Natural Hazards Research Australia

Resilience of lifelines

Scoping the field

Adriana Keating[1], Mayeda Rashid[1], Lauren Rickards[2,3], Paul Ryan[4]

[1] Monash Sustainable Development Institute, Monash University
[2] Urban Futures Enabling Capability Platform, RMIT University
[3] La Trobe Climate Change Adaptation Lab, La Trobe University
[4] Australian Resilience Centre

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We acknowledge the traditional custodians across all the lands on which we live and work, and we pay our respects to Elders both past, present and emerging. We recognise that these lands and waters have always been places of teaching, research and learning.

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Introduction

The aim of this scoping review is to scope the field and inform the conceptual framework for the Resilience of Lifelines in Rural and Regional Australia research project, funded by National Hazards Research Australia and undertaken by LaTrobe University, Monash University, RMIT University and the Australian Resilience Centre. Understanding how lifelines function and how they could function better in the context of a wide range of external and internal stressors is vital to strengthening the resilience of Australian society under climate change.

Lifelines can be defined as "the systems or networks which provide for the circulation of people, goods, services and information, upon which health, safety, comfort and economic activity depend. Lifelines are the means whereby a community supports its day-to-day activities and include mechanisms used to respond to emergencies" (Johnston et al., 2006). Central to lifelines are essential services, supply chains, and critical infrastructure (CI) including but not limited to those that provide energy, communications, food, water, and transport. So too are human relations and actions, as well as the ecological services all human activities rely on.

Lifelines are becoming a focus for the United Nations Office for Disaster Risk Reduction because they provide our most basic needs to support our wellbeing and development. In the face of rapid climate change and intensifying natural hazards, infrastructure systems are under increasing pressure to deliver resilient and reliable services (Amach and Elsworth, 2019). Moreover, unforeseen consequences can result from increasing interconnections between systems and networks, leading to greater potential for cascading disasters in which the loss of one system can trigger failures in others (Gissing et al., 2020; Australian Government, Department of Home Affairs, 2018).

An insight that has emerged from this project is that researching lifelines and their resilience is challenged by the fact that there is simultaneously a dearth and flood of research on the topic. In terms of the first, "lifeline resilience" is a phrase only used a few times in the academic research to date, and in a small array of grey literature. In terms of the latter, the concept of "lifeline resilience" - as developed through this project - requires drawing on a wide range of literatures – and indeed grey literature - from across science, engineering, business, organisational studies, psychology, economics, human geography, social work and disaster studies, among other fields. As a result, a conventional scoping review strategy is not appropriate for the topic. Instead, insights need to be pulled together through a strongly interpretive, targeted approach that includes policy and practice documentation (grey literature). Different elements of lifelines and their resilience - such as critical infrastructure, supply chains, services and community experiences - tend to be examined by different disciplinary fields. Indeed, the concept of lifelines is a truly interdisciplinary one in the sense that not only does it require the aggregation of different areas of disciplinary knowledge, it requires their integration, and hence, the development of insights novel to all of the disciplines involved. As such, lifelines have the potential to generate innovations back in the various disciplinary fields involved as they are stimulated by engagement with other disciplines on the topic, underlining the value of research on lifelines.

In addition to being internally diverse, the idea of lifeline resilience is strongly influenced by an over-arching systems-thinking approach, in that the focus is on how functional systems interact to generate emergent outcomes. However, because it also focuses attention on far-reaching, horizontal connections, unbounded situations and bottom-up perspectives, the idea of lifelines developed in this project also challenges some aspects of conventional systems thinking, notably the use of systems boundaries, the focus on idealised, ordered and often hierarchical relations, and the top-down analytical gaze. Instead, it draws on insights from social science post-structural theories about assemblage relations.

This review also highlights further challenges of researching lifeline resilience. Rather than being a straightforward topic requiring particular empirical gaps to be filled, lifeline resilience raises multiple 'How' questions for research, including but not limited to how to do interdisciplinarity well and how to work on lifeline resilience while researchers, research participants and partners are in the midst of rolling disasters. Further questions include what counts as valid data about lifeline resilience, how transferrable insights are across contexts and how to reconcile ontological and epistemological differences.

In this scoping review, we first summarise the literature on the changing nature of disaster risk in Australia. We find that the disaster risk landscape is increasingly complex and uncertain. Not only are climate-related hazards becoming more frequent and severe, they are also increasingly co-occurring, resulting in compounding and cascading events. This is driven not only by climate change, but also changes in exposure and vulnerability, including those brought on by features of contemporary lifelines systems. We then track the emergence of critical infrastructure resilience as a concept and operating principle, both internationally and in Australia. We trace the evolution of thinking from critical infrastructure protection to resilience, and what that means for the state of the art and meeting future challenges. Next, we scope the literature on lifelines resilience, defining and exploring the concept of lifelines, lifeline sectors and lifelines as a system of systems. We outline what a resilience-based approach means for lifelines. Finally, we outline the current Australian policy and stakeholder landscape in order to situate lifelines resilience in the Australian context.

Increasing complexity and uncertainty in the disaster resilience landscape

Research suggests that the frequency and severity of climate-related hazards, and disasters is increasing (CRED, 2018; Guha-Sapir, Hoyois & Below, 2015; Guha-Sapir, Hoyois, Wallemacq & Below, 2017; Mizutori & Guha-Sapir, 2018). In Australia, climate change is increasing the frequency and intensity of extreme events such as bushfires, heatwaves and floods, as well as changing baseline weather conditions (Lane et al., 2023; Borchers et al., 2020; Steffen et al., 2019; BoM and CSIRO, 2020), see Figure 1.

FIGURE 1 - FUTURE CLIMATE PROJECTIONS AS OUTLINED IN THE STATE OF CLIAMTE 2020 REPORT (BOM AND CSIRO, 2020)

Together with ongoing changes in Australian industries, settlements and lifestyles – particularly in rural and regional areas – the country is experiencing an increase in natural-hazard induced disasters (Rolfe et al., 2020; Pit, 2021; Whittaker et al., 2012, Freeman and Hancock, 2017; Rakuasa and Latue, 2023). This is also increasing the likelihood of compounding and/or cascading disasters, where multiple disasters occur simultaneously or in quick succession, and where the impacts of one event have significant indirect impacts on systems that create profound secondary losses (National Emergency Management Agency, 2023). Such impacts have huge consequences to the interconnected service systems which are lifelines to the community. The compounding impacts of Black Summer bushfires, COVID 19 pandemic and 2022 floods across Australia are a demonstration of the scale of this challenge.

The increasing co-occurrence of disasters – called compound disasters (Figure 2, left) – is being driven by climate change and exposure growth. Relatedly, the increasing convergence and integration of physical, digital and human systems is increasing the occurrence of so-called ‘cascading’ disasters (Figure 2, right). Compounding and cascading disasters have been highlighted as a major concern by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2023) and the United Nations Office for Disaster Risk Reduction (United Nations Office for Disaster Risk Reduction, 2023). Compounding and cascading disasters present considerable challenges to essential lifeline systems. These disasters often involve a series of events that magnify the initial impact, creating a chain reaction that can overwhelm the capacity of lifeline systems to respond effectively.

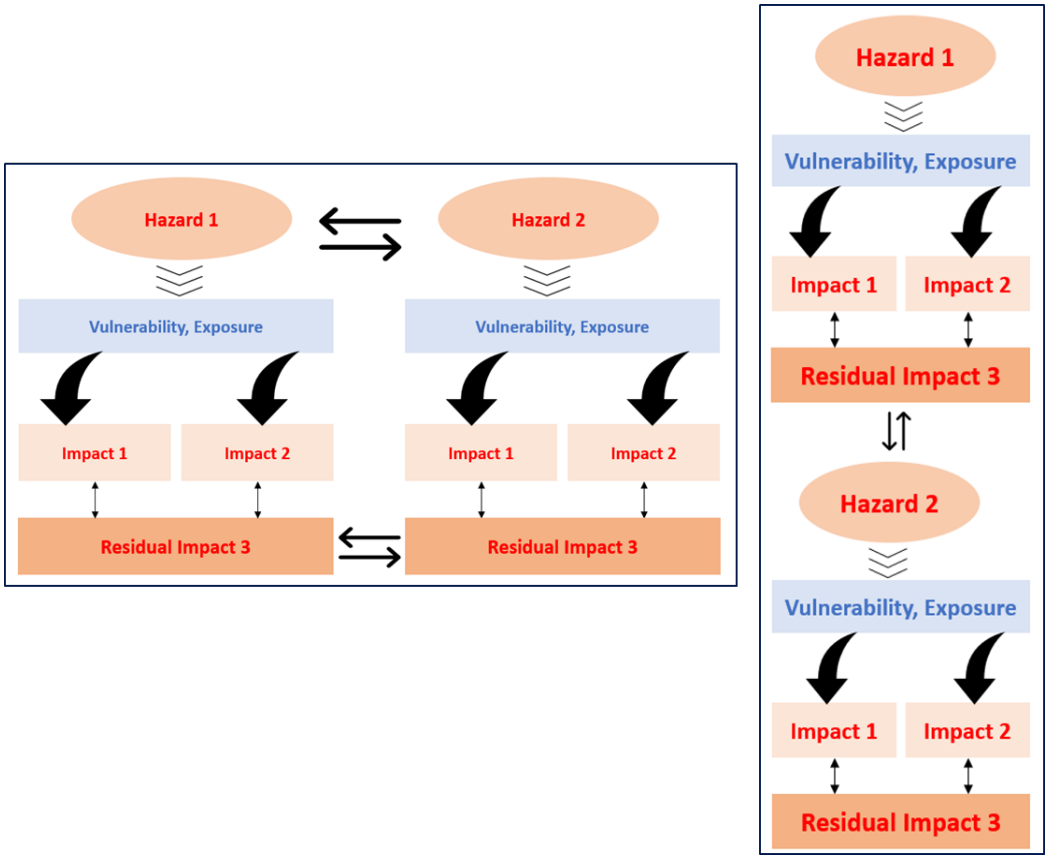

FIGURE 2 - LEFT: DISASTERS COMPOUND AND BECOME RISK MULTIPLIERS; RIGHT: DISASTERS CASCADE AND TURN INTO RISK MULTIPLIER. SOURCE: ESCAP, 2023

The 2019-2020 bushfires serve as a powerful illustration of the compounding and cascading effects of disasters on lifeline systems. The bushfires had a catastrophic impact on various lifeline systems, showcasing their interconnected vulnerabilities (Commonwealth of Australia 2021; Blaustein et al., 2023). The destruction caused by the fires led to disruptions in power supply, affecting communities and infrastructure. Power outages, in turn, influenced communication networks and essential services. Additionally, the fires strained water supply systems, especially in areas where water treatment plants were damaged, leading to challenges in providing clean and safe water to affected populations (Gasser, 2020; Resilience Rising, 2020). The lessons learned from these bushfires emphasise the importance of fostering adaptability and collaboration across lifeline systems, ensuring they can withstand and recover from the complex challenges posed by compounding disasters. This collective approach is crucial in building a more resilient and responsive infrastructure to safeguard communities in the face of future crises.

Following the bushfires, Australia faced the global COVID-19 pandemic; the pandemic strained health care systems, disrupted daily life, and impacted the economy (Nguyen et al., 2021). The need for social distancing and lockdowns made it challenging to respond to other crises effectively, compounding the challenges of disaster risk reduction efforts (Blaustein et al., 2023). In the wake of the bushfires and amidst the pandemic, Australia experienced a La Niña weather pattern, leading to heavy rainfall and widespread flooding (The Climate Council, 2020). This added to the existing challenges of bushfire recovery, as flooding affected regions that had previously endured bushfires. As of 2024, Australia is officially in an El Niño weather pattern, which is intensifying heat waves, increasing the severity of bushfires, and contributing to drought conditions (Lu,2023; CSIRO, 2023). The transition from La Niña to El Niño and another fire season has created a complex scenario of overlapping disasters. For example, regions affected by the previous bushfires and subsequent flooding are now facing a new fire season. Such evolving climate conditions and interconnected crises poses significant challenges for emergency services, infrastructure and community resilience

The emergence of critical infrastructure resilience

Internationally, the early political debates regarding the protection of CI centred around war and terrorism-related threats. For example, the 1997 United States presidential report stated that 'while poor design, accidents and natural disasters may threaten our infrastructures, we focused primarily on hostile attempts to damage, misuse, or otherwise subvert them' (The President's Commission on Critical Infrastructure Protection, 1997, p.14). Literature related to this area has typically focused on studying the probability and potential impact on various CIs, particularly focusing on the transportation sector, for example, airports and subway systems (Farahani et al., 2019). Although the emerging scholarly discourse identified a wider range of threats to CI, globally, CI policy maintains an emphasis on war and terrorism (Biskupovic, 2021). In fact, the focus was further reinforced in the US policy discussions (and around the globe) following the 9/11 terrorist attacks. Similarly, European CI protection policy development occurred only after several terrorist attacks in the region.

During the early post-9/11 era, there has been an increasing focus on developing security policies for CI protection by enhancing conventional risk management principles (Habibian & Minaie, 2018; Verner, Kim & Petit, 2017; Phillips et al., 2016; Coaffee, & Clarke, 2017). However, the increasing frequency and severity of climate-related hazards, and disasters has further directed attention to the interconnectivity of CI sectors with an emphasis on the cascading impacts of CI disruptions and the resulting effect on public safety, national security, economic activity, and overall functioning of society (Rinaldi et al., 2001; Rinaldi, 2004; Coaffee, & Clarke, 2017; Gissing, Eburn & McAneney, 2020). Furthermore, with the rapid urbanisation, fast-evolving information technology, sectoral interdependencies and privatisation of CI assets, the potential impact of CI disruption is rising significantly with escalating cascading impacts (Pescaroli et al. 2018). This has further directed the attention of CI policy towards resilience as opposed to protection (Setola, et al., 2016).

While national policies across the world continue to emphasise concepts such as risk management, protection, dependency modelling and analysis, etc., *resilience* continues to gain a more prominent role, as the umbrella term to cover the various aspects and the various stages of crisis management when a critical infrastructure system faces a disruptive event (Setola, et al., 2016). Although there is reasonable international consensus on the definitions of CI, the concepts of critical infrastructure resilience (CIR) still vary (Biskupovic, 2021; O-Donnell, 2013). Consequently, this varied concept of CIR has led to a caution in the CI literature that without an established definition, widespread use of the term has made the CIR concept too vague and consequently difficult to operationalise (Cedergren et al., 2018; Moteff et al., 2003; Rogers, 2011). Despite a lack of official, national definitions of CIR, the concept is becoming a key component in national policy and strategy as a shift towards resilience in the field of CI protection.

Resilience has become a fundamental element for many national policies related to critical infrastructure protection strategies, such as Australia, USA, UK, New Zealand; and international organisations including United Nations, European Union, OECD. Lifelines resilience is evidently essential to economic and social wellbeing. The concept of lifelines resilience is conventionally linked with the ability to cope with system wide disruptions due to extreme natural or human-made causes, shocks or accidental events, ensuring a minimal level of a specific function of infrastructure itself (Pescaroli, Wicks, Giacomello & Alexander, 2018). According to the US National Institute of Building Sciences, the nation saves $4 in future disaster costs for every $1 invested in utility and infrastructure mitigation activities (MMC, 2018). However, despite the obvious parallels between the emerging critical infrastructure and resilience as mainstream policy concerns, Coaffee, & Clarke (2017) argue that there has been "little interconnection between theory and practice", and research in critical infrastructure resilience is "still in its infancy".

While there are no established official or national definitions of CIR, one can still find several non-official definitions of the concept (Theocharidou et al., 2016). However, as noted, it is included as a key component in several national policy and strategy reports for Critical Infrastructure Protection (CIP) programs, indicating a shift towards resilience in the CI field. Nevertheless, among various definitions and approaches to CIR, some common attributes can be observed, such as the ability to recover, adapt, withstand and absorb disturbances. In a review of resilience concepts for CI, Francis and Bekera (2014) concluded that the definitions are converging towards a common definition with

common elements: absorptive capacity, recoverability, adaptive capacity and retention of identity and structure. Thus, it seems that the three resilience capacities: absorptive, adaptive, and transformative capacities, are central to these definitions and are linked with different stages of the response cycle to infrastructure disruptions.

Rinaldi and colleagues (2001; 2005) recognised the interdependencies among modern CI sectors and advocated for the need to incorporate these dependencies in resilience concepts. Most current approaches in the CI field now stress the significance of interdependencies and adopt a "system-of-systems" approach (Alsubaie et al., 2016; Ouyang, 2014). In this view, the concept of CI resilience should account for interdependencies among CIs and the potential cascading impacts, which is not commonly reflected in definitions (Theocharidou et al., 2016). Additionally, Rinaldi and colleagues (2001; 2005) also asserted that alongside the technical aspect, CI develops and retains interaction with the whole system through its “political”, “environmental”, “economic”, and “social” aspects. Therefore, the concept of CIR inherently encompasses technical, organisational, social and economic dimensions. The technological dimension refers to the physical properties of infrastructure, while the organisational dimension relates to the management of these physical components. The social dimension comprises the population and community characteristics that affect their vulnerability or adaptability to changing circumstances. A resilience-based approach for CI is gradually being adopted by nations to address the challenges and costs of maximum protection in a complex environment and to overcome the limitations of traditional scenario-based risk management.

To establish the resilience concept within critical infrastructure field, the OECD (2019, p.104) proposed the following (box 1) systems-based approach for critical infrastructure policies:

To shift from a protection centric strategy to one that emphasizes resilience, critical infrastructure policies need to feature the following qualities from a system-thinking perspective:

***All-hazards and threats**: Single-hazard policies are not sufficient to build infrastructure resilience. An all-hazards and threats forward-looking approach to critical infrastructure resilience and security enables policy makers and operators to better prepare for the unexpected.*

***System-level**: Infrastructure assets are usually only the components of a wider complex system, which should be considered in its entirety in a comprehensive resilience strategy. A system approach allows for prioritising the most critical components, and addresses weak points that create critical vulnerabilities for the entire system.*

***Multi-sectoral coordination**: Addressing interdependencies in policies requires policy makers and operators to go beyond a silo-based approach and to target the critical infrastructure sectors together. While operators tend to be well aware of their own dependencies upon critical sectors, they may not be as conscious of the dependencies others have upon their own services.*

***Public-private cooperation**: Although governments continue to own, invest in, and operate critical infrastructure in some sectors, a large share of critical infrastructure is either privately owned or operated. The resilience of these systems depends upon governments partnering with infrastructure operators from the public and private sectors in resilience efforts through the establishment of relevant governance arrangements.*

***Life-cycle approach**: Different resilience measures may apply at different phases of the infrastructure life-cycle: robustness and redundancies requires investments in the design phase, while business continuity planning and maintenance pertains to the operations, and adaptability can be based on infrastructure retrofitting. Thus, it is important to set-up a comprehensive policy that enables resilience throughout infrastructure life-cycle.*

***Entire risk management cycle**: A comprehensive resilience policy should incorporate measures throughout the entire risk management cycle, from risk assessment to risk prevention, emergency preparedness, response, recovery and reconstruction.*

***Risk-based and layered approach**: Given the considerable degree of uncertainty about future risks, the manifold dimensions of infrastructure systems vulnerability, and all the interrelationships between these systems, the prioritisation of resilience measures is essential. A risk-based and layered approach helps account for complex interdependencies, for all-hazards and across the infrastructure life-cycle.*

***Transboundary dimension**: Risks arising from interdependencies and interconnectedness cannot be fully mitigated without incorporating their international dimension. Fostering international cooperation is key to infrastructure resilience.*

BOX 1 - SYSTEM APPROACH FOR CRITICAL INFRASTRUCTURE POLICIES (SOURCE: OECD2019, P. 104)

Although across the policy landscape there is a growing emphasis on (CI) resilience, a more comprehensive and much-needed focus on lifelines aspects and related community resilience is largely missing. Recent research and reviews show that worldwide, the current policy and practice approach to CI resilience retains a limited focus on specific, endogenous technical factors and requires a more comprehensive approach that accounts for the social, institutional and governance-related aspects (Pescaroli et. al., 2018; Coaffee, & Clarke, 2017). Recognising this, Infrastructure Australia (Australia's independent infrastructure adviser which provides research and advice to governments, industry and the community on the infrastructure investments and reforms that will benefit all Australians) has proposed a shift of focus from 'resilient infrastructure' to 'infrastructure for resilience':

Resilience approach "requires a shift in focus from 'resilient infrastructure' – that is, a sole focus on the resilience of assets themselves – to 'infrastructure for resilience', meaning, the contribution of assets and networks to the resilience of the system. It requires strengthening the asset, network and sector, as well as strengthening places, precincts, cities and regions." (Infrastructure Australia, 2021)

Lifelines resilience

What are lifelines?

The significance of some infrastructure*, for example, "aqueducts", has been known since Roman times, and has evolved through history, for example, the protection of power plants during the Cold War (*Setola, Luiijf and Theocharidou, 2016*).*

Generally, infrastructure refers to the fundamental facilities and systems in urban and rural areas (e.g., railways, roads, tunnels, bridges, power grids, energy, electricity, telecommunications, water supplies, sewers, etc.) (Liu et al., 2022; Markolf et al., 2018; Feofilovs & Romagnoli, 2017). In contrast, the term 'critical infrastructure' is used by governments to describe assets that are essential for the functioning of a society and economy. These are systems and services considered to be life support networks vital to 'sustain the normal activities of the industries and communities, such as production, delivery and supply chain issues for industries, as well as commuting to work, school, church, health care, etc., for communities. These activities are affected when the related critical infrastructures are unable to provide the necessary service for the activities sustenance' (Oh, Deshmukh & Hastak, 2013). What makes this critical infrastructure 'critical' is their interdependencies with each other and interlinked service system related to the community's normal functioning (Oh, Deshmukh & Hastak, 2013). This interlinked service system creates a 'multi-infrastructure network' with nesting communities and industries.

CI is often also referred as 'lifeline infrastructures' or 'lifeline networks' or simply 'lifelines'.[1] However, the terminologies and definitions vary across countries. Countries also have their own preferences regarding which sectors and components should be included within the CI or lifelines domain. Thus, although there is not a commonly accepted definition of CI/lifelines, all definitions seem to highlight the contributing role of the CI to the society and the cascading impact in the case of a disruption (Setola, Luiijf and Theocharidou, 2016). It is difficult to track down exactly when the term lifelines became synonymous to 'critical infrastructure' in the policy language. In the USA, on October 28, 2019, with the publication of the fourth edition of the National Response Framework, the Homeland Security introduced the term lifelines/community lifelines in national- level doctrine. (Homeland Security, 2019). On the other hand, in New Zealand a National Lifelines Coordinating Committee was established in 1999 which was later which has evolved into the New Zealand Lifelines Council which is a dedicated national agency for lifelines.

[1] In the context of 'lifelines' and 'life support' systems, it is important to distinguish the two. The term 'life support' is more commonly associated with emergency services in public health system than it is with 'lifelines'. Lifelines have some defining characteristics that distinguish them from other sectors. Such as:

- They provide the services and supports needed to nearly every home, business, and organisations
- They create complex physical and digital networks interconnected inside and within and across multiple lifelines sector.
- Although delivering everyday services, an event of disruption to one lifeline system has the potential to disrupt other lifelines or whole lifelines network involving large geographical areas in a cascading effect, and life-threatening situations may arise.

Overall, we find that lifelines are defined in various ways, but can be thought of as the successful functional integration of critical infrastructure (e.g., transport infrastructure, telecommunications, access to health care and so on), supply chains, and essential services, in ways that sustain people's lives and day-to-day activities. Lifelines include not only assets, but the people and capabilities required to operate and use them, social relationships between them and the broader socio-ecological systems we are part of. They are 'systems of systems' with multiple interdependencies that not only enable services, but also increase the risk that extreme climatic events and other disruptions trigger disasters that cascade and compound across places, industries and groups. Thus, disruptions to lifelines can have far-reaching impacts and hinder emergency response and recovery efforts.

Lifelines sectors

The national definitions of CI and its sectors have evolved in response to the complexity of the physical environment and society, and changes in strategic needs (Lazari, 2014). Table 1 below shows the differences in definitions and components of CI across countries- Australia, USA, New Zealand and the UK.

TABLE 1 – DEFINITIONS AND SECTORS CONSIDERED LIFELINES IN AUSTRALIA, USA, NEW ZEALAND AND UK

	Australia	USA	New Zealand	UK
Terminology and definition	**Critical Infrastructure:** is defined in the Critical Infrastructure Resilience Strategy 2023 (Australian Government, 2023) as 'those physical facilities, systems, assets, supply chains, information technologies and communication networks which, if destroyed, degraded, compromised or rendered unavailable for an extended period, would significantly impact the social or economic wellbeing of Australia as a nation or its states or territories, or affect Australia's ability to conduct national defence and ensure national security.'	**Lifelines/community lifelines:** A lifeline enables the continuous operation of critical government and business functions and is essential to human health and safety or economic security. • lifelines are the most fundamental services in the community that, when stabilised, enable all other aspects of society to function • lifelines are the integrated network of assets, services and capabilities that are used day-to-day to support the recurring needs of the community • when disrupted, decisive intervention (e.g., rapid service re-establishment or employment of contingency response solutions) is required	**Lifelines**: are the essential infrastructure and services that support the life of our community. Water, wastewater, stormwater, electricity, gas, petroleum, telecommunications and transportation systems including road, rail, airports and ports are all included. (New Zealand Lifelines Council, 2023)	**Critical National Infrastructure (CNI):** 'Those critical elements of infrastructure (namely assets, facilities, systems, networks or processes and the essential workers that operate and facilitate them), the loss or compromise of which could result in: a) Major detrimental impact on the availability, integrity or delivery of essential services - including those services whose integrity, if compromised, could result in significant loss of life or casualties - taking into account significant economic or social impacts; and/or

		to stabilise the incident (FEMA 2023)		b) Significant impact on national security, national defence or the functioning of the state.' (National Protective Security Authority, 2023)
Lifelines/Ci Components	11 sectors and 22 asset classes: **1. Communications sector:** • telecommunications asset • broadcasting asset • domain name system **2. Data storage or processing:** • data storage or processing asset **3. Financial services and markets sector:** • banking asset • superannuation asset • insurance asset • financial market infrastructure asset **4. Water and sewerage sector:** • water asset **5. Energy sector:** • gas asset	Seven components with subcomponents in each: 1. **Safety and security** • law enforcement/security • fire service • search and rescue • government service • community safety 2. **Food, water, shelter** • food • water • shelter • agriculture 3. **Health and Medical** • medical care • public health • patient movement • medical supply chain	**A. Essential and Enabling (Lifelines) Infrastructure:** Provides services that other infrastructure needs to function (interdependencies) 1. energy 2. telecommunications /broadcasting 3. transport 4. water, wastewater and stormwater 5. flood protection 6. finance (payment services) 7. solid waste 8. data storage/ICT **B. Essential Services (Critical Customers):** Other essential services such as hospitals and financial services, that depend on	There are 13 national infrastructure sectors where several sectors have defined 'subsectors'; Emergency Services for example can be split into Police, Ambulance, Fire Services and Coast Guard: 1. chemicals 2. civil nuclear 3. communications 4. defence 5. emergency services 6. energy 7. finance 8. food 9. government 10. health 11. space 12. transport 13. water

	• electricity asset • energy market operator asset • liquid fuel asset **6. Health care and medical sector:** • hospital **7. Higher education and research sector** • education asset **8. Food and grocery sector:** • food and grocery asset **9. Transport sector:** • freight infrastructure asset • freight services asset • port asset • public transport asset • aviation asset • water asset **10. Space technology sector** **11. Defence industry sector** • defence industry asset	• ftality management **4. Energy** • power grid • fuel **5. Communications** • infrastructure • responder communications • alerts, warnings and messages • finance • 911 and dispatch **6. Transportation** • highway/roadway/motor vehicle • mass transit • railway • aviation • maritime **7. Hazardous Material** • facilities • HAZMAT, pollutants, contaminants	lifelines infrastructure to function: 1. health and aged care 2. education 3. corrections 4. emergency management and emergency services 5. financial services 6. fast moving consumer goods 7. community facilities 8. major industry (New Zealand Lifelines Council, 2023)	

		In addition, within their policy and systems, USA also has 16 CI sectors, which are: 1. chemical 2. financial services 3. commercial facilities 4. food and agriculture 5. communications 6. government facilities 7. critical manufacturing 8. health Care and public health 9. dams 10. information technology 11. defence industrial base 12. nuclear reactors, materials, and waste 13. emergency services 14. transportation systems 15. energy 16. water and wastewater systems However, within these sectors, there are four designated lifeline functions – transportation, water, energy, and communications - which means that their reliable operation is so critical that a disruption or loss of one of these functions will directly affect the security and resilience of critical infrastructure within and across numerous sectors.		

Lifelines as a system of systems

Interdependency is the complex relationship among the critical infrastructure systems or lifelines network. The interconnected infrastructure components constitute a 'system of systems' where disruption of service in one infrastructure element affect the service and functionality of other systems and networks through cascading impacts and affect the resilience of the entire lifelines system covering vast geographical areas (Rinaldi et. al., 2001; Habibian & Minaie, 2018; Verner, Kim & Petit, 2017; Phillips et al., 2016). Rinaldi (2004) defines interdependency as 'a bidirectional relationship between infrastructures through which the state of each infrastructure is influenced by or correlated to the state of the other,' and identifies four primary classes of interdependencies:

- Physical Interdependency – two infrastructures are physically interdependent if the state of each depends upon the material output(s) of the other. Physical interdependencies arise from physical linkages or connections among elements of the infrastructure.
- Cyber Interdependency – an infrastructure has a cyber interdependency if its state depends on information transmitted through the information infrastructure. The computerisation and automation of modern infrastructures and widespread use of supervisory control and data acquisition systems have led to pervasive cyber interdependencies.
- Geographic Interdependency – infrastructures are geographically interdependent if a local environmental event can create state changes in all of them. This implies close spatial proximity of elements of different infrastructures, such as collocated elements of different infrastructures in a common right-of-way.
- Logical Interdependency – two infrastructures are logically interdependent if the state of each depends upon the state of the other via some mechanism that is not a physical, cyber or geographic connection. For example, various policy, legal or regulatory regimes can give rise to logical linkage among two or more infrastructures.

Pederson, Dudenhoeffer, Hartley and Permann (2006) further expanded these classes into the following categories:

- Policy/procedural– the effect of a policy or a procedure of one infrastructure on all other social and economic sectors; an example is a flight ban for an area and/or for a duration
- Societal - influencing factors such as public opinion, confidence, fear, or cultural issues from one component on other although no physical linkage or relationship may exist – for public support or opposition to road pricing and how it influences other sectors (for example,energy consumption, locational decisions of firms and residence). However, such influences might be time dependent in nature and may decline or increase over time after original formation.

The increased acknowledgement of such complex interdependency among various CI systems over time led to the prioritisation of lifelines resilience. CI researchers suggest that the interdependencies of different infrastructure systems or networks must be acknowledged when evaluating lifeline resilience (Habibian & Minaie, 2018). While it is necessary to have a deeper understanding of interdependencies and their implications for lifelines resilience, Rinaldi et al. (2001) point out that it will requires 'a comprehensive R&D agenda that encompasses multiple disciplines ranging from engineering and complexity science to sociology, policy research and political science'.

Critical infrastructure resilience

While the concept of resilience in the CI literature and policy remains somewhat ambiguous, as discussed above, the shift towards a 'systems of systems' approach and resilience thinking demonstrates a concerted effort to tackle the entrenched, systemic issues related to managing CI under climatic and societal change. Along with the move towards resilience we observe a move from CI to lifelines. These two conceptual and policy shifts are intimately connected and can be thought of as twinned, where the shift towards resilience thinking requires a reorienting of the way in which we conceptualise and ultimately prioritise the outcomes of decisions and actions. Instead of focusing on the protection and persistence of CI systems, resilience thinking asks us to focus on the impact that the structure and functioning of CI systems have on the resilience of lives, livelihoods and environment – lifelines.

This shift can be explored by expanding on the differences between a risk management approach to a resilience approach to CI/lifelines. Whereas a risk approach requires building critical infrastructure systems resistant to identified threats, a resilience approach embraces uncertainty and disruption through continuous anticipation and adaptation adaptive process. Defining CI resilience as an 'ongoing adaptive *process*- that is, not as something a system has, but a characteristic of the way it behaves', Park et al. (2013) illustrated a comparison between risk vs resilience perspectives within CI systems (see Table 2).

TABLE 2 - COMPARISON OF RISK AND RESILIENCE APPROACHES

Aspects	Risk Management	Resilience
Design principles	Preservation of status quo, that is, avoid transformative change; minimise risk of failures	Adaptation to changing conditions without permanent loss of function (e.g., changing paths, if not destinations) Acknowledgment of unknown hazards. Intentional failure may be allowed at subsystem level to reduce the possibility of permanent loss of function in larger system
Design objectives	Minimisation of probability of failure, albeit with rare catastrophic consequences and long recovery times	Minimisation of consequences of failure, albeit with more frequent failures and rapid recovery times
Design strategies	Armoring, strengthening, oversizing, resistance, redundancy, isolation	Diversity, adaptability, cohesion, flexibility, renewability, regrowth, innovation, transformation
Relation to sustainability	Security, longevity	Recovery, renewal, innovation
Mechanisms of coordinating response	Centralised, hierarchical decision structures coordinate efforts according to response plans	Decentralised, autonomous agents respond to local conditions
Modes of analysis	Quantitative (probability-based) and semiquantitative (scenario-based) analysis of identified hazards in context of utility theory (i.e., costs & benefits)	Possible consequence analysis of involving scenarios with unidentified causes

Similarly, Coaffee and Clarke (2017) also illustrated the differences between the critical infrastructure protection vs resilience approaches (see Table 3).

TABLE 3 - CRITICAL INFRASTRUCTURE - PROTECTION VS RESILIENCE (SOURCE: COAFFE & CLARKE, 2017)

	Critical Infrastructure Protection (engineering resilience)	Critical Infrastructure Resilience (social-ecological resilience)
Aim	Equilibrium Existing normality Preserve Stability	Adaptive New normality Transformative Flexible
Focus	Endogenous Short-term Reactive Hardened structures	Exogenous Long-term Proactive Redesigned processes
Critical Infrastructure Approaches	Techno-rational Technical Homogeneity Robustness Recovery Fail-safe Protection Optimisation Single-sector focus	Complex adaptive Socio-technical Heterogeneity Malleable Realign Safe-to-fail Predictive Greater redundancy/diversity Dependencies

Although there is no agreed international measurement approach for lifelines resilience, there is broad agreement on why it should be measured (Coaffee and Clarke, 2017; Rinaldi et al., 2001; Habibian and Minaie, 2018; Davis et al., 2018). Habibian and Minaie (2018) identified six primary components or dimensions of infrastructure resilience:

1. hazards
2. risk analysis
3. gap analysis
4. innovative technologies
5. dependencies
6. funding.

Habibian and Minaie (2018) argue that these dimensions 'form the backbone of a process for assessing, prioritising, and addressing infrastructure resilience gaps (vulnerabilities and risks) in the development of an implementation plan that eliminates the identified resilience gaps' (p.43).

Besides measuring CI resilience, there is also emphasis on fostering resilience for which it is essential to identify the contributing resilience factors to the lifelines system (Mendonca, 2008; Hollnagel, Nemeth & Dekker, 2008). Coaffee and Clarke (2017) argued that focusing on characterising resilience in context, articulating its key constituents and accordingly raising awareness of intervention requirements will help building resilience within organisations and networks. In this regard, Davis et al. (2018) identified seventeen characteristics of resilient lifelines and categorised them into four resilience domains: organisational, technical, and social and economic (see Table 4). They also proposed that these characteristics and indicators to be used as checklist for evaluating resilience for a lifeline organisation and undertaking improvement measure.

TABLE 4 - CHARACTERISTICS OF RESILIENT LIFELINES (DAVID ET AL. 2018)

Resilience domains	Characteristics of resilient lifelines
Organisational	1. Has an organisational structure capable of cost-effectively managing, coordinating and implementing core resilience activities in a safe and reliable manner 2. Has organisational stability and capacity. 3. Has adequate support and resources to implement resilience measures. 4. Has plans for expected scenario events, including regional and local events 5. Maintains emergency plans and exercises them, consistent with expected hazard scenario impacts 6. Has commitment to continual development and improvement
Technical	1. Has established performance objectives and performance criteria based on defined metrics 2. Is aware of the hazards and threats, understands potential impacts to the system and its life cycle, and has established procedures to address them 3. Identifies vulnerabilities and minimises them in accordance with established performance objectives with short-term, intermediate-term and long-term priorities 4. Is able to measure and quantify resilience 5. Develops post-event priorities on how to maintain services and methods to restore lost services to different customers 6. Has well-informed highly capable incident management system 7. Is able to enhance resilience through betterment processes during permanent repair of damaged facilities 8. Is able to manage and help control cascading events

Social and economic	1. Understands the direct and indirect social and economic impacts that may result from damaged system (in current and future states) 2. Is able to provide adequate and reliable postincident emergency accessibility services throughout operational areas 3. Has good communications with customers, community leadership (within service area and areas of operation), and other lifeline systems (Davis et al. ,2018)

Australian policy and stakeholder landscape

Many countries, including Australia, have developed sophisticated policies and legislation to deal with CI protection and resilience in the event of a disaster, in line with global trends. As outlined above, resilience thinking has increasingly become a central concept in CI policies. Therefore, it is important to understand how resilience is conceptualised and used in these policies in the Australian context.

In Australia, the concept of CI was tentatively established within the national policy landscape in the early 1990s, gaining dominance in the post-9/11 era. While the concept and definition of CI evolved internationally, its definition remained notably and deliberately constant in Australian federal policy since the mid-2000s (O'Donnell, 2012; 2013). The Commonwealth, State and Territory governments share the following definition of critical infrastructure (CI):

Those physical facilities, supply chains, information technologies and communication networks which, if destroyed, degraded or rendered unavailable for an extended period, would significantly impact the social or economic wellbeing of the nation or affect Australia's ability to conduct national defence and ensure national security.

Following the trends in the USA and Europe, the Australian Government has taken steps to build a public-private partnership approach between businesses and government, primarily via the establishment of the Trusted Information Sharing Network for Critical Infrastructure Resilience (Commonwealth of Australia, 2015). TISN includes 14 groups which focus on various CI sectors, including groups on banking and finance, communications, education and research, food and grocery sector, liquid fuels, and water services (Cyber and Infrastructure Security Centre, 2023) The goal of TISN and these groups is to build CI resilience in an all-hazards context by establishing a cross-sector approach and identifying of cross-sector dependencies.

Setola, et al. (2016) observe a strong business-oriented trait in the Australian CIR approach in policy, which emphasises on bringing business practices in line to pursue a common goal- 'the operability of the infrastructure under adverse circumstances' (pp. 15). At the same time, O-Donnell (2013) observe that within the Australian policy framework, CIR had been conceptualised through four distinct lenses:

1. as a policy concept that evolved from an earlier concept of protecting CI from terrorism to the present concept where it incorporates broader threats and hazards
2. as a business model that focuses on organisational resilience
3. as cyber systems where various CI sectors are interconnected and interdependent on the cyber system
4. as engineering design and strategic asset management.

Alongside the above concepts, within the National Critical Infrastructure Resilience Strategy 2015, the community resilience concept is also evident (Commonwealth of Australia 2015). However, given the recent reformation of critical infrastructure policy in Australia with the Amendments of the *Security of Critical Infrastructure (SOCI) Act 2018* (Cth), which came into force in April 2022, analysis on the impact of this discourse on policy is yet to emerge. Overall, policy developments for CI resilience in Australia are in the early stages of experimentation and implementation, and there is more work to be done to establish and assemble an evidence base for effective policy interventions.

Below we present an overview of the federal-level groups and processes in Australia that contribute to enhancing lifeline resilience and overall resilience. Each group and process is classified based on its focus on policy, cyber, or other disaster-related aspects and we also highlight their interactions.

Federal-level groups

- Department of Home Affairs (Policy)
  - Coordinates national efforts in emergency management, border protection and national security.
  - Oversees the implementation of resilience-related initiatives and frameworks.
- Emergency Management Australia (EMA) (Policy, Disaster)
  - A division of the Department of Home Affairs responsible for coordinating national emergency management and disaster resilience efforts.
  - Works closely with state and territory emergency management agencies, as well as the Australian Institute for Disaster Resilience..
- Australian Cyber Security Centre (ACSC) (Policy, Cyber)
  - Part of the Department of Home Affairs, responsible for strengthening Australia's cyber resilience and coordinating the national response to cyber threats. The ACSC within Australian Signals Directorate leads the Australian Government's efforts on national cyber security.
  - Collaborates with the Critical Infrastructure Centre , state and territory governments and industry partners to protect critical infrastructure from cyber risks.
- Critical Infrastructure Centre (CIC) (Policy, Cyber, Disaster)
  - A government initiative under the Department of Home Affairs that focuses on managing risks to critical infrastructure.
  - Contributes to policy development, cyber security and disaster response by working with the ACSC and other relevant agencies to protect critical infrastructure assets.
- Australian Institute for Disaster Resilience (AIDR) (Policy, Disaster)
  - A national centre for knowledge and expertise on disaster resilience, offering education, training and resources to various stakeholders.
  - Collaborates with EMA and other federal, state and local agencies to support disaster resilience efforts.
- Australian Business Roundtable for Disaster Resilience and Safer Communities (Policy, Disaster)
  - A private sector initiative that advocates for policy reforms and investments to enhance disaster resilience and climate change preparedness.
  - Collaborates with the government, non-government organisations and the private sector to promote resilience and risk reduction measures.

Frameworks and strategies

- National Disaster Risk Reduction Framework (NDRRF) (Policy, Disaster)

- A coordinated strategic approach to reducing disaster risks across Australia, developed by the Department of Home Affairs.
- Involves collaboration with federal, state, and local governments, private sector and community organisations to build the resilience of communities, businesses and critical infrastructure to withstand the impacts of disasters better.

- National Climate Resilience and Adaptation Strategy (NCRAS) (Policy, Disaster)
  - A comprehensive strategy that outlines Australia's approach to managing the risks and opportunities associated with climate change.
  - Involves collaboration between various government agencies, industry sectors and community stakeholders to develop and implement effective adaptation measures.

- Cyber Security Strategy (Policy, Cyber)
  - A national strategy that aims to strengthen Australia's cyber resilience and protect its digital infrastructure from cyber threats.
  - Implemented by the ACSC in collaboration with other government agencies, businesses and the wider community.

- Critical Infrastructure Resilience Strategy (Policy, Cyber, Disaster)
  - Developed by the Department of Home Affairs and Cyber and Infrastructure Security Centre to protect Australia's critical infrastructure from a wide range of threats, including natural disasters, terrorism and cyber-attacks.
  - Implemented in coordination with the CIC, ACSC and other relevant federal and state agencies.

- Trusted Information Sharing Network (TISN) (Policy, Cyber, Disaster)
  - Facilitated by the Department of Home Affairs, the TISN promotes information sharing and collaboration between the government and critical infrastructure owners/operators.
  - Supports the Critical Infrastructure Resilience Strategy by fostering cooperation and promoting the sharing of best practices and lessons learned.

- Protective Security Policy Framework (PSPF) (Policy)
  - Overseen by the Department of Home Affairs, the PSPF provides guidance to government agencies and organisations on how to protect their people, information and assets.
  - Contributes to overall resilience by ensuring that federal entities follow prescribed guidelines and implement appropriate protective security measures.

Interactions between federal-level groups and processes

The interactions between the various federal-level groups and processes related to lifeline resilience and overall resilience in Australia can be summarised as follows:

- The Department of Home Affairs oversees and coordinates the efforts of EMA, ACSC, CIC and other relevant agencies to develop and implement resilience-related initiatives and frameworks
- EMA collaborates with AIDR, state and territory emergency management agencies, and other stakeholders to share information, resources and expertise in disaster management
- The ACSC works closely with the CIC, state and territory governments, and industry partners to assess and mitigate cyber risks to critical infrastructure, including lifeline sectors
- The CIC plays a central role in coordinating the efforts of the ACSC, other relevant federal and state agencies, and critical infrastructure owners/operators to implement the Critical Infrastructure Resilience Strategy
- The AIDR partners with EMA, state and local governments, and community organisations to support disaster resilience efforts through education, training and resource sharing
- The Australian Business Roundtable for Disaster Resilience and Safer Communities engages with the government, non-government organisations, and the private sector to advocate for policy reforms and investments that enhance disaster resilience and reduce long-term costs
- The implementation of the NDRRF, NCRAS, Cyber Security Strategy, Critical Infrastructure Resilience Strategy, TISN, and PSPF involves collaboration and coordination between various government agencies, private sector partners and community organisations to ensure a comprehensive and integrated approach to enhancing Australia's resilience.

Conclusion

This scoping review has endeavoured to sketch the concepts, debates and issues relevant to the Resilience of Lifelines in Rural and Regional Australia research project. The review outlined the increasing challenge of compounding and cascading disasters, a challenge that centres what we come to define as lifelines. We traced the evolution in thinking from critical infrastructure protection to lifelines resilience and outlined the 'new' paradigm which is primarily concerned with supporting social and economic wellbeing. Drawing on systems thinking and resilience theory, the review sketched out a conceptualisation of lifelines resilience in order to inform the project's objectives. Finally, we outlined the complex Australian policy landscape.

The review has uncovered a number of converging trends that are resulting in a proliferation of complexity and uncertainty, and an urgent need to shift policy and practice in order to meet this contemporary crisis. In undertaking this review it was revealed that there is a significant volume of relevant research, however, it is being produced in a disjointed way. Much like the practice of lifelines resilience itself, this review has identified the need for the application of systems thinking to the challenges described, multi- and transdisciplinarily and more clarity around the deep conceptual underpinnings of the space.

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