Assessment of Powerco's Network Evolution Plans

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Prepared for Powerco Ltd

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Contents

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1. Executive Summary

The result of clean energy transformation, new electrical devices, and consumer interest in new devices will mean increased importance of electricity to New Zealand's economy and everyday life. Traditional uses of electricity will remain, and new uses will emerge across domestic, commercial and industrial applications, as well as initiatives to meet New Zealand's climate change obligations. Many emerging technology devices, such as photovoltaic solar power (PV), electric vehicles, and storage batteries will connect to the 400/230 Volt low voltage electricity distribution network, and will cause it to be used in ways it was never designed for.

Preparing for this change, as well as finding ways to fully utilise the existing network, is essential. The evidence collated in this report shows substantial research and innovation has been carried out world-wide to ensure safe, reliable, stable and economic operation of electricity distribution networks for each country, particularly in the light of emerging technology. The report shows the importance of Powerco's proposed Network Evolution Plan to prepare for the future electrification of our economy. It concludes that the activities within Powerco's plan are a proactive approach to preparing for the future, to avoid a costly reactive 'catch up' after large uptake of emerging electrical technologies.

The following table summarises Powerco's planned network evolution activities, in order of Priority defined by Powerco, gives a summary of countries where similar activities were found to be taking place, and the expected benefits of the activity.

Network Evolution Activity	**Countries where similar activities are occurring in the distribution industry and research**	**Benefits**
1. Automatic fault detection and location	Europe, Australia. IEA lists it as an area where substantial benefit will be gained	Reduced frequency and duration of unplanned outages, reduce cost of finding faults, more rapid isolation of potentially unsafe faults.
2. Voltage support applications	Europe, Germany, Sweden, UK, NZ	If voltage and the connection of emerging technology is managed well, benefits will be maintained supply quality without the need for large investment in the network, thereby limiting price rises to customers. Benefits may also be increased ability of networks to host PV (i.e. more PV able to export to networks).
3. Automatic restoration (self-healing) and network reconfiguration (linked to automatic detection)	Europe, UK, Japan, Korea, Australia	Potential to improve supply quality without the need to reinforce the electricity distribution network in traditional ways. Benefits will be maintaining supply quality without major additional cost.
4. Smart meter data analysis	UK, Europe	Relevant to the concept of use of data to improve service delivery to customers. Smart meter data is seen by the IEA as crucial in the future to reduce the frequency of unplanned outages.

Network Evolution Activity	**Countries where similar activities are occurring in the distribution industry and research**	**Benefits**
5. Electric vehicle charging control systems	Netherlands, Germany, UK, Europe generally	Benefits to consumers will be the ability to charge electric vehicles without increased power prices brought about by extensive and costly network upgrades. The IEA asserts that coordination of charging stations through digital technologies (smart-charging) will be required to take full advantage of the opportunity electric vehicles represent.
6. Integrating community energy schemes	Germany, Netherlands	This can be applied to communities serviced by traditional distribution lines that have become uneconomic to service. The result is better management of supply across the network.
7. Demand management	Netherlands, UK, Europe generally, USA, Korea, Australia, New Zealand	Demand response to manage network peaks, energy prices, and provide ancillary services is very relevant, especially in enabling the demand side to participate in managing the network and ultimately actively helping establish wholesale electricity prices. A benefit, as demonstrated by practice, is management of network size and therefore avoiding reinforcement of the network. The IEA believe that digital technology will open up more demand response opportunities, with the benefits potentially enormous through avoiding investment in new infrastructure. It also aids in the integration of variable renewable energy sources.
8. Network Insights (low voltage feeders, transformer monitoring, etc.)	USA, Europe, Japan	This activity is highly relevant given most emerging technology is connecting to the low voltage network. The benefit to the customer will be a network capable of connecting the new devices they wish to connect to it without escalating costs.
9. Real time asset ratings	UK, Europe, Australia	The benefit to the customer is maintenance of service quality and management of costs by better use of assets by the distribution company. By using assets more efficiently, new assets can be avoided, and in turn the need for large price rises can be better managed. It has been proven to be of benefit in the UK. The IEA sees remote monitoring that allows equipment to be operated more efficiently and closer to its optimal conditions as part of the industry's future.
10. Energy storage	UK, Germany, Netherlands, Europe generally, Japan, USA, Australia	Optimisation of solar self-consumption, network management, and increasing the penetration of solar PV in networks. Ultimately these will benefit the consumer by making solar more economic and avoiding traditional network upgrades and the associated cost of upgrades.

2. Introduction

Electricity is vital to the New Zealand economy, in such industries as food production, manufacturing, commerce, telecommunications and Internet infrastructure. It is also vital to households, for such services as space and water heating, lighting, cooking, and a multitude of other appliances.

Internationally, much electricity has been generated by fossil fuels, such as coal and gas. The move by most countries to reduce greenhouse gas emissions has led to the development of renewable electricity technology, such as photovoltaic (PV) solar and wind, which can now generate electricity at costs comparable to fossil fuel technology. Electricity has been identified by many countries as the first energy source to target because of renewable technology, and the carbon emissions associated with electricity generation. Incentives were offered to develop rooftop and utility scale solar installations, and large wind farms. As a result, progress has been made towards transitioning electricity generation to renewables, and reducing greenhouse gas emissions. Countries, especially the United Kingdom (UK), European countries, and Scandinavia are now turning their attention to the rest of their energy systems, recognising the role renewable electricity has in 'decarbonising' the whole energy economy. In its November 2017 Industrial Strategy, summarised in the appendix, the UK states: "*The move to cleaner economic growth – through low carbon technologies and the efficient use of resources – is one of the greatest industrial opportunities of our time.*"[51]

New Zealand has a different starting point, with a largely renewable grid. However, other parts of New Zealand's energy system and economy produce greenhouse gasses, such as transport, stationary heating, and agriculture. In line with the planned use of renewable electricity to decarbonise economies in other parts of the world, New Zealand has an opportunity to decarbonise its economy using renewable electricity. This would be through replacing fossil fuel use in the remainder of its electricity generation, followed by electrifying transport and stationary heating. Studies show that this could almost achieve New Zealand's Nationally Determined Contribution under the Paris Agreement, ratified by New Zealand in 2016.[1] This would involve the uptake of electric vehicle technology (e-mobility), use of electric heating including heat-pumps, and greater energy efficiency.

As well as the opportunity renewable electricity presents to decarbonise the economy, consumers are showing increasing interest in renewable energy, including rooftop solar, and electric vehicles. Almost universally, this technology connects to the electricity grid at the low voltage level, either in homes, or business connections.[i] Consequently, the low voltage electricity network is starting to be used in ways it was never designed for. This change in use will only increase over time. In addition to this, competitive retail electricity markets are offering consumers new pricing structures, with the benefits of demand response becoming clear. 'Internet of things' (IoT) technology is opening up possibilities to control appliances to respond to real-time retail prices, and battery technology is becoming available for homes and businesses. While there is some market development required to take full advantage of these new technologies, they are recognised to be exponential, improving in price, performance, and uptake rapidly. New ways of trading renewable electricity are also emerging, such as peer-to-peer

[i] The low voltage network is the 400 Volt / 230 Volt network that supplies most homes and businesses in New Zealand. A low voltage network typically connects to the 11kV network via a transformer, and can have between 1 and as many as 300 properties connected to it. They may be overhead, underground, or a combination of both. They are typically radial, with no interconnection to other low voltage networks (interconnection between networks would create a meshed network). However, some low voltage networks can be connected to other low voltage networks, via re-closers, to enable 'back feed'. This helps with re-connection to some parts of the networks during faults, or continued supply during planned outages, but such 'back feed' is not normally activated.

markets, which have the potential to rapidly increase the uptake of small-scale renewable energy – photovoltaic solar (PV) in particular.

Global trends and policy show a very strong drive to the 'clean energy transition' and therefore more rapid uptake of renewable energy technology. Public attitudes are also shown to be strongly in favour of renewable energy. Policies in other countries, and public attitudes, are summarised in the Appendix. They indicate more products available, at better prices, and increasing opportunities for New Zealand consumers to take up this technology. This implies an increasing rate of emerging technology, discussed earlier, connecting to the grid, via the low voltage network, and therefore increasing changes in the way it is used.

The coincidence of clean energy, new technology, including e-mobility, and consumer interest in it, place far more importance on the grid and the electricity distribution network. To ensure ongoing economic quality of supply, and to understand how new technologies may affect the network, many distribution network owners are investigating and trialling new technology and expending more effort on understanding their low voltage networks. This is with a view to evolving their networks for the expected wave of new devices connecting to them. They are also innovating to optimise their businesses, looking at new ways of delivering electricity reliably and cost effectively to prepare for the changes to come. This is consistent with distribution network owners taking on a role of Distribution System Operators (DSOs). DSOs manage the increasingly complex energy system, with complexity driven by rapid new technology uptake and changing consumer behaviour.[ii,2]

This report assesses the Network Evolution Plan of Powerco, to understand its relevance to distribution companies and importance, or otherwise, of investing in such activities.[iii] It does this by undertaking a review of international research and innovation activities, generally aligned with Powerco's Network Evolution Plan. International activities are discussed in detail by country in Section 3. They are then summarised against each of Powerco's network evolution activities In Section 4. In Section 5 the report then comments on the relevance of each of Powerco's proposed network evolution activities to distribution companies, the importance of each activity, and potential benefits to customers. The report ends with a brief conclusion, Section 6. An appendix contains evidence of the world-wide move to clean energy and the emerging technology that goes with it.

For consistency, the term 'distribution business' is used to refer to a generic set of companies that own and operate electricity distribution assets, and provide electricity distribution services with those. The exceptions are where the literature reviewed refers specifically to another term, such as distribution system operator. It is noted that Powerco's Network Evolution Plan sets out a pathway to evolve to a Distribution System Integrator, then Distribution System Operator. The activities within Powerco's Network Evolution Plan will help prepare Powerco for this new role.

[ii] This is identified by the United Kingdom's National Infrastructure Commission, in its Smart Power report, the first of three looking at vital infrastructure improvements needed in the UK (UK National Infrastructure Commission, Smart Power, 4 March 2016, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/505218/IC_Energy_Report_web.pdf).

[iii] Powerco's Network Evolution Plan is part of its Customised Price Path (CPP) Main Proposal, 12 June 2017.

3. International Research and Innovation in Electricity Distribution

This section reviews international research and innovation activities happening in electricity distribution networks. In examining activities, priority was given to areas where change is occurring in the way customers are using the network, or new devices are connecting to the network. Priority was also given to new practices being researched and trialled to solve specific business problems, either by particular companies, or across an industry. Often this latter priority intersects with the activities around change, since the change presents new business challenges. Furthermore, while some academic research was reviewed, most of the review is of activities carried out by industry, or industry with researchers, where new techniques were actually applied, usually in early stages through trials. Most academic research reviewed is that carried out with industry partners; the link being considered a means to transfer new knowledge generated to industry where it can be implemented.

Industry research organisations, industry commissioned research, or industry bodies were also considered for the closeness of their research to implementation. Regulators, government and government policy, industry observer groups, and regulator commissioned independent assessments were also considered, since this can set priorities for research, and be an independent view on where companies should be innovating. Sources of research and information include:

1. The Institution of Engineering and Technology (IET) Power and Energy Series, which provides a review of European, USA, and Asia-Pacific research to 2014, and a research outlook beyond 2014. This review is covered separately at the end of the Section.
2. 2016 and 2017 International Solar Integration Workshops and Wind Integration Workshops held annually in Europe, which are well attended and contributed to by industry (November 2016 Austria, October 2017 Berlin). These provide a collection of industry research in distributed energy carried out beyond 2014, in particular in Europe, but include the USA, parts of Asia and Africa.
3. The inaugural E-Mobility Symposium (October 2017 Berlin), which also provides a good summary of recent industry research in Europe, USA, and parts of Asia and Africa, in electric vehicle grid integration.
4. Organisations not necessarily involved in distribution engineering themselves, but who give an indication of future research and innovation needs. These include the International Renewable Energy Agency (IRENA), an intergovernmental organisation whose mission is "*Supporting countries in their transition to a sustainable energy future*"; the International Energy Agency (IEA), an autonomous intergovernmental organisation "*which works to ensure reliable, affordable and clean energy for its 29 member countries and beyond*"; and the USA National Renewable Energy Laboratory (NREL), the U.S. Department of Energy's (DOE's) primary national laboratory for renewable energy and energy efficiency research.
5. The USA headquartered Institute of Electrical and Electronic Engineers (IEEE); and the USA Electric Power Research Institute (EPRI), a non-profit organization funded by the electric utility industry which conducts research on issues related to the electric power industry.
6. Ofgem, UK Office of gas and electricity markets.
7. Australian Network Transformation Roadmap project and distribution company activities.
8. New Zealand GREEN Grid project – three key findings of relevance to New Zealand distribution companies.

3.1 Europe and the European Union

3.1.1 Netherlands: Universal Smart Energy Framework

The Netherlands has developed the Universal Smart Energy Framework (USEF) to "*drive the fastest, most cost-effective route to an integrated smart energy future.*"[3] The USEF has been established by the USEF Foundation, a non-profit partnership of seven organisations (ABB, Alliander, DNV GL, Essent, IBM, ICT Automation and Stedin).

The USEF Foundation recognises the global drive to drastically reduce CO_2 emissions and dependence on fossil fuels. It therefore recognises the need to use more renewable energy, which is becoming more economically viable. It points out that much of the new renewable resource is variable, giving rise to a need for more flexibility to respond to renewable variability. It also recognises the growing demand for electricity from electric vehicles, space heating and heat pumps. These types of load increase the system peak load, but have inherent storage that can be used to shift energy use. Finally, the USEF Foundation recognises the digitization of society, enabling the almost completely free exchange of information between any device and 'actor' in the system. It posits that this will be a crucial element to balancing supply and demand in the energy system.

> *"Today, the number of players involved is increasing and existing market roles are changing. The electricity market needs to adapt to this new reality; it needs to fully integrate all market players—including flexible demand, energy service providers, and renewables."*[3]

The USEF addresses the need for distribution system operators, and their role in optimising the supply of the electricity distribution network, rather than always reinforcing the network, to maintain lower costs:

> *"The most prominent issue to resolve is the increase in grid capacity demand caused by electric vehicles, electric heat pumps, and PV solar panels. Without incentives based on the actual local distribution grid load, the collective simultaneous response from end users' smart devices can increase the peak load on the system even further instead of relieving it. Though it is possible to increase grid capacity through grid reinforcements, this is a time-consuming and costly solution. Hence it would be wise if the flexibility provided by demand-response assets can also be used by grid operators to reduce the loads on their networks and prevent expensive grid capacity investments. As a result, the role of the distribution network operator (DNO) will change into that of a distribution system operator (DSO), who will need to actively manage the available capacity in its network and provide market services to do so."*[3]

The USEF also addresses prosumers (consumers owning power production assets who wish to actively participate in the energy market) and the emergence of innovative organisations bringing many end-users together. An example given is the development of energy communities that seek to make their neighbourhoods energy neutral.

Implementations of the USEF by Netherlands distribution companies have begun, with two summarised below:

- A paper by authors from Stedin, a Netherlands distribution company, discusses an implementation of the USEF.[4] The authors make the point that solving bottlenecks in the electricity distribution network from new devices like PV, heat-pumps, and electric vehicles with traditional grid reinforcement will require massive investments, and therefore energy flexibility in supply and demand is needed.

- A paper by authors from Stedin, a Netherlands distribution company, provides analysis of electric vehicle charging integration using the USEF framework.[5]

Other innovation projects from the Netherlands industry have involved the use of battery storage to overcome congestion with utility scale PV schemes connected to the electricity distribution network via long feeders (the scheme investigated is in Jordan).[6]

3.1.2 Germany

As a world leader in small-scale rooftop PV deployment, Germany is active in innovation involving the deployment of PV in electricity distribution networks. For example:

- Research by a German company and Swedish university.[7] This research investigates optimising the voltage control capabilities of PV inverters in the electricity distribution network depending on their location on a low voltage feeder. This is relevant, as the effectiveness of voltage control varies depending on proximity to the distribution transformer. This research proposes coordination amongst inverters on the same feeder.
- Investigation by a German university, DSO and distribution owner and inverter manufacturer.[8] Collectively they have investigated optimal methods of voltage control on low voltage feeders with distributed generation (specifically PV) present.

Innovation in Germany is also turning its attention to electric vehicle charging and battery storage. Examples are given below:

- University research, showing that electric vehicles may impact voltage power quality (causing low voltage), and that battery storage can be used to alleviate this.[9, 10]
- A German consortium from ABB and EWE, a north-western distributor, discusses the Green2store project, which introduces the 'storage cloud' concept. The project is researching the impact of decentralised battery energy storage systems on a high level of renewable penetration in distribution systems. It is supported by the German Federal Ministry for Economic Affairs and Energy, and led by the distribution system operator EWE NETZ, with ABB.[11]
- A team from a German research institute ZAE Bayern, with a local utility, installed a community energy storage scheme (CESS) in Epplas as part of the Smart Grid Solar (SGS) research project.[12] They investigated the operational strategy of the CESS to provide reserves, increase community solar self-consumption, and peak-shaving. In this respect this also contributes to demand management and energy storage.

3.2 United Kingdom

The UK regulator, Ofgem, has actively supported innovation projects, with the aim of "*helping make the energy networks smarter, and accelerate the development of a low carbon energy sector and delivering financial benefits to consumers.*"[13] An example of encouraging innovation is the Low Carbon Networks Fund (LCNF) to March 2015. An objective of the LCNF was to incentivise distribution network operators to include innovation as part of their core business. A review of the LCNF by Pöyry Management Consulting (UK) Ltd made several findings:[14]

1. The LCNF has encouraged DNOs to innovate and to include innovation as core business with signs of transfer to business as usual. While current benefits are about one third of the total funding cost, the potential future net benefit from the LCNF projects is estimated to range from 4.5-6.4 times the cost of funding the scheme.

2. Projects that focus on the connection of distributed generation and flexible demand have a high potential value and are most likely to be readily incorporated into current-day business practice.

The report made several conclusions, including:

1. Ofgem should continue to fund distribution network operator innovation.
2. DNOs should jointly publish an 'innovation roadmap', developed in conjunction with the system operator, transmission companies, other parties such as independent DNOs and other participants like gas, heat networks, and transport.
3. There should be greater focus on the sharing of project knowledge and learning – particularly across and between the DNOs to maximise the benefits and value of LCNF initiatives and innovation.

An earlier study of LCNF learnings, by EA Technology, found that:[15]

1. All DNOs are incorporating demand response as part of their approach to network investment.
2. All DNOs are using forms of active network management, such as 'smart fuses' and automatic network configuration to meet demand.
3. Some DNOs have trialled electricity storage, but found it is difficult to justify economically to only manage network demand. Other services, such as providing System Operator services and energy balancing, might improve the economic case.
4. Dynamic rating of assets has proven beneficial in some cases, and has been incorporated into normal practice by some DNOs.
5. A range of voltage management devices had been deployed through the LCNF to more actively manage voltage deeper into the network than previously.
6. DNOs have explored ways to accelerate the connection of renewable generation to the electricity distribution network. This has led to greater engagement with those wishing to connect, and faster and less costly connection.

Ofgem continues to see innovation as important in the future. Part of the UK Government's Industrial Strategy is the Clean Growth Strategy.[16] A core component of this is Ofgem's future facing work to enable the energy systems transition – "Upgrading our energy system: Smart Systems and Flexibility Plan".[17] In this Ofgem notes that:

> "*A key role for the Government and Ofgem is to create the environment for new ideas to flourish by removing barriers to innovation. Our energy system needs technologies and infrastructure that are both cheap and clean, but it also needs innovation in processes, transactions and consumer offerings."*[17]

In this strategy, Ofgem gives examples of innovation, including:

- The Electric Nation electric vehicle charging trial by Western Power Distribution, testing whether this can unlock capacity on their network for more electric vehicles to be deployed before reinforcement is needed.

Ofgem also indicates in this that policies on small-scale low-carbon generation will look to ensure system and consumer benefits of storing electricity for self-consumption and export to the grid at peak times are realised. The UK's Clean Growth Strategy also discusses:

- Implementation of actions from the Smart Systems and Flexibility Plan to ensure participation of energy storage and demand side response in the market; and

- Provision of at least £70 million over the next five years (to 2021) to support innovation in energy storage, demand side response and other smart energy technologies, including up to £20 million for vehicle-to-grid products and services.

The previous discussion deals directly with innovation by UK DNOs. There is also substantial research between universities and industry in the UK, such as the Oxford-Martin renewable energy programme, investigating integration of renewables into the grid, and University of Manchester research, such as trialling battery energy storage systems with industry.[18, 19]

3.3 Japan

Focus on renewables by Japan was precipitated by the March 2011 nuclear power plant accidents from the Great East Japan Earthquake and Tsunami. To late-2016, 80GW of solar PV was developed, with a feed-in tariff scheme. This is far greater than outlooks projected. Studies show that it is possible to enhance operation and optimise assets in networks to increase renewables in the future.[20] Consequently, the Japanese New Energy and Industrial Technology Development Organization (NEDO)[21] is currently spending US$1.27 billion on projects which include:

- Energy conservation (US$91.8 million); and
- Rechargeable batteries and energy systems (US$30 million).

Further, the Ministry of Economy, Trade and Industry (METI) established a working group in 2014 on Grid Connection of Renewable Energy, under the New and Renewable Energy Subcommittee, to verify the utility companies' capacity of power grid connection for renewable energy, as well as to devise measures for increasing such capacity.[22] They recognise the need to improve power grid infrastructure to be able to connect renewable energy, and meet Japan's 2030 renewable energy targets. Research with industry is actively investigating ways to optimise electricity distribution networks with high penetration of PV.[23]

3.4 USA

In its 2017 State of the Technology Report, the Electric Power Engineering Institute (EPRI) highlights a future "*in which customers have flexibility to use, produce, and manage energy as they choose, while improving access to reliable, safe, affordable, and cleaner energy.*"[24] The report covers a broad range of EPRI research areas, from renewable energy, improved protection, nuclear, and water and power integration. It points to a future of greater electrification using efficient electrical heating, transport, distributed generation, and more wind energy, providing customers with lower costs and improving the environment.

EPRI is also actively involved in distribution planning tool studies associated with integration of distributed energy resources into the electricity distribution network.[25] In this work the EPRI author makes the point that, just as capacity planning studies are performed for accommodating new load, hosting capacity planning studies are needed for integrating new distributed energy resources (DERs). To meet this challenge, the industry needs appropriate methods to plan for and integrate DERs into the distribution process.

The IEEE sees renewables as having a major role in the future, with innovation required in areas such as integrating variable renewable sources, providing better forecasting, and integrating markets and renewables.[26]

Research is active in areas such as storage, where NREL researchers estimate that 19GW of energy storage (15GW of new storage) could enable 50% PV penetration in California.[27] This assumes a significant increase in demand response and electrification of personal transport to minimise the need for energy storage. NREL also found that vehicle electrification in particular could provide flexible demand to absorb large midday spikes of PV generation that would otherwise be curtailed.

Energy storage research and innovation is becoming more active in certain states. According to a paper by GE Consulting, California, Oregon, and New York states have passed laws that require (or will allow requirements of) targets for storage.[28] However, companies still struggle to find commercial projects to monetise the large number of benefits that storage can bring to the system. The paper concludes that, while there are potential opportunities, participants will only be able to access the numerous benefits of storage as rules evolve to allow aggregators into the market and allow market participants to access more of the value stream. It also concludes that dynamic pricing is likely to drive much more storage down to the residential level.

3.5 Australia

A large project has been underway in Australia for a number of years to develop a network transformation roadmap to 2050 to deal with potential changes to the electricity industry.[29] It builds on four scenarios, identified by the Australian Future Grid Forum in 2013, involving a range of consumer engagements from 'set and forget' (least involvement by the consumer), through 'rise of the prosumer' (where the consumer actively engages, including providing energy), 'leaving the grid' (involving large scale distributed generation), to 'renewables thrive' (essentially the clean energy transition with large scale distributed and central renewable development).[30] The network transformation roadmap was developed considering these scenarios. The UK went through a similar exercise, but chose only one of its four scenarios to develop its roadmap ('two degrees', so called as it represents the clean energy transition goal to limit global warming to two degrees). The Australian network transformation roadmap identified a number of 'megashifts' in electricity in its scenarios:[31]

- Electricity storage;
- Low growth or declining demand for centrally supplied electricity, resulting from: (a) increased rooftop photovoltaic solar; (b) the global financial crisis and economic downturn (including reduced commodity prices, especially minerals, which is particularly relevant to Australia); (c) energy efficiency (resulting in part from sustained high prices); (d) shifts in the economy from materials based manufacturing to service based industries; and (e) more energy efficient appliances and buildings; and
- Greenhouse gas abatement.

Given electricity storage features as a megashift, and the large development of PV (6.5 GW to 7 November 2017[32]), it is not surprising that research around PV and storage is underway. Australian industry innovation and research includes:

- CSIRO Renewables and Energy research, which includes energy storage (including new battery technology), solar and electricity grid modelling.[33]
- Ausgrid (NSW distribution company) 'Demand management innovation allowance research and trials', aimed at reducing peak demand for deferral of investment, funded by the Australian Energy Regulator through the demand management innovation allowance. Ausgrid has also undertaken research into solar and embedded generation, focused on demand management and better integration into the electricity distribution network.[34]
- Energex (Queensland distribution company) 'Smarter Energy' programme, trialling battery storage technology, to understand how customers configure and use battery systems, and to explore the possibilities of using battery storage to manage peak demand.[35] The goal of this is to reduce expenditure on the network.

- Citipower and Powercor (Victorian distribution companies), investigating automatic fault detection, isolation and recovery, with the goal being a 'self-healing' network to return supply to customers quickly after a fault.[36] Citipower and Powercor are also undertaking battery storage trials for the purpose of peak shaving (to defer capital upgrades) and increasing reliability to certain areas.[37]

Australia also has numerous large scale solar installations connected to the electricity distribution network (249 over 100kW to 7 November, averaging 1.75MW each, and totalling 436MW), with some research into connection of these plants underway, as well as assessment of such plant for future connections. An example is given in the paper by the Australian Energy Market Operator (AEMO) author.[38] This paper discusses lessons learned from connection of a number of large-scale solar farms to weak connection points in the Australian national electricity market power system. It discusses the requirements proposed to manage the low system strength connections. Examples include: a solar farm connected to a remote isolated part of the network; and multiple concentrated connections of wind and solar farms in close proximity, where in aggregate the network connection is very weak. The paper investigates issues such as inadequacy of solar inverters, the need for modifications in inverter control systems, and the use of simulation models.

3.6 New Zealand

A review of New Zealand innovation is not presented, since this is an international review. However, the GREEN Grid research project, conducted closely with industry, is briefly reviewed, as it contains some outcomes that give opportunities for innovation by distribution companies with emerging technologies. They include:

- Research and measurements, clearly showing the power quality issues that will be experienced when PV solar and electric vehicles reach certain penetration levels, causing congestion in low voltage electricity distribution networks.[39, 40, 41] The effects are very dependent on where these emerging technologies are employed in a network, and on the network parameters themselves, which vary hugely between different networks.
- The development of a guide for the connection of inverter-based small-scale distributed generation to the electricity distribution network.[42] This covers a variety of technologies that might export to the low voltage electricity distribution network, in particular PV solar, but also storage batteries and electric vehicles. The purpose of the guide is to ensure a rollout of PV that does not lead to congestion, but which also maximises the PV householders can install. The guide gives opportunity for improving practices in EDBs for connecting such devices to the network, and falls within Powerco's 'voltage support applications' and 'network insights' projects of its Network Evolution Plan.
- Recommendations on ancillary services for dealing with increased frequency variability as more wind generation is added to the New Zealand grid (results that are as yet unpublished in full). GREEN Grid research shows that the need for reserves and frequency-keeping will increase as more wind generation is added, as discussed in Section 4.7. Demand response may prove more valuable then, and will introduce more competition in the frequency keeping supply. This falls within the 'demand management', 'electric vehicle charging control systems' and 'energy storage' projects of Powerco's Network Evolution Plan.

3.7 Across-country

3.7.1 The International Energy Agency (IEA)

Pointing to opportunities for further innovation, the International Energy Agency, in its November 2017 report 'Digitization and Energy', sees opportunity for convergence of energy and digital technologies to improve the delivery of electricity.[43] It sees opportunity for:

- Improved efficiencies by lowering the rate of electrical losses, for example *"…through remote monitoring that allows equipment to be operated more efficiently and closer to its optimal conditions, and flows and bottlenecks to be better managed by grid operators. Additional gains are possible through enhanced connectivity."*[43]
- Reduced frequency of unplanned outages, by use of digital data and analytics. This may be through better monitoring and predictive maintenance, as well as limiting the duration of downtime by rapidly identifying the point of failure. This reduces costs and increases the resilience and reliability of supply, resulting in cost savings to the utility and the economy.
- Extension of operational lifetimes of network components through improved maintenance and reduced stresses on equipment.

The IEA also notes that:

- The low-voltage electricity distribution network will be central to realising the potential of digital technologies to transform the electricity system.
- Distribution grids will increasingly have to take on the role of balancing supply and demand, including hosting more heterogeneous distributed energy resources, including EVs, solar PV, and battery storage.

The IEA gives four main elements of the transformation of the electricity system that digital technologies can make possible or support:

1. Smart demand response

   The IEA concludes that, while practiced for many years, there is much greater potential demand response available in the future, through automation, IoT devices, and deployment of electric vehicles and smart charging. The IEA points out that the benefits are enormous, through avoiding investment in new electricity infrastructure. However, while the potential benefits are enormous the financial savings to individuals may not be sufficient to persuade a large proportion of consumers to participate in demand response on their own. This highlights the need for regulatory and policy frameworks that distribute the costs and benefits adequately through incentives for both system operator and consumers. The IEA also notes the importance of ensuring cybersecurity.

2. Integration of variable renewable energy sources

   The IEA believes that there is vast untapped potential for digitally enabled demand response, with storage, to cost-effectively help accommodate more variable renewables. In turn this will help accelerate the decarbonisation of the electricity sector.

3. The growing role of electric vehicles

   Co-ordination of electric vehicle charging with digital technology (smart-charging) will be crucial to supporting more electric vehicles, and taking advantage of the opportunities they present.

4. Distributed generation, mini-grids and 'prosumers'

   Digital technology will support greater co-ordination of distributed generation through, for example, balancing with demand response, and supporting activities like peer-to-peer trading.

3.7.2 International Renewable Energy Agency (IRENA)

IRENA published a working paper in June 2017, entitled Accelerating the Energy Transition Through Innovation.[44] In this paper they establish the importance of the transition to renewable energy, and note the rapid progress of renewable technologies in the electricity sector in recent years, such as solar and wind. Thus, they demonstrate why the electricity sector is a vital part of the energy transition, the purpose of which is to achieve greenhouse gas emission reduction.

IRENA is clear that innovation is one of the key factors that will drive the energy transition process in decarbonising the energy sector. They define innovation: *"At its core innovation is the application of new technologies and practices with enhanced and desirable features."*[44] IRENA provides recommendations to policy makers to nurture innovation and expand it beyond R&D. IRENA also recommends:

- Decarbonisation of the energy end-use sectors; and
- Pursuing power-system integration of renewables: renewable power already has a strong business case, but achieving its potential requires additional efforts in innovation for systems integration.

3.8 IET Review of distribution grid related research and innovation world-wide

In July 2016 the IET published a book titled 'Smarter Energy: from smart metering to the smart grid' in its Power and Energy Series.[45] The book was edited by academics specialising in smart grids from the University of Durham, UK, and Princeton University, industry practitioners from a distribution network operator, IBM, and Iberdrola (a Spanish electric utility based in Bilbao, Basque Country). It contains papers and research results by leading academics and innovators that address the challenges in building smart energy systems. The editors note the challenges facing the industry as:

> "*Delivering a secure supply that supports economic and population growth; replacing aging infrastructure with affordable, reliable, flexible generation, transmission, and distribution; and meeting ever more stringent carbon reduction obligations.*"[45]

They note the increasing concentration of:

> "*distributed intermittent generation; increasing numbers of virtual power plants and microgrids backed up by local storage; interconnected smart appliances generating huge volumes of data through the 'Internet of Things'; widespread uptake of electric vehicles; application of everyday automated demand response; and prosumers who will need and expect new, radically different, ways of engaging with the energy industry.*"[45]

The editors began by reviewing recent and ongoing research focused on the smart grid domain. They collated distribution grid related research and innovation activities co-funded by the European Commission, activities co-funded by similar initiatives in the USA and Asia and Pacific countries. This serves as a useful collation for this study; a summary of research conducted, and research outlook, is given below. Finally, the authors noted areas for improvement in cyber security and scalability of applications from small scale to large-scale projects.

3.8.1 IET Power and Energy Series review: Europe (2002-2014)[45]:

Research underway was classified into the following categories:

Smart network management

This encompasses implementations that focus on increasing the operational flexibility of the electricity grid, such as sub-station automation, grid monitoring and control. The typical goal was to improve the observability and controllability of networks.

Key themes addressed in the observability related projects were:

- *implementation of smart meters to collect and store, on demand and in real-time, specific high quality and accurate data for each consumer and group of consumers;*
- *improving distribution grid monitoring to cope with volatile states in the grid;*
- *real-time asset monitoring; and*
- *fault identification and localization.*

Key themes addressed in the controllability related projects were:

- *implementation of new capabilities for frequency control, reactive control, power flow control;*
- *controllable distribution sub-stations, controllable inverters and charging stations;*
- *development and testing of distributed generation and intelligent load controllers;*
- *smart protection selectivity (smart relays);*
- *smart auto-reconfigurable networks, easily stabilizable online tap changers;*
- *dynamic line rating; and*

- *deployment of a range of leading-edge transformers across a number of low- and medium-voltage circuits, together with the use of capacitors, volt-ampere reactive (VAR) control devices and electronic boosters which when optimized together can lead to reduced losses from the power system*.

Integration of large-scale Renewable Energy Sources (RES)
Key focus areas were:

- Tools for planning, control and operation of renewables to facilitate their market integration;
- Integration of demand side management (DSM) and ancillary services by distribution system operators to support transmission system operation;
- Tools to forecast RES production; and
- Off-shore networks for wind power integration.

Integration of Distributed Energy Resources (DERs)
Projects have focused to date on new control schemes and new hardware/software solutions for integrating DERs while assuring system reliability and security. Technical aspects considered include:

- Implementation of voltage control and reactive power control of DERs for the provision of ancillary services;
- DER production forecasts and active/reactive power measurement for network observability;
- DER protection settings for anti-islanding operation;
- Use of storage together with distributed generation for voltage control, power flow modulation, and balancing;
- Centralised versus decentralised control architectures; and
- Aggregation of controllable DERs into virtual power plants and micro-grid configurations.

Aggregation
These projects focused on implementing aggregation mechanisms to aggregate supply and demand flexibilities of decentralised resources, taking into account grid constraints and market signals (into such entities as virtual power plants and demand response).

Smart customers and smart home
These projects involved testing smart appliances and home automation together with new tariff schemes.

Electric vehicles and vehicle2grid applications
These projects focused on the smart integration of electric vehicles into the electricity network.

Smart metering
The focus to date was primarily smart metering installations. It is noted that these are part of a wider smart grid project with one of more additional applications.

3.8.2 IET Power and Energy Series review: Europe Outlook[45]

The outlook for European research, summarised by the editors, from the updated 2016 European strategic energy technology (SET) plan is summarised below. In essence, the SET plan aims to accelerate the EU energy system transformation in a cost-effective way. The SET Plan sets out to achieve this by moving to a more flexible, decentralized, integrated, more sustainable, secure and competitive electricity system. Priority actions identified in the SET Plan, related to electricity distribution, are:

1. Renewable technologies at the heart of the new energy system;

2. Reduced cost of key technologies, through coordinated research and innovation and scaled up manufacturing;
3. A smarter energy system empowering the consumer;
4. Increased energy efficiency, which includes building methods but also appliance efficiency, better control and energy management, and exploiting advances in ICT;
5. Increase the resilience, security and smartness of the energy system, which includes innovative power electronics, demand response, storage, efficient heating and cooling technologies (such as heat pumps), and cyber security of networks; and
6. Boost energy storage, particularly in the light of e-mobility – this looks for higher energy density, longer life and reduced cost batteries.

Finally, in the outlook for research and innovation in Europe is the SmarterEMC2 project.[46] This project implements ICT tools that support customer side participation and renewable energy source integration, and facilitates open access in the electricity market. The SmarterEMC2 project includes: co-sharing of ICT infrastructure; metering data sharing and value-added services; demand response solutions; management of the distribution grid; prosumer related research; communication technologies; and storage.

3.8.3 IET Power and Energy Series review: United States of America[45]

The editors assessed research in the USA from projects funded by the US Department of Energy (DoE) and the Advanced Research projects Agency - Energy (ARPA-E). Funding priorities included:

- The DoE funded projects in smart grid investment, smart grid demonstration project, and renewable and distributed integration. Smart grid demonstration projects included verification of smart grid viability, costs and benefits, and validation that smart grid business models could be replicated at scale. They also included energy storage technologies (batteries, flywheels, and compressed air storage) for load shifting, ramping control, frequency regulation, distributed applications and the grid integration of renewable resources such as wind and solar.
- ARPA-E provided 12 grants in 2015 aimed at real-time coordination between distributed generation and bulk power generation, while proactively shaping electricity load. Activities are also underway in distributed energy asset communication, to act in concert to solve local and system-wide grid challenges.

A condensed summary of the areas covered by the many research and innovation projects is given below.

1. Demand response and distributed energy resource control. Projects include:
    - New approaches focusing on data management (University of Vermont); coordination algorithms for control to provide frequency regulation services (University of California);
    - Real-time guidance in the coordination of distributed energy resources and demand response by system operators (Arizona State University);
    - Scalable and secure coordination of consumer flexible load and distributed energy resources by combining millions of distributed energy resources with embedded sensors and computing, power electronics and networking with cloud computing to provide a residential energy gateway (Stanford University);
    - Distributed flexibility resource by aggregating flexible loads and distributed energy resources to provide synthetic reserve services to the grid, leveraging short-term

weather forecasts to give the reserve potential to the system operator on a day-ahead basis (General Electric consortium);

- A distribution network management framework that unifies real-time voltage and frequency control at the home-controller level with the network-wide energy management at the distribution system operator (voltage control) and system operator (frequency control) level (National Renewable Energy Laboratory);
- A control framework for coordinating the flexibility of distributed energy resources (Pacific Northwest Laboratory);
- Frequency-based load control architecture for frequency response capability (Northwestern University consortium);
- Implementation of technology that monitors grid voltage and frequency, and controls the target load to address excursions, with functionality integrated into demand response that enables water heater controllers and 'smart circuit' controllers (National Rural Electric Cooperative); and
- A cloud-computing solution that provides synthetic regulating services to the grid (Eaton Corporation).

2. Peer-to peer networks
   Techniques developed for cloud-based and distributed peer-to-peer networks, to enable coordinated response of many local units to adjust consumption and generation (University of Minnesota).

What is clear from these projects is the large emphasis on demand response to provide flexibility to manage variable renewable generation resources, either directly or indirectly by frequency regulation. In addition, there is a prevalence of projects to enable local network voltage control from distributed energy resources.

3.8.4 IET Power and Energy Series review: China[45]

China has focused to date on strengthening ultra-high voltage transmission from the resources in its west to the higher demand areas of the east. Hence its activities tend to focus on the high voltage grid. However, it has developed extensive solar power potential and has ambitious electric vehicle plans. It clearly recognises the economic potential of the global 'energy transition', and is positioning itself as a technology leader in this.

3.8.5 India[45]

India has invested large amounts in smart meter rollouts and smart grid projects. These have so far verified: smart metering data to support demand forecasting, peak load management and dynamic tariffs; smart metering as a tool for outage management and integration of distributed generation; and smart metering can be used to improve the power quality, reliability and network control management.

3.8.6 South Korea[45]

South Korea has a stated intention of combining its well-developed Internet and electronics industry with the electricity grid through the Internet of Things. This is demonstrated through the Korea Electric Power Corporation (KEPCO) investing $7 billion in smart grid technologies and signing a deal with telecommunications operator LG Y+ to develop next-generation smart grid technologies by combining electricity and IoT technologies. Funded projects relevant to distribution are:

1. Development of intelligent distribution management systems;
2. Development of consumer integrated resource management systems for high value-add power services;
3. Development of power electronics technology for distributed generation; and
4. Energy management system development for the micro-grid.

4. Overview and Benefits of the Network Evolution Activities Planned by Powerco

This section begins by discussing the benefits of each of the network evolution activities planned by Powerco. The activities discussed are from a revised prioritised list from the CPP proposal, provided by Powerco. The following section (Section 5) then collates the international activities identified in the previous section with the network evolution activities planned by Powerco.

4.1 Automatic fault detection and location

Benefits of automatic fault detection and location include faster resolution of outages, more rapid restoration of supply to customers, and more rapid location and resolution of potentially unsafe faults. Fault detection and location reduces the time and cost to find a fault, although it still requires innovation for it to work reliably. From the author's experience, faults are often high-impedance, caused by such things as trees brushing a line intermittently, debris blown onto a line, or an insulator that only shows a fault in damp weather. High-impedance faults can be more difficult to find due to the low fault currents, and the often-intermittent nature of them.

Some distribution companies have implemented 'direction to fault' indicators to isolate faults to regions. While these have improved time to locate faults, they still require traversing the line, either by road vehicle or by air. Hence finding the fault can still take considerable time and expense. Fault finding can be particularly difficult in long rural electricity distribution networks, such as Powerco's network, where there are substantial distances that must be travelled to visibly locate a fault. Accurate automatic fault location has the potential to reduce expenditure and improve network reliably substantially.

4.2 Voltage support applications

Voltage support, or management, may be required in areas of high PV concentration, when solar irradiance is high, and occupancy of homes low (during summer daytimes for example). This can be managed with new PV inverter technology, as per the EEA Guide for connection of inverter-based small-scale distributed generation, but requires changes to distribution companies' internal processes to implement it - hence there is still innovation required to implement this.[47] This is an example of a customer side solution for voltage management. The opposite may occur with electric vehicle connections, where there is currently no support for voltage management that may be required. As electric vehicle batteries become larger, and if home connected chargers become larger as a result, the load may grow to a point at peak times where low voltage becomes an issue, and voltage support is required. Otherwise, if voltage falls too low, charger equipment, and other household appliances, may malfunction. While a lot of information is known about typical PV installation sizes, and customers installing it are required to apply to the distribution company, not as much information is known about electric vehicles.

The distribution industry, and therefore customers, will benefit from innovation in this area. If voltage and the connection of emerging technology is managed well, benefits will be maintained service quality without the need for large investment in the network. Benefits may also be increased ability of networks to host PV.

4.3 Automatic restoration (self-healing) and network reconfiguration (linked to automatic detection)

The implementation and appropriate use of new devices may improve supply reliability and reduce interruptions to supply, or reduce interruption duration. This requires innovation by distribution companies to plan for and incorporate such devices in their networks. It may also require greater instrumentation of the network to support decision making by automatic restoration systems.

Including the management of PV and electric vehicle connection to the network, to ensure orderly rollout, there are tools available to understand the capacity of each part of the electricity distribution network to host PV (it varies depending on the load voltage network characteristics), but no tools available to understanding the electric vehicle hosting capacity. Similar to 'Voltage support applications', innovation is required to support distribution companies with this.

Benefits of automatic restoration and network reconfiguration include reduce outage duration and less investment in traditional networks by use of 'smarter' devices to manage network connectivity.

4.4 Smart meter data analysis

Smart meter data has already been used to understand outages to customers, and help locate which network assets are affected by an outage. It provides greater insights to customer consumption than ever before, with many smart meters in New Zealand capable of providing power quality information, which may assist distribution companies understand power quality on low voltage networks.[48] If smart meters can be used in this way, it could reduce the cost of monitoring the low voltage network, and improve its reliability from more knowledge about the network. The use of smart meters to understand network configuration and parameters has also been suggested, which could reduce maintenance costs of dispatching maintenance crew to locations of known problems (for example, a building connected to the wrong phase, causing imbalance). If smart meter data can be used for such solutions, the benefits would be reduced outage durations, reduced costs of maintenance and greater understanding of the network to support new devices connecting to it.

4.5 Electric vehicle charging and control

While the energy requirement of conversion to electric vehicles has been shown to be modest, the potential increase in peak demand in local low voltage networks could be large. As more electric vehicles connect to the network, and electric vehicle chargers increase in power requirements, new network peaks may occur. These will require costly upgrades to electricity distribution networks unless they are managed.

In addition to the innovations required to manage electric vehicle connection and potential voltage level issues, including the need for voltage support discussed earlier in 'voltage support applications', management of electric vehicle charging will be required when electric vehicle penetration reaches certain levels. This will be to manage network size, avoid network upgrades, and avoid peak loads on the network. Activities to date have given insights into the potential impact on the grid from electric vehicle charging, indicating the need for control. The e-mobility symposium held in Europe is starting to share information amongst the industry on the challenges and potential solutions.

Research and innovation to deal with electric vehicle charging control needs to start early to ensure appropriate charging control systems are in place before new network peaks occur. Benefits to consumers will be the ability to charge electric vehicles without increased power costs brought on by extensive and costly network upgrades.

4.6 Integrating community energy schemes

The concept of community energy scheme is broad, and is taken here to include such innovations as peer-to-peer trading to build virtual communities across the grid. It is also taken to include the use of community level storage to manage self-consumption at the community level, and communities supplied by alternative means to traditional networks (for example, remote area power supplies). The support of such activities by distribution companies is vital in so much as it supports prosumer activity while ensuring a reliable supply and avoiding the need to upgrade the network. It may also be used by distribution companies as non-traditional means of supply of a community, such as supplying with renewable energy and battery to replace a long distribution line that is expensive to maintain.

In the remote area power supply case, consumers will benefit through more economical means of supply, lowering costs to the distribution company and in turn to the consumer. In the peer-to-peer trading case, consumers with solar will be given the opportunity to benefit through ways to sell their excess solar. Community level storage will benefit consumers through increased self-consumption of their solar output.

4.7 Demand management

Demand management is taken to be demand response – the active reduction of demand in response to some need, such as removing network congestion. Demand response has been practiced to varying extents by distribution companies for many years, mainly to manage the size of electricity distribution networks and thereby defer network upgrades, and to even defer transmission network upgrades in some areas.

Demand response is now also seen as a means of preparing for the rollout of more wind and solar renewable generation. Wind and solar are inherently variable in nature, and demand response is a way of balancing the variability. World-wide this is proposed widely and attempted. New Zealand is somewhat different in that it has a large hydro resource which can balance the variability from wind. It does this through a number of mechanisms which include inertia, droop-response (where the governor adjusts the turbine's wicket gates as system frequency varies – system frequency indicating the status of generation and demand balance), and the frequency-keeping ancillary service (a centralised 'time keeping' generator adjustment, that ensures no on-going drift of frequency outside a set band – it acts to adjust the output of selected frequency keeping generators to maintain the average system frequency at 50Hz). Such continuous governor action and wicket gate adjustment does cause wear and tear on generators, and requires generators to generate at less than their maximum or optimal output. It therefore comes at a cost. It is desirable for the demand side to be able to provide such a service as an alternative to hydro, and in doing so, introduce more competition in the supply of frequency keeping, as well as give the demand side an opportunity to participate in the market.

Studies by the GREEN Grid project show that, as more wind generation is added to the New Zealand grid, the need for reserves and frequency keeping will increase. Demand response may prove more valuable then, to introduce more competition in the frequency keeping supply.

Benefits to consumers will derive from deferring, or avoiding, investment in distribution and even transmission assets, and revenue streams from ancillary service provision, thereby reducing price rises to consumers. It is also conceivable that, in the future, demand may be able to respond in real-time to wholesale prices and thereby manage the cost of energy and/or transmission constraints.

4.8 Network insights (low voltage feeders, transformer monitoring etc)

What is clear from all the literature reviewed, and activity in New Zealand in the past few years, is that the low voltage electricity distribution network is where most new technology (such as inverter-based PV, electric vehicles, heat-pumps, and new lighting technology) is connecting. Research and practical measurements have shown that this will use the low voltage network in ways that it was never intended. Furthermore, the low voltage network is the least understood part of most distribution company networks, because it is vast (for example, there about 30,000 separate low voltage networks in Powerco's electricity distribution networks alone), and the cost of understanding it has been prohibitive. Moreover, with the nature of loads historically, a standard set of design and operating principles have been suitable to apply to most low voltage networks. With the new types of load, and ways of using low voltage networks, greater insights into the low voltage network are essential. This includes understanding the ability of low voltage networks to host PV and electric vehicles as mentioned above, monitoring networks to understand how they are used, and better understanding of the networks' parameters. This will become an important part of distribution company asset management.

The benefits to the consumer are on-going connection of emerging technology to the network without having to reinforce the network by traditional means, such as upgrading network infrastructure. In turn price rises will be minimised.

4.9 Real-time asset ratings

As shown in the UK, use of real-time asset ratings has proven beneficial in some cases to optimise the use of assets – for example, to run assets harder as their ratings increase. This is relevant in New Zealand, where peak load typically occurs on a winter evening, which is coincident with colder temperatures. At these times electricity assets, such as distribution lines, may be able to be carry more current than their nominal rating due to decreased resistance with decreased temperature, and increased ability to disperse heat in colder temperatures. If rating assets in real-time can avoid the need to replace or upgrade the assets, it may provide substantial benefit in terms of reducing expenditure.

4.10 Energy storage

Energy storage has been trialled and used extensively world-wide. Uses include: community energy schemes to provide reserves and optimise solar self-consumption; network management; and increasing the penetration of solar PV in networks. As concluded by an Ofgem review, it is difficult to make an economic case for storage for network management alone. Hence other benefits, such as reserves, energy price exposure, and solar self-consumption need to be accounted for (as identified by the Rocky Mountain Institute work and Transpower storage report[49, 50]). This then requires some way of managing storage for all these services. Perhaps the greatest innovation New Zealand could achieve with storage at present is incorporation of it into the electricity market such that it can be used for the multiple services. In turn, the economic case for storage would improve. Nevertheless, the use of energy storage, in particular battery storage, may be appropriate in specific projects to address network needs.

5. Powerco's Network Evolution Programme: International Activities, Benefits and Relevance

Table 1 collates the international activities identified in Section 3 with the network evolution activities planned by Powerco, discussed in Section 4. In doing so it demonstrates that there is research and innovation activity happening internationally in the same areas. Table 1 also identifies:

- typical benefits that have been realised, or are expected to be realised, from investment in similar innovative/R&D type work in other jurisdictions;
- the relevance and importance of the Network Evolution Plan activity to electricity distribution companies;
- the match with what other distribution companies internationally are investing in; and
- how the benefits might be shared with customers and other stakeholders.

Table 1: International research and innovation activities by each of Powerco's proposed network evolution activities.

Network Evolution Plan Activity	International Activities	Typical benefits that have been realised, or are expected to be realised, from investment in similar innovative/R&D type work in other jurisdictions.	The relevance and importance of the network evolution plan activity to distribution companies, and match with what other distribution companies internationally are investing in. How might benefits be shared with customers and other stakeholders.
1. Automatic fault detection and location	• IET Power and Energy Series review, European activities: Smart network management, fault identification and localization. • IEA: predict reduced frequency of unplanned outages by use of digital data and analytics. • Australia: Citipower and Powercor, investigating automatic fault detection and isolation and recovery. • Many distribution companies have practiced fault detection for many years, and have strived for fault location technology.	• Benefits include faster resolution of outages, which restores supply to customers sooner. Fault location reduces the time, and therefore cost to find a fault. • Fault location is still an inexact science, needing improvement. • Hence the IEA's belief that digital data and analytics will help improve fault location.	• Accurate fault location has the potential to reduce expenditure and improve network reliably substantially. This is through reducing the time to locate faults, which lowers the cost of finding them, and restores supply in a shorter time. • Evidence from Europe and Australia demonstrates this is a priority for other distribution companies. • If faults can be located accurately and rapidly, the benefit will be improved supply quality.
2. Voltage support applications	• Germany and Sweden: university and industry, investigating voltage control using inverters based on their location in a low voltage network. • Germany: university, DSO and distribution owner, investigating optimal voltage control on distribution feeders with PV present. • UK (some DNOs): An Ofgem LCNF review showed deployment of a range of voltage management devices through the LCNF, to more actively manage voltage deeper into the network than previously. • IET Power and Energy Series review, Europe Outlook: SmarterEMC2 project - management of the distribution grid. • NZ: GREEN Grid industry-university, EEA guide for connection of inverter-based small-scale distributed generation.	• Over-voltage from PV will be an issue in certain networks. Voltage control using inverters can alleviate this, and expand the capacity of networks to host PV. • Under-voltage from electric vehicles is potentially a major issue, with no standard tools to deal with it. It could lead to equipment malfunction. • Innovation to support the roll-out of electric vehicles would be beneficial.	• Emerging technologies are predominantly connecting to the low voltage network, which will challenge traditional assumptions made in the design and operation of the network. • Substantial activity is taking place on voltage support, by researchers and industry internationally. • The distribution industry, and therefore customers, will benefit from innovation in this area. If voltage and the connection of emerging technology is managed well, benefit will be maintained service quality without the need for large investment in the network. Another benefit may be increased ability of networks to host PV.
3. Automatic restoration (self-healing) and network reconfiguration (linked to automatic detection)	• Projects included in automatic restoration are: the control of networks to manage voltage power quality and the management of PV (and EV) connection to ensure an orderly rollout that avoids the need to reinforce the network. These could equally apply to the 'Voltage support applications'. • UK: all DNOs, an Ofgem LCNF review showed that all DNOs are using forms of active network management, such as 'smart fuses', and automatic network configuration to meet demand. • Japan: university with Tokyo Electric Power Company: Investigates the effectiveness of measures to deal with reverse power flows caused by large penetration of PV. • IET Power and Energy Series review, Europe Outlook: SmarterEMC2 project - management of the distribution grid. • IET Power and Energy Series review, Korea: intelligent distribution management systems. • Australia: Citipower and Powercor, combined with fault detection and restoration, to enable network 'self-healing'.	• The implementation and appropriate use of new devices may improve supply reliability and reduce interruptions to supply, or reduce interruption duration. This may require instrumenting of the network, and innovation from distribution companies to incorporate new devices. • The management of PV and electric vehicle connections will avoid congestion, and potentially even maximise a network's ability to host such technology. Substantial innovation is required to understand electric vehicle hosting capacity and implement systems to ensure orderly rollout.	• The activity is relevant in its potential to improve supply quality without the need to reinforce the electricity distribution network in traditional ways. • The activity is practiced elsewhere in the world. • Benefit will be maintaining supply quality without major additional cost.

Network Evolution Plan Activity	International Activities	Typical benefits that have been realised, or are expected to be realised, from investment in similar innovative/R&D type work in other jurisdictions.	The relevance and importance of the network evolution plan activity to distribution companies, and match with what other distribution companies internationally are investing in. How might benefits be shared with customers and other stakeholders.
4. Smart meter data analysis	• UK: regulator, Ofgem. The UK Government is committed to ensuring that every home and small business in the country will be offered a smart meter by the end of 2020. Smart meters are a critical building block, creating new opportunities for new services and business models which benefit consumers and the overall system. • IET Power and energy series review, Europe: Smart network management, implementation of smart meters to collect and store, on demand and in real-time, specific high quality and accurate data for each consumer and group of consumers. • IET Power and energy series review, Europe Outlook: SmarterEMC2 project - metering data sharing and value-added services. • IET Power and energy series review, India: smart metering for demand forecasting, peak load management outage management and tariff design. • IEA, reduced frequency of unplanned outages by use of digital data and analytics.	• Already used in some networks to understand network outages and which assets are affected. Can be used to measure power quality, but little actual implementation of this has taken place. • May also be used to understand network configuration and parameters. Both could improve reliability from more knowledge about the network.	• Smart meter data is a further source of data about distribution companies' customers, and the network. Provided with such data there is potential for innovative analysis to further improve service distribution service delivery. • Real-time data delivery, and other data available from smart meters, such as power quality, may open even more opportunities. • The activity is relevant to the concept of use of data to improve service delivery. Internationally there has been research conducted, and smart meter data is seen as crucial in the future to reduce the frequency of unplanned outages.
5. Electric vehicle charging control systems	• The existence of the E-Mobility Power System Integration Symposium - the inaugural one was held in Berlin, Germany, on 23 October 2017. • Netherlands: Stedin, distribution company, analysis of electric vehicle charging integration using the USEF framework. • Germany: universities, show that electric vehicles may impact voltage power quality, and that battery storage can be used to alleviate this. • UK: regulator, Ofgem, gives the Electric Nation electric vehicle charging trial run by Western Power Distribution as an example of unlocking additional electricity distribution network capacity before reinforcement is needed. • IEA, coordination of charging stations through digital technologies (smart-charging) will be required to take full advantage of the opportunity EVs represent. • IET Power and Energy Series review, Europe: Electric vehicles and vehicle2grid applications. • IET Power and Energy Series review, Europe Outlook: SmarterEMC2 project - communication technologies	• When electric vehicle penetration reaches certain levels, charging control may be required. • In addition to the electric vehicles management innovations discussed above (voltage support applications) this will be to avoid the need to upgrade the network. • The activities underway internationally are considered essential to avoid new network peaks.	• The activity is relevant given the rapid uptake of electric vehicles, and their increasing range, and therefore the likely power requirements to charge them. • While the energy requirement of conversion to electric vehicles has been shown to be modest, the potential increase in peak demand in local low voltage networks could be large. As more electric vehicles connect to the network, and electric vehicle chargers increase in power requirements, new network peaks may occur. These will require costly upgrades to electricity distribution networks unless they are managed. • Research and innovation to deal with electric vehicle charging control needs to start early to ensure appropriate charging control systems are in place before new network peaks occur. • Benefits to consumers will be the ability to charge electric vehicles without power price increases brought on by extensive and costly network upgrades.
6. Integrating community energy schemes	• Germany: research institute, Bavarian Centre for Applied Energy Research, ZAE Bayern, with a local utility, investigated operational strategies for a community energy storage scheme to provide reserves, increase community solar self-consumption, and peak-shaving. This also contributes to demand management and energy storage. • Netherlands: industry organisation, Universal Smart Energy Futures (USEF) framework. Addresses prosumers (consumers owning power production assets who wish to actively participate in the energy market) and the emergence of innovative organisations bringing many end-users together. An example given is the development of energy communities that seek to make their neighbourhoods energy neutral.	• Combined with demand management and energy storage, the use of storage with PV, in particular, to increase self-consumption, minimise impact on the grid, and improve the economics of PV to the consumer is an important service that distribution companies can provide.	• International activities focused on storage batteries to increase community self-consumption of renewable energy and manage peaks. • This can be applied to communities serviced by traditional distribution lines that have become uneconomic to service. • The result is better management of supply across the network.

Network Evolution Plan Activity	International Activities	Typical benefits that have been realised, or are expected to be realised, from investment in similar innovative/R&D type work in other jurisdictions.	The relevance and importance of the network evolution plan activity to distribution companies, and match with what other distribution companies internationally are investing in. How might benefits be shared with customers and other stakeholders.
7. Demand management	• Netherlands: industry organisation, Universal Smart Energy Futures (USEF) framework - consortium of companies. Emphasises the importance of demand flexibility. Introduces the DSO as part of its framework. • Netherlands: Stedin, distribution company, discusses a USEF implementation to manage load peaks from PV, heat pumps and electric vehicles. • UK: review of Ofgem's LCNF found that projects that focus on flexible demand have a high potential value. • UK: all DNOs, an earlier Ofgem LCNF review showed that all DNOs are incorporating demand response as part of their approach to network investment. • IEA: Digital technology will open up more demand response opportunities, with the benefits potentially enormous through avoiding investment in new infrastructure. Also aids in the integration of variable renewable energy sources. • IET Power and Energy Series review, European activities: Integration of large-scale renewable energy sources. Aggregation, where projects focused on mechanisms to aggregate supply and demand flexibilities of decentralised resources to build virtual power plants and demand response. • IET Power and Energy Series review, Europe Outlook: SmarterEMC2 project - implements ICT tools that support customer side participation. • IET Power and Energy Series review, USA: Numerous demand response and distributed energy resource control projects underway. • IET Power and Energy Series review, Korea: Consumer integrated resource management systems for high value-add power services. Combines IoT and electricity. • USA, IRENA: Strongly recommends demand response as a means of dealing with integration of more renewables. • Australia: Ausgrid and Energex demand response programmes for capital deferral. • NZ: GREEN Grid industry-university, recommends demand side provision of a range of frequency keeping ancillary services to deal with more variable renewable energy (specifically wind).	• Increased demand response is seen as a means of preparing for the rollout of more variable renewables. • Studies show how demand response services from the demand side can aid the integration of higher proportions of renewables. • Practical experience from many distribution companies shows how the network size can be managed with demand response.	• Demand response to manage network peaks, energy prices, and provide ancillary services is very relevant, especially in enabling the demand side to participate in managing the network and ultimately actively helping establish wholesale electricity prices. • International experience, practice, and outlook is extensive. The activity is therefore very relevant. • The benefit, as demonstrated by practice, is management of network size and therefore avoiding reinforcement of the network. • Potential benefits that are crucial for increased variable renewable generation, such as wind and solar, are balancing of variable renewable generation. While this is possible with hydro in New Zealand, as the amount of wind generation increases, the need for the frequency keeping ancillary services to manage the variability will increase. Provision of frequency keeping services from the demand side will provide an alternative to hydro, which will help manage the cost. • Other benefits of demand response will be in managing the energy price, ultimately through being able to determine demand in real-time, in conjunction with a real-time wholesale electricity market. • The benefits to the customer will be management of the cost of network provision, and increased renewable energy generation. • Another potential benefit may be the ability to participate in setting wholesale electricity prices in concert with many other consumers.

Network Evolution Plan Activity	International Activities	Typical benefits that have been realised, or are expected to be realised, from investment in similar innovative/R&D type work in other jurisdictions.	The relevance and importance of the network evolution plan activity to distribution companies, and match with what other distribution companies internationally are investing in. How might benefits be shared with customers and other stakeholders.
8. Network Insights (low voltage feeders, transformer monitoring, etc.)	• Included in network insights is understanding hosting capacity of the low voltage network for distributed energy resources (PV and electric vehicles). • USA: EPRI authored paper makes the point that, just as capacity planning studies are performed for accommodating new load, hosting capacity planning studies are needed for integrating new DER. To meet this challenge, the industry needs appropriate methods to plan for and integrate DER into the distribution process. • IET Power and Energy Series review, European activities: Smart network management, improving distribution grid monitoring to cope with volatile states in the grid.	• The low voltage electricity distribution network is where most new technology is connecting. Research and practical measurements have shown that this will use the low voltage network in ways that it was never intended. The low voltage network is the least understood part of most distribution company networks, and because it is vast, the cost of understanding it has been prohibitive. With the nature of loads historically, a standard set of design and operating principles have been suitable to apply to most low voltage networks. • With the new types of load, and ways of using low voltage networks, greater insight into the low voltage network is essential. This includes understanding the ability of low voltage networks to host PV and electric vehicles (as mentioned above), monitoring networks to understand how they are used, and better understanding of the networks' parameters. This will become an important part of distribution company asset management.	• This activity is highly relevant given most emerging technology is connecting to the low voltage network. • Greater understanding of the low voltage network, its use, parameters, and ability to host emerging technologies will become part of distribution company asset management. • The benefit to the customer will be a network capable of connecting the new devices they wish to connect to it without escalating costs.
9. Real time asset ratings	• IET Power and Energy Series review, European activities: Smart network management research and implementations involving real-time asset monitoring and dynamic line rating. • UK: some DNOs, an Ofgem LCNF review showed that dynamic rating of assets has proven beneficial in some cases, and has been incorporated into normal practice by some DNOs. • The IEA predicts remote monitoring that allows equipment to be operated more efficiently and closer to its optimal conditions.	• As shown in the UK, use of real-time asset ratings has proven beneficial in some cases to optimise the use of assets. In New Zealand, if rating assets in real-time can avoid the need to replace or upgrade the assets, it may provide substantial benefit in terms of reducing expenditure.	• This activity is relevant to distribution companies in better managing their assets. It has been proven to be of value internationally. • The benefit to the consumer is maintenance of service quality and management of costs by better use of assets by the distribution company.

Network Evolution Plan Activity	International Activities	Typical benefits that have been realised, or are expected to be realised, from investment in similar innovative/R&D type work in other jurisdictions.	The relevance and importance of the network evolution plan activity to distribution companies, and match with what other distribution companies internationally are investing in. How might benefits be shared with customers and other stakeholders.
10. Energy storage	• Germany: Consortium from ABB and EWE, a north-western distributor. Green2store project, introduces the 'storage cloud' concept. Investigating the impact of decentralised battery energy storage systems. • Germany: research institute and utility. Investigating community energy storage schemes to provide reserves and optimise solar self-consumption as part of the Smart Grid Solar project. • UK: some DNOs. An Ofgem LCNF review showed that some DNOs are trialling storage for network management, but needed to consider other services to make an economic case. • UK: Ofgem. Indicates it will look to measure system and consumer benefits of storing electricity for self-consumption, and export to the grid at peak times, are realised in policies on small-scale low-carbon generation. • Japan: NEDO, a range of projects which include rechargeable batteries and energy systems. • USA: NREL. Estimate that 19GW of energy storage could enable 50% PV penetration in California. Followed up by a 2017 NREL report. • USA: GE Consulting. Point out that California, Oregon, and New York have passed laws that require (or allow requirements of) targets for storage. Notes that there are difficulties accessing the value of storage until rules evolve to allow aggregators into the market and allow market participants to access the value. • IET Power and Energy Series review, Europe Outlook: SmarterEMC2 project - storage. • IET Power and Energy Series review, USA Review: Demand response and distributed energy resource control. • Australia: CSIRO, Energex, Citipower and Powercor battery storage projects and trials. • UK: As part of the UK Government's clean growth strategy (part of its Industrial Strategy) at least £70 million over the next five years will be provided to support innovation in energy storage, demand side response and other smart energy technologies, including up to £20 million for vehicle-to-grid products and services. • UK: Government's Clean Growth Strategy (part of its Industrial strategy), discusses implementation of actions from the Smart Systems and Flexibility Plan to ensure participation of energy storage and demand side response in the market. • Netherlands: industry. Investigate the use of battery storage to manage connection of large scale PV plants to the electricity distribution network via long distribution feeders.	• Benefits include optimisation of solar self-consumption; network management; and increasing the penetration of solar PV in networks. • As concluded by and Ofgem review, it is difficult to make an economic case for storage for network management purposes alone. Hence other benefits, such as reserves, energy price exposure, and solar self-consumption need to be accounted for. This then requires some way of managing storage for all these services. Perhaps the greatest innovation New Zealand could achieve with storage at present is incorporation of it into the electricity market such that it can be used for the multiple services. In turn the economic case for storage would improve.	• International activity shows substantial research and innovation with storage to manage a variety of challenges in distribution networks. Storage will become increasingly relevant as its price reduces and markets develop to enable the variety of potential benefits of storage to be harnessed. • Ultimately benefits will be through better management of network peaks, better solar self-consumption, energy price management, and ancillary service provision. These can be maximised by storage being located in the distribution network or ideally 'behind the meter', as shown by studies. The benefits to the customer will be reduced electricity prices, but will only provide a net benefit when storage cost is low enough and, in most cases, when all of these benefits can be realised. • There may be specific cases where battery storage provides an innovative way to manage network needs now. Examples include alternatives to traditional distribution lines (such as remote area power supplies), or providing continued supply to areas, at times such as line maintenance, to avoid needing to provide physical redundancy, such as building a second line.

6. Conclusion

The international review shows high-level acknowledgement of the importance of electricity infrastructure, especially distribution, by Governments and inter-governmental agencies. This is in the context of the electrical power system as a vital infrastructure, as well as having a central role in solutions to the clean energy transition. This has translated to funding for research and/or innovation activities relating to emerging technologies, in countries such as the UK, Germany, the USA, Japan and Korea. This is for the dual reason that the research is necessary for the energy transition, and industrial development. Furthermore, some countries, such as the UK, have directly funded innovation by distribution companies.

The review shows a large amount of research and innovation taking place around the world in emerging technologies in electricity distribution. There is also an acknowledgement that distribution network companies need to transition to become distribution system operators, using emerging technologies to provide a range of solutions to meet the needs of consumers.

It is clear from this review that the network evolution activities planned by Powerco are consistent with those elsewhere in the world. There is widespread agreement that they will provide benefit to distribution system operators and consumers, and that they are relevant to distribution businesses who will face increasing challenges from a variety of emerging technologies connecting to their networks, now and in the future. Many of the activities are undertaken to avoid traditional reinforcements to the network. Without at least some of the proposed activities, such reinforcement would be required, ultimately leading to price rises for the consumer. The activities within Powerco's plan are a proactive approach to preparing for the future, to avoid a costly reactive 'catch up' after large uptake of emerging electrical technologies.

It is recommended that, when executing the Network Evolution Plan, Powerco undertake careful prioritisation of the activities planned, carefully define their scope to ensure maximum benefit, and make use of existing practices and technology where possible. With regard to energy storage, it is recommended that activities concentrate on how to utilise the multiple benefits potentially available from storage, acknowledging that there may be specific projects where storage already provides a solution to address network needs.

Appendix – global clean energy

United Kingdom

In its new industrial strategy, 27 November 2017, the United Kingdom recognises opportunities related to clean energy and e-mobility in what it refers to as four grand challenges:[51]

1. Artificial intelligence, of which it aims to put the UK at the forefront
2. Global shift to clean growth, of which it aims to maximise the advantages for the UK
3. The future of mobility, in which it aims to become a world leader in shaping mobility
4. Ageing of society, where it intends to harness the power of innovation to help meet the needs of changing demographics.

Clean growth refers to low carbon technologies and the efficient use of resources. The UK Government refers to it as "*…one of the greatest industrial opportunities of our time.*"[51] The strategy notes that "*The Paris Agreement of 2015 commits countries to revolutionising power, transport, heating and cooling, industrial processes and agriculture. The effect of these changes will be felt by businesses throughout the economy, and will involve the reallocation of trillions of pounds of public and private finance towards the pursuit of cleaner growth.*"[51]

The strategy states:

> *"A national electricity grid was a great British technical achievement. Now we are setting ourselves the challenge of remodelling it so it can handle many different sources of clean energy, and use new technologies to store energy and manage demand. We will launch a new Industrial Strategy 'Prospering from the energy revolution' programme to develop world-leading local smart energy systems that deliver cheaper and cleaner energy across power, heating and transport, while creating high value jobs and export capabilities"*[51]

That governments such as the UK Government consider its electrical grid amongst its four industrial strategy priorities highlights the critical role electricity plays in clean growth. With new forms of energy connecting to the grid, and it being used in new ways, the importance of the electricity grid and distribution network will continue to grow.

The future of mobility includes electric vehicle technology and self-driving cars. In the strategy, the Government states that it will invest heavily in charging infrastructure and R&D for new charging technologies. It commits to publishing "*a strategy on government support for the transition to zero emissions road transport, ensuring the UK continues to be a world leader in the development, manufacture and use of these vehicles.*"[51]

Germany

Germany uses the word "Energiewende" to refer to the Energy Transition. In its 2015 Energy Research Report, *"The energy turnaround – a good deal of work, research funding for the energy transition"*[52] the German Federal Ministry for Economic Affairs and Energy (BMWi), discusses the need for innovations to *"expand and upgrade"* the electricity network to deal with challenges from decentralised and fluctuating renewable energy. Discussed in this is the 2013-launched interagency funding initiative, "Sustainable power grids".[53] Projects within the sustainable power grids funding initiative are many and varied, and include:

- The proactive distribution network, involving anticipating congestion in the network (voltage level exceedance or overloading), requiring state determination. This applies state estimation to the network with the challenge of minimal network data. It also investigates optimal placement of measurements points in the network. The information aids the distribution network operator in operating the network and managing congestion.

- Its goal to create open, non-discriminatory, standardised access and transferable distribution coordination of the different 'players' using the distribution network. In addition, it aims for a flexible and reliable network, with optimal asset utilisation and reduced reinforcement costs, such that the distribution network contributes to an affordable energy transition.
- Voltage control to enable PV systems to continue to export to the grid without the need to reinforce the distribution network. This includes new power electronic devices to control voltage – leading to new export technology.
- Intelligent distribution automation, intelligent control and different network topologies, service platforms for load management to manage variable renewables, given the high cost of storage (known as the Servicing project)
- Combining several distributed generators and loads into a combined 'virtual power plant' which is operated in a coordinated manner (known as the Grid Integration project). As a result, a 'smart market' can be introduced to trade energy between them.

In addition, the BMWi is supporting substantial research of battery storage for the purpose of wind and solar regulation, network congestion management, and frequency control. This includes combining batteries with PV systems to increase self-consumption (tens of thousands of German homes now have battery storage systems) and for electric vehicles.

Europe

In Europe, a revised European Commission renewable energy target aims to increase the share of renewable electricity to 50% by 2030 (from the current 29%), as well as mainstream renewables in heating and cooling (which includes a move to heat-pump heating and cooling) and decarbonise transport (moving to electric vehicles).[54] This is part of a wider package of measures aimed at providing the stable legislative framework needed to facilitate the clean energy transition.[55] Europe sees this as an opportunity for European leadership in the clean energy transition, leading to economic and job growth, as well as reducing climate change.

Studies by the European Union show that achieving the climate change mitigation target of the Paris Agreement (staying below 2^{o}C temperature rise) is possible technically due to accelerating decarbonisation trends, an increased electrification of final demand, and changes in the primary energy mix that include a phase out of coal and reduction of oil and gas. In addition, it yields co-benefits via improved air quality that largely offset the cost of climate change mitigation.[56]

The USA

In the USA, despite the Trump Administration's announced intention to pull the U.S. out of the Paris Agreement and to roll back the Clean Power Plan, U.S. non-federal actors (such as states, cities and businesses) have taken on leadership for America on climate change, and are committing to reducing greenhouse gas emissions. This can be seen in the America's Pledge.[57]

Public Attitudes

While these deal with government policy, it appears from a recent green energy survey of 26,000 people across 13 countries that public attitudes support renewable energy, with support rooted in: national pride about technology leadership; concern about climate change; economic benefits; and societal benefits (particularly around reduction in health issues).[58] Attitudes showed that people want their country to increase usage of a variety of renewable energy types including solar, and offshore and onshore wind. The survey included 26,000 respondents, 2,000 per country nationally representative of the online population in age, gender, region and income. Countries surveyed include Canada, China, Denmark, France, Germany, Japan, the Netherlands, Poland, South Korea, Sweden, Taiwan, the UK and the USA.

The public attitude from this survey is broadly consistent with UK public attitudes, surveyed and summarised in the report "Energy and climate change public attitude tracker – Wave 23".[59] It is used to gauge public attitudes in the UK towards Energy and Climate Change strategies. It found 82% of respondents supported the use of renewable energy, an increase from 77% in June.

What might be possible?

Pushing the boundaries to what might be possible is a study conducted by a team from Stanford University, University of California at Berkeley, Technical University of Berlin, Germany, and Aarhus University, Denmark.[60] The study looks at the reduction in energy needs by 139 countries if they were to all convert from fossil fuel use to renewable energy (wind, water and solar) by 2050. It also ranks the countries according to their current status of achieving such a transition, and the assumed percentages of each generation type (wind, hydro, and solar) assumed to meet the transition. The results show New Zealand has approximately 11% renewable generation capacity installed today of what is required to fully transition the economy to renewable energy (estimated to be 66GW), ranking it 20th in the world. China has 5.8% and ranks 39th, while the USA has 4.2% and ranks 52nd of the 139 countries studied. This indicates substantial renewable development required by these large economies to reach such a goal. The paper also indicates the size of the renewable industry, the potential employment growth, and economic opportunities for countries that export renewable energy technology. The results also give breakdowns by countries of the types of renewable power required to meet such a target, and shows very high amounts of residential, commercial and utility scale solar required in New Zealand.

Additionally, and seemingly at the boundaries, is the concept of a 'super grid'. This recognises the increasing importance of electricity to society, and the challenges faced by increased variable renewable energy. The 'super-grid', or global electricity network, involves the interconnection of continental networks to make use of the time varying nature of renewable resources (solar in particular) and provide more resource for balancing variable renewable energy. The worldwide technical organisation, CIGRE (Conseil International des Grands Réseaux Electriques), has launched a pre-feasibility study on the economic interest of a global electricity network for inter-continental and cross border backbone interconnections. Researchers from Europe and China are already investigating the feasibility of such a network.[61] The American based Institute of Electrical and Electronic Engineers (IEEE) have recognised the advantages of a global power grid, or 'super grid' for some time and have published research and articles related to it for several years.[62]

The Stanford study and global network represent possibilities some way into the future. However, the review of policy in the UK, Germany, Europe, and the USA shows a very strong push at present to clean energy, with electrification using renewable energy at its heart, and e-mobility. Studies also show strong public support worldwide for renewable energy technologies. It is therefore reasonable to expect increased renewable energy technology connecting to the grid, and new ways of using electricity to convert to renewable energy use. Since much of the renewable generation, and new loads, will connect to the electricity distribution network, it is only reasonable to expect distribution owners and operators to want to evolve their networks to cope with such change in the future. This is to continue to be able to provide a reliable level of supply cost effectively.

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