Handbook for Implementing the Principles for Resilient Infrastructure
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How to make infrastructure resilient
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This handbook provides guidance for the implementation of the Principles for Resilient Infrastructure, which have been developed by the UN Office on Disaster Risk Reduction (UNDRR) and consulted with over 100 countries. The principles support the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030 and the Sustainable Development Goals (SDG), in particular SDG9 on resilient infrastructure.

Infrastructure resilience is the timely and efficient prevention, absorption, recovery, adaptation and transformation of national infrastructure’s essential structures and functions, which have been exposed to current and potential future hazards. Implementing resilience across all disruption phases should be done through collaborative risk and uncertainty management, multi-hazard assessment, and methods that embrace the systemic nature of national infrastructure.

The Principles for Resilient Infrastructure address the gaps in current infrastructure planning, financing, design, development, and operation, which do not fully consider either the interdependent nature of infrastructure and services, or the increasingly complex nature of risks and the cascading impacts that a disaster can have across the whole infrastructure system.

The handbook shows a way to think, design, and run infrastructure as a whole system, while implementing net resilience gain (i.e., an important commitment to ensure that any interventions to parts of a national infrastructure system do not reduce national infrastructure resilience).

A set of key actions support the implementation of each Principle (see Figure 1). The handbook develops these key actions into interventions from different stakeholders and includes a key performance indicator for each action (see Section 2 and 3). It provides guidance on what interventions to take, what to measure, and how to monitor improvement in the resilience of national infrastructure. The handbook concludes by introducing a governance framework for developing an implementation plan for infrastructure resilience (see Section 4).

The handbook is part of a set of enablers, supported by the UNDRR, to help nations achieve resilient infrastructure. These include a resilient-infrastructure stress-testing model, among other initiatives.
The governance framework is the national control system to implement infrastructure resilience. Resilient infrastructure is achieved by compliance with the Principles for Resilient Infrastructure. Key Actions define the scope of each principle and what must be done to implement the principle. Several stakeholders must intervene to implement a Key Action. A key action has one Performance Indicator; the assessment of all Performance Indicators shows how resilient a nation’s infrastructure is.
2. Stakeholders

The handbook organizes information by infrastructure stakeholders who are critical for implementing the Principles for Resilient Infrastructure. It provides tailored guidance to the following groups: government, regulators and operators; owners and financial partners; planners, designers, engineers, and contractors; and institutions, academia, and civil society.

The handbook shows how the principles allow stakeholders to design, maintain, and adapt infrastructure, while also highlighting what interventions are relevant at different phases of resilience (i.e., preparation, absorption, recovery and adaptation).

The primary interactions between stakeholders are shown in Figure 2.
Figure 2: Primary interactions between stakeholder groups

RESILIENT GOVERNANCE
GOVERNMENT

RESILIENT INVESTMENT
OWNERS

RESILIENT SOLUTIONS
ENGINEERS, CONTRACTORS*

FINANCIAL PARTNERS

PLANNERS, DESIGNERS

OPERATORS*

INSTITUTIONS

ACADEMIA

CIVIL SOCIETY

END USERS, RESIDENTIAL, INDUSTRIAL, COMMERCIAL, GOVERNMENT

* includes supply chain
Rectangle: collaboration boundary for multi stakeholder groups
Intra-link between rectangles with same colour: collaboration among one stakeholder group
Inter-link between rectangles with different colours: collaboration among multi stakeholder group
Note: Resilience resource flows among multi-stakeholders include resilient governance, resilient investment, resilient solutions, resilient innovation and application.
Each stakeholder group (see definition in Box 1) has an important role to play and can add value to infrastructure resilience, for example:

- **Government** can initiate changes to national policy for infrastructure resilience, allocate necessary funding to resilience-building activities, and require that the tendering process for infrastructure projects gives appropriate weighting to resilience considerations.

- **Regulators** can monitor disruptions to critical services, require operators to improve their resilience, and introduce obligations on infrastructure operators to develop and maintain long-term resilience strategies.

- **Operators** can monitor their capacity to absorb disruptions caused by different types of hazards and realize retrofit improvements that improve their ability to absorb future ones.

- **Owners** can raise infrastructure-resilience standards, invest in skills and capacity to achieve infrastructure resilience, and require operators to assess potential hazards.

- **Financial partners** can collect data on hazards and vulnerabilities to improve risk management, and integrate resilience considerations into their decision-making processes.

- **Planners, designers and engineers** can establish initial asset resilience through appropriate plans and designs, provide handover documents and models that inform operational decisions for maintaining resilience, and design ways to collect operational data for monitoring resilience during the operational stage.

- **Contractors** can develop and implement tools that anticipate future needs and generate system resilience, while also creating tools to collect operational data.

- **Academia** can support innovation through research in engineering, architecture, planning, construction and other topics.

- **Institutions** can support resilience by sharing their knowledge and the experience of their industry members, while also providing training for updating knowledge and skills.

- **Civil society organizations** mediate relations with communities by improving local people’s capacity to understand infrastructure resilience; providing a stronger context in communities to support infrastructure resilience; and representing and being the voice of people in the community. They can help engage the public at large, for instance by promoting responsible practices that will increase the resilience of infrastructure systems. They also engage in decision-making, planning and monitoring of infrastructure systems (e.g., through stakeholder consultations) and can be involved in construction works (e.g., local community projects).
Stakeholders will have different roles and types of interventions over time:

- **Lifecycle phase:** Stakeholders might be involved in different stages of the lifecycle of an infrastructure sub-system. Broadly these lifecycle stages are: before its construction, during construction (pre-operational), during operations (operational), and at end of life. Interventions to improve resilience can be implemented at any lifecycle stage.

- **Resilience phase:** The interventions that stakeholders will need to take may be relevant at different phases of resilience: preparation, absorption, recovery and adaptation. It is essential that steps are taken by stakeholders across all resilience phases. The interventions taken by stakeholders to improve resilience may occur during any of the phases of resilience, despite the fact that an absence of infrastructure resilience is obvious only when hazards and threats manage to disrupt the flow of critical services.

Stakeholders may also express these roles in different ways depending on the community dynamic and culture, so local contextualization is needed. However, one organization may have alternative roles in different infrastructure programmes. For example, the government may also be a (public) investor in some programmes, or private owners may also be operators in some schemes. Stakeholder groups in this report define functional responsibilities and these functions may be conducted by different organizations and entities depending on the projects.

Each country will have their own combination of stakeholders related to infrastructure resilience. The arrangement of stakeholders will vary from country to country and from project to project so the stakeholder classification should be interpreted broadly.
Government for the purpose of this handbook refers primarily to national governmental bodies with powers to develop public policy and make decisions for public goods. In practice, government is run at multiple levels, including regional and local. They have a role in producing clear, proportionate and realistic ambitions for the resilience of infrastructure services, and assessing whether existing structures, powers and incentives enable operators to achieve these ambitions or where changes are needed. The role of governments as an infrastructure owner is dealt with under owners below. Government (including regulation) influences, directs and supports the agenda for resilient infrastructure.

Regulators are formal organizations ensuring that other stakeholders implement public policy as defined by government, and take action where the implementation falls short of expectations. Regulators set technical standards for infrastructure resilience and enforce them. For infrastructure resilience, there are often sectoral regulators, such as the water-sector regulator, as well as financial regulators, such as the insurance-industry regulator.

Operators refers to public and private organizations delivering critical products and services (e.g., transport agencies, energy-network providers). Operators include entities that provide solutions for infrastructure operations (e.g., data and digital companies, utility companies). Operators focus on asset management and operational availability. They may focus on critical components which are assets, interdependencies, or sub-systems whose failure would create significant disruption or losses. They comply with regulations and standards using the designs, technologies and solutions provided by designers and contractors. Operators manage, maintain and recover infrastructure according to the standards, codes, policies, legislation and regulations agreed by government and institutions.

Owners of infrastructure are legal entities able to issue contracts for the procurement of products and services that deliver services to their customers. Individually or jointly, the public sector and private sector can be owners. Private owners are motivated to invest in infrastructure where the risk and return is acceptable. Government as a public owner, or when acting as a regulator of private investments, has a responsibility to protect investments and the public.

Financial partners are entities providing financing resources and financial services to the infrastructure owner (for new infrastructure or major adaptations) and the operator (for existing infrastructure). The cost of infrastructure finance will depend on the risk profile of the underlying infrastructure system, which depends on its resilience. Financial partners (such as banks and investors, pension funds, private equity firms) provide capital or risk-coverage services (such as insurers and reinsurers). Financial partners have a critical role in ensuring the value of resilience is understood when investments are assessed.

Planners identify, assess and decide what schemes best provide required services to the public. They may focus on a specific geographic region or area, or on a particular infrastructure sector. Planners work with investors to establish the economic requirements and feasibility of proposed schemes. Planners also align the desired outcomes of new projects with the services provided by existing infrastructure, to ensure successful integration of new and existing assets.
Designers prepare and modify designs for construction projects. They include architects and consultants. They are involved in the design and construction of parts of national infrastructure and are often the source of innovation for data and disaster preparedness, emergency planning and recovery.

Engineers develop safe and feasible technical solutions.

Contractors can be employed by, or work in conjunction with, designers and engineers, and they implement proposed schemes. The work of contractors is required during the initial construction phase of an asset’s lifecycle but can also be necessary to conduct maintenance and repair during the operational phase. Contractors are typically required to conduct their work in agreement with national standards and regulations. Contractors include organizations that supply materials, products and skills for construction purposes. Contractors cover large-scale, national or international firms, construction material supply companies and local, small-scale builders and their supply chains.

Academia develops innovative tools and solutions through research and education. Academic institutions can be publicly or privately owned. Through research, academic institutions can lead the development of new methods for the assessment and improvement of resilience in infrastructure. Academic institutions educate the designers and engineers of the future, aligning their curriculum with the requirements of professional bodies.

Institutions include the wide array of not-for-profit organizations that have a presence in professional and expert domains, express the interests and values of their members, mostly based on scientific considerations. They are non-profit organizations with a specific mission, such as civil engineering excellence, or who advocate improvements such as climate resilience, early warning or disaster-risk recovery. Institutions may have professional chambers and typically build capacity through training and support for resilience activities.

Civil society organizations include the wide array of non-governmental and not-for-profit organizations that have a presence in public life, represent the interests and values of their members and others, based on ethical, cultural, political, religious, or philanthropic considerations. They typically allow vulnerable or excluded groups, as well as at-risk communities, to have a voice in public decision-making, and are interested in good outcomes for individuals and the environment.
Implementing the Principles for Resilient Infrastructure requires interventions by all the stakeholders, which are grouped in this section by the key actions under each principle. In addition, key performance indicators are provided to assess the current implementation of the principles in a country.

However, this assessment should consider the local context and available resources and tailor stakeholder interventions accordingly. Similarly, the indicative scoring criteria for each key performance indicator should be adapted to the country's circumstances.

Users should use the scoring process to gather evidence of existing practices and define the country's level of ambition for the future. Each country should look at its priorities and capacity to set the level of ambition for the resilience of its infrastructure system. This ambition can be reviewed as part of the yearly assessment of the implementation plan to adapt to changing priorities and conditions (see section 4).

3 Stakeholder interventions / Performance indicators
Principle 1 (P1) - Continuously learning

The goal of this principle is to develop and update understanding and insight into infrastructure resilience. The main actions to realize this goal are presented below.

P1.1 Expose and validate assumptions

Assumptions are embedded in models, plans, and operating systems, such as climate-change scenarios used for infrastructure asset design. Despite having significant consequences for the systemic resilience of critical infrastructure, these assumptions are not always tested or made explicit, nor reported regularly and transparently. When disruptions and disasters happen, the assumptions must also be reviewed and revised.

a. Stakeholder interventions

Each stakeholder has a specific role in implementing this action.

**Government**

- Guide infrastructure sectors on collecting data about assumptions made in infrastructure models, plans and operating systems.

- Publish timely statistics and studies on assumptions made and highlight opportunities and priorities for improvement.

- Incentivize other stakeholders to share relevant information about their assumptions.

**Regulators**

- Request information from owners and operators about assumptions in data, models and plans.

- Monitor the quality, comprehensiveness and relevance of assumptions made and determine the weaknesses to be addressed in subsequent iterations of models, plans and operating systems

- Track owners’ and operators’ capability to validate and improve their assumptions.

**Designers, planners, engineers, and contractors**

- Collect data during the planning, designing and construction phases, and then report information about assumptions embedded in models, plans and operating systems to regulators and operators.

**Operators**

- Provide reporting on the assumptions made to regulators and ensure that assumptions do not understate the current and future resilience of critical services.

- Collect and investigate data on failures of infrastructure systems and correlate these data with assumptions made. Identify anomalies and plan for upgrades.

**Academia**

- Develop innovative tools and models to anticipate potential hazards that can affect assumptions made previously and expose vulnerabilities.

**Institutions**

- Use the knowledge and experience of the members to assess and validate assumptions and priorities.
b. Example of interventions

The Wellington Lifelines Regional Resilience Project details how investing in infrastructure resilience reduces the national economic impact of a large earthquake. As part of the project, an assumptions report was produced to provide explanation on the assumptions underpinning the economic modelling tool that was used to translate infrastructure damage and other forms of physical disruption into estimates of economic impacts. By having these assumptions published, users can more easily understand how economic impacts are estimated, but also check whether those remain valid over time.


c. Performance assessment

KPI Name: Management of modelling assumptions

Rationale: Modelling assumptions, including the testing of a limited range of scenarios, plays a critical role in infrastructure resilience. Transparent reporting of the assumptions used helps reveal weaknesses and limitations. Different hazards and infrastructure systems require different reporting schedules. For example, cyber threats and communications infrastructure are far more dynamic than dams and earthquakes. The extent to which assumptions are tested and checked for quality; and whether the results are used to review and improve models, plans and operating systems will indicate the accuracy of a nation’s assessment of its systemic resilience.

What to consider:

A. Scope of assumptions: the number of models, plans and operating systems (used for decision-making for infrastructure resilience) for which assumptions are reported.

B. Frequency for reporting assumptions: frequency of reporting of models, plans and operating systems related to the number of disruptions and the critical level of the risk.

C. Testing level for assumptions: the proportion of assumptions that are tested and validated.

D. Review level for assumptions: the implementation of recommendations to improve assumptions.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Modelling assumptions used for making decisions on infrastructure resilience are systematically reported, frequently published, tested and reviewed for all sectors.

4 Modelling assumptions are reported, published, tested and reviewed for most infrastructure systems but not for all.

3 Modelling assumptions are reported, published, tested and reviewed for some infrastructure systems but not for most of them.

2 Modelling assumptions used for making decisions for infrastructure resilience are tested, reported and reviewed but not published.

1 Modelling assumptions used for making decisions for infrastructure resilience are tested and reviewed but not reported nor published.

0 Modelling assumptions used for making decisions for infrastructure resilience are not tested, reviewed or reported.

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P1.2 Monitor and intervene appropriately

Monitoring the performance of each critical component of national infrastructure must be prioritized to have appropriate granular data for decision-making and interventions. The monitoring systems should consider multiple hazards and incorporate means to mitigate against inaccurate data.

a. Stakeholder interventions

Each stakeholder has a specific role in implementing this action.

**Government**

- Design public policies for infrastructure monitoring.
- Invest in building capacity to develop, test and implement intervention strategies, using evidence from infrastructure monitoring, for preventing and absorbing hazards in a timely and appropriate way.
- Ensure monitoring does not create undesirable social and environmental outcomes (e.g., breach of privacy).

**Regulators**

- Enforce government rules and regulations on infrastructure monitoring and sensing through compliance checks (e.g., random investigations).
- Implement deterrents to undesirable practices such as individual tracking (e.g., fines).
- Conduct workshops and consultations with the industry to determine monitoring requirements.

**Owners**

- Request critical asset monitoring and sensing on new and existing infrastructure, and demand that operators develop skills in data collection and disruption prevention, for example against cyber threats.
- Direct designers and engineers to prioritize asset monitoring and interventions to where it will be most effective.

**Financial partners**

- Review whether a sufficient budget is allocated to monitor real-time infrastructure performance that allows timely interventions when assessing investments.
- Include covenants in the loan documents and clauses in the insurance contracts regarding the borrower or policyholder’s infrastructure-monitoring capacity.
- Inquire about the results from the infrastructure performance sensing throughout the project lifecycle.

**Planners and designers**

- Plan ways to include monitoring and sensing into specific infrastructure systems, while providing for integration with computing and telecommunications systems.

**Engineers**

- Devise, design and manufacture monitoring and sensing systems, including solutions for retrofit in existing infrastructure, and design the integration with computing and telecommunications systems.
**Operators**

- Implement monitoring, sensing and early-warning systems (these may include sensors and devices), collect robust data, conduct analysis, use strategies to intervene to prevent disasters, and recommend adaptations to existing infrastructure systems.

- Use timely and effective information produced by monitoring to minimize outages of critical services.

**Academia**

- Provide fundamental research on how to create proactive strategies adapted to specific local contexts to protect infrastructure, both in large and small-scale systems, by using monitoring and sensing. This involves research into monitoring mechanisms for early warning, such as sensors and devices, mechanisms for secure information management, data science, devising and testing strategies to protect infrastructure, managing errors and uncertainties.

**Institutions**

- Establish professional development methods to increase the skills of stakeholders in the use of monitoring mechanisms, sensors and devices, and the information collected.

b. Example of interventions

Namibia Sensor Web Pilot Project was created as a testbed for decision-support systems to monitor floods and enable flood-risk assessment. One of the services currently available through the Sensor Web infrastructure is a flood-mapping service provided by the Institute of Space Research (SRI) of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine. The service provides flood extent maps derived from satellites. The maps are provided on demand and delivered within 12 hours after image acquisition. The services are run within the grid infrastructure developed at SRI. Using satellite data allowed the government to select reliable services, reducing the time required for delivering flood protection, prevention and information services to the end users of infrastructure.

Another example is the Fusion Analytics for Public Transport Emergency Response initiative launched by the Singaporean government. The objective is to use big data to improve the country’s public transport system by more quickly responding to train breakdowns, delays and other unexpected incidents. These data provide the opportunity to develop detailed models of how users move through the city, helping government understand traffic patterns, how citizens use the urban transport system and key problems with existing routes.

c. Performance assessment

KPI Name: Critical asset monitoring and intervention.

Rationale: Tested and ready-to-use strategies to intervene to protect the delivery of critical services will improve the capacity of infrastructure operators to identify potential risks in advance, absorb any negative effects, and minimize outages of critical services. Meanwhile, investment in monitoring and sensing provides the data needed for decision-making to prevent interruptions in critical services.

What to consider:

A. Scale of monitoring: the number of critical assets, interdependencies, and other systems that are monitored.

B. Spread of monitoring: the number of relevant hazards that are monitored and the relevant alternative means of monitoring that are implemented.

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C. **Scope for interventions:** the number of tested strategies that provide interventions to resolve risks identified by monitoring evidence.

D. **Capacity for interventions:** the number of relevant operators that are trained to implement interventions.

**Indicative scoring criteria:** The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5. Monitoring of infrastructure systems and hazards is comprehensive and frequent enough (ideally in real time), and there are enough well-trained operators to test and implement the corresponding interventions for preventing critical service interruptions.

4. Monitoring of most infrastructure systems and hazards but not for all or not with enough frequency, and it is not always possible to have well-trained operators to test and implement the corresponding for preventing critical service interruptions.

3. Monitoring of some infrastructure systems and hazards but not for most of them or frequency of monitoring is low, and there are not enough well-trained operators to test and implement all of the corresponding interventions for preventing critical service interruptions.

2. Monitoring of very limited infrastructure systems and hazards or only sporadically monitoring, and there are limited well-trained operators to test and implement corresponding interventions for preventing critical service interruptions.

1. Monitoring of very limited infrastructure systems and hazards, and there are no well-trained operators to test and implement the corresponding interventions for preventing critical service interruptions.

0. No monitoring systems in place.

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**P1.3 Analyse, learn and formulate improvements**

To formulate interventions, there is a need to analyse and learn from past experiences (including disaster records and scientific research), current evidence, and feedback on resilience infrastructure and hazards.

**a. Stakeholder interventions**

**Government**

- Disseminate and embed lessons learnt on disaster risks vulnerabilities and exposure, to inform decision-making.

**Regulators**

- Use findings and existing knowledge to revise existing regulations.

**Owners**

- Create demand for vulnerability knowledge and hazard scenarios, as well as resilience assessments, and use lessons for future decision-making.

- Collect data about the potential vulnerability of infrastructure systems at different time scales, e.g. next five years, next 50 years.

- Establish learning loops to continuously update investment priorities, modelling assumptions, emergency management plans and recovery strategies.

**Operators**

- Provide government and owners with data on infrastructure-resilience capacity and learning mechanisms.

- Use past experiences to develop optimal recovery strategies and improve system response.
**Institutions**

- Establish communities of practice and learning loops to continuously revise and update existing academic knowledge.

**b. Example of interventions**

The OILL process (observations, insights, lessons identified and lessons learnt), included in the Australian Disaster Resilience Handbook Collection, provides guidance on lessons management for all types of sectors. Lessons management refers to collecting, analysing, disseminating and applying learning experiences. The OILL process allows for implementing robust and scalable lessons-management processes. Furthermore, having common processes for lessons management across agencies, sectors and jurisdictions facilitates information sharing and analysis.

**c. Performance assessment**

**Key performance indicator details**

**Name:** Comprehensive learning mechanisms.

**Rationale:** Resilience-oriented learning mechanisms empower infrastructure decision-makers to understand how they can improve systemic resilience and create net resilience gains.

**What to consider:** The depth and breadth of formalized learning mechanisms (e.g., methods, rules, processes, frameworks) for infrastructure resilience within all critical infrastructure sectors.

**Indicative scoring criteria:** The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Comprehensive learning mechanisms exist; and are shared, used and updated by all stakeholders so that resilience strategies are based on previous lessons and scientific evidence.

4 Comprehensive learning mechanisms exist but have not been used in live situations – only after drills and resilience strategies are only partially based on previous lessons and scientific evidence.

3 The need to learn is acknowledged and there are some attempts to share lessons, but it is not systematic and not regularly considered in future resilience strategies.

2 Post-event learning is planned by some stakeholders, but to varying degrees and not systematically shared.

1 Any provision for post-event learning is rudimentary at best.

0 There are no learning mechanisms in place related to disaster risks.

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P1.4 Conduct stress tests

Stress testing, drills and compliance testing are widely used in many industries to provide invaluable insights in analysing system failure modes and system vulnerabilities. Comprehensive stress testing will enhance the resilience of critical infrastructure to build with the future in mind at systems level. Tests perform best when they are realistic, standardized and inclusive of the broadest range of stakeholders. They should be regular and proportionate, overseen by regulators, and meet a nation’s resilience standards.¹

a. Stakeholder interventions

**Government**

- Develop resilience strategies across infrastructure sectors according to the stress-test results.

**Regulators**

- Introduce regulations or policies for infrastructure operators to ensure they undertake regular stress tests.
- Promote sharing of best practice in stress testing across relevant operators.

**Operators**

- Carry out regular and proportionate stress tests to ensure infrastructure systems and services meet government’s resilience standards and to identify vulnerabilities and options for improvement.
- Provide the government with detailed, confidential accounts of the outcome of stress tests and publish summaries.

**Academia**

- Conduct research and analysis on various stress-test models and provide evidence for developing standards on stress testing.

**Institutions**

- Provide lessons from stress testing to help government develop and maintain long-term resilience strategies across infrastructure sectors.

b. Examples of interventions

**Example 1**: The engineering risk-based multi-level stress-test methodology developed for the STREST project enhances the evaluation of the risk exposure of critical infrastructure against natural hazards. To account for the diversity of critical infrastructure, it considers a wide range of potential consequences of failure, multiple types of hazards, and the availability of human and financial resources. Each stress-test level is characterized by a different scope (component or system) and by a different complexity. The outcome of stress tests is a grade.⁵

**Example 2**: The United Nations Office for Disaster Risk Reduction (UNDRR) has developed strategies for stress testing the resilience of important infrastructure that could be affected by multiple stressors, including climate change. Stress testing the resilience of infrastructure supports the prioritization of sectors and needs in the face of tight budgets.⁶

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c. Performance assessment

**KPI Name:** Stress-test pervasiveness and quality.

**Rationale:** Regular and proportionate stress tests create knowledge on how infrastructure will react to hazards and how it will respond to decision-making processes. This knowledge creates insight that motivates interventions to reduce risks and to prepare stakeholders.

**What to consider:**

A. Stress-test pervasiveness level: the depth and breadth (see banding below) of formalized stress-testing mechanisms for all critical infrastructure sectors

B. Compliance level with standards: the sum of all ratings for each infrastructure organization on their stress-testing compliance with resilience standards

**Indicative scoring criteria:** The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Annual suite of stress tests validated by professionals as a realistic representation of ‘most severe’ and ‘most probable’ scenarios across all critical infrastructure sectors, and implemented according to formal international or national-level standards.

4 Annual suite of stress tests broadly thought to be realistic but with some deficiencies, and implemented according to formal standards developed at sub-national level.

3 Annual suite of stress tests insufficient in some significant respects (e.g., a too-limited breadth of hazards being used) or limited to just a single infrastructure sector, and implemented according to informal national-level guidelines.

2 Less than annual stress tests, and implemented according to informal guidelines at local or project level.

1 Ad hoc partial stress tests – not all scenarios incorporated and tested, not realistic, and implemented according to informal guidelines at local or project level.

0 No stress tests and no corresponding standards or guidelines.
Principle 2 (P2) - Proactively protected

The goal of this principle is to proactively plan, design, build and operate infrastructure that is prepared for current and future hazards.

P2.1 Raise essential safety requirements

Programmes for new infrastructure systems and upgrades to existing infrastructure should expect to raise the baseline for essential safety requirements, while adopting a pessimistic view of the potential for lifecycle hazards (e.g., be prepared for worst case, reasonable worst case and extreme but plausible scenarios).

a. Stakeholder interventions

Government

- Collect and publish safety-related data (e.g., record critical asset safety levels).
- Fund safety-improvement programmes and commission research programmes on safety improvement.
- Update safety-level advice based on data on future hazards and previous lessons.
- Disseminate safety-related data on governmental websites or at industry events.

Regulators

- Set out the latest safety guidelines and legislate (e.g., building and construction standards and codes).
- Monitor the implementation of safety guidelines and assess improvements required.

Owners

- Request higher levels of safety baselines to guarantee resilient delivery and operation of assets and protect investments.
- Require resilient assessment based on different safety standards for infrastructure design.

Operators

- Develop staff skills to operate at new levels of safety standards (e.g., training).
- Consider retrofit and system enhancement.

Planners, designers, engineers and contractors

- Translate resilience and safety-improvement programmes into designs, plans, solutions, and construction approaches (e.g., through building information modelling (BIM) and other technical design methods).

Financial partners

- Revise investment strategies to favour engineering solutions with higher safety baselines.
- Quantify benefits from higher safety investment.

Academia

- Devise and recommend resilience and safety-improvement mechanisms.

Institutions

- Provide training and development for staff on safety skills.
b. Example of interventions

Since Fukushima Daiichi NPS Accident, Japan has improved its safety awareness and ability to secure the resilience of nuclear infrastructure. The new safety requirements began to be implemented in July 2013. They significantly raise the assumption level of disasters to include accidents where frequency was extremely low, while requesting comprehensive assessments for external events such as fires, volcanic eruptions and landslides. The new regulatory requirements are based on the defence in depth concept (i.e., multiple layers of redundant defensive measures for potential human and mechanical failures).7

c. Performance assessment

KPI Name: Safety-design improvements.

Rationale: Raising the safety baseline of infrastructure designs will create better capacity within structural, operational and emergency-management processes to respond to future hazards of greater magnitude.

What to consider: The number of new infrastructure programmes, in any form of infrastructure, dedicated to resilience in planning, design, construction or operation in the last year that considered lifecycle hazards and recommended safety-baseline increases or improvements.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 All the new infrastructure programmes dedicated to resilience in the last year considered lifecycle hazards and recommend safety-baseline increases or improvements.

4 Most of the new infrastructure programmes dedicated to resilience in the last year considered lifecycle hazards and recommend safety-baseline increases or improvements.

3 Some new infrastructure programmes dedicated to resilience in the last year considered lifecycle hazards and recommend safety-baseline increases or improvements.

2 Few new infrastructure programmes dedicated to resilience in the last year considered lifecycle hazards and recommend safety-baseline increases or improvements.

1 Very limited new infrastructure programmes dedicated to resilience in the last year considered lifecycle hazards and recommend safety-baseline increases or improvements.

0 No new infrastructure programmes dedicated to resilience in the last year considered lifecycle hazards and recommend safety-baseline increases or improvements.

P2.2 Exceed basic requirements for critical components

Critical components of national infrastructure must exceed basic reliability and durability requirements, so the infrastructure systems are more resilient to future hazards.

a. Stakeholder interventions

Government

- Identify critical components of national infrastructure and prioritize them for necessary upgrades.

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• Direct asset reviews,

• Conduct analysis and engage with other stakeholders in defining standards for critical components.

• Set the standard for critical component performance (e.g., at least level IV ASCE).  

**Owners**

• Demand that critical components of infrastructure systems exceed basic requirements.

• Assess the existing components or asset base which needs upgrades.

• Calculate costs to upgrade to increase safety level of critical components.

**Operators**

• Provide information on the performance of critical components for strength and stiffness.

• Incorporate findings and lessons learnt into other systems.

**Planners, designers, engineers and contractors**

• Design and build critical components to satisfy high levels of strength and stiffness (e.g., use experiments and tests).

**Institutions**

• Provide consultations regarding exceeding basic reliability and durability requirements of critical components.

**b. Example of interventions**

A risk category is a categorization of structures to determine hazard loads based on the risk associated with unacceptable performance. Risk category IV criteria include both strength and stiffness: resilience of physical assets is a combination of designing strength and flexibility for most types of structures.  

American Society of Civil Engineers (ASCE) risk category IV are buildings that are considered essential for continuous use, particularly in response to disasters such as hospitals, fire stations and police stations.

**c. Performance assessment**

**KPI Name:** Critical component tolerance.

**Rationale:** Exceeding basic component-level reliability and durability requirements will achieve higher system-level reliability and durability, which can delay performance degradation, reduce system failure probability, and improve adaptability to long-term hazards effectively.

**What to consider:** The number of critical components of national infrastructure in ASCE risk category IV (or equivalent system that indicates the highest level of protection).

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Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 All the critical components of national infrastructure in ASCE risk category IV or national equivalent.

4 Most of the critical components of national infrastructure in ASCE risk category IV or national equivalent.

3 Some critical components of national infrastructure in ASCE risk category IV or national equivalent.

2 Few critical components of national infrastructure in ASCE risk category IV or national equivalent.

1 Very limited critical components of national infrastructure in ASCE risk category IV or equivalent.

0 No critical components of national infrastructure in ASCE risk category IV or equivalent.

P2.3 Consider complex interdependencies of connected networks

The availability of alternative networks delivering the same or similar critical services, such as road and rail, provides systemic resilience. But different networks, such as power and transport, coupled may become highly interdependent and increase the risk of indirect failures being transferred across sectors.\(^{12}\) The complex interdependencies of connected networks must be considered in the (re-) design of national infrastructure to reduce the risk of cascading failures.

a. Stakeholder interventions

Government

- Require operators and designers to manage interdependencies of interconnected infrastructure that may lead to failures either now or in light of future hazards.

Operator

- Assess exposure to interdependencies’ failures and allocate resources to reduce the vulnerability of interconnected infrastructure to cascading failures.

- Devise operational and recovery strategies to determine changes needed to reduce risk of cascading failures now and in light of future hazards.

- Use technology (e.g., computational modelling) to monitor and assess exposure to interdependencies between different infrastructure sectors.

Planner, designer, engineer and contractor interventions

- Design infrastructure networks to provide alternative routes to deliver critical services that do not exacerbate cascading failures.

- Negotiate alternative routes with infrastructure operators.

Academia

- Conduct research to develop strategies for continuity of critical services in the event of interdependency-related hazards and in light of future hazards.

Institutions

• Provide consultation in defining codes, standards and regulations regarding avoiding the risk of cascading failures.

b. Example of interventions

The New York City Council Committee on Environmental Protection convenes city agencies and major private infrastructure-service providers in the energy, transportation, water and wastewater, and telecommunications sectors to outline its objectives for working together, including: identifying critical infrastructure in New York City that could be at risk from the effects of climate change, facilitating knowledge sharing, developing design standards for infrastructure (e.g., Climate Resiliency Design Guidelines). The guidelines include recommendations on evaluating how climate hazards affect service or resource interdependencies between the project in design and other facilities or service-utility providers, as well as the risks from coincident events (e.g., extreme precipitation occurring during an extreme surge event). Any stakeholder can apply these guidelines to ensure that its infrastructure design is based on interdependencies consideration.13

c. Performance assessment

KPI Name: Alternative routes to control cascading failure.

Rationale: Systemic resilience is improved when there is more than one pathway to deliver a critical service because the alternative mechanisms to provide the services provide redundancy.

What to consider:

A. The coverage of cascading control: the number of operators that address interdependencies (e.g., through storage, alternative sources or ability to de-couple.)

B. The availability of alternative routes: The total number of possible alternative routes or modes to deliver the same critical service.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 No service interruption due to the availability of alternate routes or mode to deliver the same critical service.

4 No interruption in most infrastructure services due to the availability of alternate routes or mode to deliver the same critical services.

3 Limited interruption in some infrastructure services due to the availability of alternate routes or mode to deliver the same critical services.

2 Limited interruption in most infrastructure services due to the availability of alternate routes or mode to deliver the same critical services.

1 Significant interruptions in some infrastructure services due to the unavailability of alternate routes or mode to deliver the same critical services.

0 Significant interruptions in most infrastructure services due to the unavailability of alternate routes or mode to deliver the same critical services.

P2.4 Embed emergency management

Emergency management is critical for infrastructure resilience and disaster risk reduction and requires logistical resources as well as ensuring that infrastructure can provide access to first responders.

a. Stakeholder interventions

**Government**

- Provide financial resources to support the development of mature emergency plans and resources for the recovery of critical services in the event of an emergency.
- Assess existing capacity to manage emergencies.

**Operator**

- Devise, regularly test and improve emergency plans; and prepare pre-disaster recovery plans.
- Develop unified incident-command systems involving the appropriate range of public and private stakeholders; and develop response and recovery resource surge arrangements.
- Increase staff knowledge to deal with disruptions (e.g., drills, scenario testing).
- Collect information on emergency plans and their success using feedback from operators involved in emergency situations.
- Provide information as to the effectiveness of emergency management plans to government.

**Planner, designer, engineer and contractor interventions**

- Consider emergency events in their schemes for early warning and proactive response (e.g., design infrastructure with escape routes, access for emergency services, adequate redundancy of systems, and control centres).

**Financial partners**

- Ensure investment in emergency facilities to reduce losses.
- Assess the adequacy of emergency plans during financial analysis.
- Adjust insurance premiums based on operators' strength of emergency management.

**Institutions**

- Train and develop the skills of planners, designers, engineers and contractors to embed emergency management.
- Collect information on emergency plans and their success to continuously improve plans, designs and solutions that embrace emergency management.

**Civil society organizations**

- Collaborate with operators to prepare local communities for emergencies and participate as trained volunteer civil-protection forces when available.
- Prepare newsletters and community notices to raise awareness and improve community preparedness.
b. Example of interventions

Transport for New South Wales (NSW) uses table-top exercises and weather modelling at key locations to plan for emergency response to extreme weather. This gives a good understanding of not only the impact to rail assets and services, but also the capability of the network to provide evacuation routes to displaced persons during an emergency event. Transport for NSW can estimate the ability to evacuate passengers by rail based on several contingencies, including operating without signals, operating without electricity, and operating without both with diesel trains. This ability to predict a level of operation even in the worst of circumstances allows better inter-agency emergency planning for extreme events and contributes to a more resilient NSW.14

c. Performance assessment

KPI Name: Emergency management readiness.

Rationale: The investment in capacity to manage emergencies related to disrupted infrastructure systems has a direct relationship with the ability to recover critical services.

What to consider: The depth and breadth of formalized emergency-management mechanisms for all critical infrastructure sectors.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Mature and annually tested emergency-management plans, with strong financial support and governance, that provide back-up and dispatch of resources for effective early warning and critical services recovery.

4 Mature and regularly tested emergency-management plans with some limitations on resources or governance.

3 Emergency-management plans with some significant limitations or limited to just a single infrastructure sector.

2 Immature emergency plans that rely on informal relationships and do not account for future expectations of hazards.

1 Ad hoc emergency-management planning with minimal financial support.

0 No emergency-management planning.

P2.5 Design infrastructure to fail safely

When infrastructure is disrupted, it must be able to fail safely to protect its occupants by maintaining critical life-support conditions or passive survivability, for example through adequate storage, control over thermal capacity, appropriate back-up energy supply and security of hazardous materials. Safe-to-fail features are also important to avoid the failed infrastructure creating cascading impacts to other assets.

a. Stakeholder interventions

Government

• Communicate the importance of safe-to-fail infrastructure systems and components

• Encourage safe-to-fail systems and components requiring contractors and operators to report on their practices, and planners, designers and engineers to demonstrate compliance with good practices.


Regulators

- Collect evidence of the implementation of safe-to-fail solutions and of the reduced losses resulting from their implementation.

Owners and financial partners

- Invest only in those schemes and programmes that properly address storage capacity, thermal safety, energy supply and safe hazardous-material provision to support safe-to-fail outcomes.

Planners, designers and engineers

- Apply methods for safe-to-fail systems and components in their plans, designs and schemes and report on their activities (e.g., plan for back-up energy-supply solutions and design for hazardous substances controls).

Operators and contractors

- Implement operational and construction practices which deliver safe-to-fail systems and components, and report to the regulator about their practices.

Academia

- Devise fundamental knowledge to continuously improve approaches, technologies, methods in safe-to-fail systems and components for planned, in-construction, and operational infrastructure, and then feeds their findings back to the industry.

Institutions

- Develop training and skill-sharing schemes for their members to provide education and case studies of mechanisms for safe-to-fail solutions using academic know-how and industry good practice.

b. Example of interventions

The Indian Bend Wash, located in the city of Scottsdale, is an example of safe-to-fail flood infrastructure in the Phoenix metropolitan area. Constituting a length of 11 miles of parks, lakes, walking paths and golf courses, Indian Bend Wash is a greenbelt for the city that absorbs excess stormwater that otherwise would flood the city. Most of the year Indian Bend Wash serves as a place of recreation for city residents, and when it rains, it mitigates flooding that could damage the city. Whatever infrastructure is lost within the greenbelt is both minimal and relatively affordable when compared to the fiscal damages from flooding in neighbourhoods. By using this project as a case study, professionals can analyse and understand the benefits and difficulties of a successful safe-to-fail project.  


c. Performance assessment

KPI Name: Capacity and stability for safe-to-fail.

What to consider:

A. The storage capacity for safe-to-fail: Available storage capacity needed in the worst case of failure to maintain critical life-support conditions.

B. The back-up energy supply for safe-to-fail: Available back-up energy supply needed in the worst case of failure to maintain critical life-support conditions and support a controlled switch-off of infrastructure operations.

C. The security of hazardous materials for safe-to-fail: Number of hazardous materials stored or present in national infrastructure that are in scope of hazardous-material coding and management plans and is secured appropriately in the event of infrastructure failure.
Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Deliver safe-to-fail solutions in the worst case of failure for all critical infrastructure assets.
4 Deliver safe-to-fail solutions in the worst case of failure for most critical infrastructure assets.
3 Deliver safe-to-fail solutions in the worst case of failure for some critical infrastructure assets.
2 Deliver safe-to-fail solutions in the worst case of failure to a few critical infrastructure assets.
1 Deliver only partial safe-to-fail solutions in the worst case for critical infrastructure assets.
0 The existing solutions in the worst case of failure cannot guarantee adequate storage capacity and back-up energy supply are available to maintain critical life-support conditions.

There are several references that can be used for scoring this indicator, including: (i) LEED guidance identifying options for storage capacity for rainwater management; (ii) RELI specifying that indoor temperatures must be at or below outdoor temperatures in the summer, and above 50°F in the winter for up to four days; (iii) System flexibility of a power system, which is calculated by summing the amount of flexibility provided by online and offline generators; (iv) Hazardous Materials Indicator Code (HMIC) providing a coding system for hazardous materials in defence and aerospace.

P2.6 Design for multiple scales

Infrastructure designed to provide redundancy of critical services at different scales makes critical services less likely to be interrupted during a hazard. For example, a water-management programme can include water-storage tanks at community centres or other public facilities, to provide a back-up supply of water for multiple households in the event of a disruption in the water systems at regional or national level. In countries with low capacity to develop plans regionally, national policies tend to spill over to local policies. Improved co-ordination between levels of government and the scale for allocating public responsibilities and resources is therefore necessary.

a. Stakeholder interventions

**Government:**

- Request clarification from operators about functionality at national, regional and local levels, to encourage thinking about multiple scales of delivery.

**Regulators:**

- Encourage owners toward systems thinking and multiple scales for resilience, proposing improvements and norms which take account of sectoral differences.
 Owners

• Require that planners, designers and engineers consider diversity of scales in design for new infrastructure or adaptations to existing infrastructure.

Planners, designers, engineers and contractors

• Provide for flexibility and resourcing for diversity of scales to deal with failure of smaller components through regional or national redundancy (e.g., large power plants that can provide back-up power in the event of a local outage).

Operators

• Ensure that critical services can be delivered through a diversity of scales: national, regional and local, and operationalize redundancy for smaller-scale solutions.

Academia and Institutions

• Provides insight into assessment of diversity of scale and training and skills to develop competency to work with diversity of scale.

b. Example of interventions

The UK water-system regulator, Ofwat, is encouraging modular or adaptive solutions (where components can be easily replaced or upgraded), that can be scaled up when new information arrives, and that enable interventions at systems level as well as at the individual infrastructure level.21

Another example is the UK Infrastructure Transitions Research Consortium (ITRC) MISTRAL programme, that has developed a highly integrated analytics capability to inform strategic infrastructure decision-making across scales, from local to global.22

KPI Name: Cross-scale inter-connectivity.

Rationale: Diversity in the scale of national infrastructure (a mix of national or backbone networks, plus regional and local provision) improves systemic resilience when scales can inter-operate effectively (i.e., when one is not available, another can meet demand temporarily).

What to consider:

A. The number of effective inter-connections, i.e., those that connect alternative scales in infrastructure.

B. The number of potentially useful inter-connections. i.e., all existing effective inter-connections plus all possible future effective inter-connections.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 All infrastructure systems have sufficiently cross-scale redundancy to maintain services objectives in the event of a primary failure.

4 Most of the infrastructure systems have sufficiently cross-scale redundancy to maintain services objectives in the event of a primary failure.

3 Some infrastructure systems have sufficiently cross-scale redundancy to maintain services objectives in the event of a primary failure.

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Few infrastructure systems have sufficiently cross-scale redundancy to maintain services objectives in the event of a primary failure.

Very limited infrastructure systems have sufficiently cross-scale redundancy to maintain services objectives in the event of a primary failure.

No infrastructure systems have sufficiently cross-scale redundancy to maintain services objectives in the event of a primary failure.

P2.7 Commit to maintenance

A commitment to maintenance is required to reduce the impact of hazards and therefore increase systemic resilience.

a. Stakeholder interventions

Government

- Communicate the importance of maintenance for infrastructure systems and components.
- Update the authority of the regulator to demand compliance with good practice for maintenance and to collect evidence of maintenance designs, schemes and practices.

Regulators

- Demand compliance with good maintenance practices and collect evidence about the deterioration of assets due to lack of maintenance and about the reduced losses from the implementation of maintenance.

Owners and financial partners

- Prioritize investments into infrastructure that deal with maintenance explicitly.
- Set aside specific budget for infrastructure maintenance.

Planners, designers and engineers

- Address maintenance in plans, designs and schemes, and report on their activities.

Contractors

- Construct new infrastructure so it is easy and predictable to maintain, and report to the regulator about their practices.

Operators

- Commit to maintenance in operational systems, and report to the regulator about their practices.
- Identify maintenance needs and areas for improvement (e.g., Use condition monitoring and assessment).

Academia

- Devise fundamental knowledge on approaches, technologies and practices for better maintenance, and then feed their findings back to industry.

Institutions

- Develop training and skill-sharing schemes for their members to provide education and case studies of good practice on infrastructure maintenance using academic know-how and industry good practice.
b. Example of interventions

In the Netherlands, ProRail is using an asset-management database called SpoorData which creates a form of infrastructure passport including both configuration and control data of the infrastructure to analyse the usability of infrastructure assets. Configuration data consists of the (static) object data about ‘what is it’, ‘what can it do’ and ‘where is it’. Control data (dynamic) includes the maintenance data, failure data and condition data of an object.23


c. Performance assessment

KPI Name: Preventive maintenance investment.

Rationale: Regular and preventative performance-based maintenance sustains system performance effectively and increases operating life, reducing the probability that infrastructure components fail due to ageing and exposure to hazards.

What to consider:

A. Infrastructure performance usability level, which is defined based on a set of operational characteristics of the infrastructure depending on the infrastructure type and norms. For road infrastructure as an example, the Road Association of Spain assesses road-performance usability level based on surface scanning.24

B. Infrastructure maintenance budgets (e.g., Infrastructure maintenance budgets are available from OECD).25

### Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Well-funded maintenance budgets and preventative-maintenance investment to support system performance usability for all infrastructure sectors.

4 Well-funded maintenance budgets and preventative-maintenance investment for critical infrastructure sectors but limited maintenance budget for other infrastructure sectors.

3 Limited maintenance budgets and preventative-maintenance investment to support system performance usability for all infrastructure sectors.

2 Limited maintenance budgets and preventative-maintenance investment for critical infrastructure sectors but only marginally-funded maintenance budget for other infrastructure sectors.

1 Marginally-funded maintenance budgets and preventative-maintenance investment to support system performance usability for all infrastructure sectors.

0 No maintenance budgets and preventative-maintenance investment to support system performance usability for most infrastructure sectors.

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P2.8 Devise long-term investments

Long-term investment in infrastructure supports the economy, enhances productivity, and creates jobs. More broadly, government expenditure invested in disaster risk reduction provides a proxy for the ambitions to raise investment into resilience. Putting emphasis on a life-cycle approach allows government to attract backing from long-term investors, such as pension funds, that have an interest in maintaining the value of their assets over a long period of time.

a. Stakeholder interventions

**Government:**

- Create public policies that reward investment in resilience and require that public procurement considers lifecycle costs.
- Design procurement contracts that incentivize long-term investment in resilience (e.g., revise force-majeure provisions in public-private partnership (PPP) contracts so that the private partner has a vested interest in reducing disaster risks, as opposed to transferring force-majeure risks entirely to the public partner).

**Regulators**

- Prepare regulations based on sector inputs and local contexts, which encourage profits to be reinvested into resilience activities.
- Collaborate with the insurance industry to put in place regulations that incentivize insurance companies either to invest directly in infrastructure resilience or to design contracts that push policyholders to invest in resilience.

**Financial partners**

- Develop investment strategies that integrate the long-term benefits of investment in resilience. Incentivize owners, planners, designers, engineers and contractors to innovate for resilience and reward them through lower insurance premiums that reflect the lower likelihood of future claims.
- Provide parametric insurance based on predefined trigger events (e.g., covering flood losses in case of a pre-defined amount of rain) that protect from hazards the value of long-term investment.
- Integrate multi-risk hazards into financial modelling to test the resilience of infrastructure to different scenarios.
- Re-run financial models to quantify benefits from the improved resilience options over the asset lifecycle.
- Include resilience-related clauses in loan covenants.

**Owners**

- Maintain strong balance sheets capable of absorbing shocks and enabling long-term investment.

**Academia**

- Conduct research into forecasting, prediction and analytics to quantify in financial terms future exposure to risk trends.

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Institutions

- Develop guidance and build skills and competencies for long-term investment in resilience.

b. Example of interventions

The Coalition for Climate Resilient Investment has developed Guidelines for Integrating Physical Climate Risks in Infrastructure Investment Appraisal. These guidelines propose a collaborative approach of various specialists in a joint effort to advance a dynamic impact assessment of physical climate risks (PCRs), which can be incorporated in investment decision-making. The approach combines three main expert subject-matter areas: climate science, infrastructure asset management and engineering, and infrastructure finance.

28

KPI Name: Relative investment in resilience.

Rationale: Investment in infrastructure must be focused on the long term and on next generations. Appropriate investment to sustain resilience over the whole lifecycle of an infrastructure component (asset or sub-system) will reduce the pervasive short-term focus and assure a focus on long-term increased resilience.

What to consider: Investment in resilience over the lifecycle of the infrastructure asset.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Investment in increasing the lifespan of infrastructure components and rehabilitating or refurbishing those reaching end of life, which meets the long-term needs of all infrastructure sectors.

4 Investment in increasing the lifespan of infrastructure components and rehabilitating or refurbishing those reaching end of life, which meets the long-term needs of most infrastructure sectors.

3 Investment in increasing the lifespan of infrastructure components and rehabilitating or refurbishing those reaching end of life, which meets the long-term needs of some infrastructure sectors.

2 Limited investment in increasing the lifespan of infrastructure components and rehabilitating or refurbishing those reaching end of life, which just meets short-term needs of infrastructure sectors.

1 Very limited investment in increasing the lifespan of infrastructure components and rehabilitating or refurbishing those reaching end of life.

0 No investment in increasing the lifespan of infrastructure components and rehabilitating or refurbishing those reaching end of life.

Principle 3 (P3) – Environmentally integrated

The goal of this principle is to work in a positively integrated way with the natural environment. The main actions for realizing this goal are presented below.

P3.1 Minimising environmental impact

Minimising the adverse effect of infrastructure projects and operations on the ecosystem will reduce the risk of natural hazards and climate change.

a. Stakeholder interventions

Each stakeholder has a specific role in implementing this action.

**Government**

- Demand that contractors and operators minimize environmental impact through monitoring and advice.
- Manage data collection, recording and provision related to environmental-impact performance.
- Commission research on environmental impacts and incorporate findings into construction standards and codes.
- Mandate different impact assessments (e.g., environmental-impact assessments) to be performed before implementation depending on the scale and impact of the infrastructure considered.

**Regulators**

- Monitor and control the environmental impacts from infrastructure systems (e.g., audits).

**Financial partners**

- Apply rigorous environmental-impact assessment in investment decision-making.

**Planners, designers and engineers**

- Estimate and assess environmental impacts (e.g., system-dynamics modelling to measure stocks and flows of emissions).
- Examine alternatives and propose solutions that minimize negative environmental impacts.
- Collaborate with contractors and operators to ensure the implementation of plans, designs and schemes use processes that minimize environmental impact.
- Consider nature-based solutions where possible, to upgrade traditional approaches.

**Contractors**

- Make choices about materials, excavation and disposal of waste from construction that avoid environmental impact.

**Operators**

- Take actions to minimize environmental impacts (e.g., choose logistics methods for the supply of fuels and other resources that minimize negative environmental impact).
- Implement sensors and human examinations for measuring emissions, pollution and other negative environmental impacts.
**Academia**

- Conduct research on solutions that minimize the negative unintended systemic effects of the interventions (rebound effects) and promote restorative nature.

- Find ways to balance reduced impact trade-offs with other desired outcomes (e.g., increased mobility).

**Institutions**

- Provide skills and consultancy to enable professionals and regulators to reduce environmental impacts and improve regulations.

**b. Example of interventions**

China Hai Basin Integrated Water and Environment Management Project is to form an integrated approach to water-resource management and pollution control in the Hai River Basin, with the intention to improve the environment in the Bohai Sea area. This project includes reducing the pollution of the Bohai Bay and reversing the trend of water-quality deterioration and overuse of surface and groundwater resources from the basin. As approximately half of the wastewater pollution in the Hai River Basin comes from small and medium-sized cities, the project also aims to resolve the issue of wastewater pollution from these communities within the project area. For this project, a mixed-methods approach is taken, and the assessment focuses on the natural and ecological environments. This includes examining how wastewater treatment and recycling, and management of surface water and groundwater resources, affect soil conservation, forestry and vegetation, and the ecological environment of wetlands. 29

**c. Performance assessment**

**KPI Name:** Environmental impact assessment.

**What to consider:**

A. Potential environmental impacts for each project regarding emission, wastes, biodiversity, ecosystem services and transforming green spaces.

B. Particularly sensitive environmental systems within the impact area of the project.

**Indicative scoring criteria:** The following criteria could be used for scoring this indicator on a scale from 0 to 5:

- 5 Obligations and legislation for environmental-impact assessments of all infrastructure projects are in place, in line with international good practices, and enforced.

- 4 Obligations and legislation for environmental-impact assessments for some infrastructure projects or sectors are in line with international good practices and enforced.

- 3 Obligations for environmental-impact assessments are in place and enforced, but do not meet international good practices or fail to consider important environmental factors (e.g., biodiversity).

- 2 Obligations for environmental-impact assessments are in place but not systematically enforced.

- 1 Obligations for environmental-impact assessments are in place but not enforced nor meet international good practices.

- 0 No obligations and legislation for environmental-impact assessments of infrastructure projects are in place and enforced.

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P3.2 Use environmental solutions

The use of ecosystem assets and services, environmental infrastructure, green or blue infrastructure, environmental regeneration, or nature-based solutions, improves resilience by reducing stresses on the infrastructure systems.\(^\text{30}\)

a. Stakeholder interventions

*Governments*

- Provide incentives and support for using environmental solutions.\(^\text{31}\)
- Promote the use of environmental solutions and accounting for natural capital (i.e., measuring the changes in stock of natural capital and value of ecosystem services, for example through the use of natural-capital accounting).

*Planners, designers and engineers*

- Evaluate the cost benefits of environmental solutions in comparison to other conventional or grey alternatives.
- Apply environmental solutions as substitutions for grey assets (e.g., use environmental-impact assessment for assessing suitable green or blue solutions such as wetlands restoration).

*Operators*

- Monitor and report the costs and benefits of using environmental solutions.

*Academia*

- Conduct studies and analyses on natural capital and environmental solutions.

*Institutions*

- Provide professional training and services in identifying and evaluating ecosystem services and natural capital for the benefit of infrastructure resilience.

b. Example of interventions

Mangroves provide shoreline protection from climate-related and other disasters such as storms and tsunamis, and reduce flood-risks, inundation and erosion. Indonesia's mangroves also help mitigate the impact of climate change as they store a significant amount of carbon ~ 3.1 billion tons – equivalent to the greenhouse-gas emissions produced by approximately 2.5 billion vehicles driven for one year. For people living in coastal areas, mangroves are not just mere plants. Mangroves, which grow on the coastline and river mouths, serve as a barrier to seawater abrasion and reduce the risk of floods. They are the guardians of local homes and livelihood.\(^\text{32}\)

c. Performance assessment

**KPI Name:** Environmental solutions consideration.

**Rationale:** Using natural-capital accounting increases the likelihood of properly valuing the contribution of ecosystem assets and services to infrastructure resilience. It helps evaluate whether environmental solutions are more beneficial than traditional grey (non-environmental) solutions in having more-resilient infrastructure.


What to consider:

A. The stocks and flows of natural assets used as green or blue infrastructure.

B. Cost-benefit of utilising environmental solutions compared to utilising traditional grey (non-environmental) solutions.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Ecosystems assets and services are systematically considered as an option when assessing infrastructure development and their contributions to resilience are properly valued (e.g., through natural-capital accounting).

4 Ecosystems assets and services are systematically considered as an option when assessing infrastructure development but their contributions to resilience are not properly valued.

3 Ecosystems assets and services are sometimes considered as an option when assessing infrastructure development and their contributions to resilience are valued.

2 Ecosystems assets and services are sometimes considered as an option when assessing infrastructure development but their contribution to resilience is not valued.

1 Ecosystems assets and services are rarely considered as an option when assessing infrastructure development and their contribution to resilience is not valued.

0 Ecosystems assets and services are not considered as an option when assessing infrastructure development and their contribution to resilience is not valued.

Countries could assess their use of Natural Capital using a recognised or emerging framework, such as:

- The System of Environmental-Economic Accounting (SEEA), a framework that integrates economic and environmental data to provide a more comprehensive view of the interrelationships between the economy and the environment, as well as the stocks and changes in stocks of environmental assets.\(^\text{33}\)

- The Wealth Accounting and the Valuation of Ecosystem Services (WAVES), which is a partnership that promotes the mainstreaming of natural resources into development planning and national economic accounts.\(^\text{34}\)

- The International Union for Conservation of Nature (IUCN), which defines standards to equip users with a robust framework for designing and verifying nature-based solutions (NbS). The standard consists of eight criteria and 28 Indicators. Criterion 8 focuses on identifying economic viability of NbS using a cost-effectiveness study, cost-benefit assessment, or a multi-criteria economic analysis.\(^\text{35}\)

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P3.3 Integrate ecosystem information

Nationally significant infrastructure projects tend to have far-reaching impacts on the environment that may affect short and long-term resilience. Good design helps infrastructure project to respond to its context, reconciling it with its environment. Understanding the structure of its surroundings, topography, ground conditions, vegetation, microclimate and ecology at each site is the starting point for planning and moving toward more-environmentally-progressive solutions.\(^{36}\)

a. Stakeholder interventions

Governments

- Define design guides and codes at national and local levels for the use of environmental information in infrastructure planning.
- Promote the use of environmental information in infrastructure planning.

Regulators

- Establish evaluation mechanisms to track the effective use of environmental information in urban planning and infrastructure development.

Planners, designers, and engineers

- Provide master plans, urban plans and local development plans that consider the opportunities and threats from surrounding natural environment affecting the infrastructure project.

Academia

- Conducts studies on environmental information and its value for urban planning and infrastructure development.

Institutions

- Review and comment on effectiveness of urban planning and the use of environmental information for increased infrastructure resilience.

b. Example of interventions

A few decades ago, Singapore decided to channel the Kallang River, creating a linear fenced canal that was a clear dividing line between the park and community. In dire need of an upgrade, the concrete canal could be redesigned, but Singapore’s national water agency decided to naturalize the river by restoring the original riverbed and floodplain. A master plan was provided to analyse the natural environment. The 2.7 km straight concrete drainage channel was torn down and transformed into a meandering 3.2 km long natural river. The result is a blue-green infrastructure project that provides flood prevention and improved water quality, increasing the benefits of the canal to the community. Combining natural materials, civil-engineering techniques, and plants that can filter and absorb water was essential to stabilize the riverbanks and prevent erosion. The National University of Singapore carried out a cost-benefit analysis that reported that rebuilding the concrete canal would cost about US$94 million (133 million SGD, Singapore dollars). Naturalization, on the other hand, was just under US$50 million (70 million SGD) and further contributed to expanding and reconnecting the park areas to the city.\(^{37}\)

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c. Performance assessment

KPI Name: Integration of environmental information for planning.

Rationale: Including environmental and ecosystem information in the planning phase of new developments can help avoid losses caused by conflict with environmental context.

What to consider: The use of environment information in planning for infrastructure developments and adaptations (e.g., the share of infrastructure projects properly using environmental information compared to all infrastructure projects).

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Environment information, including findings from environmental assessment, is incorporated into the planning process of all infrastructure projects.

4 Environment information, including findings from environmental assessment, is incorporated into the planning process of most infrastructure projects.

3 Environment information, including findings from environmental assessment, is incorporated into the planning process of some infrastructure projects.

2 Environment information, including findings from environmental assessment, is partly incorporated into the planning process of some infrastructure projects.

1 Limited environment information is incorporated into the planning process of some infrastructure projects.

0 No environment information is incorporated into the planning process of infrastructure projects.

P3.4 Maintain the natural environment

Maintenance of the natural environment around infrastructure locations reduces exposure to damage and disruption of infrastructure services.

a. Stakeholder interventions

Government

• Must lay down policies so that contractors and operators maintain the surrounding natural environment to reduce threat of disruptions to critical services.

• Commission research programmes on natural-environment maintenance for the benefit of infrastructure resilience.

Regulators

• Ensure adherence to regulation that requires operators to maintain the surrounding natural environment.

• Implement monitoring and control of natural environment maintenance by operators (e.g., audits).

Financial partners

• Finance investments that support natural-environment maintenance.

• Recognize the increased risk for investments without proper natural-environment maintenance.

Planners, designers and engineers

• Estimate and assess the need for natural-environment maintenance as part of their plans, designs and schemes.
• Take measures in plans, designs and schemes to reduce the need for natural-environment maintenance.

**Operators and contractors**

• Take actions to maintain the natural environment and assess the effectiveness of this maintenance (e.g., record differences in actual and planned maintenance, use digital methods to record natural-environment maintenance).

• Recommend improvements for proactive maintenance (e.g., model the likely growth of vegetation and impact of hazards, use drones to capture data on the extent of potential damage).

• Inform the public about maintenance practices.

**Academia**

• Provide research on methods for natural-environment maintenance and investigate alternatives for detecting, scheduling and delivering timely and appropriate maintenance.

• Conduct research and field studies to provide fundamental insights into alternatives for maintenance of different natural environments (rivers, lakes, coasts, vegetation, flora, rocks, banks and culverts).

• Devise tools to assess the effectiveness of natural-environment maintenance (e.g., use modelling to determine optimal and flexible schemes for planning and scheduling timely maintenance).

**Institutions**

• Provide skills to prioritize and schedule maintenance of the natural environment around infrastructure locations.

• Encourage the sharing of successes across the industry, and conduct expert events.

b. Example of interventions

Green infrastructure can increase the resilience of transportation infrastructure. For example, planting trees and other vegetation along roadways provides shade, reducing the amount of heat absorbed by the road. This can help to mitigate the risk of thermal cracking and other damage caused by extreme temperatures. In addition, trees can help address the risk of flooding and erosion along the road by absorbing large amounts of water and limiting flows into stormwater systems. However, poor maintenance of trees reduces the resilience of roads in several ways. For example, dead trees may fall onto the road or nearby infrastructure, causing damage and potential safety hazards, while trees with invasive root systems can damage pipes and cables, leading to costly repairs and disruptions to services.

c. Performance assessment

**KPI Name:** Provisions for natural environment maintenance.

**Rationale:** Lowering the downtime caused by surrounding natural environment increases resilience of infrastructure systems. This is achievable by managing and maintaining well the natural environment at and around infrastructure locations.

**What to consider:**

A. Duration of unscheduled downtime caused by surrounding natural environment.

B. Regulation related to natural-environment maintenance.
Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Adequate regulatory provisions for maintaining the surrounding natural environment by infrastructure operators are in place and enforced for all infrastructure sectors.

4 Adequate regulatory provisions for maintaining the surrounding natural environment by infrastructure operators are in place and enforced for critical sectors infrastructure sectors.

3 Adequate regulatory provisions for maintaining the surrounding natural environment by infrastructure operators are in place but only partially enforced for infrastructure sectors.

2 Adequate regulatory provisions for maintaining the surrounding natural environment by infrastructure operators are in place but generally not enforced for infrastructure sectors.

1 Adequate regulatory provisions for maintaining the surrounding natural environment by infrastructure operators are in place for limited infrastructure sectors and generally not enforced.

0 Adequate regulatory provisions for maintaining the surrounding natural environment by infrastructure operators are not in place for any infrastructure sector.

P3.5 Use local sustainable resources

Resources available locally - such as raw materials, products and parts, local energy and skills - provide greater resilience than those distant or provided through complex supply routes.

a. Stakeholder interventions

**Government**

- Identify local resources and encourage their use for infrastructure projects, for instance through procurement or regulation, incentives and disincentives.
- Make provision to increase local capacity and encourage its use.

**Regulators**

- Ensure adherence to procurement regulations.

**Planners, designers, engineers and contractors**

- Consider the availability of local resources in planning and design choices.
- Substitute distant or single-sourced materials, as well as non-renewable resources, with locally available resources.

**Operators**

- Use local resources in operational phases and record the actual use of local resources.
- Evaluate and monitor the effectiveness of local resources (e.g., analyse of the benefits of using local resources).

**Academia**

- Provide research on the alternatives for local materials to substitute for traditional materials.
b. Example of interventions

The Indian Government has promoted solar rooftop photovoltaic systems among rural and urban areas recognizing that this decentralized technology is best suited for providing energy security by using local renewable resources.38

c. Performance assessment

KPI Name: Consumption of local sustainable resources.

Rationale: A higher proportion of local energy consumption and other local resources, adjusting for local capacity, improves the resilience of infrastructure by increasing access during disturbances.

What to consider:

A. The proportion of local renewable energy: the annual consumption of energy coming from local resources (renewable energy or material resources) divided by the total annual energy consumed.

B. The proportion of local materials: the annual consumption of materials coming from local sources (rather than national or international supply chains) divided by the total annual materials consumed.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Sustainable procurement requirements exist and are enforced for all infrastructure at national and subnational level.

4 Sustainable procurement requirements exist and are enforced for some infrastructure at national and subnational level.

3 Sustainable procurement requirements exist and are enforced for some infrastructures.

2 Sustainable procurement requirements exist for infrastructure developments, but are only partially enforced.

1 Sustainable procurement requirements exist for infrastructure developments, but are not enforced.

0 No sustainable procurement requirements exist.

Principle 4 (P4) – Socially engaged

The goal of this principle is to develop active engagement, involvement and participation across all levels of society. The main actions to realize this goal are presented below.

P4.1 Inform people about disruptions

Ensuring good quality of communication to infrastructure stakeholders and users of critical services about disruptions will reduce demand for services and allow operators to focus on the recovery of critical services.

a. Stakeholder interventions

Government

• Define guidelines for providing clear emergency messages (e.g., select the lowest literacy level for emergency messages that are compatible with the literacy level of the population).

• Mandate obligations to develop appropriate communication facilities (e.g., obligation on the digital communications sector to provide agreed levels of service in the event of disruption or emergency, investment in alternative communications channels).

• Ensure contractors and operators conduct regular testing and use appropriate channels for emergency communications.

Planners, designers and engineers

• Integrate emergency communication in their solutions.

• Plan for communications channels that will be available to people using critical services, so they can receive information in the event of disruption or emergency.

Contractors and operators

• Provide plans and instructions for communicating with people using critical services to receive information in the event of disruption or emergency.

• Use social media as well as traditional communications via radio and television.

• Have a hierarchy of preferred communication channels that are available during a disruption or emergency, and select the highest available one.

• Use communications channels available during a disruption or emergency to transmit information about disruptions.

Institutions and civil society

• Promote the use of accessible communications channels in local communities and improve knowledge about their use during an emergency.

• Recognize that some groups of the population may be disadvantaged or culturally excluded and may not have access to communications generally available to others.

• Collaborate with planners, designers, engineers, contractors and operators to provide plans and instructions for acting in emergency situations to deliver key messages.

• Use training and community events to share knowledge and build local understanding.
**b. Example of interventions**

**Example 1:** A major public-health challenge is to communicate effectively with vulnerable populations about preparing for disasters and other health emergencies. People who are deaf or hard of hearing (Deaf/HH) and older adults are particularly vulnerable during emergencies and require communications that are accessible and understandable. A study explored issues related to emergency preparedness materials (EPM) for deaf/HH and older adult populations, to assess the availability and readability of materials for these populations.  

**Example 2:** Hurricane Katrina provides a major lesson on communication challenges. Strategies in response to a disaster include the use of portable back-up systems, mobile platforms and radio systems to overcome the consequences of failed communications systems and failures in energy systems that trigger failures in communications systems.

**c. Performance assessment**

**KPI Name:** Communication facilitation.

**Rationale:** Informing people in a way suitable to their literacy level and communication access will allow them to prepare effectively for, and respond to, resilience-threatening situations.

**What to consider:**

A. Readability of messages, including considering different native languages.

B. Access level of population to communication channels during a disruption or emergency.

**Indicative scoring criteria:** The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5. The literacy level used in all emergency messages can be read by the target community and can be accessed by communication channels available to all the community.

4. The literacy level used in all emergency messages can be read by most of the target community and can be accessed by communication channels available to most of the community.

3. The literacy level used in most emergency messages can be read by most of the target community or can be accessed by communication channels available to most of the community.

2. The literacy level used in most emergency messages can be read by less than half of the target community or can be accessed by less than half of the community because of the communication channels used for the emergency messages.

1. The literacy level used in any emergency messages cannot be read by most of the target community or cannot be accessed by most of the community because of the communication channels used for the emergency messages.

0. The literacy level used in any emergency messages cannot be read by most of the target community and cannot be accessed by most of the community because of the communication channels used for the emergency messages.

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P4.2 Raise resilience literacy

Education in resilience increases resilience literacy and the ability of the population to engage and support infrastructure resilience.

a. Stakeholder interventions

**Government**

- Promote education about resiliency, taking advantage of formal education programmes and local media, depending on the target audience.
- Consider introducing resilience literacy content in the curriculum of secondary schools.
- Evaluate the level of knowledge in the population about infrastructure resilience and collect data about the literacy levels of the population.
- Empower the regulator to track improvements in resilience literacy.

**Regulators**

- Collect information on improvements to resilience literacy.
- Track and enforce education-system compliance.

**Operators**

- Contribute to updating and improving educational content for consumers that is appropriate for the national literacy level.

**Academia and institutions**

- Provide scientific knowledge on the effectiveness of higher resilience literacy.
- Contribute to updating and improving educational content and programmes on resilient infrastructure.
- Provide teaching materials to train educators, and guidelines on how to include training in education programmes.

**Civil society**

- Support government, regulator and operator initiatives to increase resilience literacy of communities.

b. Example of interventions

Literacy in resilience can help individuals understand the importance of infrastructure resilience and support initiatives to improve it. For example, a community with resilience literacy may be more likely to advocate for the installation of backup systems or the reinforcement of critical infrastructure. Similarly, literacy in resilience can enhance community preparedness and response to different hazards, which can reduce the overall impact of these hazards on infrastructure disruptions.
c. Performance assessment

**KPI Name:** Training in infrastructure resilience.

**Rationale:** Children, adolescents and adults who become equipped with the knowledge, skills and values to make responsible choices and take appropriate action to sustain infrastructure resilience will provide support and protect the resilience of infrastructure. Typical content for providing resilience of infrastructure education should cover: a) necessity and techniques of responsiveness to reduce consumption (avoiding unnecessary demand) to minimize pressure on supply side; b) updated information on new technical advancements and transition plans to increase awareness and acceptance; c) developing resilience literacy by teaching relevant terminologies for more effective communication. School programmes could include these elements through case studies, awareness campaigns and field trips that help children understand the concept of resilience and how to apply it in their communities.

**What to consider:** Schools, education, and training establishments have educators trained in infrastructure resilience or programmes for communities to build resilience literacy not associated with the formal education system.

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**Indicative scoring criteria:** The following criteria could be used for scoring this indicator on a scale from 0 to 5.

Schools, education, building resilience programmes and training establishments (accessible by the public) provide:

5 Mandatory infrastructure resilience training and activities to all children (above 11 years) and adults, which are provided by teachers with up-to-date training in infrastructure resilience.

4 Mandatory infrastructure resilience training and activities to most children (above 11 years) and adults, which are provided by teachers with up-to-date training in infrastructure resilience.

3 Optional infrastructure resilience training and activities to most children (above 11 years) and adults, which are provided by teachers with training in infrastructure resilience.

2 Optional infrastructure resilience training and activities to most children (above 11 years) and adults, which are provided by teachers who may not have training in infrastructure resilience.

1 Optional infrastructure resilience training and activities to some children (above 11 years) and adults, which are provided by teachers who may not have training in infrastructure resilience.

0 Optional infrastructure resilience training and activities to few or no children (above 11 years) and adults.

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P4.3 Incentivize demand behaviour

When supply of infrastructure services becomes challenging, incentives for reduced demand will improve resilience and can avoid disruption.

a. Stakeholder interventions

**Government**

- Define obligations for infrastructure sectors to adopt incentive policies or strategies for demand reduction, demand shifting or demand avoidance.
- Prioritize critical services to vulnerable and disadvantaged users and those providing social infrastructure (hospitals and fire services) or essential industrial, business or government services in case of disruptions.
- Empower the regulator to collect information on the scale and diversity of incentives.

**Regulator**

- Define reporting mechanisms to track and enforce incentive policy or strategy for demand reduction.
- Assess the success of incentives.

**Operators**

- Promote incentive strategies to users and record the scale and diversity of use of incentives.
- Record data related to causes and durations of interruptions related to excessive consumer demand.

**Academia**

- Provide guidelines and tools on incentives that allow users to be responsive to operator requests for demand management.

**Institutions**

- Implement two-way communication between academia and operators to share each other’s findings on successful practices.

**Civil society**

- Identify the best approaches to increasing public participation and engagement.

b. Example of interventions

In November 2022, the British government launched an information campaign to persuade the British public to save energy ahead of the cold winter months. The government said the public information campaign, called Help for Households, would offer technical tips and advice for people to cut their energy use while still staying warm. These include measures such as draught-proofing windows, turning down radiators in empty rooms, and reducing boiler temperatures.

44 Financial Times, Rishi Sunak signs off on £18mn public information campaign to save energy, [Online]. Available: https://www.ft.com/content/d55c422f-ec1e-47c6-a298-984c057bd8a5

**c. Performance assessment**

**KPI Name:** Demand management effectiveness.

**Rationale:** Incentives for demand reduction lead to greater resilience through reduced demand during supply disruptions. The effectiveness of incentive schemes can be evaluated by the reduction in the duration of infrastructure interruptions caused by excessive end-user demand affecting infrastructure resilience (e.g., peak hours). It is expected that excessive end-user demand will vary at different times of the year, so the indicator should be measured regularly (e.g., monthly).

**What to consider:**

A. The penalties or strategies or obligations for demand reduction.
B. The requirement for periodic reporting of demand reduction.

C. The interruption to service due to excessive user demand.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 No interruption because of excessive demand.
4 Few interruptions because of excessive demand.
3 Half of all interruptions are because of excessive demand.
2 Above half of all interruptions are because of excessive demand.
1 Most of interruptions are because of excessive demand.
0 All interruptions are because of excessive demand.

An illustration of how this indicator can be computed is the Council of European Energy Regulators (CEER), which has routinely analysed and reported since 2001 on the quality of electricity and gas supply in European countries, focusing on the interruption data. The main indicators covered in this report include: System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI). In these series of reports, distinctions are made between interruptions based on criteria of their cause.45

P4.4 Encourage community participation

Engaging appropriately with communities and users on infrastructure resilience, including understanding them and their composition, is an opportunity to build connection and understanding between operators (and contractors) and users. It is also an opportunity to minimize negative community behaviour toward infrastructure systems (e.g., vandalism). Furthermore, including the community that benefits from, or faces the risk of, infrastructure in the decision-making progress, responds to a social-justice perspective and brings local knowledge into infrastructure resilience.

a. Stakeholder interventions

Government

• Encourage operators to develop community-participation programmes.

• Engage with civil society to obtain participation from users and communities.

Regulators

• Monitor community participation and report on its effectiveness (e.g. reduced vandalism from construction sites, proactive co-creation of community response to disruptions).

Operators and contractors

• Engage with civil society to conduct public-outreach events.

• Shape the goals for community participation with communities.

• Collect and provide information on outputs and impact of community participation.

Civil society

- Identify and engage target communities to create participation and receive feedback.
- Communicate the needs of users and their communities to contractors and operators.
- Build on trust to gain participation.

b. Example of interventions

A participatory budget in Brazil's Porto Alegre supports participation in a city of over 1.4 million inhabitants, as well as for prioritizing public investments based on three main criteria: unmet basic needs, population, and citizen preferences. The budget is just one element in a broader complex system of participatory governance.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 All people in the target community are participating and contributing to shaping resilience outcomes.
4 Most of the people in the target community are participating and contributing to shaping resilience outcomes.
3 Half of the people in the target community are participating and contributing to shaping resilience outcomes.
2 Below half of the people in the target community are participating and contributing to shaping resilience outcomes.
1 Few people in the target community are participating and contributing to shaping resilience outcomes.
0 No people in the target community are participating and contributing to shaping resilience outcomes.

An example for computing this indicator is the Pinellas County Metropolitan Planning Organization (MPO) in Florida that examines several indicators to evaluate its information activities, including the number of hits on its website and the number of times relevant documents and maps were visited and viewed. Counting mechanisms were built directly into their website. The MPO also used a pop-up web survey to learn how citizens stayed informed about MPO activities. The MPO also developed and implemented a tracking system to capture data about its public-outreach events (which could be categorized as either consult or involve).

Name: Community participation.

Rationale: Informing and engaging the community improves the sense of belonging and trust, which strengthens the resilience of infrastructure.

What to consider:

A. The scale of participation: Number of engaged people in informing processes and public outreach events.

B. The quality of participation based on feedback from community participants and the level of participation and contribution to shaping resilience outcomes.


Principle 5 (P5) – Shared responsibility

The goal of this principle is to share information and expertise for coordinated benefits. The main actions to realize this goal are presented below.

P5.1 - Harmonize open standards

Common standards and practices can facilitate the sharing of data across sectors and ensure they are usable by all infrastructure stakeholders. As such, harmonized open-data standards enable collaboration between different stakeholders, including governments, private organizations and the public. This allows for better coordination and information sharing, which can improve the overall resilience of infrastructure systems. This also facilitates innovation by enabling developers to create new applications and services based on open data, which can lead to solutions to improve infrastructure resilience.

a. Stakeholder interventions

Government

• Engage with stakeholders and experts to select or devise information-sharing standards and incorporate them into regulation and law.

Regulators

• Enforce government rules and regulations through checks on compliance with information-sharing standards and deterrence to undesirable practices (e.g., fines).

Planners, designers and engineers

• Create designs that facilitate information collection throughout the infrastructure lifecycle.

• Select necessary and appropriate information-sharing standards for the project.

• Develop and use building informational modelling (BIM), which is a digital representation of the physical and functional characteristics of an infrastructure asset.

• Standardise handover documents at the end of the pre-operational stage.

Contractors and operators

• Collect construction and operational data formatted in compliance with relevant standards.

• Ensure that relevant operational data is made available where possible or appropriate, to support infrastructure resilience.

• Use sensors to collect data and information systems to consolidate and analyse data.

• Adhere to data-sharing protocols (publication format and templates).

• Adopt good data stewardship to preserve and improve the information content, accessibility, and usability of data and metadata.  

Institutions

• Provide training and skills development in standards for sharing information on infrastructure resilience.

b. Example of interventions

The Common Alerting Protocol (CAP), proposed

by the International Telecommunication Union (ITU), offers a format for exchanging all-hazard emergency alerts and public warnings over a broad diversity of ICT networks. By disseminating a consistent warning message over multiple warning systems, the effectiveness of the message increases while simplifying the warning task.\(^{50}\)

c. Performance assessment

**KPI Name:** Compliance with open standards for information sharing.

**Rationale:** Planning and design stages should consider standards and ensure relevant data can be sourced and reported in accordance with them.

**What to consider:**

A. Percentage of project assets that meet information-sharing standards.

B. The scope of resilience-related information covered by information-sharing standards.

C. The scale of operational data that is published according to open standards.

D. The frequency of publication of operational data.

E. The frequency of compliance checks.

**Indicative scoring criteria:** The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Infrastructure projects are subject to formal, national-level information-sharing standards.

4 Infrastructure projects are subject to formal, regional or local-level, information-sharing standards.

3 Infrastructure projects are subject to informal, national-level information-sharing guidelines.

2 Infrastructure projects are subject to informal, regional or local-level, information-sharing guidelines.

1 Infrastructure projects set out their own information-sharing policy,

0 Infrastructure projects are not subject to any information-sharing standards or guidelines.

**P5.2 - Cultivate collaborative management**

Fostering open communication within and between sectors and enabling inter-sectoral exchange will provide opportunities for learning and improvement in infrastructure resilience. For example, the collaboration between the power and transport sectors can increase infrastructure resilience by improving the coordination of infrastructure planning, ensuring that new power and transportation infrastructure projects are designed and built with the needs of both sectors in mind.

**a. Stakeholder interventions**

**Government**

- Work with stakeholders and experts to encourage multi- and trans-sectoral collaboration for better infrastructure resilience.

**Contractors and operators**

- Create methods of communication and exchange to share and embrace the knowledge available from infrastructure stakeholders.

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Civil society

- Represent their communities on boards
- Engage with communities to gather key information and communicate this effectively to contractors and operators.

b. Example of interventions

A way to enable better coordination and cooperation is to create a register of critical infrastructure assets. By having a centralized list of assets, it is easier to share information and coordinate efforts to protect these assets. For example, in Australia, the government has created a Register of Critical Infrastructure Assets, which addresses gaps in the Australian government’s understanding of who owns and controls critical infrastructure assets.

C. Performance assessment

KPI Name: Collaborative management.

Rationale: Collaborative teams improve resilience through shared motivations and objectives for resilience. It is important to establish an environment in which relationships can be developed for sharing knowledge and expertise across boundaries.

What to consider: The scope and scale of formal collaborative management.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 A large variety of organizations, including community organizations, are involved in a cross-sector partnership designed to identify and address vulnerabilities in critical infrastructure systems. Meetings are held at least twice a year.

4 A large variety of organizations, including community organizations, are involved in a cross-sector partnership designed to identify and address vulnerabilities in critical infrastructure systems. Meetings are held at least once a year.

3 A limited variety of organizations are involved in a cross-sector partnership designed to identify and address vulnerabilities in critical infrastructure systems. Meetings are held at least twice a year.

2 A limited variety of organizations are involved in a cross-sector partnership designed to identify and address vulnerabilities in critical infrastructure systems. Meetings are held at least once a year.

1 There is a cross-sector partnership in place to address vulnerabilities in critical infrastructure systems, but the partnership is largely inactive.

0 There is no formal cross-sector partnership in place.
P5.3 - Establish clear accountability

Identifying the responsibilities of different stakeholders and organizations in their objectives, operations and assets, and putting these responsibilities at the centre of communication and engagement efforts, will create transparent and explicit pathways to ensure accountability for infrastructure resilience.

a. Stakeholder interventions

**Government**

• Assign clear accountability and roles to operators and other stakeholders.

• Develop and implement an accountability system for infrastructure resilience.

• Provide clear lines of communication.

**Regulators**

• Enforce compliance with accountability rules for infrastructure resilience.

• Report on the rules effectiveness.

**Planners, designers and engineers**

• Provide plans and designs in alignment with accountability requirements.

• Engage with contractors and operators as required to comply with accountability requirements.

**Contractors and operators**

• Follow accountability regulations in construction and operation of assets, including supporting clear communication.

**Civil society**

• Communicate responsibilities and build capacity as appropriate in communities.

• Take action during the recovery phase and carry out assigned tasks as required.

b. Example of interventions

In 1981, the Hyatt Regency walkway collapsed in Missouri, USA, killing 114 after contractors deviated from original design plans (to improve the feasibility of construction). Investigations found that there was a significant failure in communication between engineers and manufacturers, leading to incorrect assumptions. In the aftermath of this disaster, the American Society of Civil Engineers adopted a new policy specifying that structural engineers were to carry ultimate responsibility for reviewing shop drawings by fabricators.52

c. Performance assessment

**KPI Name:** Infrastructure resilience accountability.

**Rationale:** Accountability and clear understanding of roles and responsibilities supports good governance and leads to greater resilience. Identifying the responsibilities of different stakeholders and organizations - in their objectives, operations and assets - creates accountability and clarity. Placing these responsibilities at the centre of communication and engagement efforts can enable a more co-ordinated and rapid response to threats or failure events.

**What to consider:**

A. The scope and scale of formal accountability requirements.

B. The transparency and availability of requirements.

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Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 **Infrastructure projects are subject to formal, national-level accountability standards during pre-operational, operational and post-operational stages.**

4 **Infrastructure projects are subject to formal, regional or local-level, accountability standards during pre-operational, operational and post-operational stages.**

3 **Infrastructure projects are subject to informal, national-level accountability guidelines during pre-operational, operational and post-operational stages.**

2 **Infrastructure projects are subject to informal, regional or local-level, accountability guidelines OR infrastructure projects are subject to any level of formal accountability standards during only the operational stage.**

1 **Infrastructure projects set out their own accountability policy.**

0 **Infrastructure projects are not subject to any accountability standards or guidelines.**

### P5.4 - Enhance connectivity for information sharing

Enhanced connectivity enables sharing valuable information, including data, knowledge and operational practices. Infrastructure stakeholders should have adequate platforms for sharing information securely on infrastructure resilience (see P5.5). Beyond digital connectivity, it is important to establish an environment for sharing resilience knowledge across boundaries, including technical and specialist expertise. Appropriate information could also be shared between nations to improve learning from each other.

#### a. Stakeholder interventions

**Government**

- Creates and utilizes data-sharing platforms with sufficiently robust and pervasive communication channels to disseminate information to relevant stakeholders effectively.
- Collate and share data rapidly during disruptions to enable a co-ordinated response.
- Conduct post-disaster reviews and analyse the effectiveness of communication channels for future failures of the same type.
- Creates networks to ensure academic research is driven by policy needs.

**Operators**

- Develop skills in sharing information.
- Develop information-sharing mechanisms with neighbouring jurisdictions and other infrastructure operators for mutual aid.
- Immediately after failure, disseminate relevant information about affected areas to response teams through pre-established communication channels.

**Academia**

- Create strong partnerships with government and industry (engineers, designers, contractors) to ensure that industry or policy needs lead research and that innovative solutions are fed back into public policy and industry.

**Institutions**

- Develop training and skill-sharing schemes for sharing knowledge and expertise within their organizations.
b. Example of interventions

In the US, Information Sharing and Analysis Centres (ISACs) have been established to help critical infrastructure owners and operators protect their facilities, employees and customers from cyber and physical security threats and other hazards. ISACs collect, analyse and disseminate actionable threat information to their members, and provide members with tools to mitigate risks and enhance resiliency. The National Council of ISACs (NCI) oversees the work of ISACs to facilitate cross-sector coordination, particularly during security incidents and disasters with natural-hazard origin.53


c. Performance assessment

KPI Name: Shared data.

Rationale: Data sharing between organizations and with the public can generate shared insight and prevent the repetition of mistakes or failures. This can support necessary adaptations or facilitate a more effective response to threats of hazards.

What to consider:

A. Scope of membership of relevant data stewardship organizations for national statistical data.54

B. Frequency of data publication or refreshing.

C. The extent to which data is shared.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Data sharing capacity and platforms are developed and project data is shared with a national-level data-stewardship institution and refreshed every six months or less.

4 Data sharing capacity and platforms are partially developed and project data is shared with a national-level data-stewardship institution and refreshed every six to 12 months.

3 Data sharing capacity and platforms are fragmented and project data is shared with a regional or local-level data-stewardship institution and refreshed every six months or less.

2 Data sharing capacity and platforms are limited and project data is shared with a regional or local-level data-stewardship institution and refreshed every six to 12 months.

1 Data sharing capacity and platforms are non-existent and project data has been shared with a stewardship institution but not refreshed, OR project has assigned its own data steward within the operational team.

0 The project has no data stewardship.

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P5.5 - Assure data safety to develop trust

Good data practices encourage sharing of data between organizations and improve resilience to malicious attacks. While sharing data brings many benefits, it can only be achieved if the data is secure. P5.5 thus underpins the successful implementation of P5.4, which is concerned with sharing data. Implementing data governance, accountability, privacy and security are essential to building trust. Establishing data-stewardship organizations (such as national statistic offices for infrastructure performance data), government regulations, and technologies such as secured gateways, are some of the ways data security can be improved.55

a. Stakeholder interventions

Government

- Develop and formalize data-security regulations for the purposes of infrastructure resilience.
- Set out requirements for data-security assessment.

Regulators

- Enforce government rules and regulations on secure information sharing.
- Conduct data-security assessments and collect and monitor data-security assessment results.

Planners, designers, engineers and contractors

- Secure data during the design and construction phase through adherence to data-security standards.

Operators

- Ensure security while storing and sharing data
- Develop public trust in their data security through transparent reporting and frequent assessment.

Academia

- Research into data-security measures and mechanisms.

b. Example of interventions

The Wider Eastern Information Stakeholder Forum (WEISF), UK, is a partnership network of information-governance professionals supporting good information governance and best practice. It helps partners with GDPR (General Data Protection Regulation) compliance and transparency in sharing data. The partners work together to develop a standardized ISP template and publish ISPs on the WEISF portal for transparency. The protocol details how and what data partners share. It also explains the legal basis for sharing.56

c. Performance assessment

KPI Name: Data governance.

Rationale: Organizations that are involved in sharing data must ensure that data security is implemented. Loss or corruption of data will destroy confidence and trust. Secure data practices encourage sharing of data between organizations and improve resilience to malicious attacks. The development and implementation of secure data practices also builds public trust.

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What to consider:

A. Scope and scale of data-security standard.

B. Frequency of audit or assessment.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Project data is subject to formal, national or international-level, security standards. Implementation of data standards is audited annually.

4 Project data is subject to formal, regional or local-level, security standards. Implementation of data standards is audited annually.

3 Project data is subject to some formal security standard. Implementation of data standards is audited less than annually.

2 Project data is subject to informal security guidelines. Implementation of data standards is audited less than annually.

1 Infrastructure projects set out their own data-security policy.

0 Project data is not subject to any security standards or guidelines.

P5.6 - Share risk-and-return information

The disclosure of high-quality information related to risk assessment is critical for effective decision-making by investors and other stakeholders, and for securing investments in resilience. Investor demand for greater transparency includes requests for the disclosure of non-financial information, such as environmental, social, and governance (ESG) as well as climate-change data, that allows the resilience of infrastructure to be assessed more accurately. This type of information sharing also facilitates the pricing of social benefits, such as quality-of-life improvements, reduced casualties and enabling investment in other sectors.

a. Stakeholder interventions

Government

• Emphasizes the importance of sharing risk-and-return information between owners, investors and other relevant stakeholders.

Regulators

• Define clear guidelines for risk-and-return transparency mechanisms (e.g., ESG reporting) that will encourage or eliminate impediments to resilient infrastructure investment.

• Promote risk-sharing mechanisms for infrastructure projects based on the needs of stakeholders and lessons learnt from previous risk-sharing schemes.

Owners and Financial partners

• Implement risk-and-return transparency mechanisms but safeguard the release of information that would affect the security of national infrastructure.

• Assess liability in the event of force majeure and the consequences of risk transfer on investment capital.

Planners, designers, engineers, contractors and operators

• Cooperate in evaluating and updating risk information and transparency reporting on plans, schemes, existing systems and components.
**Academia**

- Conduct fundamental and applied research on transparency of risk-and-return information, including strategies to address unintended consequences.

**Institutions**

- Develop training and skill-sharing schemes for their members on risk-and-return transparency using academic know-how and industry good practice.

**Civil society**

- Represent the public, businesses and industry in supporting risk assessments for transparency of planned and operational systems.

b. Example of interventions

Different rating tools have been developed to provide investors with information about the resilience of infrastructure assets (e.g., Envision, GRESB). Another example is the Real Estate Resilience Tool developed by UNDRR, which provides information and a strategic-level evaluation to help real-estate business leaders in any setting to value, assess and plan for asset and operational resilience.

c. Performance assessment

**KPI Name:** Risk reporting obligations.

**Rationale:** The transparency and availability of information to forecast revenue and costs, and have effective risk-and-return assessment, is a paramount consideration to securing investment in resilient infrastructure. Sustainable development projects fail if they are not risk-informed and risk resilient.

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**What to consider:**

A. Risk reporting by infrastructure actors.

B. Functioning formal committee (government body, international standard organization or similar) responsible for defining risk-reporting obligations.

<table>
<thead>
<tr>
<th>Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
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</table>
Principle 6 (P6) – Adaptively transforming

The goal of this principle is to adapt and transform to changing needs. The main actions to realize this goal are presented below.

P6.1 - Choose manageable solutions

The selection of infrastructure solutions should consider the skills and resources available, their fitness and acceptability for the local contexts, and their ability to handle a changing environment. In this context, adopting modular approaches can provide benefits. Modularity is the extent to which components of a system can be separated or decoupled from one another, or added to the system, without affecting the functioning of other components. Using modular components can provide flexibility and simplify repair. Also, it is important to consider the manageability and feasibility of the solutions to be implemented. It may be appropriate to adjust the complexity of solutions in response to changing operating conditions and transform the infrastructure as the availability of resources and needs of users evolve.

a. Stakeholder interventions

**Planners, designers and engineers**

- Work with civil society to assess the local resources and capacity available.
- Design systems according to local resources and capacity.
- Provide designs that consider the local context when selecting the level of modularity and complexity.

**Contractors**

- Develop supply chains that facilitate appropriate levels of modularity and complexity.
- Prioritize locally available resources and repair knowledge.

**Operators**

- Consider the local context in which the project operates when making decisions regarding site selection, component selection and maintenance provision.
- Ensure maintenance and repair facilities are available.

**Academia and institutions**

- Promote modular design and context-appropriate solutions through education and training.

b. Example of interventions

In 2021, Population Matters, a UK-based charity, launched a crowdfunding campaign with Komb Green Solutions (a community-based organization) in Kenya to provide emergency flood protection for the People’s Park they had created for children and youth of the Korogocho slum, which was almost washed away. The funding was used to build robust gabion walls - rock and wire mesh flood defences - to ensure that the park will be protected during future extreme weather events.

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c. Performance assessment

**KPI Name:** Modularity and complexity.

**Rationale:** Modularity (of products, processes, supply chains) provides flexibility as components can be replaced more easily. On-site repair knowledge enables rapid and effective response. Selection of appropriately complex technology can enable training for on-site maintenance or repair (in line with community education levels).

**What to consider:**

A. The number of prefabricated components used in construction.

B. The number of modular components used in construction.

C. The ease of securing replacement parts (including wait time).

D. The complexity of maintenance needs.

E. The scope or scale of in-house maintenance.

F. The proximity of suppliers and any outsourced maintenance providers.

G. Capacity to evolve with the environment and needs.

**Indicative scoring criteria:** The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5. **Modularity is used wherever suitable for the given service.** Repair complexity is low or trained staff are on site. Parts are easily available and accessible.

4. **Modularity is used wherever suitable for the given service.** Repair services are on site or within an hour of the site and parts are easily available and accessible.

3. **Modularity is used on occasion when suitable for the given service.** Repair services are within an hour of the site. Most common parts are easily available and supply chains are established for all parts.

2. **Modularity is used on occasion when suitable for the given service.** Repair services are within hours of the site. Most common parts are easily available.

1. **Modularity is not used even when suitable for the given service.** Repair services are within a day of the site. Some replacement parts are available.

0. **Modularity is not used even when suitable for the given service.** Repair services are not established. No replacement parts are accessible.
P6.2 - Create adaptive capacity

Build adaptive capacity into infrastructure systems at all lifecycle stages to allow flexibility in decision-making, transitioning and problem solving. Adaptive capacity must be created to anticipate supply and demand shifts, included in business-continuity planning and operation management, and monitored and reviewed during design and operational stages, and multi-year planning cycles.

a. Stakeholder interventions

Planners, designers and engineers

- Provide designs that allow usage to be measured and enable future changes to capacity.

Contractors

- Build adaptive capacity into supply chains (e.g., have a list of reserve suppliers).

Operators

- Make provision for the appropriate level of capacity (amount and quality of resources) that meets resilience needs now and in the future.
- Monitor capacity during the operational stage and receive alerts.
- Make interventions to ensure capacity can meet demand.
- Ensure vulnerable users are prioritized for service provision when capacity is close to limits.

Academia

- Provide forecasting tools to anticipate changes in service demand.

b. Example of interventions

In Indonesia, adaptive capacity was created using opportunities at the water-food-energy nexus. Resilient agroforestry solutions were promoted to increase water security using flexible land-use approaches and integrative planning tools such as LUMENS (land use for multiple environmental services).

c. Performance assessment

KPI Name: Adaptive capacity

Rationale: The definition of adaptive capacity is the ability or capacity of a system to modify or change its characteristics or behaviour to cope better with existing or anticipated external stresses. Adaptive capacity is created by having processes to provide capacity in response to changing operational conditions. This requires monitoring physical status, operating status and service level of infrastructures to have the evidence to trigger the adaptive capacity. Flexible capacity allows the system to adapt to changing operational conditions.

What to consider:

A. Data-storage capacity.
B. Flexibility of data-storage methods (fixed versus flexible).
C. Service capacity.
D. Confidence in, and volatility of, expected service demands.
E. Flexibility in service capacity.
F. Supply-chain capacity.
G. Number of potential alternatives to supply.

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Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Capacity (of data storage, service and supply chain) is known. Demand is monitored. There is significant scope to adjust capacity. Alternative suppliers have been identified and relationships established.

4 Capacity (of data storage, service and supply chain) is known. Demand is monitored. There is some scope to adjust capacity. Alternative suppliers have been identified and relationships established.

3 Capacity (of data storage, service and supply chain) is known. Demand is estimated. There is some scope to adjust capacity. Alternative suppliers may have been considered.

2 Capacity (of data storage, service and supply chain) is known to an extent. Demand is estimated. There is limited scope to adjust capacity. Alternative suppliers may have been considered.

1 Capacity (of data storage, service and supply chain) is known to an extent. Demand is estimated. There is very limited scope to adjust capacity. Alternative suppliers may have been considered.

0 Capacity (of data storage, service and supply chain) is not known. Demand is not monitored. Capacity is fixed. No alternative suppliers have been identified.

P6.3 - Develop flexible management

Dynamic and flexible management or organizational structures enable adaptation in the event of a disturbance. Flexible management allows the workforce to adapt dynamically to changing needs, and to work effectively together without delays or confusion in disaster situations.

a. Stakeholder interventions

Government

- Mandate assessment of operating practices and disaster preparedness.

Operators

- Develop and reinforce dynamic management with an emphasis on the importance of disaster-management skills across management teams, and the explicit consideration of disaster-scenarios management.
- Use previously defined lines of command, responsibilities, communication channels and roles when a disruption occurs.
- Work with civil society organizations and engage these in disaster-response planning.

Institutions

- Provide relevant training and education on the use of dynamic teams during disruptions.
b. Example of interventions

Infrastructure investments intended to reduce risks to known hazards can face procedural challenges that increase vulnerabilities and reduce flexibilities. An example of this is the extreme flooding in 2011 in the Mississippi River Basin, when a last-minute legal appeal delayed blowing up two levees as designed in anticipation of overflowing. The failure to anticipate the judicial processes delayed adaptive actions and exacerbated the damage caused. Improved flexible judicial processes might have reduced the flood damages.61

What to consider:

A. The level of representation (inclusion and diversity) of disaster-response teams and specialists in management.

B. Extent to which disaster planning spans teams.

C. Ease with which employees can contact management including transparency.

D. Scope of formal reporting and whistleblowing procedures considering the appropriateness of feedback channels.

E. Scope and frequency of audit or assessment.

F. Level of community engagement.

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Disaster-management training is available for all employees and required for those in management. There are formal reporting and whistleblowing procedures in place for employees and formal communication channels for community engagement. Operators are subject to frequent assessment.

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4 Disaster-management training is available for most employees and required for certain employees. There are formal reporting and whistleblowing procedures in place for employees and formal communication channels for community engagement. Operators are subject to frequent assessment.

3 Disaster-management training is available for employees. There are formal reporting and whistleblowing procedures in place for employees and informal communication channels for community engagement. Operators are subject to infrequent assessment.

2 Disaster-management training is available for managers. There are informal reporting and whistleblowing procedures or guidelines in place for employees and informal communication channels for community engagement. Operators are subject to infrequent assessment.

1 Support is available for employees wishing to seek external disaster-management training. There are informal reporting and whistleblowing procedures or guidelines in place for employees and informal communication channels for community engagement. Operators are rarely assessed.

0 Disaster-management training is not provided. There are no reporting and whistleblowing procedures in place for employees and no communication channels for community engagement. Operators are not subject to assessment.

P6.4 - Enable capacity for transformation

Capacity for transformation allows infrastructure to adapt beyond its primary purpose. Analysis of small-scale failures or near-failure events should be used to revise management strategies. Organizations should anticipate the expected change in operational best practices as new evidence becomes available. After a failure, systems must be built back better to address the vulnerabilities that allowed failure to occur. Transformation capacity focuses on knowing the boundaries of existing infrastructure systems and how infrastructure systems might be viable beyond the boundaries. It provides flexibility in future situations and can prevent or mitigate potential failure scenarios.

a. Stakeholder interventions

Financial partners

• Assess the risks that the system is no longer able to keep pace, and the need to improve capacity for transformation and extensibility.

• Provide funding and financing to support measures taken by operators to ensure saturation is not reached.

Planners, designers and engineers

• Design options that are flexible to changes in demand and capacity.

**Contractors and operators**

- Monitor demand and ensure that capacity can meet expected future demand either through demand reduction or increasing capacity.

- Develop partnerships with relevant organizations and share data to identify areas of shared capacity.

- Work with partner organizations to distribute demand effectively.

**b. Example of interventions**

In 2011, during a period of extreme weather in Winnipeg, Canada, officials broke through a section of the Assiniboine River dyke to facilitate the controlled release of floodwaters. The dyke was surrounded with large limestone boulders, or rip rap, to absorb the impact of the water and reduce the speed of flow. The breach consisted of a cut less than a metre in depth. The aim of the breach was to allow water to disperse slowly across fields, fill behind roads and spill at low points along roads, before ultimately spilling into the La Salle River. This was done to prevent an uncontrolled breach downstream, which could affect 850 homes and an area of 500 square kilometres. While originally designed to protect the area's road network and nearby land, officials could utilize the dyke for another purpose, to mitigate the risk of more severe disruption downstream.


**c. Performance assessment**

**KPI Name:** Ability to adapt.

**Rationale:** Adaptive transformation is the outcome of implementing adaptive capacity, which leads to transformed infrastructure that has better systemic resilience. Building adaptive capacity and connecting system sections allows for the redistribution of stress (high demand or low resource level) when the network is near maximum capacity. This is done by creating a network of adaptive units, able to reduce demand or increase supply capacity for a given unit under high stress. This manages the risk of saturation. Saturation occurs when the system is no longer able to respond to keeping pace with changing demands, disturbances and challenges. Having redundancy when offering a service allows demand and resources to be shared to adjust to demand levels during disruption or stress.

**What to consider:**

- A. The levels of connectivity between infrastructure components.
- B. The flexibility of connections between components.
- C. The levels of redundancy in the network.
- D. The number of vital components (without redundancy).
- E. The amount and proximity of neighbouring infrastructure that provides comparable services.
- F. The scope of the formal reporting procedure and scope or frequency of assessment.
Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Component connections mapped and vital components identified. Critical services have redundancy. Plan in place in case of vital component failure. Neighbouring services identified and failure plan in place that involves utilising capacity of neighbouring services. Operational processes and failure plans assessed frequently and formal reporting procedure in place for employees.

4 Component connections mapped and vital components identified. Most critical services have redundancy. Plan in place in case of vital component failure. Neighbouring services identified and failure plan in place that involves utilising capacity of neighbouring services. Operational processes and failure plans assessed somewhat frequently and formal or informal reporting procedure in place for employees.

3 Component connections mapped and vital components identified. Some critical services have redundancy. Plan in place in case of vital component failure. Neighbouring services identified and relationships established. Operational processes and failure plans assessed somewhat frequently and formal or informal reporting procedure in place for employees.

2 Component connections not mapped but vital components identified. Some critical services have redundancy. Plan in place in case of vital component failure. Neighbouring services identified but not part of any failure planning. Operational processes and failure plans assessed infrequently and informal reporting procedure in place for employees.

1 Component connections not mapped but vital components identified. Critical services have minimal or no redundancy. Some guidelines in place in case of vital component failure. Neighbouring services identified but not part of any failure planning. Operational processes and failure plans assessed infrequently and informal reporting procedure in place for employees.

0 Component connections not mapped. Critical services have no redundancy. No plans in place in case of component failure. No neighbouring services engaged with. No assessment of operating processes and no reporting procedure in place for employees.

P6.5 - Allow for human discretion

Incorporate manual overrides and human-in-the-loop provisions to allow for human discretion. This should include defining the specific conditions in which standard operational practices can be overridden while having flexibility for unexpected situations. Emphasis should be placed on developing skills amongst operational staff at all levels, with appropriate training and testing to enable them to have the authority for autonomous intervention. Processes that contain human and digital systems must ensure operational safeguards. While automation may be more efficient in everyday operations, incorporating the capacity for tested manual control enables the human in the loop to respond to surprises by opening and closing paths for service flow, allowing infrastructure to function beyond designed thresholds, and switching on and off back-up resources. This can enable fast interventions in response to unexpected disturbances.

a. Stakeholder interventions

**Government**

- Provide guidance and regulation on override capacity requirements.
- Conduct investigations into accidents and system failures and ensure any suggested changes in override systems as a result are implemented.

**Regulators**

- Monitor compliance with override capacity requirements and report on non-compliance.

**Planners, designers and engineers**

- Consider what levels of automation and human in the loop are necessary for each project and provide designs and builds that facilitate override capacity.
- Provide detailed instructions on how to operate override systems to operators.

**Contractors and operators**

- Train staff in how to operate override systems and ensure these can be used when needed.

**Institutions**

- Consult with designers and operators to assist in developing the regulations and workforce skills necessary for successful implementation of override systems. This is particularly important where the public have access to, and may need to utilize, override systems in an emergency.

b. Example of interventions

China Airlines Flight 140 crashed due to issues with autopilot manual overrides. An automated system was programmed to ignore manual controls in an aborted landing situation, but the human pilots tried to continue the landing. The conflicting signals resulted in the aircraft stalling and crashing. The autopilot for this aircraft type was reprogrammed so that it would never ignore a manual override. The aviation industry has worked to find the right balance between automated systems and manual-override capacity. Pilots regularly land manually to maintain confidence in the procedure for emergencies. The flight-crew human-factors handbook recognizes the importance of human judgement and discretion during in-flight incidents.

c. Performance assessment

**KPI Name:** Capacity for human intervention.

**Rationale:** Human discretion means giving operators the ability to exercise their own judgment and override standard procedures or automated responses in unexpected or exceptional circumstances. Incorporating manual overrides into systems during the design phase allows rapid response to critical threats. For response systems to be effective in crisis scenarios, staff must be trained to operate override systems, and test or practice regularly.

**What to consider:**

A. Number of systems with designed-in manual override ability in times of disaster.

B. Workforce preparedness for hazards including skills for autonomous intervention.

---

Indicative scoring criteria: The following criteria could be used for scoring this indicator on a scale from 0 to 5:

5 Formal training is available for employees wishing to learn how to operate equipment or learn emergency skills. A defined percentage of employees are required to have received resilience, safety, override and emergency training at a level that ensures redundancy in staff trained for a given emergency role or on a specific piece of equipment. Frequent emergency drills (every six months or less).

4 Formal training is available for employees wishing to learn how to operate equipment or learn emergency skills. A defined percentage of employees are required to have received resilience, safety, override and emergency training at a level that ensures redundancy in staff trained for a given emergency role or on a specific piece of equipment. Frequent emergency drills (every six to 12 months).

3 Formal training is available for some employees wishing to learn how to operate equipment or learn emergency skills. A defined percentage of employees are required to have received resilience, safety, override and emergency training at a level that ensures redundancy in most emergency roles or operators for specific pieces of equipment. Somewhat frequent emergency drills (every 12 to 24 months).

2 Informal training is available for some employees wishing to learn how to operate equipment or learn emergency skills. A defined percentage of employees are required to have received resilience, safety, override and emergency training. Infrequent or informal emergency drills.

1 Informal training or financial support for external training is available for some employees wishing to learn how to operate equipment or learn emergency skills. Some employees are required to have received resilience, safety, override and emergency training. Infrequent or informal emergency drills.

0 No training is available for employees wishing to learn how to operate equipment or learn emergency skills. No employees are required to have received resilience, safety, override and emergency training. No emergency drills.
As laid out in the previous section, the implementation of the principles of resilient infrastructure requires interventions from all stakeholder groups across all critical infrastructure sectors. The interventions from each stakeholder will often involve two or more sectors and organizations because of interdependencies between them, requiring moving away from a silo approach and adopting a multidisciplinary approach.

The following nine steps are recommended for implementing a national infrastructure-resilience programme using the Principles for Resilient Infrastructure. Figure 3 shows these steps and uses the Deming cycle of plan, do, check, act (also known as adjust).

Figure 3: The governance framework, based on the plan-do-check-act (PDCA) cycle, also known as the continuous improvement cycle or Deming’s Cycle of Continuous Improvement

1. Decision making, control and accountability
2. Initial national assessment
3. Prioritization (of the SMART plan)
4. Funding
5. Manage implementation of key actions
6. Incident investigations
7. Annual/Continuous assessment
8. Communicate
9. Update (the SMART plan)
Step 1: Decision-making, control and accountability

Output: the method for decision-making, control and accountability for implementing national infrastructure resilience.

Stakeholder roles:

- Government nominates a government department to lead establishing the method of governance (central, polycentric, multi-level).

- Representatives of infrastructure stakeholders are invited for consultation, lobbying, clarification of scope and scale.

- Consensus is achieved on the mode of governance, and controls are established to ensure ethical and robust attention to the initiative.

There is a need for coordination and clarity about responsibilities as jurisdiction over infrastructure resilience is typically fragmented across multiple government organizations and several levels of the administration. Jurisdiction for some functions over a critical infrastructure may arise at a ministry or federal department; but jurisdiction over other functions may arise at the state or sub-national level and in many countries it can also be found at local level.

National governments must establish a structure and strategy to implement the principles through top-down, bottom-up or mixed approaches, and focus on improving the supply or reducing (or redistributing) the demand. Examples from the water and energy sectors are provided in Table 1, which shows governance strategies in the four quadrants: top down, increase supply; top down, reduce demand; bottom up, increase supply; and bottom up, reduce demand.

Table 1: Governance examples from the water and energy sectors

<table>
<thead>
<tr>
<th>Water-sector example</th>
<th>Top down</th>
<th>Bottom up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply increase</td>
<td>National programme for reduced leakage in water-distribution networks</td>
<td>Community or building-scale water storage and use (not potable)</td>
</tr>
<tr>
<td>Demand decrease</td>
<td>Regional or territorial curtailment of mains water use</td>
<td>Local action on reuse of waste water for irrigation</td>
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</table>

<table>
<thead>
<tr>
<th>Energy system example</th>
<th>Top down (Institutionally sustained)</th>
<th>Bottom up (User sustained)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply increase</td>
<td>Building new hydropower plant to increase generation capacity</td>
<td>Building distributed battery storage fed by decentralized rooftop solar panels</td>
</tr>
<tr>
<td>Demand decrease</td>
<td>Behind-the-meter appliance-efficiency upgrade programmes</td>
<td>Community-driven behavioural reform, shifting time of use</td>
</tr>
</tbody>
</table>
Step 2: Initial national assessment

Output: An initial assessment of the stock of national infrastructure resilience can follow a simple classification system of red, amber, green, for each of the principles, and ideally for each of the key actions, providing a compound national assessment (see example below in Table 2).

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
<th>Goal</th>
<th>Key Action</th>
<th>Country Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principle 1</td>
<td>Continuously learning</td>
<td>Develop and update understanding and insight into infrastructure resilience.</td>
<td>P1.1 Expose and validate assumptions</td>
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<td></td>
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<td>P1.2 Monitor and intervene appropriately</td>
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<td></td>
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<td>P1.3 Analyse, learn and formulate improvements</td>
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<td></td>
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<td></td>
<td>P1.4 Conduct stress tests</td>
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<tr>
<td>Principle 2</td>
<td>Proactively protected</td>
<td>Proactively plan, design, build and operate infrastructures that are prepared for current and future hazards.</td>
<td>P2.1 Raise essential safety requirements</td>
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<td></td>
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<td>P2.2 Exceed basic requirements for critical components</td>
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<td>P2.3 Consider complex interdependencies of connected networks</td>
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<td>P2.4 Embed emergency management</td>
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<td>P2.5 Design infrastructure to fail safely</td>
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<td>P2.6 Design for multiple scales</td>
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<td>P2.7 Commit to maintenance</td>
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<td>P2.8 Devise long-term investments</td>
<td></td>
</tr>
<tr>
<td>Principle</td>
<td>Description</td>
<td>Goal</td>
<td>Key Action</td>
<td></td>
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<tr>
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<td>------------------------------</td>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
| Principle 3 | Environmentally Integrated   | Work in a positively integrated way with the natural environment | P3.1 Minimising environmental impact  
P3.2 Use environmental solutions  
P3.3 Integrate ecosystem information  
P3.4 Maintain the natural environment  
P3.5 Use local sustainable resources |
| Principle 4 | Socially engaged             | Develop active engagement, involvement, and participation across all levels of society | P4.1 Inform people about disruptions  
P4.2 Raise resilience literacy  
P4.3 Incentivize demand behaviour  
P4.4 Encourage community participation |
| Principle 5 | Shared responsibility        | Share information and expertise for coordinated benefits | P5.1 - Harmonize open standards for sharing information  
P5.2 - Cultivate collaborative management  
P5.3 - Establish clear accountability  
P5.4 - Enhance connectivity for sharing information  
P5.5 - Assure data safety to develop trust  
P5.6 - Share risk and return information |
| Principle 6 | Adaptively transforming      | Adapt and transform to changing needs         | P6.1 - Choose manageable solutions  
P6.2 - Create adaptive capacity  
P6.3 - Develop flexible management  
P6.4 - Enable capacity for transformation  
P6.5 - Allow for human discretion |
Stakeholder roles:

• Regulator facilitates or manages the assessment and collects the evidence.

• Operators, contractors provide operational and construction information.

• Planners, designers and engineers provide planning and design information (on work in progress).

• Institutions and academia provide information on hazards: environmental and social.

• Civil society (representing the public, businesses and industry) provides public, business and industrial concerns and potential concerns.

• Owners and financial partners highlight risks and willingness to fund or finance investment for reduced disruptions.

• Government accepts the assessment and recommends it for the next step (prioritization).

Assessment of the nation’s stock of resilience must consider all critical services as a whole, and not rely exclusively on sectoral assessment of resilience. A holistic assessment will highlight those parts of infrastructure that are the weakest links in the chain of service delivery. Understanding the weakest links enables the prioritization of stakeholder interventions and thus identifies the key actions with the greatest impact on national resilience. In addition to the assessment, an ambition can be determined annually that sets out a target level for infrastructure resilience.

Figure 4 – Example of an initial national assessment

Coding: future need (blue), ambition (orange) and current state (grey)
An example of an initial national assessment is shown in Figure 4. Here, on a scale of 0-5, each principle for infrastructure resilience is assessed qualitatively. The grey area is the assessment of the current stock of the nation’s infrastructure resilience. The assessment of the future need for infrastructure resilience is shown in blue, while the ambition, set out in orange, is an assessment of the affordability and investment that the nation can achieve for infrastructure resilience.

The principles with the greatest gap could be prioritized first. For example, P3 Environmentally integrated and P4 Socially engaged, have the greatest gap between current state and ambition, and P4 Socially engaged and P6 Adaptively transforming have the greatest gap between current state and future need.

The gaps can be addressed by the interventions related to the respective key actions and principles. These interventions can include structural (e.g., engineering solutions to improve the safety of physical assets) and non-structural measures (e.g., policies and capacity development).

Step 3: Prioritization

Output: Specific, measurable, achievable, relevant, and time-bound (SMART) actionable implementation plan that considers the priorities and interdependencies of the infrastructure systems identified in the initial national assessment.

Stakeholder roles:

- Regulator facilitates or manages the prioritization and recognizes trade-offs.
- Operators identify the most critical components or sub-systems to service delivery.
- Contractors advise on delivery feasibility: value chain, materials, workforce capacity.
- Planners lead an in-depth review of the alternatives for the implementation of key actions.
- Designers and engineers provide technical feasibility advice.
- Institutions and academia provide information on hazards: environmental and social.
- Civil society identifies the most pressing concerns for people and workplaces.
- Owners and financial partners identify costs and assess risk or returns.
- Government considers alignment with manifesto and long-term public goals.

The implementation plan is based on the initial assessment conducted in Step 2, which identifies key actions and interventions required for enhancing national infrastructure resilience. However, the ability of a nation to achieve the identified priorities will also depend on the maturity of infrastructure-resilience capabilities embedded in organizations.

To make progress in delivering infrastructure resilience, organizations may need to increase the maturity of their capabilities by making incremental changes. For example, for information-management capabilities, this could translate as: first building foundations that enable quantification of infrastructure resilience (Level 1), then progressing toward appropriate standards for resilience (Level 2), then reaching full compliance with standards (Level 3), and ultimately leading organization projects and programmes for setting future standards (Level 4).
Step 4: Funding

Output: Agreed financial plan for funding the identified priority actions.

Stakeholder roles:

- Regulator facilitates or manages the assignment of costs and funds to the SMART implementation plan.
- Owners and government identify sources of funding and secure contracts for the first two years.

Step 5: Implement the prioritized key actions

Output: Implement the SMART implementation plan according to the priorities and funding available.

Stakeholder roles:

- Regulator updates policies, legislation and regulation where required to mandate the implementation of the key actions.
- Operators and contractors revise and adapt their operations according to the SMART implementation plan supported by regulatory changes and agreed funding.
- Planners, designers and engineers use the agreed priorities from the SMART implementation plan to revise existing schemes and apply to new schemes.
- Institutions and academia to support, advise and provide consultation on the SMART implementation plan and provide skills training on changes to regulatory systems.
- Civil society raises preparedness, awareness and participation in planning and recovery (including from disruptions caused by adaptations).
- Owners obtain funding for the resources needed for the SMART implementation plan; they control financial transactions.
- Government ensures accountability for investments.
- Institutions and academia to support, advise and provide consultation on the SMART implementation plan and provide skills training on changes to regulatory systems.
- Civil society raises preparedness, awareness and participation in planning and recovery (including from disruptions caused by adaptations).
- Owners obtain funding for the resources needed for the SMART implementation plan; they control financial transactions.
- Government ensures accountability for investments.

Step 6: Conduct incident investigations

Output: Incident investigation and reporting (the same approach can be extended to near misses).

Stakeholder roles:

- Regulator facilitates and collects data on infrastructure incidents, escalates issues to government and reports on incidents; and a review is conducted on whether governance continues to be fit for purpose, and changed if not.
- Operators and contractors provide data on incidents.
- Planners, designers and engineers use information on incidents to improve schemes and technical solutions.
• Institutions and academia analyse incidents and their environmental and social impacts, and provide insights and recommendations for their future avoidance.

• Civil society provides information on the impact of incidents.

• Owners and financial partners assess the financial and economic consequences of incidents.

• Government ensures incident knowledge is fed into annual and continuous assessment for re-prioritization of the SMART implementation plan and related regulations.

Step 7: Annual or continuous assessment

Output: Quantitative re-assessment of stock of national infrastructure resilience.

Stakeholder roles:

• Regulator facilitates or manages the assessment, collects the evidence and reviews implementation of the SMART implementation plan, and determines net resilience improvement.

• Operators, contractors provide operational and construction information.

• Planners, designers and engineers provide planning and design information (on latest work in progress).

• Institutions and academia provide information on latest hazards: environmental and social.

• Civil society provide updates on public, business and industrial concerns and potential concerns.

• Owners and financial partners update information on risks and revised willingness to fund investment for reduced disruptions.

• Government accepts the updated assessment and recommends it for re-prioritization of the SMART implementation plan.

Step 8: Communicate

Output: Communications on infrastructure-resilience information and stakeholder roles and accountabilities.

Stakeholder roles:

• Regulator communicates policies, legislation, regulations, consultation summaries and the SMART implementation plan.

• Operators, contractors provide communications on incidents in real time and report on these and also on incidents avoided.

• Planners, designers and engineers communicate their assumptions and ambitions for infrastructure-resilience management and the success of embedded assumptions.

• Institutions and academia collect and share best practices.
• Civil society (representing the public, businesses and industry) communicate their experience of interruptions to critical services and success of alternatives means to access critical services.

• Owners and financial partners communicate the financial and economic effect of the SMART implementation plan on risks and returns.

• Government shares the success of the programme for national infrastructure resilience.

Step 9: Update plan

Output: Revised SMART (actionable) implementation plan of prioritized interventions addressing the interdependencies of the infrastructure systems.

Stakeholder roles:

• Regulator facilitates or manages the changes to the priorities.

• Operators review critical components and sub-systems to service delivery in light of improvements and revised hazards and propose changes to priorities.

• Contractors review priorities upon value chain, materials and workforce capacity in light of improvements to resilience and revised hazards, and propose changes to priorities.

• Planners review success of options and alternatives for implementing key actions in light of improvements to resilience and revised hazards, and propose changes to priorities.

• Designers and engineers update technical feasibility advice and propose changes to priorities based on improvements to resilience and revised hazards.

• Institutions and academia update information on hazards and propose changes to priorities based on the changed hazard landscape.

• Civil society revises the most pressing concerns for people and workplaces and proposes changes to priorities to address the most urgent.

• Owners and financial partners revise costs and re-assess risk or returns in light of improvements to resilience and revised hazards.

• Government considers alignment with manifesto and long-term public good. They can also consider lessons learnt from organizations in other countries to improve implementation plan.
Conclusion

The Handbook for Implementing the Principles for Resilient Infrastructure guides countries willing to improve the resilience level of their infrastructure systems. By using this handbook and implementing the principles, countries can make progress toward the targets of the Sendai Framework for Disaster Risk Reduction 2015-2030 and the Sustainable Development Goals (SDG), particularly SDG9, on resilient infrastructure.

Improving infrastructure resilience at a system level requires a multi-stakeholder approach. Key actions under each of the principles are detailed in this handbook with explanations, proposed interventions, examples, and indicators to facilitate their implementation. The handbook also provides a governance framework to incorporate these key actions into an implementation plan that considers the country’s priorities, context, and available funding.

Countries can assess the resilience level of their infrastructure system using the indicators provided for each key action of the principles. An initial baseline assessment will help prioritize the principles that require immediate attention while periodic reviews of these indicators will allow the tracking of resilience progress. Countries can also use the proposed interventions for each stakeholder group to develop their implementation plan.

To support countries in enhancing infrastructure resilience, UNDRR has started working with selected countries to conduct an initial assessment and develop an implementation plan. The experiences from these initial implementations will serve as case studies providing valuable lessons on the use of this handbook. As these experiences accumulate, UNDRR will refine methodologies and tools to further facilitate the implementation of the principles and assist countries in building infrastructure resilience.
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