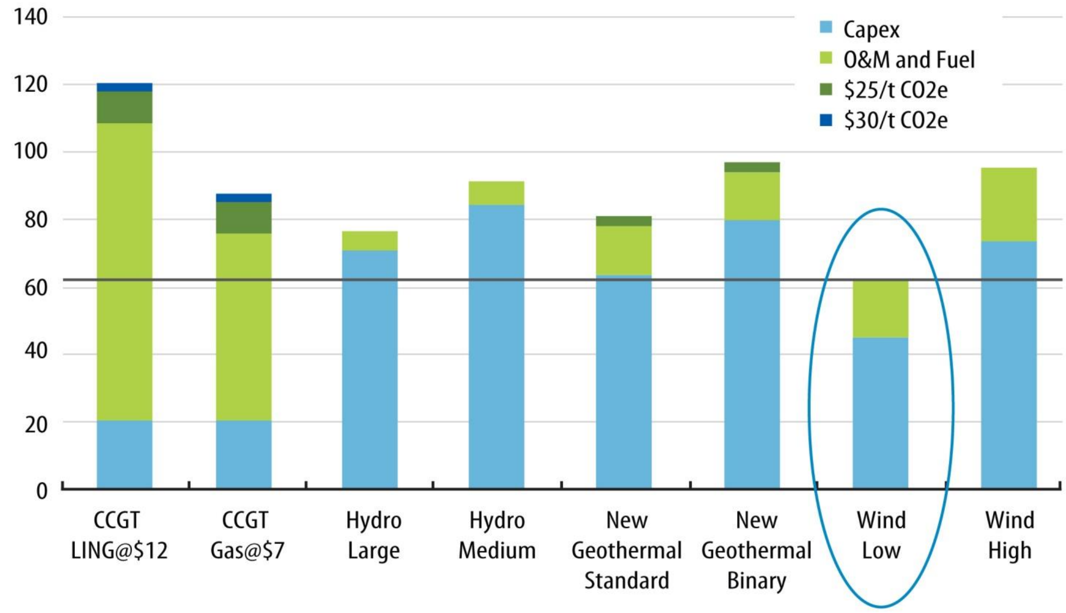
NZWEA published the Deloitte Report and has used it extensively to communicate the actual cost of wind generation. NZWEA went a step further and applied cost reduction curves to the figures Deloitte generated to get a cost estimate of wind generation in 2016. At a good site NZWEA estimated that costs for wind generation could be around NZ$65/MWh in 2016. A project that reached financial closure in 2014 had a cost of just over NZ$70/MWh so, NZWEA's estimates of 2016 costs, whilst optimistic may be close to reality.

LRMC – 2010$/MWh



Source: Meridian Energy, Deloitte analysis

LRMC - 2016 $/MWh



Recommendations

A wind energy association is a very important part of developing the wind industry. It is recommended that:

- Governments support the establishment of a wind energy association - government support was critical to the New Zealand association becoming established.
- Over time government should encourage industry to run the organisation.
- The association should have a clear constitution, elected board and as funds become available employ staff.
- The association organises an annual conference and meetings/workshops on specific topics.
- The association develops a work programme involving:
    - Public awareness.
    - Coordinating whole of industry responses to issues such as noise.
    - Support consenting (permitting) efforts.
    - Engage in discussions with government on policy and government initiatives that impact the whole industry.
    - Health and safety in the wind industry.
    - Providing and actively communicating accurate information on the wind industry.

Research

Researchers led the early stage of the development of the wind industry in New Zealand. The research was funded by the Government which was keen to see New Zealand's sources of energy diversified following the oil price shocks of the 1970s. Two or three researchers were absolutely critical to the development of the wind industry. They systematically collected data, made international connections and promoted New Zealand's wind generation potential to students.

Once the wind industry started to build farms connections with researchers dropped off. Current links between the research and wind sectors in the wind area are not strong in New Zealand. In comparison there are comparatively strong connections in the geothermal area between the research community and the electricity industry. It is not clear why there are comparatively poor links between the wind industry and research communities. Possible reasons include:

- Key researchers passed away and no researchers filled their place.
- The government substantially reduced funding for energy research in the 1980s as oil prices stabilised.
- New Zealand relied on imported technology. Some in the industry suggest that there is little need for New Zealand research given the wind regime is now well understood.
- Wind data for a site are commercially sensitive and a private good.
- Generally poor connections between the research and industry sector in New Zealand compared with many other jurisdictions.
- Generic knowledge that can be applied to the New Zealand situation, i.e. a limited number of issues that require New Zealand research.

Summary and conclusion

Supporting the following areas will assist with the development of the wind industry:

- Academics: Early academic interest resulted in NZ having a good understanding of its wind resource and an awareness of the wind generation potential. The academics played an important role in raising the profile of wind generation and identifying the opportunities of wind generation.
- "First mover" individuals. The early stages of the wind industry in New Zealand was driven by individuals.
- Smaller companies that can move quickly: In New Zealand it was the smaller organisations in the electricity sector that did the early exploring of wind generation. These organisations can move more quickly than the larger ones to develop wind projects.
- Trials. In New Zealand installing a single wind turbine substantially lifted confidence in wind technology.
- First projects. The first projects will be expensive as the industry learns to develop wind projects. Government support for first projects is helpful to reduce costs.
- Develop a wind integration project that develops scenarios for wind development. Understanding the characteristics of wind in an economy's electricity system will greatly assist the system operation and grid management part of the electricity system to understand the characteristics of wind generation and the benefits wind generation can bring to grid systems. Grid integration studies build confidence in integrating wind into grid systems and create a platform for the development of innovative solutions that harness the benefits of the modern power electronics in wind turbines.
- Local solutions to maintenance issues. Local engineering companies will make a significant contribution to the wind industry. Companies and organisations need to be engaged early in the development of the wind industry and may provide innovative solutions to operations and maintenance issues.
- Smaller as well as larger projects. There is a tendency to "think big" when considering windfarms. Smaller, distributed windfarms may have a range of benefits, from greater public acceptance to improved grid resiliency.
- A wind Industry association is a very important part of helping a wind industry become established. An industry association should be set up as the industry develops. Government support may be needed to help the association become established. Industry association is very important to help the industry grow.
- Develop a set of planning and management tools for windfarms, such as a noise assessment framework, landscape methodologies, good understanding of particular environmental issues, such as potential impacts on birds. Government needs to take a leadership role so that the planning and management tools are seen as having independence from the industry.
- Development of monitoring and complaints procedures. Industry should establish clear procedures for identifying and managing issues that arise. The New Zealand experience is that issues will arise. The affected community will expect robust procedures to be in place to deal will issues that arise.

- Robust environmental decision-making processes. Some people will remain opposed to wind generation for a variety of reasons. There is little that can be done to work with this section of society. A clear and robust decision-making process is needed that enables opponents to be heard.