

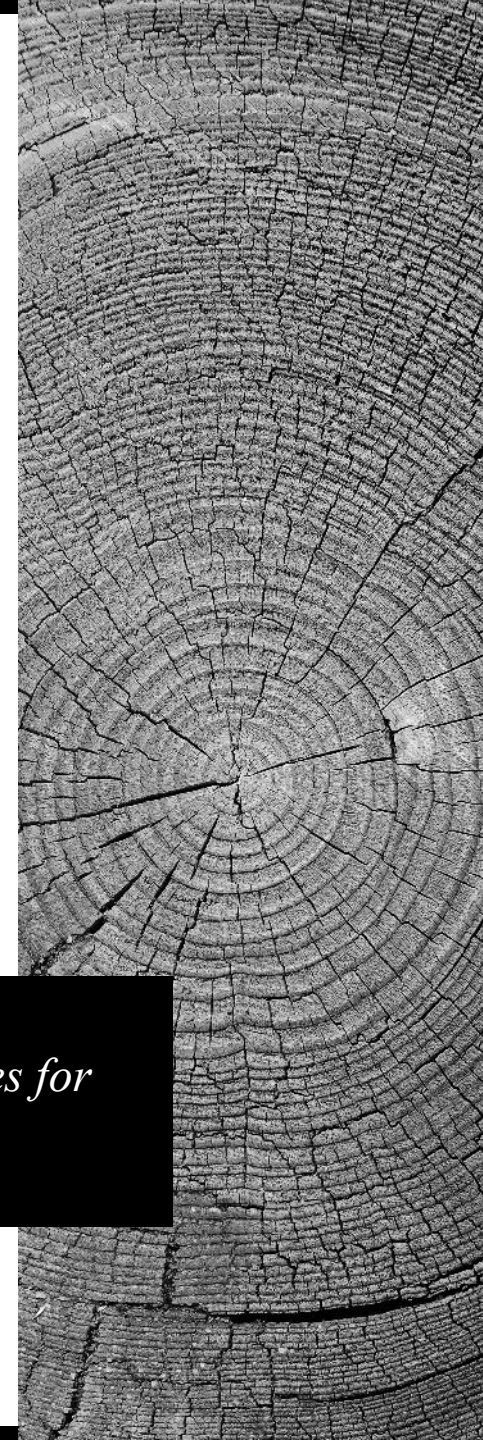
Professor Liz VARGA

12 Mar 2024

EPSRC Supergen Energy Networks Hub  
Risk and Resilience Day

# ENERGY RESILIENCE IN THE CONTEXT OF INFRASTRUCTURE RESILIENCE

*Framework and principles for  
Infrastructure Resilience*



# INFRASTRUCTURE

## Definition

system of people, resources, facilities, equipment and services that **enable the functioning of society and the operation of an organization**

[SOURCE: ISO 9000:2015, 3.5.2 / ISO 22300: 3.1.128]

# CRITICAL INFRASTRUCTURE

## Definition

systems and assets, whether physical or virtual, providing essential functions and services to society, whose incapacitation or destruction would have a **debilitating impact on security, national economic security, national public health or safety**, or any combination of these.

[SOURCE: RESILENS project]

facilities, systems, sites, information, people, networks and processes, **necessary for a country to function and upon which daily life depends.**

It also includes some functions, sites and organisations which are not critical to the maintenance of essential services, but which **need protection due to the potential danger to the public** (civil nuclear and chemical sites for example).

Critical National Infrastructure is a subset of National Infrastructure which, if damaged, would have **major impacts on a national scale**

[UK GOVERNMENT RESILIENCE FRAMEWORK (2023)]

# TYPES OF INFRASTRUCTURE

## Economic infrastructure

- Energy
- Telecom
- Transportation
- Water supply
- Sanitation

## Social infrastructure

- Banking & Finance
- Hospitals
- Education
- Emergency Services
- Government services

# RESILIENCE AND RISK

## Resilience

ability to **absorb and adapt** in a changing environment

[SOURCE: ISO 22300:2021 3.1.206]

- **infrastructure resilience**

the ability of timely and efficient prevention, absorption, recovery, and adaptation of infrastructure in a changing environment

[SOURCE: Adapted from UNISDR, 2016]

## Risk

**effect of uncertainty** on objectives

Note 1: An effect is a deviation from the expected. It can be positive, negative or both, and can address, create or result in opportunities and threats.

Note 2: Objectives can have different aspects and categories, and can be applied at different levels.

Note 3: Risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood.

[SOURCE: ISO 31000:2018, 3.1]

# RISK ASSESSMENT IS NOT THE SAME AS RESILIENCE ASSESSMENT

## National Risk Register (NRR)

- The risks that meet the threshold for inclusion in the NRR would have a substantial impact on the **UK's safety, security and/or critical systems at a national level.**
- 9 risk themes
  - **Terrorism**
  - **Cyber**
  - State threats
  - Geographic and diplomatic
  - **Accidents and systems failures**
  - **Natural and environmental hazards**
  - Human, animal and plant health
  - Societal
  - Conflict and instability

<https://www.gov.uk/government/publications/national-risk-register-2023>

# NATIONAL RESILIENCE ASSESSMENT (2022)

## TARGETS OVER THREE PERIODS

- Now:
  - **Risk**: Refresh the National Security Risk Assessment (NSRA) process (the main tool for assessing the most serious civil contingencies risks facing the UK); appoint Head of Resilience
  - **Responsibilities and Accountability**: create a new resilience function to deliver longer term capability building and risk mitigation to strengthen Government structures
  - **Partnerships**: cooperation and prevention
  - **Communities**: work with voluntary and community sector
- 2025: **Skills**: UK Resilience Academy
- 2030:
  - **Investment**: coordination and prioritisation;
  - **Partnerships**: Build upon existing resilience standards for CNI to create common but flexible resilience standards across CNI, and do more on the assurance of CNI preparedness

# EU DIRECTIVE ON THE RESILIENCE OF CRITICAL ENTITIES (CER) (2022)

- Obligations of **Member States**
  - for a national strategy, regular risk assessment, identification of entities that provide essential services, support for critical entities
- **Critical Entities**
  - will identify risks, take measures to enhance their resilience, notify significant disruptive incidents to the national authorities
- **A Critical Entities Resilience Group**
  - will facilitate cooperation among Member States, including sharing information and good practices.
- The **European Commission**
  - will provide support, including on cross-sectoral risks, best practices, methodologies, cross-border training and exercises to test the resilience of critical entities.

[Introduction into the proposed EU-Directive on the resilience of critical entities - Eurisy](#)



# PROPERTIES OF CNI FOR RESILIENCE

Concerns **direct physical protection**, e.g. the erection of flood defences.

The capability of infrastructure to **maintain operations** under a range of conditions, e.g. electrical cabling is able to operate in extremes of heat and cold



The **adaptability of an asset or network**, e.g. the installation of back-up data centres

An organisation's ability to **respond to and recover from disruption**

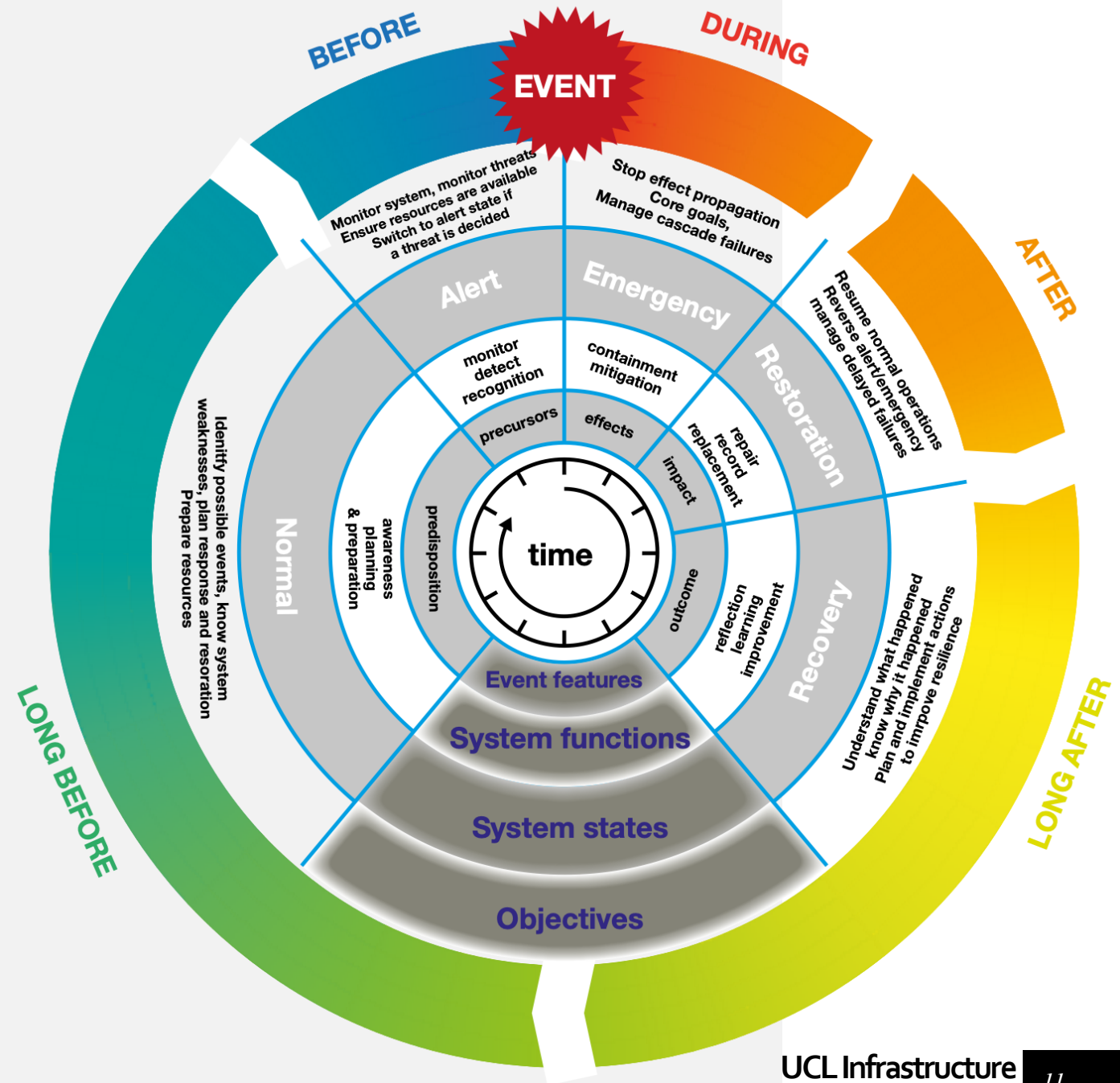
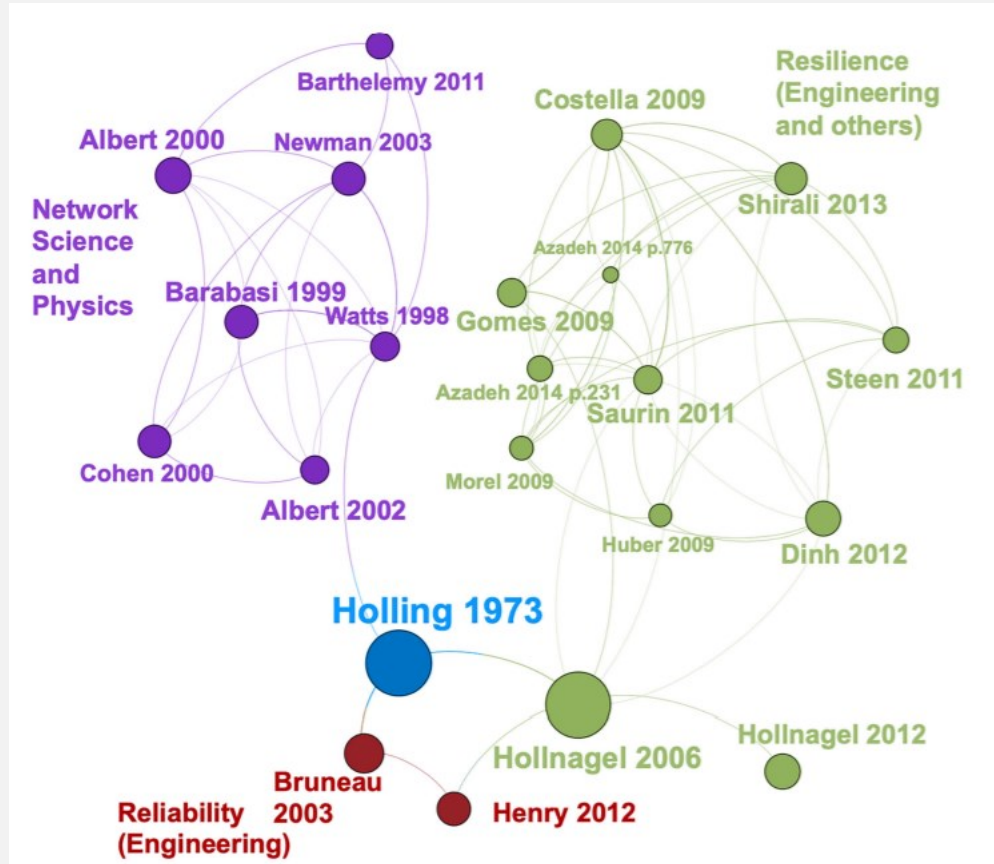
<https://www.gov.uk/government/publications/sector-resilience-plan-2014>

# FOUR ABILITIES OF A RESILIENT BUILT SYSTEM

Ability	Description
<b>The ability to address the actual.</b>	Knowing what to do: how to respond to regular and irregular disruptions and disturbances either by implementing a prepared set of responses or by adjusting normal functioning.
<b>The ability to address the critical.</b>	Knowing what to look for: how to monitor that which is or can become a threat in the near term. The monitoring must cover both events in the environment and the performance of the system itself.
<b>The ability to address the factual.</b>	Knowing what has happened: how to learn from experience, in particular how to learn the right lessons from the right experience – successes as well as failures.
<b>The ability to address the potential.</b>	Knowing what to expect: how to anticipate developments, threats, and opportunities further into the future, such as potential changes, disruptions, pressures and their consequences.

(Hollnagel et al, 2014)

# RESILIENCE LIFE CYCLE

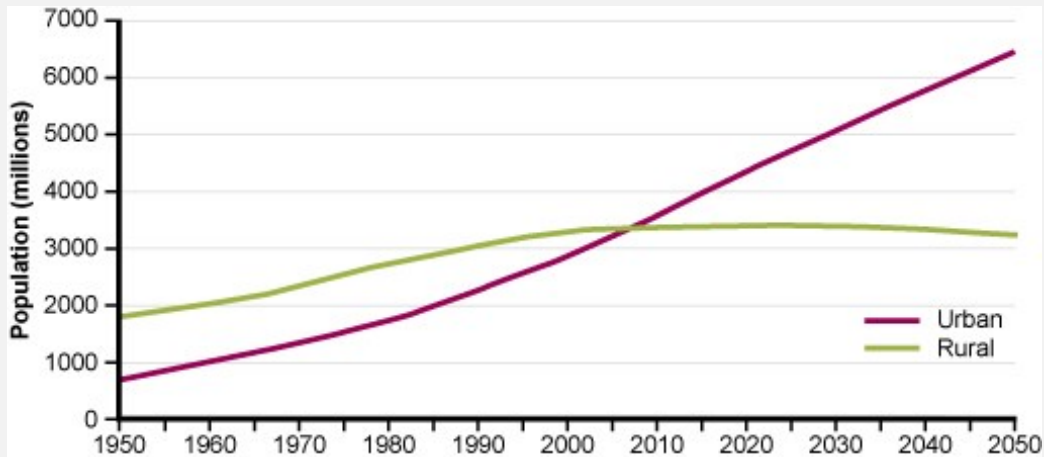


<https://ieeexplore.ieee.org/document/8948008>

Punzo et al 2020

# SOCIETAL CHANGE

## Urbanisation & Population growth



<https://www.un.org/en/development/desa/publications/2014-revision-world-urbanization-prospects.html>

United Nations 2014

## Productivity & Efficiency

‘Just in time’, ‘Agile’

Uncontrolled demand

Supply Chain

<https://www.sciencedirect.com/science/article/pii/S1364032120303798>

4DS:

Soutar, I. (2021). Dancing with complexity: Making sense of **decarbonisation, decentralisation, digitalisation and democratisation**. *Energy Research and Social Science*, 80(July), 102230.

<https://doi.org/10.1016/j.erss.2021.102230>

# CLIMATE CHANGE

	Temperature changes	Sea-level rise	Changing patterns of precipitation	Changing patterns of storms
<b>Transport</b>	<ul style="list-style-type: none"> <li>– Melting road surfaces and buckling railway lines</li> <li>– Damage to roads due to melting of seasonal ground frost or permafrost</li> <li>– Changing demand for ports as sea routes open due to melting of arctic ice</li> </ul>	<ul style="list-style-type: none"> <li>– Inundation of coastal infrastructure, such as ports, roads or railways</li> </ul>	<ul style="list-style-type: none"> <li>– Disruption of transport due to flooding</li> <li>– Changing water levels disrupt transport on inland waterways</li> </ul>	<ul style="list-style-type: none"> <li>– Damage to assets, such as bridges</li> <li>– Disruption to ports and airports</li> </ul>
<b>Energy</b>	<ul style="list-style-type: none"> <li>– Reduced efficiency of solar panels</li> <li>– Reduced output from thermal plants due to limits on cooling water temperatures</li> </ul>	<ul style="list-style-type: none"> <li>– Inundation of coastal infrastructure, such as generation, transmission and distribution</li> </ul>	<ul style="list-style-type: none"> <li>– Reduced output from hydropower generation</li> <li>– Disruption of energy supply due to flooding</li> </ul>	<ul style="list-style-type: none"> <li>– Damage to assets - e.g. wind farms, distribution networks</li> <li>– Economic losses due to power outages</li> </ul>

# CYBER ATTACKS ON CNI

- The UK is the third most targeted country in the world for **cyber-attacks**, after the US and Ukraine.
- In recent years the UK has seen the use of offensive cyber capabilities by state and non-state actors proliferate, exacerbated by Russia's full-scale invasion of Ukraine.
- The UK Government's [National Cyber Strategy 2022](#) and the [Government Cyber Security Strategy 2022-2030](#) recognised cyber threats to UK Critical National Infrastructure (CNI) - infrastructure whose disruption would have significant national impact - as an area of particular concern.
- **Digital infrastructure is critical for supporting growth** and helping to transform the delivery of public services. It is a keystone in developing critical and emerging technologies within the [Science and Technology Framework](#), and is essential to UK national security under the [2023 Integrated Review Refresh](#).
- Much of the **UK's CNI is underpinned by this digital infrastructure**, which must be resilient to cyber-attack if it is to fulfil such fundamental roles in the UK economy.

<https://committees.parliament.uk/work/7934/cyber-resilience-of-the-uks-critical-national-infrastructure/>

# SUSTAINABILITY/SDGS

## *ESG & Circular Economy*

**Sustainability:** reduced use of non-renewable materials; reduced waste, recovery, maximise material efficiency, Assets sweated

**SDG7: Affordable & Clean Energy** – Ensure access to affordable, reliable, sustainable and modern energy (<https://sdgs.un.org/goals/goal7>)

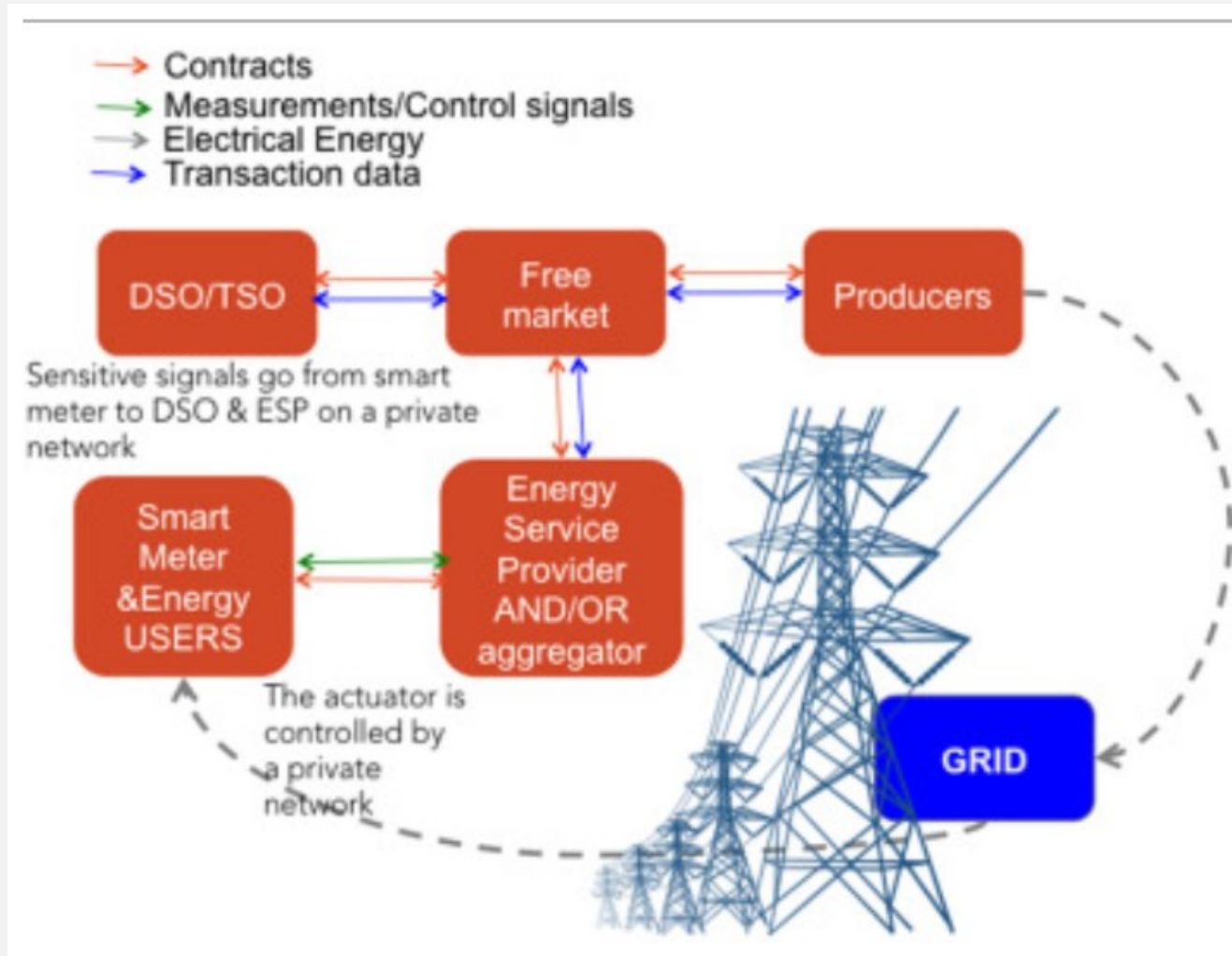
**SDG11: Sustainable Cities & Communities** – Make cities and human settlements inclusive, safe, resilient and sustainable (<https://sdgs.un.org/goals/goal11>)

**Environment, Social, Governance (ESG)** – 97% of infrastructure companies with core and non-core infrastructure assets are exposed to ESG risks that have some potential to impact their credit ratings if the risks are not actively and appropriately managed.

<https://www.linklaters.com/en/insights/thought-leadership/esg/risks-and-opportunities>

**Circular economy:** design for decomposition (and extraction/re-use of highest value materials)

# DECARBONISATION

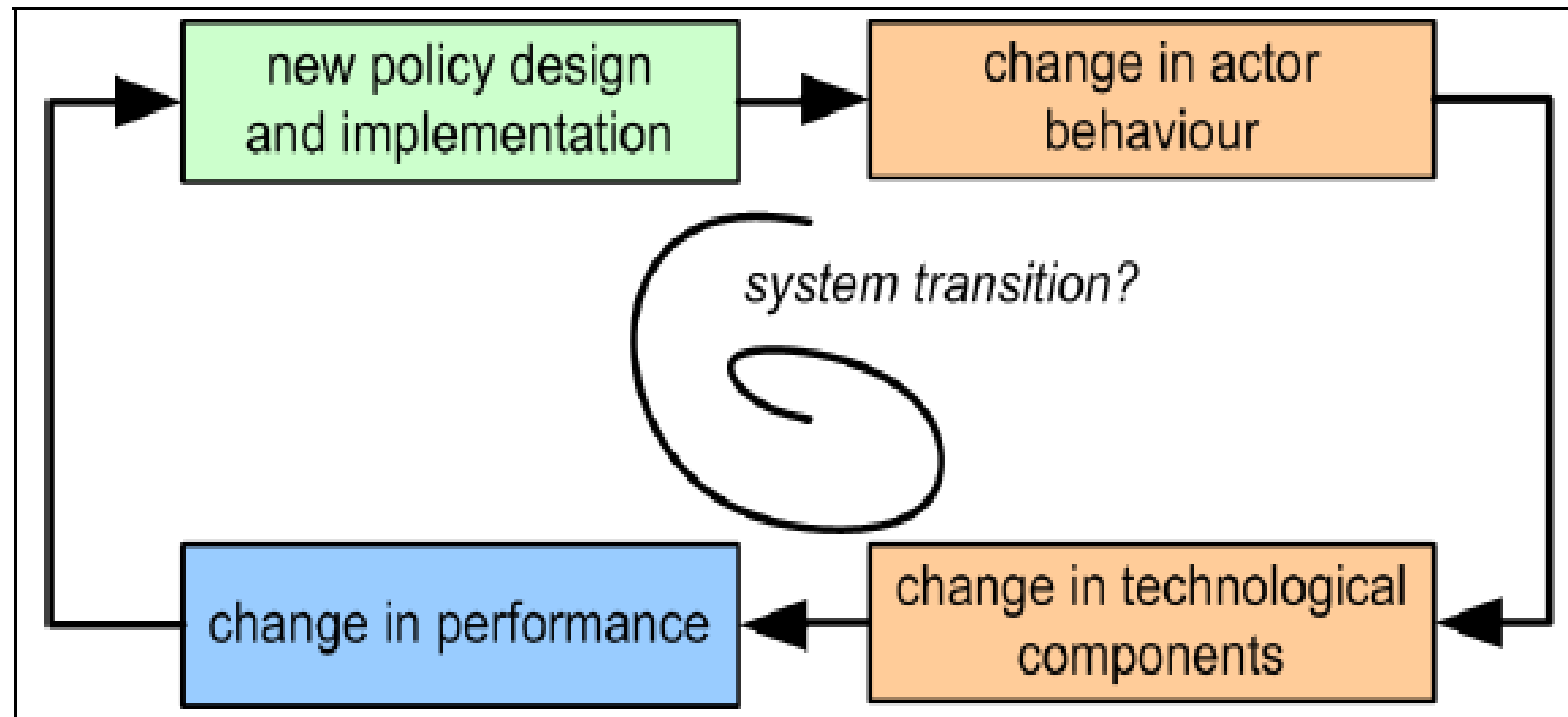


Di Silvestre, M. L., Favuzza, S., Riva Sanseverino, E., & Zizzo, G. (2018). How Decarbonization, Digitalization and Decentralization are changing key power infrastructures. In *Renewable and Sustainable Energy Reviews* (Vol. 93, pp. 483–498). Elsevier Ltd.

<https://doi.org/10.1016/j.rser.2018.05.068>



# ENERGY TRANSITIONS – STOP/START



Chappin, E. J. L., & Dijkema, G. P. J. (2010). Agent-Based Modeling of Energy Infrastructure Transitions. *International Journal of Critical Infrastructures*, 6(2), 106–129. Retrieved from <http://chappin.com/emile/docs/Chappin10a.pdf>

# DESIGN AND INTERDEPENDENCIES

## Designs that create fragility:

Solutions are built on top of previous solutions (rather than being replaced)

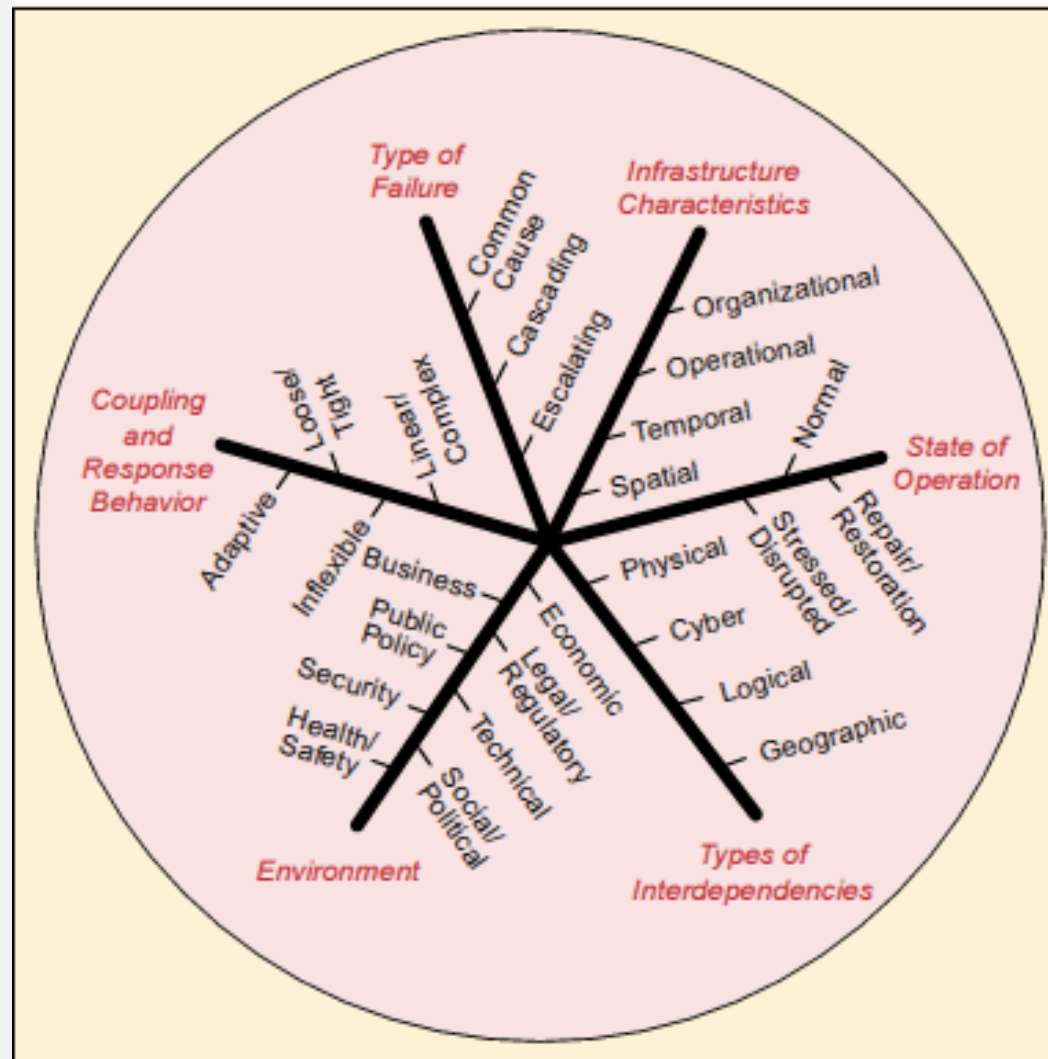
Solutions are integrated (e.g. co-located)

Assets are used for multiple purposes

Designs cannot 'afford' redundancy

## Interdependencies that create vulnerabilities:

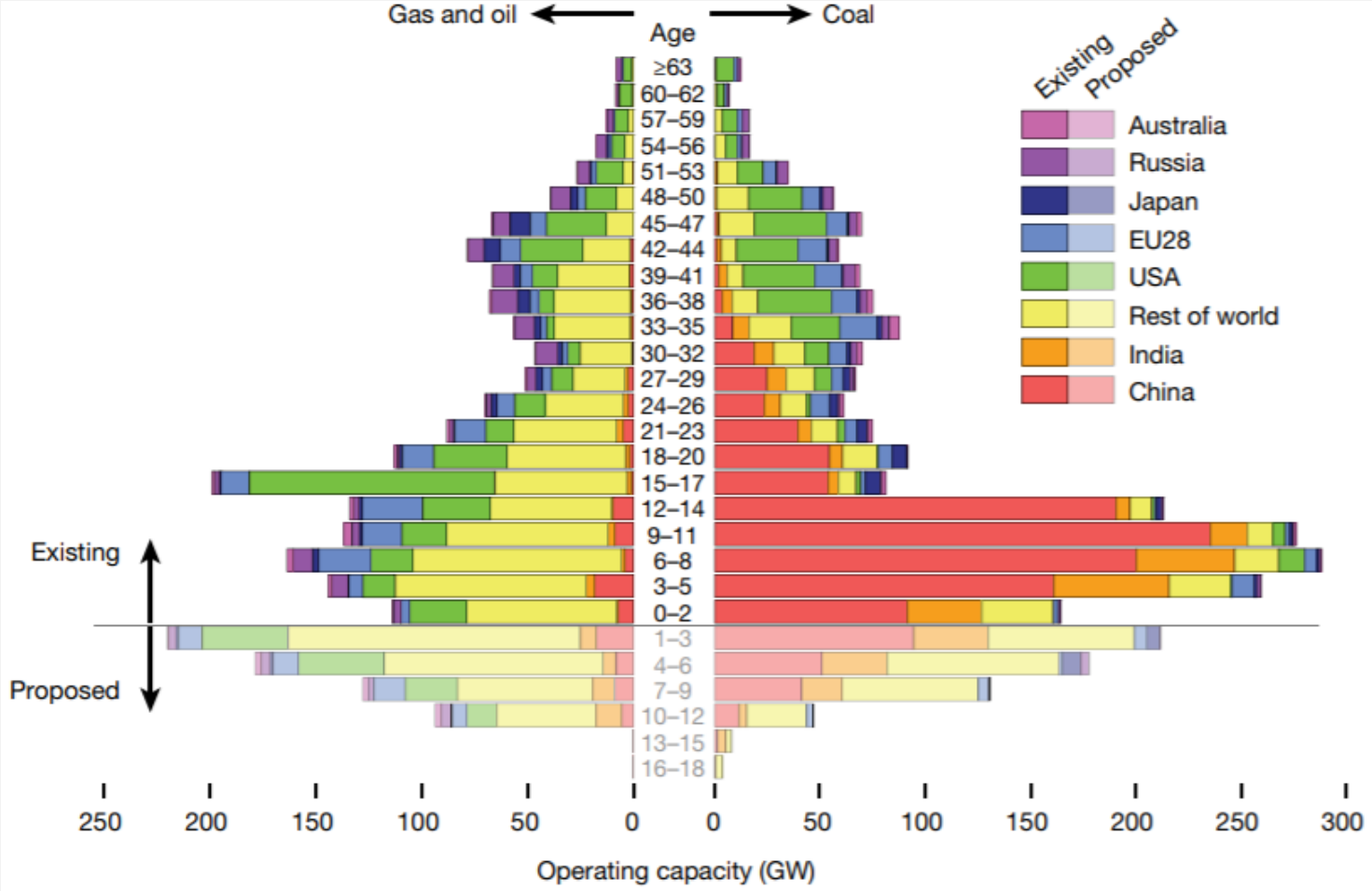
Physical, cyber, logical, geographical



<https://ieeexplore.ieee.org/document/1265180>

Rinaldi 2004

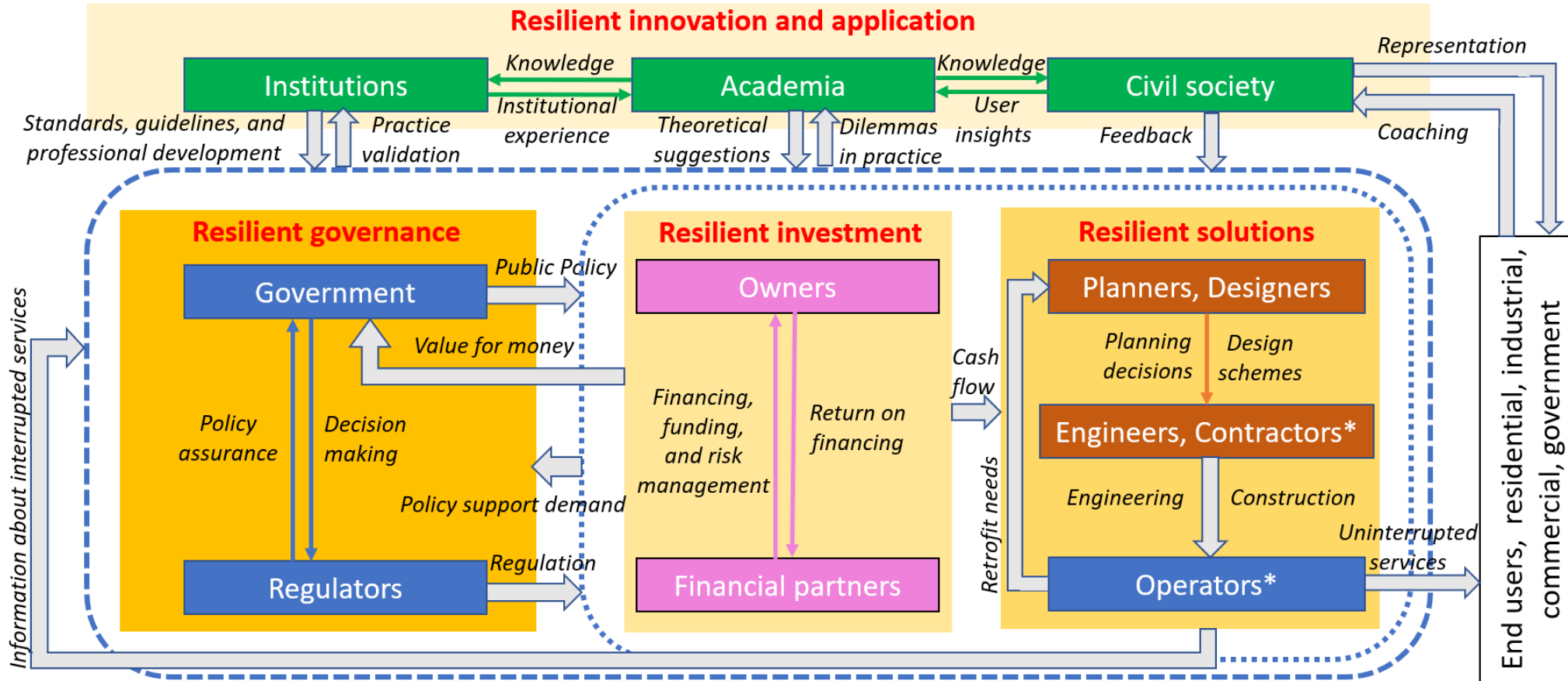
# AGING & REDUCED MAINTENANCE



<https://www.nature.com/articles/s41586-019-1364-3> Tong et al 2019

# COORDINATION

*Diversity across government, markets, technical, end use; professionals*



(2023) Handbook for implementing the *Principles for Resilient Infrastructure*.

<https://www.undrr.org/publication/handbook-implementing-principles-resilient-infrastructure>

# MULTI-HAZARDS

*Sendai*

<https://council.science/wp-content/uploads/2020/06/SendaiFrameworkReport-EN.pdf>  
Sendai Framework, Mid term review, 2023



# PERFECT STORM: WATER, ENERGY, FOOD (LAND)



Beddington, J. (2009). Food, Energy, Water And The Climate: A Perfect Storm Of Global Events? *Sustainable Development UK Annual Conference, QEll Conference Centre, London, 19 March 2009*. Retrieved from <http://webarchive.nationalarchives.gov.uk/20121212135622/http://www.bis.gov.uk/assets/goscience/docs/p/perfect-storm-paper.pdf>

# STRATEGY: STANDARDS/PRINCIPLES



## UNDRR (2022) Principles for Resilient Infrastructure

<https://www.undrr.org/publication/principles-resilient-infrastructure>

## UNDRR (2023) Handbook for implementing the Principles for Resilient Infrastructure

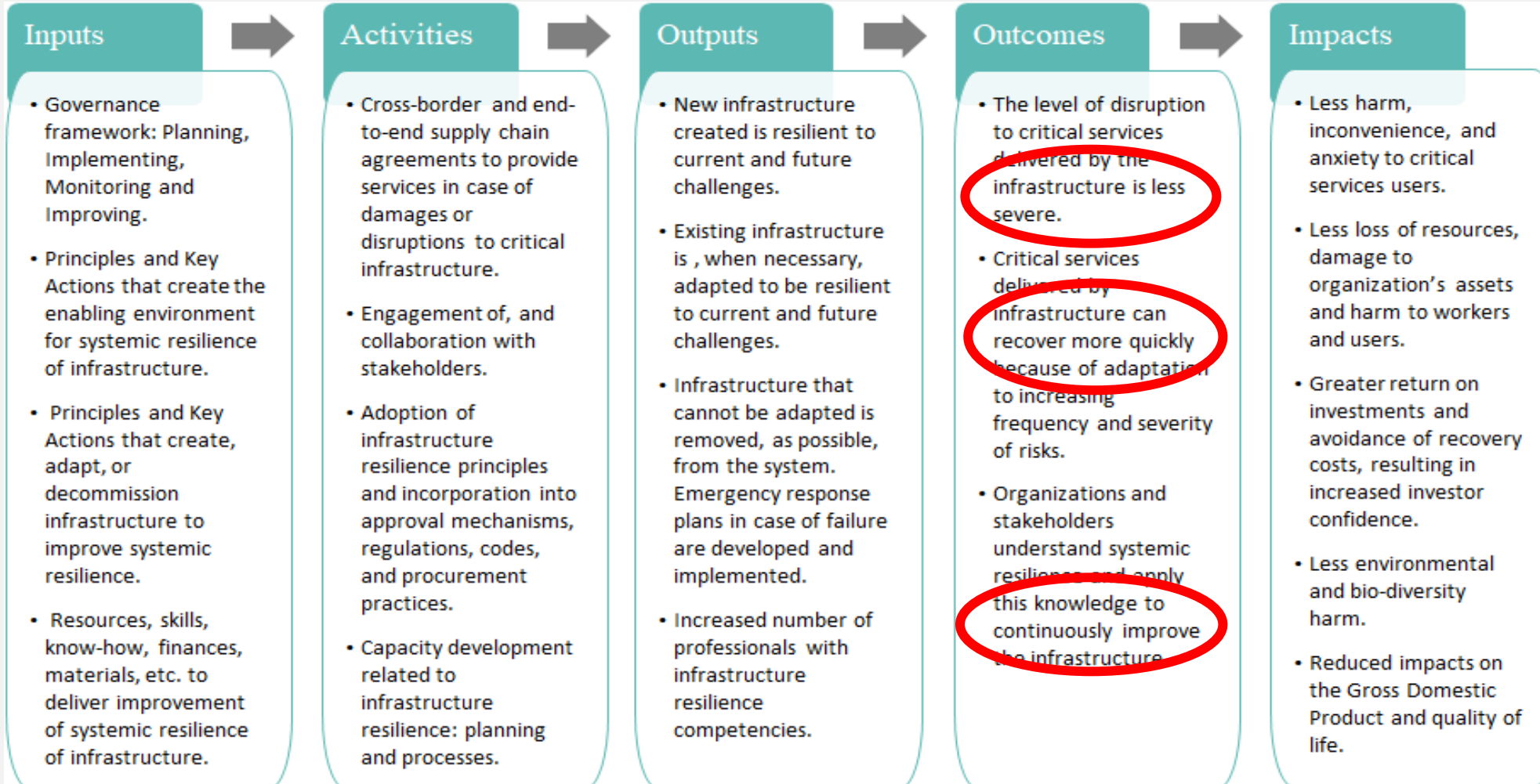
<https://www.undrr.org/publication/handbook-implementing-principles-resilient-infrastructure>

### Working Draft validation

- ISO 31000 – Risk Management
- ISO 22361 – Crisis Management
- ISO 22301 – Business Continuity Management Systems
- ISO/WD 22366 – Energy Resilience (in progress)
- ISO/CD 22371 – Urban Resilience (in progress)
- ASTM E3341 – Standard Guide for General Principles of Resilience (USA)
- BS 65000 – Organizational Resilience: Code of Practice (UK)
- BS 67000 – City Resilience: Guide (UK)
- Sendai Framework
- Resilience Principles – Infrastructure Australia

# THEORY OF CHANGE

*Systemic resilience: resilience across interconnected infrastructure and across all lifecycle stages of infrastructure (design, build, operate, decommission) during disruption(s)*





# PRINCIPLES

*a primary assumption forming the basis of a chain of reasoning*

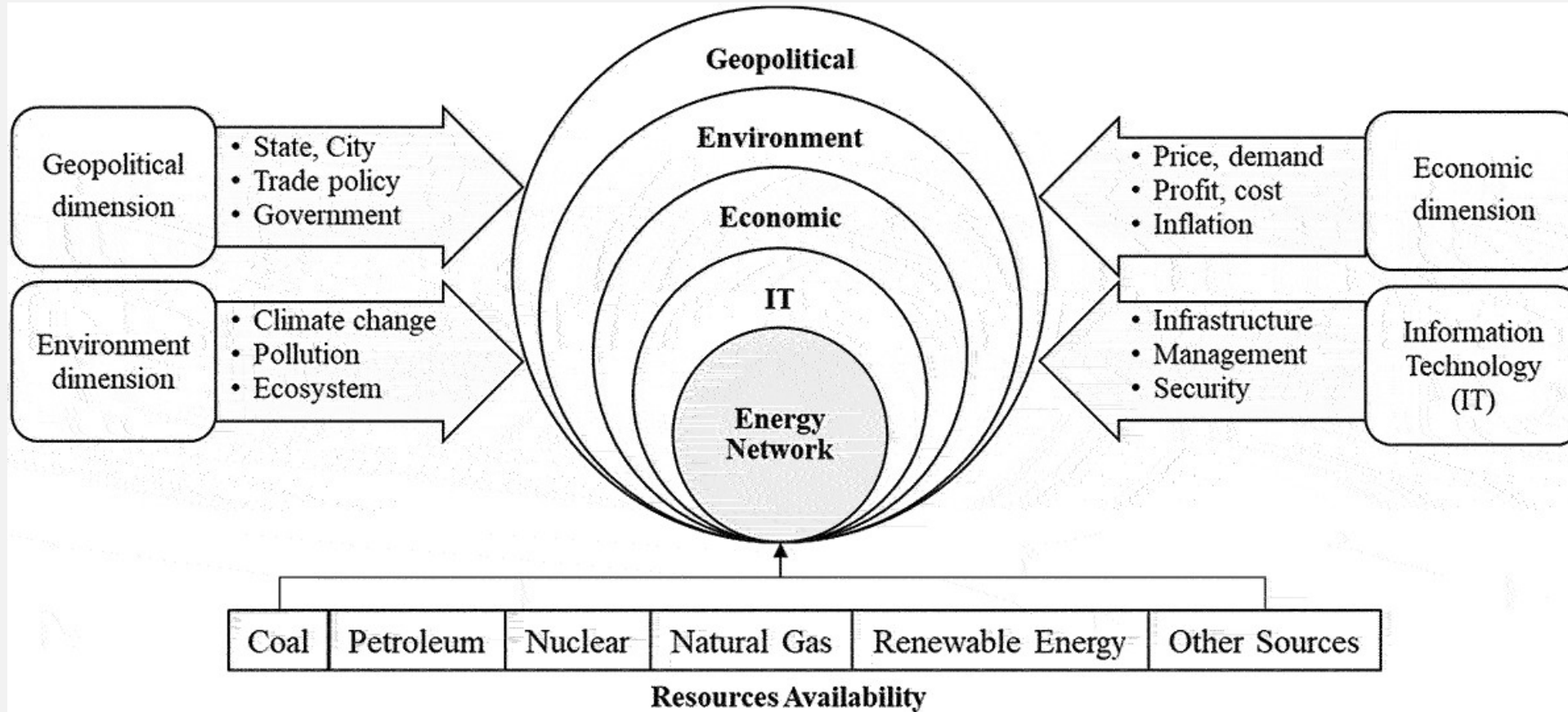
## Principles 1, 2, 3

- **P1: Continually learning and improving**
  - monitoring; modelling; testing; transparency
- **P2: Proactively protected**
  - investment; design; construction; built infrastructure maintenance; risk management
- **P3: Environmentally integrated**
  - emissions and impact control; natural environment solutions; use of ecosystem information; natural environment maintenance

## Principles 4, 5, 6

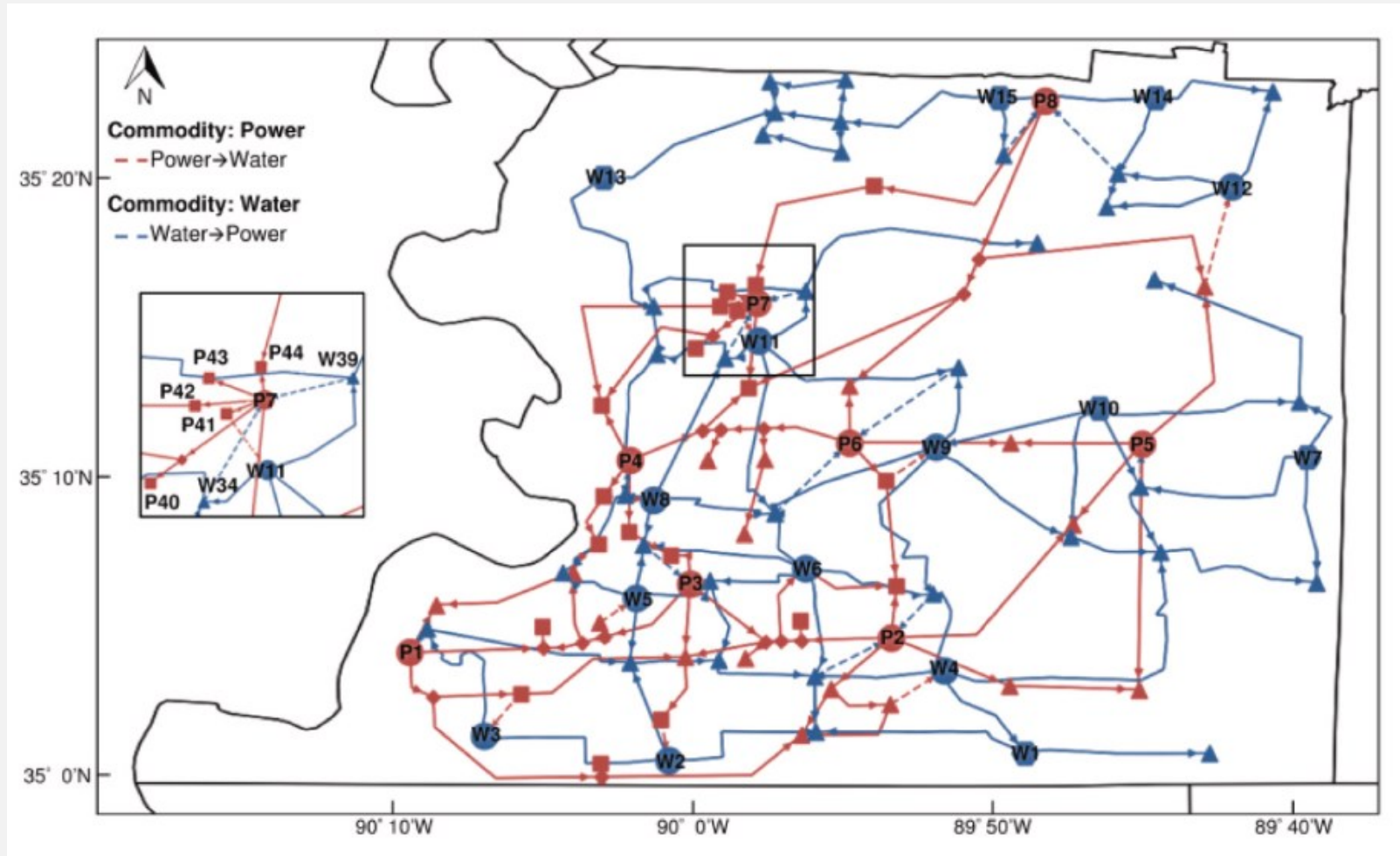
- **P4: Socially engaged**
  - resilience literacy, managing demand, stakeholder participation
- **P5: Clearly defined accountabilities and shared responsibilities**
  - collaborative management; common standards; information: sharing, security, and governance; threat management; risk transparency and mitigation
- **P6: Adaptively transforming**
  - choose manageable solutions; capacity building; flexible management; human discretion; safe human interfaces

# STRATEGY: CONDITION BASED MONITORING



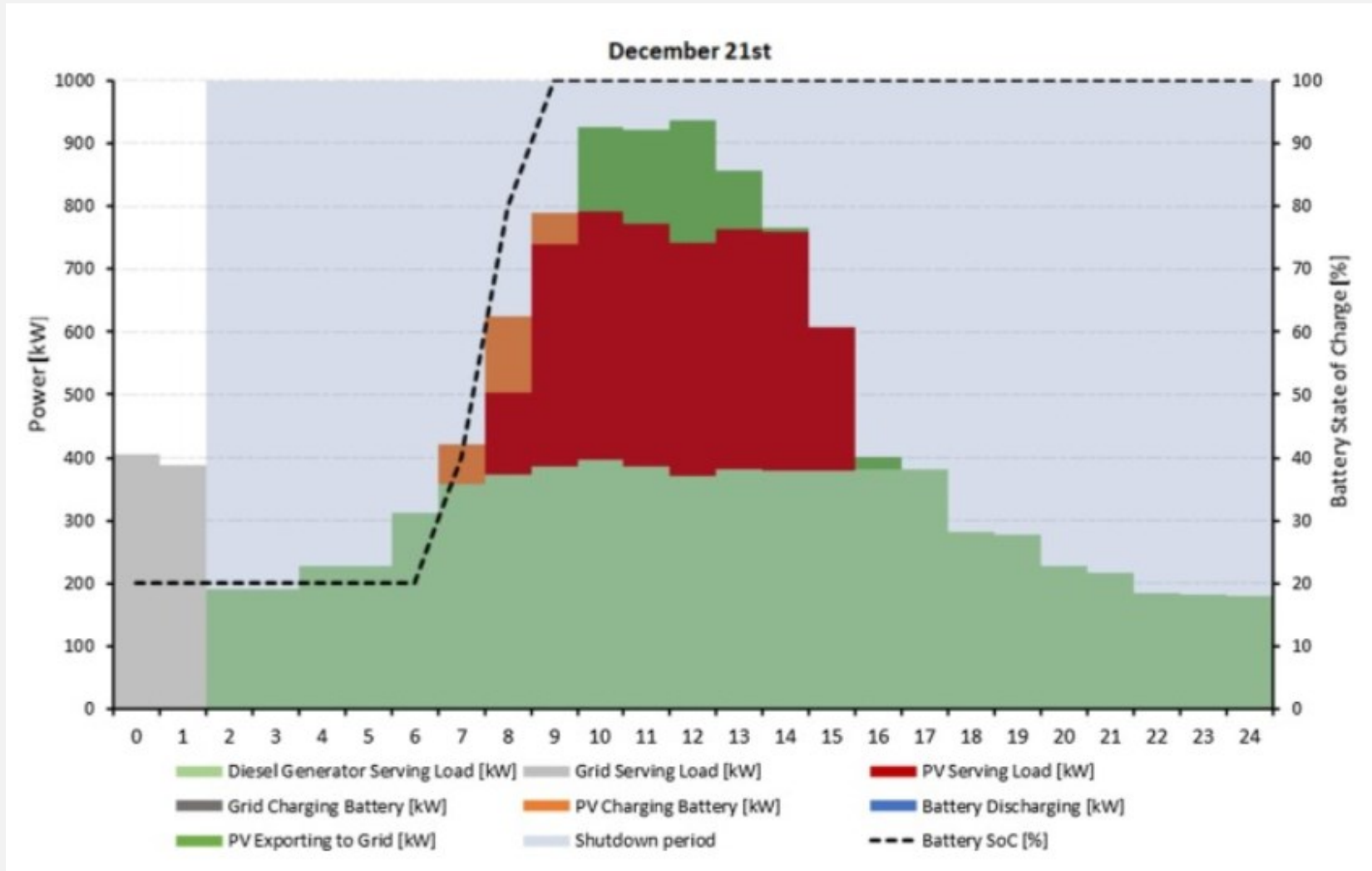
Yodo, N., et al. (2023). "Condition-based monitoring as a robust strategy towards sustainable and resilient multi-energy infrastructure systems." Sustainable and Resilient Infrastructure

# STRATEGY: MULTI-OBJECTIVE SCENARIO MODELING



Tiong, A. and H. A. Vergara (2023). "A two-stage stochastic multi-objective resilience optimization model for network expansion of interdependent power–water networks under disruption." *International Journal of Critical Infrastructure Protection*

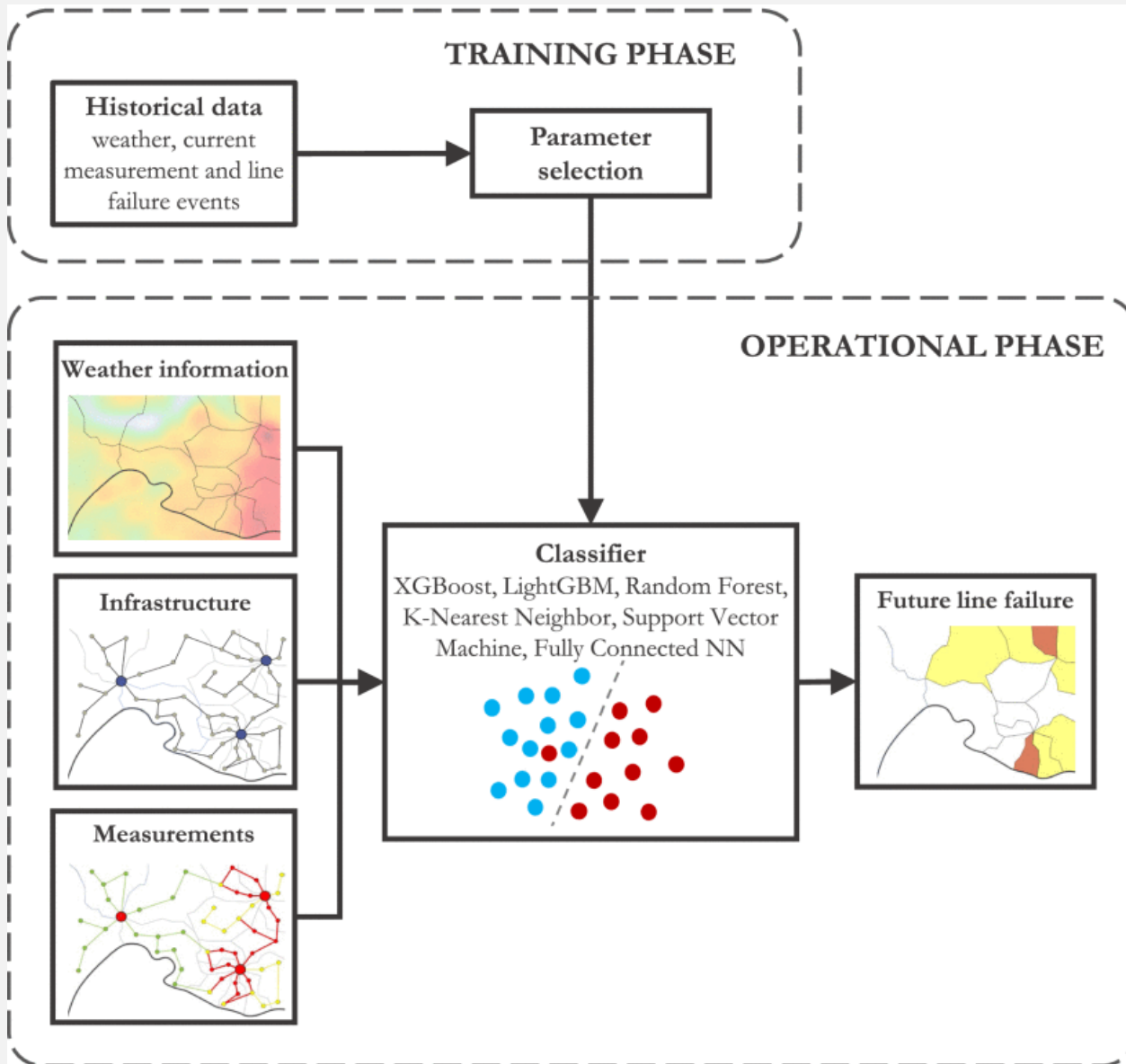
# STRATEGY: STORAGE



Lagrange et al (2020) Sustainable microgrids with energy storage as a means to increase power resilience in critical facilities, IJEPES

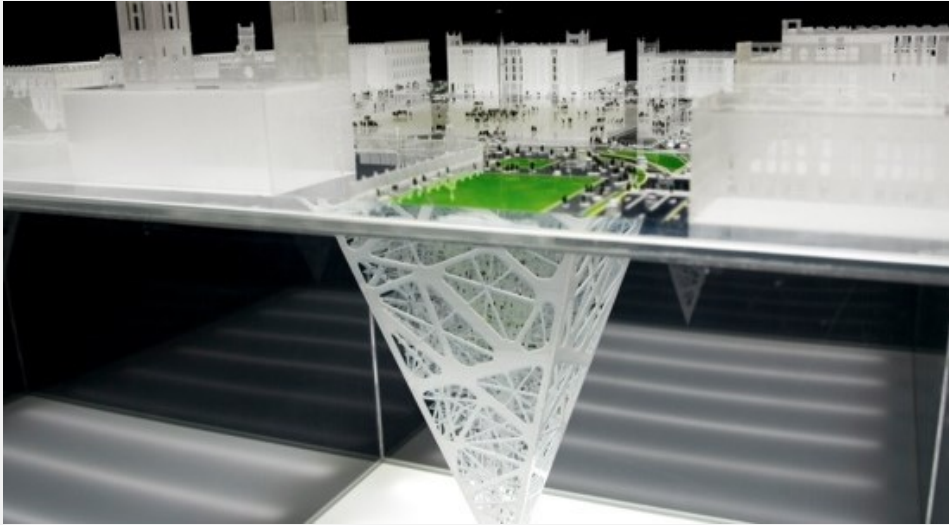
<https://www.sciencedirect.com/science/article/pii/S0142061519330595>

# STRATEGY: DATA SCIENCE



Atrigna, M., et al. (2023).  
"A Machine Learning  
Approach to Fault  
Prediction of **Power  
Distribution Grids** Under  
Heatwaves." IEEE  
Transactions on Industry  
Applications

# STRATEGY: VIGNETTES



Purpose: to encourage radical approaches to thinking about future infrastructure provision, with a focus on rationalisation, efficiency, sustainability and resilience in preparation for the challenging times ahead.

Karaca, F., Raven, P. G., Machell, J., Varga, L., Camci, F., Chitchyan, R., ... Janus, T. (2013). Single infrastructure utility provision to households: Technological feasibility study. *Futures*, 49.

<https://doi.org/10.1016/j.futures.2013.03.003>

# THANK YOU

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🌐 <https://www.ucl.ac.uk/infrastructure-systems/infrastructure-systems-institute>

# RESILIENT TO DIGITALISATION REBOUND EFFECTS

- **Direct** Rebound: occurs for the same service that had original benefits: price goes down, demand rises, and overall more consumption
- **Jevon's Paradox or Backfire:** Same as Direct, but rebound has more mechanisms/is more general
- **Indirect (Induction, etc):** Cheaper coal led to more steam engines, or more income means more spending on something else
- **Time rebound:** Time saving is monetised as opportunity cost (earnings in time saved); energy expended to save travel time
- **Macro/General Equilibrium:** boosts to total factor productivity (in particular, capital and labor productivity from (energy efficiency) technologies:

Coroama, VC, Mattern, F (2019) Digital Rebound - Why Digitalization Will not Redeem us our Environmental Sins. In Annika Wolff, editor, Proceedings of the 6th International Conference on ICT for Sustainability, ICT4S 2019, Lappeenranta, Finland, Volume 2382 of CEUR Workshop Proceedings, CEUR-WS.org, 2019. [https://ceur-ws.org/Vol-2382/ICT4S2019\\_paper\\_31.pdf](https://ceur-ws.org/Vol-2382/ICT4S2019_paper_31.pdf)