Principles for RESILIENT INFRASTRUCTURE

UNDRR
UN Office for Disaster Risk Reduction

SENDAI FRAMEWORK
FOR DISASTER RISK REDUCTION 2015-2030

SUSTAINABLE DEVELOPMENT GOALS

Overview

This report describes a set of principles, key actions, and guidelines to create national scale net resilience gain and improve the continuity of critical services such as energy, transport, water, wastewater, waste, and digital communications, which enable health, education, etc. to function effectively.

The interconnected Principles for Resilient Infrastructure provide normative goals and desirable outcomes for systemic resilience of infrastructure to meet the targets of the Sustainable Development Goals (SDGs) and the Sendai Framework for Disaster Risk Reduction 2015-2030. The key actions and governance guidelines for resilient infrastructure communicate the collaborative activities by which infrastructure will become more resilient, together with the mechanisms for improvement and monitoring infrastructure at national scale that will deliver net resilience gain and improved provision of critical services.

These principles are applicable to any level of government, institutions, donors, investors, owners, regulators, operators, designers and contractors, service providers, and international organisations that are interested in implementing a set of actions to improve infrastructure resilience contributing to positive economic, social and environmental outcomes.

** Please note that this report is a summary of the 'Principles for Resilient Infrastructure'. Please refer to the full report for more details including further explanation of each principle and its key actions and global examples.*

Sendai Framework
Target D

Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030.[1]

D1 COMPOUND — Damage to critical infrastructure attributed to disasters.

- **D2** — Number of destroyed or damaged health facilities attributed to disasters.
- **D3** — Number of destroyed or damaged educational facilities attributed to disasters.
- **D4** — Number of other destroyed or damaged critical infrastructure units and facilities attributed to disasters*.

D5 COMPOUND — Number of disruptions to basic services attributed to disasters.

- **D6** — Number of disruptions to educational services attributed to disasters.
- **D7** — Number of disruptions to health services attributed to disasters.
- **D8** — Number of disruptions to other basic services attributed to disasters*.

* *The decision regarding those elements of critical infrastructure to be included in the calculation will be left to the Member States and described in the accompanying metadata. Protective infrastructure and green infrastructure should be included where relevant.*

* *The decision regarding those elements of basic services to be included in the calculation will be left to the Member States and described in the accompanying metadata.*

[1] For all Sendai Framework targets and their indicators see: https://www.preventionweb.net/sendai-framework/sendai-framework-monitor/indicators

Introduction

A 2016 report by New Climate Economy [1] calculated the need for approximately US$90 trillion investment into infrastructure over a period of 15 years, more than what is in place in the entire current stock today. By 2019, the Global Commission on Adaptation had highlighted the urgent and global environmental and economic imperatives to address the resilience and adaptation of infrastructure systems [2]. COP26 [3] the United Nations Climate Change Conference held in 2021, highlights the increasing urgency for action.

If mobilised, infrastructure investments would not only replace ageing infrastructure but also establish new and much needed infrastructure systems. However, the current approach to infrastructure planning, financing, design, development, operations and decommissioning, does not fully take into account 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. A "think resilience" approach would address these concerns, encouraging a more comprehensive way of looking at risks and interlinkages, adaptable to specific national risks to resilience.

Today, more people than ever are dependent on the services delivered by critical infrastructure systems, covering energy, transport, water, wastewater, waste, and digital communications. Social infrastructures, such as health and social care, education, police and prisons, fire and emergency services, rely on critical services. Our society is heavily dependent on the effective and efficient operation of critical infrastructure systems to deliver public services, enrich living standards and stimulate economic growth. Infrastructure systems are the backbone of modern economy, and critical infrastructure resilience is essential to develop sustainably. Robust and resilient infrastructure is a key driver of local and national economic growth. The reliability, performance, continuous operation, safety, maintenance, and protection of critical infrastructures are national and local priorities around the world.

Through engagement with member states, the United Nations Office for Disaster Risk Reduction (UNDRR) has recognised that one of the key gaps in the infrastructure resilience arena is a shared view of: what infrastructure is in scope; the extent of resilience; the scale and ambition for resilience; the definition of resilience; and what can be done to improve infrastructure resilience. A set of Principles for Resilient Infrastructure could assist in raising awareness and setting a common basic understanding.

Principles for Resilient Infrastructure will:

I. Assist in raising awareness and setting a common basic understanding of what "resilient infrastructure" constitutes;

II. Form the basis for planning and implementation of infrastructure projects that take resilience as a core value;

III. Communicate the desired outcomes of national infrastructure systems to establish resilience of critical services; and,

IV. Assist the public and private sectors in making risk-informed policy and investment decisions.

The principles have been developed using extensive literature review and expert consultations. These principles have been refined with the input and feedback of over 100 experts in the fields of infrastructure and resilience. See Annex A for more details on the method used to develop the principles and the list of institutions consulted during the process.

The Principles for Resilient Infrastructure embrace the ambitions of the Sustainable Development Goals [4] especially SDG9 and directly support the Sendai framework [5] in particular, Global target D to substantially reduce disaster damage to critical infrastructure and disruption of basic services. Annex B maps the inter-linkages with SDGs, the Sendai Framework and the United Nation's definition for resilience.

This report also introduces a new commitment to 'net resilience gain', similar to Net Zero, that all interventions into infrastructure, not just those specifically targeted at enhancing the resilience of that system, must demonstrate that they enhance the systemic resilience of infrastructure and not damage the wider context.

Infrastructure Resilience

Infrastructure resilience is generally viewed as the phases of disruption management: to prevent, absorb, recover and transform from disruptions caused by a hazard, in a timely and efficient manner. We build on the United Nations definition of resilience [6] by recognising that delivering resilient infrastructure needs both the creation of capacity for each of the phases of hazard management, as well as to recognise (1) the changing nature of risks and uncertainties; (2) the increasingly challenging nature of multi-hazards; (3) the need to use trans-disciplinary, systemic methods that consider both the life-cycle of national infrastructure and its interdependent, multi-sectoral nature.

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 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.

National Infrastructure is an open complex interdependent system comprised of the: a) physical built infrastructure networks, buildings, and assets, b) governance structures; c) regulatory frameworks; d) management processes associated with the six economic infrastructure sectors of which it is comprised (energy, transport, water, wastewater, waste, and digital communications); e) interdependencies within and between each of the above; f) interdependencies between each of the above and the dynamic external context within which it is embedded [7]; g) the systems and technologies that control and deliver outputs; h) human factors, such as skills, knowledge; and i) the natural environment's resources and features with which it is integrated and allows it to deliver the goods that provide people and organisations with critical services.

Systemic Resilience is a property of an infrastructure system that arises dynamically when the national infrastructure is organised in a such a way that it can provide agreed critical services (power, heat, communications channels, mobility services, potable water, wastewater and waste removal) despite endogenous and/or exogenous hazards, and despite the addition, modification and removal of infrastructure components.

Net Resilience Gain

To assist in moving toward highly resilient infrastructure systems we introduce the commitment of net resilience gain which requires that all interventions into infrastructure, not just those specifically targeted at enhancing the resilience of that system, must demonstrate that they enhance the systemic resilience of infrastructure and not damage the wider context. Interventions must therefore reduce systemic resilience or create systemic resilience. The target for the systemic resilience of an individual nation will reflect the nation's ambitions for uninterrupted critical services.

Net Resilience Gain is a long-term collaborative commitment to both (a) avoid systemic resilience loss, which reduces or removes actions that erode, reduce or undermine systemic resilience; and (b) to enhance systemic resilience, which prioritises actions that create systems intrinsically resilient to potential disruptions.

There are many global initiatives supporting the goal of Net Zero greenhouse gas emissions, insofar as net emissions of carbon dioxide (CO2) by human activities must approach zero in order to stabilize global mean temperature [8], but there are none for resilience which is a critical pillar to support Net Zero.

By adapting the Net Environmental Gain Principle, the value of targeting Net Resilience Gain in a national infrastructure system is defined as follows: a) all infrastructure interventions should leave critical services in a measurably better state compared to current baselines; b) resilience frameworks and analysis should be used in decision making for infrastructure; c) infrastructure investors, developers, providers and operators should follow the mitigation hierarchy when delivering net resilience gain by: i) avoiding impacts as far as possible; ii) minimising unavoidable impact; iii) as a last resort, compensating for unavoidable losses wherever the greatest benefits can be delivered, either locally or nationally, first considering compensating for losses within the development footprint.

Governance

A method of governance, implementation and monitoring is required to support the adoption of the principles and key actions, and to demonstrate that they provide the anticipated outputs: benefits, outcomes and impacts. A theory of change is developed to provide a golden thread connecting the implementation of the principles and key actions (inputs) to their consequences (outputs), shown in Figure 1.

The adoption and implementation of the principles requires a national scale decision on the policy for adoption. Nations may adopt the principles in a voluntary manner, through national legislation or regulation, and/or through adoption of international standards.

The principles, through an assessment of the results of the key actions can be used to indicate the degree of national resilience of operational and future infrastructure, and to highlight the areas for improvement. Changes may be put into practice through implementation of the principles across the whole lifecycle of national infrastructure: new infrastructure projects, operational practices for maintenance, emergency and recovery plans, regulations (for monitoring, reporting), investment decisions (e.g., public-private investment), infrastructure decommissioning, and so on. The principles may also expose areas that currently constrain resilience, for example, tendering and procurement processes that constrain the ability of a nation to have more resilient infrastructure.

The governance and practices are shown visually in a standard theory of change representation demonstrating how Inputs, lead to Outputs, lead to Outcomes, lead to Impact. See Figure 1.

Figure 1 Principles for Resilient Infrastructure – Governance and Theory of Change

Direction of Change ↑ | Feedback ↓

IMPACT	Greater continuity of services, and better public health and wealth	Greater investor confidence	Less environmental harm and less wasted resources	Less inconvenience
OUTCOMES	Fewer failures, losses and near misses through better resisting and absorbing hazards	Rise in national resilience of critical services by better accommodating, adapting, transforming and recovering in the face of hazards		Increased knowledge
OUTPUTS	Infrastructure projects and enhancements are delivered "resilient ready"			Regulator reporting
INPUTS practice	Infrastructure changes, projects, operations, processes, investments, etc. demonstrate how they implement the principles			Regulator monitoring
INPUTS policy	Principles adopted into national approval mechanisms		Targets for national infrastructure resilience and net resilience gain are established	

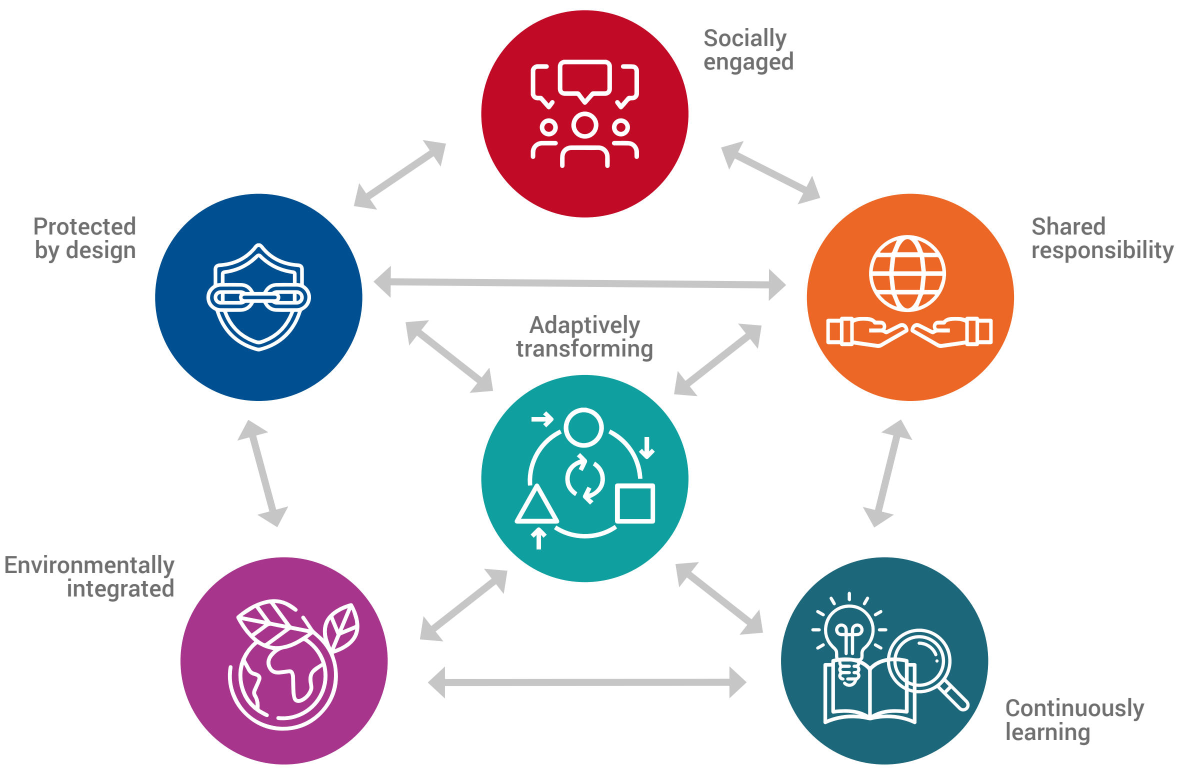
Principles for Resilient Infrastructure

A set of six interconnected Principles for Resilient Infrastructure as shown in Figure 2 and listed below.

- **Adaptively transforming**
- **Environmentally integrated**
- **Protected by design**
- **Socially engaged**
- **Shared responsibility**
- **Continuously learning**

Each principle has a normative goal, similar to the Sustainable Development Goals [4] and the Sendai Framework for Disaster Risk Reduction [5], enabling continuous improvement of national infrastructure resilience. Together the six goals form a system of goals that achieve net resilience gain across all lifecycle stages of infrastructure (design, build, operate, de-commission) assuring the continuity of critical services through all phases of hazard response (preparation, absorption, recovery, and adaptation). Given this focus on assuring critical services, and thus being infrastructure centric, it is outside the boundary of this work to consider for example how society might be resilient without critical services, or how communities can be resilient to critical services.

Figure 2 Principles for Resilient Infrastructure



PRINCIPLE 1 (P1):

Adaptively Transforming

The goal to adapt and transform to changing needs.

BACKGROUND

This principle recognises that the demands placed on our infrastructure systems in the future may look different from the demands placed on them today. Developing systems with this in mind encourages us to incorporate flexibility into supply chains, delivery methods, organisational structures, and operational methods. Some of these future challenges may be unexpected, requiring infrastructure to adapt beyond expected boundaries in order to absorb the disruption. Resilient infrastructure must be able to adapt and transform rather than just bounce back. This demands a focus on context and awareness of change, human discretion to override systems which respond only to old norms, and embracing complexity so that infrastructure is sufficiently adaptive. Adaptivity must go beyond the design phase, forming part of an ongoing cycle where the outcomes of continuous learning are implemented as changes in relevant infrastructure, management, and information systems.

KEY ACTIONS

P1.1 Design safe-to-fail infrastructure

Design safe-to-fail infrastructure to ensure safety is not compromised. Safe-to-fail infrastructure accepts that there may be circumstances in which the infrastructure is no longer able to provide the services it was designed for, but ensures that this failure occurs in such a way that safety is not compromised.

P1.2 Create adaptive capacity

Build adaptive capacity into infrastructure during the design stage, to allow flexibility in decision making, transitioning and problem solving.

P1.3 Develop dynamic structures

Develop dynamic management/organisational structures to enable the workforce to adapt in the event of a disturbance. This can go beyond organisation boundaries to include a dynamic and evolving relationship with consumers.

P1.4 Enable extensibility

Allow for deviation beyond standard operational practices. Extensibility allows infrastructure to adapt beyond its primary purpose, recognising that the adaptive capacity of any unit at scale is finite. Extensibility focuses on knowing the boundaries of existing solutions and how they might be viable beyond them.

P1.5 Allow for human discretion

Incorporate manual overrides and human-in-the-loop provision to allow for human discretion.

P1.6 Adopt the appropriate level of complexity

Adopt the appropriate level of complexity by selecting viable solutions that can handle the variability of a changing environment. The variety and complexity of solutions for resilient infrastructure must contain as much variety and complexity as the environment [9].

PRINCIPLE 2 (P2):

Environmentally Intergrated

The goal to work in a positively integrated way with the natural environment.

BACKGROUND

This principle recognises the importance of avoiding harm to the natural environment (required to avoid feedbacks such as climate change), as well as the opportunities of working with the natural environment in a positive way, such as planting trees to reduce speed of flood water spread. Environmental compatibility refers to integration with the natural environment to employ natural capital in favour of adding to its value without harming natural ecosystems.

KEY ACTIONS

P2.1 Use nature-based solutions

Incorporate nature-based solutions to provide the best suitable mix of grey and blue-green solutions. Natural capital can be applied to provide nature-based solutions to support the resilience of infrastructure systems by increasing their reliability [10].

P2.2 Integrate ecosystem information

Integrate ecosystem information into the decision-making process to avoid natural risks. Including ecosystem information in decision-making could help to avoid development losses from ignorance of ecosystem function as well as reducing the likelihood of infrastructure investments causing large ecosystem losses for small development gains.

P2.3 Minimise environmental harm

Minimise environmental harm by minimising the effect of infrastructure projects and operations on the ecosystem. Doing this will avoid triggering risk of disasters with a natural hazard origin. Infrastructure systems can directly trigger a disaster with a natural hazard origin or they can make changes on their surrounding environment with long-term negative impacts.

P2.4 Maintain the natural environment

Pro-actively manage the natural environment (overgrown vegetation, risk of flooding, etc.) around infrastructure locations to reduce exposure to vulnerabilities. Improving natural environment management and maintenance is a no-regrets option for boosting the resilience of infrastructure assets [10].

PRINCIPLE 3 (P3):

Protected by design

The goal to design infrastructures that are prepared for hazards.

BACKGROUND

Infrastructure is exposed to various hazards both known and unknown. And the nature of hazards is constantly changing. This includes amplitude and frequency of hazards, multi-hazards occurring concurrently or close after each other, and even new hazards such as climate change, sea level rise, and nuclear pollution. The best time for investment in readiness for hazards is at the design stage which must proactively consider potential negative impacts of disturbance events and disasters with natural hazard origin on the full lifecycle of infrastructure provision.

KEY ACTIONS

P3.1 Raise essential safety requirements

Design infrastructure systems that raise essential safety requirements. Designs for infrastructure systems should be pessimistic in terms of the potential for lifecycle hazards with built-in plans for scenario testing and stress testing. Designs should raise essential safety requirements to cope with non-climate-related disasters with natural hazard origin such as earthquakes and include various design measures to respond to climate-related hazards such as sea level rise; human-induced threats such as terrorism and cyber-attacks; and public health emergencies such as COVID-19.

P3.2 Exceed component level requirements

Design critical components of national infrastructure to exceed basic reliability and durability requirements. Critical components play a vital role in the whole infrastructure system operation. Exceeding basic component-level reliability and durability requirements will achieve higher system-level reliability and durability, which can effectively delay performance degradation, reduce system failure probability, and improve adaptability to long-term hazards.

P3.3 Consider complex interdependencies of connected networks

Design infrastructure to avoid the risk of cascading failures from complex interdependencies. When alternative networks, such as road and rail, are available to deliver the same or similar critical services, they provide systemic resilience. But when different networks such as power and transport are coupled, vulnerabilities to failures can increase. The complex interdependencies of connected networks should be considered in the (re-)design for new infrastructure investments to reduce the risk of cascading failures.

P3.4 Embed emergency management

Embed mature emergency management plans with sufficient financial support and strong governance. Design and deploy emergency management plans in advance to respond to different disturbances and guarantee that the back-up and dispatch of critical services can meet basic human needs.

P3.5 Use local sustainable resources

Use local and sustainable resources. The availability and sustainability of resources required for infrastructure operations is improved through a resilient design strategy preferring the use of local, sustainable resources. Resources, especially single sourced, non-renewable, and distantly located, are easily affected by disturbances.

P3.6 Design for multiple scales

Design for multiple scales to maximize the value of resilience investments. Preventive and adaptive design solutions to achieve resilience should be addressed at different disaster scales, geo-political scales (including individual infrastructures, communities, cities, and larger regional and national scales), and different time scales (from immediate to long-term), to maximize the value of resilience investments.

P3.7 Commit to maintenance

Improve maintenance and operations through developing infrastructure asset management schemes including an inventory of all assets, operation conditions, as well as all the strategic, financial, and technical aspects of the management of across their lifecycle. And combine routine maintenance (e.g., annual frequency) with periodic maintenance (e.g., every 5 years) for an extended lifetime of an infrastructure and a better performance level over time.

PRINCIPLE 4 (P4):
Socially engaged

The goal to develop active engagement, involvement, and participation with people.

BACKGROUND

Social responsibility is becoming increasingly prominent as an alternative mechanism to prevent and respond to system's failure [11]. Being socially responsible depends on increasing social awareness, taking a more active role, and improving self-management skills, resulting in more consciousness about how our decisions and behaviours can affect others [12]. It leads to a growing number of mindful individuals acting better to do no harm to society and benefit the whole community. Infrastructure systems are not just technical systems but socio- technical systems. Socio-technical challenges can be addressed by improving social responsibility to make more resilient systems. This includes aspects of awareness, activism, and incentivization of people for all concerns [13].

KEY ACTIONS

P4.1 Inform people about disruptions

Informing people about upcoming or ongoing disruptions to reduce pressure on the operating systems. The majority of consumers have little awareness of the consequences of their consumption behaviour of critical services. This is especially true in emergency situations with demand and supply mismatches where consumers do not know if their consumption behaviour challenges the resilient operation of infrastructure systems.

P4.2 Raise resilience literacy

Educate consumers with necessary information on resilience. A two-way relationship between the public and infrastructure owners/operators can improve resilience from both sides.

P4.3 Incentivise demand behaviour

Incentivise consumers to reduce demand and provide demand response. Incentive-based control schemes aim at incentivising users to make adjustments in their consumption behaviour.

P4.4 Encourage community participation

Encourage community participation to reduce vandalism and theft, which will reduce outages and damage. Vandalism of infrastructure assets can be life threatening and creates untold disruptions.

PRINCIPLE 5 (P5):

Shared responsibility

The goal to share information and expertise for coordinated benefits.

BACKGROUND

In order to move away from the traditional siloed approach to information, a collaborative approach must be encouraged for the sharing of data, knowledge, and expertise. Organisations with common interdependencies should be able to share data in a standardised way and generate shared insights into how to handle common threats. Shared knowledge across sector boundaries can also be in the form of human skills and expertise. A cooperative approach to management and planning benefits from diverse knowledge and experience, while public engagement can bring both confidence and insight. Information sharing allows systems to learn from mistakes and prepare a coordinated response to shared hazards or vulnerabilities. As complex systems, the networks of infrastructure, data, and affected stakeholders often cross sectoral and geographic boundaries. Therefore, a shared approach to resilience must involve international and cross-sectoral efforts, accounting for complex interdependencies between systems to best prevent cascading failure.

KEY ACTIONS

P5.1 Harmonise open standards

Develop and follow common standards and practices for straightforward sharing of information. Harmonised open standards will facilitate the sharing of data across sectors [14].

P5.2 Cultivate collaborative management

Cultivate collaborative management and encourage sharing of expertise across boundaries. Foster open communication within and between sectors. Encourage and develop polycentric governance, which provides opportunities for learning and experimentation, enables broader levels of participation, creates modularity, and builds redundancy that can minimize and correct errors in governance [15].

P5.3 Establish shared responsibilities

Proactively establish a shared understanding of resilience goals, giving explicit consideration to acceptable outcomes, thresholds and timelines. Identify the responsibilities of different stakeholders and organisations in terms of their objectives, operations, and assets, and put these responsibilities at the centre of communication and engagement efforts.

P5.4 Enhance connectivity for information sharing

Enhance connectivity for valuable information (data/practice/knowledge) sharing, including with resilience networks such as membership-based groups.

P5.5 Assure data safety to develop trust

Assure data safety to develop trust between organisations and with the public. While data sharing brings many benefits, it can only be achieved if companies and consumers have confidence that their data is secure. Implement data governance, accountability, privacy, security, etc.

P5.6 Share risk and return information

Secure investments in resilience by sharing risk and return information. The disclosure of high-quality information related to risk assessment, financial reports, regulatory filings, accounting information, etc is critical for effective decision-making by investors and other stakeholders.

PRINCIPLE 6 (P6):

Continuously learning

The goal to develop understanding and insight into infrastructure resilience.

BACKGROUND

The internal complexity and external hyperconnectivity of infrastructures make it difficult for stakeholders to clearly grasp the status of resilience in national infrastructure, which undermines the ability of system operators to prevent, contain and recover from outages. Therefore, it is necessary for planners to actively prepare for the scale of potential hazards that infrastructures may suffer, for operators to sense the dynamic changes in the operating status of infrastructures to detect anomalies rapidly, and for decision makers to learn and continuously devise strategies to optimize the resilience of infrastructures. The lifecycle-integrated smart mechanisms of planning, monitoring, and learning provide various stakeholders with comprehensive understanding of infrastructure resilience and its capacities.

KEY ACTIONS

P6.1 Expose and validate assumptions

Expose and validate assumptions about the resilience of infrastructure to potential threats, in order to assess the future risks to critical services. Infrastructure planners, policy makers and scenario analysts should expose assumptions about infrastructure systems, and validate them through scenario analysis (computationally, mathematically, using Delphi, professional engineering, and other engagement tools, etc.) to characterize potential threats and assess the future risks to critical services.

P6.2 Monitor and intervene appropriately

Monitor performance in real time and intervene at an appropriate time-scale. Infrastructure operators should monitor the status of national infrastructure to sense system performance in real time to trigger early warning and rapid disruptive impact assessment, and to support decision making for interventions at an appropriate time-scale.

P6.3 Analyse, learn, and formulate improvements

Formulate strategies for infrastructure resilience improvements that are based on learnings, feedback and analysis of previous disturbances, data and models. Infrastructure decision makers should formulate strategies for infrastructure resilience based on the learning of historical feedback of infrastructures after disturbances with the assistance of knowledge management, big data analysis, machine learning, etc.

P6.4 Stress test

Develop strategies to continually assess resilience and expose system weaknesses through collaboration with relevant stakeholders and the public. Regular stress testing exercises standardised where appropriate, and compliance testing should be common practice. Disaster preparedness exercises and emergency drills should establish best practice in crisis management and improve community resilience. Exercises should extend beyond sectoral and geographic boundaries to engage with all relevant stakeholders.

Conclusion

The resilience of essential services provided by national infrastructure has never been more important. This report presents a set of six Principles for Resilient Infrastructure that will support national net resilience gain. Key actions are defined for each principle, making the adoption of the principles actionable.

These principles are recommended to all levels of governments, investors and infrastructure stakeholders. The principles can be used to determine the resilience of national infrastructure systems and pave way for de-risking investments. They are not intended for assessment of individual assets or components of infrastructure. An overview of the governance for the adoption of the principles is described in the theory of change in Figure 1, and these principles may also be developed as an international standard.

Each of the six Principles for Resilient Infrastructure contribute in specific ways to delivering Net Resilience Gain. Adoption of the principles and key actions is proposed in nations ready to improve resilience outcomes. Adoption in emerging, developing and developed countries exposed to a variety of hazards and conditions of national infrastructure would aid the collection of feedback to improve the principles and key actions. It is also recommended to work with global infrastructure organisations to seek their endorsement and to create local opportunities for translation into best practice guidance.

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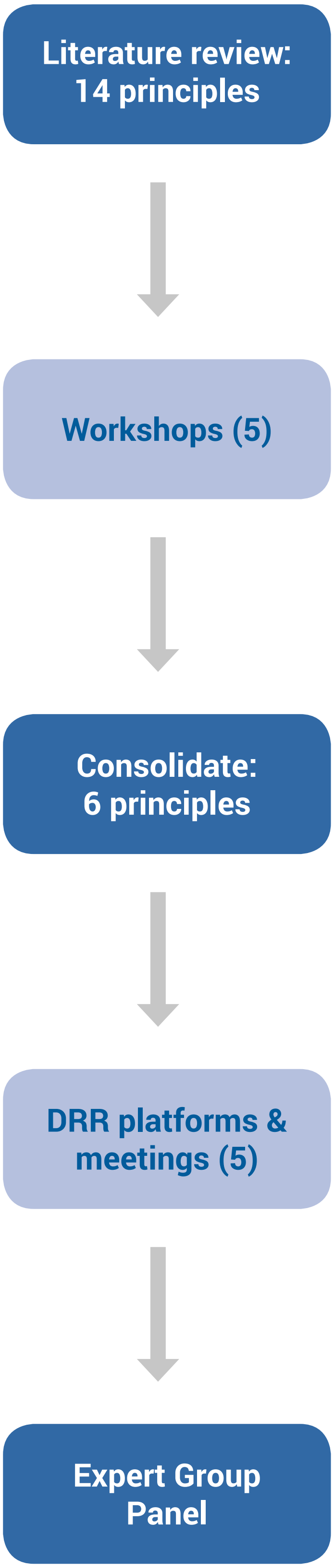
ANNEX A

Method and Consultations



Over 100 Experts have been consulted on the Principles for Resilient Infrastructure, including the following Organisations:

AECOM
African Association of Architects
Africa Business Group
African Research and Impact Network (ARIN)
African Risk Capacity
Arup
AUDA-NEPAD
Bamboo Capital Partners
Chartered Association of Building Engineers
Coalition for Disaster Resilient Infrastructure (CDRI)
Coalition for Climate Resilient Investment (CCRI)
Columbia University
Co-operators, Canada
European Commission
FIABCI Arabic Countries
Global Center on Adaptation (GCA)
Global Infrastructure Basel Foundation (GIB)
Infrastructure Canada
Infrastructure Projects authority, UK (IPA)
Institution of Civil Engineers (ICE)
JP Morgan
Kenya Private Sector Alliance
KPMG
Lloyds Register Foundation
Marsh
McKinsey
Ministry for Climate Crisis and Civil Protection, Greece
Morgan Stanley
Nuclear Decommissioning Authority
OECD
Private Finance Advisory Network (PFAN)
Resilience Shift
RBN Fund Managers
Stantec
Texas A&M University
UK National Infrastructure Commission
UK National Preparedness Commission (NPC)
UN Economic Commission for Latin America and the Caribbean
UN Financing for Sustainable Development Office
Unisa Enterprise (Pty) Ltd
University of Huddersfield
University of Oxford
Willis Towers Watson
World Business Council for Sustainable Development (WBCSD)
WSP

ANNEX B

Mapping of Key activities of Principles for Infrastructure Resilience to Target D of Sendai Framework for Disaster Risk Reduction (SFDRR), Goal 9 of Sustainable Development Goals (SDGs) and Resilience Capabilities

Principle	Key Activity	Target D SFDRR[2]	Goal 9 SDGs	Resilience Capability
ADAPTIVELY TRANSFORMING	P1.1 Design safe-to-fail infrastructure	-	9.1: Develop quality, reliable, sustainable, and resilient infrastructure, including regional and transborder infrastructure	Absorb failures
	P1.2 Create adaptive capacity	D4		Resist and absorb failures; Adapt to failures; Enhance recovery process
	P1.3 Develop dynamic structures			Adapt to failures; Enhance recovery process
	P1.4 Enable extensibility			Adapt to failures; Absorb failures
	P1.5 Allow for human discretion			Resist failures; Adapt to failures; Enhance recovery process
	P1.6 Adopt the appropriate level of complexity	-		Adapt, transform, and recover more easily
ENVIRONMENTALLY INTEGRATED	P2.1 Use nature-based solutions	D4, D8	9.4. Greater adoption of clean and environmentally sound technologies and industrial processes.	Resist in the face of risk of disasters with a natural hazard origin; Absorb effects of disasters with a natural hazard origin ; Accommodate the natural environment
	P2.2 Integrate ecosystem information	D8	9.4. Taking environmentally friendly measures and being more adapted to natural environment can support both sustainability of environment and resilience of infrastructure systems and reduced CO_2 emissions.	Prevent the risk of disasters with a natural hazard origin; Adapt to natural environment conditions
	P2.3 Minimise environmental harm	D4, D8		Prevent the risk of disasters with a natural hazard origin
	P2.4 Maintain the natural environment			Prevent disruptions caused by disasters with a natural hazard origin
PROTECTED BY DESIGN	P3.1 Raise essential safety requirements	D4, D8	9.1 Develop quality, reliable, sustainable and resilient infrastructure	Prevent from all disasters
	P3.2 Exceed basic requirements for critical component			Prevent from all disasters
	P3.3 Consider complex interdependencies of connected networks	D4, D8		Absorb failures
	P3.4 Embed emergency management	D8		Resist and absorb failures
	P3.5 Use local sustainable resources		9.4. Resource-use efficiency.	Resist failures
	P3.6 Design for multiple scales			Enhance recovery process
	P3.7 Commit to maintenance	D4, D8	9.1 Develop quality, reliable, sustainable and resilient infrastructure	Adapt to all disasters

[2] Refer to page 3 for the Sendai Framework for Disaster Risk Reduction Target D indicators.

	Key Activity	Target D SFDRR[2]	Goal 9 SDGs	Resilience Capability
SOCIALLY ENGAGED	P4.1 Inform people about disruptions		9.1. By providing requirements necessary for having more informed, educated, active and engaged people, not only is the resilience of infrastructures increased but human well-being and development can be improved. 9.c. Making people more familiar with technical advancement and providing more accessible communication technologies support resilience of both infrastructure and human societies.	Prevent unmanageable loads of usage; Resist in emergency situations with lower supply level
	P4.2 Raise resilience literacy			Support transformation to apply more technical advancements necessary for being more resilient
	P4.3 Incentivise demand behaviour			Prevent unabsorbable high loads of usage; Resist abrupt failures by manageable level of usage
	P4.4 Encourage community participation			Prevent man-made interruptions; Enhance recovery process through public participation
SHARED RESPONSIBILITY	P5.1 Harmonise open standards	D4, D8	• 9.5. Taking these actions can enhance upgrading the technological capabilities and encouraging innovation. • 9.b. Support domestic technology development, research, and innovation in developing countries, including by ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities. • 9.c. Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet.	Resilience for whole lifecycle
	P5.2 Cultivate collaborative management			Prevent failure; Enhance recovery process
	P5.3 Establish shared responsibilities			Support transformation to data-based approaches to be more resilient; Prevent failure; Enhance recovery process
	P5.4 Enhance connectivity for information sharing			
	P5.5 Assure data safety to develop trust			Support transformation to data-based approaches to be more resilient
	P5.6 Share risk and return information	D8		Prevent failure
CONTINUOUSLY LEARNING	P6.1 Expose and validate assumptions	D4, D8	9.5. Taking these actions can enhance scientific research, upgrade the technological capabilities, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending.	Prevent all risks
	P6.2 Monitor and intervene appropriately			
	P6.3 Analyse, learn, and formulate improvements			
	P6.4 Stress test			

[2] Refer to page 3 for the Sendai Framework for Disaster Risk Reduction Target D indicators.