Critical Infrastructure Lifelines and

The Politics of Anthropocentric Resilience

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Abstract

The discourse of resilience has increasingly been utilised to advance the political prioritisation of enhanced security and to extend the performance of risk management in the Anthropocene. This has been notably advanced through integrated approaches that engage with uncertainty, complexity and volatility in order to survive and thrive in the future. Within this context, and drawing on findings from a number of EU-wide research projects tasked with operationalising critical infrastructure resilience, this paper provides a much- needed assessment of how resilience ideas are shaping how critical infrastructure providers and operators deal with complex risks to 'lifeline' systems and networks, whilst also illuminating the tensions elicited in the paradigm shift from protective-based risk management towards adaptive-based resilience. In doing so, we also draw attention to the implications of this transition for organisational governance and for the political ecologies of the Anthropocene that calls for more holistic, adaptable and equitable ways of assessing and working with risk across multiple systems, networks and scales.

Key words

Resilience, Anthropocene, critical infrastructure, adaptation pathways, politics

Critical infrastructure lifelines and the politics of anthropocentric resilience

For humanity to survive in the Anthropocene, we need to learn to live with and through the end of our current civilisation. Change, risk, conflict strife and death are the very processes of life, and we cannot avoid them. We must learn to accept and adapt.

Roy Scranton, *Learning to Die in the Anthropocene* (2015, p.22)

Resilience is the ability of a system to survive and thrive in the face of a complex, uncertain and ever-changing future. It is a way of thinking about both short term cycles and long term trends: minimizing disruptions in the face of shocks and stresses, recovering rapidly when they do occur, and adapting steadily to become better able to thrive as conditions continue to change. A resilience approach offers a proactive and holistic response to risk management.

Siemens, *Toolkit for Resilient Cities* (2013, p.3)

Introduction

The Anthropocene can be viewed as an epoch which began in the mid-twentieth century through a rapid increase in technological change, population growth and consumption, and which is increasingly characterised by complex and dynamic system interaction, future volatility and ultimately an imperative to rethink the relationship of humans with nature, environment and technology. Concomitantly, in the early twenty-first century – catalysed by the devastating events of 9/11 and the release of the fourth Intergovernmental Panel on Climate Change (IPCC) report in 2007 highlighting unequivocal evidence of a warming climate – ideas and practices of *resilience* have become a central organising metaphor within policy-making processes and the expanding institutional framework of national security and emergency preparedness. For many, resilience offers an integrated approach for coping with all manner of disruptive events, as well as a new way to engage with future uncertainty (Chandler, 2014; Coaffee, Murakami Wood, & Rogers, 2008; Walker & Cooper, 2011; Zolli & Healy, 2013). As we will argue in this paper, resilience thinking has subsequently been utilised to ‘extend’ established risk management approaches and to advance ways of surviving and thriving in the future through adaptation and long-term transformative action.

In many ways it is the spectre of unanticipated catastrophe that has driven the interest in resilience as a universal remedy for a range of ‘natural’ and human-induced risks (Aradau & van Munster, 2011). Recent decades have been remarkable for the volume of high-impact anthropocentric disasters, such as the impact of Hurricane Sandy or the cascading effects following the Tohuku earthquake, and which have highlighted the vulnerability, complexity and interdependency of contemporary life. Pointing towards the new climatic norm of the Anthropocene, Fisher (2012, p. 3) has also highlighted the dramatic increase in ‘weather-related catastrophes’, such as floods, storms and drought, which have increased exponentially between 1900 and 2005. These events have foregrounded the political prioritisation of enhanced security – often badged as resilience – as a political imaginary of being ‘insecurity by design’ (Evans & Reid, 2014). Such attention to governing insecurity has been highly related to historical and geographic contingency which sees governmental and corporate approaches to contingency planning, protection and resilience differentially applied in accordance to context (Lentzos & Rose, 2009). The frequency and severity of recent crises have further channelled attention to vulnerable physical assets, with a particular focus on *critical infrastructure* whose disruption have the potential to significantly affect public safety, security, economic activity, social functioning or environmental quality.

Specifically post-9/11, there has been focus within security policy upon *critical infrastructure protection* using conventional risk management principles and on the interdependency and interoperability of these systems and, by extension, the cascading effects of a breakdown in one system on other interconnected systems.[1] The increased acknowledgement of such complex risk has, over time, led to a prioritisation of *critical infrastructure resilience.* However, despite the clear parallels between the emergence of critical infrastructure and resilience as mainstream anthropocentric policy concerns, there has been relatively little interconnection between theory and practice. Emerging approaches to improving critical infrastructure resilience are still in their infancy, with e orts focused predominantly upon single infrastructure sectors, across a number of easily compared critical infrastructure sectors and at limited spatial scales.

Drawing on the results from a number of EU-wide research projects tasked with operationalising critical infrastructure resilience,[2] this paper illuminates how resilience ideas are shaping the ways in which critical infrastructure providers deal with complex risk and the tensions elicited in the transition from protective-based risk management towards adaptive-based resilience. In doing so, we will highlight the implications for this new way of working for organisational governance and for the importance of the political ecologies of the Anthropocene that call for more holistic and integrated ways of assessing risk and new modes of equitable governance across multiple systems, networks and scales (Biermann, 2014; Crutzen & Stoermer, 2000).

The remainder of the paper proceeds in three main sections. *First*, we frame our discussion through ideas of how to 'survive' anthropocentric challenges that require a different social–spatial framing, politics and ways of adapting to uncertainty. Here we view resilience as a supposed antidote – a new *biopolitical nomos* – to such anthropocentric destabilisation and insecurity, in contrast to a conventional probabilistic 'risk-based' world. *Second*, we operationalise ideas of change brought about by the Anthropocene and resilience discourse through the lens of critical infrastructure assessment and illuminate a normative paradigm shift from protection towards resilience. *Third,* we draw the key themes of the paper together in articulating how future critical infrastructure operations will need to adapt to the challenges of uncertainty and system interdependences in the Anthropocene. Drawing on detailed empirical survey work across Europe with a range of critical infrastructure providers, we also illuminate a series of interrelated barriers that has made the operationalisation of resilience approaches di cult to achieve in practice.

Survival in the Anthropocene

The Anthropocene presents a new role for humanity as the driving force behind planetary systems whilst at the same time operating within a world of 'persistent uncertainty' (Biermann, 2014) – a condition where the broader security concerns of nations have been increasingly rewritten to secure the conditions necessary for human life, for our very survival as a species.

In 2000, Crutzen and Stoermer first suggested that human-generated changes to the biosphere, including climate change, urbanisation, the deployment of nuclear weapons, large-scale biodiversity loss and accelerating landscape transformation, were creating a new geological epoch which they termed, the Anthropocene. Most recently, in a seminal paper in *Science,* Waters et al. (2016) concluded that 'the Anthropocene is functionally and strati-graphically distinct from the Holocene', and began with the 'Great Acceleration' in the mid-twentieth century. However, despite its geological basis, the Anthropocene has redefined critical human–environment relationships, the key role of risk in mediating this under-standing and illuminated how, in particular, the global climatic system is becoming more volatile, bringing new challenges for humanity (Oldfield et al., 2014). Despite dire warnings of increased storms, droughts and floods (IPCC, 2014), some suggest that the primary challenge will be political and in how humanity collectively builds adaptable governance systems that tackle the challenges of climate change and enhance resilience (Biermann et al., 2015). Whilst concerns over climate change are most commonly used to articulate the nature and the impact of the Anthropocene, it can also be considered a much wider conceptual frame for understanding human–environmental relationship and their political significance. However, there is a paradox at the heart of these understandings of the Anthropocene: whilst humans are increasingly shaping the environmental conditions, the ability to do this in a conscious and deliberate way is hampered by our inability to tackle the complex interactions and interdependencies involved, and thus the true nature of anthropocentric risk to global society.

Managing anthropocentric risk

Social scientists for many years have studied the risks from natural hazards and the need to make contingency against their impact (Kates, 1962; White, 1942). However, accounts regarding the impact of technological and anthropocentric risk only became prevalent in the late 1980s and 1990s, which suggested that concerns about such risks had become de ning societal characteristics (Adams, 1995; Beck, 1992; Douglas, 1994). This new range of 'risk theory' emerged primarily around concerns about global environmental hazards, the trans-national nature of such risk and the effect of such risk in challenging existing political governance configurations. Most notable amongst this canon of work was Beck's (1992) *Risk Society – Towards a New Modernity*. Published in the wake of the Chernobyl nuclear catastrophe in Ukraine, *Risk Society* considered what society might look like when disputes and conflicts about new types of risk produced by industrial society are fully realised.3 *Risk Society* starkly illuminated the magnitude and boundless nature of the global risks, and how this is transforming the way in which risk is imagined, assessed, managed and governed, but not eradicated. Beck's work provided the impetus for further academic thought related to the impact of the emergence of a set of newly de ned and ubiquitous 'mega-scale' risks on the workings of global society that 'cannot be delimited spatially, temporally, or socially' (Beck, 1995, p. 1). As Giddens (2002, p. 34) reiterated:

> *... whichever way you look at it, we are caught up in risk management. With the spread of manufactured risk, governments can't pretend such management isn't their business. And they need to collaborate, since very few new-style risks have anything to do with the borders of nations.*

Risk Society is a story of survivability. As Blowers (1999, p. 256) commented, 'Risk Society is a pessimistic and conflictual diagnosis of modern societies ... that is exposed to risks from high technology ... that imperil our very survival'. new risk theory also further exposed the disenchanted world of formalised instrumental rationality abundant in the 'iron cage' of bureaucracy (Weber, 1958) and the absence of social and cultural factors involved in discussions about risk that had been hidden beneath a preference for objective approaches to risk assessment – the 'possibility of calculation' (Giddens, 2002, p. 28).

These new understandings of risk are echoed in more recent discourses on the critical thresholds of the Anthropocene. For example, current attempts to tackle climate change have exposed the failures of contemporary decision-making, highlighting that 'neither traditional risk management strategies nor conventional economic decision-making can be relied on to govern in the face of increasingly likely extreme events' (Dalby, 2013a, p. 189). The Anthropocene ushers in an unknown future that requires policy-makers to shift their focus both from an appreciation of risk to one of criticality and in identifying and understanding those aspects essential for human well-being. This is particularly the case with regard to the long-term significance of system interdependencies and issues of social and spatial justice (Biermann, 2014; Dalby, 2013b; Mabey, Schultz, Dimsdale, Bergamaschi, & Amal-lee, 2013).

From risk to resilience

The anthropocentric view of risk has significantly contributed to the rise of *resilience* as the policy metaphor of choice for coping with and managing future uncertainty and the incorporation of 'the dynamic interplay between persistence, adaptability and transformability across multiple scales and time frames' (Davoudi, 2012, p. 310). Whilst the concept of resilience is closely associated with an engagement with risk, a critical schism emerges between resilience and more established risk management practices (Baum, 2015; Suter, 2011); should resilience be considered as the end goal of traditional risk management approaches? Is it a new consideration for risk management? Does it extend current risk management practices? or does resilience require an entirely different paradigm for considering future uncertainties?

The shift towards resilience approaches is also not without critique, posing some fundamental questions of resilience for whom, by whom? (Coaffee & Lee, 2016). Much of this critical assessment concerns the alleged tarnishing of resilience ideas through 'neoliberal decentralisation' (Amin, 2013) and a post-political landscape understood as the foreclosing of political choice, the delegation of decision-making to technocratic experts, growing public disengagement from politics and ultimately the closing down of political debate and agency (Flinders & Wood, 2014). The emerging canon of work in 'critical resilience studies' has high-lighted the ways in which resilience policy and practice indicate a shift in the state's policies, reflecting a desire to step back from its responsibilities to ensure the protection of the population during crisis and to delegate to certain professions, private companies, communities and individuals.4 Through the lens of resilience policy, we can therefore chart new forms of precautionary governance, attempts to create resilient citizens, the drawing in of a range of stakeholders to the resilience agenda and the corresponding adoption of new roles and responsibilities in enacting policy priorities. Whilst we are sympathetic to critical accounts and especially their powerful expose of who wins and who doesn't in neoliberal governance, we, like others, prefer to focus upon our analysis on a more inductive and performative approach which views resilience as a multiplicity of related, and often experimental practices. Like Brassett and Vaughan-Williams (2015, p. 34) in this paper we

> seek to reflect and develop upon a notion of resilience as an ongoing interaction between various (and often conflicting) actors and logics, one which can be viewed as

far more contingent, incomplete and contestable in both its characteristics and effects than is usually acknowledged in the existing literature.

In resilience practice, as a consequence of anthropocentric uncertainty and the associated need to protect lifeline systems and infrastructures, there has been a growing interest in utilising the concept of resilience for critical infrastructure assurance. As Evans and Reid (2014, p. 18) note, 'critical infrastructure is now central to understanding living systems' and politically, the combined lifelines deemed necessary for security, survival and growth. But as Dalby (2013a) further argues, conventional approaches to designing critical infrastructure that leave too many key decisions to the market to decide are fundamentally awed, and policy-makers need to make large, far-reaching decisions if they are to avoid major disasters in the future. Moreover, the changing material politics, geographies and governance arrangements associated with critical infrastructure – the 'collective equipment' of state power (Foucault, Guattari, Deleuze, & Fourquet, 1996) by which control might be exerted, socio-economic restructuring advanced and inequity concretised – is also of critical concern. It is to such recent attempts to enhance the resilience of critical infrastructures that this paper now turns in order to articulate recent attempts to refocus the need to secure infrastructure through the lens of resilience rather than probabilistic risk management.

Enhancing critical infrastructure resilience

The last 20 years have been remarkable for the volume of high-impact crises, disasters and global incidents with the ability of providers to assure the security and continuity of infra-structure becoming of high importance. Critical infrastructure assurance is therefore progressively moving away from a focus upon protection towards emphasising resilience.[5] It is perhaps the cascading effects of a breakdown in one system on other interconnected systems, which have provoked most significant concern – often articulated through the spectre of low probability–high consequence 'Black Swan' events. The failures of infrastructure illustrated during 9/11, the 2011 Tohuku earthquake in Japan or Hurricane Sandy in2012 upon new York, highlight the vulnerability and potential weaknesses of our critical systems and man-made infrastructure and how such failures often have common roots, particularly around path dependencies and institutional failings (Dueñas-osorio & Vemuru, 2009). Increasingly, infrastructural assemblages are being viewed as 'complex adaptive systems' with an emphasis on the ability to adapt to such conditions of uncertainty and volatility (Comfort, 1994; Longstaff, 2005). In turn, this has catalysed the emergence of *resilience* as a way to assess the complex challenges that critical infrastructure faces as well as providing a potential framework by which to respond.

As the critical infrastructure sector has become a larger, more complex and an increasingly interconnected amalgamation of social, technical and economic networks, so, the risk of breakdown has risen. The growing interest in applying resilience methods in securing critical infrastructure has grown as traditional risk management methodologies have proved ineffective in the face of growing complexity and the unpredictability of threats, and growing knowledge about interdependency and cascade effects amongst critical infrastructure sectors. In the Anthropocene, where such volatility is a *leitmotiv* and where security is being constantly recast as resilience, assuring the functioning of critical infrastructure against a range of known and unknown unknowns (notably the impacts of climate change being seen as an imminent security threat or threat multiplier) has become a core challenge of government. As Perelman (2007, p. 23) highlighted, in the post-9/11 age 'the allure of resilience is stoked by the contradictions and thorny trade-o s inherent in traditional concepts of 'national security' in an age of increasing social-technical complexity, transnational 'globalization,' and 'asymmetric' conflict'. Moreover, as national/homeland security has been reconfigured, so previously irreconcilable socio-political objectives (e.g. security against attacks vs. security against natural disasters, disease, accidents, etc., and centralised command and control versus communal collaboration) increasingly come into focus (*ibid*.). As security 'comes home' and becomes more localised (Coaffee & Wood, 2006) so the impulse to completely eliminate risk and uncertainty and prevent harm is destabilised and security is recast. In many cases, the assumptions of positivist and instrumentally rational risk management have been turned on their head forcing the abandonment of the Modernist dream of total control, alongside a shift from traditional Euclidian, Cartesian and Westphalian notions of scale and territory.

By contrast, the current push for resilience increasingly highlights the importance of sub-national responses to new security challenges, 'placing the needs of the individual, not states, at the centre of security discourses' (Chandler, 2012, p. 214). Resilience-thinking is thus increasingly forcing operators of infrastructure to work with the irreducibility of risk and uncertainty, to devise a range of alternative visions of the future, and to advance more deliberative and scalable methods that seek *adaptation* through flexibility and agility.

At the crux of the move *from* critical infrastructure protection *to* critical infrastructure resilience has been a struggle between what Perelman (2007, p. 24) referred to as *hard* and *soft* paradigms of security. Here, the hard paradigm represents the path of conventional security policies and practices associated with prevention and resistance, whilst by contrast, the soft paradigm is associated with adaptation and resilience – a move away from technocratic and techno-rational approaches and towards more socially grounded transformative approaches (Coaffee & lee, 2016). Perelman (2007) further cites the work of influential American physicist Amory Lovins on future energy demand (Lovins, 1976) who highlighted the advantages of the soft resilient path over the hard brittle path:

> *[T]he soft path appears generally more flexible – and thus robust. Its technical diversity, adapt- ability, and geographic dispersion make it resilient and offer a good prospect of stability under a wide range of conditions, foreseen or not. The hard path, however is brittle; it must fail, with widespread and serious disruption, if any of its exacting technical and social conditions is not satisfied continuously and indefinitely. (ibid, p. 88, emphasis added)*

Redefining the protectionist reflex through resilience

In times of vulnerability there is a natural impulse to evoke a 'protectionist re ex' in order to ensure safety (Beck, 1999, p. 153). Such a reflex has been very evident in critical infrastructure protection programmes that have adopted approaches involving the 'hardening' of critical assets to increase 'resistance' and 'robustness'. Ironically, the net effect of such actions often leads to what are known as 'robust-yet-fragile' systems that are increasingly susceptible to unexpected threats and cascade failures (Carlson & Doyle, 2000). An opposing approach is taken by those emphasising the 'soft' – more resilient – path: 'first, it takes a holistic view of 'infrastructure' as complex, dynamic, adaptive, even living *systems*, rather than discrete, concrete, fixed *assets*. And second, it aims at *softening* the brittleness of systems ...' (Perelman, 2007, p. 28).

A protection-based approach to critical infrastructure is, in large part, a legacy of ingrained engineering-focused approaches to *risk management*, where an epistemic focus upon ordering and probability, a requirement for optimisation and control, and a near exclusion of social and human factors has created a very different reality from what is increasingly becoming known as *resilience management*. This emerging approach goes beyond risk management to address the complexities of large integrated systems and the uncertainty of future threats. As Linkov et al. (2014, p. 407) note, '... risk management helps the system prepare and plan for adverse events, whereas resilience management goes further by integrating the temporal capacity of a system to absorb and recover from adverse events, and then adapt'.

In terms of governance, the application of risk management for critical infrastructure is traditionally premised on a command and control approach from central government, and actualised through meta-strategies linked to national security or emergency management.[6] Such a static and often short-term approach to complex governance is what classic ecological resilience theory identifies as a 'rigidity trap' where such management can lead to institutions lacking diversity and becoming highly connected, self-reinforcing and in flexible to change (Gunderson & Holling, 2002). In counter-response, and again drawing on established resilience ideas of Panarchy, 'adaptive management' is seen as necessary to enhance responsiveness, agility and resilience in interconnected systems. As such, we increasingly see critical infrastructure providers moving towards advancing horizontally integrated approaches where adaptability – 'the dynamic capacity to effect and unfold multiple evolutionary trajectories ... which enhance the overall responsiveness of the system to unforeseen changes' (Pike, Dawley, & Tomaney, 2010, p. 4) – is central to effective future action.

Concomitant to the shifting nature of governmental control is the central nature of technology in decision-making and the continual quest for technological 'silver bullets' to help cope with new security challenges. Here, Perelman (2007, p. 39) argues that a more process-based viewpoint should dominate and that 'in place of the hard path's technocratic tunnel vision, the soft paradigm aims at investing in *social*-technical innovation processes ... [that] points toward managing technology and tangible infrastructure not as autonomous ‘assets’ but as dependent elements of complex, socioeconomic systems’.

The resilience turn

The so-called ‘resilience turn’ (Coaffee, 2013) in the early 2000s saw resilience approaches and initiatives embedded within an array of global initiatives, national policies and more local practices, notably critical infrastructure. In critical infrastructure, early attempts to mitigate vulnerabilities tended to utilise conventional risk management approaches that struggled with accounting for complexity and interdependencies, and socio-economic and organisational issues. The US was amongst the first nations to develop a national strategy for the identification, management and protection of critical infrastructure through the 1997 President’s Commission on Critical Infrastructure Protection (CCIP) and has been at the fore-front of the shift from protection to resilience. The failures that followed the 9/11 attacks prompted a further addressing of vulnerabilities in the nation’s critical infrastructure preparedness. In 2002, the US Congress funded the creation of the Critical Infrastructure Protection (CIP) Project to undertake applied research on critical infrastructure and to anticipate and reflect changes in the national risk environment (Mayberry, 2013). Subsequently, a new way of perceiving and prioritising threats, vulnerabilities and consequences to critical infrastructures – based on ideas of resilience – was put in train in early 2006 when, in a presentation to the Homeland Security Advisory Committee (HSAC), the Critical Infrastructure Task Force (CITF) recommended ‘Critical Infrastructure Resilience’ as the top-level strategic objective – the desired outcome – to drive national policy and planning (Pommerening, 2007, p. 10). Most recently in the 2013 Presidential directives on ‘national Preparedness’ (PPd-8) and on ‘Critical Infrastructure Security and Resilience’ (PPd-21) promote an all-hazards approach which stresses the importance of anticipating cascading impacts and high- lights the shared responsibility of critical infrastructure protection and resilience to all levels of government, the private sector and individual citizens (Obama, 2013).

The US policy chronology noted above is by no means unique amongst advanced nations illuminating how critical infrastructure policy in many countries is incrementally shifting from being protection-focused towards the more integrated resilience paradigm. However, in spite of this expanding interest in the vulnerability of critical infrastructure, there are only a very small number of formal definitions for critical infrastructure resilience, currently in use. In the US, critical infrastructure resilience is now framed by the resilience cycle and defined as the 'ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event' (DHS, 2009). By contrast, Australia has an 'all hazards strategy' that provides a foundation for collaboration and organisational resilience building rather than a probabilistic risk management framework. It is contended that this better enables owners and operators to prepare for and respond to a range of unpredictable or unforeseen disruptive events. This is underpinned by two core objectives that treat foreseeable and unforeseen risks differently: adopting either a mature risk assessment approach to foreseeable risks to the continuity of their operations that underpinned prior critical infrastructure *protection* programmes, or extending this into an approach focused upon *resilience* so that 'critical infrastructure owners and operators are effective in managing unforeseen risks to the continuity of their operations through an organisational resilience approach' (Australian Government, 2010, ibid, p. 14). This latter approach places an emphasis upon dealing with complexity and advancing adaptive capacities within organisations to respond to, recover from and prepare for a range of disruptive challenges.

The transition in critical infrastructure resilience assessment

Whilst there is no agreed international measurement approach for critical infrastructure resilience, there is broad agreement on why we need to measure it. Such agreement focuses upon being better able to characterise resilience in context and to articulate its key constituents so as to be better able to raise awareness of where interventions might be placed in order to build resilience within organisations and networks. This allows additional focus upon allocating resources for resilience in a transparent manner and more broadly to monitor policy performance, as well as to assess the effectiveness of resilience-building policy through comparison of policy goals and targets against outcomes (Prior & Hagmann, 2013, pp. 4–5).

This transition in critical infrastructure assurance from protection towards resilience can be represented as a continuous process of change, exemplified by the models of assessment adopted by critical infrastructure providers that are progressively shifting from a highly quantified metrics approaches towards emphasis on a cyclical and adaptive learning process.

Schematically, we can conceptualised this transition as a series of overlapping phases that seek to assure the continuation of critical infrastructure lifelines (Figure 1).

Within this conceptualisation, phase 1 is characterised by approaches that focus upon highly technical considerations (e.g. physical or informational) within a single critical infra- structure sector (e.g. energy, water or transport), at limited spatial scales (e.g. solely critical infrastructure facilities) and has typically led to enhanced physical characteristics notably:

- *Robustness*: the inherent strength or resistance in a system to withstand external demands without degradation or loss of functionality;
- *Redundancy*: system properties that allow for alternate options, choices and substitutions under stress;
- *Resourcefulness*: the capacity to mobilise needed resources and services in emergencies;
- *Rapidity*: the speed with which disruption can be overcome and safety, services and financial stability restored (Bruneau et al., 2003).

The technical emphasis of these critical infrastructure qualities understands resilience primarily as resisting and recovering from 'known threats'. By focusing upon the protection, preservation and recovery of single assets, these efforts to achieve resilience have, all too often, failed to account for cascading effects, unexpected events or the more integrated underpinnings necessary for critical infrastructure resilience.

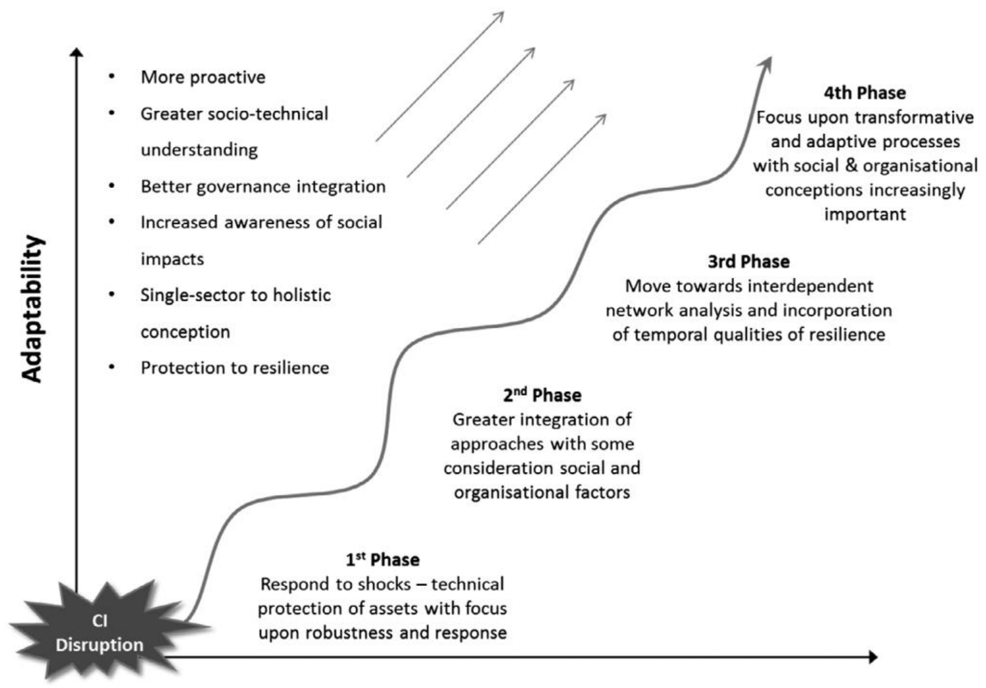

Figure 1. Transitions in critical infrastructure assurance.

In an attempt to evolve these characteristics into a more integrated understanding, sub-sequent approaches (phase 2) have sought to consider a range of social, economic and organisational factors alongside easily quantified protective criteria. For example, O'Rourke (2007, p. 27) proposed a 4 × 4 matrix that maps the four 'qualities' of robustness, redundancy, resourcefulness and rapidity, against technical, organisational, social and economic factors (Figure 2).

In a practical example, the US national Infrastructure Advisory Council (NIAC) report that outlines resilience practices for the electricity sector utilised a similar approach around the headings of robustness, resourcefulness, rapid recovery and adaptability, subdivided into people and processes, infrastructure and assets and whether unintentional, intentional or cyber acts (NIAC, 2010). despite this advancement, there has been widespread comment about the limitations of such approaches, including the lack of meaningful social and organisational considerations, that these technical-focused initiatives discourage necessary adaption (Fisher & Norman, 2010) and that they are based upon a false idea of equilibrium and stability (Sikula, Mancillas, Linkov, & McDonagh, 2015). Notably, the measures utilised within typical phase 2 approaches are only measurable *after* an event has occurred.

In response, a third phase of critical infrastructure assurance has evolved around the idea of interdependent, network systems study; in effect adding an 'anticipatory' temporal dimension, including qualities that can be measured before an event or failure occurs (Linkov et al., 2014). For example, the US Army Corps of Engineers have produced a resilience measure (RM) consisting of a 4 × 4 matrix where one axis contains the major subcomponents of any system and the other axis lists the stages of a disruptive event (Figure 3).

Collectively, these 16 cells provide a general description of the functionality of the system through an adverse event and assess resilience by assigning a score to each cell that reports the capacity of the system to perform in that domain and over time (Linkov, Larkin, & Lambert, 2015).

Dimension/Quality	Technical	Organisational	Social	Economic
Robustness	Building codes and construction practices for new and retrofitted structures	Emergency operations planning	Social vulnerability and degree of community preparedness	Extent of regional economic diversification
Redundancy	Capacity for technical substitutions and "work-arounds"	Alternate sites for managing disaster operations	Availability of housing options for disaster victims	Ability to substitute and conserve needed inputs
Resourcefulness	Availability of equipment and materials for restoration and repair	Capacity to improvise, innovate, and expand operations	Capacity to address human needs	Business and industry capacity to improvise
Rapidity	System downtime, restoration time	Time between impact and early recovery	Time to restore lifeline services	Time to regain capacity, lost revenue

Figure 2. Matrix of critical infrastructure resilience qualities (adapted from O'Rourke, 2007).

	Prepare	Absorb	Recover	Adapt
Physical				
Informatio n				
Cognitive				
Social				

Figure 3. A resilience measure for critical infrastructure (adapted from Linkov et al., 2015)

Whilst phase 2 and 3 assessment methodologies have been advanced as workable mechanisms for resilience assessment and as a basis for making decisions about protective measures, they remain technologically orientated and facility-focused, with an assessment approach relying on workable yet cost and time intensive procedures performed via accompanying software. Despite this increasing sophistication of approaches to assessing critical infrastructure resilience, they have struggled to include 'organisational beliefs and rationalisations' (Boin & McConnell, 2007, p. 56) and the path dependencies that have been increasingly identified as key barriers to enhanced resilience. It is these facets that have become central to an emerging fourth phase transition where organisational resilience is a key consideration and is understood as a property of an organisation that allows it to adapt proactively, following appropriate risk and resilience assessments. In some contexts, critical infrastructure operators are beginning to future-proof their decision-making by advancing a range of dynamic adaptive policy pathways in response to deep uncertainties about the future that can no longer be predicted by using traditional foresight and risk assessment methods. As Haasnoot, Kwakke, Walker, and ter Maat (2013, p. 485) highlight:

They develop a static 'optimal' plan using a single 'most likely' future (often based on the extrapolation of trends) or a static 'robust' plan that will produce acceptable outcomes in most plausible future worlds ... However, if the future turns out to be different from the hypothesized future(s), the plan is likely to fail.

Organisations need more than a Plan A. By contrast, an adaptation pathways approach provides an analytical approach – a form of 'iterative risk management' – to explore a set of possible actions based on alternative developments over time. Such an approach highlights potential lock-ins, path dependencies and tipping points which specify the conditions under which a pre-specified action to change the plan is to be taken (Coaffee & lee, 2016; Haasnoot, Middelkoop, Offermans, van Beek, & van Deursen, 2012; Kwadijk et al., 2010). Whist such an approach is not novel in resilience studies with work focusing on experiential learning and adaptation central to ideas of adaptive management which formed the cornerstone of classic ecological resilience theory current adaptation pathway approaches take this one step further in grounding their work in the interdependencies and complexity of multiple interlocking infrastructures whilst presenting alternative ways of getting to a desired end point in the future. A focus upon such adaptation pathway processes essentially mainstreams resilience-thinking, adaptation and sometimes transformation into infrastructure planning rather than relying on short-term, incremental changes that will, in most cases, fail to shift organisation custom and practice from a protective risk-based mind-set.

Internationally, such an approach has been advanced predominantly in response to cli- mate change, notably by the IPCC, who in a 2014 report, advanced the idea of climate resilient pathways (Figure 4): 'sustainable-development trajectories that combine adaptation and mitigation to reduce climate change and its impacts ... [including] iterative processes to ensure that effective risk management can be implemented and sustained' (IPCC, 2014, p. 87). Such pathways can be either progressive or regressive; either leading to a more resilient world through adaptation and learning, or lower resilience as a result of insufficient mitigation and failure to learn; and which can be irreversible in terms of possible futures (ibid, p. 88).

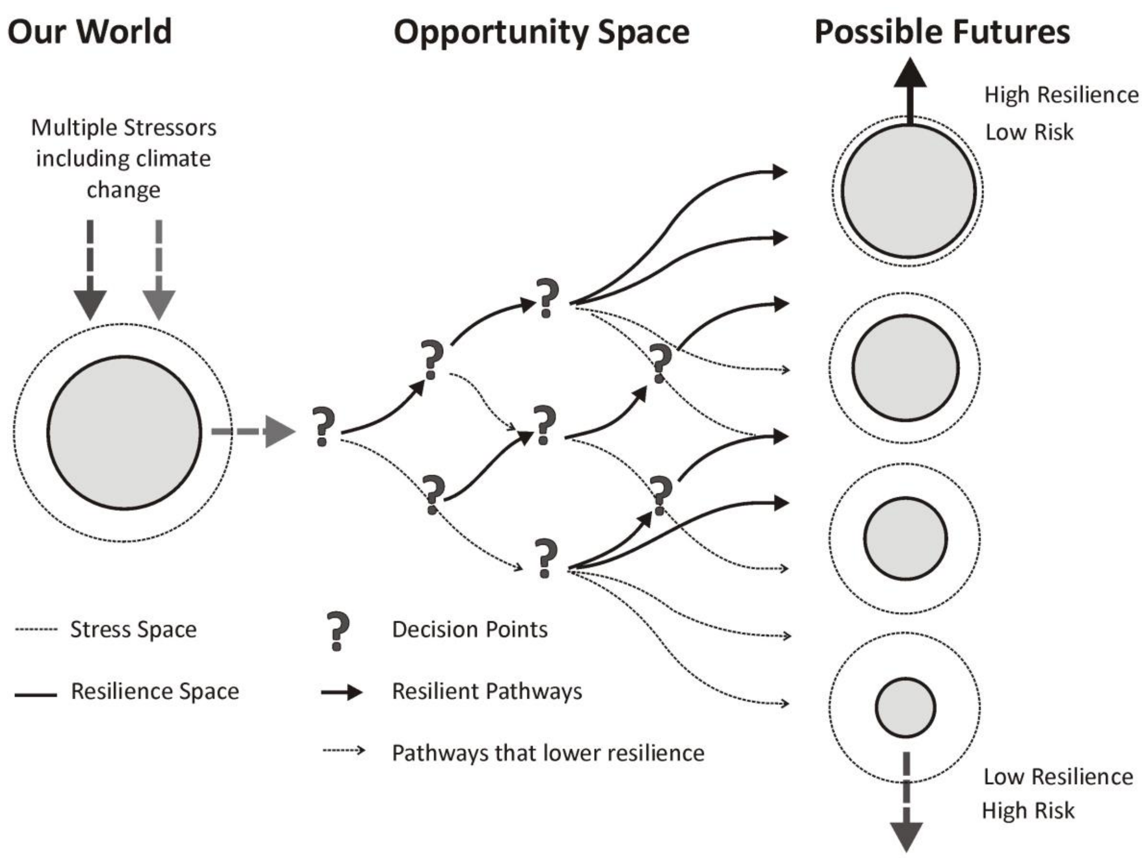

Figure 4: Opportunity spaces and climate resilient pathways (adapted from IPCC, 2014)

In another example, adaptation pathway ideas have been fully integrated into the Dutch Adaptive delta Management (ADM) approach to enhancing climate resilience which seeks to be 'anticipative' of future conditions and stop 'tipping points' being reached. In the ADM has sought to understand how resilience ideas are shaping the ways in which critical infra-structure providers deal with complex risk, and the tensions elicited in the transition from protective approaches towards approaches founded on the basis of greater resiliency and how such assessment can be both accurate and fit of purpose.[8] An analysis of the survey data illuminates a range of barriers to implementation that we can categorise as knowledge, assessment and/or operational barriers. First, knowledge barriers that were identified in our survey notably included the lack of a clear practical definition of resilience, difficulties of information sharing between providers that hindered joint-working, and the lack of integration of resilience-type ideas within established assessment tools and methods. Second, resilience assessment barriers included a perceived difficulty in evaluating the impact of resilience measures that might be introduced, particularly where the cost–benefit analysis was not clear, as well as concerns around sharing of sensitive information with other organisations (a key part of advancing a critical infrastructure resilience approach is to develop a way of governing where providers and operators of multiple infrastructures work together for mutual benefit).

Together, these knowledge and assessment barriers typically combined with shortcomings in institutional infrastructure and serve to create a range of organisational barriers to the operationalisation of resilience practice. Here, the focus of many critical infrastructure operators is on developing a 'culture of resilience', which normalises and mainstreams resilience practice, and enhances so-called organisational resilience – 'the ability of an organization to anticipate, prepare for, and respond and adapt to incremental change and sudden disruptions in order to survive and prosper'.[9] Here our research data illuminated strong resistance to changing organisational culture amongst many providers as a result of a paucity of guidance and corresponding technical know-how, as well as the human resources to facilitate resilience, a disinterest of managers in perusing a 'resilience agenda' (with resilience often perceived as a passing buzzword), and the absence of any regularly framework that prescribed and could be used to enforce change. From a more operational focus, many providers also reported difficulty in making a (financial) case for enhancing system redundancy – a key component of enhancing system resilience – and perpetual problems of balancing the requirement for short term efficiency and optimisation with the need to pro- vide resilience through flexibility and adaptability to cope with unexpected disruption.

Towards an extended and equitable ecology of anthropocentric resilience

In her critique of how states respond to low probability–high consequence events – an increasingly common feature of the Anthropocene – Amoore (2013, p. 60) highlighted the ways in which new forms of risk calculus has extended traditional risk management approaches based on probabilities by advancing a 'politics of possibly'. As she noted,

> *the emerging security risk calculus is not a more advanced form of abstraction than one might find in statistical or prudential modes, but rather it is a specific form of*

abstraction that distinctively coalesces more conventional forms of probabilistic risk assessment with inferred and unfolding futures.

This does not infer a seismic break with tradition, but rather a transitionary process by which more intuitive and adaptively focused processes underpinning resilience are laminated over the calculative rationality of conventional risk management and assessment methodologies. In this paper, we have outlined such an ongoing transition towards resilience in critical infrastructure operations, highlighting the difficulties inherent in this process and the dearth of agreed ways forward within the sector. As Suter (2011, p. 5) noted, 'it remains often unclear if and to what extent the introduction of resilience changes the existing practices of critical infrastructure protection'. Moving from rhetoric to implementation in critical infrastructure, resilience is therefore not without its challenges and thus acknowledging and actualising how the role of resilience could drastically improve the security landscape for many critical infrastructure owners and operators, within their own context, is therefore crucial. Current practice in resilience assessment and promotion for critical infrastructure is too often limited to specific, endogenous technical factors. Unlike protection, resilience is not easily definable across all infrastructures, nor is it accurately measurable. As Pommerening (2007, p. 18) highlighted, 'there is a curious disconnect between recommending coping and adaptation strategies for new stages of stability, and the fact that we have just as little knowledge about how those stages will look'.

It can be seen from the foregoing discussion and emerging findings presented in this paper that there is a pressing need to address the shortcomings of traditional 'siloed' thinking and more 'traditional' views of 'hard' critical infrastructure protection that seeks bounce back to a pre-shock state rather than advancing more evolutionary 'bounce forward' pathways that seek to construct an approach more applicable to coping with increasingly complex and non-linear systems. This reflects a wider journey from the traditional, techno-rational approach with prescriptive, rigid methodologies, to a wider socially and organisationally informed extension of risk management that seeks a more transformative understanding of critical infrastructure resilience. Figure 5, provides a summary of this transition through number of criteria by which the appropriateness of protection measures versus resilience measures could be assessed.

Whilst enhancing critical infrastructure resilience is of vital concern given the nature of anthropocentric risk, we need to remain cognisant of its potentially inequities. Critical infra-structure resilience is not purely technocratic or value neutral and can have significant impacts upon social and spatial justice across a range of interlocking scales as new approaches, processes, actors and technologies are pulled together and deployed in the name of resilience. As Fainstein (2015, p. 157) notes, resilience in certain situations 'obfuscates underlying conflict and the distribution of benefits resulting from policy choices'. Critical infrastructure is far from inanimate and is increasingly imbued with agency (Evans & Reid, 2014, p. 19). While often critical infrastructure resilience is masked in highly technical models showing complexity and indeterminacy there is a need to more fully engage with 'softer' approaches emphasising such agency, that, to date have been missing from critical infra- structure assessment and future planning. As such we should seek 'greater resilience *of the whole*, not just of what may be bureaucratically or politically deemed 'critical' to certain limited interests' (Perelman, 2007, p. 40). Moreover, the advance of softer approaches, more grounded in social science methodologies, can assist critical infrastructure providers under-stand the complex multi-scalar and multi-institutional context in which they operate. As recent work on what has been termed 'resilience multiple' reminds us, context is vital and understanding how different perspectives and expertise in relation to resilience can be hybridised, and can help reconcile 'the tension between a desire for open, non-linearity on the one hand and a mission to control and manage on the other' as well as how different adoptions of resilience invoke 'differing spatialities, temporalities and political implications' is vital (Simon & Randalls, 2016, p. 3). Such a combinational approach also talks to ongoing discussions about the changing nature of expertise linked the new *zeitgeist* of resilience. In current mobilisations within the critical infrastructures sector providers are confronting complex risk, necessitating that required expertise has to become more di use, pluralistic and integrative. This is leading to many viewpoints, methodologies and 'ways of doing' resilience being combined in operationalising it in practice. Given the slow nature of organisational change, this will however take time, patience and a willingness to embrace change and difference across the critical infrastructure sector. In particular it will require an inculcation and adoption of certain values, practices and research methodologies that focus upon more than the instrumentally rational and embraces adaptation, flexibility and grounded approaches that are more sociologically and politically informed.

	Critical Infrastructure Protection	Critical Infrastructure 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

Figure 5. Differences between critical infrastructure protection and critical infrastructure resilience.

Orchestrating such a coherent, sociotechnical and integrated approach to meeting the generational challenge of building resilient infrastructure is a significant challenge confronting the Anthropocene – and its academic theoreticians – over the coming decades. This is starkly represented in the Un Sustainable development Goals (SDGs) released in September 2015 where the discourse of resilience is utilised to highlight how global society should respond proactively to a range of shocks and stress and how we might collectively operationalise a joined-up response through developing 'quality, reliable, sustainable and resilient infrastructure' (Target 9.1) in order to advance global sustainable development.

Notes

1. A further result of this trend has been the expansion of infrastructures considered to be critical and which has seen a shift from the line-based systems of public utilities, to more complex social infrastructures which safeguard the wellbeing of citizens and private enterprises performing societally significant roles.

2. See acknowledgements for details.

3. *Risk Society* was first published in German as *Risikogesellschaft* in 1986.

4. Such a Foucauldian-inspired interpretation argues that resilience encourages individuals to autonomously act in the face of a crisis and which precipitates citizens behaving and adapting according to prescribed moral standards (Joseph, 2013). As Welsh (2014, p. 16) highlighted, resilience policy is 'a post-political ideology of constant adaptation attuned to the uncertainties of neoliberal economy where the resilient subject is conceived as resilient to the extent it adapts to, rather than resists, the conditions of its suffering'.

5. Not all infrastructure is deemed to be 'critical', and thus infrastructure can be categorised using some form of 'criticality' scale to assess its value and the impact of its loss/disruption.

6. Many commentators argued that after 9/11 many states responded by returning to or reinforcing authoritarian command and control types approaches to managing aspects of emergency management or what was increasingly termed resilience (see for example, Alexander, 2002).

7. The formation of adaptation pathways are linked to the acknowledgement of uncertainty in climate change and thus bases much of its thinking on a scenario matrix which looks at the linkages between climate change and socio-economic development.

8. This research was carried out by way of two large-scale surveys of 40 + critical infrastructure operator's across Europe in 2015 and 2016. These surveys were conducted as part of the work underpinning the EU funded RESIlEnS project in which the authors were seeking to undertake a gap analysis of the current approaches to risk and resilience management within the infrastructure sector.

9. This definition comes from the recently published British Standard on organisational Resilience (2014).

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