Monday, 12 September 2016

Distributed Infrastructure Network RNC Project

12th September 2016

Rural PCL: Electricity Distribution Network Assessment to Extreme Natural Hazard

Yang Liu and Nirmal Nair

Discussion Research Slides
RNC Analytical Framework for Electricity Resilience

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Outline

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- Reliability and Resilience for Electricity networks
- Review Power system Reliability framework
- Reliability methodology and its applications (technical/regulatory/economic)
- Possible Resilience Framework to RNC Distributed Infrastructure Project needs for Extreme Natural Hazard (Research/Development)
- Alignment with RNC Distributed Infrastructure project & Methodology
- Rural PCL Case Study

Electricity Reliability and Resilience

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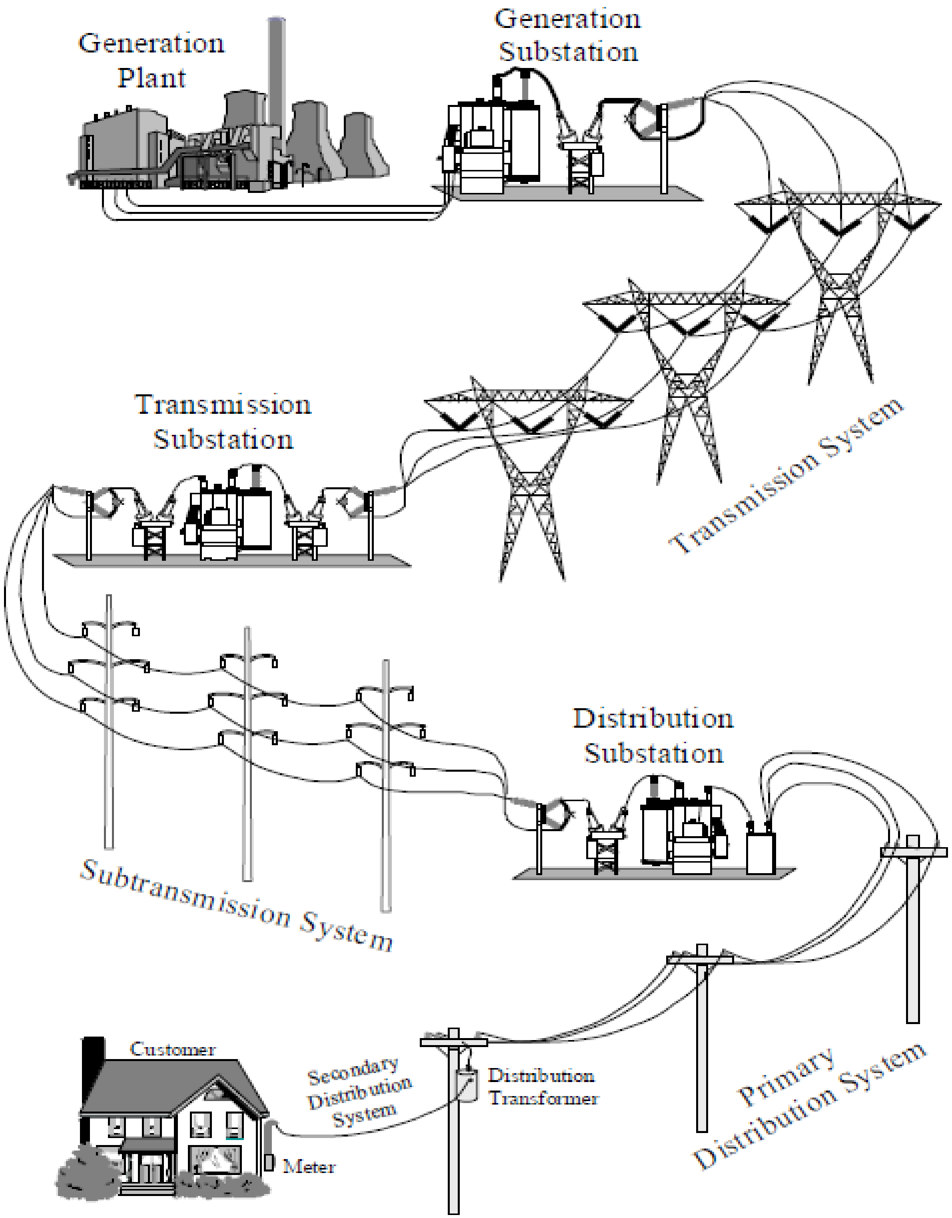
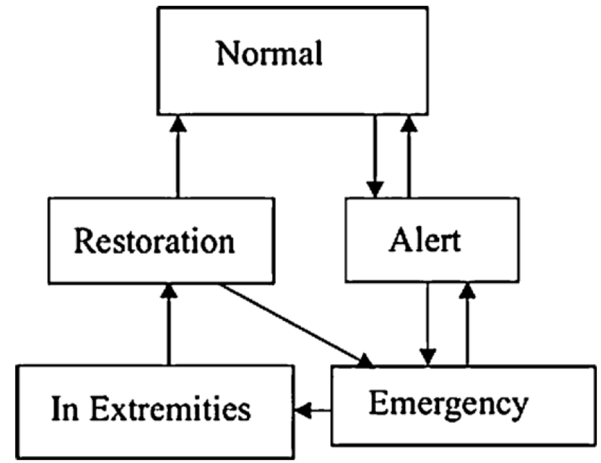
- Need to differentiate the "blackouts" from extreme weather events and natural disasters

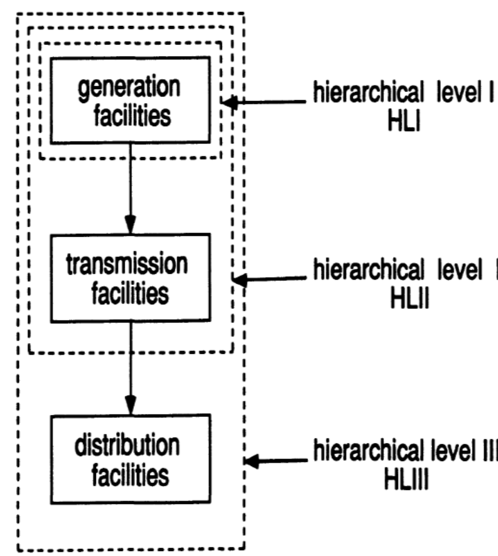
- Electricity as an essential service (critical infrastructure) need to be
  - **Reliable** during normal conditions and expected contingencies
  - **Resilient** to high impact low probability (HILP) events like extreme hazards

- Power system resilience – A definition
  - Ability of a power system to **withstand** HILP events, rapidly **recover** from such events and **adapt** its operation and structure to be better prepared for similar events in the future

Reliability Evaluation Framework



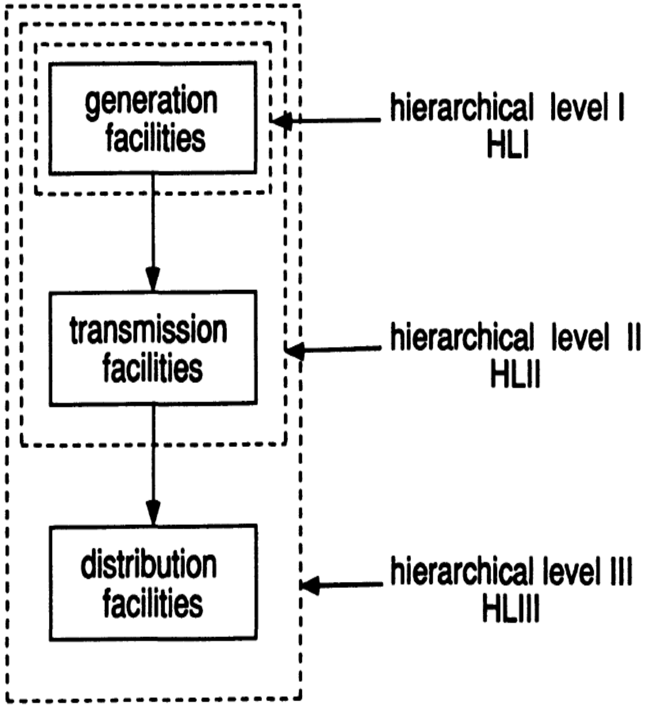




HLI Reliability Evaluation- Reliability Indices

Generation **Adequacy** Indices in HLI Studies

- LOLE :loss of load expectation
- LOEE :loss of energy expectation
- LOLF : loss of load frequency
- LOLD: loss of load duration



HL II Reliability Evaluation-Reliability Indices

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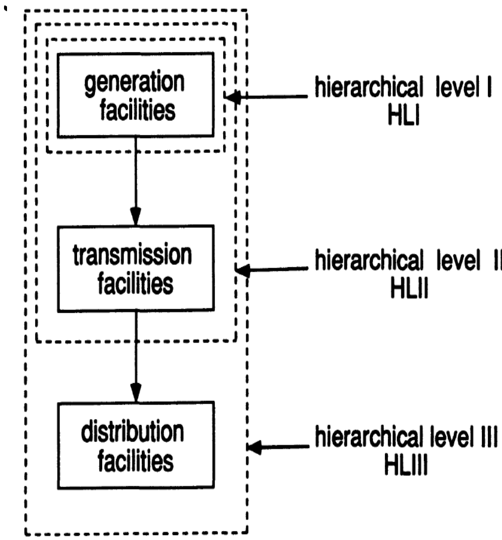
Adequacy Indices factoring **transmission/sub-transmission** Studies

- PLC: Probability of Load Curtailments
- EFLC: Expected Frequency of Load Curtailments
- EDLC: Expected Duration of Load Curtailments
- ADLC-Average Duration of Load Curtailments
- ELC-Expected Load Curtailments
- EDNS-Expected Demand Not Supplied
- EENS-Expected Energy Not Supplied
- BPII-Bulk Power Interruption Index
- BPECI-Bulk Power/Energy Curtailment Index
- BPACI-Bulk Power-Supply Average MW Curtailment Index
- MBPCI-Modified Bulk Power Curtailment Index
- SI-Severity Index



HLIII Reliability Evaluation-Reliability Indices

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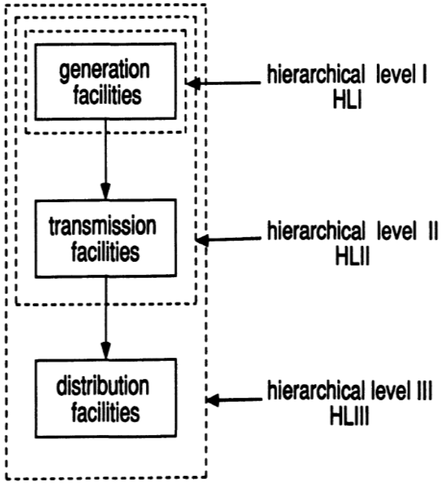
Adequacy Indices in **Distribution System** Evaluation

- SAIFI-System Average Interruption Frequency Index
- SAIDI-System Average Interruption Duration Index
- CAIFI-Customer Average Interruption Frequency Index
- CAIDI-Customer Average Interruption Duration
- ASAI-Average Service Availability Index
- ASUI-Average Service Unavailability Index
- ENS-Energy Not Supplied
- AENS-Average Energy Not Supplied
- ACCI-Average Customer Curtailment Index



Reliability Evaluation-Methods and Simulation

- Simulation Approaches in Reliability Evaluation
  - State Sampling Approach
  - State Duration Sampling Approach
  - System State Transition Sampling Approach
- Evaluating System Reliability by Monte Carlo Simulation

Existing uses of Reliability Analysis

- Economic
  - Value of Lost Load (VoLL)
  - Investment decision regarding upgrade
  - OPEX/CAPEX decisions for both HLIII and HLII
  - Contracting decisions

- Benchmarking
  - Comparative performance amongst HLIII entities
  - Strategies for medium/long terms investment decisions

- Regulation
  - NZ Commerce Commissions 5 year price path
  - Introduction of new technologies and pricing for reliability benefits

Reliability & Resilience approach to RNC Distributed Infrastructure

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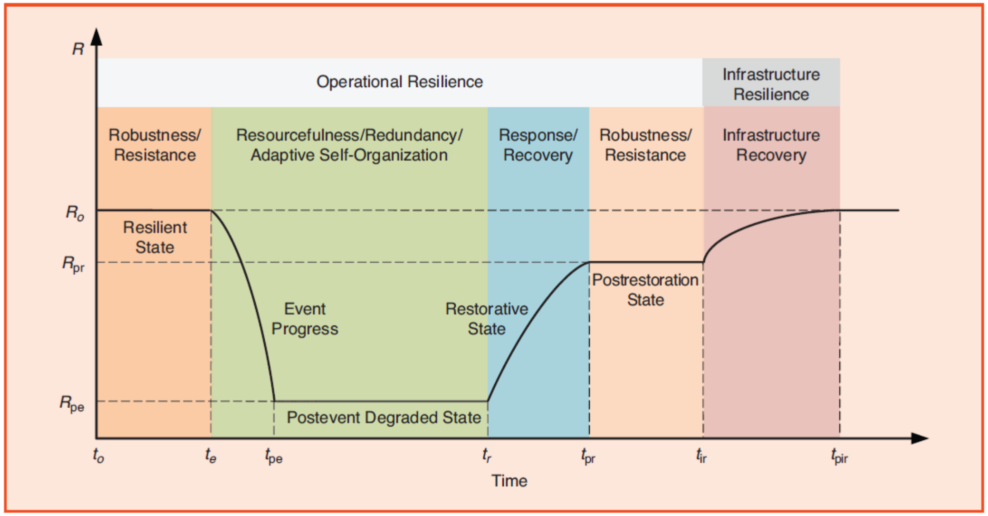
- Typical reliability studies values are very high (e.g. HLI 99.xxx%)
- Value of Lost Load (VoLL) based on industrial, commercial and residential classification
- Improving reliability for HLIII involves OPEX (tree-cutting, maintenance etc.) and CAPEX (new lines, automation etc.)
- Simulations usually run long-term averages

table 1. Reliability versus resilience.

Reliability	Resilience
High probability, low impact	Low probability, high impact
Static	Adaptive, ongoing, short and long term
Evaluates the power system states	Evaluates the power system states *and* transition times between states
Concerned with customer interruption time	Concerned with customer interruption time *and* the infrastructure recovery time

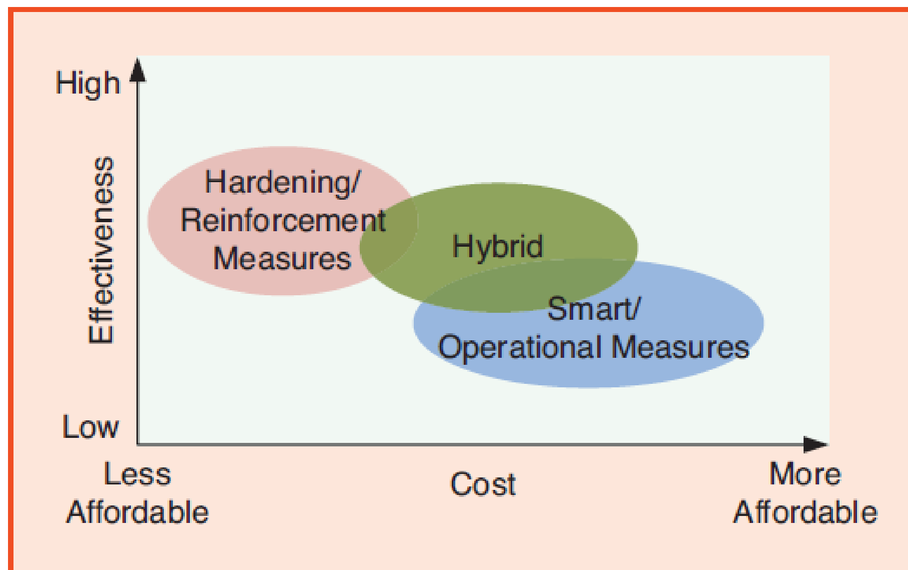
- For this project "**extreme natural hazard**" is the focus
- Notion of **Resilience** in this context needs consensus from inter-dependent infra models
  - Needs to incorporate back-up power supplies (alongside HLI studies)
  - Can assess measures like temporary transmission building, rerouting etc. (along HLII)
  - Involve temporary distribution measures factoring emergency, RMA etc. Technical measures like allowing islanded or micro-grid operation etc. (alongside HLIII)

Potential RNC framework to assess electricity distribution



Conceptual Resilience Curve associated with an "event"

Conceptual view for costing of Resilience Improvement Measures



RNC: Overall Project Framework

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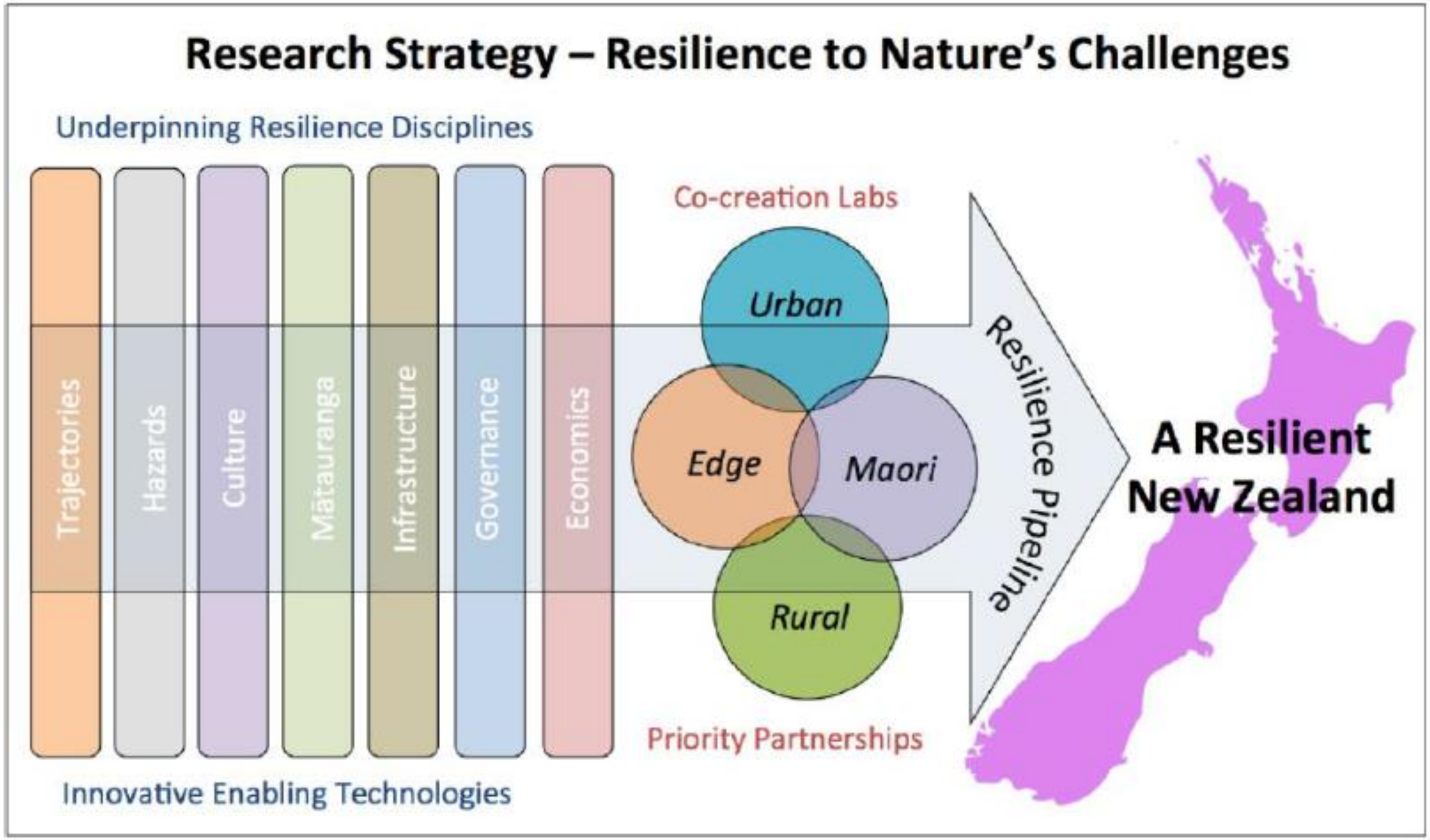
RNC



Distributed Infrastructure Network Research Interactions

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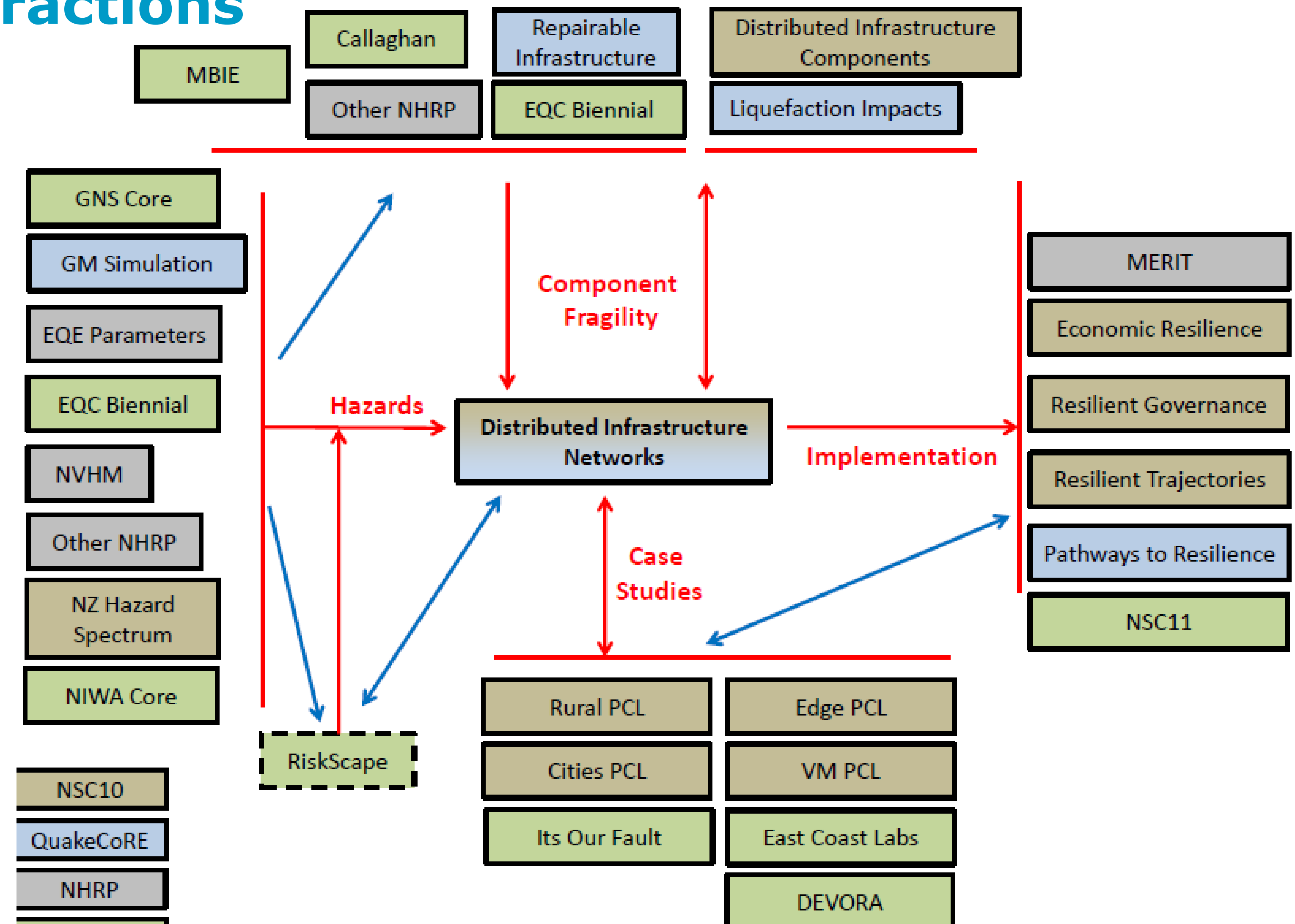

Research Structure

Distributed Infrastructure Network: Infrastructure interdependencies

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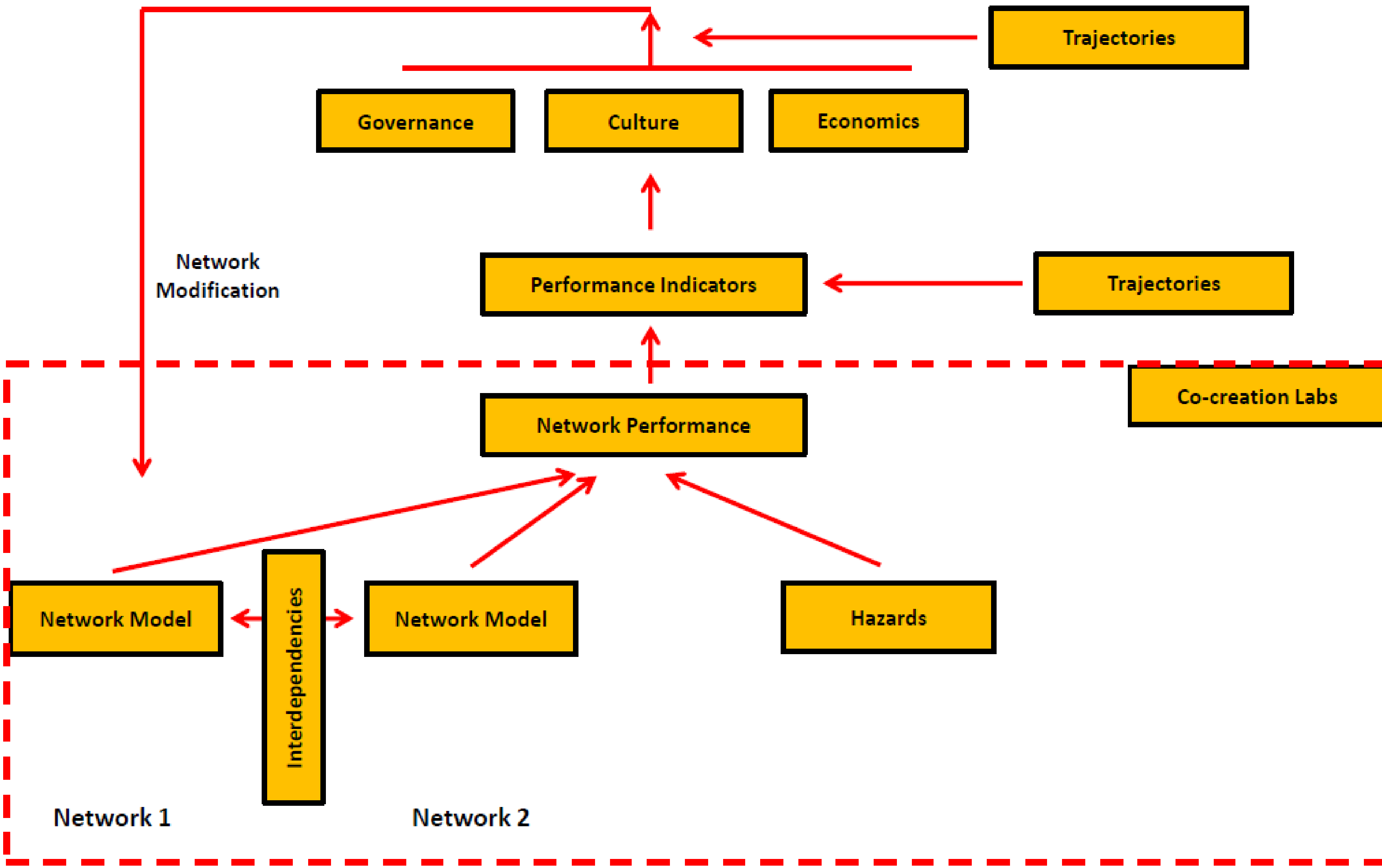

Typical Lifeline Sector Inter-dependency Chart

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	Airport	Broadcasting	Electricity	Fuel	Gas	Ports	Rail	Roads	Telecomms	Wastewater	Water Supply	Comments
Airport		3	2	2	3	3	3	1	3	2	2	Dunedin Airport self sufficient 3-4 days with backup generators for terminal building and control tower plus 500,000l water, and on site wastewater treatment/disposal. Fuel critical but 3-4 days storage and larger aircraft could refuel at destination airports. Road access critical but airport serviced from 3 directions providing alternates if one closed.
Broadcasting	3	0	2	3	3	3	3	2	3	3	3	Mt Cargill Transmission Facility is self sufficient for generators / fuel for 20 + day.
Electricity	3	3	1	2	3	3	3	2	2	3	3	Distributors and generators rely on Transpower network being operational. Fuel, roads and telecomms become more critical (1) in coordinating and emergency response situation.
Fuel	3	3	1	1	3	1	3	1	2	3	2	Can gravity feed or use air compressors/pumps to supply from terminals (could also be used at fuel stations but would be unmetered supply) if electricity failure. Water required at flammable sites (petrol) but self contained water supplies now required. All fuel comes in via ship and distributed via roads.
Gas	3	3	2	3	3	1	2	1	2	3	1	Gas comes in via rail and port and is distributed by pipe and road - Fryatt Street is the main road to and from the terminal. Water supply required for fire fighting, though alternatives are sea water pump (if electricity operating) or fire service appliance (if available).
Ports	3	3	1	2	3	0	1	1	2	3	2	Electricity backup on for emergency functions, > 24 hours would have significant impact on operations. 2/3 of cargo is transported to / from the port by rail, the rest by road. Road also required for staff access. Fuel required for ship bunkering. Water supply required for staff but could bring in.
Rail	3	3	2	1	3	3	0	1	3	3	3	Roads critical for transfer of freight and passengers. Electricity critical for network control. Fuel required to operate trains.
Roads	3	3	3	3	3	3	3	1	3	3	3	Main dependency is between NZTA and local road authorities. While traffic lights require electricity, manual traffic management can occur and in other places traffic should revert to normal road rules.
Telecomms	3	3	2	3	3	3	3	2	1	3	3	Require electricity but main sites have generator backup while smaller sites have battery backup that can operate 4-60 hours. Telecommunications network is highly interconnected meaning many telcos rely on other's assets. Roads required for access to sites - more critical in emergencies.
Wastewater	3	3	1	3	3	3	3	2	2	0	2	Dunedin's main Musselburgh PS is the only sewer PS with backup generation on site. Most PS have emergency storage in dry conditions of between 2 and 8 hours and designed spill structures to discharge overflows safely to waterways. Treatment plants do not have backup generation though some biological treatment would still occur in ponds/wetlands.
Water Supply	3	3	1	3	3	3	3	2	2	3	0	Water pump stations and treatment plants do not have on site generators, relying on treated storage reservoirs (typically holding 1-3 days supply) to maintain supply until electricity restored. Reliance on telecommunications for automated control, loss of which could cause reduction in water quality.

1 = Critical for Service to Function 2 = Critical for service to function but some backup or part function. 3 = Not required for service to function. 0 = Not Applicable

ASSESSMENTS
INTERDEPENDENCE OF ENGINEERING LIFELINES FOR RECOVERY FOLLOWING A DISASTER

These are Dependent on These → ↓	Roading	Railways	Sea Transport	Air Transport	Water Supply	Sanitary Drainage	Storm Drainage	Mains Electricity	Standby Electricity	Gas	Fuel Supply	~~Fuel Supply~~ Telephone Systems	VHF Radio	Broadcasting
Roading		1	1	1	1	1	3	1	1	1	5	3	3	3
Railways	5		1	1	1	1	1	3	3	3	5	3	3	1
Sea Transport	5	5		1	3	3	1	5	5	2	5	5	5	1
Air Transport	5	1	1		3	3	1	5	5	1	5	5	5	2
Water Supply	5	1	4	4		5	1	5	4	1	4	5	3	4
Sanitary Drainage	5	1	4	4	5		4	5	4	1	4	5	3	4
Storm Drainage	5	1	1	1	1	1		5	4	1	4	5	3	2
Mains Electricity	5	1	1	3	1	1	3		5	1	5	5	5	3
Standby Electricity														
Gas	5	1	1	3	1	1	1	1	1		5	5	5	1
Fuel Supply	5	2	5	2	2	1	1	5	5	1		5	4	2
~~Fuel Supply~~ Telephone Systems.	5	1	1	4	2	1	3	4	5	1	5		4	4
VHF Radio	4	1	1	3	2	1	1	4	5	1	5	4		4
Broadcasting	4	1	1	3	4	4	4	4	5	1	5	4	4	
Total Assessment of Dependency by other utilities	58	17	22	30	26	23	24	47	52	13	57	54	47	31

Interdependence assessment against each lifeline item on a scale from 1-5 (low-high requirement for operation)

Holistic Top-Down Impact Views

- Can feed into each infrastructures detailed bottom-up model
- Hazard risk assessment through fragility modelling

Draft Work Scope Outline for Electricity Network

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- Current network performance and risk profile
    - Recovery options
    - Physical network

- Emergency network management procedures (while network repairs are underway)

- Network retrofit and improvement

- Modelling inter-dependencies with other Infrastructure

Proposed Resilience Analysis Methodology

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Disaster Forecast Estimation and Simulation

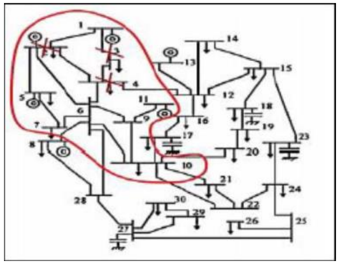
Event

Hardening and Resilience Investment

Corrective Actions and Emergency Response

Damage Assessment and Restoration

- Vegetation Management
- Undergrounding
- Elevating substation, etc.



- Emergency load shedding
- Special protection systems
- Islanding Schemes, etc.

- Microgrids Operation
- Distribution Automation
- Mobile Transformers, etc.

Disaster Impact Estimation and Simulation

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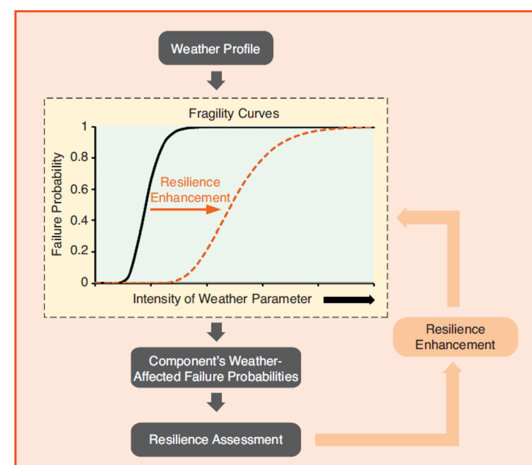
Component Modelling - Data Fitting
- Generalized Linear Models
- Tree based Models

System Modelling - Monte Carlo Simulation
- Disaster Model
- System Outage Simulator

System Analysis & Optimization
- Hardening and Resilience Investment
- Damage Assessment and Restoration

Example: Evaluating resilience for extreme weather events



NZ Transmission Network: HLII Assessment

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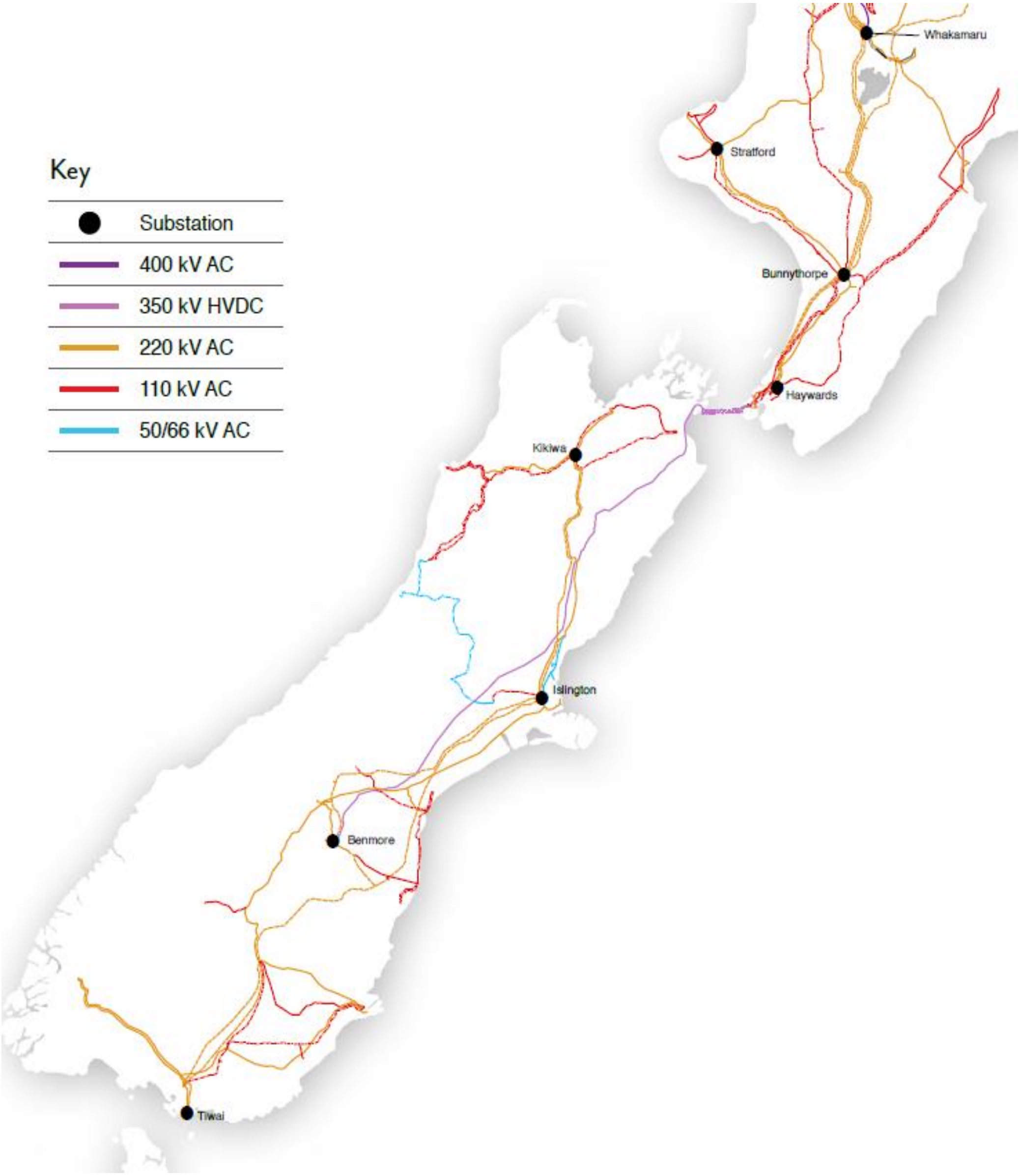
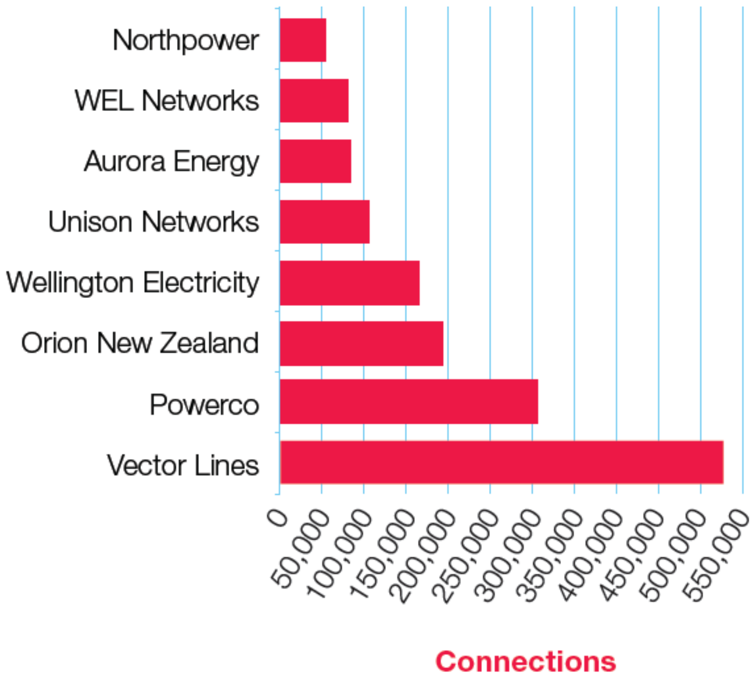
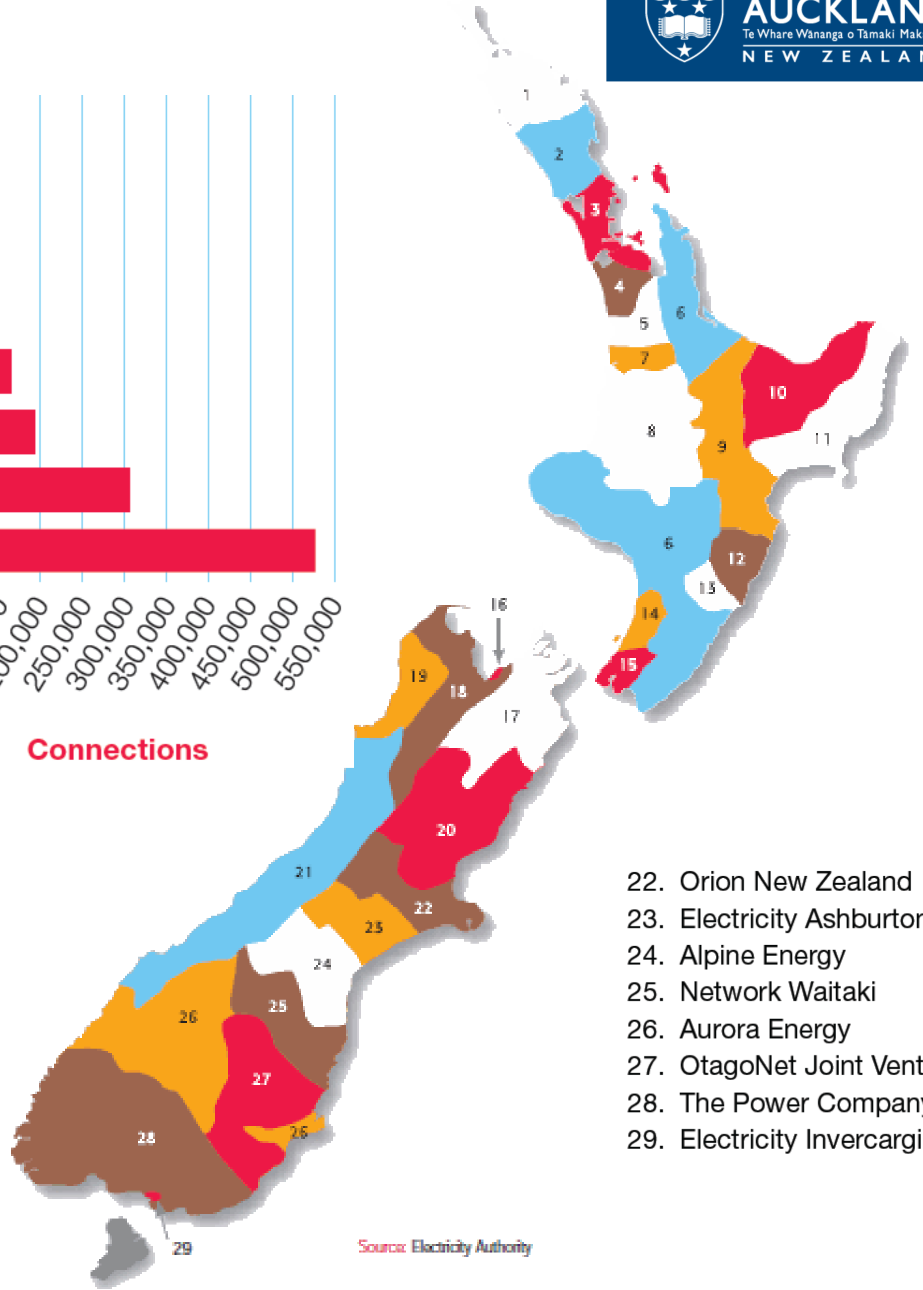


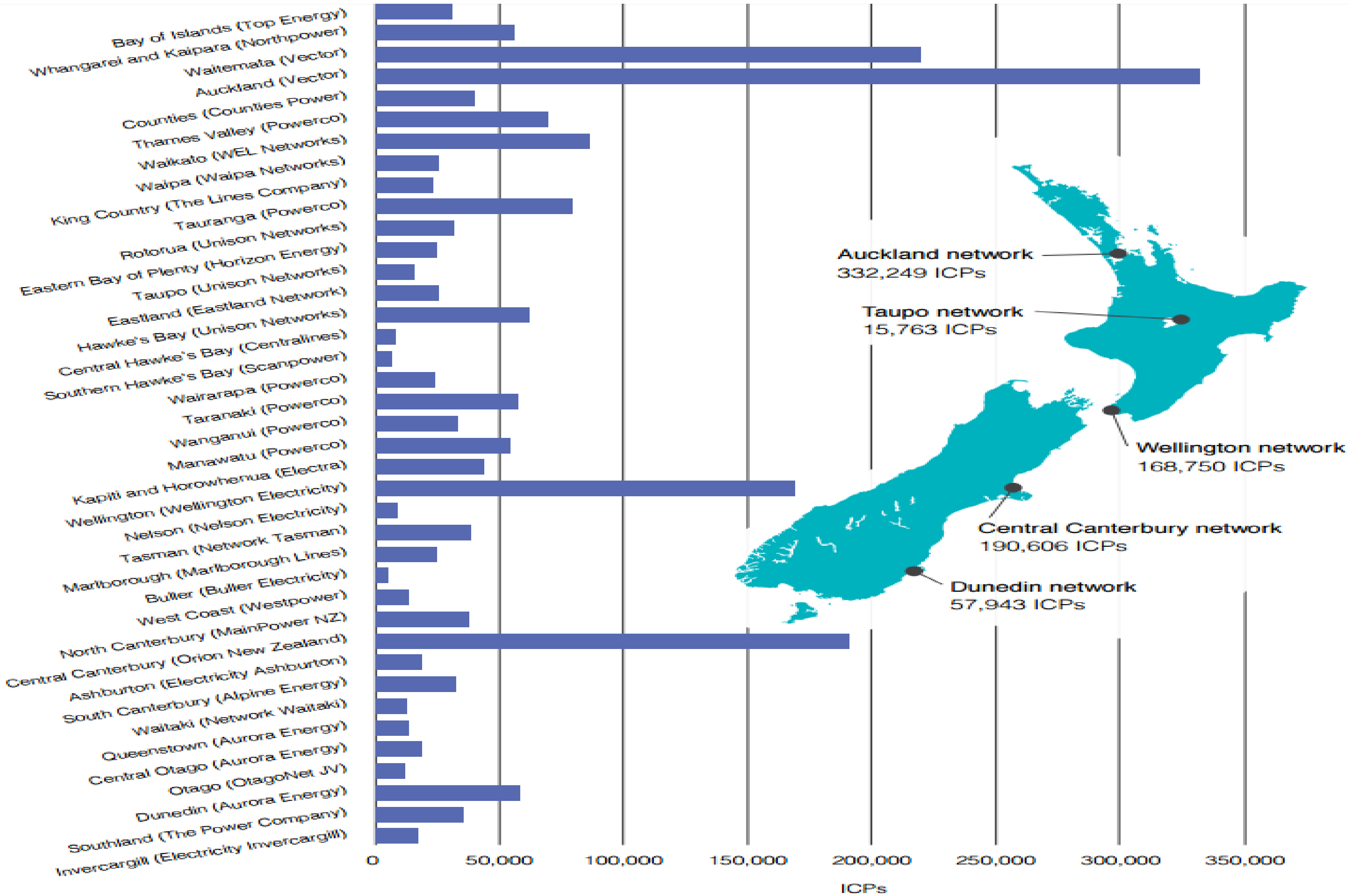
NZ distribution utilities





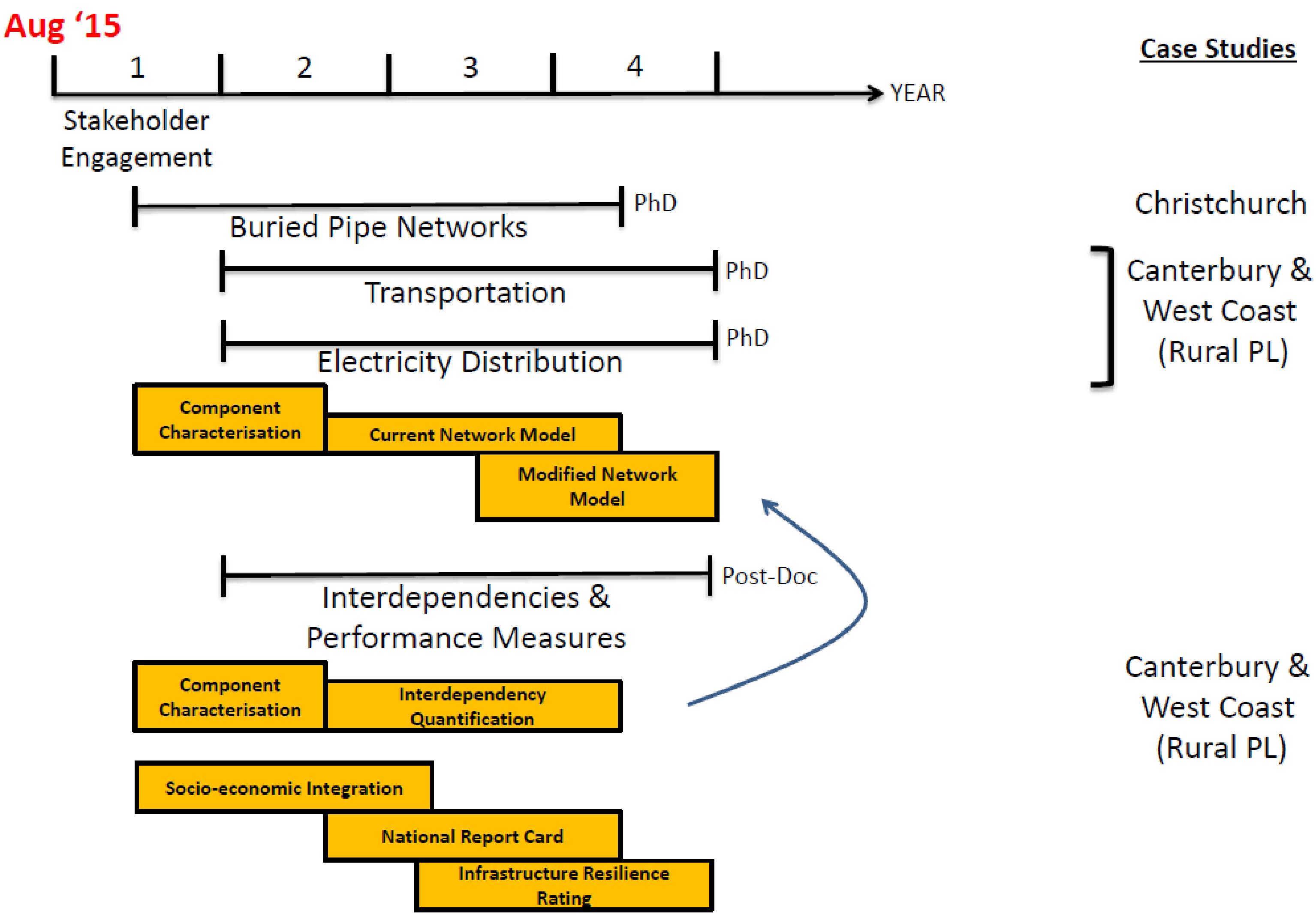
1. Top Energy
2. Northpower
3. Vector
4. Counties Power
5. WEL Networks
6. Powerco
7. Waipa Networks
8. The Lines Company
9. Unison Networks
10. Horizon Energy Distribution
11. Eastland Network
12. Centralines
13. Scanpower
14. Electra
15. Wellington Electricity
16. Nelson Electricity
17. Malborough Lines
18. Network Tasman
19. Buller Electricity
20. Mainpower New Zealand
21. Westpower
22. Orion New Zealand
23. Electricity Ashburton
24. Alpine Energy
25. Network Waitaki
26. Aurora Energy
27. OtagoNet Joint Venture
28. The Power Company
29. Electricity Invercargill

NZ Distribution Network: HLIII Assessment



Rural NZ electricity distribution Case study: West Coast

Structure



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