

NATIONAL
INFRASTRUCTURE
COMMISSION



RESILIENCE STUDY

Scoping report



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Foreword

Events this summer have provided a clear reminder of why the resilience of the UK's economic infrastructure really matters. We have seen the damage that particular hazards can cause, but also how disruption in one infrastructure sector can cascade into others.

As ever, there are things we can learn from these disruptions. Infrastructure tends to be invisible until things go wrong, but we need to plan ahead to make sure things run smoothly. And we also need to pay attention to and, more importantly, act on warning signs. We know that there are vulnerabilities across our infrastructure systems and, while we cannot prevent them all, addressing potential problems in advance is usually preferable to dealing with them after they arise.

Finally, we need to focus on the services that infrastructure delivers. To be resilient, we need to move beyond managing individual risks or assets, to thinking about the system as a whole and how the services we all rely on can be sustained and disruptions minimised. It is this type of holistic approach that the Commission is trying to develop through its resilience study.

To achieve this, however, we need to think more about the interdependencies between different sectors and do more to manage cross cutting challenges. We should also consider how to better take into account public expectations of infrastructure services – we are all infrastructure users, after all.

This report sets out how the Commission will approach the next phase of the study. Tools, data and knowledge are continuing to improve and our approach to resilience will need to evolve over time. In our final report next spring, the Commission will set out a framework for how we can best assess and improve resilience, as well as making nearer term policy recommendations.

To support this work, we are also launching a call for evidence, as meeting the challenge of systemic resilience will require consideration of a wide range of data and perspectives. We are grateful to the many organisations and individuals who have already contributed to the Commission's work on resilience and look forward to continuing this engagement over the coming months.



Sir John Armitt
Chair, National Infrastructure Commission

In brief

The UK's current and future economic infrastructure must be resilient to the growing challenges of climate change, population growth and an increasing reliance on, and integration of, digital technologies. This is on top of day-to-day challenges around changes in the economy, from natural hazards and from security threats. The Commission's initial work suggests that more could be done to ensure the UK's economic infrastructure is resilient, both now and in future.

It is difficult to find examples of holistic and cross sector approaches to resilience, and there is not yet an overall understanding of the resilience and vulnerabilities of the UK's economic infrastructure. As well as the absence of a holistic view, there are also a number of cross cutting resilience challenges which require significant changes to the current approach to address them. These gaps will be the Commission's focus in the next phase of the study.

In support of this, the three key questions that will frame the next phase of the Commission's work are:

1. **What are the systemic issues that make infrastructure vulnerable to current shocks and future changes and how could they be addressed?**
2. **What does the public expect of infrastructure services and how should their views be considered in decisions about resilience?**
3. **What changes to governance and decision making could improve current levels of resilience and ensure future challenges are addressed?**

Analysis of these questions will enable the Commission to make both policy recommendations on resilience, where near term changes are needed, and to develop a framework for identifying and addressing resilience issues now and in the future. This framework will primarily be for application in future National Infrastructure Assessments (the next is expected in 2023), but will also be sufficiently flexible to be used more broadly and to reflect improvements in knowledge and data over time.

To support this work in the main phase of the study, the Commission is launching a call for evidence. The questions for this are set out in Chapter 5.

1. Background

By 2050, the UK's population and economy will have grown significantly.¹ Climate change is increasing the incidence of extreme weather events – such as drought and flooding – and will require a transformation in energy, waste and transport.² Other infrastructure sectors, in line with society and the global economy more broadly, are becoming increasingly reliant on digital technologies, which can introduce new vulnerabilities to established systems.³

The UK's current and future economic infrastructure systems must be resilient to these and other future changes. Society and the economy depend on infrastructure services, and they are particularly susceptible to many of these emerging threats. For example, as more of the UK's energy comes from renewables, the energy sector must adapt to a less consistent energy supply, including through increased use of energy storage and flexible demand.⁴ Infrastructure must also be prepared for an increased chance of drought and flooding and the UK's digital and transport infrastructure must adapt to society's increasing reliance on connectivity.

The need for resilience is not new and it is not difficult to find historical examples of where infrastructure has been insufficiently resilient. But given that economic infrastructure systems are becoming increasingly interdependent, the potential for well intentioned decisions in one sector to have adverse impacts and cascade effects in others, is likely to increase in future.

Baltimore Tunnel Fire, 2001

On 19 July 2001, a 62-car freight train carrying hazardous chemicals came off the tracks in Baltimore's Howard Street Tunnel, starting a large fire. There were impacts on rail network traffic, road traffic, and emergency services, as might be expected. The disruption to rail services spread to the other states, disrupting steel production by delaying coal and limestone deliveries.

But the impacts did not stop there. The tunnel fire caused damage to an overlying water main, which caused 20-foot geysers to erupt at street level and, in turn, led to localised flooding of up to three feet. This flooding went on to disrupt electricity supplies to 1,200 residences.

The derailment also damaged fibre optic cables, which caused disruption to telephone lines, mobile signal, and internet. This caused significant disruption to several businesses.⁵

Flooding in Lancaster, 2015

In December 2015, storm Desmond brought record rainfall to the UK, which was followed by severe floods in Cumbria. Despite recent investment in improved flood defences at the Lancaster substation, the defences were breached. The electricity supply to over 55,000 properties in the surrounding area was lost. The economic damage was estimated to be approximately £1.6 billion.⁶

Investment in the substation in 2010 had upgraded the site to provide defence against a 1 in 100 year flood, but the volume of rainfall exceeded the existing forecast models.⁷

Ofgem has said that this event demonstrated “the need for the regular review of network resilience by the network companies, underpinned by monitoring of impacts, and use of the latest science and information available on potential climate impacts at a national and local level.”⁸

The Commission

The National Infrastructure Commission was established in 2015 to provide impartial, expert advice on the UK’s long term infrastructure needs. This includes the publication of a five-yearly National Infrastructure Assessment, the first of which was published in July 2018. Alongside this, the Commission carries out specific in-depth studies into the UK’s most pressing infrastructure issues, as requested by the government, and publishes an annual monitoring report taking stock of the government’s progress in taking forward recommendations made by the Commission.

The Commission’s remit covers the UK’s economic infrastructure: transport, energy, water and wastewater, flood resilience, digital connectivity, and solid waste. The Commission’s work is guided by its objectives to support sustainable economic growth across all regions of the UK, to improve competitiveness and to improve quality of life.

Resilience in the Commission’s previous work

Since the Commission was established in 2015, it has reviewed evidence on economic infrastructure challenges, and produced reports for government on a range of infrastructure related areas. Some of these have covered resilience and this study will aim to build on these previous findings and recommendations.

In 2016, the Commission published four papers on the drivers of future infrastructure supply and demand. The papers covered the environment and climate change, economic growth, population change and demography, and technological change.

In 2017, the Commission published a paper on the resilience of digitally connected infrastructure systems with UCL and Arup. The key finding was that a methodology for better addressing resilience, capturing cross-sector issues, digital and physical infrastructure as well as the human elements of the system is required.⁹

The Commission also published a report on technology in 2017, Data for the Public Good, which considered the benefits of enabling new technologies through better infrastructure data. This included cutting disruptions to train journeys, reducing traffic jams and enabling a more

coordinated approach to extreme weather events.

The National Infrastructure Assessment, published in July 2018, provided a long-term strategy for how to deal with a range of resilience relevant issues, particularly flooding and drought and changes affecting supply and demand for infrastructure services over the long term. The Assessment's recommendations relating to resilience include:

- delivering nationwide full fibre broadband, to prepare for increasing demand for data
- enabling the increasing deployment of renewables, as well as the delivery of the charging infrastructure needed for a rapid update of electric vehicles
- increased funding and new powers for cities to develop integrated strategies for transport, employment and housing
- delivering a national standard of flood resilience for all communities by 2050
- building resilience to extreme drought through additional water supply and demand reduction.

In December 2018, the Commission published its Performance Measures Data, summarising the current quality of UK's economic infrastructure. This included a number of metrics to assess resilience, including the number of homes at risk of flooding and travel time reliability.

Terms of reference for the study

On 29 October 2018, the Chancellor asked the Commission to undertake a study on the resilience of the UK's economic infrastructure. The terms of reference for the study requested that the Commission:

1. Review UK and international knowledge and approaches relating to the resilience of current and future economic infrastructure systems, including how this can be best understood, definitions, ways of assessing resilience, treatment of interdependencies and the management of the risk from different threats and hazards.
2. Develop an understanding of public expectations and response to the potential loss of infrastructure services and review alternative options and contingency planning, for example, in the light of technological advances such as cyber threats, and behavioural changes.
3. Develop an analytical approach that can be used to better understand the resilience of economic infrastructure systems, and the costs and benefits of measures to improve this.
4. Undertake pilot analysis of infrastructure systems (for example through 'stress tests' of sectors, geographical areas or companies) to identify actions to improve the resilience of national infrastructure systems and inform investment decisions.
5. Make recommendations to government on the resilience of economic infrastructure, how best to assess resilience, sharing of good practice, actions needed and data collection or analysis to inform the next National Infrastructure Assessment.

The full terms of reference for the study can be found at www.nic.org.uk/resilience/.

As well as making specific recommendations to improve infrastructure resilience, the study will also help to build the data and tools needed for the Commission to incorporate resilience into its future work, particularly in future National Infrastructure Assessments.

Scope

The terms of reference for the study exclude issues relating to foreign ownership, specific critical national infrastructure assets, industrial relations, national security concerns, the security of supply chains, and issues relating to the UK's withdrawal from the European Union. Analysis of malicious threats, skills and the financial stability of infrastructure operators were limited to the scoping stages of the study, which this report completes, and so will not be considered in future work.

These wider issues are all important for delivering resilience overall. However, they will not be a focus for the main phase of the study as, where action is necessary, it will need to be taken forward in the short term by government. Skills and malicious threats will manifest very differently across the system and different sectors. The Commission's long term, cross cutting focus means it is better placed to develop a systemic approach to resilience.

While the Commission's remit also covers solid waste and flood management, the Commission has taken the decision to focus on the digital, power, transport and water sectors in this study. This reflects the interconnectedness between these networks. Work to date has identified that the solid waste sector generally has longer timescales between hazard emergence and service impact, and has less interdependency with other infrastructure sectors. The study will therefore only consider it where there are specific dependencies across sectors. The Commission has already made a number of recommendations to address flood risk in the National Infrastructure Assessment, the main one being that government should set out a strategy to deliver a nationwide standard of resilience to flooding with an annual likelihood of 0.5 per cent. Accordingly, flood risk will be considered within the study, but as a crosscutting hazard, rather than a separate infrastructure sector.

The Commission's approach to resilience

Definition

There are a wide range of definitions of resilience. Some of the terms most commonly used to define resilience in infrastructure systems are:

- resist – the ability to withstand possible hazards
- absorb – the capacity of the system to limit the damage incurred during an event
- recover – the ability for the system to return to its original state following an event
- adapt – the system's ability to change to maintain its function in a new environment.¹⁰

Several definitions of resilience extend it to include planning (anticipation or design) and dynamic improvement (transformation or growth). This suggests that resilience is not a fixed property; it changes over time in response to shifting challenges and objectives. A summary of existing definitions of resilience is included in Annex A.

Rather than limiting itself to a specific definition, the Commission will continue to apply a broad understanding of resilience for this study, in order to look holistically at the resilience of infrastructure systems to understand problems and potential solutions. This should best enable the Commission to address systemic and cross cutting challenges.

The difference between resilience and risk management

Resilience is about the ability to continue to function effectively in the face of future challenges. The requirements to achieve it change over time, as challenges alter. This means that thinking about resilience encourages a dynamic and holistic approach, one that looks at the system as a whole over time and the service that it delivers, rather than focussing on the risks to individual assets.

Achieving resilience is also about having the right processes in place. Effective risk management is essential, but a truly resilient system is also able to respond effectively to as yet unknown, or difficult to predict challenges. Resilience requires both an understanding of vulnerabilities, interconnections and interdependencies, and having the capability to adapt to the combination of pressures¹¹ and uncertainty that infrastructure systems face.

Analytical approaches

Similarly, there also exists a wide range of possible approaches to analysing resilience, with different methods using a variety of different types of data or models.¹² Some measure the system itself, whereas others measure the outcome, the outputs, or the post event outcomes of the system.

The Commission, working with UCL, has identified and explored a range of analytical approaches and tools that are used to measure and assess the resilience of economic infrastructure.¹³ This work has been complemented by the output of academic reviews.¹⁴

No single approach to analysing resilience will be perfect for every aspect of the UK's economic infrastructure system. This study will therefore use the most appropriate tools from a variety of approaches and disciplines. Further details of the analysis the Commission plans to undertake during the remainder of the study are set out in chapter 4.

Scoping Phase

The resilience study is being undertaken in two phases:

- a scoping phase – including a scoping consultation, which has looked at current evidence and approaches to resilience; and
- a main phase – concluding with a final report, with details of analysis undertaken, key findings, and recommendations to government, expected to be published in Spring 2020.

During the scoping phase, the study team have carried out a broad desk based study of existing knowledge across resilience and commissioned a social research project, which has begun to investigate public expectations related to infrastructure resilience.

The Commission also carried out a public consultation (in March to April 2019) which received feedback from a wide range of different organisations and individuals¹⁵ and bilateral discussions with practitioners from a range of sectors such as telecoms, regulators, consultants, banking and actuaries.

This report concludes the scoping phase of the study. It sets out the Commission's analysis so far, of both existing and developing evidence around the resilience of the UK's economic infrastructure and how this work will frame next phase of the study. As well as outlining the key workstreams that will be taken forward in the main phase of the study, it also launches a call for evidence, to gather further information to support this analysis.

2. Current resilience landscape

As set out in the Terms of Reference, the study team have carried out a review of UK and international knowledge and approaches to the resilience of economic infrastructure, which this chapter summarises. The Commission engaged with a wide range of stakeholders to inform this understanding, including carrying out an in house review of current approaches to resilience, and bilateral discussions with practitioners from a range of sectors such as telecoms, regulators, consultants, banking and actuaries. The public scoping consultation, which received feedback from 69 different respondents,¹⁶ has also informed this review, as well as guiding the approach to the main phase of the study.

The main finding of this review is that there is a significant focus on resilience issues in individual sectors, but there is currently limited understanding of the resilience and vulnerabilities of the UK's economic infrastructure. Some organisations have begun to look at cross cutting resilience challenges, but the current approach is insufficient to address them.

Roles and responsibilities

The Commission has mapped roles and responsibilities for the resilience of UK infrastructure. This is set out in detail over the rest of the chapter, however, a high level summary of the separation of roles is also set out below.

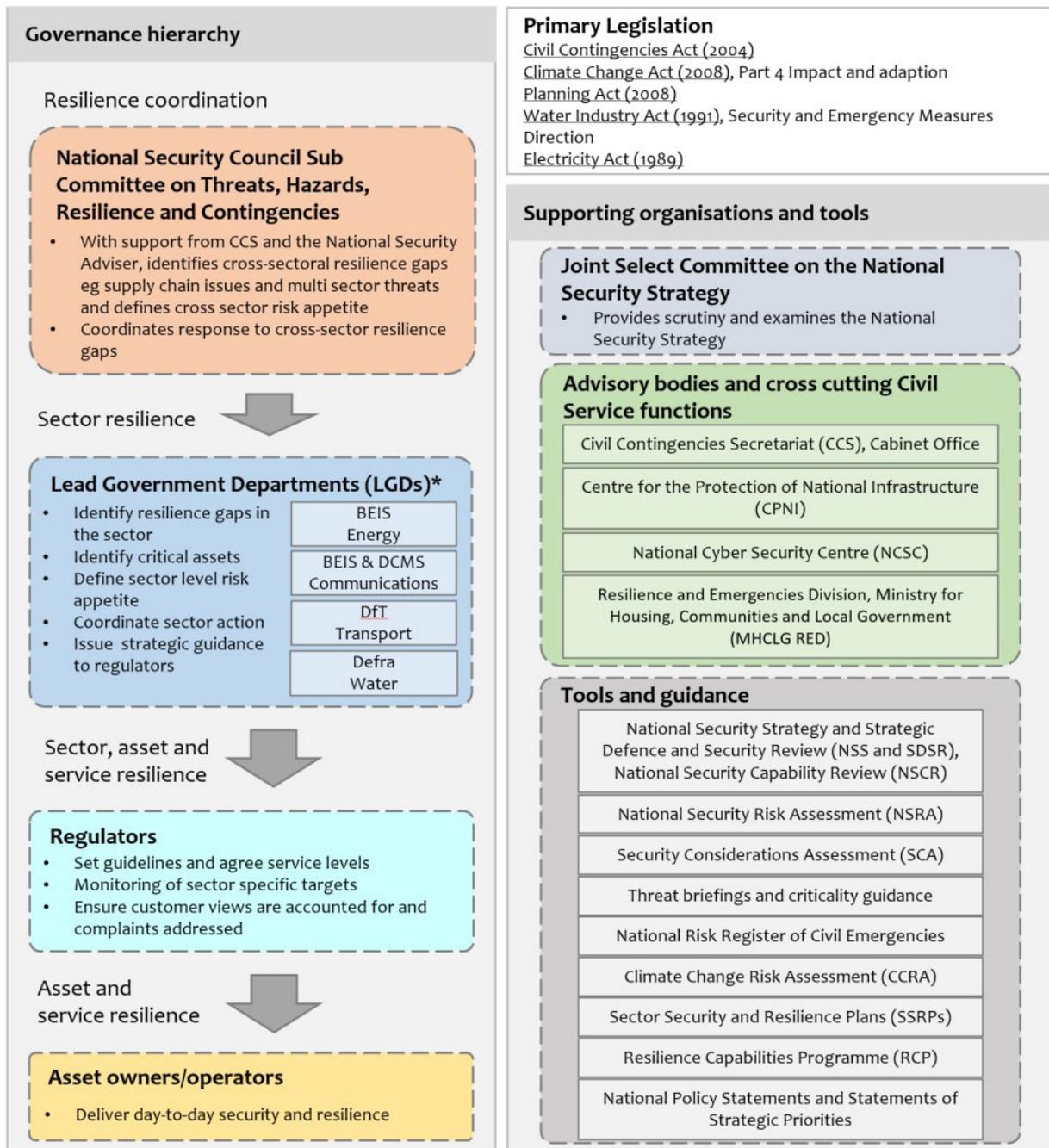
- Policy and strategy:
 - Cabinet Office has oversight of infrastructure resilience and provides coordination. They publish a summary of sectoral resilience plans,¹⁷ based on the work of lead departments.
 - Government agencies provide central government, regulators and infrastructure owners and operators with advice on infrastructure risks and mitigation. These include the Committee on Climate Change, the National Cyber Security Centre and the Centre for Protection of National Infrastructure.¹⁸
 - Lead Government Departments (and, where relevant, devolved administrations) are responsible for security and resilience policy development and planning in their sectors (e.g. Defra for water).

- Emergency response:
 - Cabinet Office has overall responsibility for planning emergency response and recovery related to the most serious events, assessing preparedness and ensuring that responders (including infrastructure operators) have satisfactory plans.¹⁹
 - Local authorities and emergency services are required to identify and assess the likelihood and impact of potential emergencies in their areas under the Civil Contingencies Act 2004. They are also required to develop plans to respond to those emergencies.²⁰

- Levels of service:
 - Lead Government Departments can set formal legislated and regulated targets for levels of infrastructure services, such as for power cuts and water supply interruptions longer than a specified duration.
 - Regulators facilitate the operators' role in delivering strategic government objectives and ensure that relevant legislation is observed, for example as part of sites' licence conditions.²¹ Some regulators can intervene and require organisations to meet security and resilience obligations or standards as conditions for their continued operation.²²
 - Infrastructure owners and operators are responsible for the day to day operation of infrastructure. They carry out risk assessments and make decisions on proportionate and cost effective mitigations.

Communities and members of the public also have a growing impact on system resilience. Preparation can allow them to cope with short interruptions, and they can also influence the resilience of the system. For example, the predicted move to electric vehicles means individuals could potentially play a role in providing additional flexibility for the energy system through smart charging, evening out daily supply and demand.²³

Figure 1 is a simplified representation of the key roles and responsibilities for resilience across sectors.



* Some responsibilities lie with the devolved administrations. This complexity is not represented.

Figure 1: Resilience roles and responsibility

Policy and strategy

A large part of the responsibility for resilience of critical infrastructure lies with the owners and operators. However, government departments, the devolved administrations, agencies and regulators play an important part in ensuring that policies are in place and complied with, and that investment in infrastructure considers the needs for security and resilience.²⁴

For example, the Home Office and the Centre for the Protection of National Infrastructure support lead government departments for each infrastructure sector on matters of security and security mindedness. Cabinet Office supports lead government departments on resilience and cyber security and Defra provides support on climate change adaptation.²⁵ HM Treasury supports departments on financing and investment in infrastructure.

Cabinet Office

The Cabinet Office has overall responsibility for planning the emergency response to the most catastrophic events. They assess preparedness and ensure that infrastructure operators and others (such as emergency services) have satisfactory plans to cope with a range of hazards and to recover from serious emergencies that could affect the provision of services.

As part of this role, Cabinet Office publishes summaries of the Sector Security and Resilience Plans (SSRPs) for each of the UK's 13 critical national infrastructure sectors – which include social infrastructure, as well as economic infrastructure systems and assets. The summary sets out sectors' resilience to the relevant risks identified in the National Risk Assessment and identifies future priorities for improving resilience. The annual public summaries are very high level, but the latest publication identifies some actions to improve the system, including the need: for proportionate actions to build 'black start' resilience for energy (the procedure to recover from a total or partial shutdown of the transmission system); to build resilience from cyber-attacks for energy, transport and communication systems; and to improve incident response within the transport and water sectors. The document also recognises the need to improve the understanding of risk across all sectors.²⁶

Lead government departments

In consultation with infrastructure owners and operators, regulators and government agencies, lead government departments produce the SSRPs mentioned above. The relevant Secretaries of State also have the power to set strategic directions and priorities for some of the regulators of infrastructure services. Strategic Policy Statements, or Statements of Strategic Priorities (depending on the sector) set out the government's steers to regulators, including specific resilience duties. These were set out for the digital sector in 2019 and the water sector in 2014.²⁷ Guidance and a draft statement were set out for the energy sector in 2013.²⁸

The devolved administrations also play a significant role in this process, carrying out analogous functions in areas of devolved responsibility.²⁹ They also provide input into sector specific plans for the UK as a whole, for example on transport.

The infrastructure sectors that this study is focussing on are privatised, except for road transport, and the permanent railway infrastructure. They are regulated by economic, environmental and consumer regulators, which are generally independent from government. However, the government has an important role in setting the legislation the operators must comply with, as well as providing directions to the regulators and remits (where required by legislation).

Transport is different though, as the Secretary of State is directly responsible for the strategic objectives and investments for the strategic road network. They set strategic direction for the rail industry in England and Wales, the overall strategy for ports and national aviation policy.³⁰

The Climate Change Act created a responsibility for government to assess climate risks and develop National Adaptation Plans to address these. The Act also states that government can ask operators to report on their plans to manage these risks (Adaptation Reporting Power Reports). The first round of reports was mandatory, whilst the subsequent two rounds have been voluntary.

Resilience and the planning system

In England and for reserved matters, National Policy Statements provide the basis for decisions around nationally significant infrastructure projects. They include criteria identifying ‘nationally significant’ projects and the framework within which Examining Authorities (Panels formed under the Planning Act 2008) make their recommendations to the Secretary of State on whether projects are needed or approved. These National Policy Statements include requirements for the infrastructure brought forward to have a resilient and adaptable design to cover current and future risks, such as coastal change and flood risk. Specifically, the Planning Act 2008 requires the Secretary of State to have regard to the “desirability of mitigating, and adapting to, climate change in designating an NPS (National Policy Statement)”.³¹

The entire lifespan of a facility is to be considered in its planning phase, which should ensure consideration of current and future hazards. Whilst the NPSs appear to consider flood risk, other climate related risks such as water scarcity, subsidence, windstorm, overheating are not as prominent.³² NPSs currently cover energy (including generation, gas and networks), water (and wastewater), and transport (ports, airports and national networks).

For other, non-nationally significant projects in England, the National Planning Policy Framework (NPPF) sets out the requirements around resilience that are relevant to local planning.³³

Government agencies

Several government agencies have major roles in providing advice and, in some instances, assurance on resilience. The Committee on Climate Change (CCC) is required to advise government on climate change risks and published the UK Climate Change Risk Assessment Evidence Report in 2017 to support the government’s production of the latest 5 yearly Climate Change Risk Assessment. The CCC also scrutinises the government’s work on managing climate risks.

The Centre for the Protection of National Infrastructure (CPNI) is the government authority responsible for providing protective security advice to the UK’s national infrastructure. CPNI provides advice and assistance to the lead government departments responsible for the protection of these sectors from national security threats.³⁴ It also provides advice relating to the implementation of a security minded approach, given the number of organisations needing to look at potential security issues, such as increasing levels of collaboration and sharing of data and information. Alongside this, the National Cyber Security Centre (NCSC) has responsibility for ensuring the protection of IT networks, data and systems of critical national infrastructure from cyber attacks.³⁵

The terms of reference for this study exclude issues relating to specific national infrastructure assets, national security concerns, and malicious threats for the main part of this study. However the Commission will continue a dialogue with the CPNI and NCSC on these issues, not least because some of the advice provided by CPNI and NCSC does not only apply to national security concerns, but also to responding to the vulnerabilities arising from the increased use of, and reliance on, information and communication technologies.

Other government agencies also have resilience responsibilities, mainly in relation to their roles as non economic regulators. For example, the Environment Agency is responsible for taking a strategic overview of the management of all sources of flooding and coastal erosion,³⁶ whilst the Drinking Water Inspectorate ensures that drinking water is safe.³⁷

International approaches to resilience

There is considerable international interest in infrastructure resilience. During the course of the scoping phase of the study there have been major reports published by:

OECD – Good Governance for Critical Infrastructure Resilience³⁸ - The OECD have proposed a Policy Toolkit on Governance of Critical Infrastructure Resilience, which suggests governments address seven interrelated governance challenges.

World Bank – Lifelines: The Resilient Infrastructure Opportunity³⁹ - For people in developing countries, infrastructure disruptions are an everyday concern affecting well-being, economic prospects, and quality of life. The report identifies significant economic benefits from investment in resilience, but suggests it is not just about spending more. Investing in regulations and planning, early stage project design, and maintenance can significantly outweigh the costs of repairs or reconstruction after a disaster strikes.

G20 - Principles for Promoting Quality Infrastructure Investment⁴⁰ (adopted by finance ministers 8-9 June 2019) - Recognises the importance of building resilience against natural disasters and other risks and emphasises the urgent need to ensure long term adaptability. It also suggests that disaster risk management planning should influence the design of infrastructure and ongoing maintenance.

There are a number of other international initiatives which are also relevant, many of which include UK researchers:

The Global Commission on Adaptation - Launched in October 2018 to encourage the development of measures to manage the effects of climate change through technology, planning and investment. Infrastructure is included in the six ‘Action Tracks’ and a flagship report was published in September 2019 with a Year of Action following the United Nations Climate Change Summit on 23rd September 2019.

Coalition for Disaster Resilient Infrastructure - The Government of India has proposed to establish a global Coalition for Disaster Resilient Infrastructure, building on international workshops held in New Delhi in 2018 and 2019. This highlights the contribution that resilient infrastructure can make to the reduction of disaster and climate risk including the Global Targets of the Sendai Framework for Disaster Risk Reduction, the Sustainable Development Goals and the Paris Climate Agreement. The coalition is intended to provide a framework for collaboration.

Modelling and analysis - The work in UK on the National Infrastructure Systems Model (NISMOD), Multi-Scale Infrastructure Systems Analytics (MISTRAL) and the Data and Analytics Facility for National Infrastructure (DAFNI) is complemented by similar efforts in the USA (e.g. the National Research Council report on Sustainable Critical Infrastructure Systems), the Netherlands (e.g. Knowledge for Climate) and Australia (e.g. the Critical Infrastructure Protection Modelling and Analysis programme).

Global resilience - There is also ambitious action taking place at other levels, both globally (e.g. the Global Risk Assessment Framework aims to improve the understanding and management of current and future risks, at all scales, to better manage uncertainties and mobilise people, innovation and finance) and at city level (e.g. through the 100 Resilient Cities network which has helped cities around the world).

Sector specific strategies and plans

As well as the national level policies outlined above, individual infrastructure operators implement strategies to deliver the resilience duties set by these policies, following the guidelines and obligations issued by the sector specific regulators. The approach to resilience and the resulting strategies vary significantly across sectors.

Some of these strategies, although sector specific, require significant local coordination. For example, the Civil Contingencies Act (2004) requires Category 2 responders, many of whom are private sector bodies (e.g. utilities and transport companies), to co-operate and share information with Category 1 responders (e.g. emergency services and local authorities) to inform multi agency planning frameworks.⁴¹

As noted in the policy and strategy section, the devolved administrations and devolved agencies (e.g. Transport Scotland) also play a significant role in this process in areas of devolved responsibility.

Digital

Ofcom sets out network functioning obligations under Section A of the General Conditions of Entitlement, including those related to access and interconnection, compliance with EU and international technical standards, service availability and emergency service access, and emergency planning.⁴²

Operators are accountable for decisions related to the implementation of network architecture, network resilience, capacity, and design choices that affect connectivity and performance.

The Electronic Communications Resilience and Response Group (EC-RRG) coordinates the telecoms sector emergency response capability through ownership and maintenance of a National Emergency Plan for Telecoms.⁴³ This includes the National Emergency Alert for Telecommunications protocol for response to critical events.

Energy

Ofgem, as the regulator, sets price controls for the transmission and distribution of electricity and gas and provides funding to maintain the health of the networks to ensure they are maintained in a safe and reliable condition.

National Grid, as Electricity Systems Operator, carries out its own assessment of present, emerging and future risks. It publishes an annual Future Energy Scenarios report,⁴⁴ which in turn informs broader recommendations on system requirements. National Grid is also the System Operator of the gas transmission system, providing an incentive framework to maintain and improve operational efficiency, and uses demand forecasting to help the industry to make efficient decisions in balancing supply and demand positions.

For both electricity and gas distribution systems, the Energy Networks Association generally takes a relatively short to medium term view of resilience, based on the emerging threats identified under the Energy Emergencies Executive framework.⁴⁵

There is a National Emergency Plan for downstream gas and electricity which describes arrangements between BEIS, industry, Ofgem and other parties for safe and effective management of emergencies.⁴⁶ The Energy Emergencies Executive, and Energy Emergencies Executive Committee develop and implement emergency arrangements, as well as providing ongoing assurance on energy resilience and preparedness. Specific Task Groups have been established on electricity, gas, communications, cyber security, and black start as well as a Pandemic Steering Group.⁴⁷ The Energy Emergencies Executive Committee has also recently been asked to establish what caused the power cuts on 9 August 2019 and assess whether the correct procedures were followed.⁴⁸

Transport

The Department for Transport sets the government's strategic goals for the road and rail networks and approves funding for Highways England and Network Rail's short term (five year) investment strategies. The need for major new roads, railways, airports and ports capacity is identified by the department through the NPS process.

Responsibility for emergency plans and responses in the transport sector is devolved to infrastructure owners and operators.⁴⁹ The Department for Transport works with industry stakeholders to develop a common assessment of risks and ensure that proportionate and cost-effective mitigations are in place. Alongside this, Highways England works with local highway authorities and emergency services to respond to incidents on the road network.⁵⁰

Water

Ofwat, the economic regulator of the water sector, has a specific resilience duty, which it is discharging by setting resilience specific incentives to water companies, such as drought resilience, water supply interruptions and sewer flooding.⁵¹ It has also provided guidance through its Resilience in the Round publication.⁵²

Water companies are required to prepare and update Water Resources Management Plans and Drainage and Wastewater Management Plans every 5 years. These assess the capacity needed for water and waste water looking 25 years ahead, considering climate change and population growth.⁵³

As in other sectors, individual companies are responsible for planning for and responding to emergencies⁵⁴ in the water sector, including through the statutory provision of a minimum amount of water per customer. Companies are also required to draw up specific plans to manage drought emergencies. Emergency measures include reducing demand, restricting water use and withdrawing more water from the environment.⁵⁵

Levels of service

Levels of service are a way of measuring the performance of infrastructure systems, based on an assessment of the outputs (i.e. the service) that they deliver to users. Regulators assess the performance of infrastructure providers against levels of service relating to resilience. The thresholds for acceptable levels of service are typically based on balancing the costs, benefits and risks with customer expectations.⁵⁶ This means that investments in resilience are often linked to whether it is acceptable to raise bills or fares to pay for them.

Some sectors have minimum guaranteed levels of service; if operators' service drops below these standards they must compensate their customers. The precise requirements vary between sectors, but most are based around disruptions lasting longer than a specified duration. Examples of this approach can be seen in the policy for power cuts, water supply interruptions, and delays or cancellations of rail services. There are also standards for the availability and minimum levels of telephone and data services.⁵⁷ Many of these standards do not apply in the broad circumstances of 'adverse weather', although the standard for power cuts clearly sets quantitative thresholds in terms of storm severity.⁵⁸ There are a mix of both statutory and non-statutory minimum standards.

The Commission has worked with Arup to collate the metrics that are currently used to set or assess levels of infrastructure service, including some discussion on how they have been determined.⁵⁹ This work concluded that how levels of service are set differs significantly across infrastructure sectors and that current committed levels of service mostly cover everyday events, rather than low probability, high impact ones. The implications and effectiveness of this approach will be assessed over the remainder of the study.

Limitations of the current approach to resilience

The resilience landscape, described above, includes plans to address aspects of resilience in individual sectors (often with a strong security focus). However, they are not sufficient to ensure that the UK's economic infrastructure system as a whole is resilient. Firstly, the effectiveness of different plans warrants further consideration – for example, common challenges such as vulnerabilities from flooding, changes in temperature and rainfall patterns in the rail, road, water and energy sectors are currently not fully and consistently addressed.⁶⁰ But the fact that the current landscape is focussed on individual sectors is itself limiting;⁶¹ it is difficult to find examples of holistic and cross cutting approaches and there is not yet an adequate understanding of the resilience and vulnerabilities of the UK's economic infrastructure as a whole.

The following chapter sets out why these issues need to be considered in more detail and the specific cross cutting challenges which the Commission has identified.

3. The case for change

Resilience will become increasingly important in the coming years as the UK's economic infrastructure faces the challenges of climate change, increasing population and adapting to advances in technology. The current approach, however, may be insufficient to meet such cross sector challenges.

While it will be important for lead government departments, regulators and infrastructure operators to review and strengthen plans in individual sectors, the Commission's analysis is focused on identifying the key cross cutting challenges that are not being addressed. This should avoid duplication and complement existing sector specific approaches that have been developed in both government and the private sector.

This approach, based on the evidence generated during the scoping phase of the study, has led the Commission to focus on 3 key questions for the main phase of the study:

1. **What are the systemic issues that make infrastructure vulnerable to current shocks and future changes and how could they be addressed?**
2. **What does the public expect of infrastructure services and how should their views be considered in decisions about resilience?**
3. **What changes to governance and decision making could improve current levels of resilience and ensure future challenges are addressed?**

Work commissioned from University College London (UCL), including a literature review and an expert workshop, helped to inform the questions and workstreams which will structure the main phase of the study. These questions were refined from a series of hypotheses to identify the areas where further work could improve the resilience of economic infrastructure,⁶² as well as an assessment of a variety of criteria including alignment with the Commission's objectives. The full paper setting out how these hypotheses were developed can be found at www.nic.org.uk/our-work/resilience/. The questions were further tested through the public consultation.

As shown in Figure 2, the 3 questions for the main phase were based on grouping the final hypotheses around 3 themes.

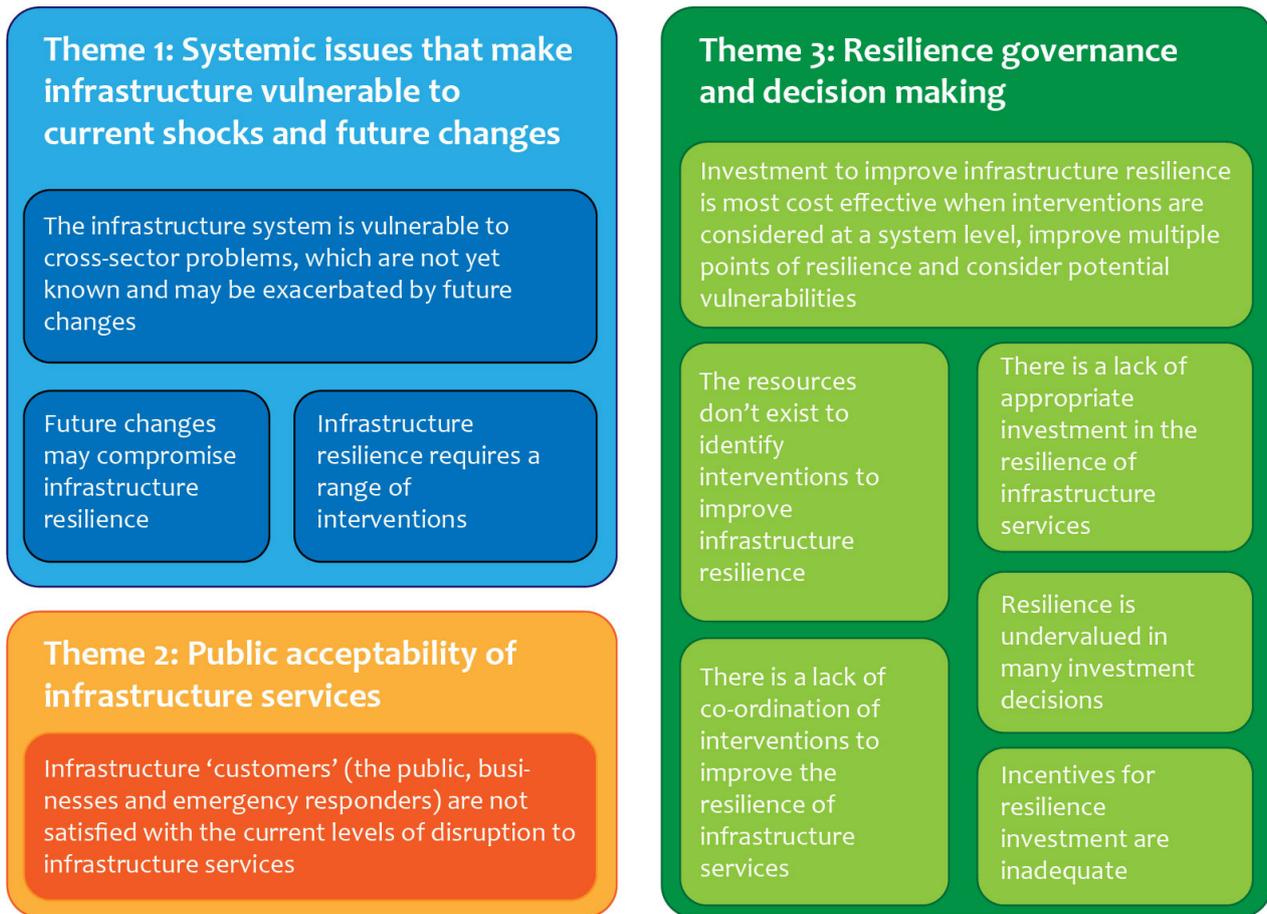


Figure 2: Thematic grouping of hypotheses⁶³

The following sections set out the Commission's rationale for selecting these questions and hypotheses.

Systemic resilience and vulnerabilities

There is already an existing body of literature highlighting specific gaps on infrastructure resilience, including the Commission's own analysis and recommendations. In the first National Infrastructure Assessment, the Commission recognised the need to focus on specific hazards – particularly drought and flood resilience – while also acknowledging the need for “more in-depth analysis of infrastructure resilience, as previously indicated in the Commission's Process and Methodology consultation”.⁶⁴

Academic literature often describes infrastructure as a ‘complex system’.⁶⁵ As such, we can expect it to demonstrate properties that cannot be explained by looking at individual sub-systems in isolation. This means that, while many failures will still result from the inherent vulnerabilities within individual sub-systems,⁶⁶ the growing interconnectedness and interdependencies between different sectors could exacerbate these vulnerabilities or lead to new ones.⁶⁷

Analysis so far indicates that individual infrastructure operators, regulators and government departments are not fully addressing these interdependencies. The lack of a cross sectoral approach to resilience was a key theme in responses to the scoping consultation and respondents welcomed the Commission taking a systems based perspective. Responses included concerns over the historic absence of meaningful analysis of the cross sectoral impacts of failure and the limited collaboration to address these issues.

“No detailed assessment of infrastructure cross-sector dependencies exists today, nor any assessment of how these may change with future trends in respective infrastructure sectors.” (National Grid)

“No attempt has been made to quantify the risk of systemic shocks or collapse.” (Individual response)

There is an increasing awareness of the importance of digital technologies within the resilience landscape, both for resilience enhancement (e.g. through models and digital twins) and increasing vulnerability (e.g. programming errors, cyber threats and overdependence).

“New networks of digitally connected infrastructure present unintended vulnerabilities and unforeseen cascade effects which need to be... investigated; understood; planned for; and anticipated. Enhanced digital connectivity facilitates the development of smart infrastructure and while it enables more efficient management and maintenance it also carries more risk.” (Institution of Engineering and Technology)

There was also an awareness throughout the responses that the environmental, societal and technological landscape is changing rapidly, creating new emerging threats that haven't been accounted for in existing resilience approaches and infrastructure design.

“[The next NIA] should explore... how resilience can be maintained in this new era amidst growing threats such as cyber activity and extreme weather events, while continuing to keep costs low for the public.” (Energy Networks Association)

Public expectations of infrastructure resilience

Even if systemic vulnerabilities were known, public expectations of infrastructure are complex, and it can be difficult to predict how people will respond to the loss of infrastructure services in different circumstances. Understanding what is and is not acceptable to the public is a key factor for determining the appropriate levels of resilience for the UK's economic infrastructure. However, understanding public expectations is a significant exercise, not least because it depends on several factors, including previous experience, and changes over time.⁶⁸

The Commission has contracted a social research project to understand the public's expectations of infrastructure resilience. While this work is not yet complete, analysis so far (including of existing literature on public expectations) suggests that people have limited awareness of the growing challenges facing the UK's economic infrastructure and are not necessarily prepared for the deterioration in service that may occur without further action to enhance resilience.

This hypothesis, along with the more detailed analysis described below, will continue to be tested and assessed as the social research project is completed.

Understanding public expectations around service levels

The Commission's initial research has found that, across the different infrastructure sectors, there are varying levels of evidence on public expectations around service levels and on whether these are being met.

Some information on the public's view of the water sector is available from the engagement undertaken by operators in the development of their business plans and Water Resources Management Plans. Across the other sectors, most evidence comes from academic literature, government publications and news reports. It suggests that public expectations around resilience differ across sectors: for example, there is a reported low tolerance of telecoms interruptions⁶⁹ and energy security seems to be of high public concern^{70,71}. On the other hand, rail passengers are reported to be aware that disruptions can happen, but expect to be supported during such events.⁷²

It also is not currently straightforward to establish how – and how effectively – infrastructure operators take public views on resilience into consideration when making investment decisions. For example, while willingness to pay is used across different sectors,⁷³ there are significant limitations to this and other techniques used to gauge public opinion, including the challenges of pushing beyond stated preferences to establish consumers' revealed preferences.⁷⁴ Any lack of alignment between public expectations and the actual level of service delivered is likely to have implications for how people respond to disruptions.

The importance of communication

Research suggests there is a disparity between public expectations and operators' abilities to meet these expectations in times of crisis. The public generally expect continuity of infrastructure services and prompt recovery after a disruption.⁷⁵ However, some research has found that effective communication during all phases of a disruptive event (before, during and after) may be able to affect people's reaction to the disruption.⁷⁶ Barriers to communication include the use of technical jargon, lack of clarity over risks and uncertainties, and the mode of communication.⁷⁷ The need for effective communication is particularly pertinent, as ongoing engagement with the public will be necessary to prepare communities to respond to predicted resilience challenges.

Governance and decision making

There is currently limited focus on the resilience of the infrastructure system as a whole and responsibility for resilience falls across several government departments and wider organisations, as shown in Figure 1. In general, this has led to a lack of clear and consistent objectives around resilience, including from government.

A lack of effective cross cutting governance and decision making can lead to practical barriers to addressing resilience, such as limitations on data quality, availability and sharing (due to commercial confidentiality and other sensitivities). Consultation responses pointed to a culture of working in silos within the UK's infrastructure sectors, which prevents data and knowledge exchange and leads to a lack of understanding of infrastructure interdependencies.

“There is currently a lack of collaboration and co-sharing of data and flexibilities in relation to key infrastructure, which is hampering long-term resilience planning and delivery of collaborative projects. This lack of data sharing between sectors is often due to security issues.” (Confidential)

Respondents to the consultation frequently cited a lack of consistency around resilience as a key barrier in assessing and achieving resilience in the system overall. Respondents suggested that a consistent modelling approach for resilience needs to be established and shared across sectors. Related to this, respondents noted that comparing and assessing resilience is difficult when design standards aren't consistent. For example, there are no consistent standards on how to consider climate change projections when designing for resilience, and there is limited sharing of good practice.

“[There] needs to be a consistently applied appraisal framework across sectors e.g. common approach to CBA and uncertainty; assumptions made during options appraisal.” (Network Rail)

Alongside this, there are differing approaches between sectors. Some specific challenges, such as the provision of a minimum supply of water, are regulated. This signals a very low acceptability of failure in these areas, but equivalent requirements are not universal.

How resilience is valued more broadly – including economic, societal, environmental and political dimensions – is also an area of inconsistency. Different frameworks for valuing resilience are used across sectors and it is perceived that, in practice, cost benefit analysis seldom adequately captures the value of resilience, as it does not fully quantify factors such as quality of life, societal or environmental benefits. This also reinforces the need to consider the role of communities in how decisions are made, both to aid consideration of wider costs and benefits and also to ensure that decisions consider public expectations, even if these are uncertain.

Respondents suggested that the current governance and decision making do not sufficiently facilitate long term investment in resilience. They suggested two key reasons for this:

- the need for regulators to balance long term infrastructure needs with affordability of bills, which can limit incentives to invest
- the mismatch in timing between different regulatory cycles and a lack of mechanisms for sharing costs between different organisations, which can act as a barrier to co funding within and across sectors.

To address this, respondents highlighted the need to align the priorities of government, regulators and industry and the potential benefits of joining up **planning cycles and funding mechanisms across sectors**.

There may also be inconsistencies in whether planned responses are deliverable and acceptable in practice. For example, the National Infrastructure Assessment identified that the planned use of standpipes and rota cuts during a drought is likely to be impractical and politically unacceptable. There can also be temporal differences between what is considered acceptable before and after events, with flooding an obvious example.

4. Next steps: the main phase of the Resilience Study

Over the coming months the study team will undertake analysis and develop a clear set of outputs for the final report. These will help to deliver an analytical approach that can be used to better understand resilience and suggest improvements, as well as practical changes. The second National Infrastructure Assessment is expected to include recommendations around resilience, informed by the output of this project.

The key outputs from the main phase of the study are expected to be:

- A framework to consider resilience across economic infrastructure, primarily for application during future National Infrastructure Assessments, but which can also evolve over time as knowledge improves
- Policy recommendations on resilience, including changes needed in the short term (for example changes in governance or decision making) and more strategic recommendations about the research, tools and data that will be needed to improve resilience in the medium to long term.

A fuller explanation of these outputs is summarised below.

The Commission will carry out analysis to deliver these, as well as continue to work with a range of external stakeholders, and will involve the Design Group, the Commission's Young Professionals Panel and relevant members of the Commission's Technical and Analytical Panels.

Developing a framework for resilience

The Commission will seek to design a framework which can be applied to assess resilience and ensure that it is considered across the Commission's work. It will need to be sufficiently flexible to be used across different projects and to reflect improvements in knowledge and data over time. The aim will therefore be to develop a systematic framework to identify resilience challenges and prioritise where to carry out further detailed policy and economic analysis in future National Infrastructure Assessments and other studies. This will also provide a basis for the monitoring and evaluation of resilience issues.

Policy recommendations

The study will also aim to identify a range of short term policy recommendations to improve resilience, which could be made before the framework is fully developed. This could include, for example, where the Commission has identified data, analysis or knowledge gaps. While longer term policy recommendations are unlikely to be developed in detail within this study, the framework should establish a basis from which more detailed policy recommendations can be made in the next National Infrastructure Assessment.

The recommendations in the final report will be made to government, which has an obligation to respond as soon as practicable – usually within six months.

Planned analysis to support these outputs

The analysis to help deliver these outputs has been framed around the questions set out in Chapter 3. Each piece of work will aim to test the methods to develop long term recommendations, which will make up the resilience framework described above, as well as identify the shorter term recommendations that this study will make.

Systemic resilience and vulnerabilities

The Commission will test two approaches to addressing systemic resilience and vulnerabilities, to identify and prioritise:

- the sources of physical vulnerability across the infrastructure networks
- the policies, incentives and other national level decision making that impact the level of service delivered by UK infrastructure during normal operation and during emergencies.

This work will help identify the key gaps and vulnerabilities which need to be addressed. It will also support the work on governance and decision making, by setting out the relative influence of national level decisions such as specific legislation, regulatory incentives and planning cycles.

Public acceptability of infrastructure services

As noted above, the Commission has commissioned a social research project around the public's expectations of infrastructure. Work so far has involved a series of workshops, which will be supported by further quantitative research. The social research will provide the main body of evidence on current and future public expectations across infrastructure sectors, both in ordinary operating conditions and following a significant disruption or event. This will help determine whether there are patterns, such as minimum expectations, that could be used to inform a framework for assessing levels of service.

Governance and decision making

The third question around governance and decision making will be analysed in two ways:

- Once the main physical and decision making vulnerabilities are identified through the work set out above, the Commission will carry out further analysis to understand who should tackle which vulnerability and whether there is the need for new policy or regulatory actions.

- The Commission will assess the current approaches used to determine levels of service and whether it is possible to develop a consistent framework (or set of principles) to define levels of service across each sector. If this is the case, the Commission will carry out further work to understand who should apply which part of the levels of service framework, and whether there is a need for new policies, regulatory incentives, standards, guidelines and/or principles to support this.

As well as providing building blocks for the framework, the results of this analysis will also inform the development of broader policy recommendations to improve governance and decision making.

Scenarios for modelling

To develop the framework set out above, particularly to identify the physical and governance vulnerabilities, the study team will carry out some modelling work. This will require a set of scenarios to represent future changes of the system. The Commission plans to develop the future scenarios based on the recommendations from the first National Infrastructure Assessment.

5. Call for evidence

In order to inform the workplan set out above, the study team has identified a number of areas which would benefit from further evidence. The specific issues and questions in this call for evidence (detailed below) will complement and inform the workplan set out in the preceding chapter, allowing robust testing of the Commission's hypotheses and the framework and recommendations delivered by the study. In particular, the study team would welcome detailed, qualitative evidence around how existing and emerging resilience issues are currently addressed, including international examples where relevant.

The questions in the call for evidence have been arranged around each of the three themes for the main phase.

Systemic issues that make infrastructure vulnerable to current shocks and future changes

1. What systemic vulnerabilities in the UK physical infrastructure network arise from its network architecture?
 - Examples of systemic vulnerabilities that originate from the structure of the network at a system level, including the physical and virtual connectivity of assets (but not individual assets themselves) within and between sectors.
2. What are the physical components of the digital network that should be mapped in order to assess this sector's contribution to systemic vulnerabilities?
3. Aside from those included in the last National Infrastructure Assessment, what future changes to infrastructure policy, supply and demand and systems' physical architecture need to be tested to develop a holistic understanding of future system vulnerabilities?
4. How have the current approaches to infrastructure resilience changed over time in order to become more effective?
 - Examples of good practice approaches to resilience that demonstrate how an organisation, or sector has responded to significant changes including, but not limited to; technology, disruptive events and/or changing user demands.

Public acceptability of infrastructure services

5. How are costs, benefits and public expectations balanced when setting levels of service?
 - Examples of how each of these factors have been considered when setting a desired level of service, either as a requirement or a target.

6. Should a consistent approach be used to set levels of service in different sectors? If so, what principles could be used to ensure that different sectors take a consistent approach which reflects the expectations of citizens?
7. How does the public respond to infrastructure disruptions and what is its appetite for making different sectors more resilient?
 - Please provide evidence from direct public engagement which demonstrates public tolerance of disruption and the appetite for resilience investment in the sectors covered by the study (energy, water, digital and transport). This includes, but is not limited to, outputs from willingness to pay surveys, focus groups and deliberative public engagement.

Resilience governance and decision making

8. What are the main policies, incentives, information flows and other national level decisions that affect the level of the services delivered by UK infrastructure under normal operating conditions, as well as during emergencies?
9. How does the infrastructure system respond to uncertainty?
 - Examples of how uncertainty over a particular variable, such as the nature of an anticipated risk, has affected the level of resilience decision makers choose to build into a system.
10. How have system wide resilience challenges been addressed effectively in the past?
 - Examples of how different policies, incentives or decisions across a system have interacted effectively to address an identified cross sector vulnerability and improved the resilience of the system overall.

6. How to respond

Responses should preferably be no longer than five pages in total (not including supplementary data files) and should be emailed to **resilience@nic.gov.uk**.

The deadline for submissions is **20 October 2019**.

Evidence will be reviewed thereafter by the Commission. If further information or clarification is required, the study team will contact you. The Commission may publish any responses received. If you believe there is a reason why your response or any part of it should be considered confidential, please provide details.

In exceptional circumstances, the Commission will accept responses in hard copy. If you need to submit a hard copy, please send your response to the Commission Secretariat at:

Resilience Study Consultation
National Infrastructure Commission
Finlaison House, 15-17 Furnival Street
London, EC4A 1AB.

FOI and privacy statements

Information provided in response to this consultation, including personal information, may be subject to publication or disclosure in accordance with the Freedom of Information Act 2000 (FOIA) or other relevant legislation.

If you want information that you provide to be treated as confidential please be aware that, under the FOIA, there is a statutory code of practice with which public authorities must comply and which deals, amongst other things, with obligations of confidentiality.

In view of this, it would be helpful if you could explain to the Commission why you regard the information you have provided as confidential. If the Commission receives a request for disclosure of the information, it will take full account of your explanation, but cannot give an assurance that confidentiality can be maintained in all circumstances. An automatic confidentiality disclaimer generated by your IT system will not, of itself, be regarded as binding on the Commission.

The Commission will process your personal data in accordance with relevant data protection law.

Annex A: Definitions of resilience

		plan	resist	absorb	recover	adapt	transform
United Nations Office for Disaster Risk Reduction	“to resist, absorb, accommodate, adapt to, transform and recover” ⁷⁸		resist	absorb/ accommodate	recover	adapt	transform
UK Cabinet Office	“to anticipate, absorb, adapt to and/or rapidly recover from a disruptive event” ⁷⁹	anticipate		absorb	recover	adapt	
Scottish Government	“the capacity ... to adapt in order to sustain an acceptable level of function, structure, and identity” ⁸⁰					adapt	
US Department of Homeland Security	“withstand and recover rapidly” ⁸¹	(also noted in document)	withstand		recover	(also noted in document)	
Australian Government	“coordinated planning...; responsible, flexible and timely recovery measures; and... provide a minimum level of service during interruptions... and return to full operations quickly” ⁸²	plan		Provide a minimum level of service during interruptions	recover		
UK National Cyber Security Centre	prepare, absorb, recover and adapt ⁸³	prepare		absorb	recover	adapt	
UK Department for Transport	withstand, operate and recover ⁸⁴		withstand		recover		
European Commission Joint Research Centre	absorb, adapt, transform ⁸⁵			absorb		adapt	transform
OECD public Government Committee	“ability to resist, absorb, recover from or successfully adapt to adversity or a change in conditions” ⁸⁶		resist	absorb	recover	adapt	
US National Academy of Science	“the ability to plan and prepare for, absorb, recover from, and... adapt to adverse events” ⁸⁷	plan/prepare		absorb	recover	adapt	
Cities Resilience Index ⁸⁸	“accepting of uncertainty and change; reflective; adaptive; robust; resourceful/efficient; integrated; diverse; and inclusive”. Reflective, Flexible, Integrated, Robust, Resourceful, Redundant, Inclusive	reflective	robust	robust/ redundant		adaptive/ flexible/ resourceful	

100 Resilient Cities	“survive, adapt and grow”; also uses the seven qualities as used above by the Cities Resilient Index ⁸⁹	reflective	robust	robust/ redundant		adapt	grow
Reliability Engineering & System Safety: A review of definitions and measures of system resilience ⁹⁰	commonly used: absorb, recover, adapt			absorb	recover	adapt	
IGRC Resource Guide on Resilience: Resilience: Approaches to Risk Analysis and Governance ⁹¹	planning, absorb, recovery time, adaptive management	planning		absorb	recovery time	adaptive management	

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