WORKING TOGETHER ON RESILIENCE

SEPTEMBER 2018

SETTING THE SCENE:

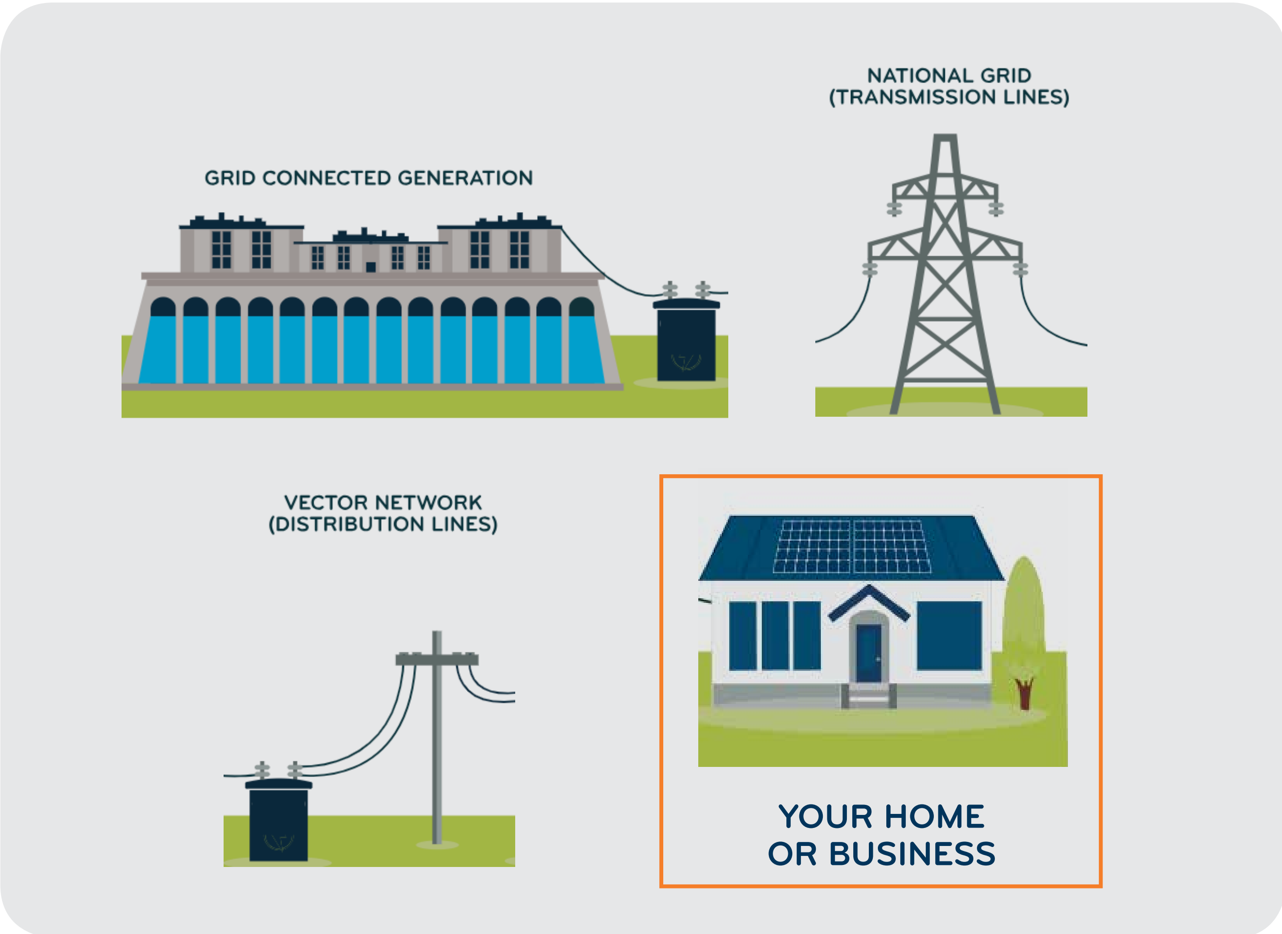
INCREASING THREATS TO ELECTRICITY RESILIENCE ACROSS THE SUPPLY CHAIN

KEEPING THE LIGHTS ON AMID INCREASING COMPLEXITY

- Electricity consumption is changing rapidly as consumers electrify their lives, increasing expectations on the reliability of the energy system. Consumer dependency on electricity will continue to rise with the advent of new technology solutions and the uptake of electric vehicles.
- In parallel with the rising importance of the electricity system, the impacts of environmental factors, such as climate change, are increasingly being felt in New Zealand and across the world. With climate change increasing the likelihood of adverse weather events, it is clear that the number and duration of electricity outages will rise.
- This paper discusses the resilience of the electricity system from an electricity distribution business (EDB) perspective. Other parts of the electricity system, while not specifically discussed, play a critical role in energy resilience, therefore the resilience of the whole system is important.
- As increased electricity system resilience comes at a cost ultimately borne by consumers, Vector believes that the various options, trade offs, and costs should be transparent, especially as new technology creates greater choice for household-based resilience options. These options, such as household battery and solar installations, and Vehicle to Grid electric vehicle chargers, have additional benefits over and above increased customer resilience, for example off-setting energy costs and providing carbon benefits.
- While the Vector network currently provides, on average, 99.7% reliability, with the increasing criticality of electricity, consumers may no longer find this sufficient. To increase the resilience of the network however, Vector does not want to burden future generations with costly solutions that have long-term regulated cost-recovery periods, may only benefit a limited number of consumers, and that cannot ensure the lights will stay on. For example, where there are resilience threats to generation and transmission due to drought or equipment failure, this will have a flow on impact to the distribution network, regardless of the newly implemented network-focussed resilience measures.
- With the emergence of new technology, there are increasing resilience options for consumers, outside of network scale measures. These consumer-focussed solutions provide households and businesses with greater control, have shorter financial returns that do not burden future generations, guarantee consumers directly benefit from resilience investments, and as mentioned, provide further benefits, such as off-setting energy costs.
- This paper aims to create transparency, to support consumers to understand the options available to them and the trade offs required to take control over their energy resilience. While previously only network, transmission or generation-based solutions were available to increase resilience, the emergence of new technology, and the rapidly declining cost curve for these technologies, is creating new opportunities for customer controlled resilience options.

RESILIENCE MUST BE SYSTEM-WIDE

THE ELECTRICITY SUPPLY CHAIN IN NEW ZEALAND:




Dry lake bed – high country NZ


Transmission tower failure – South Australia


Tree damage – 10 April storm Auckland

THREATS TO RESILIENCE IMPACT EACH SEGMENT OF THE ELECTRICITY SUPPLY CHAIN DIFFERENTLY

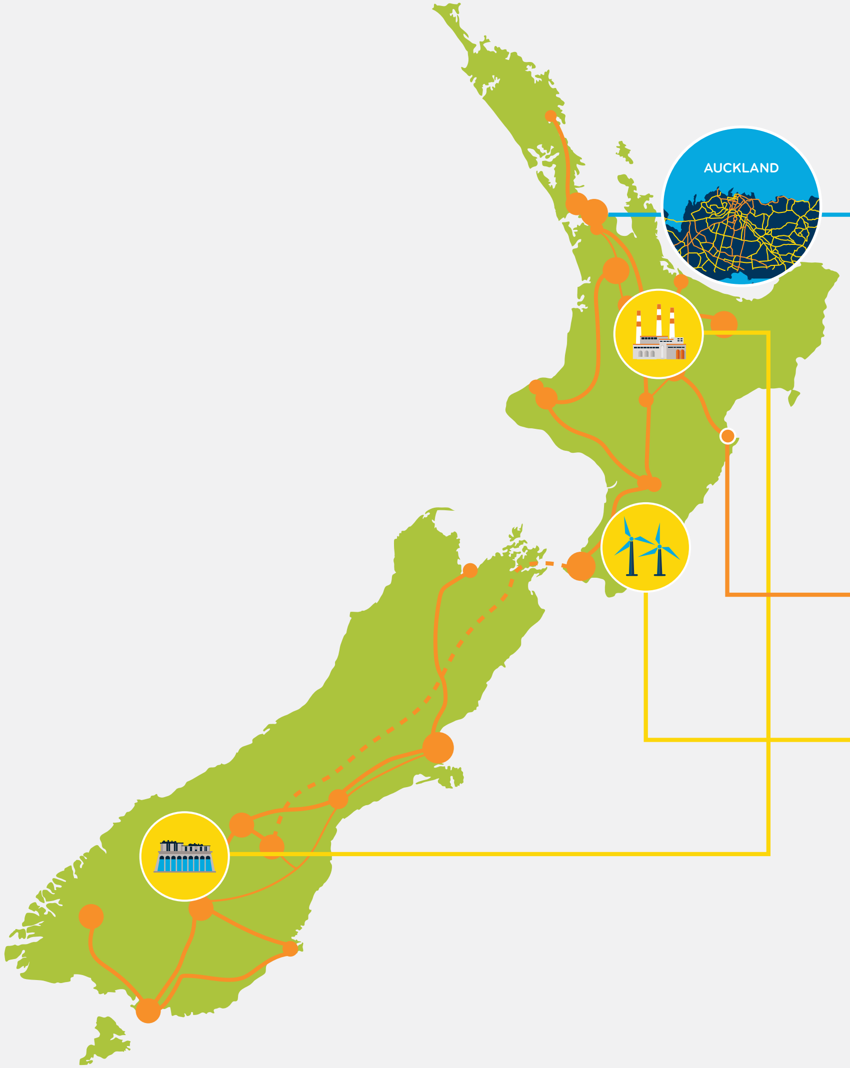
The electricity supply chain is an interdependent system that includes large-scale generation, transmission lines, distribution networks and customers. The resilience of supply must therefore be understood from a system-wide perspective.

There are a wide range of factors which can affect the resilience of electricity at each stage of the supply chain. Some of these threats are unique to generation, transmission or distribution, while others are common across the supply chain, however the magnitude of the impact may differ. The diagram on the next page illustrates which resilience threats are common to all elements of the supply chain, and highlights some of the unique threats, such as vegetation and vehicles, at each level of the supply chain.

On any given day, there are likely to be multiple threats to resilience, for example a combination of drought and high temperatures. These threats can heighten resilience risks, create short-term localised damage, or create wide spread and long-term challenges to electricity supply.

The New Zealand electricity system is particularly vulnerable to environmental impacts with 80% of our electricity coming from climate-dependent wind and hydro generation. New Zealand's remote location in the South Pacific also makes it prone to natural disasters. Auckland is at risk from a wide range of natural disasters due to its location on a narrow coastal land mass on top of a volcanic field.

Environmental factors, including climate change, in combination with natural hazards will impact each part of the electricity system differently, but ultimately affect customers directly.



DISTRIBUTION

- HIGH WINDS
- FLOODING
- SEA LEVEL (HIGH TIDES/COASTAL EVENTS)
- VEGETATION
- VEHICLES (CAR VERSUS POLE)
- ANIMALS TOUCHING ELECTRICITY LINES

TRANSMISSION

- HIGH WINDS
- FLOODING
- COOK STRAIT CABLE FAILURE
- SEA LEVEL (HIGH TIDES/COASTAL EVENTS)

GENERATION

- LOW WIND LEVELS
- WATER TEMPERATURE
- DROUGHT

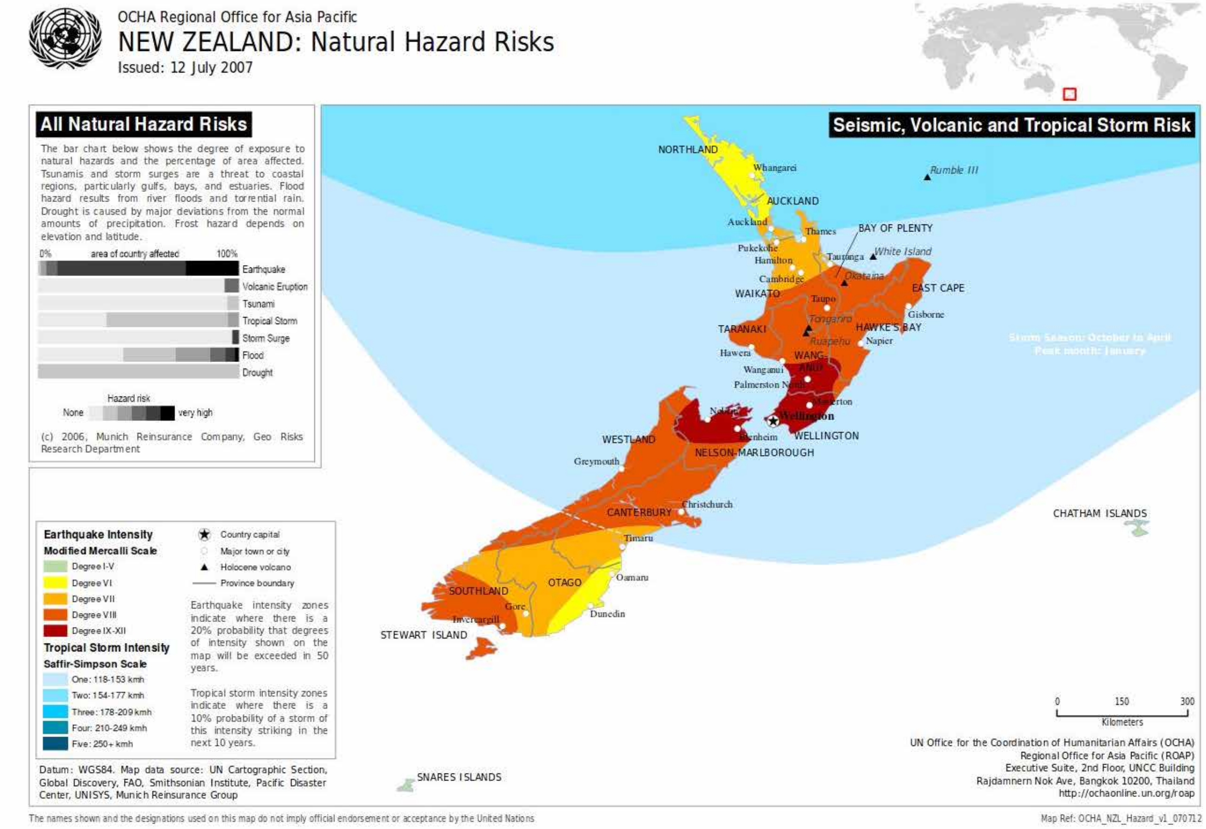
CROSS SUPPLY CHAIN

- EARTHQUAKE
- CYBER-ATTACK
- VOLCANIC ACTIVITY (ASH TRAVEL AND IMPACT)
- FIRE
- EQUIPMENT FAILURE
- LANDSLIDES/EROSION
- AIR TEMPERATURE
- LIGHTNING
- GEOMAGNETIC REVERSAL (EXTENDED PERIOD OF WEAK MAGNETIC FIELD)
- SOLAR FLARES (INCLUDING CORONAL MASS EJECTION)

THE FACTS AND FIGURES:

UNDERSTANDING THE IMPACTS OF EMERGING ENVIRONMENTAL FACTORS SUCH AS CLIMATE CHANGE

EXAMPLES OF KEY ENVIRONMENTAL RISKS - NEW ZEALAND



The October 1995 eruptions of Ruapehu volcano deposited 7.6 million m3 of coarse ash into the Tongariro river catchment, leading to high levels of suspended ash. This catchment feeds the Rangipo power station (120 MW). While generation remained continuous throughout the eruption, two Francis turbines and all auxiliary components that had been in contact with ash-laden intake water were found to have suffered greatly accelerated abrasion damage, with 16 years' damage sustained in 6-7 months. A refurbishment program installed hardened components. Turbidity instrumentation was also installed

RECENT EARTHQUAKE DISASTERS INCLUDE:

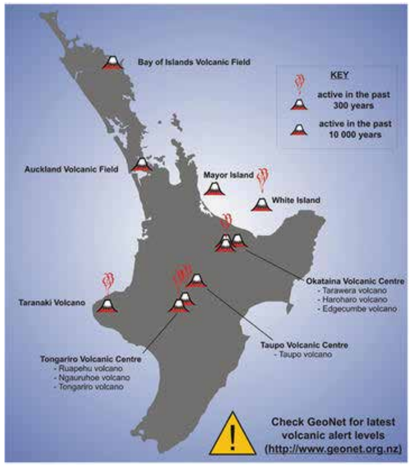
- 2010/11 earthquakes in Christchurch;
- 2016 Kaikoura earthquake.

RECENT STORMS AND FLOODS INCLUDE:

- Lower North Island 2004 floods;
- Winter Weather Bomb 2008;
- Ex-Tropical cyclone Wilma 2011;
- Cyclone Gita 2018;
- Auckland Storm 2018.

RECENT DROUGHTS INCLUDE:

- In 2008, following two years of dry weather, New Zealanders were asked to cut electricity consumption by 15% or face rolling power cuts.

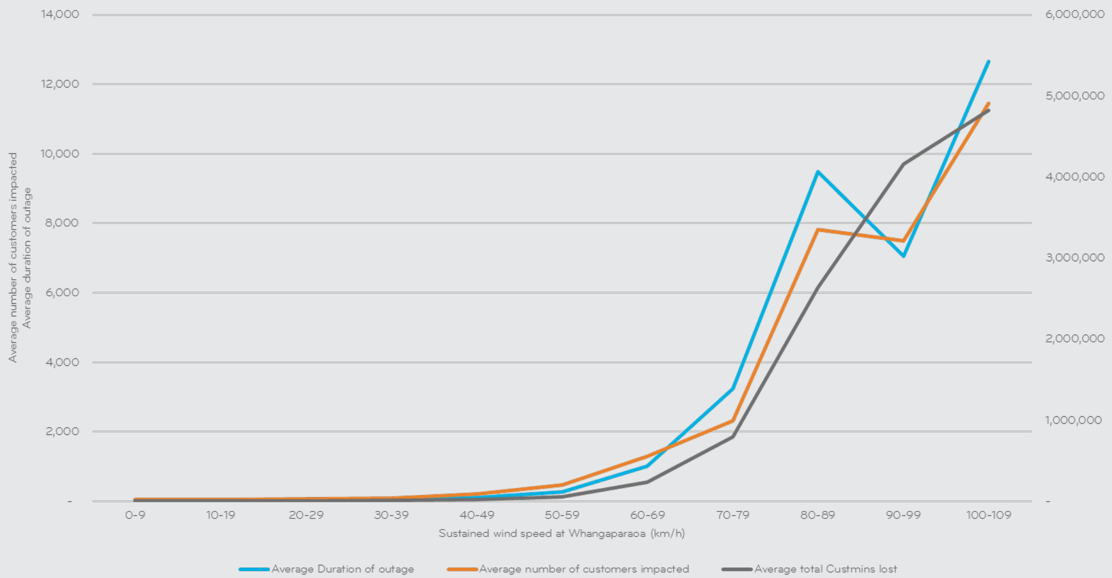


http://www.gns.cri.nz

KEY CLIMATE CHANGE RISKS TO VECTOR'S NETWORK

- Vector has undertaken an assessment of the risk of different climate parameters to the Auckland electricity and gas network - The Physical Effects of Climate Change report, completed by EY in November 2017 (Ref. 1).
- An analysis of Vector's outage data revealed climate variables, particularly wind, with historically high impacts.
- The graph below shows that as sustained wind speeds on the Vector network exceeded 70km/h there is a significant increase in the duration of outages (blue line), customer minutes lost (grey line) and number of customers affected (orange line).
- The EY model projects that the number of hours with wind in the 70-80km/h range will increase significantly.
- Taking the 75th percentile output (1 in 4 chance) the projected increase in customer minutes lost is expected to increase by 200% by 2030 and almost 400% by 2050.
- The impacts of climate change are felt across the electricity supply chain, as illustrated below.

Average outage duration, customers impacted and total customers lost based on wind speed (2004-16)



Key climate change risks on whole electricity system

Table 2
Potential climate impacts per asset class

	Generation				T&D	
	Thermal	Hydro	Wind/PV	Biomass	Lines	Stations
Air temperature	●	●		●		
Water temperature	●			●		
Water availability	●	●		●		
Wind speed			●		●	
Sea level	●	●	●	●	●	●
Floods	●	●	●	●	●	●
Heat waves	●		●		●	●
Drought	●	●		●		
Storms					●	●

Source: Adapted from Asian Development Bank (2012).

1. The results of EY's work, including the assumptions and qualifications made in preparing the report, are set out in The Physical Risks from Climate Change - Report of Findings for Vector Limited dated November 2017 ("Report"). The Report has been prepared for Vector. EY disclaims all liability in relation to any other party who seeks to rely upon the Report or any of its contents.

CUSTOMER CHOICE:

EMPLOYING BOTH CUSTOMER AND NETWORK-FOCUSSED SOLUTIONS FOR INCREASED RESILIENCE

A SHARED APPROACH TO RESILIENCE

A smart, resilient, energy future will embrace multiple solutions to increase resilience.

EDBs typically have the following investment options to improve resilience:

- Establishing microgrids using distributed and renewable generation;
- Undergrounding or relocating exposed parts of the network;
- Using new technology network storage options (becoming increasingly feasible by rapidly falling costs);
- Using new technology options such as aerial bundled conductors and smart poles (enabled by declining costs of sensors and network communication technology);
- Changing the configuration of the network to be more meshed;
- Utilising temporary generation; and
- Increasing vegetation cut zones, removing trees that can fall on lines and limiting third party asset strikes (vegetation management is also under the control of the government, councils, and other infrastructure providers, as well as consumers).

Undergrounding is an example of the challenges EDBs face in improving resilience alone. EDBs cannot simply underground entire networks as the cost would be an unmanageable burden on consumers (an estimated $5.5 billion to underground the remaining 45% of Vector's overhead network).

In addition, an overhead network typically has an economic life of 40 years. If an EDB prematurely replaces an overhead network with an undergrounded network, there is a significant cost impact on future generations of consumers, since the costs are recovered over the 40 year economic life of the asset.

This solution also cannot ensure resilience against adverse events such as flooding and earthquakes.

Alternatively, a household can purchase a small mobile generator, which has a two year payback, compared to the increase in line charges to underground the network. This solution also provides the guarantee that the consumer will receive the benefit of the investment without cross-subsidisation or burdening future generations.

Customers' now have individual options to improve resilience, thanks to new technology and reducing costs, including:

- Mobile on-site generation;
- Permanent on-site generation;
- Renewable generation;
- On-site storage solutions;
- Solar energy and battery solutions;
- Vehicle-to-Home (V2H) solutions that utilises the energy stored in a EV to supply a home during an emergency; and
- Private on-site asset management (e.g. sewerage systems).

Under a shared resilience model, customers, electricity supply chain participants (generators, Transpower, distributors), and government (both central and local) work collaboratively to develop a suite of targeted solutions that acknowledge the various trade-offs, including cost, life span, number of customers affected, and the resilience threats mitigated.

As environmental factors and changing consumption patterns increase the threats posed to our electricity supply, it is vital that we work together now, to embrace a resilient energy future.

INVESTMENT OPTIONS FOR AN EDB TO IMPROVE RESILIENCE

OPTION	DESCRIPTION	COMMENT
Microgrids	Distributed generation combined with new storage options to island electricity supply to a small group of consumers during a grid emergency.	Cost effective option made possible by improved efficiency of batteries and declining cost.
Underground or relocate existing overhead lines	Exposed parts of the overhead network are put underground (e.g. where there is a high occurrence of car vs. pole incidents.)	Very expensive with a financial burden on future generations due to the long-life nature of the assets and the write-down of existing assets.
Network storage	New battery and other storage technology.	Cost effective option due to improved efficiency of batteries and declining cost. Can be scaled over time. Has optionality to relocate when needed.
Network design changes	Deploy new conductor types (e.g. aerial bundled conductors).	A feasible option based on increasing maturity of the required technology. Challenge to retrofit due to economic write down of existing conductors.
Network topology	Add additional circuits by meshing traditional radial lines.	Increase resilience where the customer segment has migrated from rural to urban, typically on the fringes of the network, as the city expands.
Distributed generation	Where network support is only required for short periods of time, create permanent connection points for fast deployment of mobile generation during emergencies.	A good substitute for building traditional lines with a shorter economic life, which provides more investment flexibility. Can use renewable and/or fossil fuel.
Temporary generation	Large and small scale mobile generation used to support consumer load during emergencies.	Typically fossil fuel generation so has implications for noise and pollution control. Very flexible investment option.
Provide infrastructure for alternative fuel source	Where economical, electricity can be substituted with reticulated gas networks to provide additional resilience.	If reticulated gas exists locally, it could be a cost-effective way to provide alternative heating and cooking options if the electricity network is affected by an emergency.
Vegetation clearance* outside regulated cut zones	Increase the regulatory cut zone as per the Electricity (Hazards from Trees) Regulations 2003.	Need legislation to support a risk based approach to vegetation management and for tree owners to pay the costs associated with managing their trees.
Third party interference* (e.g. car vs. pole)	Work with government, councils, industry, etc. to mitigate the exposure of the network to third party interference.	Ensure the impact of third party interference on resilience is understood and managed collectively.

*These are predominantly outside the control of the EDB, e.g. need to influence legislation, councils rules, other infrastructure providers and consumers in order to make changes

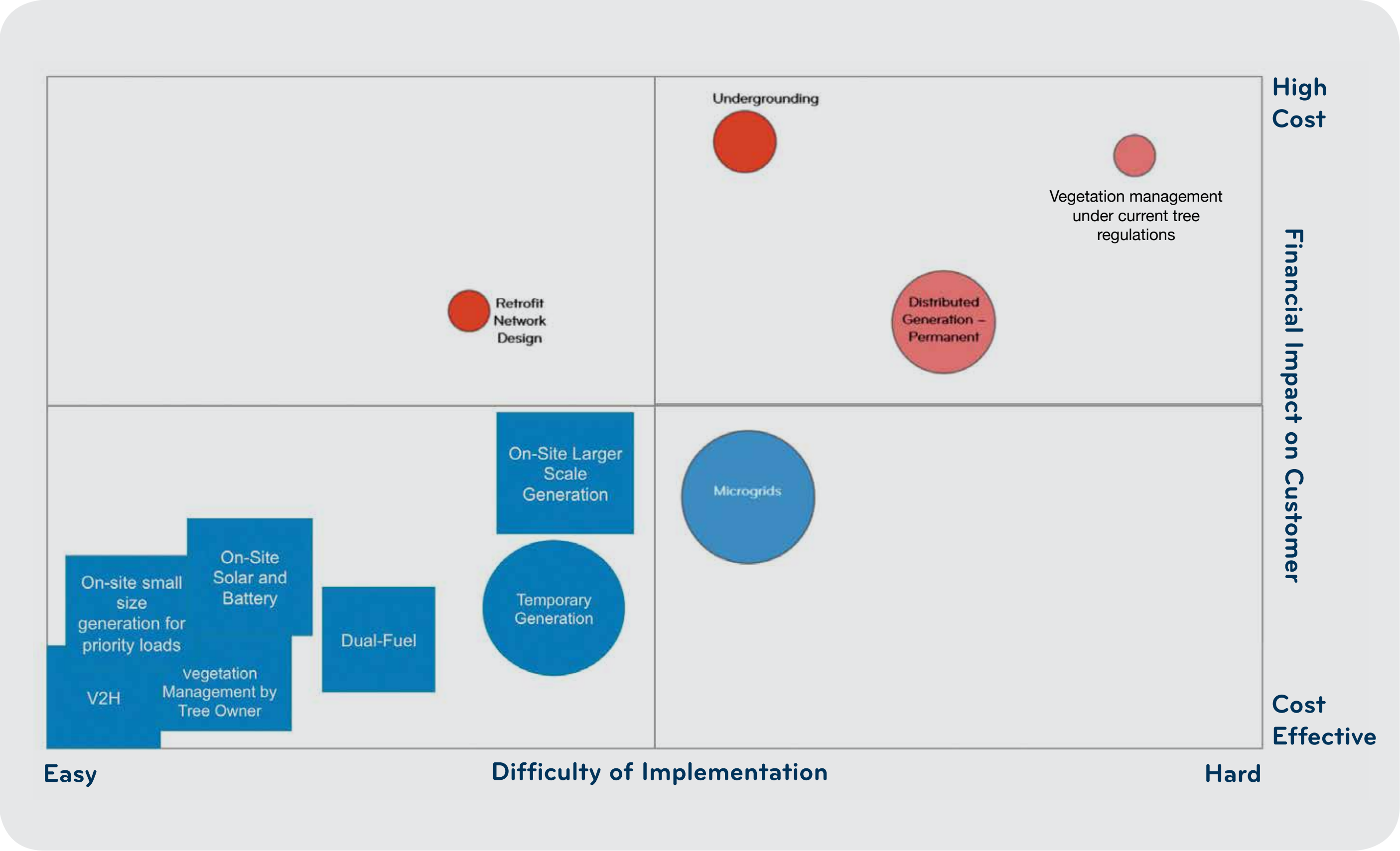
INVESTMENT OPTIONS TO IMPROVE INDIVIDUAL ON-SITE RESILIENCE

OPTION	DESCRIPTION	COMMENT
Renewable generation combined with storage	Utilising solar energy to charge a battery during network emergencies.	Very effective investment option targeting individual customer needs. Can be scaled as customer needs change.
Vehicle-to-Home (V2H) solutions	This option utilises the energy stored in an electric vehicle's battery to supply a home during an emergency - enabled by new technology and associated lower price points.	Very effective investment option providing multiple benefit streams to the customer.
Community generation	The use of privately owned microgrids to support small customer groups during emergencies.	A targeted investment option that caters for the specific needs of the community, e.g. holiday homes.
Temporary on-site generation	The use of mobile generators to supply critical loads during network emergencies.	Cost effective and flexible option because costs are only incurred when activated, but need time to deploy.
On-site storage solutions	Standalone storage options such as batteries, flywheels, hot water storage and gas bottles to provide both network and energy substitution.	The price point of these technologies is rapidly coming down, providing cost effective new, technology-based options for customers. E.g. bottled gas is a cost-effective way to provide alternative heating and cooking options if the electricity network is affected by an emergency.
Permanent on-site generation	The use of fossil or renewable generation, permanently installed on site e.g. wind power.	This is a more costly option than temporary generation but it has a much shorter deployment time.
Private on-site asset management	Ensure on-site assets are maintained, e.g. private overhead lines kept clear of trees; and mitigate the risk around critical systems such as on-site pumped sewerage through dedicated, small back-up generators.	Requires understanding of individual exposure and options available to mitigate the risk.

CUSTOMER CHOICE MATRIX

The matrix below is a tool Vector is developing to support customer decision making regarding the resilience option best placed to mitigate various threats to electricity supply.

The matrix includes both network and individual solutions and attempts to highlight the trade-offs for each potential resilience measure.



KEY:

- Squares indicate customer solutions, circles indicate network solutions.
- Size of circle or square indicates 'cost effectiveness' of the resiliency solution.
- Red indicates a higher impact on future generations, blue indicates lower impact.

POLICY AND REGULATION

THE POLICY AND REGULATORY FRAMEWORK TO SUPPORT SHARED RESILIENCE

REGULATORY FRAMEWORK TO ENCOURAGE RESILIENCE

A SHARED UNDERSTANDING OF RESILIENCE

- Designing an agreed definition and metric of resilience would support the quantification of risk and implementation of measures that could improve resilience.
- While it is important to develop a widely agreed concept of what resilience is, it is also essential that a framework for achieving resilience (and not simply reliability) is recognised in regulation and by regulators and policy makers. Industry participants cannot be expected to provide resilience for New Zealanders, while being hindered in their ability to achieve it under regulatory frameworks that do not recognise the significant impact of climate change, or the increasing criticality of electricity, for example.

RESILIENCE REGULATION

- The only official act that enforces resilience is the Civil Defence and Emergency Management Act (2002) that specifically discusses the duties of lifeline utilities.
- MBIE's Technical Working Group on Climate Change Adaptation was established in November 2016 to advise the government on how to build resilience against climate change and a stocktake report was released in 2017 to help build an industry-wide understanding of risks associated with Climate Change. However, no further resilience policy and governance structure is in place to promote resilience.
- The current regulatory framework is focussed on reliability rather than resilience, based on historical benchmarks. This does not recognise the exponential changes that are occurring due to new technology and climate change.
  A renewed focus must be given to developing:
    - an agreed upon concept of resilience;
    - an appropriate framework for measuring resilience to assess industry participants' success; and
    - regulatory recognition of the resilience framework, to ensure there are appropriate incentives for action.

REGULATORY FRAMEWORK TO ENCOURAGE RESILIENCE

RESILIENCE CONCERNS WHICH SHOULD BE RECOGNISED UNDER A STRONG REGULATORY FRAMEWORK

- **Forecasting extreme weather -** Forecasting is essential to improving preparedness and evaluating the benefit of infrastructure investment. Capturing the impact of climate change on weather patterns will be increasingly important to make long-term infrastructure planning decisions, as historic data alone fails to capture the changing weather patterns. The investment needed to undertake essential forecasting, as well as the necessary data required, must be enabled and supported by regulators.
- **A business case and financial mechanisms for resilience initiatives –** Resilience is an important consideration for the economy and all initiatives need to find the right balance between prevention and response. Traditional business case approaches only consider normal operation and do not recognise the value of certain investment alternatives in increasing resilience, which slows down the deployment of new energy technology and analytics that can make vital contributions. A paradigm shift in financial mechanisms and business case modelling is required across industry and government.
- **Regulation to encourage investment in new technology –** Regulatory support of new technology is essential to increase business certainty. The long-term investment recovery framework for poles and wires increases the risk of investment stranding and new technology solutions provide credible alternatives for networks to renew and adapt to changing energy needs of consumers. Consideration for accelerated depreciation must be given as the pace of change quickens.
- **Widening investment considerations to allow for resilience –** Under the current regulatory framework spending is based on historical benchmarking, however what has been done previously, will no longer be appropriate to ensure resilience in future. Following Superstorm Sandy and the extensive damage done to regional distribution systems and substations, the New Jersey Board of Public Utilities approved more than $1 billion for hardening and modernizing Public Service Enterprise Group (PSEG) electric and gas infrastructure.
- **Recognition of climate change –** Climate change resilience is not currently considered by the Electricity Authority and Commerce Commission, which discourages appropriate investment and appears to run counter to the government's stated aims of achieving carbon neutrality. Climate change must be recognised across all regulation and regulators, not confined to climate legislation.
- **Access to data –** Data is increasingly important for the resilience of the energy sector. Due to a quirk in the market structure, most electricity retailers refuse to share timely and sufficiently granular data, jeopardising the resilience of electricity networks. Regulators must recognise the public value inherent in leveraging New Zealand's successful smart meter roll out for the benefit of network planning. As experienced by Vector in the recent April storm event, access to data is an essential component of adaptability and recovery from adverse events. Vector had limited oversight of the outages on its network at the low voltage and customer level, and was therefore hindered in its ability to restore power. Timely access to this granular data must be provided to EDBs, as the body responsible for the resilience of our electricity networks.

LEGISLATIVE CHANGE TO ENCOURAGE RESILIENCE

VEGETATION MANAGEMENT

- The challenge for network companies under the Electricity (Hazards from Trees) Regulations 2003, is that only vegetation in a limited area can be trimmed, essentially where it is almost directly against power lines – the 'growth limit zone'. This hinders EDBs' ability to adequately protect the electricity network during adverse weather events, where trees damage power lines from outside of the growth limit zone.
- The Electricity (Hazards from Trees) Regulations 2003 are highly prescriptive as they focus on set distances between trees and lines. For the vast majority of trees, these distances are grossly inadequate. For example, in some cases no action can be taken until a tree branch is as close as half a metre from a line. This is a very small gap and clearly insufficient to prevent trees swaying in high winds to clash with lines. Some trees are also very fast growing and might require two trims in a season, which is both costly and inefficient. Fast-growing trees also tend to be less resilient to high winds and therefore pose a greater risk.
- The regulations take account of only two parties — the lines company and the tree 'owner'. There can be significant issues identifying the tree owner, which can be different to the landowner or occupier. For example, in the case of forestry, the tree owner might be a post office box in Geneva. While tree owners may be difficult to locate and/or communicate with, at-risk trees continue to grow. The two parties must follow a complex process involving the measurements of tree distances within various zones, issuance of formal 'cut and trim' notices for every tree, and punitive action procedures to be followed. While the failure to obey a cut and trim notice could result in a theoretical $10,000 fine, there is no record of a fine ever being imposed.
- Even after a tree is cut the problem persists. While a newly-pruned tree might be physically separated by up to 1.5m from a line, the tree may tower many metres directly above a line, meaning branches can fall across conductors, shorting them out or bringing them down.
- There is an urgent need to move to a modern, principles-based framework, which allow EDBs to carry out and act on risk assessments for trees near power lines and oblige tree-owners to take more responsibility for their own trees. The risk assessment could include factors such as; customer numbers that might be affected by an outage, tree species, age and condition of the tree, overhanging branches and fall distance, issues of public safety, risk of fire etc.
- A review of the tree regulations by MBIE was signalled three years ago in the government's infrastructure plan released in 2015. A review was timetabled to be carried out in the 2017-19 financial years. However as far as Vector understands, no form of vegetation management review has yet to commence.
- In Vector's view, it is not equitable for lines customers to bare the cost of vegetation damage or cutting when land owners should be accountable for this. Conceptually, simply expecting lines businesses to cut customer owned trees and spread these costs across all customers does not align with the principles of cost causation and is effectively increasing costs to consumers via those tree owners avoiding their vegetation management responsibilities and creating an impost onto electricity consumers.

CASE STUDIES

CASE STUDIES FOR SHARED RESILIENCE

VECTOR CASE STUDY IN SHARED RESILIENCE

- V2H (Vehicle to Home) is an innovative solution that allows customers to supply their home with the energy stored in an electric vehicle (e.g. Nissan Leaf). This is of great benefit to customers, especially during network outages.
- Vector is the only utility in Australasia trialling 3kW and 6kW V2H units. Figure B depicts the combination of loads that could be supplied using a 6kW V2H solution.
- Using a 28kWh Nissan Leaf EV, a residential customer could supply a 6kW load for more than four hours and a 3kW load for more than nine hours.
- V2H is an example of a cost effective, non-network alternative to network reinforcing that gives the customer choice and control.

Figure A: V2H supply chain

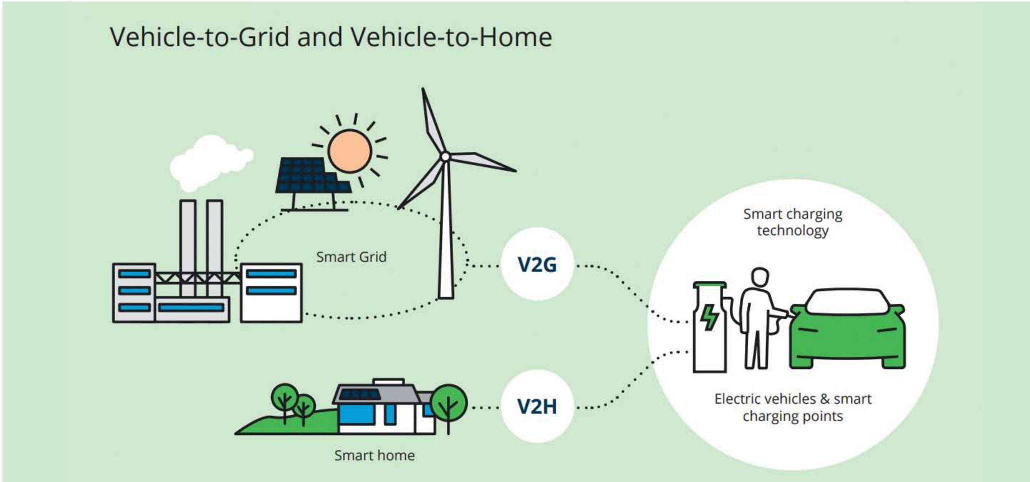
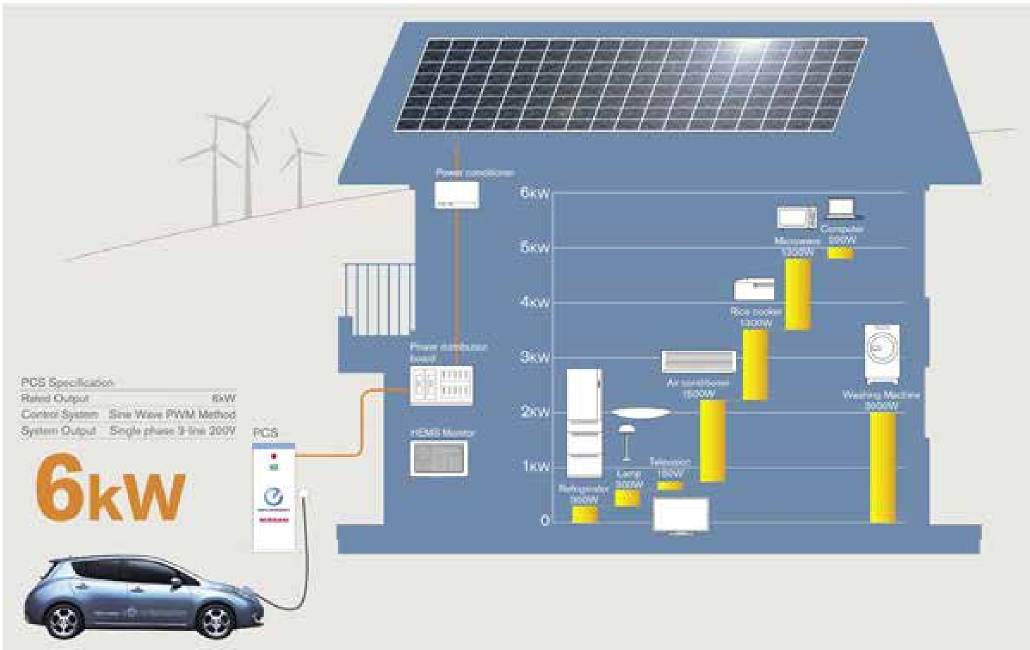


Figure B: Possible load combinations supplied by V2H



VECTOR CASE STUDY - DISTRIBUTED VS. SYSTEM OPTION

In remote locations, ensuring resilience with traditional network solutions is often cost-prohibitive relative to the number of customers served. In addition, climate change is creating access issues across Vector's network through road and land slips. This is where microgrids become economic to deploy.

Most microgrids are network connected but can 'island' themselves in the event of a network outage. This enables microgrids to provide those connected to them with backup power and improves electricity resilience to remote communities in a cost effective way.

Kawakawa Bay is a remote, coastal community, supplied via a 11kV feeder that follows the road across a precarious landscape. The road is very susceptible to slips and the effects of climate change mean it is happening more often. There is no practical way to run a different supply into the area. Vector is deploying a 1MW/1.7MWh microgrid to improve resilience in this area of the network.

Vector's microgrid location at Kawakawa Bay

Road slips causing a power line to fall over at Kawakawa Bay

INTERNATIONAL CASE STUDY

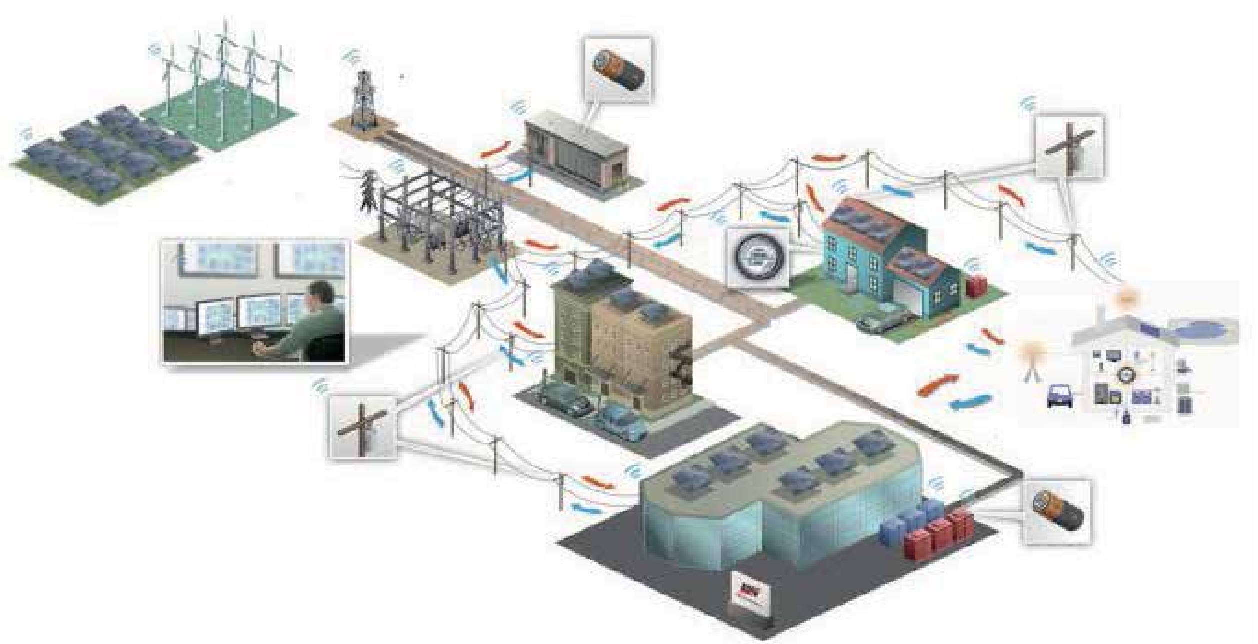
MICROGRIDS IN AMERICA AND JAPAN

JAPAN

The Fukushima disaster in March 2011 triggered a discussion on resilience. A new growth strategy called 'Rebirth of Japan' was formulated that emphasised the development of smart grid innovation as a vehicle to increase disaster resilience. (Ref. 2).

The Japanese government supported this with a 'National Resilience Program', which provided 3.72 trillion yen/$33.32 billion in funding for the 2017 fiscal year, which will be increased by 24 percent in 2018. The programme has spurred the creation of microgrids and distributed power generation across Japan, reducing municipalities dependence on large power plants.

The city of Higashi Matsushima, with 40,000 inhabitants, chose to construct a self-sustaining system capable of producing an average of 25 percent of its electricity without the region's local power utility. In the case of a severe event that cuts supply to this small city, the independent microgrid with its solar PV panels, biodiesel generators and batteries can run the city for at least three full days.



AMERICA

The Borrego Springs microgrid was developed from an existing utility circuit as a 'proof-of-concept' (Ref. 3) in a remote area of California. The project demonstrated that the microgrid could reduce the peak load on the circuit by 15 percent or more, and energy storage was shown to firm the intermittency of rooftop solar photovoltaic (PV) systems. Most importantly, it demonstrated the ability to island in and out an entire microgrid seamlessly in order to improve resilience:

- **Planned Outage** (June 2012) the microgrid provided power to 2,128 customers for 5.5 hours;
- **Planned Islanding** (Q1 2013) conducted seven islanding events over three days;
- **Windstorm** (April 2013) the microgrid provided power to 1,225 customers for 6 hours;
- **Flashflood** (August 2013) CES units islanded six customers for 5.5 hours; and
- **Intense Thunderstorms** (September 2013) the microgrid provided power for up to 1,056 customers for more than 20 hours.

2. https://www.japantimes.co.jp/community/2017/03/04/how-tos/will-ever-see-no-obstacles-way/#.Wt6SnmeYPoo

3. San Diego Gas & Electric (2013), Borrego springs microgrid demonstration project

INTERNATIONAL CASE STUDY

KEEPING THE LIGHTS ON DURING HURRICANE SANDY

- Hurricane Sandy left 8.5 million people without power in 21 American states - the highest outage total for any American extreme weather event in history and the second-costliest hurricane ever to hit America (after Hurricane Katrina).
- While most of downtown Manhattan had no power, New York University's 13.4MW CHP plant and self-sufficient microgrid system, which distributes electricity independently, supplied electricity to 26 of its buildings.
- In the year after Sandy (2012-13), America dedicated $56 million to microgrids (Ref. 4).
- In 2014, the North-eastern states spent $84 million on microgrids, with at least one in nearly every state. The State of Connecticut had one microgrid before the storm, now it has eight. New York went from 10 microgrids pre-storm to 17, while New Jersey jumped from three to seven.

New York during Hurricane Sandy

Photo credit Iwan Baan

4. https://www.greentechmedia.com/articles/read/five-years-after-sandy-is-the-northeast-closer-to-resilience

INTERNATIONAL CASE STUDY

SUPERSTORMS DRIVE INVESTMENT OPTIONS AT CONSUMER LEVEL

Severe weather is the leading cause of outages in America, causing over 87% of outages (Ref 5), and the American Department of Energy has recognised that the frequency and intensity of storms are increasing. Seven of the ten most costly storms in American history occurred between 2004 and 2012 (Ref 6).

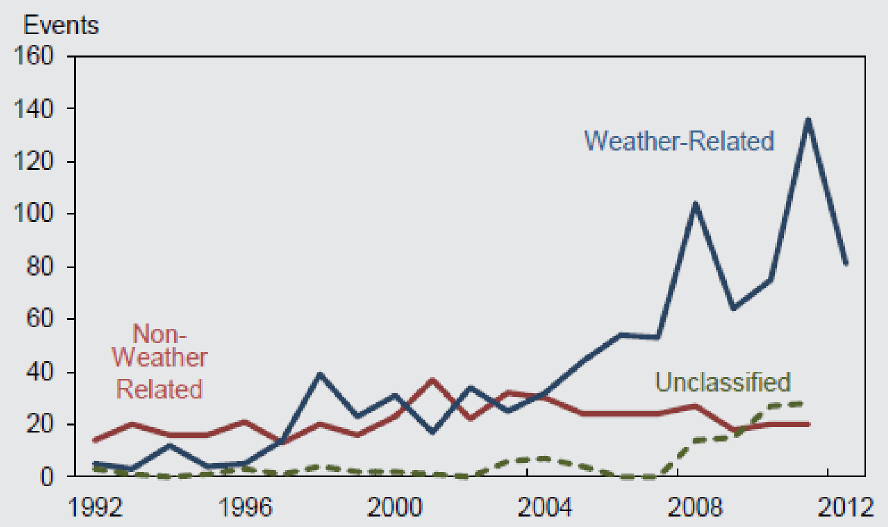
Superstorm Sandy in 2012 is now often credited with changing the face of America's grid, after leaving 8.5 million people without power.

Importantly, in New York State it has led to the REV (Reforming the Energy Vision), aimed at, amongst other things, building a more resilient energy system by giving consumers more options to procure and control their consumption at an individual level:

"Meanwhile, technological innovation and increasing competitiveness of renewable energy resources, combined with aging infrastructure, extreme weather events, and system security and resiliency needs, are all leading to significant changes in how electricity is generated, distributed, managed and consumed. Regulatory changes under the REV initiative are promoting more efficient use of energy, deeper penetration of renewable energy resources such as wind and solar, wider deployment of "distributed" energy resources, such as micro grids, vehicle to grid solutions, roof-top solar and other on-site power supplies, and storage. It is also promoting markets to achieve greater use of advanced energy management products to enhance demand elasticity and efficiencies. These changes, in turn, will empower customers by allowing them more choice in how they manage and consume electric energy." (Ref. 7)

Categorised outages in the American electricity system

Observed Outages to the Bulk Electric System, 1992-2012



Source: Energy Information Administration

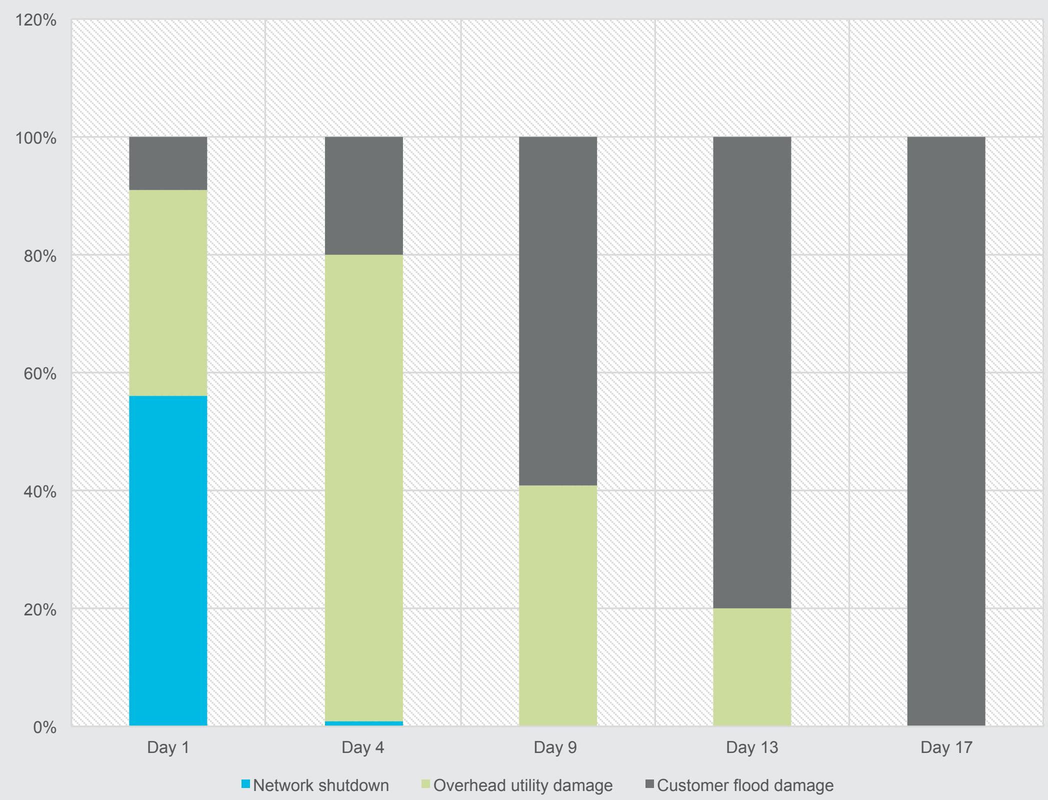
5. Quoted in Resiliency: How Superstorm Sandy Changed America's Grid, Greentech Media, Stephen Lacey, June 10 2014
6. Economic benefits of Increasing Electric Grid Resilience to Weather Outages, Executive Office of the President, August 2013
7. www.dps.ny.gov/W/PSCWeb.nsf/All/CC4F2EFA3A23551585257DEA007DCFE2?OpenDocument

INTERNATIONAL CASE STUDY

HURRICANE SANDY AND THE IMPACT ON THE UNDERGROUND NETWORK

- During Hurricane Sandy, the storm surge sent water into many underground substations in New York City. Restoring a flooded substation takes much longer than restoring a downed power line that's been damaged by ice or wind because you have to deal with the large amounts of water, rust, and mud left trapped in the structure. (Ref. 8).
- Switchgear, relay panels, transformer fans, pumps, and control kiosks are among the most susceptible pieces of substation equipment. Once all the water has been pumped out, each piece of equipment must be thoroughly dried and cleaned; even small amounts of moisture and dirt can render some electrical equipment inoperable.
- While almost half of the outages during Hurricane Sandy were caused by overhead line failure, customers affected by unexpected substation flooding experienced more significant outage durations.
- Customers with overhead line damage had service returned by day 17 after the storm, while those who had suffered outages caused by underground equipment flooding were without power even after day 17. (Ref. 9).

Percentage of customers still without power for days after the super storm passed



8. https://www.greentechmedia.com/articles/featured/resiliency-how-superstorm-sandy-changed-americas-grid#gs.M2DsOWw
9. Massachusetts Department of Energy Resources (2014), Feasibility study for undergrounding electric distribution lines in Massachusetts

UNDERGROUNDING AS A RESILIENCE OPTION HAS TRADE-OFFS

BENEFITS OF UNDERGROUNDING EXISTING OVERHEAD ASSETS INCLUDE:

- Decreased outages from certain weather events (including falling trees in high winds);
- Reduced exposure to lightning;
- Increased visual appeal;
- Reduced tree cutting and related costs, which also supports the 'greening' of urban areas; and
- Ability to maintain facilities at ground level, rather than from poles and bucket trucks.

CHALLENGES OF UNDERGROUNDING EXISTING OVERHEAD ASSETS INCLUDE:

- The biggest challenge is who pays for the undergrounding and the associated write-down of existing overhead assets; and whether the regulator would approve this expenditure;
- Significant costs due to additional civil construction works, disruption, ground conditions and more complicated design (up to 10x more costly than overhead) (Ref. 10);
- Replacement and asset management are more costly and difficult - visual inspection is not possible;
- Repair times for underground cables are substantially longer than for overhead construction, driving up maintenance costs and duration-based reliability indices;
- Additional faults due to dig-ins, with construction works that are not related to electricity networks creating outages;
- Increases flooding and earthquake risk;
- Underground congestion in high density areas leads to de-rating of new cables;
- Tree roots can damage assets; and
- Undergrounding existing assets takes a long time due to the long economic life of existing assets.

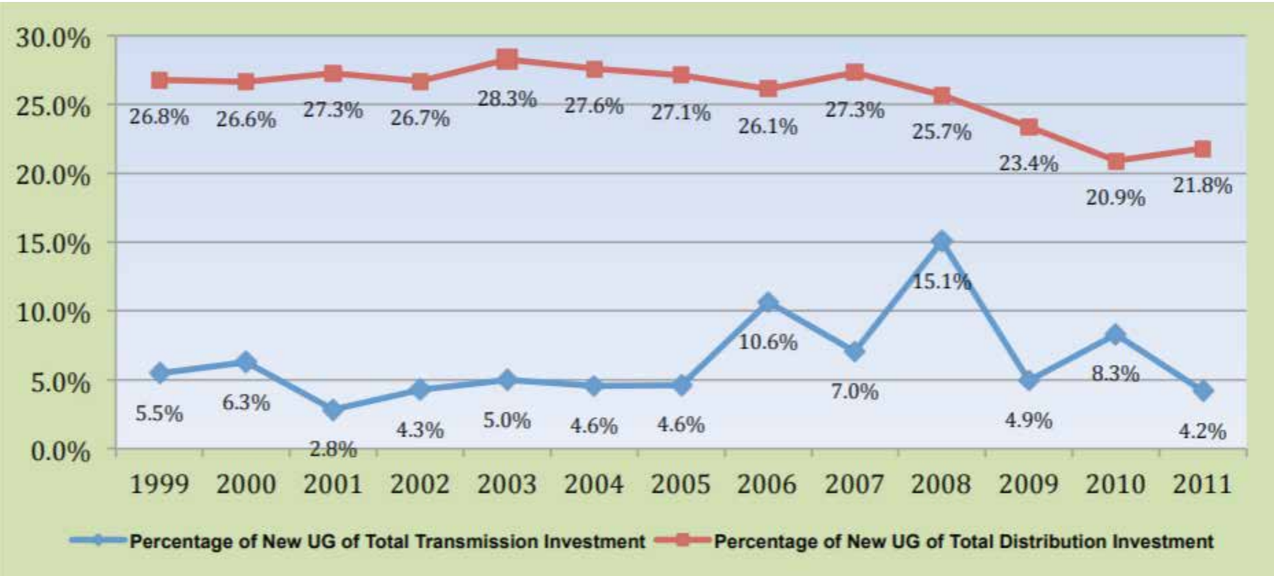
Based on American-wide data, undergrounding reduced the frequency of outages, but may not impact total outage duration due to slower restoration processes. A New York study found that outage duration noticeably increased in undergrounded areas. (Ref. 11)

10. EEI (2012), Out of Sight, Out of Mind, Undergrounding Report
11. Massachusetts Department of Energy Resources (2014), Feasibility study for undergrounding electric distribution lines in Massachusetts

VECTOR'S ONGOING INVESTMENT IN UNDERGROUND LINES

- Vector's published Asset Management Plan forecast an average investment in new underground lines of **21% of total capital expenditure.** This includes investments in underground lines for new subdivisions and asset relocations, as required under the Unitary Plan.
- This compares favourably with the data provided by USA utilities to the EEI shown in Figure C. (Ref. 12).

Figure C: Percentage underground investment of total capex (USA utilities)



12. EEI (2012), Out of Sight, Out of Mind, Undergrounding Report. http://www.eei.org/issuesandpolicy/electricreliability/undergrounding/Documents/ UndergroundReport.pdf

CUSTOMERS' WILLINGNESS TO PAY FOR UNDERGROUNDING

- The Edison Electric Institute (EEI) polled USA electricity customers concerning their willingness to pay for undergrounding after Hurricane Sandy.
- The results indicated that **60% of electric customers were willing to pay at least 1-10 percent** more on their power bills for undergrounding and another 11 percent of customers were willing to pay up to 20 percent more. (Figure D)
- However, **fewer than 10 percent (Figure E) of the customers polled were willing to incur a bill increase of 100%** to pay the more realistic cost for undergrounding. This information confirms the experience of most utilities and state commissions that the cost of undergrounding is a very important consideration and that customers have limited tolerance for higher utility service costs to pay for undergrounding. (Ref. 13)

Figure D: Willingness to pay for undergrounding

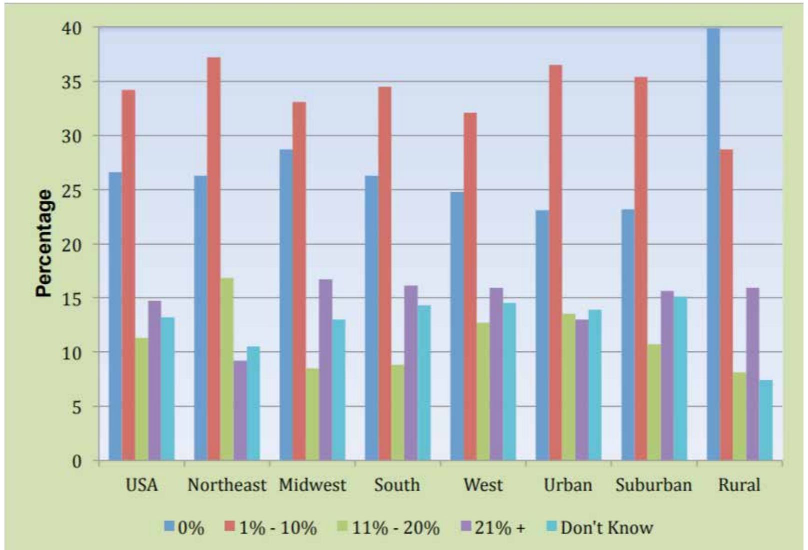
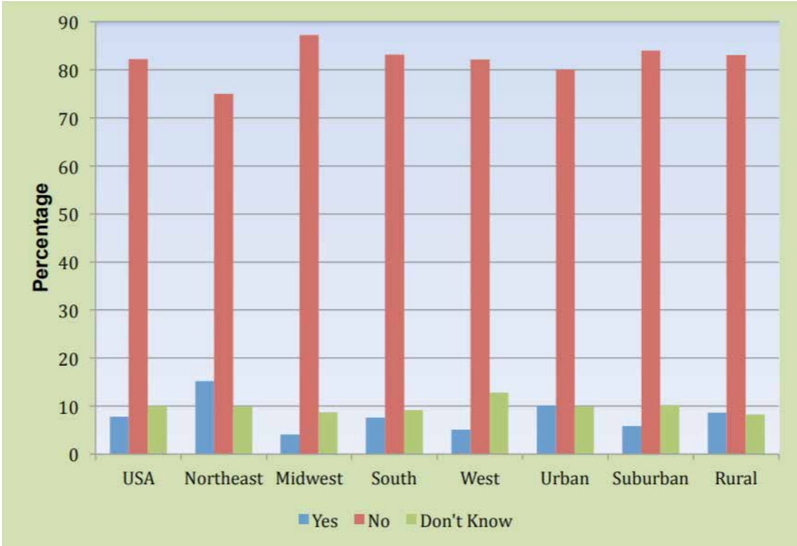


Figure E: Willingness to pay for undergrounding when doubling the bill



13. EEI (2012), Out of Sight, Out of Mind, Undergrounding Report. http://www.eei.org/issuesandpolicy/electricreliability/undergrounding/Documents/UndergroundReport.pdf

VECTOR'S NETWORK IS MORE UNDERGROUND THAN ITS PEERS

- Vector's network is **55% underground.** The average percentage of undergrounding across New Zealand EDBs is 27%.

- Figure F gives a comparison of where Vector sits compared to all 29 EDBs in New Zealand, based on the number of ICP/km2; while Figure G shows the % underground in Australia.

- Another example is Japan. Its electricity system is dominated by overhead lines. In Tokyo, only 7% of the electricity lines are underground and for Japan as a whole, only 1% are underground (Ref. 14).

Figure F: Percentage undergrounding in NZ

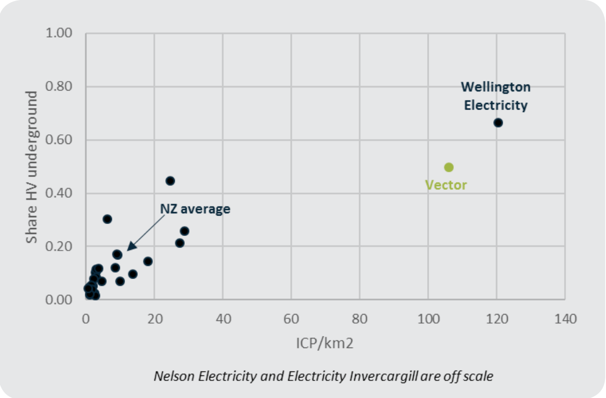


Figure G Percentage undergrounding in Australia

STATE	CITY	% UNDERGROUND
Victoria	Citipower (Melbourne city)	40%
	Jemena (North West metropolitan Melbourne)	30%
	SP Ausnet (rural Victoria – rest of state not covered by Powercor)	14%
Queensland	Ergon Energy	6%
	Essential Energy (rural NSW)	5%
NSW	Ausgrid (Sydney, Central Coast and Hunter Valley)	35%
Tasmania	TasNetworks (One DNSP for State)	11%
TasNetworks (One DNSP for State)	SA Power Networks (one DNSP for State)	10%
ACT	EvoEnergy (One DNSP for region)	55%

14. https://www.japantimes.co.jp/community/2017/03/04/how-tos/will-ever-see-no-obstacles-way/#.Wt6SnmeYPoo

ESTIMATED COST TO UNDERGROUND THE VECTOR NETWORK

Cost for urban Auckland

$3.6B

or

Additional $870 lines charges pa (i.e. more than double) for the average customer compared to 700$/year today.
Assuming the regulator will allow the expenditure.

+

Cost for rural Auckland

$1.9B

or

Additional $460 lines charges pa for the average customer compared to 700$/year today.
Assuming the regulator will allow the expenditure.

These estimates exclude significant additional costs other infrastructure providers such as Auckland Council, Auckland Transport and Chorus will incur to relocate, reconnect and reinstate their services.

All costs based on figures from Vector database

UNDERGROUNDING AUCKLAND'S URBAN NETWORK

The estimated cost to underground the network does not include the following additional costs:

- Write-down of the economic life of existing overhead assets;
- Ground conditions, which affect the feasibility of directional drilling and may require more expensive rock breaking and open trench works (Figure H);
- Economic impact on businesses, with potential for delay and increased construction cost as some public works can only be carried out outside business hours;
- Traffic management cost and increased traffic congestion cost given that many electricity lines will need to be buried under Auckland roads (Figure I); and
- Underground congestion due to other utility services could de-rate cables.

Figure H: Ground conditions in Auckland

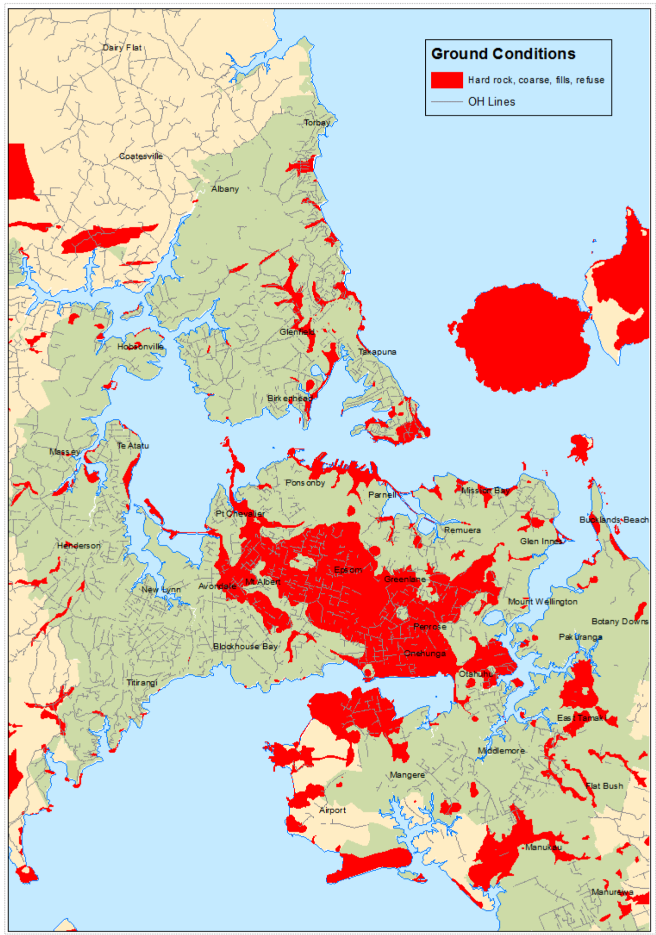
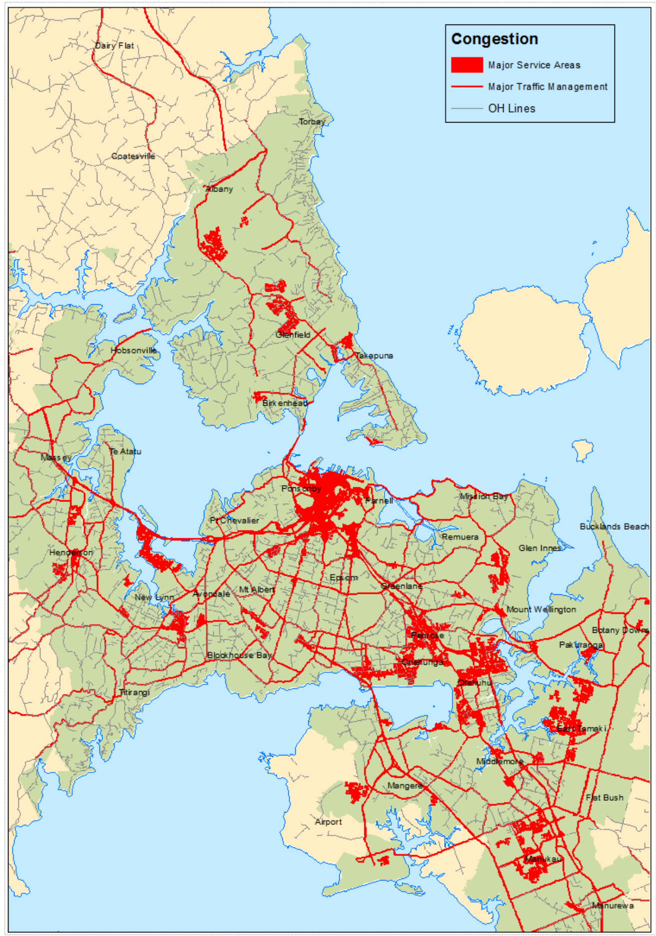


Figure I: Major roads and business areas



UNDERGROUNDING AUCKLAND'S RURAL NETWORK

- Rural Auckland is a large part of our service territory (Figure J), but only 5% of Auckland customers (30,000 ICPs) live in rural areas.
- In rural settings, the construction costs per kilometre are lower than in urban environments due to simpler local conditions, but the very low population density means that considerably more lines are required to service a customer than in an urban environment.
- Overall, the density effect largely outweighs the lower construction cost. This makes undergrounding prohibitively expensive in rural settings. The low population density also means that the benefits from increased resilience are smaller.

Figure J: Urban and rural areas within Vector's service territory

INTERNATIONAL CASE STUDY

NORTH CAROLINA UNDERGROUNDING FEASIBILITY STUDY

In early December 2002, a major ice storm blanketed much of North Carolina with up to an inch of ice, causing an unprecedented power outage to approximately two million electric utility customers. In the immediate aftermath of the storm, the public expressed considerable interest in burying all overhead power lines in the state. (Ref. 15). A public undergrounding feasibility study was kicked off, which released the following recommendations in November 2013:

- Underground lines would be prohibitively expensive as it would cost approximately $41 billion, nearly six times the net book value of the local utilities' current distribution assets, and would require approximately 25 years to complete. (Ref. 16).
- For customers, the ultimate impact of the capital costs alone on an average residential customer's monthly electric bill would be an increase of more than 125%. Rates would also be impacted by the higher operation and maintenance costs associated with direct-buried underground systems, particularly in urban areas, where underground conductors are four times more costly to maintain than overhead facilities.
- Investor-owned utilities in North Carolina compared five years of underground and overhead reliability data and found the frequency of outages on underground systems was 50% less than for overhead systems, but the average duration of an underground outage was 58% longer.

15. North Carolina Natural Disaster Preparedness Task Force - Nov 2003
16. Shaw Consultants (2013), Study of the Feasibility and Reliability of Undergrounding Electric Distribution Lines in the District of Columbia

NEW TECHNOLOGY OPTIONS – VECTOR SMART POLE

Vector has designed a new generation of public street poles, i.e. the 'Smart Power Pole' (Figure K), that hosts various public services such as efficient LED street lighting, electric vehicle (EV) charging, telecommunication equipment and air pollution sensors, whilst integrating aerial bundled conductor (ABC) at a height out of most houses' line of site and above many tree heights to make it less susceptible to vegetation.

Using ABC increases the resilience of overhead lines without the high construction cost, longer outage restoration times, and public disruption of undergrounding. In contrast with traditional non-insulated lines, an ABC line will continue to operate when in contact with tree branches as the insulated conductor will protect against flashovers.

Low voltage ABCs are used on every continent and in a total of approximately 80 countries (including Australia, Ireland, UK, France, Sweden). France's long history using ABC goes back to the mid-1950's. Today, 83% of all low voltage overhead lines in France are bundled, which represents 46% of all low voltage lines (if undergrounded lines are included) (Ref. 17).

The experience overseas summarises the advantages of ABC as:

- Visually less intrusive;
- Reduced tree clearance required due to compact design - in France, low voltage ABC has reduced tree cutting by a third;
- Cheaper, easier and quicker to install than underground cables;
- Improved safety; and
- Improved reliability in comparison with bare conductor overhead.

Figure K: Smart Power Pole

17. ENEDIS (201), network infrastructure statistics, accessed online in May 2018 on http://www.enedis.fr/donnees-relatives-aux-lignes-et-aux-postes

NEW TECHNOLOGY OPTIONS - DISTRIBUTION AUTOMATION AND SMART METERING

DISTRIBUTION AUTOMATION (DA)

Vector is deploying more DA to increase visibility and controllability of the distribution system by installing additional devices such as remote fault indicators and reclosers. Automated feeder switches, used in conjunction with reclosers, open and close a feeder section without the need to dispatch a lines mechanic. DA improves resilience through:

- Sectionalisation - limiting the damage on a distribution circuit and minimising the number of customers affected;
- Diagnosis - the smaller the network is sectioned, the quicker a fault can be located; and
- Restoration - automatic restoration can be done remotely and does not require dispatching of resources.

Vector has deployed 300 high voltage auto-recloser programmes since 2007. As outlined in the 2018 Asset Management Plan, Vector will invest $26.3M to increase the automation of switching points, using remotely controllable reclosers and smart analytics; and increasing the number of auto-reclosers on urban feeders.

SMART METERING

Vector uses its SCADA network to monitor and control the high voltage network, but has limited oversight at the low voltage and individual customer level.

Smart meters at customer premises could provide valuable information on the low voltage network during disruptive storm events that can accelerate and streamline the diagnosis of faults and the restoration effort.

Smart meters are equipped with outage notification capabilities that allow the devices to transmit a 'last-gasp' alert when power to the meter is lost. The information can be integrated into Vector's outage management system (OMS) to provide an additional way to pinpoint the outage area and help to assess the damage.

Smart meters can also transmit 'power on' notifications to operators when power is restored, or even allow utilities to 'ping' meters in the affected areas to assess the outage boundary and verify the restoration progress, enabling field crews to be deployed more efficiently, thus reducing the restoration time.

In New Zealand, smart meter data is held by the retailers and not readily accessible to electricity distribution businesses. This barrier means that the customer benefits from smart meters in improving reliability and resilience remains untapped.

DISTRIBUTION AUTOMATION AND SECTIONALISATION IN USA

The Chattanooga Electric Power Board (EPB) installed more than 1400 automated feeders with corresponding communication and information management (Ref 18). This was financed through a US$111M stimulus grant from the Department of Energy (DOE) through its Smart Grid Investment Grant program (authorized by the 2009 American Recovery and Reinvestment Act). The project entailed installing a dedicated fibre-optics communications system and smart distribution to deliver the following benefits (Ref 19):

- **Resilience** - Automatic reconfiguration prevented outages for many customers (purple in Figure L) and significantly reduced the number of circuits requiring manual repairs (green in Figure L). The installed fibre-optic network allows EPB to manage a greater number of restoration crews following a storm event. In a July 2012 derecho that affected half of EPB's customers, EPB's response was up to 17 hours faster because of the automated feeder switches, which restored power to 40,000 customers instantly. (Figure M)
- **Financial Savings** - Annual savings of US$200k due to a decrease in the number of dispatched restoration crews.

Figure L: Service disruption from a major storm in the distribution area of Chattanooga Electric Power Board

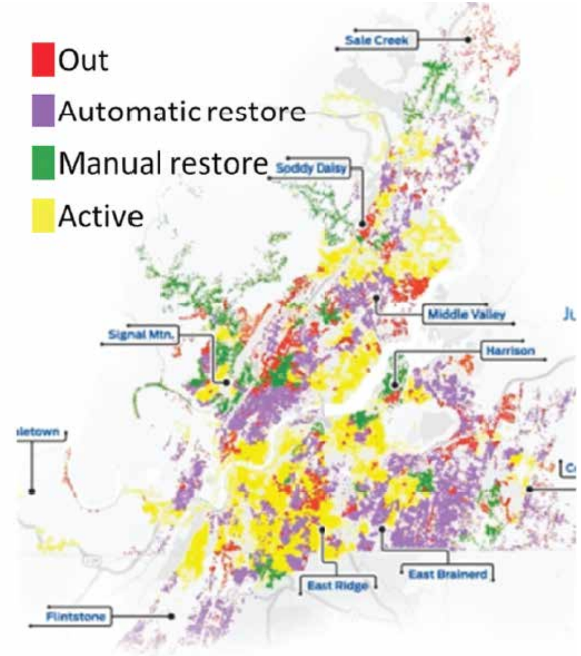


Figure M: Automation has greatly reduced the number of customer-hours of outage experienced

18. National Academy Science (2017), Enhancing the Resilience of the Nations Electricity System

19. Glass, J. 2016. "Enhancing the Resiliency of the Nation's Electric Power Transmission and Distribution System," presentation to the Committee on Enhancing the Resilience of the Nation's Electricity System, September 29, Washington, D.C.

INTERNATIONAL CASE STUDY

SMART METERS PROVIDING RESILIENCE DURING HURRICANES

The US has achieved widespread, measurable improvements in grid resilience under the 2009 American Recovery and Reinvestment Act, which resulted in grants for 99 Smart Grid Investment Projects (Ref 20):

HURRICANE IRENE (2011)

- More than 6.5 million people in the United States lost power during Hurricane Irene (Ref 21). Smart grid investments made before Irene's landing lessened the storm's impact for thousands of electricity customers. Investments in smart meters improved outage notification and response time, greatly reducing the duration of outages. In Pennsylvania, the Pennsylvania Power & Light's (PPL) smart grid investments in distribution automation technologies made a difference for 388,000 customers who lost power.

HURRICANE SANDY (2012)

- In the Washington D.C. metropolitan area, the Potomac Electric Power Company (PEPCO) said it was able to restore power to 130,000 homes in just two days after Sandy thanks to smart metering infrastructure. With smart meters connecting roughly 425,000 homes, PEPCO received 'no power' signals that allowed them to quickly diagnose and locate outages.
- Even after the power was restored, PEPCO was able to continually 'ping' meters to verify that service was restored, which avoided the need to send repair crews.

NORTH AMERICA WINTER STORM (MID-FEBRUARY 2014)

- In Pennsylvania, the resilience benefits from smart meters can be highlighted by comparing the difference in restoration times after Hurricane Sandy in 2012 with 10 percent smart meters deployed and the winter storms two years later with 50 percent smart meters deployed. Following a February 2014 storm, PECO restored service an estimated three days faster, and automatically restored about 37,000 customers in less than five minutes using Automated Feeder Switching (Ref 22).

Florida utility, Florida Light and Power (FLP), noted that investments of $2.6B resulted in fewer outages and faster restoration times during **Hurricane Matthew.** These investments included:

- Automated switches, which prevented at least 25,000 outages; and
- With more than 4.8 million smart meters, FLP was able to identify which customers were impacted in real time and schedule faster, less expensive responses.

20. The White House (2013), Economic benefits of increasing electric grid resilience to weather outages

21. Avila, Lixion A. and Cangialosi, John. (2011),Tropical Cyclone Report: Hurricane Irene." National Hurricane Centre

22. DOE (2014), Smart grid improves grid reliability resilience and storm response

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