Integrating Resilience Strategies for No-Regret Decision-Making

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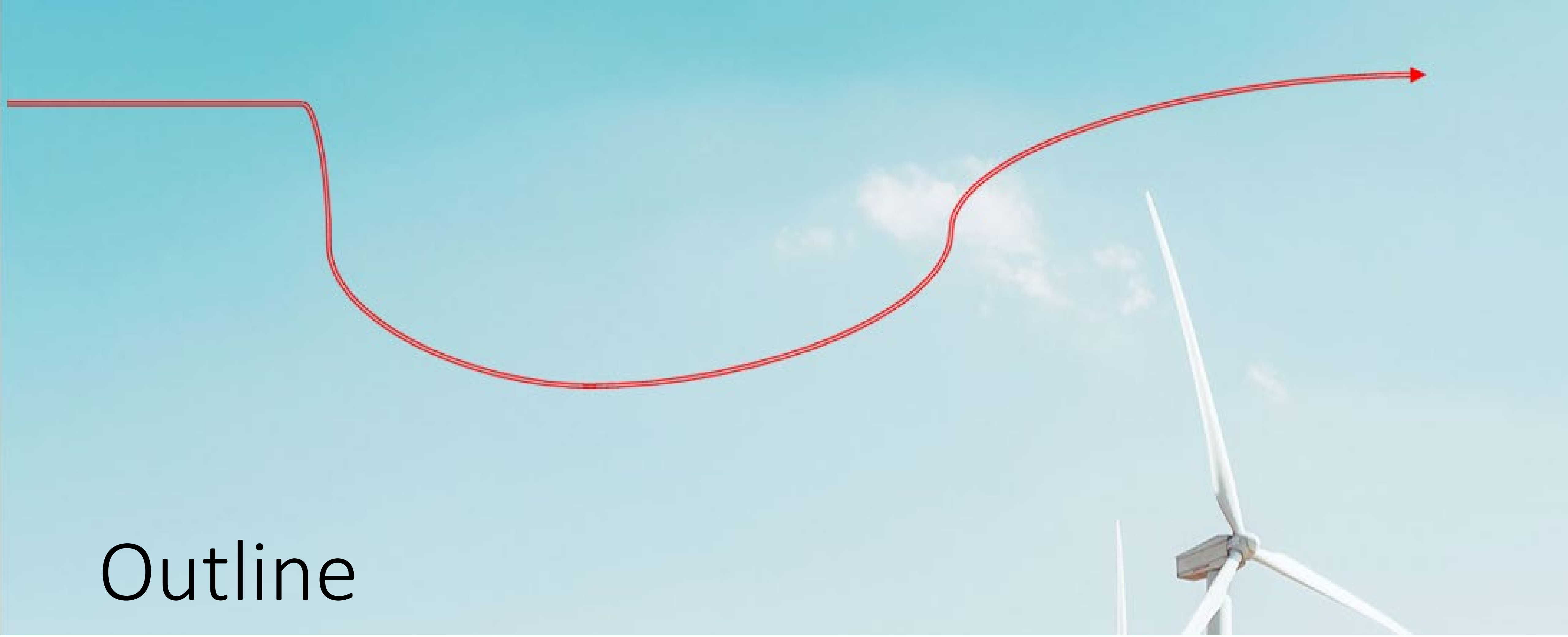
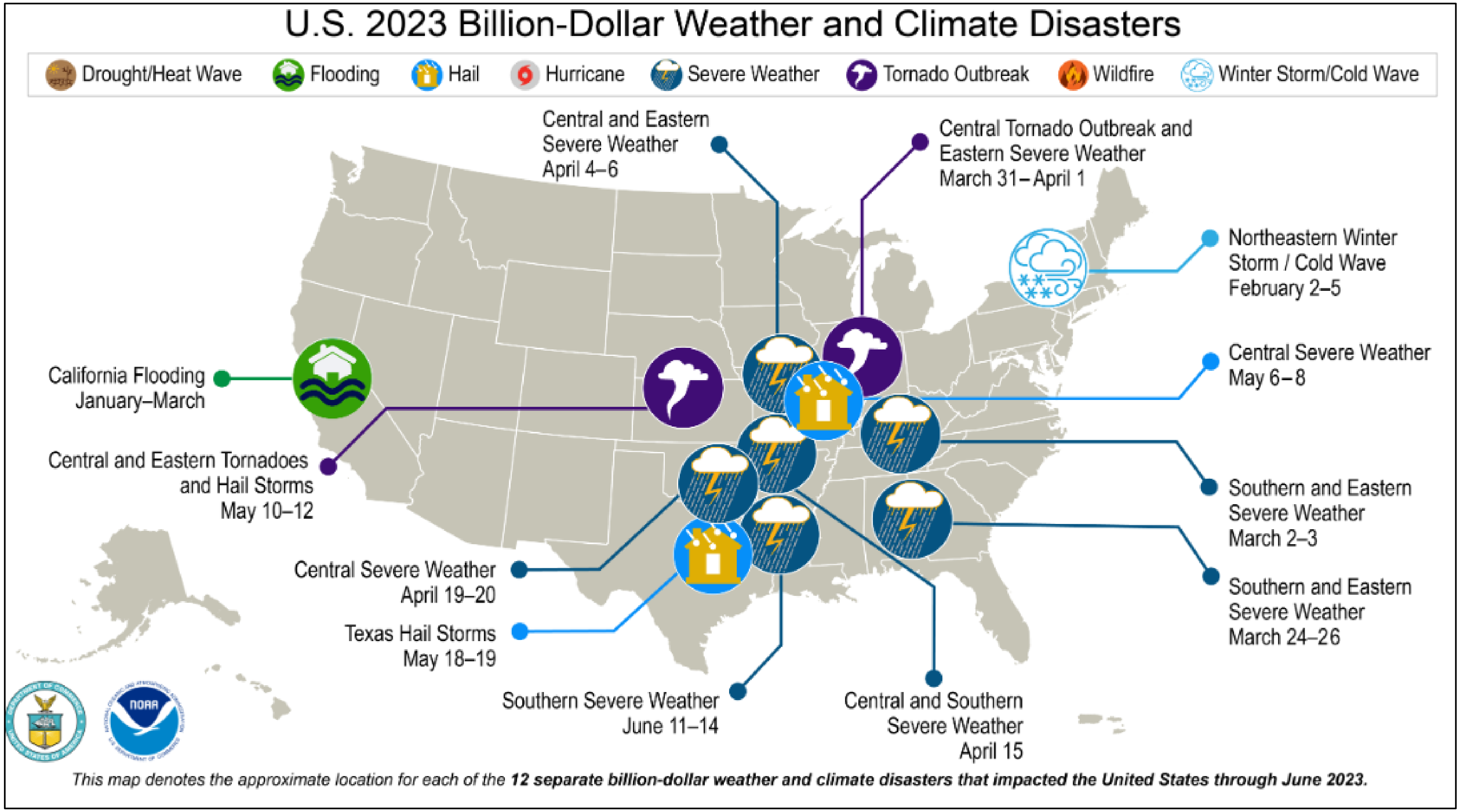


Outline

- Need for resilience
- Definition of resilience
- Broad resilience strategies for no-regret decision-making
- Case Study: NYPA background and resilience for the electricity sector

Climate events are increasingly impactful and costly

- **1980-1989**
  - 3.3 events per year
  - 21.3B USD per year*
  - 299 deaths per year
- **1990-1999**
  - 5.7 events per year
  - 32.5B USD per year*
  - 308 deaths per year
- **2000-2009**
  - 6.7 events per year
  - 60.3B USD per year*
  - 310 deaths per year
- **2010-2019**
  - 13.1 events per year
  - 96.4B USD per year*
  - 523 deaths per year
- **2020-2022**
  - 20.0 events per year
  - 151.4B USD per year*
  - 487 deaths per year



*CPI-adjusted

Image and data from NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2023). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73

Increasing climate disruption to asset management is inevitable

Image from: https://www.theguardian.com/business/2022/jul/19/why-does-britains-tarmac-melt-and-its-rails-buckle-in-heat

- Construction materials are prone to acute and chronic stressors
  - Metals buckle and asphalt melts after exceeding design temperature tolerances
  - Reinforced concrete cracks in a wetter and warmer climate
- Infrastructure usage impacted by changing demand patterns
  - Climate migration
  - Different utility/infrastructure use profiles
  - Digitalization
- Health and safety considerations affect operations
  - During extreme heat, construction work may need to shift to nights
  - Flooded roads and infrastructure increase hazards
- Infrastructure does not operate as expected/designed
  - Wildfire smoke decreases solar panel output and increases transmission line arcing
  - Extreme temperatures decrease mechanical efficiency
  - Freshwater and saltwater flooding decrease lifespans of assets

Compounding disruptions and interconnected systems are exacerbating the impacts of climate change

- Geopolitical

  S&P Global top geopolitical risks of 2023 include:
  - Russia-NATO tensions
  - Cyberattacks
  - COVID-19 pandemic fallout
- Social, including:
  - Strikes
  - Extremism
- Supply chain and technological, including:
  - Just-in-time/lean manufacturing prioritizes efficiency, leaving little buffer in supply chains
  - AI, big data, digitalization
- System of systems
  - Assets do not operate independently
  - Cyber, physical, human domains

The Port of Charleston in Charleston, South Carolina, U.S., on Wednesday, Nov. 3, 2021.
Sam Wolfe | Bloomberg | Getty Images

Geopolitical risks from: https://www.spglobal.com/en/enterprise/geopolitical-risk/#:~:text=The%20world%20is%20rapidly%20changing,and%20mounting%20sovereign%20debt%20levels.
Image from https://www.cnbc.com/2021/11/22/maurice-levy-supply-constraints-will-last-until-at-least-2023.html

Definition of resilience

Resilience is a lens for improving asset performance and focusing on disruption consequence

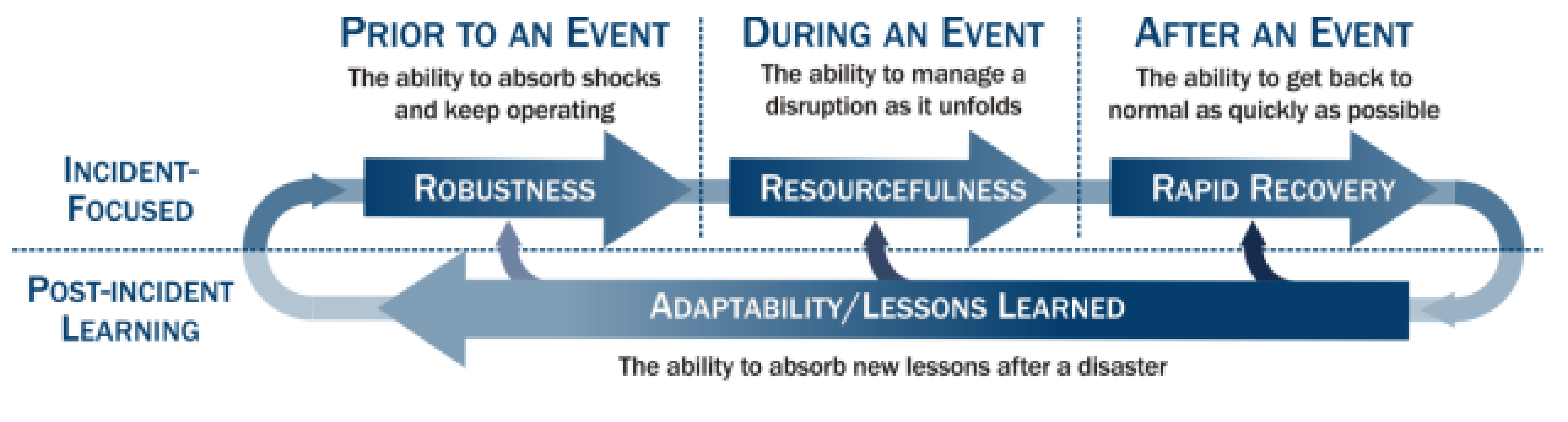


Image from: National Infrastructure Advisory Council

Resilience improves disruption response and is complementary to existing best asset management

- We increasingly cannot predict and harden against all disruptions
- Climate-informed decision making is becoming standard practice and will help ensure asset longevity

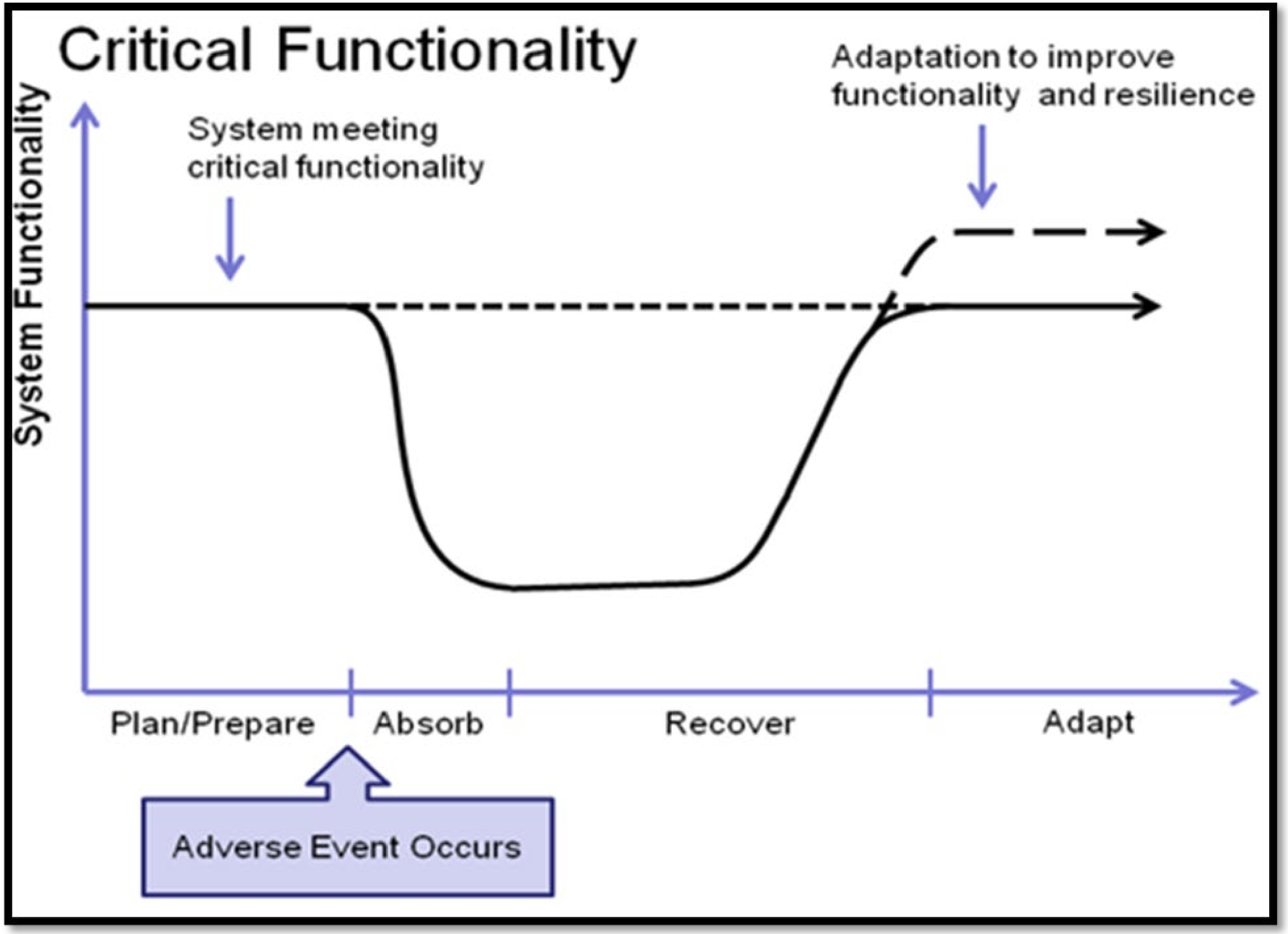
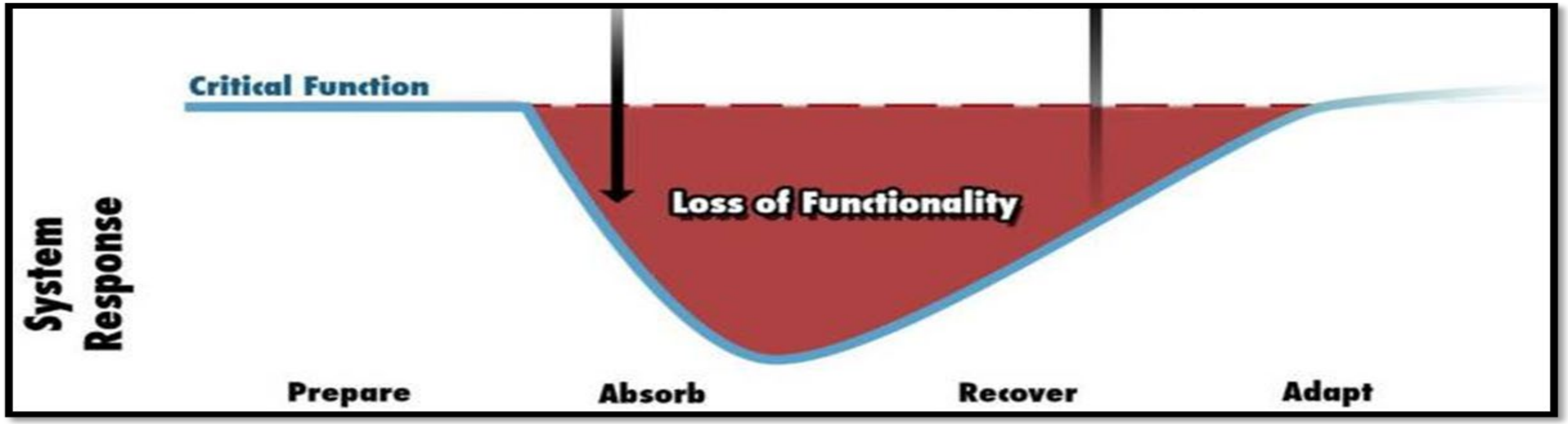


Image from: Marchese, D. & Linkov, I. (2017). Can You Be Smart and Resilient at the Same Time? Environmental Science & Technology, 51(11): 5867-5868. https://doi.org/10.1021/acs.est.7b01912

Resilience Defined



- The ability of a system to maintain a critical function given an unanticipated disruption.
- The ability of a supply chain to meet demand despite disruption.
- 4-Stage NAS Definition: Plan, Absorb, Recover, Adapt
  - National Academies of Science (NAS). (2012). Disaster Resilience: A National Imperative. The National Academies Press. https://doi.org/10.17226/13457
  - Facilitates temporal aspects of modeling resilience

RESILIENCE ANALYTICS IS AN "INSURANCE POLICY" FOR DISRUPTIONS

Image adapted from Hynes, W., Trump, B., Love, P., & Linkov, I. (2020). Bouncing forward: a resilience approach to dealing with COVID-19 and future systemic shocks. Environment Systems & Decisions, 40, 174-184. https://doi.org/10.1007/s10669-020-09776-x

Resilience ≠ Risk

- ❖ Risk = consequence x probability
- ▪ Historical trends
- ▪ Goal to “harden” the system
- ❖ Resilience = capacity to recover
- ▪ Unknown unknowns
- ▪ Goal to maintain critical function

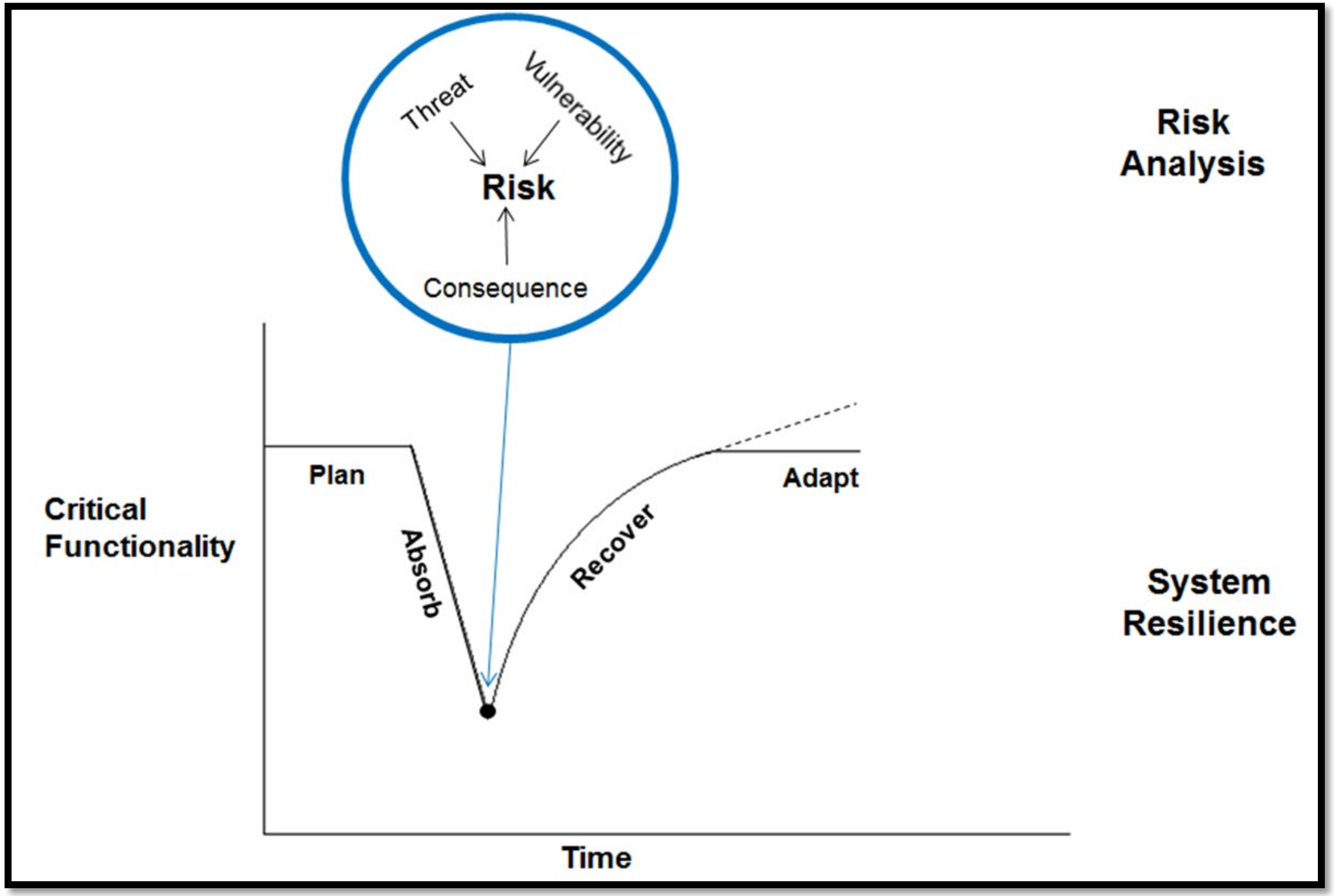


Image from: Linkov, I., Bridges, T., Creutzig, F., Decker, J., Fox-Lent, C., Kroger, W., Lambert, J.H., Levermann, A., Montreuil, B., Nathwani, J., Nyer, R., Renn, O., Scharte, B., Scheffler, A., Schreurs, M., Thiel-Clemen, T. (2014). Changing the resilience paradigm. Nature Climate Change, 4: 407–409. https://doi.org/10.1038/nclimate2227

Resilience and Reliability

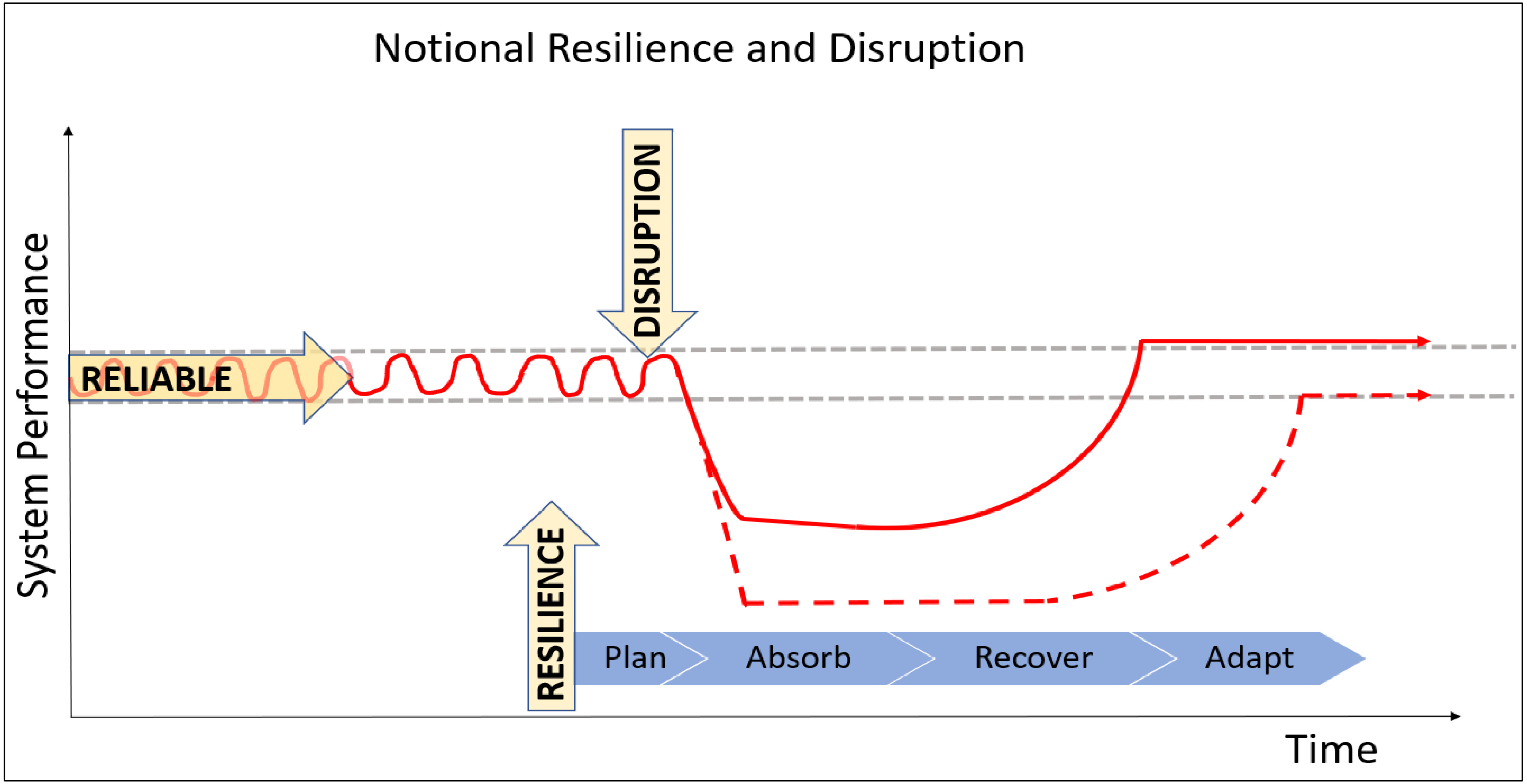
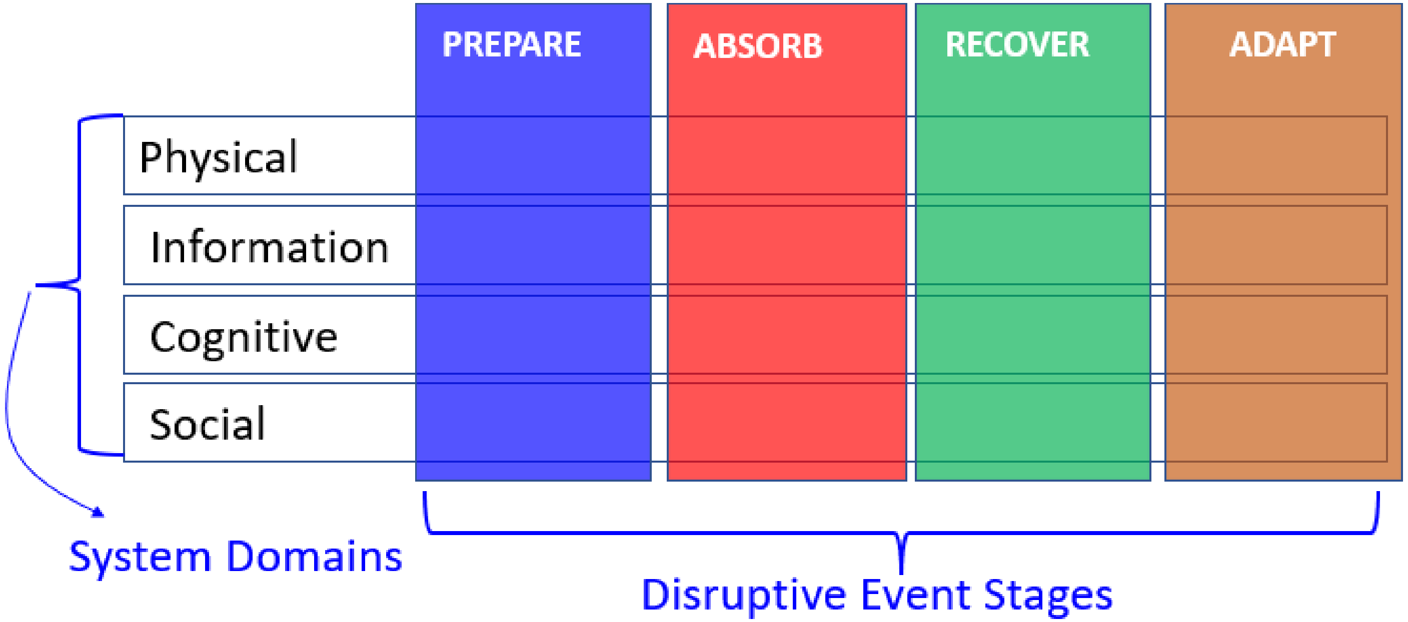


Image from: Golan, M., Mohammadi, J., Ardiles-Cruz, E., Ferris, D., Morrone, P. (2022). Power Grid Resilience: Data Gaps for Data-Driven Disruption Analysis. DDDAS 2022 Conference.

Broad resilience strategies for no-regret decision-making

The "Resilience Matrix" is a tool for developing/ organizing comprehensive resilience strategies



NAS-identified stages of change

- **Plan/prepare:** lay the foundation to keep services available and assets functioning during a disruptive event (malfunction or attack)
- **Absorb:** maintain most critical asset function and service availability while repelling or isolating the disruption
- **Recover:** restore all asset function and service availability to their pre-event functionality
- **Adapt:** using knowledge from the event, after protocol, configuration of the system, personnel training or other aspects to become more resilient

Linkov, I., Eisenberg, D.A., Bates, M.E., Chang, D., Convertino, M., Allen, J.H., Flynn, S.E., Seager, T.P. (2020). Measurable Resilience for Actionable Policy. Environmental Science & Technology, 47(18): 10108-10110. https://doi.org/10.1021/es403443n

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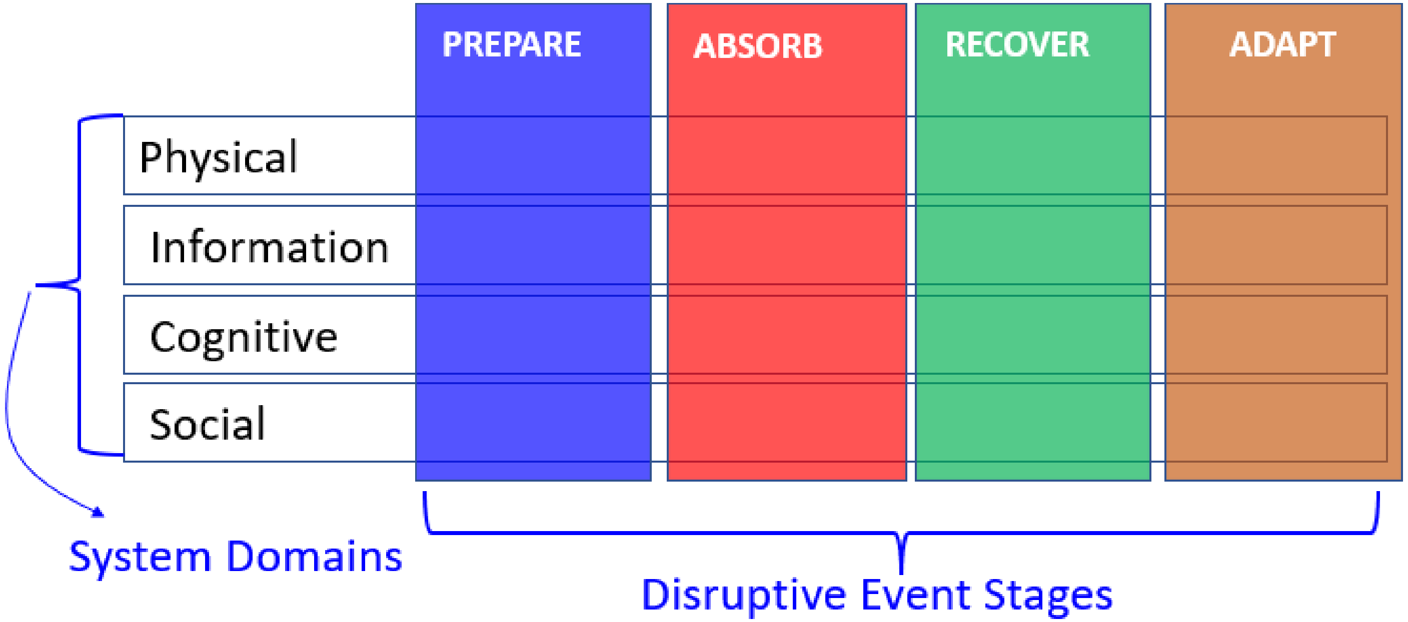
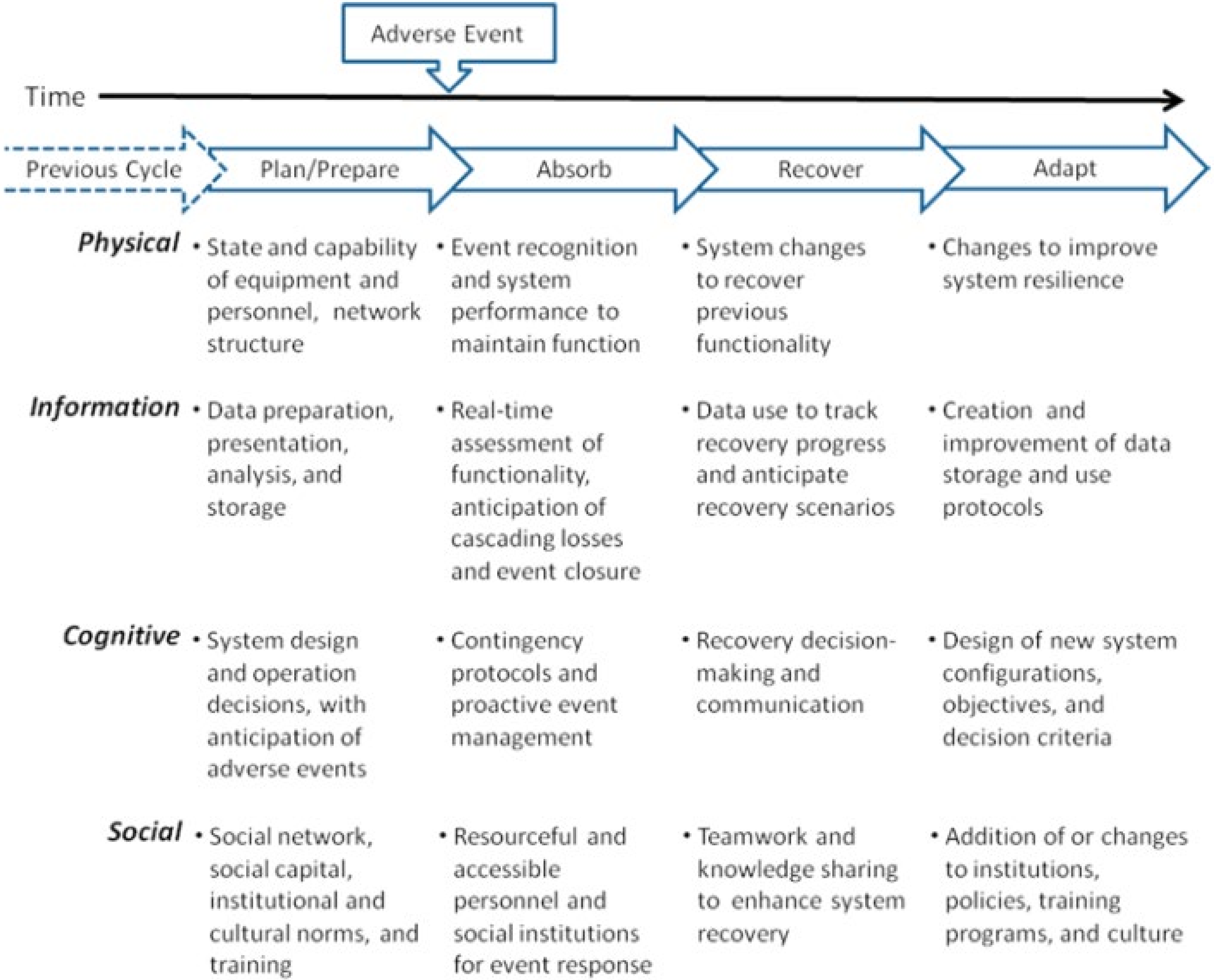


- **Physical:** sensors, facilities, equipment, system states and capabilities
- **Information:** creation, manipulation, and storage of data
- **Cognitive:** understanding, mental models, preconceptions, biases, and values
- **Social:** interaction, collaboration, and self-synchronization between individuals and entities

Linkov, I., Eisenberg, D.A., Bates, M.E., Chang, D., Convertino, M., Allen, J.H., Flynn, S.E., Seager, T.P. (2020). Measurable Resilience for Actionable Policy. Environmental Science & Technology, 47(18): 10108-10110. https://doi.org/10.1021/es403443n



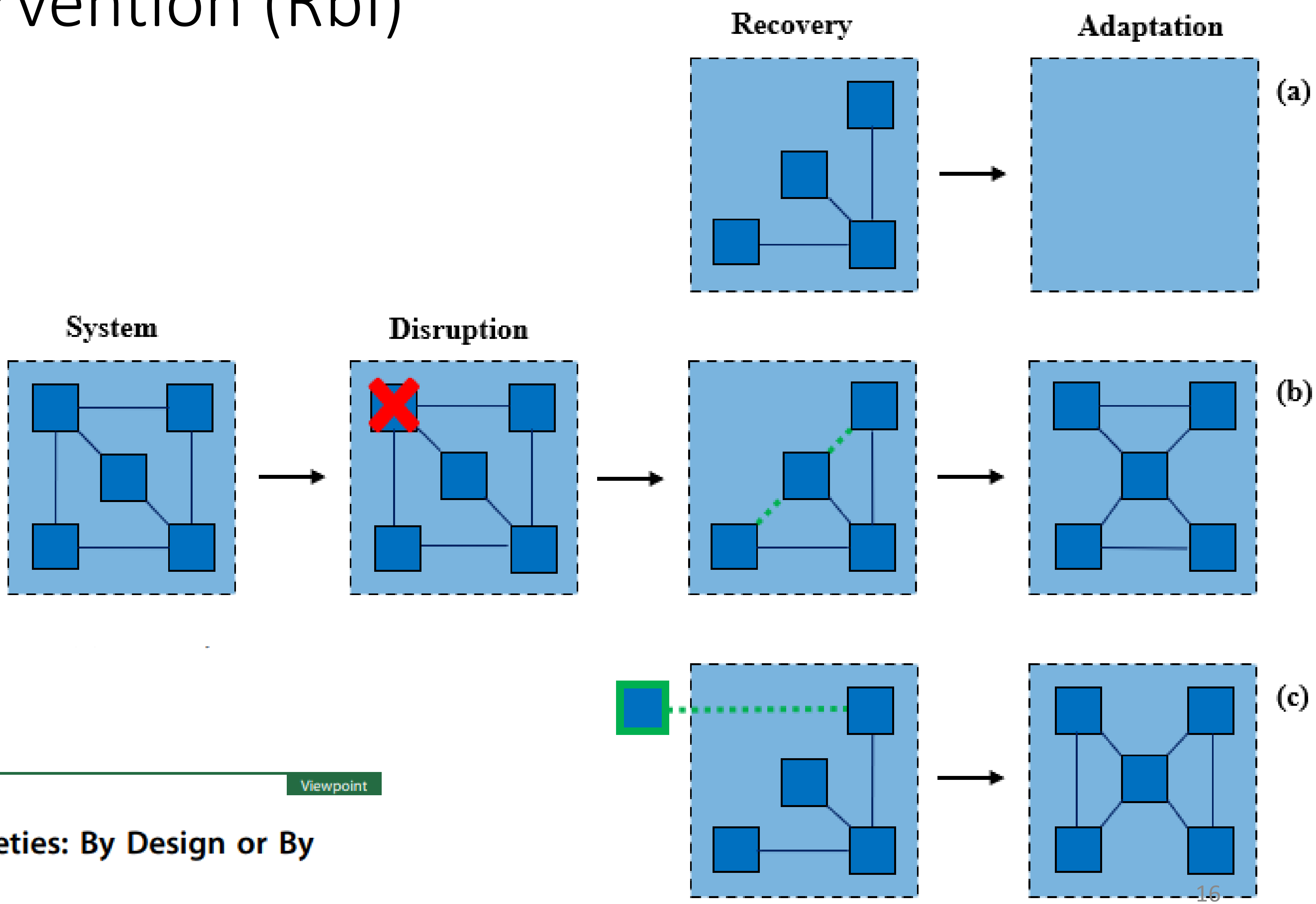
The resilience matrix can be used to map the system domains across an event management cycle

Matrix image from: Igor Linkov, Daniel A. Eisenberg, Matthew E. Bates, Derek Chang, Matteo Convertino, Julia H. Allen, Stephen E. Flynn, and Thomas P. Seager *Environmental Science & Technology* **2013** *47* (18), 10108-10110 DOI: 10.1021/es403443n

Resilience strategies can be implemented by design (RbD) or by intervention (RbI)

Notional system disruptions illustrating:

a) A non-resilient system failing after a disruptive event
b) A resilient-by-design system recovering and adapting post disruption due to internal reconfiguration
c) A resilient-by-intervention system receiving external support to ultimately recover and adapt



Environmental Science & Technology
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Viewpoint

1 **Enhancing Resilience in Post-COVID Societies: By Design or By**
2 **Intervention?**

3 Igor Linkov,* Benjamin D. Trump, Maureen Golan, and Jeffrey M. Keisler

Comparison of risk-based approaches with RbD and RbI

	Risk management	**Resilience-by-design**	**Resilience-by-intervention**
Objective	Harden individual components	Design components to be self-reorganizable	Rectify disruption to components and stimulate recovery by external actors
Capability	Predictable disruptions, acting primarily from outside the system components	Either known/predictable or unknown disruptions, acting at a component or system level	Failure in context of societal needs, may be constellation of networks across systems
Consequence	Vulnerable nodes and/or links fail as result of threat	Degradation of critical functions in time and capacity to achieve system's function	Degradation of critical societal function due to cascading failure in interconnected networks.
Actor	Either internal or external to the system	Internal to the system	External to the system
Corrective Action	Either loosely or tightly integrated with the system	Tightly integrated with the system	Loosely integrated with the system
Stages/Analytics	Prepare and absorb (risk is product of threat, vulnerability and consequences and is time independent)	Recover, and adapt (explicitly modeled as time to recover system function and the ability to change system configuration in response to threats)	Prepare, absorb, recover, and adapt (explicitly modeled as ability to recover and secure critical societal function and needs through constellation of relevant systems)

Kott, A.S., Golan, M.S., Trump, B.D., & Linkov, I. (2021). Cyber Resilience: by Design or by Intervention? *Computer, 54*, 112-117.

Measuring Resilience

- Resilience as a physical property
  - Infrastructure maintenance and repair
  - Modularity
- Resilience as a system/operational property
  - Time to recover (lost system function)
  - Lost man-hours
  - Lost selling capacity

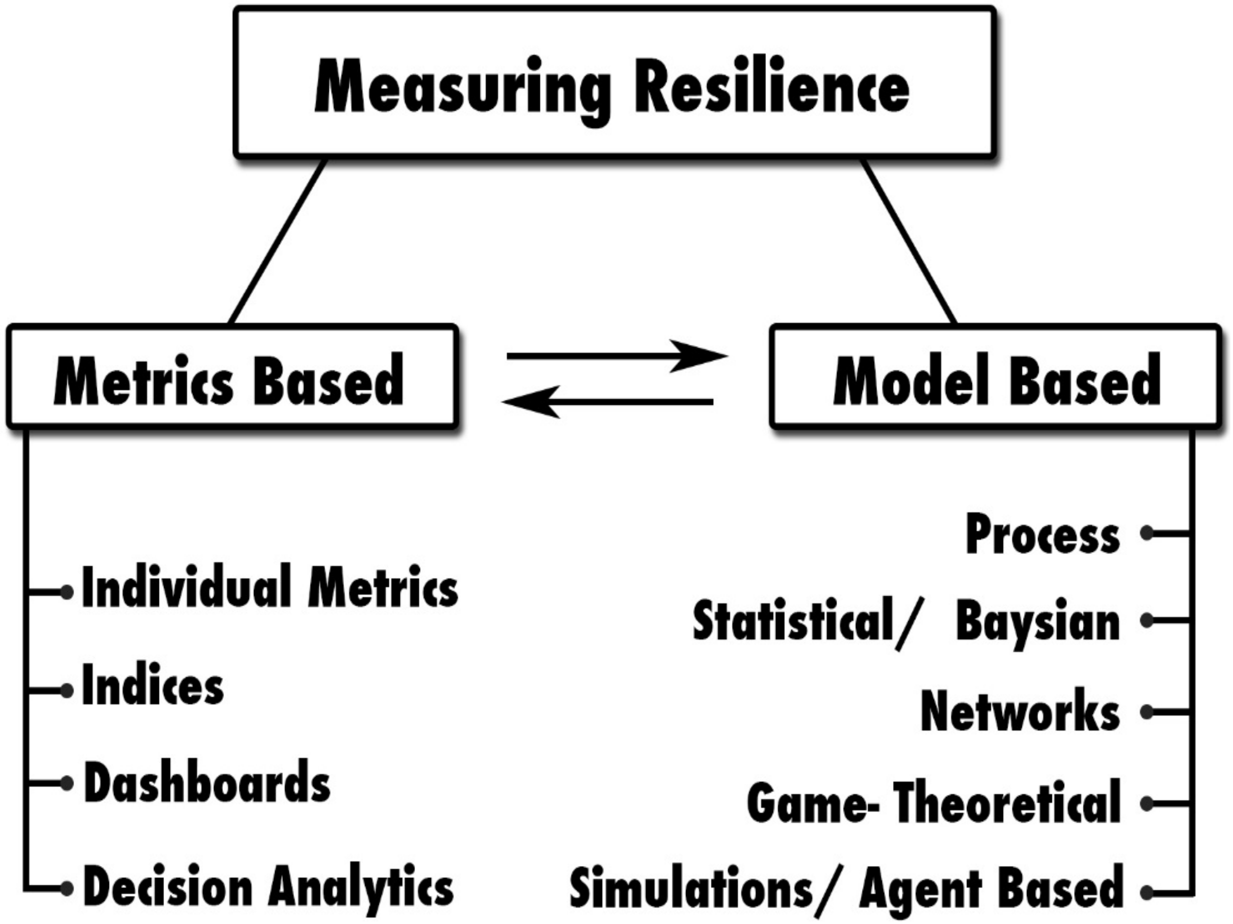


Image adapted from Hynes, W., Trump, B., Love, P., & Linkov, I. (2020). Bouncing forward: a resilience approach to dealing with COVID-19 and future systemic shocks. Environment Systems & Decisions, 40, 174-184. https://doi.org/10.1007/s10669-020-09776-x

Case study: NYPA background and resilience for the electricity sector

The New York Power Authority (NYPA) is the largest state public utility in the U.S.

25%
of the State's energy

80%+
hydropower generation

1/3
of the State's high voltage transmission lines

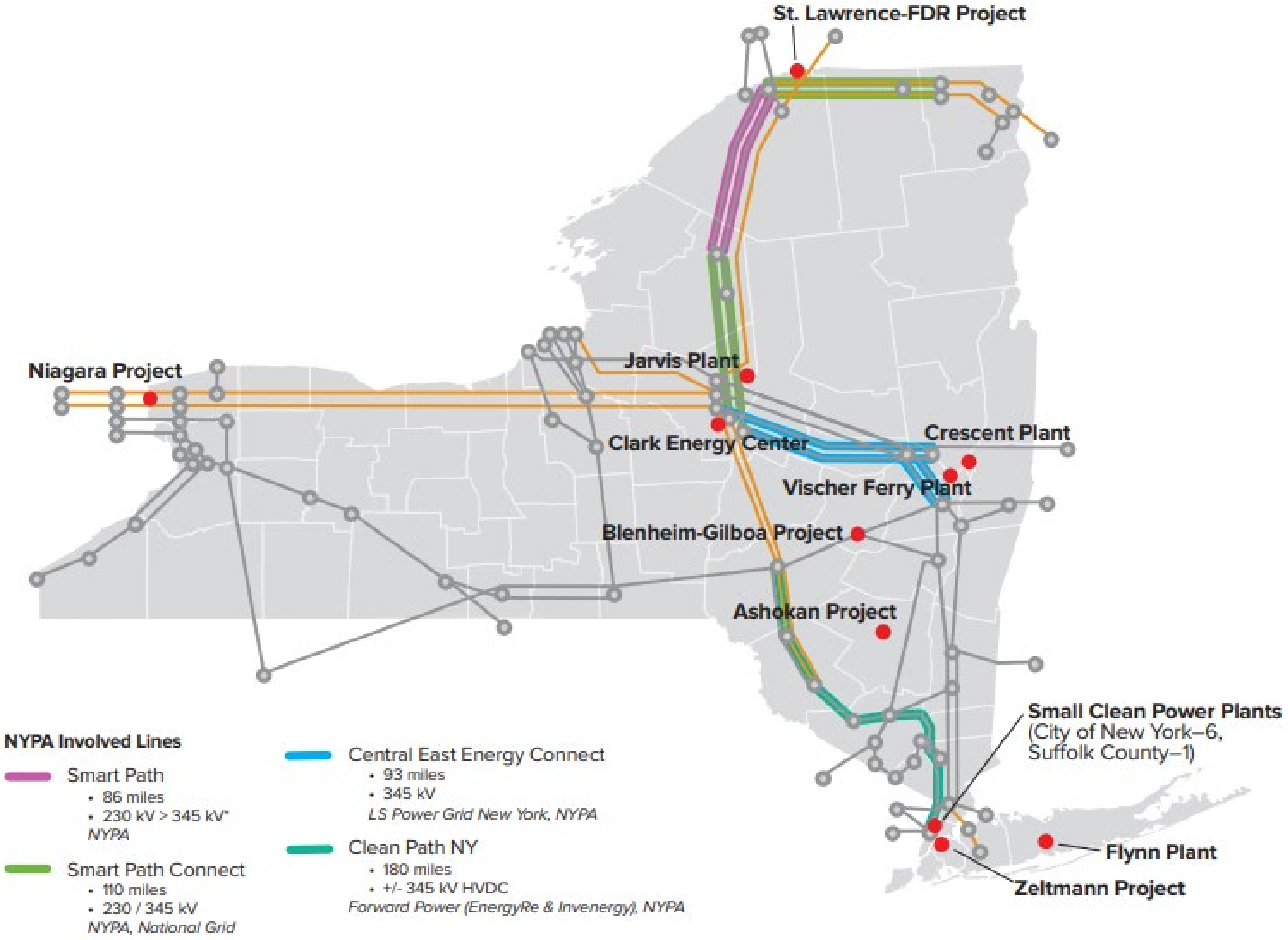


Image from: NYPA's 2022 Integrated Report
https://www.nypa.gov/-/media/nypa/documents/document-library/integrated-reports/nypa-2022-integrated-report.pdf

NYPA’s mission is to lead the transition to a carbon-free, economically vibrant New York through customer partnerships, innovative energy solutions, and the responsible supply of affordable, clean and reliable electricity

Workforce

2,560 total employees

2,077 NYPA employees

483 Canals employees

Customers & Communities

1,091 power and energy services customers

38.8 million+ MWh electricity sold

26.4 million MWh electricity generated (net)

Assets

16 generating facilities

1,460 circuit-miles of transmission lines

100K+ acres of owned or managed land and water

524 miles of Canal waterways

150 miles of the Empire State Trail

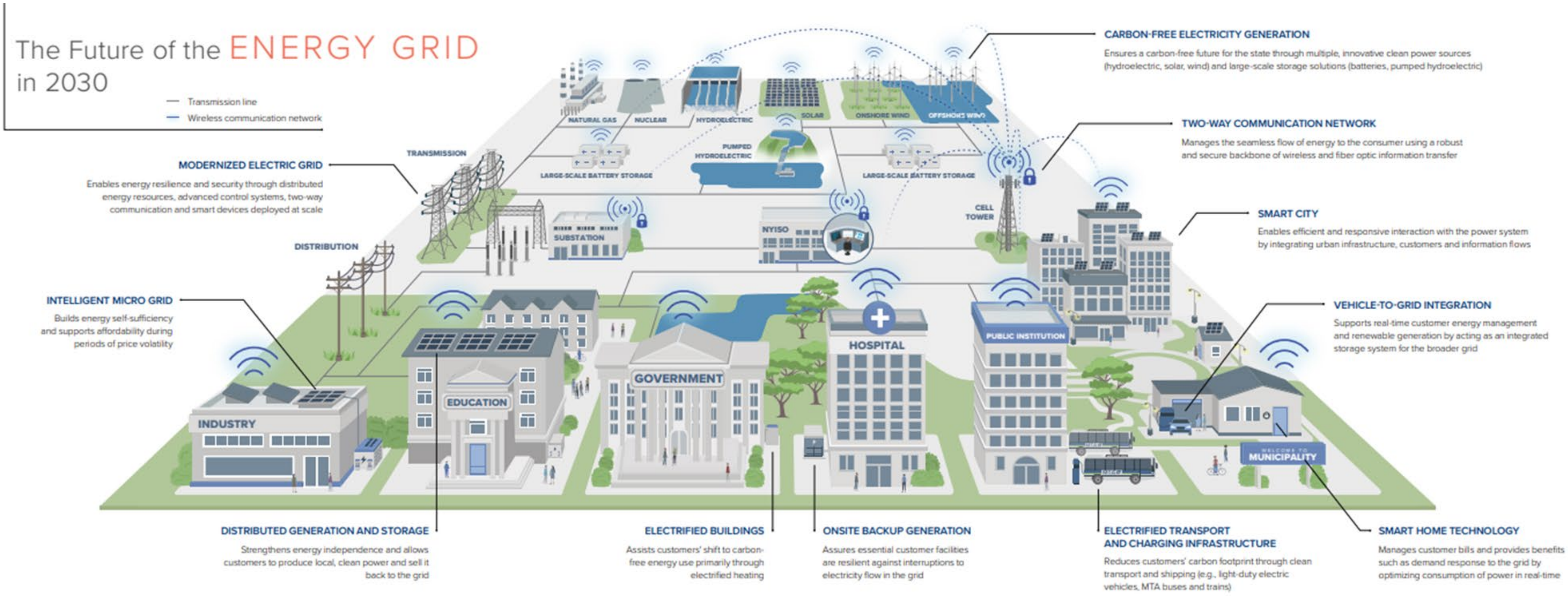
Financial Figures

$4.0 billion operating revenue

$9.6 billion total assets

Image from: NYPA’s 2022 Integrated Report
https://www.nypa.gov/-/media/nypa/documents/document-library/integrated-reports/nypa-2022-integrated-report.pdf

VISION2030, NYPA's 10-year strategic plan, was developed to help realize our vision of a thriving, resilient New York State powered by clean energy



Our strategy is focused on the energy transition in line with the state's Climate Leadership and Community Protection Act (CLCPA). The CLCPA establishes a path to decarbonization of the electricity grid by 2040 and a carbon-neutral state economy by 2050. VISION2030 targets align with the CLCPA, driving our activities and investments toward achieving the state's ambitious climate and clean energy goals.

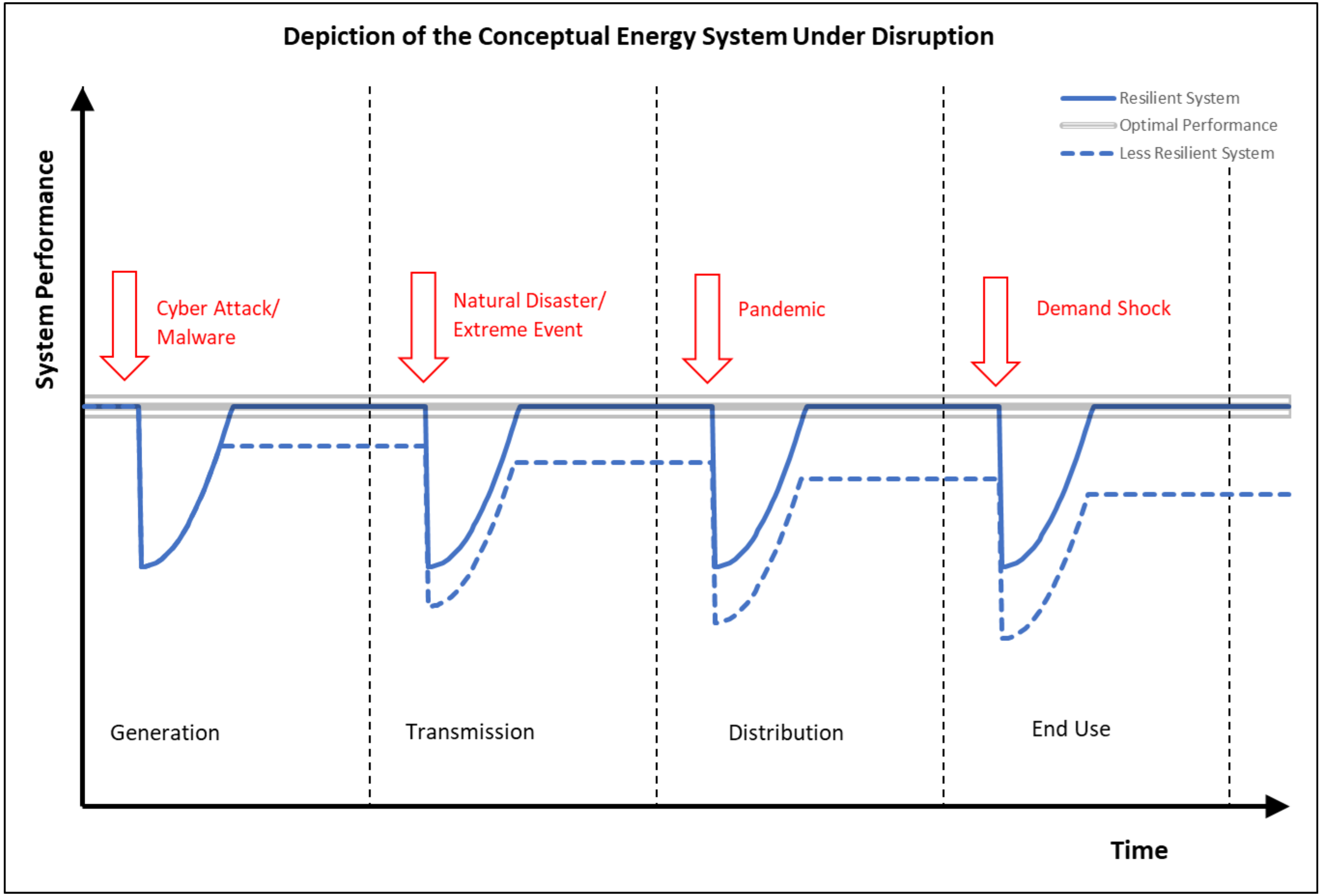
Reliability and resilience in the power grid

- Reliability
  - Expected vulnerabilities and expected consequences of a given hazard to weigh the cost and benefit of **hardening the system**[1]
  - Standardized metrics SAIDI, SAIFI, and CAIDI[1,7]
  - N-1 or N-X contingency analysis, which addresses grid operations under **predicted scenarios**[2]

- Resilience
  - Assumes the system cannot be hardened against all hazards and focuses on the ability of the system to **recover its critical function**[3]
  - Emphasizes **outage consequence** – impacts on individuals and society[2]
  - **No standardized metrics** or quantification methods[4,5,6]

"Indeed, a power grid may meet all reliability standards while it is not resilient to major events."[7]

1. Jin, A., Trump, B., Golan, M., Hynes, W., Young, M., Linkov, I.: Building resilience will require compromise on efficiency. Nature Energy 6(11), 997–999 (2021)
2. NERC: Reliability Issues Steering Committee: Report on Resilience. (2018)
3. Galaitsi, S.E., Keisler, J.M., Trump, B.D., Linkov, I.: The need to reconcile concepts that characterize systems facing threats. Risk Analysis 41(1), 3–15
4. Jufri, F.H., Widiputra, V., Jung, J.: State-of-the-art review on power grid resilience to extreme weather events. Applied Energy 239, 1049–1065 (2019)
5. Mar, A., Pereira, P., F. Martins, J.: A survey on power grid faults and their origins: A contribution to improving power grid resilience. Energies 12(24), 4667– (2019)
6. NERC: 2021 long-term reliability assessment.
7. Amani, & Jalili, M. (2021). Power Grids as Complex Networks: Resilience and Reliability Analysis. IEEE Access, 9, 119010–119031. https://doi.org/10.1109/ACCESS.2021.3107492



Golan, M.S., Trump, B.D., Cegan, J.C., Linkov, I. (2021). Supply chain resilience for vaccines: review of modeling approaches in the context of the COVID-19 pandemic. Industrial Management & Data Systems, 121(7): 1723-1748. https://doi.org/10.1108/IMDS-01-2021-0022

Energy resilience matrix - examples

	Plan and Prepare for	Absorb	Recover from	Adapt to
Physical	Energy storage capabilities, prestaged equipment	Operational system protection (e.g., pressure relief, circuit breakers), installed/ready redundant components (e.g., generators, pumps), ability to isolate damaged/degraded systems/components (automatic/manual)	System flexibility for reconfiguration and/or temporary system installation; capability to re-route energy from available sources; backup communication, lighting, power systems for repair/recovery operations	Flexible network architecture to facilitate modernization and new energy sources; sensors, data collection and visualization capabilities to support system performance trending; phase out obsolete or damaged assets and introduce new assets; update response equipment/supplies based upon lessons learned
Information	Design, control, operational, and maintenance data archived and protected; vendor information available; response/recovery plans established and distributed	Status/trend limits trigger safeguards and isolate components to stop cascade effect; critical system data monitored, anomalies alarmed; environmental condition forecast and event warnings broadcast	Location, availability, and ownership of energy, hardware and services available to restoration teams; recovery progress tracked, synthesized and available to decision-makers and stakeholders; information available to authorities and crews regarding customer/community needs/status	Initiating event, incident point of entry, associated vulnerabilities and impacts identified; community impacts, priorities, interdependencies updated to capture lessons learned; updated information about energy resources, alternatives and emergent technologies available to managers and stakeholders

Examples from: P.E. Roege, Z.A. Collier, J. Mancillas, J.A. McDonagh, I. Linkov. Metrics for energy resilience. Energy Policy, 72 (2014), pp. 249-256, 10.1016/J.ENPOL.2014.04.012

Energy resilience matrix - examples

	Plan and Prepare for	Absorb	Recover from	Adapt to
Cognitive	Understand performance trade-offs of organizational goals; periodic operator, management, and community drills	Decision making protocol or aid to determine proper course of action; awareness and focus of effort on identified critical assets and services; community response to mitigate impacts (e.g., demand curtailment)	Utilize data and decision making aids to quickly select recovery options; community members manage constrained energy resources responsibly and consistent with public guidance	Document and review management response and decision making processes; periodically revisit organizational risk tolerance and mission priorities, adjusting as necessary
Social	Identify stakeholders (internal and external); priorities and policies established for event response	Agile operational management enables rapid and effective response under changing conditions; individuals and organizations take action in response to observations and/or direction from authorities	Recovery organizations and communities follow contingency recovery plans; proactive neighborhood assistance, volunteerism, compliance with energy response manger direction	Reallocate human resources to better address adverse events; local governments and stakeholders collaborate to develop, prioritize and implement energy portfolio improvements; energy-informed culture leads to collective decisions and investments which continually improve energy effectiveness

Examples from: P.E. Roege, Z.A. Collier, J. Mancillas, J.A. McDonagh, I. Linkov. Metrics for energy resilience. Energy Policy, 72 (2014), pp. 249-256, [10.1016/J.ENPOL.2014.04.012](https://doi.org/10.1016/J.ENPOL.2014.04.012)

Specific electric sector asset examples

- Undergrounding
  - Mitigates impacts of wildfires and extreme weather
  - More aesthetically pleasing and minimizes economic and societal impacts of outages
  - Decreased need for vegetation management and impact on biodiversity
- Islanding
  - Mitigates cascading wildfire events
  - Improves maintenance capabilities and minimizes economic and societal impacts of outages

Specific electric sector asset examples

- EPRI is working with utilities on resilient pole structure

Images from: EPRI ClimateREADi WS2 TDI August 31, 2023

Thank you – Questions?

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