INFRASTRUCTURE RESILIENCE

Key principles for regulating the performance of utilities

Prepared for Commerce Commission

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Executive summary

Purpose and context

This report provides the Commerce Commission (ComCom) with principles and frameworks for evaluating infrastructure resilience investments and measuring resilience performance across regulated utilities in New Zealand. Commissioned in June 2025, this work provides a foundation for the subsequent development of ComCom's detailed approach to integrating resilience into its regulatory processes. The report is designed to support ComCom's resilience journey by raising awareness internally of key principles of resilience in infrastructure systems and subsequent implications for the current and future regulatory controls of electricity lines, gas pipelines, fibre networks, airports and water infrastructure.

Key findings

RESILIENCE REQUIRES A SYSTEM-WIDE APPROACH

Infrastructure resilience is multi-dimensional, extending beyond asset hardening to encompass service delivery, organisational capacity, and community and business preparedness. There are many ways to achieve resilience. Historically, physical system improvements, such as asset hardening and redundancy, have been the default mechanism for increasing resilience, but increasing frequency and severity of events, combined with limited resources, means that our approach to building resilience must consider a wide range of options (including temporary service delivery options and organisational capability). Effective resilience investment prioritisation depends on a clear consumer and service delivery focus rather than asset management-focused solutions.

Within a utility, there are four key areas that can impact the resilience outcomes of their service:

- **Organisational resilience** - The capacity of infrastructure operators to effectively plan for and respond to disruptions, including financial health, staff capability, leadership, and business continuity management.
- **Information and planning systems** - The availability of adequate hazard data, risk analysis processes, and investment analysis capabilities to determine minimum investment levels for resilience improvements.
- **Physical system attributes** - The physical attributes of infrastructure networks that reduce damage during events or enable rapid restoration, including asset robustness, network redundancy, and emergency response provisions.
- **Investment decision making** - Robust financial decisions based on recognised processes and techniques that ensure financially sound and well-prioritised investments.

ComCom will need to consider each of these areas to determine how they can be addressed in ComCom's processes, including price-quality pathways and information disclosure requirements.

INVESTMENT DECISION-MAKING MUST BE EVIDENCE-BASED

The report highlights the importance of evidence-based investment decision-making, including:

- Multi-hazard risk awareness across different scales and timeframes.
- Understanding infrastructure and economic interdependencies.
- Accounting for all costs and benefits, including distributional impacts.
- Understanding community risk tolerance and risk bearing capacity.
- Comprehensive option development considering co-benefits and alternative service delivery.
- Managing uncertainty through scenario analysis and adaptive planning.

EVALUATION FRAMEWORKS AND TOOLS

The report reviews multiple decision-making frameworks, including Cost-Benefit Analysis, Multi-Criteria Analysis, Real Options Analysis, and Robust Decision Making. It emphasises that framework selection should reflect the uncertainty context and availability of data. Economic modelling tools like MERIT (Measuring the Economics of Resilient Infrastructure Tool) can capture economy-wide impacts often missed in traditional analyses.

VALUE OF LOST LOAD

The Value of Lost Load (VoLL) is an established metric (particularly in the electricity sector) for quantifying the economic cost of service interruptions, representing how much customers are willing to pay to avoid outages.

VoLL can be estimated through proxy methods (using indirect indicators), survey-based approaches (directly asking customers), or revealed preference methods (observing actual behaviour). However, important limitations must be considered when applying VoLL to evaluate resilience benefits (as opposed to reliability):

- Different customer types experience varying impacts from service disruptions.
- Impacts often do not scale linearly with outage duration.
- VoLL may not adequately capture significant public health, environmental, or higher-order economic impacts.

While VoLL provides valuable monetisation of resilience benefits, it needs to be supplemented with other analysis when dealing with complex, interconnected infrastructure systems and long duration disruption events.

MEASURING RESILIENCE

Two complementary resilience measurement approaches are suggested.

- **Resilience Outcomes** - measuring actual performance after disruption events across:
    - Asset damage.

    - Asset performance and recovery.
    - Service loss impacts on consumers.
- **Resilience Capacity** - evaluating forward-looking preparedness through:
    - System attributes.
    - Organisational resilience.
    - Information and planning systems.

Potential actions for ComCom

While this report sets a foundation for ComCom to build its own practices from, we see several potential actions that could support the operationalisation of the concepts presented in this report:

1. **Develop resilience guidance** for utilities on practical resilience building steps and maturity pathways.
2. **Create business case guidance** for utilities to support investment decision-making. The report introduces a 'Robust resilience investment business case framework' which could be further developed to support utilities.
3. **Establish maturity assessment tools** to support gap analysis and practice improvement.
4. **Promote information disclosure** on infrastructure interdependencies to enable coordinated resilience planning.
5. **Support community-based resilience planning** to ensure investments align with community needs and risk tolerance.
6. **Implement resilience performance reporting** to focus infrastructure provider attention on reducing disruption and improving response capabilities.

Conclusion

Building infrastructure resilience requires moving beyond traditional engineering approaches to embrace system-wide thinking that considers organisational capacity, community needs, and interdependencies. ComCom has a significant opportunity to guide utilities on a continuous resilience improvement journey through principled investment evaluation, appropriate performance or capacity evaluation and information disclosure requirements, which enable and promote a balance between resilience benefits and consumer affordability.

Contents

PART A

1. Introduction

Infrastructure enables vital services that support wellbeing, drive a productive and sustainable economy, and help achieve broader social and environmental goals (New Zealand Infrastructure Commission, 2025a). Recent events, such as Cyclone Gabrielle, also highlight that community expectations around service interruption and restoration times are ever-growing as our communities become increasingly dependent on infrastructure services.

Infrastructure systems are subject to a wider range of threats earthquakes, volcanoes, climate change, demographic shifts, technological advancements and interdependencies. Cybersecurity is an ongoing and ever-changing threat (National Cyber Security Centre, 2024). The Department of the Prime Minister and Cabinet (DMPC) has a programme underway explicitly focusing on cyber risks (Department of the Prime Minister and Cabinet (DPMC), 2025). The World Economic Forum Global Risk Report shows deepening geopolitical and geoeconomic tensions, which could pose significant security threats (World Economic Forum, 2025). All these threats are working together to create an increasingly volatile disruption landscape that could affect critical infrastructure providers, their networks/services, and/or the communities in which they operate.

Resilience is now central to natural hazards planning in New Zealand, driven by recent experiences such as the Canterbury (2010, 2011) and Kaikōura (2016) earthquakes, Auckland Anniversary Day Floods (2023) and Cyclone Gabrielle (2023). The Draft National Infrastructure Plan, published in 2025, states: "*NZ is in the top 3 OECD countries for reported natural hazard damage. Central government spent at least $33 billion on natural hazards between 2010 and 2025, and many public assets are uninsured*" (New Zealand Infrastructure Commission, 2025a, p. 19).

Strategic support for infrastructure resilience is reinforced by the National Disaster Resilience Strategy (Ministry of Civil Defence and Emergency Management, 2019), which takes a holistic approach beyond emergency management, promoting proactive risk reduction across society. The strategy is issued pursuant to the Civil Defence Emergency Management Act 2002 (CDEM Act) and thus has the specific aim of outlining the Crown's goals in relation to civil defence emergency management. It takes a holistic and systemic approach to resilience, with considerations much wider than emergency management. The strategy highlights risk assessment and economic impact analysis to guide resilience investments. New Zealand also endorses the Sendai Framework for Disaster Risk Reduction 2015-2030, advocating for widespread engagement in reducing disaster risks through better understanding and investment in resilience. It is within this context that the Commerce Commission (ComCom) operates.

ComCom plays a central role in regulating utilities in Aotearoa-NZ, particularly sectors where competition is limited, including electricity lines, gas pipelines, telecommunications, airports and, shortly, water supply and wastewater systems. Its mandate is to promote the long-term interests of consumers through efficient, reliable service provision at a fair price.

With the ever-increasing threat landscape, resilience is increasingly integral to ComCom's regulatory approach. This is reflected in decisions (e.g., price quality pathways for electricity distribution businesses (DPP4) and expenditure allowances (RCP4)) where 1) revenue allowances have been increased to support investment in upgrades (e.g., Transpower's price quality path decisions under RCP4-DPP4) and resilience measures e.g., replacing ageing assets, expanding capacity, and mitigation of extreme weather events, and 2) introduction of 'smoothing mechanisms' that balance cost of resilience investments with affordability for consumers e.g., gradual rather than sharp increases in bills, that help household consumers adjust to increased costs. Indirectly, DPP processes may enable an infrastructure provider to raise capital to support resilience-related upgrades, provided it doesn't compromise its financial stability. Some regulated suppliers expect a large capex programme (particularly electricity networks and water/wastewater), which should provide an opportunity for increased resilience if done well.

ComCom is, therefore, both a gatekeeper and enabler – ensuring utilities invest in resilience measures and encouraging resilience improvement practices, while protecting consumers from excessive costs. This balancing act is increasingly important as pressures are placed on New Zealand's ageing infrastructure.

In June 2025, ComCom engaged ResOrgs to collate existing research and practice related to evaluating infrastructure investments and measuring resilience. This work was commissioned to provide a foundation for the subsequent development of ComCom's detailed approach to integrating resilience into its regulatory processes. This report is designed to support ComCom's resilience journey. It aims to raise awareness internally of the principles of resilience in infrastructure systems and subsequent implications for the current and future regulatory controls of electricity lines, gas pipelines, fibre networks, airports and water infrastructure.

The content is based on a literature review and expert analysis by the project team. The project team have extensive experience in asset management, risk management, economic analysis, risk management, systems thinking, and resilience. The team have worked internationally across policy, practice and research to inform the development of resilience strategies, guidance, investment business cases and more. This report brings together over a decade of focussed research and practice on infrastructure resilience as it relates to ComCom's responsibilities.

The report is split into four parts. Part A is an introduction that outlines the concept of resilience and how it applies to critical infrastructure systems in New Zealand, through reference to foundational documents including national infrastructure plans and the National Risk Register. The section includes a short overview of the current state of sectors that ComCom regulates, from a resilience perspective. This section does not provide a detailed analysis but provides a high-level perspective on the progress and challenges toward resilience maturity. Part B focusses on investment decision-making practices. It provides a set of principles for including resilience concepts in investment decision-making and outlines a range of tools and frameworks that can be used to help evaluate resilience investments from a resilience point of view. This section also includes a focussed section on the Value of Lost Load (VoLL) and its applications and limitations across infrastructure sectors. Part C contains a review of resilience measures that could be used to evaluate the resilience capacity/maturity and performance of critical infrastructure providers. Part D provides a summary of the key themes through the report and outlines a set of potential actions for enabling resilience building amongst critical infrastructure providers.

HOW IS RESILIENCE TREATED UNDER OTHER LEGISLATION?

The Resource Management and Local Government Acts

As we move from high-level strategies and policy documents through to laws and regulations, specific uses of the term 'resilience' becomes less apparent. Nevertheless, key legislation is generally sufficient to support a resilience focus, alongside other key objectives. In addition to the CDEM Act mentioned above, the most important laws and regulations currently controlling infrastructure-related decisions and investments are the Local Government Act 2002 (LGA) and Resource Management Act 1991 (RMA). The LGA sets out the roles, powers of, and obligations of local government in New Zealand. Among the core functions of local government is its role in providing good quality infrastructure and public services for the current and future needs of the community (Section 10). A core service to be considered in performing this role is the avoidance or mitigation of natural hazards (Section 11A). The stated purpose of the RMA is to promote sustainable management, with this defined as the management of natural and physical resources in a way that enables people and communities to provide for their social, economic and cultural wellbeing and for their health and safety (Section 5). It includes within its provisions the powers and procedures through which local government can set policies and assessment frameworks to guide and control land use and development, including for the purposes of avoiding or mitigating natural hazards (Sections 30 and 31). The management of significant risks from natural hazards is also listed as a matter of national importance, which must be recognised and provided for by all persons exercising functions and powers under the Act (Section 6). With the RMA being replaced with two new pieces of legislation: the Natural Environment Act and the Planning Act, the provisions above are expected to be retained and possibly strengthened.

2. Resilient infrastructure

2.1 The meaning of resilience

There are various definitions of resilience (Stevenson et al., 2015). The National Disaster Resilience Strategy defines resilience as:

"The ability to anticipate and resist the effects of a disruptive event, minimise adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving" (Ministry of Civil Defence and Emergency Management, 2019, p.18).

ComCom has developed its own definition, which is:

"Infrastructure resilience is the timely and efficient prevention, absorption, recovery, adaptation and transformation of national infrastructure's essential structures and functions (Services1, IM definition of Resilience Capx2) which have been exposed to current and potential future hazards"

[1] Services are defined in the Commerce Act 1986, part 2, interpretation:

Services includes any rights (including rights in relation to, and interests in, real or personal property), benefits, privileges, or facilities that are or are to be provided, granted, or conferred in trade; and, without limiting the generality of the foregoing, also includes the rights, benefits, privileges, or facilities that are or are to be provided, granted, or conferred under any of the following classes of contract:

a) a contract for, or in relation to,—
   i) the performance of work (including work of a professional nature), whether with or without the supply of goods; or
   ii) the provision of, or the use or enjoyment of facilities for, accommodation, amusement, the care of persons or animals or things, entertainment, instruction, parking, or recreation; or
   iii) the conferring of rights, benefits, or privileges for which remuneration is payable in the form of a royalty, tribute, levy, or similar exaction; or
   iv) to avoid doubt, the supply of electricity, gas, telecommunications, or water, or the removal of wastewater:
b) a contract of insurance, including life assurance, and life reassurance:
c) a contract between a bank and a customer of the bank:
d) any contract for or in relation to the lending of money or granting of credit, or the making of arrangements for the lending of money or granting of credit, or the buying or discounting of a credit instrument, or the acceptance of deposits;— but does not include rights or benefits in the form of the supply of goods or the performance of work under a contract of service

[2] Resilience Capx is capex for the purposes of preparing to mitigate or respond to 1 or more high-impact, low-probability events that, if the preparation is not done promptly, may have a significant impact on the EDB's ability to maintain current security or quality of supply standards; but does not include any regular: (a) asset replacement and renewal capex that is consistent with appropriate 4723266 Electricity Distribution Services Input Methodologies (IM Review 2023) Amendment Determination 2023 54 lifecycle and asset management planning; or (b) expenditure for cybersecurity;

Across most definitions of resilience, there are two core features:

- The ability to absorb the impact of a disruption, which includes the ability to anticipate and put measures in place to reduce the size of the disruption
- The ability to adapt to a disruption, which includes the ability to both recover what was in place before an event and to adapt to a new normal.

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These aspects are illustrated in Figure 1.

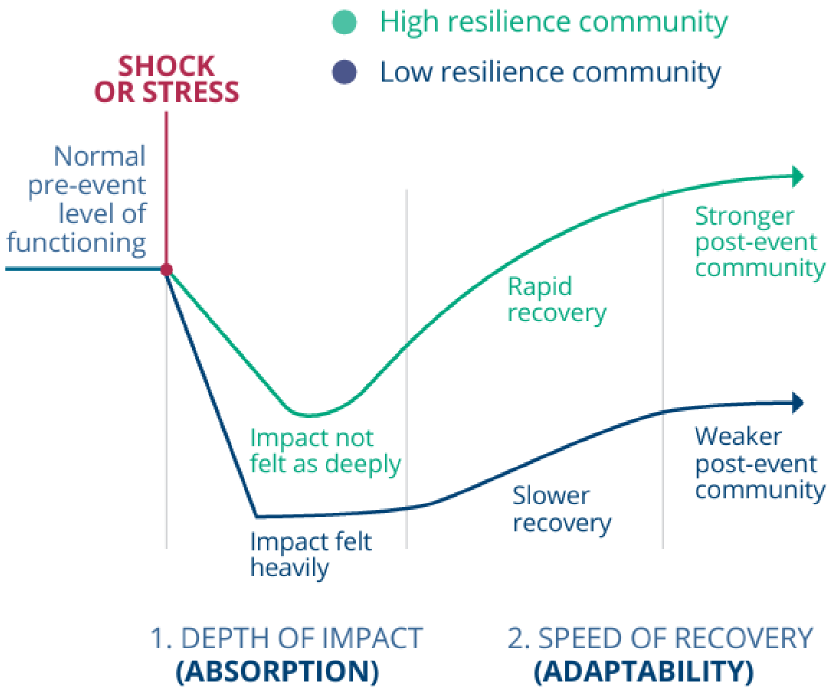

Figure 1 Model of resilience from National Disaster Resilience Strategy (Ministry of Civil Defence and Emergency Management, 2019)

Hallegatte (2014) provides an economic definition and methods for the evaluation of resilience. He defines resilience using a combination of macro- and micro-economic measures. *Macroeconomic resilience* is viewed as a combination of 1) 'instantaneous resilience', i.e., the ability to limit the magnitude of an immediate loss of income for a given amount of capital loss, and 2) 'dynamic resilience', i.e., the ability to reconstruct and recover quickly. *Microeconomic resilience* applies to households and is viewed as a function that considers the distribution of direct losses, the ability to provision basic needs, smooth shocks across time, and to share risk. When considering resilience from an economic perspective, it is often argued that the economic goal of efficiency (van Staveren, 2023, 2024), which is focused on short-term optimisation of the performance of infrastructure, may distract us from resilience, which is focused on long-term optimisation of the performance of infrastructure. Others, however, argue that 'best practice' application of evaluation frameworks and methods (as per Part B) for valuing resilience does address this concern. It is, however, important to note that the marginal cost of investing in resilience will at some point exceed its marginal benefit, i.e., consumers can be worse off with gold-plated solutions.

The term "reliability" is often applied in the ComCom context. Resilience is different to reliability in that it refers to the performance of infrastructure systems in situations that are significantly different from 'normal' operating conditions. IEEE defines reliability as "The probability that a system will perform its intended functions without failure, within design parameters, under specific operating conditions, and for a specific period of time".

It is important to recognise that there are many different types of threats that infrastructure systems need to be resilient to. These include natural hazards (earthquakes, volcanoes, floods, etc), biological hazards (e.g. pandemic), and man-made threats (e.g. terrorism, industrial disasters, cyber). These events can be acute or sudden onset, such as earthquakes, flooding, and climate-induced hazards (e.g., storms), or they can be chronic or slow onset disruptions, such as population, technology, and climate change impacts (e.g., sea level rise). See Figure 2 for an example of how to classify infrastructure threats.

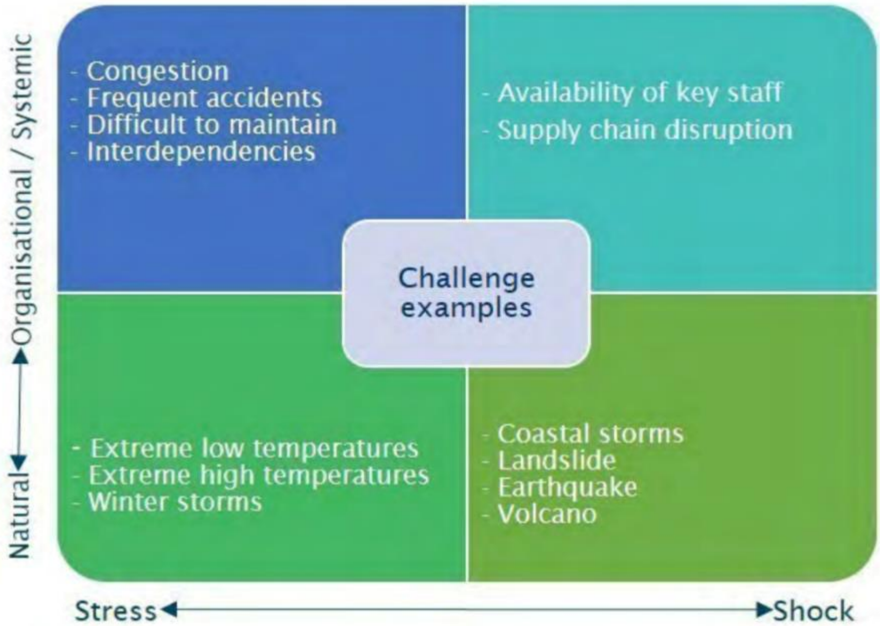

Figure 2 Shock/stress sources (Money et al., 2017)

The DPMC are responsible for maintaining the National Risk Register (NRR) (Department of the Prime Minister and Cabinet, n.d.b), a key part of the National Risk and Resilience Framework (Department of the Prime Minister and Cabinet, n.d.a). The NRR is used to identify, track and ultimately build resilience to National Risks. It currently includes 33 National Risks; those hazards and threats that could have serious immediate and/or long-term effects on New Zealand's safety, prosperity and/or national security, requiring national-level intervention and coordination across the 4Rs (Reduction, Readiness, Response and Recovery).

While it is not possible to capture every major risk facing New Zealand, the National Risk Register supports the government to make targeted decisions that focus resources where they will have the greatest impact.

The NRR includes "Significant disruption or failure of critical infrastructure", and many of the other risks have infrastructure impacts or elements to them. One national risk that has gained prominence in recent years is Space Weather: "Space weather refers to variable conditions on the sun and in the space environment that can impact Earth's magnetic field. A space weather event can cause severe geomagnetic disturbance that could negatively impact information and communications technology (ICT), global navigation satellite systems (GNSS), and other critical infrastructure" (Department of the Prime Minister and Cabinet, n.d.b)

2.2 New Zealand Infrastructure Plan

The Thirty Year New Zealand Infrastructure Plan 2015 (referred to as NIP 2015) is the responsibility of the National Infrastructure Unit within the New Zealand Treasury and is foundational when considering the resilience of national infrastructure from an economic, fiscal and well-being perspective (National Infrastructure Unit, 2015). "Resilience" is a term mentioned many times throughout the document, with a general focus on resilience to the highly hazardous environment and ongoing events that New Zealand is exposed to.

The Foreword from the National Infrastructure Advisory Board clearly includes:

".... To be effective, long-term planning will need to consider a range of questions: does an infrastructure solution meet demand; is it compliant; is it fundable; does it add to resilience; is it affordable; does it meet aspirations for local, regional and national economies? ....

Lindsay Crossen, Chair, National Infrastructure Advisory Board" (National Infrastructure Unit, 2015, p.5, emphasis added).

The NIP 2015 expands on this to state:

"... Our asset management practices also need to include a stronger understanding of the resilience of our infrastructure networks at a national, regional and local level, especially key pinch-points and the degree to which different parts of networks are critical to overall performance. There is a need to increase the sophistication of how we think about resilience, shifting beyond a narrow focus on shock events or infrastructure failure and thinking more about interdependencies, levels of service and community preparedness. A longer-term view needs to be taken with increased focus on adapting to slower changes over time, including climate change. The graphic over the page [

Figure 3] shows key elements of resilience. Importantly, increased resilience is not necessarily about making things stronger or investing more and is quite often achieved by operational changes."
(National Infrastructure Unit, 2015, p. 47)

Resilience attributes

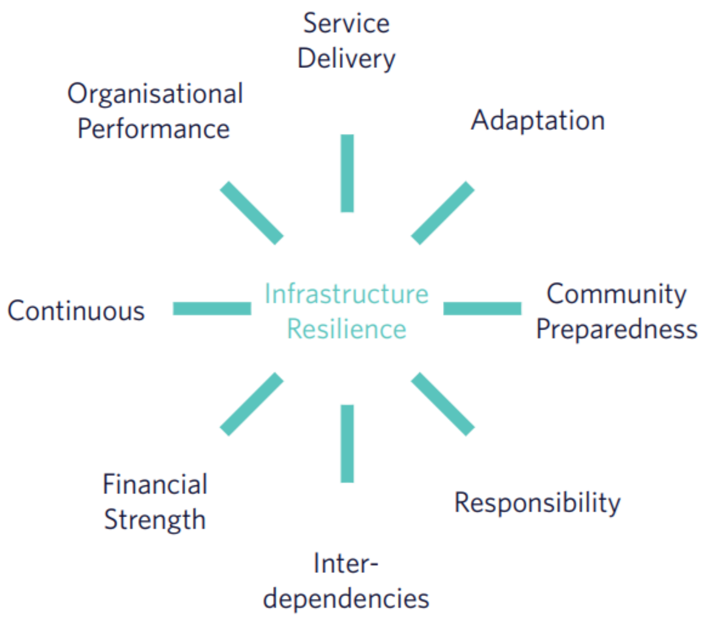

Figure 3 Infrastructure Resilience Attributes (New Zealand Treasury, 2015)

These attributes are defined as:

- **Service Delivery** - Focus on national, business, and community needs in the immediate and longer term.
- **Adaptation** - National infrastructure has the capacity to withstand disruption, absorb disturbance, act effectively in a crisis, and recognise changing conditions over time.
- **Community Preparedness** - Infrastructure providers and users understand the infrastructure outage risks they face and take steps to mitigate these. Aspects of timing, duration, regularity, intensity, and impact tolerance differ over time and between communities.
- **Responsibility** - Individual and collaborative responsibilities are clear between owners, operators, users, policymakers and regulators. Responsibility gaps are addressed.
- **Interdependencies** - A systems approach applies to identification and management of risk, including consideration of interdependencies, supply chain and weakest link vulnerabilities.
- **Financial Strength** - Financial capacity to deal with investment, significant disruption and changing circumstances.
- **Continuous** - Ongoing resilience activities provide assurance and draw attention to emerging issues, recognising that infrastructure resilience will always be a work in progress.
- **Organisational Performance** - Leadership and culture are conducive to resilience, including Resilience Ethos, Situational Awareness, Management of Keystone Vulnerabilities and Adaptive Capacity. Future skills requirements are being addressed.

At the time, there were two more novel elements to these attributes. The clear recognition that communities and end-users themselves can be strong contributors to improvements in overall infrastructure resilience has led almost all international approaches to focus on the infrastructure providers being solely responsible for infrastructure resilience. The second was financial strength, not only to invest in resilience improvements but to deal with events and challenges as they arise.

In the New Zealand context, all of these attributes are important and collectively offer substantial opportunities for resilience improvements. The Commerce Commission has the opportunity to contribute to them all, either directly or indirectly, by its approach.

The draft New Zealand Infrastructure Plan 2025 (New Zealand Infrastructure Commission, 2025b) has recently been out for public consultation. This plan is based on the New Zealand Infrastructure Strategy 2022-2052 (New Zealand Infrastructure Commission, 2025c). It focuses on the many challenges faced by the infrastructure sector: growth, ageing assets, and natural hazards. It has also been recognised that historically our total investments into infrastructure were high in comparison with other OECD countries. Yet, our efficiency in delivering the infrastructure was one of the lowest amongst other countries. Future investment into infrastructure, therefore, has to target efficiency by addressing multi-dimensional interventions such as asset renewals, including resilience improvements.

2.3 Elements of resilience - networks and operations

Infrastructure resilience is often conceptualised by four attributes of the system: robustness, redundancy, resourcefulness, and rapidity (Bruneau et al., 2003). These attributes generally represent an engineering-based perspective of resilience – focussed on assets that are designed to withstand disruption, and processes (both technical and organisational) that are established to enable a swift response and recovery after an event. These concepts reflect the wider context that each infrastructure asset, network and system sits within and look at the attributes of a system that supports resilience building. If the list is extended to include a more socio-ecological view of resilience (Rus et al. (2018)), additional attributes include reflectiveness, flexibility, inclusiveness, and integration.

ROBUSTNESS	Capacity for physical infrastructure assets to withstand the impacts of hazards without suffering serious damage or disruption to services (United Nations Office of Disaster Risk Reduction, 2022). This can be measured through different sub-measurements, such as structural robustness, procedural robustness, and interdependency robustness (Guo et al., 2021).
REDUNDANCY	The availability of back-up and/or alternative systems to continue providing services in the event of a disruption. The New Zealand Transport Agency (Waka Kotahi) defines redundancy as the “provision of functionally similar outcomes, to an acceptable standard, during lost or degraded levels of service” (Money et al., 2017).
RESOURCEFULNESS	Accounting for the “human factor” of resilience, including the capacity to anticipate and forecast hazards and disruptions without placing an over-reliance on technology (Rus et al., 2018). This is especially relevant within the scope of organisational resilience.

RAPIDITY	Overlapping with other commonly used terms such as recoverability and responsiveness, rapidity refers to the ability for infrastructure services to be quickly restored to a desired standard after a disruption has occurred (Guo et al., 2021).
REFLECTIVENESS	The ability to anticipate and accept uncertainty and change, with the ability to grow and evolve accordingly over time (Rockefeller Foundation, 2019).
FLEXIBILITY	Systems that can change, evolve and adapt when faced with changing conditions (Rockefeller Foundation, 2019).
INCLUSIVENESS	The involvement of a broad range of stakeholders within community consultation and engagement with resilience decision-making, including the most vulnerable groups (Rockefeller Foundation, 2019). It also helps to encourage a systems approach toward decision-making.
INTEGRATION	Collaborative processes between systems and institutions, to promote consistent decision-making and to ensure information is exchanged for rapid response and collaborative capabilities (Rockefeller Foundation, 2019).

To enable these attributes, a holistic view of the delivery and operation of infrastructure systems is needed, as set out in the NIP 2015 (National Infrastructure Unit, 2015). It is helpful to conceptualise three domains that are essential to support the resilience of infrastructure services: **physical** (e.g. cables, transformers, pipes, towers), **cyber** (e.g. databases, information, sensors) and **organisational** (e.g. processes, policies, human operators, administrators) (Kwasinski et al., 2024). All domains need to be considered to maximise resilience outcomes. Further to that, due to the highly interconnected and network nature of all infrastructure systems, resilience can only be improved if the systems that interact with the utility (including other infrastructure systems and emergency management systems) also exhibit high levels of resilience.

RESILIENCE THROUGH TIME

Resilience is not static, and no infrastructure system is fully resilient: the condition of the assets, the hazards that assets are exposed to, and the vulnerability of the community are changing all the time. Impact from disruptive events can also impact an organisation's resilience by the erosion of financial capital, and impact on human capital. Resilience needs to be regularly evaluated, and strategies revised to adapt to the changing conditions.

3. Sectoral context

Each of the sectors and utility providers that ComCom regulates faces unique challenges. Each organisation and sector is on a resilience maturity journey. Their progress on that journey will be impacted by the current resilience of their assets, organisation and sector preparedness (see New

Zealand Lifelines Council, 2023; Department of the Prime Minister and Cabinet, 2024). Factors affecting current resilience include:

Hazard /threat exposure

- Key threats (physical, technological/cyber, organisational) including nature and human-induced hazards.
- Where the assets are located (geography, hazards).

Vulnerability of assets

- Condition of assets (impacted by historic funding and maintenance decisions).
- Ability and cost to mitigate risks.
- Interdependencies (e.g. upstream dependencies on other infrastructure services affecting capacity to restore service after an event).

Market context

- Demand for services.
- Communities served (and resulting revenue streams).
- Downstream infrastructure and critical customer dependencies.
- Functional requirements pre and post events.
- Hazard awareness amongst consumers (and willingness to pay/demand for improved resilience).

Utility or sector attributes

- Sector norms, behaviour and mobilisation (e.g. access to industry support for resilience building).
- Engagement in the emergency management system and local lifelines groups.
- Disaster experience, recency effect.
- Organisational context/environment (including ownership model).
- Financial health of the organisation.
- Regulatory environment.
- Access to hazard information.

In this section, we provide high-level observations on how each of the sectors that ComCom regulates is affected by these factors and how this might impact their current and future resilience maturity journey. Understanding the different context of each sector is critical when ComCom is designing a regulatory approach for each sector. *Note that this does not constitute a comprehensive resilience assessment of each sector.*

3.1 Electricity transmission and distribution

3.1.1 HAZARD EXPOSURE AND VULNERABILITY OF ASSETS

The EDBs operate across a wide range of geographies, communities, and hazards, each with its unique challenges. As a result, some EDBs and their networks are significantly more resilient than others.

While many EDB sites have more than one line of electricity supply and/or alternative power sources, some parts of the network, and the supplies to some single assets, do not have either redundancy in the network or viable back-up power supplies. Electricity is one of the most depended on infrastructure systems – both by consumers and other infrastructure sectors – contributing to a high demand for, and perceived value of, resilience.

3.1.2 MARKET CONTEXT

Electricity systems across New Zealand have been tested by a range of natural hazards, human induced and technological failure events. These past events, and hazard and loss modelling, such as that undertaken for the Wellington lifelines Programme Business Case, have prompted resilience investment in assets.

Between 2010 and 2022, the investment in the electricity sector was approximately $2.4 billion (0.8% of GDP). Te Waihanga estimated that investment needs to increase to approximately 1.6% of GDP, ranging between $7.3 billion to $9.4 billion per decade (New Zealand Infrastructure Commission, 2025a). Some of the major investment drivers include population growth, shifting technologies such as electric vehicles and switching to more renewable energy sources. There is also an increased investment requirement into resilience to minimise losses with increasing intensity of hazard events (solar storms in particular are of concern moving forward).

3.1.3 UTILITY OR SECTOR ATTRIBUTES

Of all the infrastructure sectors, the electricity sector is one of the more mature in how it considers and manages hazard risks. The sector has a comprehensive regulatory environment. In addition to the Commerce Commission, the following regulators provide sector oversight:

Electricity Authority – Electricity Industry (Enforcement) Regulations 2010 and the Electricity Industry Participation Code 2010. Two relevant clauses include:

- **Effective risk management:** market participants have access to the tools they need to efficiently manage their risks and to provide signals to guide longer-term decisions, such as investment in electricity generation.
- **Regional resilience:** regions and communities have a reliable energy supply even when there are disruptions, e.g., from natural disasters, cyber-attacks or other unforeseen circumstances.

Energy Safety (WorkSafe)- Electricity (Safety) Regulations 2010. Responsible for regulations related to electrical safety.

Despite the sector, as a whole, having a relatively mature approach to resilience, there is significant variance across the sector. With 29 Electricity Distribution Businesses (EDBs), as well as Transpower managing the National Grid, the electricity network is managed by a range of organisations, with a variety of financial resources and organisational capabilities.

The sector has developed its own guidance material to support resilience building, for example, the Electricity Engineers' Association published a Resilience Guide in 2022. The guide covers opportunities to build resilience into assets (redundancy and robustness), improve organisational readiness, response and recovery and how to evaluate resilience investments (Electricity Engineer's Association, 2022). The guide includes a self-assessment tool called the Resilience Management Maturity Assessment Tool (RMMAT), designed to help utilities assess their awareness and management of hazards across the 4Rs – Reduction, Readiness Response, and Recovery.

Within the electricity sector, the Value of Lost Load (VoLL) (see Section B 2.3 for further details) is a well-used measure of the estimate of the economic impact from non-supply. While primarily designed to support decisions related to electricity system reliability, VoLL is increasingly used to support business case decisions related to asset investment decisions to reduce disruption.

3.2 Telecommunication fixed lines

3.2.1 HAZARD EXPOSURE AND VULNERABILITY OF ASSETS

The telecommunications sector is rapidly changing through technology advancements, increasing levels of intra- and inter-connectedness, and increasing consumer demand. The fixed line network contains both nodes (e.g. exchanges) and network components (e.g. fixed line transport and access links). There is active redundancy in the core fibre network connecting the major telecommunications nodes in both the North and South Islands. Major exchanges are designed to failover to other sites, adding to resilience. The highly interconnected networks make it complicated to predict the impact of specific asset outages.

The sector is highly vulnerable to electricity disruption, as evidenced most recently following 2023 Cyclone Gabrielle. Following an event, restoration of services will also be heavily impacted by disruption to roads (affecting the ability of contractors to access repair sites).

Like the electricity sector, the telecommunications sector is well-practised at responding to routine events but has not been significantly tested. Business continuity planning is improving in the sector. The sector has a high reliance on telecommunications retailers, who will alert them of problems in their networks, as well as third-party contractors that will undertake repair and recovery following an event.

3.2.2 MARKET CONTEXT

The rapid technological development has driven regular upgrading of all telecommunications components to meet increasing consumer demands. For example, the past decade saw a nationwide switch from copper to fibre. Therefore, assets were replaced for technological reasons rather than asset deterioration. Compared to other sectors, telecommunications will see only modest increases in investment needs, from the current $2.1 billion (0.7% of GDP) for the past decade to between $3.3

billion and $4.7 billion (0.8% of GDP). Renewal and upgrading in technology will drive most of the investment needs.

3.2.3 UTILITY OR SECTOR ATTRIBUTES

Similar to the electricity sector, the telecommunications sector is one of the more mature in how it considers and manages hazard risks. There is an obvious concern about interdependence between telecommunication and electricity, as was highlighted during Cyclone Gabrielle. However, the sector can, at times, be reluctant to share asset and service data with others (e.g. lifeline groups and emergency managers), which presents a challenge when trying to build the collective resilience of communities.

The Telecommunications Forum (TCF) is currently developing a Telecommunications Emergency Management Plan in response to the proposed requirements in the Emergency Management legislation (NZ Telecommunications Forum, n.d.). The TCF (and sub-group Telecommunications Emergency Forum (TEF)) plays a critical role in a response. The TEF works to ensure ongoing relationships with NEMA and other Sector Coordinating Entities, both regionally and nationally, to ensure protocols and response plans can continue to be fine-tuned and any response via the coordination channels is quickly established during an emergency event.

3.3 Gas (reticulated)

3.3.1 HAZARD EXPOSURE AND VULNERABILITY OF ASSETS

New Zealand’s gas infrastructure is principally located in the North Island. Natural gas extracted and processed from Taranaki fields is transported via two high-pressure networks that head to the North (feeding Waikato, Bay of Plenty, Gisborne, Auckland, Northland) and to the South (feeding Whanganui, Manawatu, Hawkes Bay, Wellington). Lower-pressure local distribution networks then deliver gas to most consumers.

Operationally, there is a strong interdependency of reticulated network operations and gas production sources. For example, unplanned gas field outages may require the reticulation network to respond immediately. There is also an increasing risk of stranded assets.

3.3.2 MARKET CONTEXT

Natural gas has a significant role in the national economy, with many manufacturing plants critically dependent on its provision as an energy source and/or as a feedstock for industrial processes. The electricity sector also depends on natural gas, with on-demand gas-fired generation at Huntly power station critical for smoothing out gaps between electricity supply and demand. Furthermore, many thousands of residential and commercial users rely on gas as an energy source, including critical customers such as hospitals that utilise gas for heating and sanitary purposes.

New Zealand’s gas reserves are declining, and consumers are facing affordability and unreliability of supply issues. There is also an ongoing desire and pressure to transition New Zealand consumers away from natural gas use (Electricity Authority, 2024). Uncertainty around the extent and timing of fossil gas transition, and the potential alternative uses for gas infrastructure (Firstgas, 2024), adds significant complexity to gas infrastructure investment planning.

In contrast to many other sectors, the gas sector is noticing a slight decline in investment due to large-scale electrification and limited connections to new property developments. There is some investment growth into renewable gas and an increased investment into renewables, replacement, and resilience improvements in the distribution network.

The Powerco asset management plan forecasted the investment decline from a current annual level of $21 million to approximately $17 million per annum for the next decade (2023 dollar values).

3.3.3 UTILITY OR SECTOR ATTRIBUTES

Acts and regulations that mostly impact investment are:

- Civil Defence and Emergency Management Act 2002
- Emissions Reduction Plan – 2022
- Gas Act 1992 and Gas Amendment Act 2006

The Powerco 2024 Climate Adaptation & Resilience Plan sets out the strategy for adaptation and emergency capability developments. This strategy is comprehensive and sets realistic targets for the implementation of the adaptation plan.

3.4 Airports

3.4.1 HAZARD EXPOSURE AND VULNERABILITY OF ASSETS

Airport infrastructure is relatively robust, and runways and facilities are designed to withstand moderate seismic events. Similarly, given the high international safety standards, the infrastructure is kept to a high quality and is inherently robust against the impact of other hazards such as flooding and storm events. Despite its robustness, most airports are significantly exposed to weather events as they are normally constructed on low-lying land that may, in some cases, also be close to coastal areas (e.g., Wellington and Auckland). Although the runways and facilities may have the required robustness, services the airport depends on, such as access roads, water, fuel re-supply and electricity, are often of lower robustness and thus increase the overall vulnerability of airport operations. Additional measures are often required for items such as backup fuel supply and backup electricity generation.

3.4.2 MARKET CONTEXT

The airport sector is a heavily regulated environment. For New Zealand-based airports, the Civil Aviation Authority (CAA) has primary regulatory responsibility for aviation safety and security. Providing safety and security at airports is therefore an indispensable investment. Growth in tourism is an obvious stimulus for capacity development, as has been seen recently in Auckland.

As a lifeline utility, Airports "must ensure that they can function to the fullest possible extent, even though this may be at a reduced level during, and after an emergency" (Civil Defence and Emergency Management Act 2002, ss 58(a)). As a consequence, airports may at times be called upon to undertake functions outside BAU, and it is this ability to adapt that is also important to resilience.

3.4.3 UTILITY OR SECTOR ATTRIBUTES

Airports have mature monitoring, control and management practices and are therefore advanced in their asset maturity. Given the geographical location of airports, there remains a high vulnerability of these facilities, thus emphasising the importance of building resilience in emergency response capacity and capabilities. The recent expansion of fuel surplus storage at the Auckland airport is a prime example of such strategies (Jones, 2025).

3.5 Water services

3.5.1 HAZARD EXPOSURE AND VULNERABILITY OF ASSETS

As was evident during recent events, the 3-waters network has a very high vulnerability to hazard events. For example, the 2023 Auckland anniversary flood and subsequent Cyclone Gabrielle caused an approximate $250 million worth of damage to the water infrastructure in Auckland (Forbes, 2023).

Due to the nature and location of water assets, water networks have some inherent vulnerabilities. These vulnerabilities are aggravated by poor asset condition due to systemic under-investment. Some examples include (Based on Hughes et al., 2019) :

- For gravity systems (storm and wastewater), the treatment plants are normally located at the lowest point in the network, typically close to the coastal areas. There are a number of plants that are now exposed to coastal hazards.
- The reticulation network for wastewater pipes is operating close to capacity levels. The combined impact of low capacity and poor pipe condition increases infiltration for rainwater, causing wet water overflows and overwhelming treatment plants.
- The main vulnerabilities of the water supply network are in water sourcing during dry conditions. This, combined with high leakage rates of pipes, results in water shortages becoming an issue in some centres.

3.5.2 MARKET CONTEXT

The largely publicly funded sector faces significant investment challenges that could constrain resilience building (in contrast to other sectors).

The investment priorities, for the years to come, will focus on upgrading water treatment plants, improving the performance and condition of the water reticulation network and improving the resilience of the water services following weather events. In the water sector, resilience considerations are generally secondary to supporting BAU outcomes. As of 2021, the investment shortfall has been estimated between $120 billion and $185 billion nationally (Pennington, 2021). However, there is a substantial opportunity to ensure that resilience is built into day-to-day investment decisions.

Moving forward, regulation in the water sector will focus on investment that addresses the multiple challenges faced by the sector and ensuring holistic and integrated investment analysis.

3.5.3 UTILITY OR SECTOR ATTRIBUTES

Significant governance changes are occurring in the water sector in New Zealand. One of the most significant changes is the move into a regulatory environment (Commerce Commission, 2025i). The August 2016 Havelock North gastro outbreak triggered a series of enquiries into understanding the status of water services, and some significant challenges were identified (Department of Internal Affairs, 2017). These included:

- drinking water quality is of primary concern, and
- the water asset base is in a deteriorated state following years of under-investment.
- The maturity of asset planning in the water sector is low.

4. Enabling resilience

Resilience is a multi-faceted, socio-technological phenomenon. Within a utility there are four key areas that can impact the resilience outcomes of their service (Figure 4):

- Organisational resilience.
- Information and planning systems.
- Physical system attributes.
- Investment decision-making.

ComCom will need to consider each of these areas to determine how (if at all) these can or should be integrated into ComCom's processes, including price-quality pathways and information disclosure requirements.

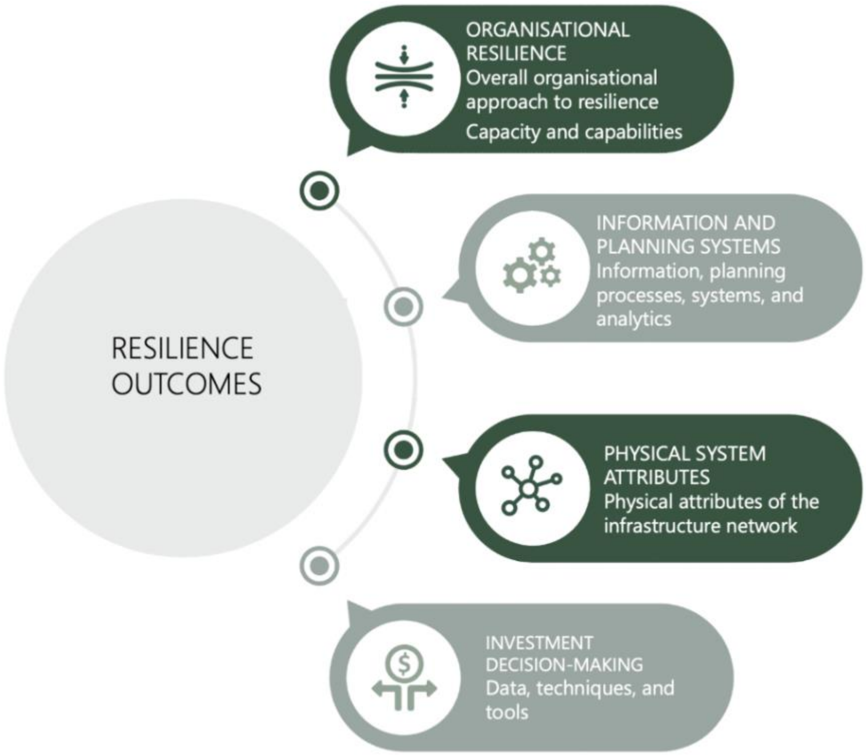

Figure 4 Resilience maturity and best practice (source: authors)

4.1 Organisational resilience

The resilience of a critical infrastructure service is dependent on the resilience of the organisation that manages the service delivery. The more resilient an organisation is, the more able it will be to manage the risks, respond to disruptions and efficiently recover and adapt. Understanding organisational resilience is a key part of evaluating the resilience of an infrastructure service.

Under the umbrella of the Sendai Framework, the UN Office for Disaster and Risk Reduction has developed a Resilience Maturity Assessment Tool (ReMA) (United Nations Office of Disaster Risk Reduction, 2025). ReMA is used to evaluate and enhance an organisation’s capacity to withstand disruptions and adapt to change. It assesses the resilience maturity according to the following six pillars:

- **Policy and governance** – Overarching approach to resilience management.
- **Leadership and culture** – Role of top management and awareness in the organisation.
- **Organisation** – Responsibilities, cross-functional liaison and risk alignment.
- **Capacity** – Limitations of the potential response and how they are resourced.
- **Operating model** – Integration of resilience with business activities.
- **Value chain** - Meeting business objectives and supplier resilience.

How to develop and grow organisational resilience is out of the scope of this report. However, we have included organisational resilience in Part C Resilience measurement, as it is a key indicator of the capacity of a utility to withstand, respond and recover from disruptions.

4.2 Information and planning systems

Resilience is enabled through good information and planning systems. Information and planning systems include the ability of organisations to recognise the priority improvements needed to enhance the resilience of their physical and organisational systems. Information and planning systems include the availability of adequate and appropriate data (including hazard and asset information, as well as understanding of critical customers), risk analysis processes, and investment analysis capabilities to determine the minimum investment levels for resilience improvements. It also includes an emergency management control system (e.g. rapid fault identification systems).

Figure 5 illustrates the different elements of the information and planning system processes as they relate to asset management.

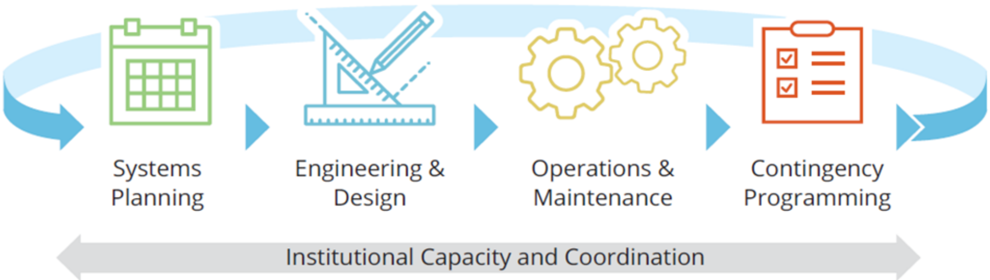

Figure 5 Maturity elements for resilience planning (The World Bank, 2017)

Details of what mature information and planning systems include are out of scope of this report. However, we have included information and planning systems in Part C Resilience measurement, as it is a key indicator of the capacity of a utility to identify risks and plan to manage them.

4.3 Physical system attributes

Resilience is also dependent on the nature and condition of the physical infrastructure network/system. This captures physical attributes that may reduce damage during disruptive events or enable rapid restoration of services through measures. This includes concepts such as asset robustness, network redundancy and emergency response provisions (as described in Section A2.2).

We have not included further detail on how to build physical system resilience as it is out of the scope of the report. However, physical system attributes are included in Part C Resilience measurement, as it is a key indicator of likely disruption from future events.

4.4 Investment decision-making

Resilience is also enabled through good investment decision-making. Robust financial decisions, based on recognised processes and techniques, will ensure financially sound and well prioritised investments. Best practice investment decision-making will be based on sufficient data and information and will use an appropriate set of techniques and tools. Sound economic principles will also be used to assess the return on investment for a range of potential intervention options, and uncertainty will be accounted for.

Part B of this report covers investment decision-making in detail.

4.5 Rest of report

Part B and Part C of this report provide background information to support ComCom in understanding how resilience considerations could be embedded in their regulatory systems.

Part B summarises resilience investment best practice. It focusses on the key principles, methods and tools to support investment decision making.

Part C provides details for how organisational resilience, information and planning systems, and system attributes for any utility could be measured to give a measure of their resilience capacity or maturity.

Part D provides some concluding thoughts on how the concepts in this report could be operationalised.

PART B Investment decision making

1. Principles

In this section, we present principles that would need to be considered for resilient infrastructure investment decision-making. These principles need to be considered by the infrastructure providers when building a resilience business case. While not all of these principles will be of direct interest to ComCom, they may indirectly contribute to consequences felt by consumers.

The principles are founded on a philosophy that infrastructure investment and planning should be based around an understanding of the infrastructure network, its users, and its deficiencies, not around single projects addressing singular issues. A wider system view is required to inform decisions and develop options and actions that provide both direct and indirect benefits to consumers. Decisions must be informed by an understanding of the hazards the network/assets are exposed to. Risks must be assessed based on the physical, spatial, logical and technical vulnerabilities and dependencies across networks. A comprehensive understanding of the impacts of disruption must be determined, including an understanding of asset criticality and any distributional impacts to consumers. Intervention options need to consider their current and future effectiveness amongst wider system activities and include consideration of uncertainty, who bears the risk and who should pay.

The principles are summarised in Figure 6. The principles are split into four groups, which generally align with the typical steps in a risk assessment process. While the principles are presented in a linear fashion and as discrete concepts, we note that there are significant overlaps between the principles and non-linearity. The interconnectedness is evident in their descriptions.

The principles provide a fulsome picture of what is required to undertake a comprehensive resilience evaluation. We recognise that it may take some time for infrastructure entities to be able to fully evaluate and account for these concepts. As resilience investment planning matures, the concepts can be considered in more detail. For those at the beginning of their resilience journey, just being aware of these concepts and acknowledging these principles will be a significant achievement and will provide a roadmap for improving their resilience investment decision-making.

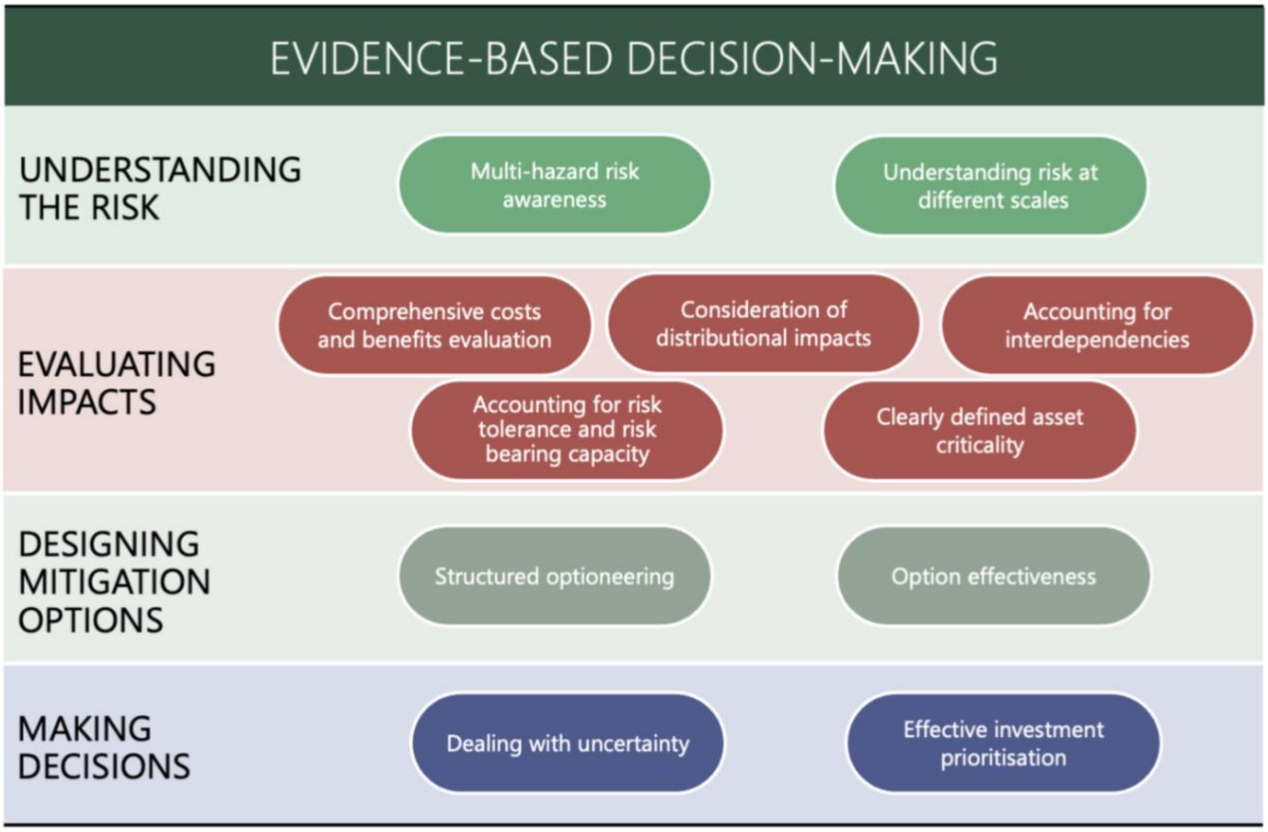

Figure 6 Summary of principles (principles are in coloured ellipses) (source: authors)

1.1 Evidence based decision-making

The rationale for adopting evidence-based investment proposals is to ensure decisions are grounded in accurate, relevant information, leading to more effective and efficient outcomes. Resilience investment requires a significant volume of data to inform the decisions, some of which could be very technical and complex. Valid information is needed to ensure that the appropriate level and quality of information is used to substantiate the needs. The data required will depend on the nature and size of the investment as well as the severity of the risk. In particular, regardless of the quality of the data, confidence in, and uncertainty of data, should be acknowledged in the assessment to allow an evaluation of whether the analysis is fit-for-purpose and provides sufficient confidence in the investment narrative.

A basic risk assessment involves the evaluation of the hazard, asset exposure, asset vulnerability, direct impacts (e.g., to fixed assets and connecting networks that impact consumers) and indirect impacts (e.g., indirectly through loss-of-service). Figure 5 shows the key technical steps followed in a risk assessment, with each step building on previous steps, but also requiring its own evidence base. Importantly, this pipeline of work is often iterative, particularly if alternative resilience building options are being tested in the assessment. The more mature the organisation is, the further along the Figure 5 continuum it progresses and/or the more robust and detailed the data and analysis are at each step in the process. For example, moving from expert judgement to comprehensive modelling, deterministic to probabilistic assessments, etc. Where possible, analysis should look beyond one asset management cycle.

The sections below are the characteristics of good evidence.

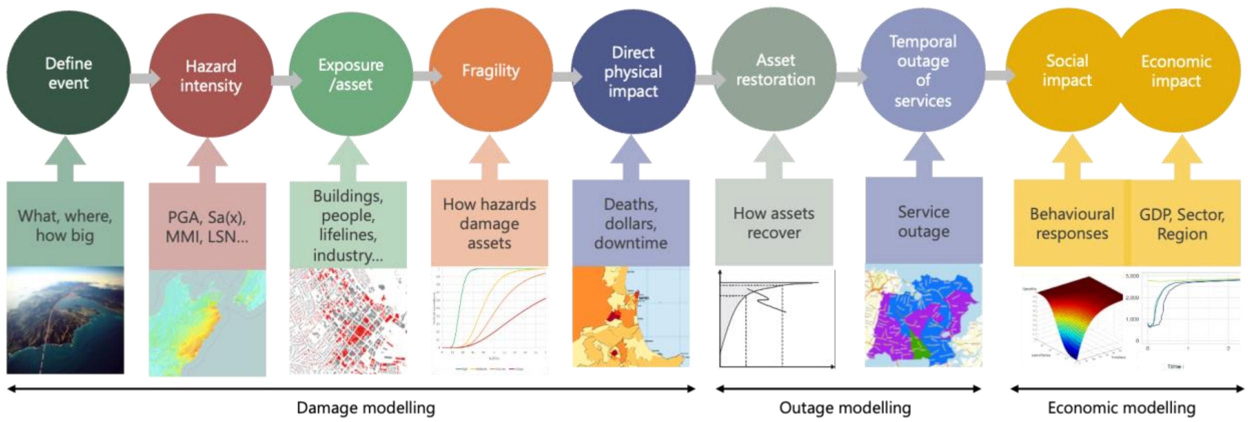

Figure 7 Risk assessment modelling process (source: authors)

1.2 Multi-hazard risk awareness

Multi-hazard risk awareness acknowledges the many hazards we must manage and the interconnected nature of natural hazards. Investment decision-making currently tends to focus on one hazard at a time (e.g. looking at seismic risks separately from flooding). But with limited resources, we need to look across hazards to work out where and how best to prioritise investments. Further, many resilience investments are evaluated based on today's knowledge of hazards, infrastructure networks and consumer needs. However, under various megatrends (e.g., climate change, emergence of disruptive technologies, increasing urbanisation, ageing populations), the frequency and magnitude of natural and human-induced events are increasing, and their impact on consumers is changing. Multi-hazard risk awareness of ongoing disruption is essential for creating enduring resilience.

Infrastructure investment decision-making must look across hazards to ensure resources are effectively prioritised. They must also look across a range of hazard severities. For systems where there is a high resilience maturity, investments should consider not only isolated single hazard risks, but repeated events and multi-hazard events, where perils occur simultaneously (i.e., are coincident) or potentially trigger cascading secondary hazards. This is particularly relevant where repeated events might impact the organisation's ability to restore services to consumers and remain financially viable. Recognising these complexities requires risk-based loss modelling to establish direct physical impacts to utilities (e.g., to fixed assets and connecting networks that impact consumers) and socio-economic modelling to understand consequences for consumers (e.g., indirectly through loss-of-service) and potentially the economic viability of the service providers themselves (e.g., substantial revenue loss).

Scenario analysis and dynamic probabilistic assessment (where possible) in resilience business case development by infrastructure providers helps move beyond traditional siloed approaches (e.g., single hazard risk assessment), fostering investments that account for dynamic, multi-hazard risks while maintaining functionality under stress for providers, enabling enduring resilience for consumers.

1.3 Understanding risk at different scales

Hazards are not static, uniform, or predictable. Effective resilience investment decisions should account for the complexity of hazard exposure and impact distribution across time and space for consumers. Any robust risk assessment should ensure that the impacts to consumers resulting from disruptive events are assessed across scales, including spatially (i.e., within the service provider's catchment), temporally (i.e., through time) and distributionally e.g., by household and business consumers). Furthermore, risk assessment through a consumer lens should also account, where possible, for known uncertainties using sensitivity analysis or decision-making frameworks and evaluation tools/techniques which deal directly with uncertainty (e.g., robust decision-making, dynamic adaptive pathways, real options analysis).

Infrastructure planning must account for both high-impact, low-probability events (e.g., earthquakes, tropical cycles) and simultaneously low-impact, high-probability risks (e.g., smaller weather events, periodic flooding, climate change) as well as both acute and chronic hazards. Spatial and temporal dynamics mean that risks to consumers resulting from utility disruption or failure may not be experienced uniformly, with disparities emerging across different consumer types. Potential disparities should be acknowledged in any risk assessment. By embedding multiscale risk equity into resilience investment decision-making, infrastructure providers can prioritise adaptive solutions that safeguard vulnerable consumers, while maintaining the revenue objectives of the provider, minimising disruption, and creating enduring resilience.

Understanding the distributional effects will help ensure that the benefits of resilience investments are spread equitably across consumers. It also potentially enables targeting of investment to create resilience for those consumers who are most vulnerable (see also Section B1.6).

1.4 Comprehensive costs and benefits evaluation

An infrastructure investment option will have a variety of impacts or outcomes; we often refer to these as the 'costs' and 'benefits'. Costs and benefits can span economic (e.g., new capital outlays, reduced risks of asset damage and business interruption), natural (e.g., alteration in pollution, biodiversity, amenity/landscape values), social (e.g. alteration in neighbourhood amenities and community connectedness), and human (e.g. incidences of disease and mortality) domains. To effectively make investment decisions, the full range of costs and benefits needs to be identified and weighed up.

The terms 'direct' and 'indirect' are often used to describe different types of impacts experienced. These do, however, mean different things in different contexts, for example, within critical infrastructure engineering, infrastructure may be both directly impacted by a hazard and indirectly through infrastructure interdependencies. In economic input-output modelling, directly impacted business consumers are those that experience a disruptive event (e.g. an electricity outage) immediately, while other businesses and consumers may be indirectly impacted due to industry supply chains. In Table 1 below the term 'higher-order' is used rather than 'indirect', although it is acknowledged that there will nevertheless be different opinions on where certain impacts sit in this classification. Regardless, an important point is that many impacts of infrastructure damage or service disruption are not felt directly or immediately but occur through the interactions of networks or systems (including economic, environmental, and social systems). Thus, some consumers impacted by an infrastructure disruption will be impacted indirectly rather than directly, and some consumers will also be both directly and indirectly impacted.

A distinction between stocks and flows is also often made when identifying impacts. A stock is a quantity of a system component at a point in time, while a flow is a movement of materials or information to or from a stock over time. When undertaking economic analysis of impacts, it is important that double counting does not occur if a combination of stock and flow impacts is considered. For example, a resilience benefit of an infrastructure investment might be reduced risks of infrastructure asset damage (stock), alongside reduced insurance premiums for those assets (flow). Including both outcomes in a benefit assessment would, however, likely be double-counting.

Table 1 Examples of Impacts from Infrastructure Damage and Service Disruption (source: authors)

		EXAMPLES OF DIRECT IMPACTS	EXAMPLES OF HIGHER-ORDER IMPACTS
MARKET VALUES	Stocks	Damage to infrastructure assets.	Fewer new public assets in the future as finances are diverted towards rebuilding.
	Flows	Businesses cannot produce without infrastructure service availability.	Businesses cannot produce without critical inputs from their disrupted suppliers. Many businesses face lower demand due to lower spending in the economy.
NON-MARKET VALUES	Stocks	Loss of mental health. Damage to natural capital. Mortalities.	Loss of trust in government and infrastructure providers.
	Flows	Interruption of ecosystem services. Incidence of disease from contaminated water.	Stress associated with lost income.

The benefits or returns on infrastructure resilience investments are typically conceptualised as the avoidance of impacts such as those described in Table 1, while costs are those involved in undertaking the necessary investments to increase resilience. In these regards, it is important that there might also be unintended negative consequences of a resilience investment (e.g. increased carbon emissions), which could be considered in the cost estimation. Similarly, a resilience investment might also have co-benefits (e.g. reduced freshwater pollution, improved efficiency), which can be considered as part of the benefits assessment.

A further point to note around negative impacts or costs of an infrastructure disruption is that these often reduce over time. For example, people's willingness to pay for avoiding a unit of electricity disruption has been shown to be less for longer disruptions (e.g. Transpower, 2018). Partly this can be explained by the concept of fixed costs – e.g., an industrial plant has the same costs for restarting machinery regardless of the outage duration. The reducing trend in costs also reflects that the longer an infrastructure disruption, the more time is available to identify and implement adaptation and recovery options (e.g. temporarily or permanently relocating, switching suppliers). Models of consumer impacts and behaviour thus often assume a rate or curve of recovery over time which is not necessarily constrained by infrastructure recovery itself (e.g. Brown et al., 2019).

1.5 Accounting for interdependencies

1.51 INFRASTRUCTURE INTERDEPENDENCIES

To enable the realisation of investment benefits, resilient investment proposals should be tested to ensure that they appropriately account for critical infrastructure dependencies. Modern infrastructure systems (energy, transportation, water, communications, etc.) are highly interdependent, meaning the operation of one system often relies on others, see for example Figure 8. Infrastructure interdependence can be defined as a bidirectional relationship between two or more infrastructure assets such that each affects the other's functionality (Rinaldi et al., 2001). A classic example is fibre and power. Power plants depend on fibre, yet the telecommunications sector depends on power to function. Because of such links, a disturbance in one infrastructure can cascade into failures in other systems, potentially escalating a localised incident into a wider crisis (Buldyrev et al., 2010; Pant et al., 2018). Understanding these dependencies (through information disclosure) may be important to the creation of resilience.

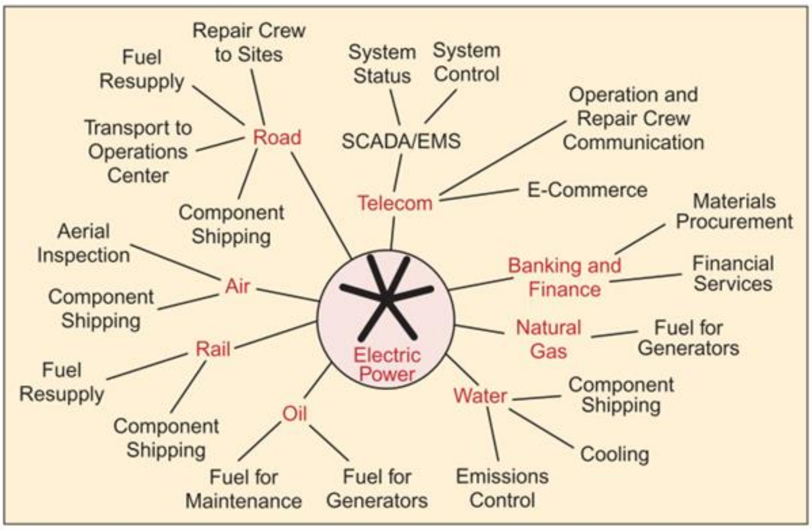

Figure 8 Types of infrastructure interdependencies: Physical, Cyber, Geographic, Logical…. (From Rinaldi et al. (2001)

Classes of infrastructure interdependency

A well-established taxonomy identifies four primary types of interdependencies based on the nature of the connection (Rinaldi et al., 2001):

- **Physical interdependency** - the output of one infrastructure is a physical input to another.
- **Cyber interdependency** - the state of one infrastructure depends on information transmitted via ICT.
- **Geographic interdependency** - infrastructure components are co-located and exposed to shared hazards.
- **Logical interdependency** - organisational or policy-based relationships that influence operations across systems.

Understanding these interdependency types helps planners anticipate failure pathways. Beyond these categories, other considerations include the degree of coupling (how tightly linked systems are) and response behaviour – tightly coupled systems can transmit disruptions faster and leave less time for intervention (Duenas-Osorio & Vemuru, 2009). Planners should also account for the state of operations (normal versus emergency conditions) since interdependencies might have different effects under stress scenarios (Ezell, 2007). Critically, traditional silo-based management of infrastructure is insufficient. Instead, resilience strategies must adopt a system-of-systems perspective (Ouyang, 2014). Studies emphasise regional coordination mechanisms and joint emergency planning to manage interdependent risks (Bruneau et al., 2003; McDaniels et al., 2007).

1.5.2 ECONOMIC INTERDEPENDENCIES

Closely aligned with infrastructure interdependencies are economic interdependencies. A fundamental resilience principle for infrastructure investment is economic network stability, which recognises that intricate interdependencies between supply chains (e.g., through the sale and purchase of commodities between industries, sales to consumers, purchases from suppliers), critical production factors (e.g., labour and capital), and broader market dynamics (e.g., supply/demand and pricing). Thus, infrastructure systems are deeply embedded within economic systems, meaning disruptions to an infrastructure provider can ripple across industries, potentially amplifying consumer vulnerabilities. Infrastructure interdependencies may impact consumers indirectly, while economic interdependencies can have far-reaching consequences affecting not only local consumers, but also downstream businesses and households in other regions and the wider national economy. In turn, these wider economic impacts will affect the economic viability of the utility company. Again, recognition of economic interdependencies (through information disclosure) may be important to creating wider economic system resilience.

1.5.3 JUST-IN-TIME PRACTICE

Infrastructure and economic interdependency issues may also arise from failure of just-in-time practices within the wider economy (i.e., in activities dependent on the provisioning of services from and to utilities) associated with disruptive events. While just-in-time practices enhance efficiency, they also heighten exposure to natural hazard or other disruptions, potentially leading to rapid fluctuations in supply, demand, and associated pricing for consumers. These oscillatory behaviours, such as sudden surges in costs or shortages, can destabilise markets and impede production chains. Effective infrastructure resilience requires mechanisms to absorb shocks, including diversified sourcing, strategic stockpiling (e.g. critical spares), and adaptive distribution networks. By considering just-in-time practices in resilience investments, we may mitigate market volatility, ensuring that levels of service to consumers are functional and responsive under disruption. Thus, the avoidance of just-in-time failures provides justification for expenditure that reduces impacts to consumers (and potentially for infrastructure providers also) through disruptive events.

1.6 Consideration of distributional impacts

Infrastructure investment decisions should consider the effects on different types of consumers to ensure that existing social inequities are not exacerbated. This consideration can factor into both the investment option identification process and the review of modelling and value estimate results and limitations.

In terms of modelling/value estimate limitations, we can note that when costs and benefits of infrastructure investments are quantified by means of markets (real or simulated), or by means of surveys that quantify willingness to pay/willingness to accept, the estimated costs/benefits may incorporate some inherent biases. This reflects that these valuation approaches are influenced by the starting distribution of wealth across society. As an illustrative example, we can imagine that if two consumers were surveyed on their willingness to pay to avoid an electricity disruption in the middle of winter, it is quite likely that the wealthier consumer will be willing to pay more, simply because this consumer has a greater level of disposable income available. Nevertheless, it would be inequitable to then assume that actions to reduce disruptions to the wealthier consumer are 'worth' more.

Some approaches have been suggested to address equity considerations in the modelling and assessment of costs and benefits, although none are without limitations. One approach is to select impacts on household 'utility' as the appropriate numeraire, noting that changes to household incomes will be more significant in utility terms for lower income households, based on the concept of declining utility of income (e.g. Kind et al., 2017). Another approach is to simply weight different types of impacts, or impacts on different groups of consumers, differently in the quantification of costs and benefits, to reflect society's equity goals or aspirations (Adler, 2016). The incorporation of such approaches can lead to different conclusions around the appropriateness of investment options, and whether costs of investments are appropriately aligned with the benefits received (see, for example, Grimson et al., 2024).

1.7 Risk tolerance and risk-bearing capacity

> "Infrastructures are socio-technical systems, and the magnitude of the impacts of failures in infrastructures also depends on the socioeconomic characteristics of the people using lifelines. However, these factors are often overlooked in infrastructure resilience assessments."
> Rahimi-Golkhandan et al. (2021)

There can be a tension between the level of service of resilience an organisation aims to achieve and what consumers need or want. Some consumers and communities arguably have higher infrastructure performance needs than others (e.g. those that are geographically isolated or those with critical industries).

When evaluating resilience investment priorities, community perspectives are an important input into the decision-making process so that community-specific levels of service and corresponding asset/network performance expectations can be clearly defined.

While hazard assessments provide technical insights into the probability, magnitude, consequences, and spatial extent of hazard events, assessing consumers' risk tolerance can help uncover consumers' willingness to pay for improved service, desired levels of service, and capacity to cope with loss of service. Any assessment of risk tolerance needs to capture the diverse needs of different consumers: across different industry sectors, private individuals, communities, regional and geographical contexts.

As well as capturing what consumers want (risk tolerance/appetite), it is useful to capture what consumers can cope with (risk bearing capacity), as they are not always correlated. If a consumer or wider community's risk-bearing capacity is exceeded, then this may compromise their ability to withstand a disruption, which will have flow-on implications for future revenue streams for the service provider. For example, work undertaken for the Wellington Lifelines Programme Business Case indicated that a lack of electricity is likely to be a key driver behind household relocation after a major Wellington earthquake. Mass relocation will affect short to medium-term revenue for lines companies. Community consultation can also help users understand the likely level of disruption and can promote individual preparedness actions.

Risk tolerance preferences can be established through consumer consultation, social impact assessments, surveys using stated preference techniques, or economic analysis (refer Section B 2.2). Risk tolerance is dynamic through time. As a result, it is something that needs to be monitored and subsequent risk management decisions adjusted over time.

The Natural Hazards Commission has produced a Risk Tolerance methodology (Toka Tū Ake EQC, 2023) to support organisations' integration of risk tolerance into risk management decision-making. Guidance on how to engage communities on risk tolerance has recently been released (Kilvington et al., 2025).

Understanding consumer perspectives is important to ensure that infrastructure investment priorities align with consumer priorities and needs, and limited resources are allocated to best effect.

1.8 Clearly defined asset criticality

Where comprehensive modelling is not feasible, the concept of infrastructure asset criticality is a useful concept to understand the relative benefits of investment in different aspects of a critical infrastructure network. Critical infrastructure assets, also referred to as nationally/regionally significant infrastructure, can be broadly defined as the systems, assets, facilities and networks that provide essential services and are necessary for national/regional security, economic security, prosperity, and health and safety of their respective cities or regions (adapted from New Zealand Treasury, 2014). The New Zealand Lifelines Council classify criticality across three different scale: Nationally Significant, Regionally Significant and Locally Significant (New Zealand Lifelines Council, 2023).

Assets with higher criticality will have a greater impact if they are disrupted. Figure 9 shows how a risk assessment can be informed by a combination of the physical vulnerability (risk to the built environment, given hazards, exposure, and infrastructure fragility) and the socio-economic vulnerability. The socio-economic vulnerability is the impact on the consumer/community when a specific asset fails. For example, a power failure would have different levels of impact depending on who was affected (e.g. hospitals, libraries, data centres, or water and wastewater systems).

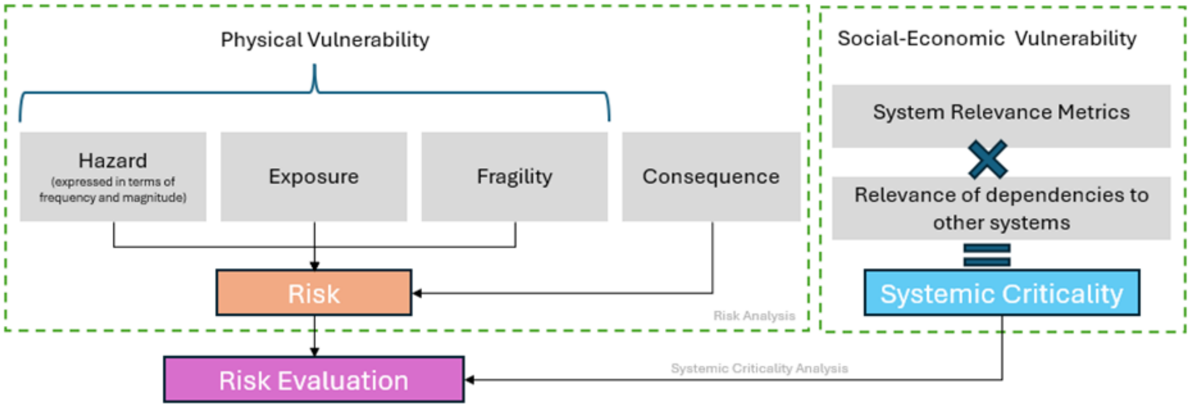

Figure 9 Criticality in risk analysis (adapted from Kruse et al. (2021))

Asset criticality can be viewed from two perspectives: criticality during business as usual (BAU) function and criticality during a disaster response.

Two Types of Critical Infrastructure

CRITICAL DURING BAU	When high-criticality infrastructure fails, it will have a major impact on vulnerable communities or environments.
CRITICAL DURING DISASTER RESPONSE (Lifeline utility)	Infrastructure that should always function (even at a reduced level) during and after a disaster event as part of emergency management planning.

Criticality can be used to prioritise infrastructure investment, especially under constrained funding environments. For example, if two infrastructure components have similar risk exposure levels, the components with higher criticality will likely be prioritised for resilience improvements.

Criticality can also be used to define variable levels of service across a network. A higher design level of service can be applied to highly critical assets. Conversely, lower levels of service can be applied to less critical assets. This helps to reduce and prioritise resilience investment across a network.

1.9 Structured optioneering

1.9.1 IDENTIFYING OPTIONS

A critical part of an effective investment case is the development of a wide range of clearly defined and considered options.

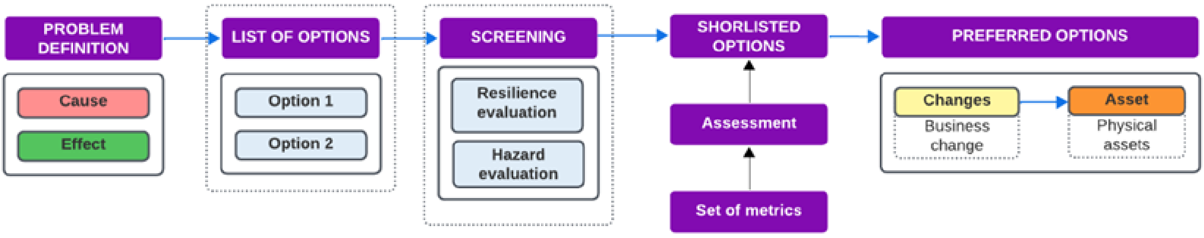

Figure 10 Example of an optioneering process flow diagram (Hasanah, 2025)

Optioneering involves evaluating multiple project alternatives or design variations to identify the most effective solution before committing resources. Rather than converging too quickly on a single preferred option, optioneering encourages a structured approach: defining objectives, identifying a broad range of options (including the 'do minimum' or baseline), assessing each against consistent criteria, and justifying the final selection (HM Treasury, 2022), see Figure 10.

In the context of infrastructure investment, especially when resilience and long-term value are critical, optioneering selects the most robust, cost-effective, and context-sensitive option. For example, when considering how to improve the resilience of a regional water supply network, planners might explore options ranging from asset upgrades to decentralised treatment, each varying in capital cost, delivery timeframe, climate exposure, and co-benefits. Table 2 lists management categories that assist in developing wide-ranging adaptation options. Intervention options should span robustness, redundancy, rapidity and resourcefulness to ensure both asset and organisational, as well as permanent and emergency response-based options are considered to meet resilience objectives.

Table 2 Risk Management Categories Guiding Infrastructure Option Development (Adopted from National Treasury South Africa, 2023)

MANAGEMENT CATEGORY	INF. STRATEGIC APPROACH	RETROFIT OR REHABILITATE STRUCTURES TO A HIGHER STANDARD OR STRENGTH	BUILDING NEW CLIMATE/HAZARD-RESILIENT ASSETS	ORGANISATIONAL ACTIONS
AVOID	Relocate	Relocate sensitive facilities or resources from direct exposure.	Site selection in an area with no or lower risk from hazard impacts.	Discontinue services in a specific area. Abandon certain technology or material (e.g. asbestos).
CONTROL	Harden and protect.	Rehabilitate and reinforce.	Use more resilient materials,	Emergency response provisions (e.g. bladders, critical

		Add supportive or protective features. Incorporate redundancy.	construction methods, or design standards. Design for greater capacity or service.	spares, etc) and permanent solutions
TRANSFER	Insurance/ transfer operational responsibility.	Insure against losses Transfer management risk to a 3-party (e.g. contractor)	Construct partial resilience requirements and combine them with a risk response and/or insurance.	Insurance of losses. Delivery models.
ACCEPT	Accept or abandon.	Keep as is, accepting a diminished level of service or performance.	Construct based on historical hazard conditions, accepting a possibly diminished level of service or performance.	No additional action.

Option development also needs to consider some wider issues and opportunities, such as:

- **Interventions with co-benefits:** Some communities do not have enough resources to meet their daily needs, let alone prepare for hazards and disruption. Interventions are needed that develop resilience and simultaneously improve the quality of life for some communities. For example, where isolation is an issue, instead of fortifying access routes, community capacity to withstand isolation for periods and provide benefits every day could be engendered (local food production, health care services, improved communication links to support remote schooling).
- **Climate change ready investments:** Investment should account for the effects of climate change – in particular, isolation of communities, likely retreat and increased hazard events. Provision of temporary or short-term management measures (with lower levels of service/robustness) may be suitable where climate change effects are likely to change the way infrastructure is used/needed, before a permanent network re-alignment is determined.
- **Adaptable solutions**: Investments should be valued based on their capacity to adapt to changing environments, including climate change, but also changing community needs, demographics, technology changes, etc. Investments that provide opportunity for future change/adaptation are valuable. For example, networks that are readily reconfigured to move with shifting communities.
- **Emerging technology:** Options and funding need to incorporate the emergence of new technology. As network technology evolves, the resilience of wider networks can either improve or worsen. This evolution of technology needs to inform any investment decisions.
- **Decentralised solutions:** Options and funding need to incorporate decentralised solutions alongside centralised resilience building efforts. Infrastructure investments are often centred on traditional networked assets. Isolation is going to be increasingly present following extreme weather events and hazards such as earthquakes. Providing decentralised infrastructure (e.g. point of use water, energy production) can reduce the impacts of isolation.

- **Alternative service options:** There will be situations where hardening assets or making them more robust will not be feasible. In these cases options for temporary service delivery options should be considered to bridge the gap while assets are repaired. For example, community water bladders and electrical generators where communities are isolated from the main grid after an event.

1.9.2 MANAGING FINANCIAL RISKS

Insurance is a key mechanism used to manage the financial risks associated with external threats. However, the cost, availability and scope of insurance must be weighed up against the cost of improving the resilience of the infrastructure network (and the impact of loss of service). Figure 9 shows three different approaches to managing natural hazard risk from a financial perspective: invest, insure or take no action. Utilities will be seeking the most optimal approach between resilience investment and insurance. Figure 10 shows the boundary between resilience investment vs. Insurance expenditure as a function of future construction costs. Future construction cost is only one variable in this consideration; other variables include the cost of capital. Infrastructure providers often use borrowed capital for major work such as resilience improvements, so the attractiveness of such an investment is also a function of the lending rate.

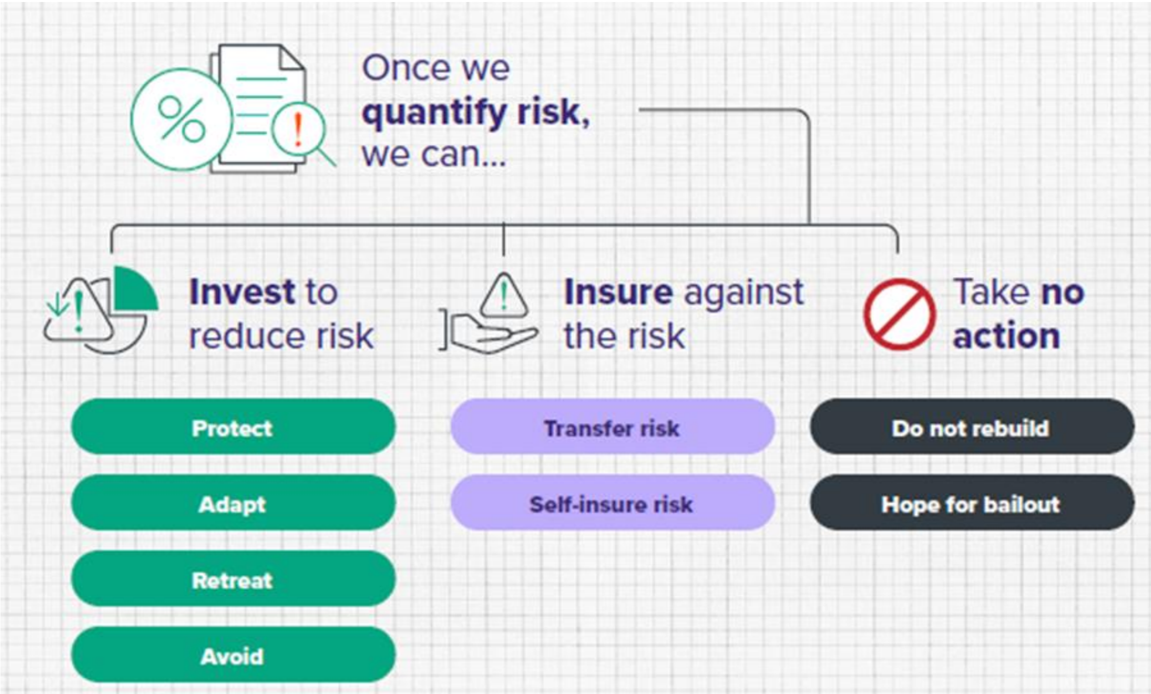

Figure 9: Management Approaches to Contingent Liabilities (New Zealand Infrastructure Commission, 2025b)

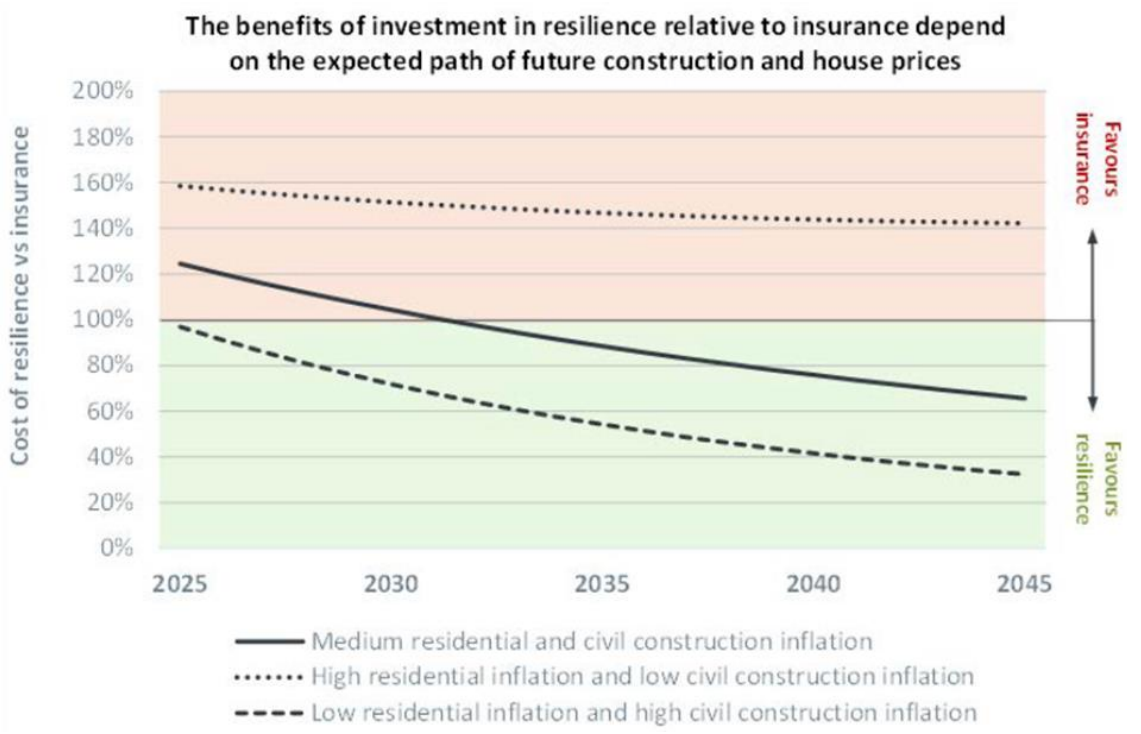

Figure 10: Resilience Investment vs Insurance as a Function of Future Construction Costs (New Zealand Infrastructure Commission, 2025b)

Traditional indemnity insurance allows organisations to recover costs after damage, while newer mechanisms, such as parametric insurance and catastrophe bonds, offer quicker, more predictable payouts based on predefined triggers (Surminski & Thieken, 2017). Both options, however, are unlikely to cover all repair needs. For governments and critical infrastructure owners, such financial instruments support faster recovery and enable better planning for residual risks. Additionally, insurers can incentivise better risk management practices by offering lower premiums for resilience-enhancing investments (Surminski & Eldridge, 2017). However, insurance contracts are negotiated annually and cannot be guaranteed beyond that period. Insurance and re-insurance availability is dependent on the drawdown of funds over time.

Ultimately, insurance alone is insufficient. It does not reduce the physical risk itself, only the financial consequences. A holistic risk management approach incorporates a combination of strategies and embeds contingency planning into infrastructure governance (Aven, 2016). As climate change and systemic shocks become more complex, blending financial and engineering risk reduction strategies is essential for sustainable resilience. Therefore, resilience investment into specific capital projects needs to be contextualised within the network resilience measures and priorities.

1.10 Option effectiveness

Option effectiveness is normally considered from a benefit-to-cost ratio (B/C ratio). However, resilience also has a temporal aspect to the effectiveness of the option. The effectiveness of options needs to be considered from both a cost perspective and the timing of an investment. For example, if the flooding risk increases with climate change, the B/C ratio for resilience investment rises accordingly. Adaptive pathway intervention strategy is a popular scheduling method for intervention under uncertainty (interventions are triggered when a threshold is reached, see Figure 11. Understanding the cost-effectiveness of intervening at different points in time is useful for a BCA analysis. In determining the best timing for intervention from an economic perspective, we may consider either the Internal Rate of Return (IRR) or First Year return (FYR).

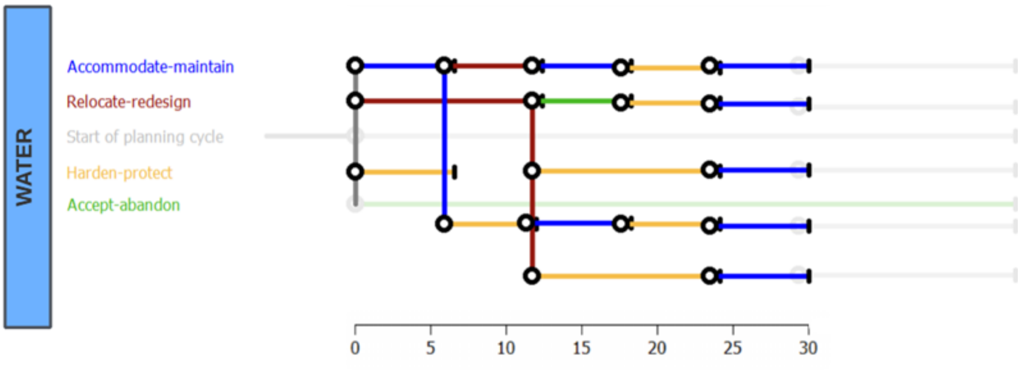

Figure 11 Example of an adaptive pathway intervention strategy

Although single capital investments are often considered for their returns in the short term, the long-term considerations are equally important. As illustrated in Figure 11, the second and third intervention options depend on the initial option chosen. The long-term view is also important in the context of climate change, which causes slow-burning stressors such as increased moisture and, in some areas, increased drought spells. For example, a significant consideration in the water sector is dealing with demand and supply considerations in the context of changing rainfall patterns.

The investment proposals should also be clear on the wider sustainability of the investment. For example, all options with a carbon reduction potential should have priority.

1.11 Investment prioritisation

Coordinated network optimisation, which emphasises the strategic prioritisation and scheduling of infrastructure projects, is an effective way to maximise interconnectivity and system-wide resilience. Project prioritisation is important both within a given organisation's investment programme and also across different utilities. While this may not be of direct interest to the Commission in terms of setting DPPs and CPPs, it has the potential to lead to significant resilience benefits to consumers (and infrastructure providers) through avoided losses associated with disruption caused by infrastructure and economic interdependencies (refer to Section B1.5). If projects are not strategically prioritised and sequenced, and a critical dependency is not managed, then consumers may not be able to realise the full benefits of investments

Investments should not be made in isolation; instead, recognising the enabling effect of, for example, road networks that facilitate 1) access to electricity, telecommunications, and essential services, while also providing 2) conduits for utilities such as water, gas, and power distribution. Recognising infrastructure as a system-of-systems allows for more efficient sequencing of projects, creates redundancy, readily enables rapid recovery to disruptive events, and ensures infrastructure supports broader economic and social resilience.

Aligning projects with Programme Business Cases across infrastructure objectives enables early adoption of risk mitigation strategies, reducing long-term vulnerabilities for all infrastructures. Fast-tracking resilience investment through integrated planning ensures resources are allocated effectively and minimises our susceptibility to multi-hazard disruptions, and enhances our post-event adaptive capacity. By embedding multi-sector dependencies into infrastructure investment frameworks, decision-makers can foster a more robust, interconnected system that remains functional and efficient under stress, ultimately safeguarding household/business consumers and realising benefits across utilities.

1.12 Dealing with uncertainty

Uncertainty is inherent in any risk assessment and subsequent investment decision related to resilience. There is uncertainty in the timing and physical impact of a hazard; our vulnerability to hazards is likely to change over time (as our climate, technology, population and our economic, social and political systems change); and the likely behaviour or response of individuals to events. As a result, precise quantitative evaluation of options and their benefits can be misleading.

Uncertainty needs to be acknowledged and accounted for to ensure that consumers are only paying for investments that will provide value to them, and utilities are appropriately managing the risk to their operations.

In some situations, analyses can seek to quantify the uncertainty mathematically (epistemic uncertainty) by looking at the statistical uncertainty in the information and data. Techniques such as Monte Carlo analysis can further quantify the uncertainty by looking at how the uncertainty across the various inputs combine. Uncertainty quantification is typically suitable where you have a well-defined 'simple' system, with inputs that can be readily quantified. Where statistical uncertainty cannot be quantified, sensitivity analysis can be used to understand what factors (or inputs to an analysis) will have the greatest impacts on the overall results. This can help identify where more information might be needed to reduce uncertainty in the analysis, and/or it can be used to check how robust a given intervention is to changing circumstances.

When there are systemic uncertainties (ontological uncertainty), i.e. it is not possible to predict what the future might look like in terms of hazards, infrastructure, population, demographics, economy, etc, then scenario testing is a useful tool to use to test the robustness of an intervention across different futures.

Other techniques, such as real options analysis, dynamic adaptive policy pathways and robust decision making, can be used to explore, test and plan for uncertainties through the decision process (refer to Section B 2.12).

2. Evaluating resilience investments

This section provides a broad overview of frameworks that may be employed by infrastructure providers and public investment decision-makers to justify investment in resilient infrastructure. We begin by providing a short review of the Better Business Case (BBC) framework, as this provides best-practice guidance for public project and programme infrastructure investment decision-making in New Zealand. The BBC Framework is largely based on Cost-Benefit Analysis (CBA). In Section B 2.12, a summary of principal alternative decision-making frameworks is presented.

In Section B 2.2, we provide a broad overview of the tools/techniques available to support CBA and other decision-making frameworks. Regardless of the decision-making framework applied, there will be a requirement to consider and evaluate the potential outcomes of implementing alternative investment options. However, it can be difficult to predict outcomes, especially when options under investigation can influence infrastructure, economic and social systems in complex ways. Furthermore, resilience benefits for consumers can be difficult to quantify given that the specific timing and nature of risks sought to be avoided/mitigated may be unknown. Added to this, certain decision-making approaches require impacts (benefits and costs) to be quantified in monetary terms. For these reasons, certain assessment tools and techniques may be employed to support decision makers in the application of decision-making frameworks.

2.1 Decision-making frameworks

2.1.1 THE BETTER BUSINESS CASE FRAMEWORK

In New Zealand, Cost Benefit Analysis (CBA) has for a long time been recognised as the key economic evaluation tool supporting the executive arms of government in undertaking their public duties, including when making decisions around infrastructure planning and investment. At the level of proposing new laws, central government agencies must perform a Regulatory Impact Analysis when considering a new national-level policy, and the Treasury encourages the use of CBA to support important public-sector decisions (The Treasury, 2005, 2015a, 2015b). The costs and benefits of introducing the Earthquake-Prone Building Policy in 2012 were, for example, calculated as part of the Regulatory Impact Analysis of the policy (Ministry of Business, Innovation and Employment, 2012).

For public finance/investment decision-making, Treasury encourages the use of its Better Business Case framework, with the framework also mandated for use in all significant public investment proposals from state sector or aligned (e.g., Transpower) agencies. Importantly, CBA is indicated as an available method or tool for use when developing the 'economic case' component of Better Business Cases. As well as publishing a general guide to CBA, the Treasury publishes various online resources, including a CBA spreadsheet model and current discount rates. Notably, the New Zealand Transport Agency (NZTA) also maintains a CBA-based Monetised Benefits and Costs Manual that sets out an assessment framework for transport investment planning used principally with state highway, but also local road infrastructure investment (New Zealand Transport Agency, 2025a, 2025b).

CBA appears to play a lesser role in infrastructure investment decision-making outside of the central government. Although Section 32 of the Resource Management Act formally places an obligation on local authorities (as water, wastewater, roading and potentially airport infrastructure investors) to include a consideration of benefits and costs of alternatives in their planning processes, this need not necessarily follow the structure of a formal CBA. In practice, a mixture of qualitative, quantitative, monetised and non-monetised information is collated in assessments, and while CBA is sometimes employed in assessing proposals of higher scale and significance, other approaches, including multi-criteria analysis, are also used (Ministry for the Environment, 2017). In practice, a range of evaluation approaches are also employed by local governments when meeting their duty under Section 77 of the Local Government Act, which requires councils to, during decision-making, consider all reasonably practicable options and assess options in terms of their advantages and disadvantages.

Although the Better Business Case framework is a well-accepted practice across infrastructure owners, the process needs a slight adjustment to cater for specific resilience aspects:

- **The Strategic Case** needs to define the problem and how resilience goals (e.g., climate adaptation equity of consumers) align with the investment's purpose.
- **The Economic Case** needs to evaluate value-for-money across options, including costed resilience co-benefits such as risk reduction and service continuity.
- **The Commercial and Financial Cases** need to address procurement and affordability, potentially incorporating risk-sharing contracts or resilience bonds.
- **The Management Case** needs to outline governance, risk, and assurance plans that explicitly include resilience performance tracking.

2.1.2 SUMMARY OF DECISION-MAKING FRAMEWORKS

There are several frameworks that are utilised when selecting alternative investment options. Essentially, these frameworks set out the general processes and criteria utilised for option selection.

Table 3 below provides an overview of these frameworks, including key advantages/disadvantages and some key references. Further commentary on these frameworks in the infrastructure resilience context can be found in Grimson et al. (2024), McDonald et al. (2020), and Smith et al. (2017).

There will be different constraints and differing levels and types of analysis costs involved, depending on the decision-making framework applied. Multi-criteria analysis, for example, may involve less analysis time spent on translating impacts into monetary metrics compared to cost-benefit analysis, but conversely may involve more demands in terms of engagement and stakeholder participation, and will not be possible without an appropriate and sufficiently mandated group of participants to be involved in the decision-making. Ultimately, framework selection should pragmatically reflect the context of the problem in light of the advantages and disadvantages of each approach.

The extent to which the potential costs and benefits of an investment option are comprehensively covered, regardless of the assessment framework selected, will also impact the level of effort and costs involved in applying each process. It is good practice, regardless of the framework applied, to qualitatively assess any costs and benefits that may occur, even if these cannot be included in a quantitative assessment.

Table 3 Decision-Making Framework used by Infrastructure Providers to Support Investment (including for Resilience)

FRAMEWORK/ APPROACH	DESCRIPTION	ADVANTAGES/LIMITATIONS	KEY REFERENCES
Cost-benefit analysis (also termed Social Cost Benefit Analysis)	Involves itemisation of individual costs and benefits of each option, and quantification of costs and benefits using a common metric of net present value.	**Advantages** • Well established, well documented and open methodology. **Disadvantages** • Inconsistent or inadequate treatment of non-quantifiable (intangible, non-market) costs and benefits. • Sensitive to selection of risk and time preference parameters. • Typical assumption of risk neutrality (i.e. ignoring risk aversion) may be inadequate for low probability, high impact risks.	Boardman et al. (2018); The Treasury (2015a).
Cost Effectiveness Analysis	Similar to cost-benefit analysis, but options are assessed based on the net present value of implementation costs.	**Advantages** • Only suitable for assessing options with the same or similar benefits. • Not necessary to quantify non-market, intangible benefits. **Disadvantages** • Inconsistent or inadequate treatment of non-quantifiable (intangible, non-market) costs. • Sensitive to selection of time preference parameters.	Acharya et al., (2024).

Real Options Analysis	An extensional method of quantifying benefits/costs that allows consideration of investment options that might adapt over time and seeks to put a value on the potential benefits of keeping options open.	**Advantages** • Allows consideration of dynamic investment options and acknowledges the value of flexibility. **Disadvantages** • Can be difficult to apply to large, complex problems. • Requires accurate estimates of risks (probabilities of different contingencies occurring), which can be challenging to obtain.	Geltner et al., (2023)
Multi-Criteria Analysis (MCA)	Comparing options by reference to an explicit set of objectives that have been identified, and for which it has been established measurable criteria to assess the extent to which objectives have been achieved.	**Advantages** • Can involve stakeholders in decision process and thus reflect multiple and potentially competing value-sets while bringing structure and openness to decision process. • Costs/benefits can be measured using multi-metrics (not limited to monetary valuations). **Disadvantages** • Subjective, i.e. depends on selection of objectives, criteria metrics, and weighting of criteria.	Infrastructure Australia (2021), Dodgson et al. (2009)

Participatory Value Evaluation	Uses survey methods to estimate the value of alternative public investment options	**Advantages** • Survey respondents can express values for outcomes not measured in markets. • Participatory approach enables incorporation of multiple value sets and can reflect risk preferences **Disadvantages** • Surveying can be time consuming and costly and results from one PVE may not be generalizable to different studies and projects. • Value estimation may not capture all consumer implications due to limited participants and/or difficulty in understanding indirect/higher-order impacts.	Dekker et al. (2019)
Robust Decision Making (RDM)	Options are selected on the basis that these perform well when compared to alternatives across a wide range of different assumptions and plausible futures. Metrics for evaluating robustness include satisfaction and regret.	**Advantages** • Acknowledges that benefits/costs of infrastructure investments may be highly uncertain. • Avoids the potentially risky approach of optimising for 'best guess' conditions. **Disadvantages** • Many practical applications are highly data and resource intensive.	Lempert et al., (2006)

Dynamic Adaptive Policy Pathways (DAPP) [1]	Maps out multiple potential pathways to achieve objectives. Involves designing series of actions that can be revised as conditions change and identifying tipping points that signal a need to reassess or shift to an alternative pathway. Applied mainly for long-lived, climate-sensitive infrastructure where future conditions are unpredictable.	**Advantages** • Acknowledges and accommodates a wide range of future scenarios without locking in irreversible decisions. **Disadvantages** • Developing and maintaining adaptive pathways requires scenario development, monitoring systems and sometimes sophisticated modelling. • Identifying reliable indicators for tipping points can be challenging.	Haasnoot et al., (2013).

Notes. 1 DAPP might best be considered a process for resilient planning and implementation under uncertainty. Given that the approach will have important implications for options identified and selected, it has been included in this table.

One filter that can be particularly helpful in selecting a decision-making framework is to consider the nature and extent of the uncertainties or 'gaps in knowledge' involved. In Figure 12, incomplete knowledge is conceptualised in two dimensions. The vertical dimension pertains to 'knowledge of outcomes', and this ranges from certainty in outcomes through to ignorance of potential outcomes. In the middle of this dimension are 'risk' based situations, when potential outcomes are known and described by probability distributions, and 'uncertainty'[3] situations, where potential outcomes are known but likelihoods are not able to be described. The horizontal axis depicts another uncertainty spectrum relating to 'knowledge of objectives', where at one end there is complete certainty in what is sought to be achieved, and at the other end is pure unawareness of the objective sought. Even when customer or community goals have been identified, a degree of uncertainty may exist on this dimension around the 'ultimate' objective of investment options because multiple objectives may be expressed (e.g. minimise investment expenditure, reduce pollution) and options rank differently for these objectives, and/or different stakeholders identify different objectives, so it is ambiguous which option performs better.

It has been suggested that CBA is best suited to situations of certainty or risk-based uncertainty (Stirling, 2010). This conclusion would apply equally to cost-effectiveness analysis and also robust decision making, with the latter requiring probability distributions of alternative outcomes to be defined. In practice, however, these frameworks are applied to situations which stretch over into the realm of 'uncertainty' and the best practice in such cases is to ensure that this uncertainty is made clear to decision makers through techniques such as scenario and sensitivity analysis (refer Section B1.12). The robust decision-making and dynamic adaptive policy pathways approaches, on the other hand, are specifically designed towards addressing situations of 'uncertainty' in terms of outcomes. A clear advantage of the multi-criteria analysis and participatory value evaluation approaches is that they help in reaching decisions when there is ambiguity in the objectives being sought, for example, differing perspectives among consumers on the relative weight that should be given to different objectives. The dynamic adaptive pathways approach often also involves elements of stakeholder participation and deliberation, which can help in reaching consensus on objectives.

[3] The term 'uncertainty' can be confusing as it is also used in the sense to describe the full range of different types of incomplete knowledge.

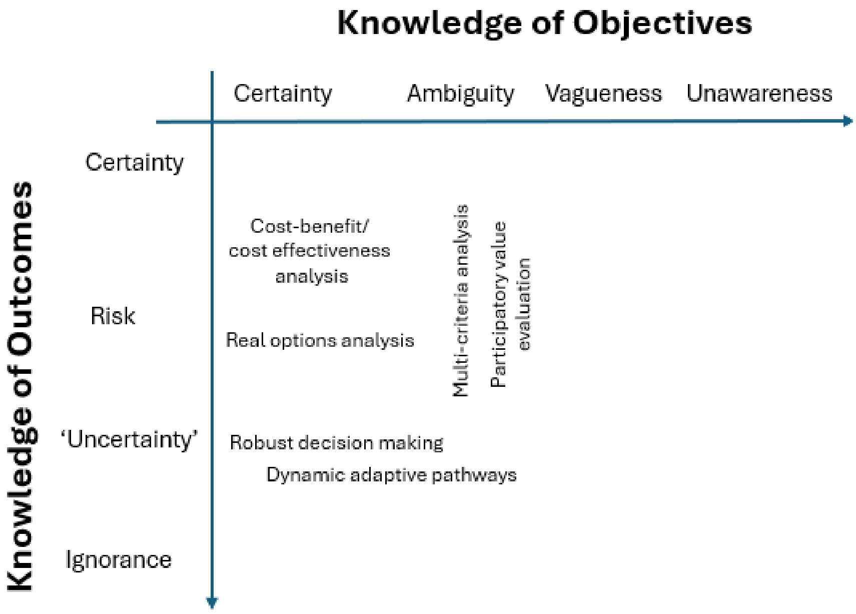

Figure 12 Uncertainty matrix and decision support frameworks (adapted from McDonald et al, 2020).

Regardless of the framework applied, there will also be several evaluation tools and techniques that can be drawn on to help resolve gaps in knowledge (see Section B 2.2 below).

2.2 Evaluation tools/techniques

In this section, we provide an outline of the evaluation tools/techniques that could be used by infrastructure providers in the decision-making frameworks above (e.g., CBA, MCA, etc) to support evaluation of component item level costs/benefits, criteria, etc. It is important to note that these tools/techniques may also be used in isolation as an evidence base for decision-making, e.g., input-output analysis, CGE and MERIT for economic impacts to analyse the impacts on business and household consumers.

Table 4 Evaluation Tools/Techniques often used in Decision Making Frameworks by Infrastructure Providers to Support Investment (including for Resilience)

EVALUATION TOOLS/ TECHNIQUES	DESCRIPTION	EXAMPLES	RELEVANT PRINCIPLES (Section B1)
ECONOMIC MODELS			
Input-output Analysis	Assist in assessing higher-order impacts by capturing economic interdependencies within a regional or national economy. Tends to focus on inter-industry supply chains. Suitable for analysis of short-term economic implications of disruptions to household/business consumers. Not suitable for understanding price dynamics. Easy to use.	Electricity disruptions in South Africa (Kingsley et al., 2020).	Evidence-based decision-making (typically suitable for only short-run, small-scale analysis of events). Economic interdependencies (as per relationships in the underlying input-output table),
Computable General Equilibrium Models (CGE)	Assist in assessing higher-order impacts by simulating the supply and demand for commodities and factors of production (labour and capital) as well as price changes and the flow of income through an economic system. There are several variants of CGE models (e.g. static, recursive dynamic, perfect foresight, etc), each of which has advantages and disadvantages. Selection of the appropriate variant depends on the application context and what questions of the model are being asked. Specialist skills required to apply.	Disruption of water system in US (Rose and Liao, 2005), Electricity disruptions in US (Wing and Rose, 2020).	Evidence-based decision-making (assuming equilibrium conditions are met). Understanding risk at different scales (only if using a multi-regional CGE). Types of costs and benefits (market valuation). Economic interdependencies (as per relationships in the underlying Social Accounting Matrix). Just-in-time practices (only if using a fully dynamic CGE). Dealing with uncertainty (through scenario analysis, does not cover deep uncertainty.
MERIT (Modelling the Economics of Resilient Infrastructure Tool)	A New Zealand-specific set of tools that assists in understanding higher-order impacts of infrastructure disruptions. MERIT's core system dynamics-based economic model is like that of a fully dynamic CGE model; however, it uniquely can trace out-of-equilibrium dynamic impacts through time to consumers of multi-hazard (coincident and cascading) events. MERIT also contains several modules to assist in quantifying initial	Wellington Lifelines – Regional Resilience Project (Wellington Lifelines, 2019). Assessment of fuel security options for NZ (Grimson et al., 2024; Smith et al., 2019).	Evidence-based decision-making (focuses on event path, including potentially out-of-equilibrium dynamics – typical of hazards). Multi-hazard risk awareness (can include coincident and cascading hazards). Understanding risk at different scales (local by statistical area, regional and national).

	direct impacts for industries, utilities and consumers. Specialist skills required to apply.		Types of costs and benefits (market valuation of disruption). Infrastructure interdependencies (via infrastructure "interfacing" models which feed into MERIT). Economic interdependencies (as per relationships in the underlying Social Accounting Matrix). Just-in-time practices (runs on daily timesteps). Structured optioneering. Option effectiveness. Investment prioritisation. Dealing with uncertainty (through scenario analysis, does not cover deep uncertainty).
Household-level modelling	Could operate as an extended version of another form of modelling (e.g. an advanced CGE/MERIT model), or a post-processing microsimulation model. The aim is to estimate economic impacts (e.g. changes in income) at the individual household or consumer level. This assists in understanding the distribution of impacts and in valuing impacts in 'utility' terms. Requires specialist skills to apply.	Assessment of fuel security options for NZ (Grimson et al., 2024; Smith et al., 2019).	Consideration of distributional impacts. Risk tolerance and risk bearing capacity.
Risk/catastrophe models	Assist in deciphering the spatial complexity of risk by bringing together spatial layers of hazards and exposure with asset/process-specific vulnerability models. Accessible and relatively simple to apply, but typically only covers human and asset losses (i.e., not disruption losses); recovery costs may be included.	RISKSCAPE[4] Resilience Explorer[5]	Multi-hazard risk awareness. Understanding risk at different scales (at the asset/building level). Types of costs and benefits (capital assets, including infrastructure assets and networks).

4 https://www.riskscape.org.nz/
5 https://resilience-explorer.org/

			Clearly defined asset criticality (when utility layers are incorporated). Dealing with uncertainty (probabilistic assessment is possible, but does not cover deep uncertainty).
OTHER MODELS			
Agent based models	Captures the dynamic interaction of many agents, typically across space and through time, and is used for modelling many different contexts. Helps to decipher system complexity by identifying the emergence of patterns and trends in behaviour that result from the collective actions of agents. Requires considerable specialist skills and time to create; for the most part, only applied in large (multi-million dollar) research projects.	Interdependencies of critical infrastructures (Casalicchio et al., 2010). Multiple infrastructures and societal impacts under typhoon scenarios (Yang et al., 2023).	Evidence-based decision-making. NB: Agent-based models are typically defined to address specific issues. For this reason, it is not possible to identify which principles this type of modelling addresses beyond evidence-based decision-making. Different flavours of agent-based methods could address any, all or some of the principles.
Integrated assessment methods	Typically involve creating critical feedback between existing disciplinary models (e.g. engineering, planning, economics), thus broadening the boundaries and system relationships under investigation.	Multiple infrastructures under Auckland volcanic event scenarios (Cardwell et al., 2020; Cardwell et al., 2021).	Evidence-based decision-making. Understanding risk at different scales (typically multiscale). Structured optioneering (potential use). Option effectiveness (potential use). Investment prioritisation (potential use).
VALUATION METHODS			
Stated preference methods	Utilise surveys or experiments to elicit what would hypothetically be paid for values, including values not traded in markets. Includes contingent valuation & choice modelling.	Value of Lost Load (VoLL) for electricity (Transpower, 2018).	Evidence-based decision-making. Types of costs and benefits (non-market valuation) Structured optioneering (potential use) Option effectiveness (potential use) Risk tolerance
Revealed preference methods	Methods that estimate the value of a non-market good or service based on observed behaviour toward some closely connected marketed good or service. Includes	Reliability of electricity (Maliszewski et al., 2012).	Evidence-based decision-making. Types of costs and benefits (non-market valuation).

	defensive expenditure, travel costs method, and hedonic pricing.		Structured optioneering (potential use). Option effectiveness (potential use). Risk tolerance.
Cost-based valuation methods	The methods assume that some set of observed market costs can be used as a proxy for a benefit/cost. For example, expenditure on health care and lost wages as a proxy measure for the costs of waterborne diseases.	Costs of Havelock North Waterborne Disease Outbreak (Moore et al., 2017).	Evidence-based decision-making. Types of costs and benefits (market and non-market valuation). Structured optioneering (potential use). Option effectiveness (potential use). Risk tolerance.

2.3 The Value of Lost Load (VoLL)

2.3.1 ESTIMATION METHODS

The Value of Lost Load (VoLL) is an ex-ante metric that has been used in New Zealand and overseas for quantifying the economic cost of service interruptions, most commonly in the electricity sector though it is increasingly used in other domains. The measure provides a monetary valuation of uninterrupted infrastructure services. Once estimated, it can then be applied to consistently evaluate the benefits of resilience investments, provided it is possible to determine for each investment the avoided service interruption faced by consumers.

VoLL is typically derived through estimating how much customers are willing to pay (WTP) to avoid outages. As highlighted in the literature (e.g., Peter, 2019; Gorman, 2022), several methods for estimating VoLL have been employed globally. Results vary considerably depending on the chosen approach and its underlying assumptions. Estimation methods generally fall into three categories:

- **Proxy methods:** These use indirect indicators such as electricity retail prices, GDP, Computable General Equilibrium (CGE) models, production functions, or wage rates to estimate economic losses from outages.
- **Survey-based/Stated preference methods:** These include Contingent Valuation (CV), Discrete Choice Experiment (DCE), or direct questionnaires about outage costs.
- **Revealed preference methods:** These infer values from observed behaviours, such as uptake of interruptible supply contracts, customer investment in backup systems, or observed demand-response during outages.

Each method has its strengths and limitations. Proxy methods are cost-effective but may oversimplify user behaviour, and if based on data from economic markets, may miss the quantification of certain impacts. Survey methods better capture subjective valuation, including people's perception of intangible impacts, but can yield inconsistent results and may miss higher-order impacts – both due to surveyed respondents not being impacted by these higher-order outcomes, and because they are not able to understand or predict such impacts. Stated preference approaches can also be sensitive to survey framing, assumptions, and strategic bias. Revealed preference approaches are more grounded in real-world decisions but are often limited by data availability. Importantly, these methods often fail to capture interdependencies across infrastructure and economic systems or the dynamic nature of recovery, which are central to true resilience (Pant, Barker & Zobel, 2014).

As Gorman (2022) highlights, reliance on single average VoLL values can be problematic, especially because electricity and other infrastructure services are used in diverse and complex ways that also vary by customer type, location and outage duration. Yet, for practicality, many regulators in the international context have defaulted to applying a limited number of average VoLL estimates for planning or reliability standards with sector-specific functions are often lacking or underdeveloped (Carvallo et al., 2022; Leštáková et al., 2024).

The choice of estimation method should align with the purpose of the analysis. For example:

- When setting reliability standards, detailed sector-specific CDFs (Customer Damage Functions) are more appropriate.
- For assessing resilience investment proposals, broader economic models may be needed to reflect indirect and cascading impacts.

2.3.2 UTILISING VALUE OF LOST LOAD FOR NON-ELECTRICITY INFRASTRUCTURE

As mentioned, VoLL is a well-established metric in electricity networks, representing the economic cost of unserved energy (e.g. an outage) per MWh. It helps monetise reliability by assigning a dollar value to outages (in New Zealand's case, about $20,000 per MWh of lost supply). Similar concepts exist for other infrastructures like telecommunications (fibre networks) and water supply, though they may not always be as formally defined or universally adopted as VoLL. For example, in the case of water, there is evidence that people would be willing to pay to avoid supply interruptions. Surveys in various countries found that customers are willing to pay higher water bills in exchange for reductions in the frequency or duration of supply interruptions. Such findings imply an implicit dollar value for preventing each hour of water outage for a household. On the business side, water outages can curtail production and cause financial losses, especially for industries that rely heavily on water (e.g. manufacturing, food processing). Refer to Table 5 for national and international examples of VoLL-type metrics.

Table 5 Summary of available metrics

SECTOR	METRIC/ APPROACH	ESTIMATED VALUE / DESCRIPTION	SOURCE/REGION
Electricity	VoLL	NZD $20,000/MWh outage cost	NZ (Electricity Authority, 2020)
Fibre/ Telecom	WTP, SLA penalties	GBP £1–3/hr (residential), >£1M/hr (national)	UK (Ofcom, 2017)
Water	Guaranteed Service Standards Compensation	£50 base + £50 per 12 hours of supply interruption; Up to £2,000 for sewer flooding;	UK Government (Ofwat, n.d.)
Fibre/ Telecom	WTP for improved reliability	USD $17.94/month (residential willingness to pay)	US (Boyce & Deller, 2024)
Fibre/ Telecom	National economic loss	€42–€50 per household per day (based on Irish telecom outage model)	IE (Lyons, Morgenroth, & Tol, 2013)

2.3.3 IMPORTANT CONSIDERATIONS REGARDING THE APPLICATION OF VOLL-TYPE METRICS

There are several matters that must be considered before determining that a VoLL type metric is an appropriate or sufficiently comprehensive measure for quantifying the benefits of a resilience intervention:

Consumer representation and distribution – different consumers will be impacted in different ways by a service disruption. VoLL-type metrics are often produced for whole consumer or sector groups, or even as an average measure across all consumers. If the types and distribution of impacted consumers differ from those considered in the original derivation of the VoLL-type metric, the VoLL-type metric may not adequately represent the values of the consumers under consideration.

Duration of outages or disruptions – as explained above in Section B1.4 the impacts of a disruption on consumers often does not scale linearly with disruption duration. However, VoLL-type metrics are typically applied in a way that will scale linearly with duration. In the case of electricity, for example, impacts ($) are often defined per unit of "load", with load being a measure of both outage magnitude and duration. Essentially, this means a disruption of twice the duration will produce twice the impact ($) when using the VoLL metric. For this reason, it is important that any VoLL-type metric used in an analysis was derived in relation to outages of sufficiently similar duration to those being considered.

Types of outages or disruptions - VoLL-type metrics are quantified for a specific outcome avoided. For an infrastructure like water, the outcome sought to be avoided can be quite complex and varied. Not only do outages vary by size and duration, there are different *types* of outages, e.g., 1) outages that involve no service provision, 2) outages that involve differing levels of service (e.g. water provided but a health risk, water provided but subject to maximum take for commercial consumers, pressure reductions) and, 3) disruptions that involve different environmental consequences such as discharges of raw wastewater to local streams. These aspects mean that, particularly for water infrastructure, it can be difficult to generate metrics that can be used in a transferable way across many different situations and contexts.

Appropriateness of using VoLL in situations of significant public health and environmental harm - Water service interruptions often have immediate health and sanitation implications, especially in emergencies (Ofwat, 2017; Han et al., 2015). Similarly, disruptions in other infrastructures may have important safety, health and/or environmental implications. For example, disruptions to telecommunications may severely hinder emergency response functions, disruptions to gas networks may be detrimental to hospital operations, and disruptions to wastewater systems may have detrimental and long-lasting environmental implications. If an infrastructure investment will significantly reduce the risks of such adverse implications occurring, it is important to consider whether these benefits are adequately captured in the VoLL-type metric, given the way in which that VoLL metric was derived. It may not be appropriate to apply the VoLL metric, or it may be necessary to supplement it with other quantitative or qualitative analysis. The World Economic Forum (2025) report, for example, stresses that valuing water resilience requires a systems-centric, multi-stakeholder framework that goes well beyond single metrics like VoLL to reflect social, environmental, and economic interdependencies.

Higher order implications – as noted above, one of the potential limitations of VoLL type metrics is that they may not adequately capture higher order impacts in the value estimation. In the case of airports, for example, disruptions can trigger cascading delays and indirect economic losses across supply chains, tourism, and regional economies. While immediate customer impacts (e.g., travel delays) may be measurable, broader macroeconomic impacts are difficult to isolate and value through market behaviours or willingness to pay metrics. Thus, if the avoidance of higher-order impacts is a key feature of an infrastructure investment, it will be important to consider how the value of these benefits for consumers can be captured in the analysis.

2.4 Evaluation of decision framework and tools

A strong business case is underpinned by robust and appropriate analysis using a fit-for-purpose framework for the investment problem at hand. The previous sections have covered a description of some of these frameworks and tools. Figure 13 provides a comparison between frameworks and tools that are typically used in the analysis of resilience improvements. It shows the assessment of these methods on the basis of criteria that were developed specifically for resilience investments. These include relevance with the context; uncertainty and risk management; data and evidence requirements; usability, innovation and adoption; technical capabilities for resilience and adaptation; and economic and social impact. The appropriateness of the tool used in a specific case will depend on the problem it needs to solve, the data availability, the level of uncertainties, and the complexity of other factors to consider.

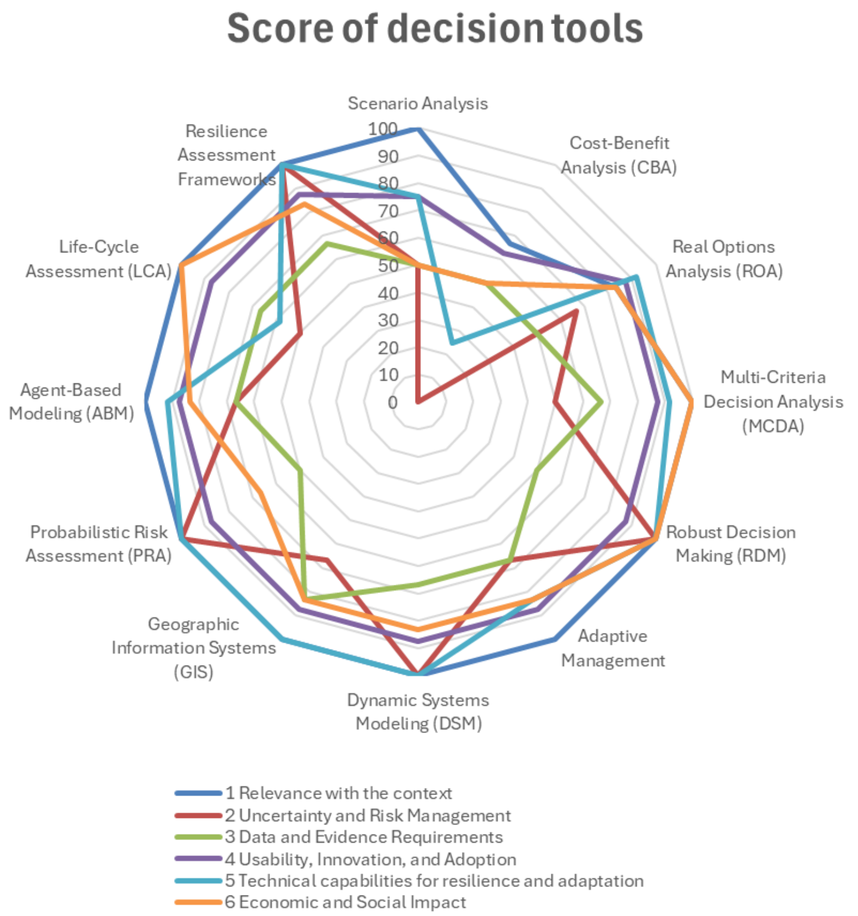

Figure 13 Decision tool comparison matrix: CBA, MCDA, ROA, RDM, Adaptive Pathways by Data Needs, Resilience Fit, Flexibility (Hasanah, 2025)

Note: The tools were assessed in their standard form. However, these tools are seldom used in isolation. By combining some of the tools and techniques, we can harness the strengths of each tool. For example, many of these tools are combined into one tool to evaluate the relative complexity of resilience improvements. For example, BCA may include scenario analysis and advanced economic loss impacts, such as those used in the MERIT tool**.**

2.5 Capturing economy-wide impacts

2.5.1 UNDERSTANDING COMPLEXITY

Recent studies emphasise the importance of assessing disasters' economy-wide impacts and improving how cost–benefit analyses (CBAs) handle risk and equity. For example, Brown et al. (2019) developed an ex-ante modelling approach for a Wellington Fault earthquake scenario that links physical infrastructure damage to community and economic disruption. Their method combined infrastructure damage maps (accounting for interdependencies) with expert-elicited estimates of post-quake behaviours (e.g. population displacement, business interruption), feeding into a dynamic economic model. This integrated scenario narrative was used to support decisions on regional infrastructure resilience investments, illustrating how understanding indirect ripple effects can guide preparedness investments.

Traditional economic evaluations of disaster risk often fall short in such complex, uncertain contexts. Smith et al. (2017) identify several critical challenges that must be addressed for better decision-support tools:

- Incorporating resilience thinking (capturing how systems adapt and recover).
- Using multi-capital assessment (valuing social, environmental, and other capitals beyond financial).
- Valuing the future appropriately (e.g. long-term outcomes and proper discounting).
- Accounting for distributional equity (who benefits or loses and the fairness of outcomes).
- Recognising societal risk appetite (the public's and decision-makers' tolerance for risk).
- Managing deep uncertainty (profound unknowns where probabilities are hard to estimate).

Addressing these areas presents opportunities for more robust economic analyses. Smith et al. (2017) recommend building organisational capacity and risk literacy so that decision-makers can better interpret and use advanced risk evaluation tools. In line with this, Grimson et al. (2024) demonstrate an extended CBA approach that embeds economy-wide modelling, risk aversion, and inequality aversion into evaluating disaster risk-reduction options. Using a New Zealand fuel supply disruption case, they show that considering how people's utility (well-being) varies with income and risk leads to more equitable valuations of resilience investments. Their dynamic economy-wide model incorporates heterogeneous risk preferences and intra/inter-generational equity weights, offering a "social welfare"-oriented analysis. Notably, the inclusion of equity-weighted and risk-adjusted metrics yielded a more balanced estimate of the benefits of mitigation, avoiding the bias of traditional CBAs that treat a dollar gained or lost equally for everyone. This work underlines that when economy-wide ripple effects and societal values (like equity) are accounted for, the justification for resilience investments can be stronger and more socially attuned.

2.5.2 MEASURING THE ECONOMICS OF RESILIENT INFRASTRUCTURE TOOL (MERIT)

MERIT was a tool specifically designed to capture some of the economy-wide impacts of disaster events described above.

MERIT is a suite of integrated spatial decision support systems designed to quantify the economic consequences of infrastructure disruptions (refer to www.merit.org.nz for further details). At its core, the MERIT suite models the dynamic interactions between households, businesses, and infrastructure systems (using its so called Dynamic Economic Model and Business Behaviours Modules) during and after disruptive events through time (i.e., up to 100 years into the future). It does so by simulating behavioural adaptations, such as changes in consumption, production, pricing and mobility. This allows MERIT to capture not only the immediate economic losses but also the cascading effects and recovery trajectories across local, regional, and national scales. A key focus of MERIT is the dynamic pathway that businesses and industries follow post an event/s. MERIT is uniquely suited to studying out-of-equilibrium dynamics associated with larger-scale disruption events.

Technically, MERIT is a system dynamics model with many of the features of a fully dynamic Computable General Equilibrium model incorporating spatially explicit infrastructure and economic information, behavioural algorithms, and scenario analysis. MERIT comprises several modules tailored to different disruption contexts.

MERIT's Dynamic Economic Module is a system dynamics-based simulation that mimics key features of a Computable General Equilibrium model, allowing it to capture both direct and indirect economic impacts of infrastructure disruptions while accounting for non-equilibrium (and out-of-equilibrium) behaviours during recovery phases.

The Business Behaviours Module integrates empirical data, such as that from the 2010/2011 Canterbury earthquakes, to estimate how organisational operability is influenced by external disruptions, internal resilience factors, and adaptive responses over time. It can also be used to evaluate the distributional impacts of disruptions, identifying which sectors, communities, or regions are most affected and when. This supports targeted resilience investments and policy interventions.

The tool also incorporates uncertainty modelling and multi-capital impact assessment, allowing users to explore trade-offs and robustness of decisions potentially under deep uncertainty. Outputs include estimates of total economic loss (e.g., value added, income, output and employment), recovery timelines, and wellbeing impacts, which can be used to inform business cases, adaptation planning, and risk communication strategies.

MERIT has been used in several resilience business case assessments covering single infrastructure and multiple infrastructure scenarios, e.g., the Wellington Resilience Business Case. It also has been used to assess the economic disruption following several disaster events including Lyttleton Port Company following the Canterbury earthquakes, the official government report on the 2016 Kaikōura/Hurunui earthquake, 2023 Auckland Anniversary Day floods, 2017 Wiri pipeline failure (findings used in Board of Inquiry evidence) and by infrastructure utilities; particularly NZTA Waka

Kotahi, who own an online version of MERIT to assess the economic disruption losses following road outages.

MERIT was developed through the Ministry of Business, Innovation and Employment Targeted Research Fundings and has continued to be developed under the Resilience National Science Challenge and various MBIE-funded Endeavour programmes (e.g., He Monga Puia – transitioning Taranaki to a volcanic future, Ngā Ngaru Wakapuke – central transition zone earthquake sequences, Sliding Lands Hōretireti Whenua – Auckland landslides).

2.6 Robust business case processes

As this section has shown, there are a plethora of considerations and tools that utilities need to weigh up when making investment decisions. There will be no one-size-fits-all approach. However, there is a set of steps that utilities should go through to develop a robust investment business case. Figure 14 summarises the aspects that need to be considered in a business case that targets investment into building resilience.

As part of its regulatory role, ComCom may want to consider using a framework like this to help evaluate the sufficiency and quality of investment business cases. More work is required to build the details around the minimum requirements at each step. In particular, the framework will need to account for the fact that business cases are rarely focussed solely on resilience. Investments will likely have multiple objectives, including capacity growth, level of service improvements, renewals.

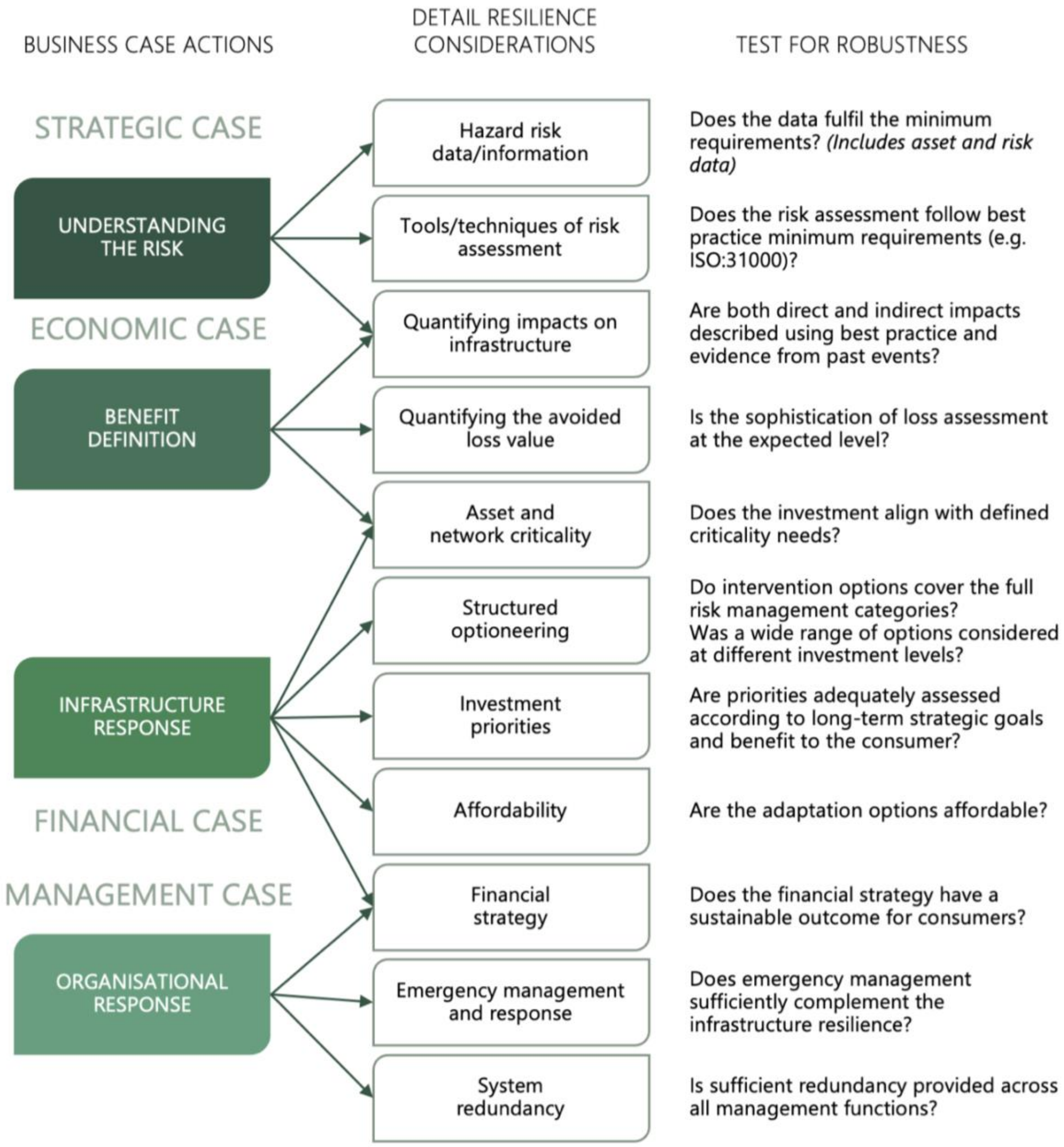

Figure 14: Robust resilience investment business case framework. (source: authors)

PART C Resilience measurement

1. When and what to measure

ComCom can impose a range of obligations on regulated utilities on how and when to incorporate resilience measures: from certification measures, through to information disclosure requirements (such as via the ComCom Performance accessibility tool). The most appropriate measures will depend on how and when ComCom choose to implement resilience reporting or evaluation requirements.

In this section, we provide a structure for the type of measures that could be used. The design and choice of specific metrics will need to be determined based on how ComCom wish to integrate resilience measurements into its regulatory processes.

Resilience can be evaluated after a disruption event i.e. Resilience Outcomes, or in a forward-looking manner i.e. Resilience Capacity.

Resilience Outcome measures could evaluate the actual performance of utility service in the aftermath of an event. They could capture actual disruption impacts both to assets and/or service provision. The performance of a utility and subsequent service delivery outcomes will be highly dependent on the nature of the event. Whether the performance is adequate or not will likely also depend on the expectations of the community. As a result, it would be difficult to set minimum service quality standards for resilience that could be applied in the same manner as SAIDI and SAIFI. Resilience Outcomes measures are likely better applied in a public information disclosure manner.

Resilience Capacity measures would evaluate the capacity of a utility and its network/assets/systems to withstand and respond to future events. As set out in Section A 4.4, this could include organisational resilience, information and planning systems, and system attributes. These could be evaluated in a number of different ways, including self-assessments, third-party assessments/audits, or modelled predictions of likely performance after an event.

Both resilience outcomes measures and resilience capacity measures could be tracked through time, to demonstrate progress against investment.

USEFUL DEFINITIONS

In this section, the terms Indicator and Metric are used.

An **indicator** is a concept that can be observed and measured.

Whereas a **metric** is a precise definition of how an indicator could be measured.

2. Resilience outcomes

We have identified three dimensions related to resilience outcomes or resilience performance: asset damage, asset performance, and service loss. Within each of these dimensions, we have identified a number of possible performance indicators. Figure 15 provides a visual summary of the potential indicators under each of the dimensions. For each indicator, a range of metrics could be defined. Table 6 to Table 8 include some example metrics for each indicator. The tables are not intended to be a comprehensive summary of possible metrics, but rather a set of illustrative examples to allow ComCom to explore what might be suitable. Where metrics were identified in the literature, references are provided. Where a specific metric was not found in the literature (either generally or for a specific infrastructure), potential metrics are noted.

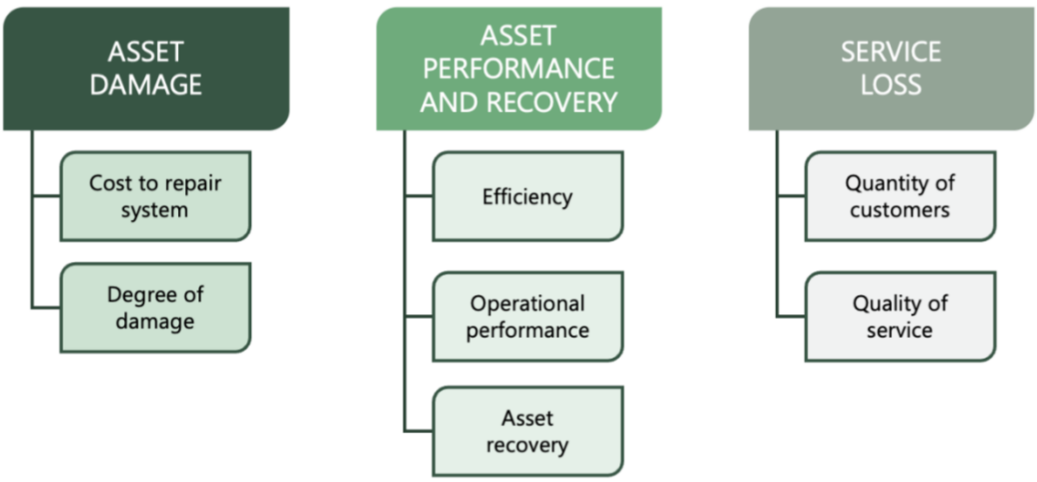

Figure 15 Resilience outcome indicators (source: authors)

2.1 Asset damage

Asset damage refers to the amount of damage expected or experienced following an event. It effectively measures the robustness of the network. These metrics could be used after an event to measure actual damage or could be used before an event to estimate the amount of damage expected in given scenarios. The latter would require significant modelling. While asset damage is a useful measure, it should be noted that this focusses on measuring network robustness, whereas resilience can be gained through a number of mechanisms. Asset damage metrics should always be used as part of a suite of indicators that capture other, non-robustness metrics.

Table 6 Asset damage indicators and metrics

INFRASTRUCTURE TYPE	COST TO REPAIR SYSTEM	DEGREE OF DAMAGE
Airport	Cost of returning infrastructure to pre-event functionality (Prior, 2015).	Value of damage based on depreciated value of assets affected (e.g. aeroplanes, catering trucks, aircraft pushback tug).
Electricity		Length or % of damaged powerlines, number or % of damaged transformers, etc. Value of damage based on depreciated value of assets affected.
Gas pipelines		Length or % of pipeline damaged. Value of damage based on depreciated value of assets affected.
Telecommunications		Length or % of fibre cables damaged, number or % of exchanges impacted.
Water		Length or % of broken water pipes.

2.2 Asset performance and recovery

Asset performance and recovery measure how quickly service can be returned to customers. These are measures of 'rapidity'. They complement asset damage measures as they allow for interventions that do not rely on just hardening the assets but that provide for fast repair following an event, which can be more feasible in some situations. Asset performance and recovery also include measures of impact on general system performance (e.g. efficiency). Like asset damage measures, these could be used after an event to measure actual damage or could be used before an event to estimate the amount of damage expected in given scenarios. The latter would require significant modelling.

Table 7 Asset performance and recovery indicators and metrics

INFRASTRUCTURE TYPE	EFFICIENCY	OPERATIONAL PERFORMANCE	ASSET RECOVERY
Airports	% of flights with on-time departures.	Number of terminals operating after event.	Length of runway useable within the specified length of time (see, for example, Mowll et al., 2023).
Electricity	% of voltage loss over specified length after event compared to pre-event levels.	% of operational power supply units after event (Bruneau et al., 2003).	% of power restored within specified time period (see, for example, Bruneau et al., 2003).
Gas pipelines	Amount of gas lost in transport.	% of gas pipeline operational after event.	% volume of gas being distributed (compared to pre-event levels) within specified length of time.
Telecommunications	% of fibre network at decreased functionality compared to pre-event levels.	% of telecommunications network operational after event.	Length of time between failure in fibre line and rerouting completed (Wosinska et al., 2009).
Water	% of water loss in system compared to pre-event levels.	Number of water leaks and water main breaks after event (Hatton et al., 2019).	%volume of water distributed (compared to pre-event) within specified length of time. Quality of water distributed (compared to pre-event) within specified length of time.

2.3 Service loss

Service loss represents the impact of disruption on consumers. These metrics are important as they focus on what consumers experience and can be achieved by both physical system design, organisational and technological means. This includes preparedness measures such as emergency water bladders or generators. Service loss metrics could potentially be used both before and after an event; however, this would require modelling or some form of assessment.

Table 8 Service loss indicators and metrics

INFRASTRUCTURE TYPE	QUANTITY OF CUSTOMERS	QUALITY OF SERVICE
Airports	# or % of customers unable to depart from the airport. # or % of customers unable to arrive at the airport.	Flight delay time (arrivals and departures) (Wang et al., 2019). Average length of flight delay time (Poo et al., 2021). Ability of airport to accept planes of certain weight or passenger capacity.
Electricity	# or % of [all/critical] customers without power after specified time period. % change in electricity load.	# or % of customers with decreased access to power (e.g. rolling power outages) after specified time period.
Gas pipelines	# or % of [all/critical] customers without access to gas after specified time period. % of critical customers reconnected after specified time period (see for example Mowll et al, 2023).	# or % of customers reporting gas pressure problems after specified time period.
Telecommunications	# or % of [all/critical] customers without access to telecommunication service after specified time period. % of customers reconnected after specified time period.	# or % of customers unable to make phone calls after specified time period.
Water	# or % of [all/critical] customer days without water / low pressure water / boil water notice (adapted Hatton et al., 2019) after specified time period.	Level and length of water restrictions (Hatton et al., 2019) # or % of customers with boil water notice after specified time period. Amount of water available per person per day within certain distance of accessibility (see for example Mowll et al., 2023).

MINIMUM LEVELS OF SERVICE

Minimum levels of service for infrastructure providers have recently been considered by government during the DPMC Critical infrastructure review and the NEMA Emergency Management Bill consultation. However, there has been significant pushback from utilities concerned that they cannot always control the large number of externalities that affect their ability to restore their service. However, Wellington Lifelines Group have established some "planning emergency levels of service" (PELOS) that set planned levels of service, through time, after a Wellington seismic event. These PELOS are used to support investment business cases, build understanding of interdependencies between utilities, and are used to help to establish community expectation for infrastructure disruption.

If ComCom wanted to establish, or require utilities to declare, minimum levels of service during disruption events, care would have to be taken to ensure that measures are designed in a way that are outcome focussed and are right sized for the utilities they apply to. Poorly designed levels of service could create incentives to inappropriately over (or under) invest in infrastructure. For example, blanket performance criteria that does not account for the criticality of the service to the community might lead to over investment in areas where service is less critical, and under investment where services are more critical.

Having target levels of service, would be useful in the development of investment cases, where investments could be evaluated against the likely change/improvement in level of service (through time).

3. Resilience capacity

We have identified three dimensions related to resilience capacity: systems attributes, information and planning systems, and organisational resilience. Within each of these dimensions, we have identified a number of possible performance indicators. Figure 16 provides a visual summary of the potential indicators under each of the dimensions. For each indicator, a range of metrics could be defined. Table 9 to Table 11 include some example metrics for each indicator. The tables are not intended to be a comprehensive summary of possible metrics, but rather a set of illustrative examples to allow ComCom to explore what might be suitable. Where metrics were identified in the literature, references are provided. Where a specific metric was not found in the literature (either generally or for a specific infrastructure), potential metrics are noted.

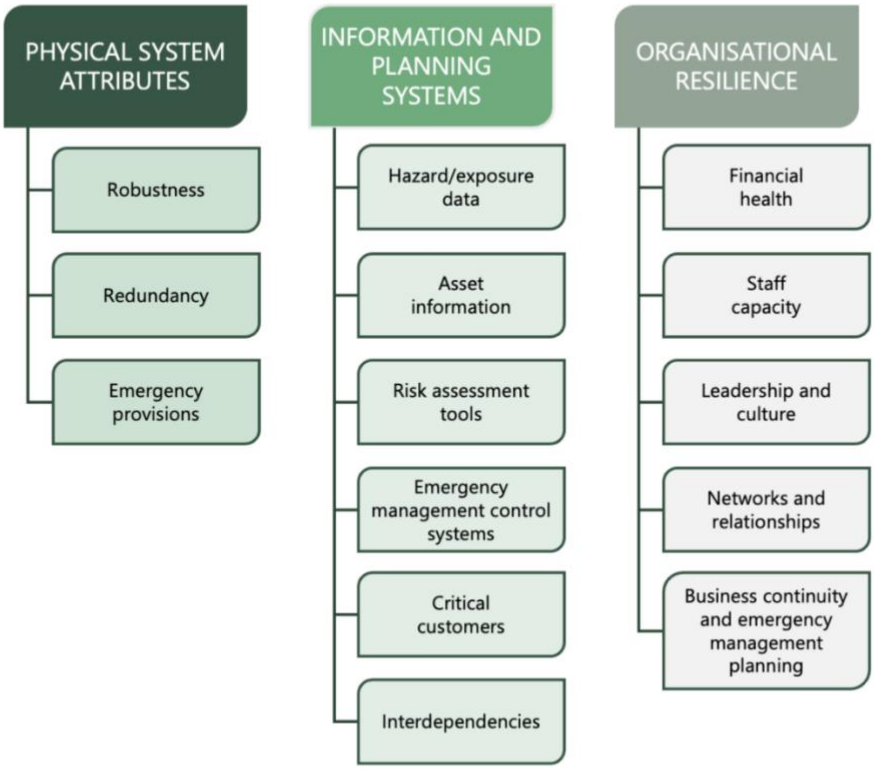

Figure 16 Resilience capacity indicators (source: authors)

3.1 Physical system attributes

Physical system attribute measures relate to the state of condition of the network (including emergency response supplies) as an indicator of likely post-event damage and function. The indicators could relate to the robustness of the assets, the level of redundancy, and resources available to support restoration. These metrics could be used before an event, to evaluate the extent to which risks have been managed in the system, but they do not directly reflect what the expected impact would be on consumers. These metrics may be challenging to design because of the wide variety of network configurations, hazards and mechanisms for delivering service after an event. This would mean that it is difficult to compare performance across organisations. However, they would enable tracking resilience improvements through time in a given utility.

Table 9 System attributes, indicators and metrics

	ROBUSTNESS	REDUNDANCY	EMERGENCY PROVISIONS
Airports Electricity Gas pipelines Telecommunications Water	% of assets strengthened to withstand [x] hazard.	% of service users that have multiple supply options.	Temporary service delivery options in place are sufficient for a x% service loss. Number and type of spare parts.

3.2 Organisational resilience

Organisational resilience includes the capacity of infrastructure operators and managers to effectively plan for and respond to disruptions. This also includes understanding the capacity of an organisation to cope with both direct and indirect losses. These indicators would be best used in a pre-event setting; however, they could also be measured after an event to monitor changes in the impact of the event on organisational capacity. There are several tools that have been developed to support, or been applied to, pre-event evaluation of organisational resilience, including the CDEM capability assessment tool (no longer in use), elements of the Electricity Engineers' Association's RAMMAT (2022), and the ResOrgs' Organisational Resilience Benchmark Tool (Lee et al., 2013). These tools include elements such as emergency management planning, response and recovery plans and procedures, staff capability to respond to events, engagement with CDEM, risk management processes, business continuity management, leadership and culture, networks and relationships and adaptive capacity. They tend to be self-assessment tools, either completed by senior managers or by staff.

While some of the indicators lend themselves to objective quantitative metrics, others rely on more qualitative assessments of capacity. Table 10 includes a combination of potential metrics and concepts that could be included in an evaluation process. Work would be needed to develop a fit-for-purpose evaluation tool.

Table 10 Operational performance indicators

	FINANCIAL HEALTH	STAFF CAPACITY	LEADERSHIP AND CULTURE	NETWORKS AND RELATIONSHIPS	DISRUPTION READINESS	FINANCIAL HEALTH
Airports Electricity Gas pipelines Telecommunications Water	Total assets ($). Revenue ($). Financial capacity to bear losses.	Number of staff trained to respond to events. Surge capacity.	Situational awareness. Staff engagement. Decision making. Innovation and creativity.	Engagement in CDEM forums, including regional lifelines groups. Engagement with sector groups (e.g. TCF).	Quality of business continuity plans.	Total assets ($). Revenue ($). Financial capacity to bear losses.

INSURANCE

Insurance has not been included in any of the metrics provided above for a number of reasons. While insurance is an important tool in the resilience toolbox, it is a very complex mechanism that needs to be evaluated on an organisation by organisation basis (as detailed in Section B1.9.2). First, not all organisations rely on insurance. Some entities self-insure. For this reason, it is better to evaluate the financial capacity of an organisation to withstand losses and to fund response and recovery activities.

Second, the availability of insurance is impacted by a range of factors and is reviewed annually. This means that looking at insurance patterns both between organisations and across time can be misleading, unless market conditions are taken into account.

Third, if utilities are measured based on their use of insurance, this could incentivise the uptake of insurance even if it is not the most prudent (financially or operationally) or effective (from a consumer, service loss perspective) approach to building resilience.

It is not impossible to develop metrics that relate to insurance; however, all the risks

3.3 Information and planning systems

Information and planning systems include the use and analysis of information that can support a good understanding of the threat landscape and how that might affect the delivery of infrastructure services to consumers and the wider impact on the community. The indicators include hazard/exposure data, asset information, risk assessment tools, emergency management control systems, understanding of customer needs, and understanding of interdependencies. The indicators would be best used in a pre-event setting. While some of the indicators lend themselves to objective quantitative metrics, others rely on more qualitative assessments of capacity. Nevertheless, an evaluation tool that covered these topics would act as a good practice guide, nudging utilities towards better practice.

Table 11 includes a combination of potential metrics and concepts that could be included in an evaluation process. Work would be needed to develop a fit-for-purpose evaluation tool.

Table 11 Information and planning systems indicators and metrics

	HAZARD/ EXPOSURE DATA	ASSET INFORMATION	RISK ASSESSMENT TOOLS	EMERGENCY MANAGEMENT CONTROL SYSTEMS	UNDERSTANDING OF CUSTOMERS' NEEDS	UNDERSTANDING OF INTERDEPENDENCIES
Airports Electricity Gas pipelines Telecommunications Water	Use of hazard/ threat data. Sufficiency of hazards/ threats included in risk assessments.	Quality of asset information.	Quality of risk assessment tools. Tools include those for managing uncertainty.	Rapid fault identification systems are in place. Operations centres are suitably resourced/ have sufficient backups in place.	Critical customers are identified. Asset criticality is defined based on customer/ community needs.	Upstream dependencies are well understood and planned for. Downstream dependencies are well understood.

4. How to measure

Regardless of what performance measures are chosen, metrics need to be designed in a way that makes them useful and reliable. The following set of criteria is useful to consider:

- Simple: easy to provide and interpret data.
- Transparent: clear what the indicator(s) does and doesn't measure.
- Relevant: indicator holds meaning for relevant stakeholders, and measurable change is expected.
- Positively framed: where possible (and if applicable), indicators are framed as desired behaviour (as opposed to avoided behaviour).
- Persistent: indicator will provide consistent insight over time.
- Predictive: there is a causal relationship between indicators and the desired outcome. Perverse impacts, due to measurement signalling, are unlikely.
- Balanced: indicator set represents the spectrum of activities and outcomes.

Resilience is a complex concept. There is a range of physical, organisational, and technological ways to achieve resilience. Resilience is also subjective, and the desired level of resilience is context dependent. Because of this complexity, the concept of 'positively framed' is very important. Any metrics being considered must be reviewed to ensure that they do not unduly promote one approach to achieving resilience (e.g. hardening assets). The metrics and how utilities are evaluated against them must be permissive and allow for utilities to build resilience in a way that makes the most sense for their context.

For similar reasons, having a balanced set of metrics is important to ensure that all elements of resilience building are captured.

Metrics can either be designed to track progress through time, or they can be turned into time-bounded target levels against which performance is measured. Given the diversity of utilities and the contexts they operate in (as noted in Section A3), it is likely that many metrics would not be suitable to compare across organisations. Instead, they would be better applied to measure resilience performance relevant to a specific utility. If used as a measure of performance after a disruptive event, the metrics may need to be tethered to a given hazard event or set of conditions.

It is also useful to apply the S.M.A.R.T goal principles when setting performance targets:

- **Specific:** What is the desired outcome and in what context/hazard event/conditions?
- **Measurable**: What data will ComCom use to decide whether utilities have met the goal?
- **Achievable**: Is the goal within the capacity and capability of the utility (and the means of the consumers)?
- **Relevant**: Does the performance target support the wellbeing of consumers?
- **Time-bound**: What is the timeline for meeting the performance target?

Last, the cost of producing/monitoring metrics should be considered. Any measurement system requires staff time and resources to capture the data or undertake the analysis necessary to produce a measure. This has implications for costs to either ComCom or consumers (depending on who is required to undertake the measurement). As the organisations that ComCom regulate are diverse in their size, capacity and resilience maturity, a range of metrics may be needed to ensure monitoring systems are right-sized.

PART D Operationalising resilience

ComCom has the potential to guide utilities on a journey of continuous resilience improvement. The principles, processes, and approaches described in this report provide a foundation for ComCom to embark on its journey toward embedding resilience in its regulatory processes. The report highlights several foundational themes that are critical to effective resilience practice.

FOUNDATIONAL THEMES

Resilience is multi-dimensional.

Resilient infrastructure systems build resilience into their physical system (asset placement, design and condition), information and planning systems, and organisational systems.

There are many ways to achieve resilience.

Historically, asset hardening and redundancy have been the default for achieving resilience. However, increasing frequency and severity of events, and limited resources, means that our approach to building resilience must be consider a wide range of options (including temporary service delivery options and organisational capability).

System understanding.

Effective investment in resilience building relies on looking beyond minimum engineering standards; it relies on understanding the (many) hazard landscape, the full impacts of disruptions (across space, through time and across different system users), infrastructure and economic dependencies, organisational and community risk tolerance.

Service and consumer (not asset) focus.

Related to the above, identifying the best options for building resilience requires a deep understanding of how service outages affect communities. Understanding their capacity and willingness to cope with disruptions, as well as their willingness to pay for increased levels of service.

Organisational capacity.

Understanding the capacity of a utility service to withstand disruptions is only partly due to the nature of the assets/networks. The financial and organisational capacity of a utility to manage a disruption plays an important part in the impact felt by consumers.

While this report sets a foundation for ComCom to build its own practices from, we see several potential actions that could support the operationalisation of the concepts presented in this report.

POTENTIAL ACTIONS

Develop resilience guidance for utilities.

There is a lack of comprehensive and cohesive advice for utilities on the practical steps that can be taken and the maturity pathway to build resilience. Some readily accessible guidance, leveraging off existing guidance where available (e.g. Electricity Engineers' Association resilience guide, 2022), would help to raise awareness of what good practice is.

Develop guidance on developing business cases for resilience.

Utilities can be reluctant to approve customised price paths from ComCom because of the challenges in making effective business cases. Some readily accessible guidance, leveraging off existing guidance where available (e.g. The Treasury (2015) Better Business Case framework), would help to raise awareness of what good practice is. Developing the Robust resilience investment business case framework presented in Section B2.6 would be a good start. Providing exemplars would also be helpful.

Develop information requirements and standards.

Several asset sectors have developed common data standards for their inventory and asset management information. For example, roading has the Asset Management Data Standards (AMDS).[6] However, data requirements for resilience do not currently exist. The Commerce Commission could encourage its regulated sectors to develop such standards.

Develop maturity assessment tools.

Whether built into regulatory processes or provided as self-assessment tools, resilience maturity tools, particularly centred around physical system attributes, information and planning systems and

[6] https://nzta.govt.nz/roads-and-rail/asset-management-data-standard/

organisational resilience, will help utilities to undertake gap analyses and identify where they could make practice improvements.

Promote information disclosure related to infrastructure dependencies.

As noted above, utilities do not operate in isolation. Utility service interdependencies can significantly impact other utilities' ability to build resilience into their own network. This, in turn, can mean that consumers may not realise resilience benefits when investments are made. By supporting information disclosure and raising awareness of interdependencies between the sectors ComCom regulates, a more community-wide approach to infrastructure resilience will be fostered and will enhance consumer benefits.

Guidance on community-based resilience planning.

Efficient investment in resilience relies on utilities understanding the needs of their communities and understanding where higher levels of resilience are needed, and less investment where needs are lower. However, there is little guidance on how to do this in practice, including how to elicit community perspectives on levels of service and, in turn, how to translate this information into asset planning.

Promote information disclosure of resilience performance outcomes.

Measuring resilience performance outcomes in a way that is comparable across events and organisations is challenging. However, requiring the reporting of performance during and after events may help focus infrastructure providers' efforts on reducing disruption and improving response and recovery capabilities.

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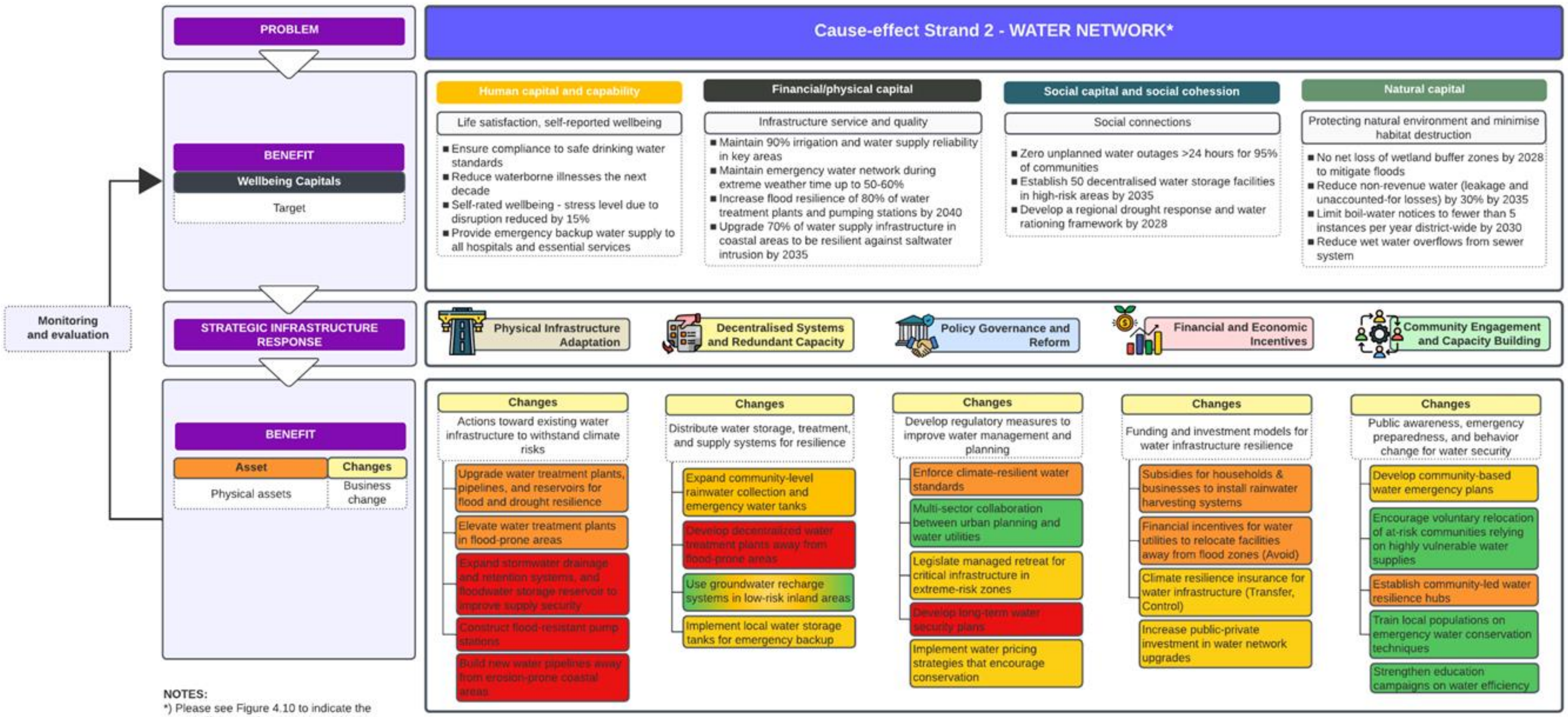
APPENDIX A: Example for Investment Logic Mapping



NOTES:
*) Please see Figure 4.10 to indicate the cause-effect map for water network

Colour-codded approach for different risk category are as follows:

Risk Management Category	Strategic Approach
Avoid	Relocate-redesign
Control	Harden-protect
Transfer	Accommodate-maintain
Accept	Accept-abandon

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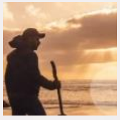

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