Resilience Roadmap

Methods Brief
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Developing Key Performance Indicators for Climate Change Adaptation and Resilience Planning

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Purpose and Definitions

This document recommends a common approach to developing key performance indicators (KPIs) for climate change adaptation and resilience planning, drawing upon current science and tools referenced throughout. The work is particularly aimed to support climate adaptation and resilience planning by US federal agencies and thus presents principally US national-level data and online resources. The approach is broadly applicable across agencies, sectors, and systems and can also be applied by state or local planners and adaptation/resilience practitioners. The KPI development approach includes:

(1) Setting the scope and goals of climate adaptation and resilience planning, following a stepwise process (Section 2).

(2) Developing KPIs to track performance and guide adaptive management, following a core set of ten process and five outcome indicators (Section 3).

Federal agency climate adaptation plans structure and schedule federal-to-local spending and actions that aim to strengthen the resilience and ensure the sustained performance of key US systems and services under climate change and its related stresses and shocks. Climate adaptation plans address the vulnerabilities and resilience needs for specific systems (e.g., energy, transport, water, defense), as well as the general resilience of the human and natural communities they support. In the KPI development approach that follows, we consider climate adaptation a *process* and climate resilience a *capability*, consistent with current US and international definitions (Table 1).

Table 1. Reference definitions of adaptation and resilience

Entity	Definition	Source
US Department of Defense (DOD)	• **Adaptation:** "Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative efforts." • **Resilience:** "The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."	DOD Directive 4715.21 (2016)
US Global Change Research Program (GCRP)	• **Adaptation:** "Adjustment in natural or human systems in response to a new or changing environment that exploits beneficial opportunities or moderates negative effects." • **Resilience:** "A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment."	US GCRP (2022)
Intergovernmental Panel on Climate Change (IPCC)	• **Adaptation:** "The process of adjustment to actual or expected climate and its effects." • **Resilience:** "The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure."	IPCC (2022)

2. Setting the Scope and Goals of Adaptation Efforts

What is the goal of the adaptation investment, and over what time frame? What systems, organizations, institutions, and stakeholders are involved? Which hazards and stresses will be addressed? Setting the scope and goals of adaptation efforts provides answers to these and other questions with central relevance to complexity, costs, and risks. A simple stepwise process (Figure 1) may guide this important framing.

Figure 1. Stepwise adaptation investment framing

These steps are considered further in following sections, with reference to current tools and resources.

2.1 Resilience of what (system, organization)?

Adaptation plans target specific systems, geographies, and supported communities. The boundaries of those systems follow established administrative and jurisdictional limits, but also commonly have broader connections across natural and human communities. Water systems are delineated along river basins, whereas energy systems are mapped along the grid and serviced populations. Our world and the systems we must adapt are interconnected, interdependent, and commonly governed across multiple layers of authority. For instance, water systems are commonly subdivided into managed systems serving distinct regions and stakeholders, all of whom are nonetheless dependent upon actions across broad river basins for their water security. Defining boundaries to include key connections and interdependencies across the target system ensures that no parts of the system, no relationships or vulnerabilities, are missed.

Questions to Consider: What are the boundaries and components of the system and/or organization? What factors influence its function? What other systems connect with it?

Three facets of resilience have prevailed in policy and practice: community, ecological, and engineering resilience.[1]

- *Community or Social resilience* refers to the ability of communities to withstand and recover from disasters, and to learn from disasters to strengthen future response and recovery efforts.
- *Ecological resilience* refers to the capacity of natural systems absorb disturbances and to adapt to changing climate and civilizational stresses without undergoing regime change.
- *Engineering or Technological resilience* refers to the capacity of an engineered system to return to and maintain its performance, near an equilibrium, following a disturbance.

Our food, energy, water, and other systems are not defined by Social, Ecological, and Technological (SET) dimensions solely, but rather by all three combined in dynamic, complex systems.[2] SET attributes drive the performance and resilience of our energy, food, transport, health, and other systems and together constitute the factors and relationships that can be adapted to build resilience.

While the driving variables of resilience are necessarily specific to each sector—agriculture is distinct from energy, and so on—a general lens by which to consider SET dimensions of a target system in an integrated resilience assessment includes:

- *Social* attributes describing conditions of governance, equity, individual and collective agency, and social capital, as well as economic incentives
- *Ecological* attributes describing the state of natural ecosystems and biodiversity, the flow of ecosystem services, and inputs to the system such as pollutants and invasive species
- *Technological* attributes, including natural and built infrastructure, technologies, operations, and knowledge systems

Questions to Consider: What key system components and SET attributes influence system function? How do these elements interact?

Sustained system performance under stresses and shocks is the central outcome of adaptation planning and resilience management efforts. The goods and services provided by a system are commonly understood and conventionally measured—for example, crop yields, water quality and quantity, energy supply, social welfare, etc. are measures we apply to understand the performance of the systems we construct and manage. Key to managing for resilience and measuring its attainment is a clear identification of the services provided by and expected of the target system. Resilience can be evaluated according to the system's performance under stresses and shocks relative to those service objectives.

Questions to Consider: What services are provided by the system? How can its function and performance expectations be set and measured?

Public policies commonly set baseline objectives for public system performance in terms of supply requirements, quality standards, and environmental imperatives such as preserving key species and habitats. In adaptation planning efforts, stakeholders should be engaged inclusively to inform performance expectations and trade-offs among resilience-building options. (See section 2.3 and [Drawing Bounds Around Your Adaptation Effort] from Resilience Metrics.[i])

2.2 To what (shocks and stresses)?

As the climate changes and conditions shift, now and into the future, our food, water, energy, health, social, and natural systems must be able to adapt in order to thrive under change; they must be resilient. To understand and plan for resilience, stressors and related system vulnerabilities or risks must be identified. Here we use stressors to refer to the shocks, stresses, and uncertainties to which a system must adapt.

Stressors are often interrelated in how they affect systems. Types of stressors include:

- *Operational:* Routine disruptions impacting performance, such as power outages, communications breakdowns, staff loss, and mechanical failures
- *Environmental:* Changes in environmental conditions influencing the system, such as ecosystem services, natural infrastructure, biodiversity, and ecological connectivity
- *Socioeconomic:* Changes in demand driven by economic and demographic growth, market volatility, and heightened social vulnerability
- *Climatic:* Shifts in temperature and precipitation and an increased magnitude and frequency of disaster events from coastal storms to wildfires
- *Unanticipated shocks and uncertainties:* Unplanned for, potentially catastrophic events (e.g., multihazard events, pandemics)

While a particular hazard or crisis may be driven by one stressor, all systems are influenced by multiple stressors, often occurring at once or in cascades. Climate change influences and exacerbates many other stressors and cannot be considered in isolation. All relevant stressors and their potentially compounding effects should be factored in when planning for resilience. Adaptation investments should holistically strengthen these complex systems, and not merely address singular stressors. Singular solutions are likely incomplete and even maladaptive.

Questions to Consider: What are the (multiple) stressors that affect the system and to which it must adapt? What key vulnerabilities does the system have?

The key drivers influencing system performance and resilience—i.e., the SET attributes identified in section 2.1—are likely the key sources of vulnerability of the system when exposed to shocks and stresses. For instance, the drainage capacity of an urban water system is central to city vulnerability or resilience to flooding events, the state of ecosystems in the wildlife-urban interface drives wildfire vulnerability, and conditions of governance and equity influence the vulnerability of key communities. Identifying key vulnerabilities enables proactive adaptation in design and operations.

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[i] Resilience Metrics results from over 10 years of collaborative research, involving a wide range of experts, decision-makers and stakeholders from across the U.S. Underlying projects were led by Susanne Moser and supported by NOA.

Question to Consider: What are the historical versus forecast magnitudes, frequencies, and variabilities of the occurrence of these stressors?

The US Global Change Research Program (GCRP) Indicators Catalog suggests measures of climate-related trends that may inform understanding and characterization of climate stressors. US GCRP's Climate Explorer offers interactive graphs and time-series maps showing climate projections for US counties. The National Centers for Environmental Information from the National Oceanic and Atmospheric Administration offer particularly useful national and regional disaster- and hazard-specific data. The US Climate Resilience Toolkit offers further resource links.

2.3 For whom (stakeholders)?

Developing a shared understanding of resilience objectives, options, and trade-offs among all stakeholders is fundamental to effective, collective, and sustainable action to adapt and to build resilience. Building resilience derives from relationships and actions, coordinated among communities and decision makers that are both dependent upon and influence the performance of the target system.

Questions to Consider: Who benefits from and who pays for resilience interventions? Who are disadvantaged and underserved? How can equitable outcomes be achieved?

Stakeholder inclusion is key to increasing justice and enhancing equity in adaptation efforts and outcomes. Disadvantaged and underserved communities are more commonly prone to exposure and vulnerability from climate change and related stressors. The Council on Environmental Quality's Climate and Economic Justice Screening Tool identifies disadvantaged communities based on indicators of climate change, clean energy, clean transit, affordable housing, legacy pollution, clean water and wastewater, health burden, and training/workforce development. EJScreen, the Environmental Protection Agency's environmental justice screening and mapping tool, combines environmental and demographic indicators in reports and maps to inform efforts related to protecting public health and the environment. The NAACP Equity in Building Resilience in Adaptation Planning toolkit suggests indicators of vulnerability and resilience equity in infrastructure, economic development, health/wellness, and culture.

Questions to Consider: Which communities and populations are dependent upon the systems and/or institutions? What environmental and biodiversity needs should be met?

In addition to human communities and vulnerable peoples, ecological communities, plant and animal species, and their invaluable ecosystem services may be impacted by adaptation decisions. The sustained functioning and productivity of ecosystems plays a key role in ensuring the resilience of critical systems—water and food systems most evidently. Planning efforts should consider the implications of adaptation choices to ecosystems and biodiversity. See also Identifying and Effectively Engaging Stake- and Rights-holders from Resilience Metrics.

2.4 Over what time period (performance life)?

Systems and structures funded and otherwise supported by government programs should be developed and strengthened to address the known and probable risks posed by stressors over their operational lifetimes. Complex infrastructure usually has a useful life of 70 years or more. In other dimensions of the built environment, at least 50 years is expected. Given the extent of development in areas at high risk of climate stressors and shocks, some systems, assets, and infrastructure will either be stranded or need to be relocated in the future. Adaptation plans should account for the probability of retreat and/or relocation of existing and future assets. The particular impacts on disadvantaged communities—who commonly reside in and rely upon high-risk geographies and systems—should be forecast and incorporated in resilience planning.

Questions to Consider: What is the expected performance life of the system? To what known and forecast stressors must it be resilient?

To help optimize the long-term resilience of systems and structures, adaptation plans and infrastructure designs should consider the best available data on the existing and probable future risks posed by natural hazards, including flooding, sea-level rise, extreme heat, drought, wildfire, and others. The Federal Flood Risk Management Standard aims to address future risks in flood-prone areas by requiring the incorporation of best available climate data or additional margins of safety into the design and construction of federally funded buildings and projects.

Question to Consider: What provisions have been made for future vulnerability assessment and further adaptation/resilience planning?

No adaptation plan is final. Under changing climate futures, a proactive approach to developing "signposts" or indicators of the need for further adaptation is warranted. Dynamic Adaptive Policy Pathways[3] describes an analytical approach to exploring and sequencing actions that can be based on uncertain future events. Resilience by Design[4] employs decision making under deep uncertainty and optimal control methods to identify design options that provide resilience capabilities over a wide range of possible futures. See also Key Dimensions of Adaptation Success from Resilience Metrics.

3. Process and Outcome Measures

Tracking and evaluating climate adaptation planning, spending, and action require two broad types of measures:

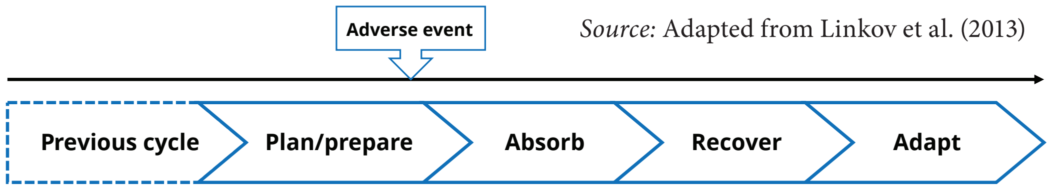
(1) *Process-related:* Informing plans, resource allocation, and operational aspects that measure the adaptation process or effort

(2) *Outcome-related:* Measuring the performance of the targeted system under stresses and shocks.

KPIs should be developed for both categories. Outcome measures should consider all facets of resilience: community, ecological, and engineering.

Figure 2. A resilience matrix of key system domains relative to an event management cycle

Source: Adapted from Linkov et al. (2013)



	Plan/prepare	Absorb	Recover	Adapt
Physical	State and capability of technology, personnel, built and natural infrastructure, and ecosystem services	Event recognition and system performance under shocks and stresses	System changes to recover prior functionality	Changes to improve system resilience
Information	Data capture, storage, sharing, and use	Real-time assessment of functionality; anticipation of failure	Data use to track recovery process and anticipate scenarios	Improvement of data storage and use protocols
Cognitive	System design and operation decisions, with anticipation of adverse events	Contingency protocols and proactive event management	Recovery decision-making and communication	New system configurations, objectives, and decision criteria
Social	Social networks and capital; institutional norms and training	Capable staff and social networks for event response	Teamwork and knowledge sharing to enhance recovery	Changes to policies, training, and institutions

3.1 Process KPIs

Common process measures may be adopted across diverse agencies, sectors, and systems, lending greater overall coherence in climate adaptation planning. A core set of such "Process KPIs," distilled from federal agency adaptation plans (2022) and current literature, are suggested in Box 1.

In 2013, Linkov and colleagues from the US Army Corps of Engineers and leading US universities produced a useful Resilience Matrix to guide comprehensive planning for disaster resilience.[5] Here we have adapted the Resilience Matrix to explicitly note the ecological dimensions implicit in their earlier work (Figure 2).

The matrix informs the identification of resilience metrics across key system dimensions and steps in an event management cycle. Process KPIs suggested in Box 1 are reflected and further elaborated in the Resilience Matrix.

Box 1. General Process KPIs for adaptation planning

- Climate resilience objectives and performance measures incorporated in planning and spending
- Assets evaluated for resilience to known and projected impacts of climate change and related stressors
- Climate adaptation plans developed, addressing multiple stressors and hazards, their relationships, and cumulative and compounding effects
- Event recognition, disaster response protocols, and capabilities tested and updated
- Public communications systems, event response networks, and outreach protocols tested and updated
- Data management systems and protocols updated to incorporate climate-related information, monitoring, and adaptive management
- Adaptation plans coordinated across relevant agencies, operators, and partners
- Staff trained in climate adaptation and resilience matters, procedures, and measures[ii]
- Regular, timely updating of hazard estimates, asset vulnerability assessments, and adaptive management to improve resilience
- Regular and timely updating of climate adaptation plans

[ii] The American Society of Adaptation Professionals' Knowledge and Competencies Framework suggests what knowledge and competencies are needed to ensure that professionals are prepared to effectively address climate change adaptation and climate resilience in the context of their work.

This framing may be helpful in planning for the resilience capabilities and performance of organizations and institutions, particularly for disaster events.

3.2 Outcome KPIs

"Outcome KPIs" may be specified and tailored to specific systems or agencies, while following a consistent, general approach. Here we suggest five core Outcome KPIs that should be included in adaptation planning (Box 2).

Ultimately, the outcome of the adaptation effort—the resilience of the target system or organization—is measured relative to expectations for the performance of that system to forecast stressors over a defined period of time.

Box 2. General Outcome KPIs for adaptation planning

- System performance under shocks and stresses
- State and performance of SET attributes influencing system resilience
- Event recognition, operational response, and recovery effectiveness
- Stakeholder inclusion, benefits, and measures of equity in resilience outcomes
- State and function of relevant ecosystems and environmental conditions

Resilience capabilities are designed for select hazards, stresses and shocks, and not for sustained performance under all stressors. Performance expectations, defined by agency mandates and informed by stakeholder preferences, risk tolerances, and cost-benefit measures inform the aim of the adaptation effort, or the resilience-building goal. The central Outcome KPI is thus system performance under shocks and stresses, evaluated relative to those expectations.

Measuring the state and performance of SET factors driving system performance informs our understanding of how complex systems function and reveals sources of both vulnerability and resilience. Performance of the data systems, technologies, communications operational capabilities and networks relied upon for event management informs operational resilience. Measures of stakeholder inclusion, equity, and environmental justice achieved under conditions of stress and disruption are key to understanding and enhancing social resilience. Ecological outcomes track the state of natural communities and biodiversity, those contributing to adaptation efforts and impacted by them, as well as relevant environmental conditions (e.g., air and water quality, pollution, greenhouse gas emissions, etc.).

Specific Outcome KPIs should be developed for and coordinated across each agency and system, as relevant. Agriculture, energy, water, transport, health, urban, environmental, and social systems all necessarily have bespoke measures of performance for the specific services they are designed and operated to deliver (e.g., water supply, food yield, wave attenuation, flooding mitigation, energy provision). They are also highly interdependent—food production relying on water, energy, and so on. The resources in Table 2 offer a wealth of indicators and metrics that may be helpful in deriving specific Outcome KPIs. See also the "Tools" page of the US Climate Resilience Toolkit, which offers numerous planning guides and case studies addressing specific sectors and systems.

Table 2. Reference outcome indicators and metrics

Entity	Definition
Hurricane Sandy Rebuilding Task Force (2013) Developing Socio-Economic Metrics to Measure DOI Hurricane Sandy Project and Program Outcomes (2015)	Economic, infrastructure, and social indicators to evaluate the Department of the Interior's projects to strengthen community and ecological resilience, including: • Human health and safety (e.g., number of households exposed to acute hazards) • Property and infrastructure (e.g., avoided costs, avoided disruption of critical services) • Economic resilience (e.g., number of work days lost, number of businesses impacted) • Community competence and empowerment (e.g., number of partnerships, number of volunteers)
National Institute of Standards and Technology (NIST) Inventory of Community Resilience Indicators & Assessment Frameworks	The NIST metric inventory is a compendium of quantitative community resilience frameworks, indicators, and measures. NIST metrics are categorized based on: • Aspects of resilience addressed (infrastructure, economics, health, social, natural, etc.) • Unit of the metric (e.g., dollars, number of buildings, number of people)
Resilience Metrics	Metadata systems and sectors (e.g., coastal, urban, infrastructure), climate hazard stressors, adaptation strategies, indicators, and how to use them. KPIs include • Economic aspects (e.g., money saved, rate/trend of sales, changes in zoning) • Environmental aspects (e.g., acres of natural shoreline area protected or restored) • Governance aspects (e.g., growth in number of champions, shift in who is at the table) • Infrastructure aspects (e.g., monetary damages sustained, # houses damaged/lost) • Social aspects (e.g., # disaster-related injuries or deaths, # environmental illnesses)

Endnotes

[1] Julie L. Davidson, Chris Jacobson, Anna Lyth, Aysin Dedekorkut-Howes, Claudia L. Baldwin, Joanna C. Ellison, Neil J. Holbrook, Michael J. Howes, Silvia Serrao-Neumann, Lila Singh-Peterson and Timothy F. Smith, "Interrogating Resilience: Toward a Typology to Improve its Operationalization," *Ecology and Society* 21, no. 2 (2016): 27. http://dx.doi.org/10.5751/ES-08450-210227; Jesse M. Keenan and Keely Maxwell, "Rethinking the Design of Resilience and Adaptation Indicators Supporting Coastal Communities," *Journal of Environmental Planning and Management* 65, no. 12 (2022): 2297–317. doi:10.1080/09640568.2021.1971635.

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[3] Marjolijn Haasnoot, Jan H. Kwakkel, Warren E. Walker and Judith ter Maat, "Dynamic Adaptive Policy Pathways: A Method for Crafting Robust Decisions for a Deeply Uncertain World," *Global Environmental Change 23, no.* 2 (2013):485. https://doi.org/10.1016/j.gloenvcha.2012.12.006.

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[5] Igor Linkov, Daniel A. Eisenberg, Matthew E. Bates, Derek Chang, Matteo Convertino, Julia H. Allen, Stephen E. Flynn, and Thomas P. Seager, "Measurable Resilience for Actionable Policy," *Environmental Science and Technology* 47, no. 18 (2013): 10108–10. doi:10.1021/es403443n.

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About Resilience Roadmap

The Resilience Roadmap project seeks to offer actionable recommendations to support the Biden administration's commitment to mobilize the federal government and the American people to build greater climate resilience in infrastructure, communities, and ecosystems, guided by principles of equity and environmental justice. Leading resilience experts from states, local communities, civil society, academia, and the private sector, many of whom formerly worked in the federal government and on the frontlines of the climate change battle, have volunteered their time and knowledge for this vital national effort.

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