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IMPACTS OF CLIMATE CHANGE ON THE ELECTRICITY TRANSMISSION INFRASTRUCTURE – REFLECTIONS ON DATA AND APPROACHES

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Overview

- Adaptation is a process, not a one-off intervention. Need to continuously assess – **adaptation pathways**.
- **Prioritization** is important – urgency, timing, scale.
- Essential to **weigh pragmatism, practicability, robustness and fitness for the future.**
- Suggest establishing a **list of principles** with regards to treatment of data, uncertainty, return periods.
- Importance of considering risks at asset level, system level and interdependencies across sectors.
- Window of opportunity: Establishing **link between resilience and net zero/ smart grids as well as nature agenda** – this is changing system requirements/set-up, investments are being made.
- **Data needs:** We need to establish a relationship between assets, systems, hazards and damages for probabilistic risk analysis:
  - Hazard data - sudden/extreme and slow onset risks. **Multi-hazard** ideally!
  - Asset data: locations and valuations
  - Systems data – including macro-economic data, sector indicators, elasticity of demand, often difficult to find
  - Damage curves
  - Adaptation assessment (CAPEX, OPEX, co-benefits, maintenance costs, etc.)
- **Most analysis on asset level, some modelling of system level, but very little on interdependencies**.
- Translating into adaptation action requires indicators and qualitative assessments: **monetization, investment return, who pays, alignment with pricing/tariff regimes?**
- **Monitoring adaptatio**n is essential – requires clear methodology.

European Taxonomy: goals and provisions on climate adaptation

The robust climate risk and vulnerability assessment shall be undertaken on a variety of physical risks

Climate Risk Taxonomy
(Task Force on Climate Related Financial Disclosure)

Transition Risks
Risks determined by the transition to a low carbon economy

Political
Reputational
Market
Technological

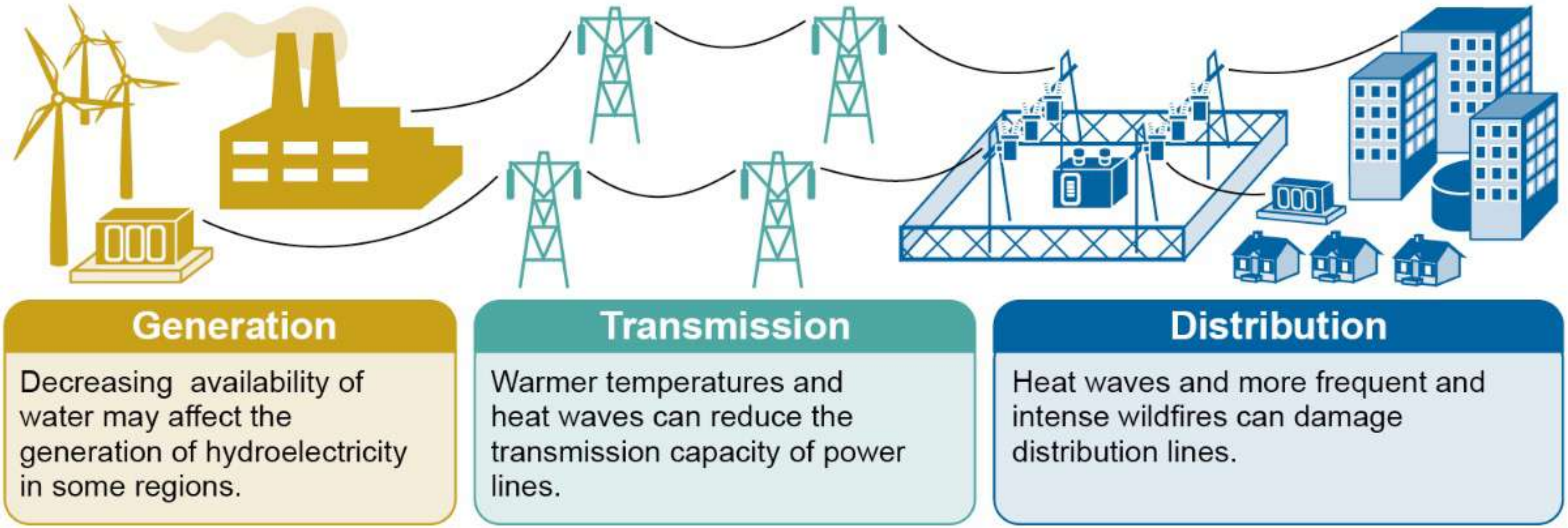
Physical Risks
Risks arising from the physical impact of climate change

Acute
Chronic

Physical Risk Taxonomy – EU Taxonomy

Temperature	Wind	Water	Solid Mass
Changing temperature (air, freshwater, marine water)	Changing wind patterns i	Changing precipitation patterns and types (rain, hail, snow/ice)	Coastal erosion
Heat stress		Precipitation or hydrological Variability	Soil degradation
Temperature variability		Ocean acidification	Soil erosion
		Saline intrusion	
Permafrost thawing		Sea level rise	Solifluction
		Water stress	
Heat wave	Cyclone, hurricane, typhoon	Drought	Avalanche
Cold wave/frost	Storm (including blizzards, dust and sandstorms)	Heavy precipitation (rain, hail, snow/ice)	Landslide
Wildfire	Tornado	Flood (coastal, fluvial, pluvial, ground water)	Subsidenc
		Glacial lake outburst	

Examples of Climate Change Effects on the Electricity Grid



Source: GAO analysis of reports. | GAO-21-346

When assessing impacts and designing adaptation measures it is important to reflect on assets, systems and interdependencies.

Climate risks will escalate

In 2020, 87% of global power generated from thermal, nuclear and hydroelectric systems directedly depended on water availability

Climate impact	Effects on generation	Effects on transmission and distribution	Effects on demand
Rising global temperatures	• Cooling efficiency • Generation potential • Need for additional generation	• Efficiency	• Cooling and heating
Changing precipitation patterns	• Output and potential • Peak and variability • Technology application	• Physical risks	• Cooling • Water supply
Sea-level rise	• Output • Physical risks • New asset development	• Physical risks • New asset development	• Water supply
Extreme weather events	• Physical risks • Efficiency	• Physical risks • Efficiency	• Cooling

Source: International Energy Agency, Climate Resilience Electricity Security 2021

According to Marsh McLennan's Flood Risk Index, over a quarter of Europe's power generation capacity may be affected by floods under 2.0 and 3.5℃ conditions

	Present Conditions	2 °C	3.5 °C
Global	23%	41%	48%
EU	**7%**	**28%**	**29%**
United States	23%	36%	41%
United Kingdom	5%	16%	18%

Source: Marsh McLennan, Flood Risk Index

Climate risks are already material to Europe’s energy security

France

France became a net energy importer in 2022 for the first time in 42 years. Prolonged drought conditions led to severe water shortages used in the cooling of nuclear plants. France’s nuclear outputs plunged by 23% in 2022.

Spain

In 2022, the cumulative impact of heatwaves, record summer temperatures and dry weather led to a 48% drop in Spain’s hydropower capacity.

Germany

The 2021 European floods damaged a considerable number of German power utilities. Over 200,000 people were impacted by power outages. RWE, a major producer, reported damages in the double-digit million Euro range.

Italy

Northern Italy was hit by hurricane-force snow winds for 3 days in 2018. The storm damaged electric transmission and distribution systems, causing over 90 blackouts, and a 5000MW gap in power supplies.

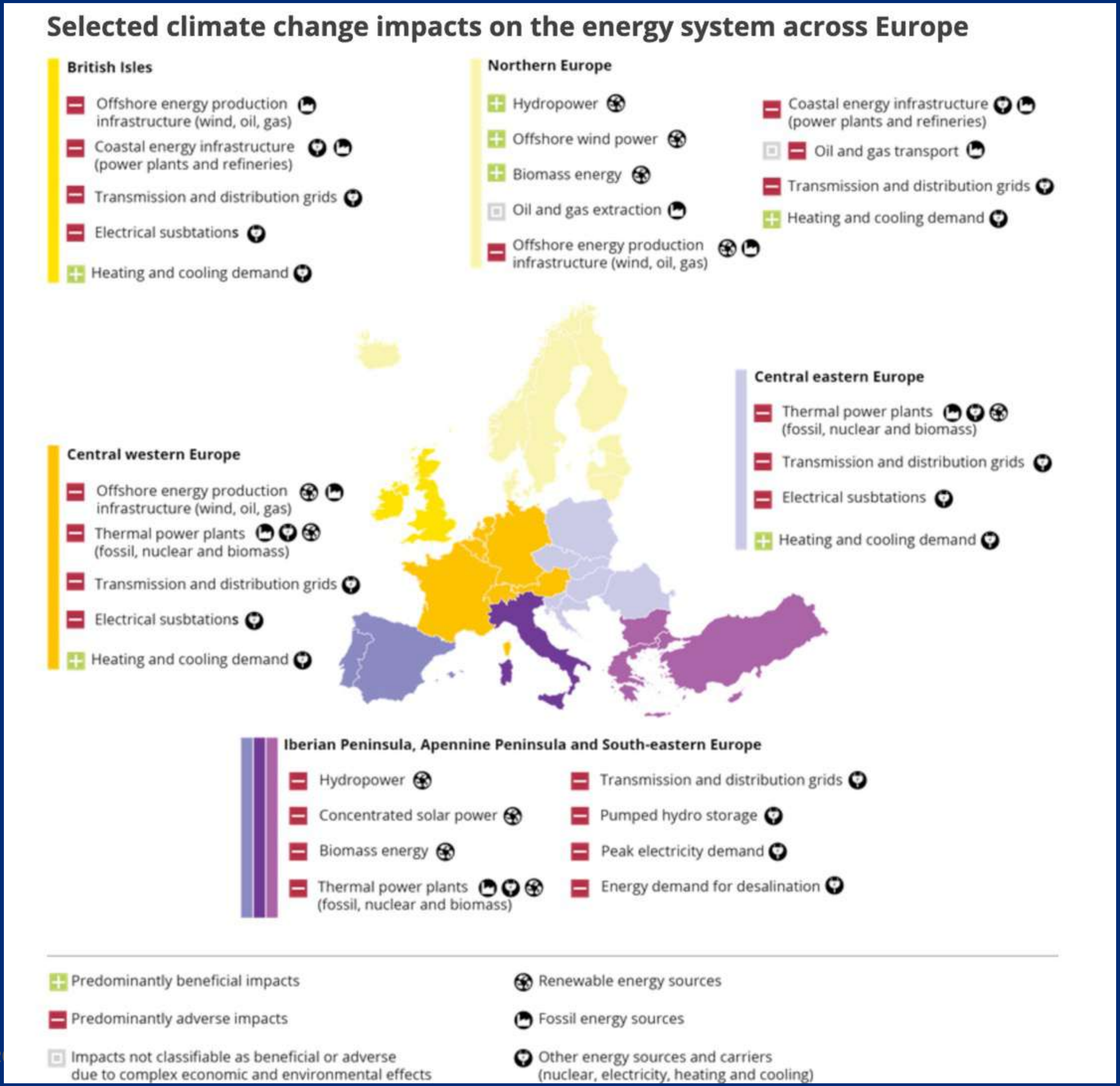
Figure 3.2 Selected climate change impacts on the energy system across Europe

	Primary energy production	Energy transformation	Transportation, transmission, distribution and storage	Energy demand
Northern Europe	Hydropower: Increasing potential due to increased streamflow Offshore wind power: Increasing potential due to increasing wind speeds Biomass energy: Increasing productivity as growing area moves north Oil and gas extraction: Increased accessibility of resources in the Arctic Offshore energy production infrastructure (wind, oil, gas): Increasing risks from sea level rise, storm surges and coastal erosion	Coastal energy infrastructure (power plants and refineries): Increasing risks from sea level rise, storm surges and erosion	Oil and gas transport: New route opportunities for sea transportation in Arctic areas due to melting sea ice Oil and gas transport: Increasing risks to pipelines in Arctic areas due to degrading permafrost Transmission and distribution grids: Increasing risk from storms	Heating and cooling demand: Reduced net energy demand due to increasing ambient temperature.
British Isles Central western Europe	Offshore energy production infrastructure (wind, oil, gas): Increasing risks from sea level rise, storm surges and coastal erosion		Transmission and distribution grids: Increasing risks from storms and inland floods Electrical susbtations: Increasing risk from inland floods	
Central eastern Europe	Mixed impacts	Thermal power plants (fossil, nuclear and biomass): Reduced output or forced shutdown due to reduced cooling water availability		
Iberian Peninsula	Hydropower: Decreasing potential due to decreasing streamflow		Transmission and distribution grids: Reduced capacity due to increasing heatwaves	Peak electricity demand: Increasing demand for cooling due to increasing heatwaves
Apennine Peninsula	Concentrated solar power: Constraints for expansion due to water scarcity		Pumped hydro storage: Reduced potential due to decreasing water availability and increasing evaporation	Energy demand for desalination: Increasing demand due to decreasing freshwater availability
South-eastern Europe	Biomass energy: Decreasing productivity due to increasing water scarcity			

Predominantly beneficial impacts
Predominantly adverse impacts
Renewable energy sources
Fossil energy sources

Assessment across Europe

Source: EEA 2019 https://www.eea.europa.eu/highlights/climate-change-puts-pressure-on -



Source: EEA 2019 https://www.eea.europa.eu/highlights/climate-change-puts-pressure-on -

The need for climate resilience

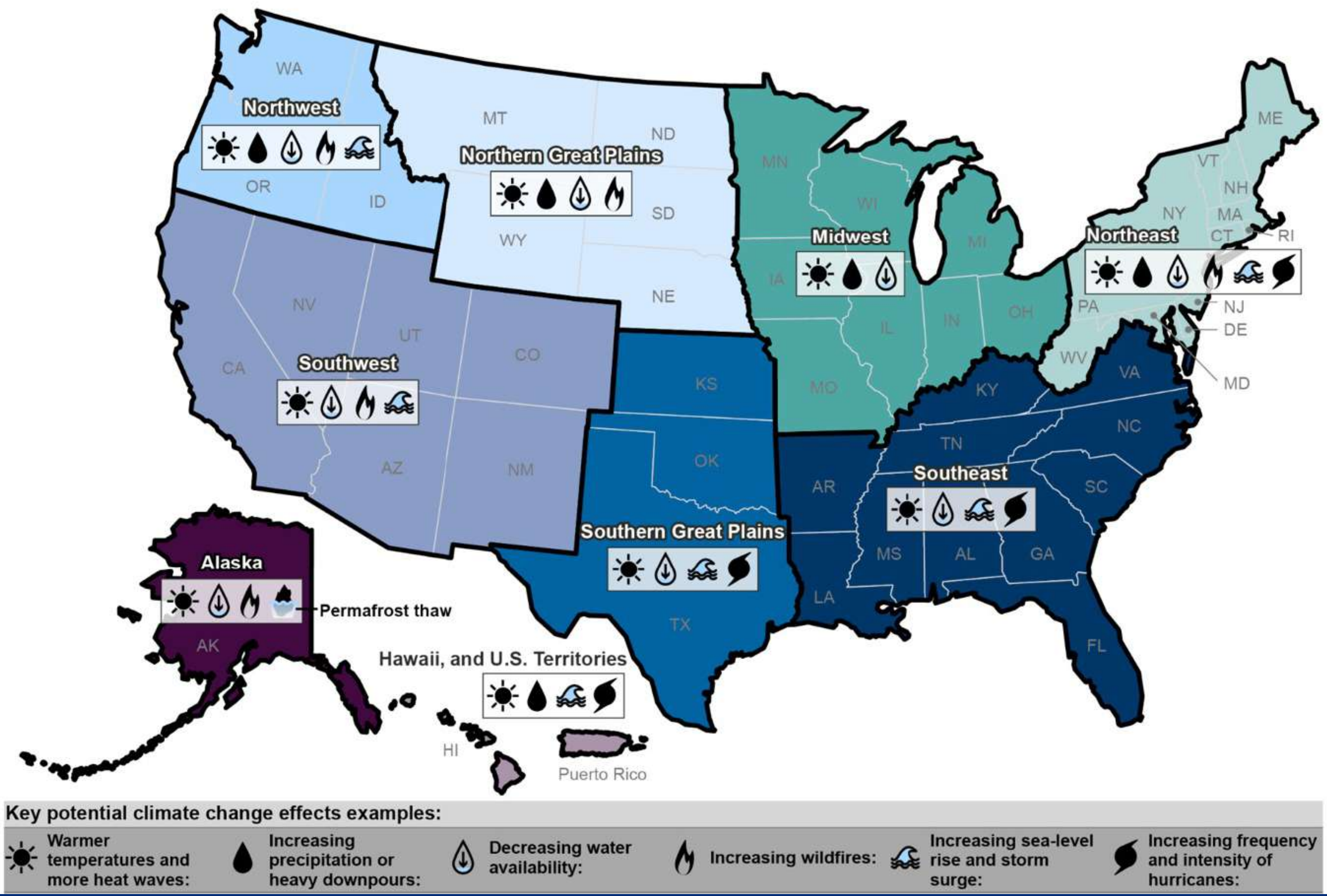
Potential impacts on the energy system due to climate trends & extreme weather events in the UK

country level assessment

Climate hazard	Expected change by 2050
Heatwaves	~50% chance of 2018 summer each year (around 10-25% currently)
Flooding (river, surface and coastal)	~5% wetter winters on average (compared to 1981-2000) ~10% increased intensity of heavy rainfall 10 – 30 cm increase in average sea levels (above 1981-2000 levels)
Drought	~10% drier summers on average (than over 1981 – 2000)
Wind strength and wind regimes	Highly uncertain
Storminess and occurrence of storm events	Highly uncertain
Snow and ice	Decreasing but still possible

Source
UKCP18 Projections; summarised in CCC (2021) Independent Assessment of UK Climate Risk

Figure 3: Potential Climate Change Effects by Region and Examples of Climate-Related Events on the Electricity Grid



Source: https://www.gao.gov/assets/gao-21-346.pdf

Hazard-level assessments

Climate hazard	Key impacts	Impacted segment	Adaptation strategies
Increased air temperatures	• Lower generation efficiency • Decreased coal-to-gas conversion efficiency • Decreased combined cycle gas turbine efficiency • Decreased solar PV efficiency	Generation	• Implement air chillers or more efficient chillers • Site new generation in cooler locations
	• Reduced carrying capacity of lines and transformers • Increased losses in lines and transformers	Delivery-Transmission & Distribution	• Underground hardware • Use more heat-resistant materials • Implement more effective cooling for transformers
	• Increased peak demand and total energy demand for cooling	Demand-End Use	• AC energy efficiency • Building thermal efficiency • Peak load shifting

Source: Burillo (2018): Effects of Climate Change in Electric Power Infrastructures

Service/system assessments

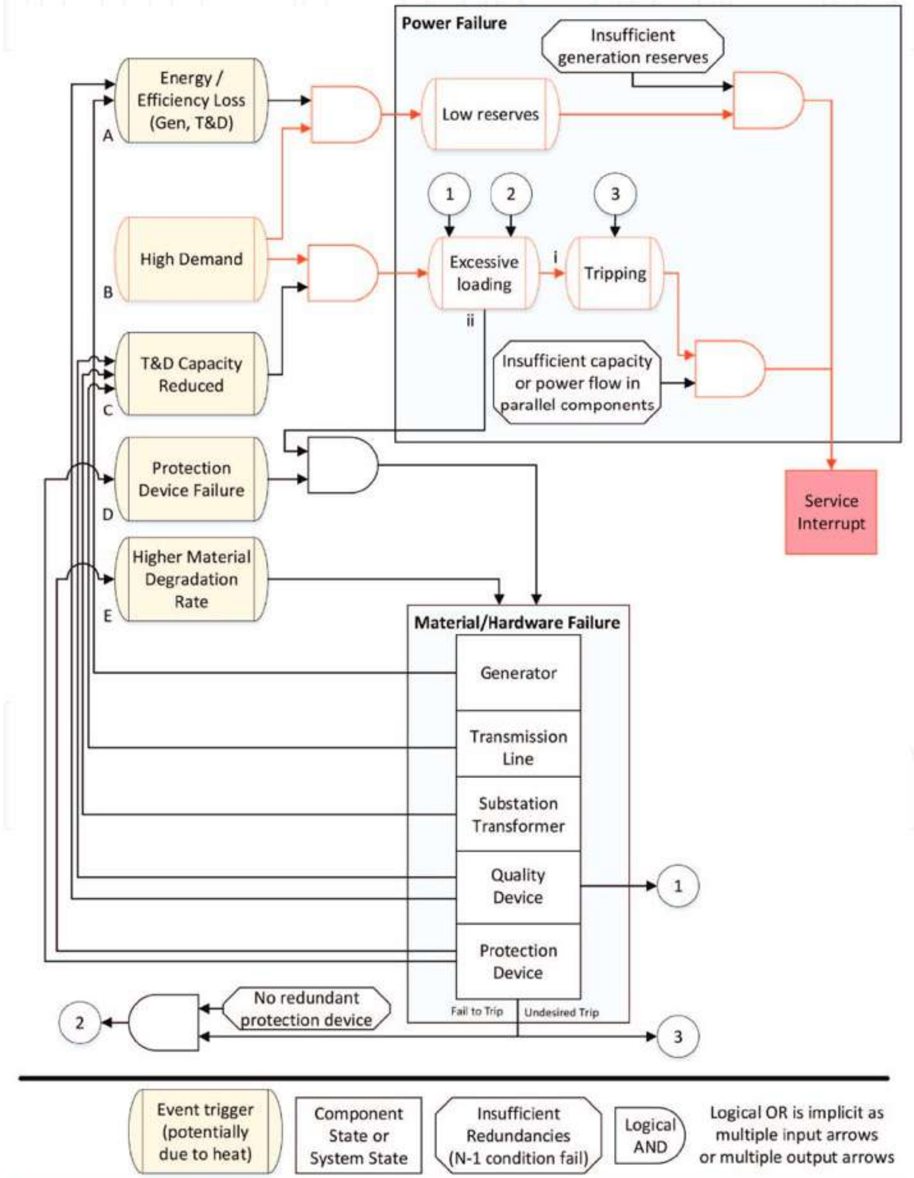


Figure 1.
Fault tree from heat wave to service interruption.

Source: Burillo (2018): Effects of Climate Change in Electric Power Infrastructures

- **Interconnections** between different industry sectors is a major source of risk for the energy network, with failures from one sector frequently causing impacts.

- **Telecommunications and road transport** are thought to be the most important sources of risk. Telecommunications are already important for automated and remotely controlled equipment, and for communication with personnel in the field.

- Risk from **telecommunications failure** has the potential to increase in the future with greater reliance on smart systems (dependent on telecommunications).

- **Road transport** is often essential for restoration of supply and access to assets for routine maintenance and emergency restoration. Societal responses to climate change may also increase the risk on the road network from the electricity network, as electric vehicles become more commonplace.

Source:https://www.energynetworks.org/assets/images/CCRA3%20report%20v1.0%20final.pdf

Delivering a reliable decarbonised power system
Key findings – planning for climate resilience

The climate risks to the electricity system are currently underplayed.

Climate-related impacts will multiply as we rely increasingly on electricity for heat and transport needs.

The **cascading impacts of electricity failu**re are already significant. The risks will grow as the economy becomes increasingly electrified and as extreme weather events become more common and severe due to climate change.

Important to build in **system-and asset-level resilience from the start.**

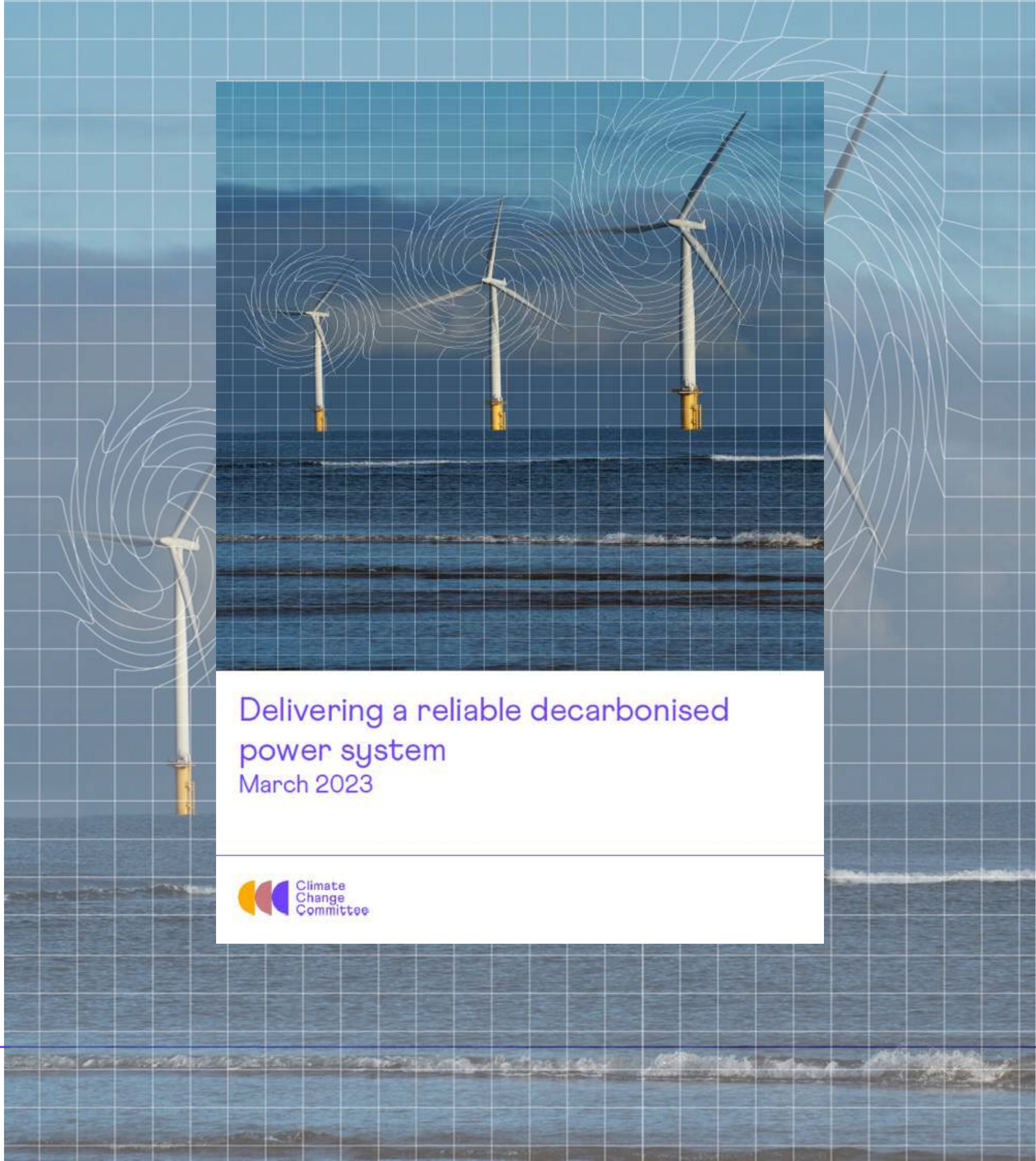


Figure 6.1 Monitoring map for energy

Reliable energy supply in a Net Zero economy

Required Outcomes

Reduced vulnerability of energy assets to extreme weather
- *Asset-level flood resilience*
- *Condition of electricity poles, gas pipes and other power system infrastructure*
- *Heat protection/operating thresholds of substations, cables, overhead lines and other power system infrastructure*
- *Ground conditions (subsidence, landslides and erosion)*
- *Abstraction restrictions imposed on generators*

System level security of supply
- *Generation capacity, flexibility and redundancy*
- *Generation mix and location*
- *Water needs for Net Zero compatible generation*

Interdependencies known and managed
- *Interdependency risks (e.g. transport, water, digital) included in climate risk assessments and adaptation action plans for all major electricity and gas producers and transmission & distribution system infrastructure operators*

Enablers

Governance
- Co-ordination of resilience responsibilities across Gov departments
- Climate resilience incorporated into relevant Net Zero policies
- Clear governance arrangements and responsibilities for climate resilience across the sector

Data
- Centralised reporting on weather-related outages
- Data on consideration of climate risk adaptation in major infrastructure project approvals
- Data provision to local resilience groups on interdependencies

Funding & investment
- £ spent (and forecast) on system resilience (e.g. flood protection, pole management, vegetation management)
- Consideration of adaptation needs in investment decisions (e.g. UK Infrastructure Bank)

Policies and plans

Legislation and regulation
- Climate resilience remit for Regulators
- Climate resilience as a statutory consideration for planning authorities decisions on infrastructure

Standards
- Minimum resilience standards for generators and transmission & distribution companies covering all CCRA risks
- Tests for climate resilience being applied to major infrastructure projects

Planning
- Clear resilience outcomes in national adaptation plans with monitoring in place
- Operator-level plans for climate resilience

Information and reporting
- Mandatory reporting on climate risk and adaptation activities by all major electricity and gas producers, transmission system infrastructure operators and regulators

Contextual factors

Hazard

Observed and projected changes in:
- summer temperatures and extreme heat events
- winter and summer rainfall and intensity of rainfall events – flooding and drought
- wind strength & regimes, storminess
- sea level rise, storm surges, coastal erosion

Exposure
- Age and condition of power infrastructure
- Location of power infrastructure
- Criticality of individual assets/number of connections

Vulnerability
- Percentage share of electrical energy from VRE
- Proportion of customers dependent solely on electricity
- Consumer bill considerations impacting ability to invest in new infrastructure and resilience activities
- Proportion of power users in remote communities

Source: CCC analysis.
Notes: Italicised text indicates suggested measures for each outcome.

Monitoring Adaptation progress

Table 6.1
Progress summary – Energy

	Delivery and implementation	Policies and plans	Summary
Outcome 1: Reduced vulnerability of energy assets to extreme weather	Mixed progress	Partial policies and plans	• Climate change is a consideration in statutory planning applications for new infrastructure and reports submitted under the Adaptation Reporting Power demonstrate progress in some areas. • Some specific policies and standards exist to increase asset resilience, such as for flood protection of substations. • There is a need for minimum resilience standards and a clearer climate resilience remit for regulators. • Some progress in flood resilience, but more information is needed for other hazards, including heat and drought.
Outcome 2: System level security of supply	Mixed progress	Limited policies and plans	• Government has committed to a decarbonised, secure energy supply by 2035 and acknowledged the need for resilience, but there is no defined standard for system level resilience and delivery challenges remain. • More research is needed to understand possible climate impacts on the energy system, and this must be integrated into system design and investment processes.
Outcome 3: Interdependencies identified and managed	Unable to evaluate	Insufficient policies and plans	• Coverage of interdependency risks has improved in some adaptation plans but this remains an area of significant challenge. • It is not possible to assess progress in delivery across the whole energy system due to a lack of data for generators.

Relevant risks from CCRA3:
Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures (I1); risks to infrastructure services from river, surface water and groundwater flooding (I2); risks to infrastructure services from coastal flooding and erosion (I3); risks to bridges and pipelines from flooding and erosion (I4); risks to hydroelectric generation from low or high river flows (I6); risks to subterranean and surface infrastructure from subsidence (I7); risks to energy generation from reduced water availability (I9); risks to energy from high and low temperatures, high winds, lightning (I10); risks to offshore infrastructure from storms and high waves (I11); risks and opportunities from summer and winter household energy demand (H6).

(d) Recommendations to close policy gaps

Table 6.2 provides a set of targeted recommendations to close key outstanding policy gaps identified within this sector.

Table 6.2
Recommendations

Primary responsibility	Recommendation	Timing
DESNZ	Conduct a review of governance arrangements for resilience to climate hazards in the energy system, to ensure they are fit for the new expanded and more diverse low-carbon system given increasing societal reliance on electricity.	2024
DESNZ	Designate Ofgem and parties responsible now and in the future (including the new Future System Operator) for the maintenance of energy sector codes and standards, with a clear mandate to ensure climate and weather resilience.	2024
FSO	Ensure that future system design explicitly plans for the range of climate hazards that will face the energy system over its lifetime.	Ongoing
Cabinet Office	Develop a pathway to setting appropriate minimum resilience standards (both at asset and system level) to relevant climate hazards identified in the UK Climate Change Risk Assessment (CCRA), covering all relevant parties.	2028 latest
Ofgem	Extend requirements for reporting on outages to include the cause, duration and customers affected for all outages, and collate this as a national indicator.	2024
Defra	Mandate reporting on climate risk and adaptation plans by all generators, network operators and regulators under the Adaptation Reporting Power.	2023
Defra	Coordinate a systematic assessment of risks posed from cascading impacts across multiple sectors due to failures of the decarbonised energy system as part of the next round of the Adaptation Reporting Power.	2025
DESNZ	Commission further research to improve understanding of how climate change is altering key weather hazards that will impact the energy system.	Ongoing

The adaptation toolbox

Engineered
Structural measures to control water and reduce the potential impacts of flooding

Policies and regulations
Building codes, mandatory resilience standards, risk disclosure requirements, and others

Nature-based
The restoration, preservation, and management of natural capital (e.g., ecosystem protection and soil rehabilitation)

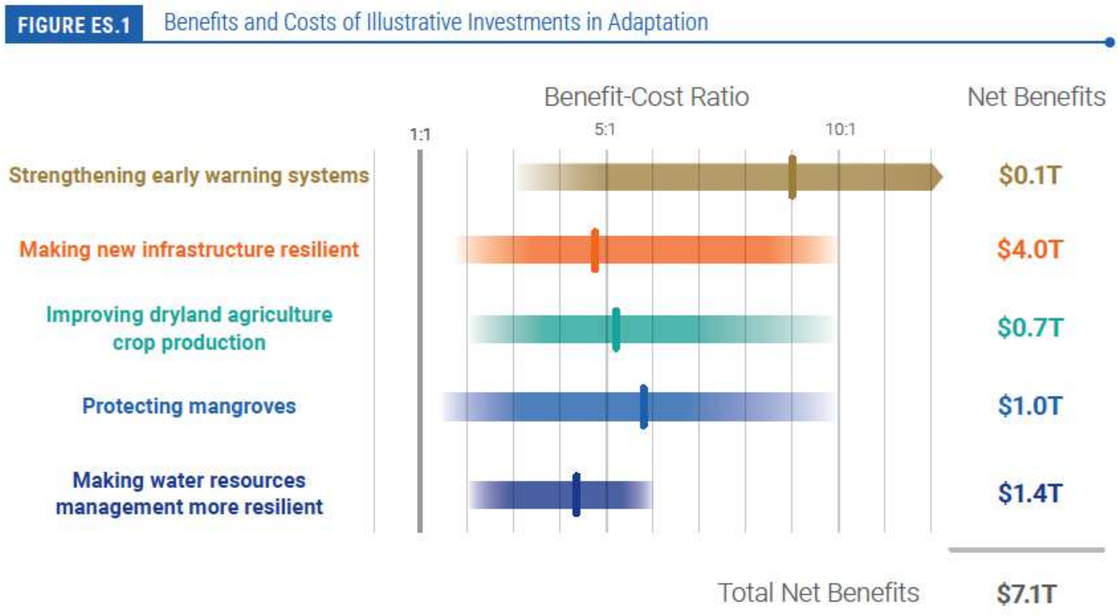
Risk transfer
Traditional insurance and reinsurance, and innovative risk transfer solutions (e.g., parametrics, risk pools)

R&D and data
Advancements in risk analytics, modelling, monitoring, and forecasting

Behavioral
Risk information sharing, evacuation training, supply chain diversification, and others

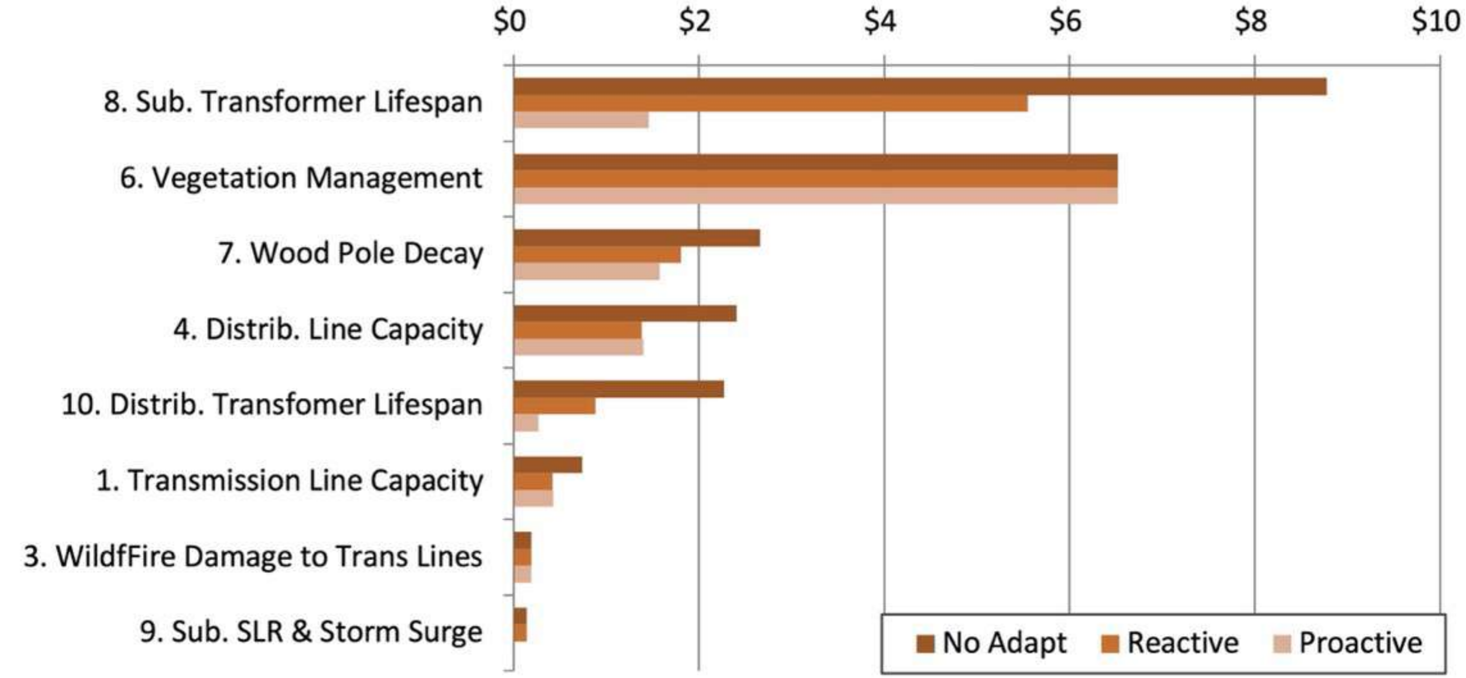
Although society has a **portfolio of risk management tools at its disposal**, many of these tools are **currently underutilized, underfunded or inefficiently implemented**, while in developing countries, availability and affordability present key challenges.

The costs and benefits of adaptation



Source: Global Commission on Adaptation, 2019

Impact Type	RCP4.5			RCP8.5		
	No Adapt	Reactive	Proactive	No Adapt	Reactive	Proactive
8. Substation Transformer Lifespan	$5.4	$2.6	$0.5	$8.8	$5.5	$1.5
6. Vegetation Management	$3.7	$3.7	$3.7	$6.5	$6.5	$6.5
7. Wood Pole Decay	$1.4	$0.8	$0.9	$2.7	$1.8	$1.6
10. Distribution Transformer Lifespan	$1.2	$0.8	$0.8	$2.4	$1.4	$1.4
4. Distribution Line Capacity	$1.1	$0.3	$0.04	$2.3	$0.9	$0.3
1. Transmission Line Capacity	$0.4	$0.2	$0.2	$0.7	$0.4	$0.4
3. Wildfire Damage to Trans Lines	$0.1	$0.1	$0.1	$0.2	$0.2	$0.2
9. Substation SLR and Storm Surge	$0.07	$0.07	$0.01	$0.14	$0.14	$0.01
TOTAL	**$13.4**	**$8.5**	**$6.2**	**$23.7**	**$16.9**	**$11.9**



Source: Fant et.al. (2020): Climate change impacts and costs to U.S. electricity transmission and distribution infrastructure

- **Data needs:** We need to establish a relationship between assets, hazards and damages
  - Hazard data
  - Asset data: locations and valuations
  - Damage curves
  - Macro-economic data, sector indicators – elasticity of demand, often difficult to find
  - Adaptation assessment (CAPEX, maintenance costs for each measure, cost of labour etc.)
- **Limits of ROI for adaptation:** ROI presents information in one easy-to-understand metric; this is part of its appeal, but also, of course, this can prevent consideration of other important features of projects that are not inputs into the ROI calculation. When broader social and environmental benefits are included, the analysis is often termed “social return on investment,” or SROI.
- **Risk analysis** is an important consideration in the RROI concept and underlying CBA approach. Probability event scenarios, the consideration of future probabilities of events, identification of direct and indirect risk exposure, frequency, and magnitude should be incorporated into the RROI assessment.
- **Types of impacts** included in the cost benefit analysis: To establish the total cost of a disaster, its indirect costs also need to be estimated. Calculating both direct and indirect costs in addition to non-economic impacts, is challenging.
- **Cost-benefit analyses** require the collection of extensive and reliable data, as well as data that are standardized; however, this data collection and organization can be costly. This can certainly be a “road-block” when performing a CBA

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