Factoring climate resilience into the design of clean power infrastructures

IAEA Webinar – Vienna, 8 June 2021

Dr. Bertrand Magné - Planning and Economic Studies Section

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

The rationale for built-in resiliency

A key feature of decarbonized power systems

More severe weather conditions are to be expected irrespective of the climate state reached ultimately

Policy relevance

No energy asset is immune to future impacts of climate change

A matter of security of supply

Coordinated approach and adequate financing mechanisms are needed to address climate vulnerability of energy infrastructures

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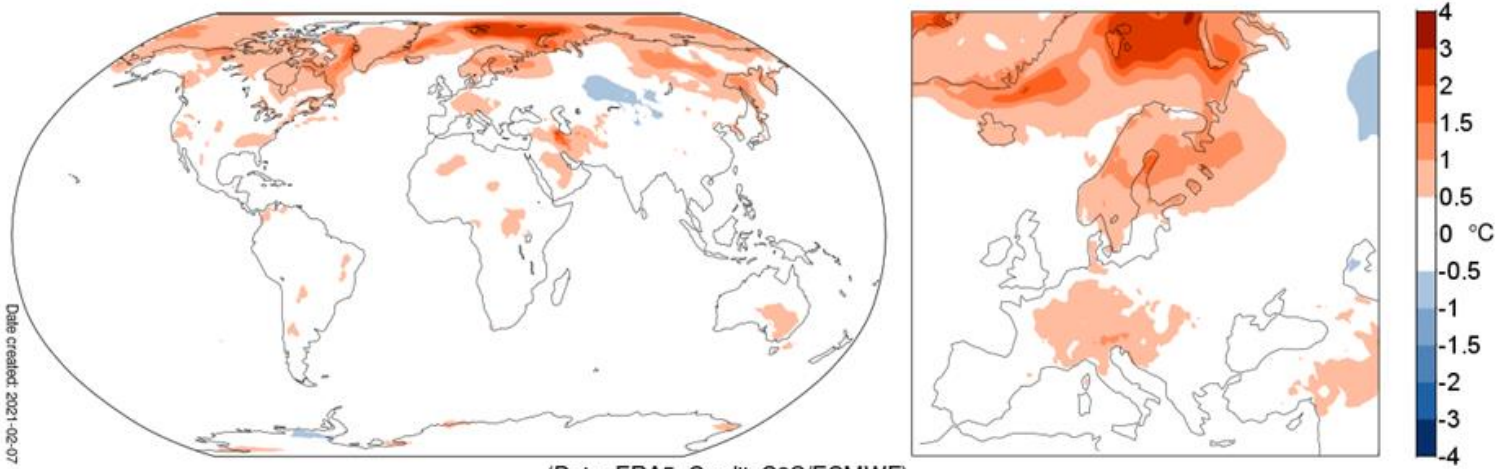
Our climate is changing gradually

Surface air temperature for January, difference between 1981-2010 and 1991-2020



(Data: ERA5. Credit: C3S/ECMWF)

- Climate effects are particularly pronounced at **high latitudes**
- An increase in **average air and seawater temperature**, increased **precipitations**, **more frequent weather extremes** as well as **reduced snow and ice covers** are already being felt

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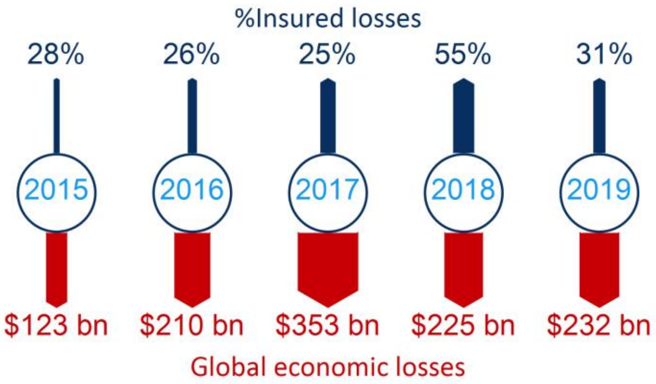
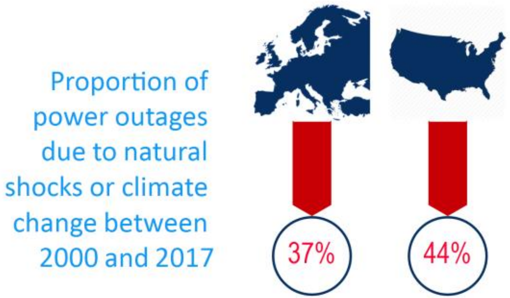
Impacts of more severe climate changes

Severe environmental conditions episodically affect infrastructures worldwide, at great economic and social expense for asset owners, insurers and local communities

Frequent weather disasters generate large economic losses yearly…



… and are often at the origin of power outages



Power outages result in economic losses for **utilities**, **grid operators**, **households**, **society as a whole**

Source: IAEA (Forthcoming) *Transitions to low carbon electricity systems: Key economic and investment trends - Changing course in a post-pandemic world*

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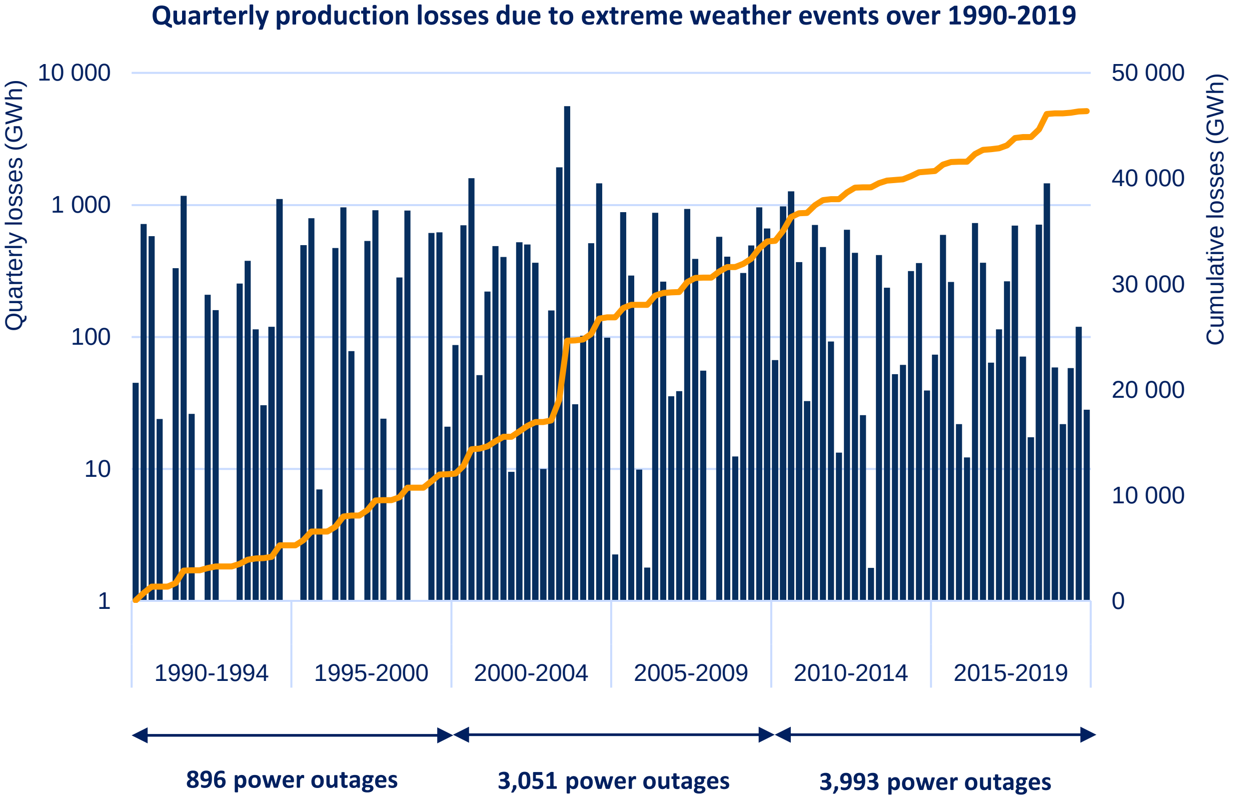
Nuclear power plants also need to adapt to changing weather conditions

Lessons from 30 years of weather-induced nuclear power disruptions



Shutdowns reported more frequently

- Across **all geographies and climatic zones**
- **River-cooled** power plants are particularly affected

Decreasing economic severity

- Rising **awareness** among operators and regulators; **Adaptation measures** to offset threats to production and service reliability
- Modest cumulative economic impacts in the last three decades, approaching 50 TWh (or 1.2 TWh per year on average), i.e. **less than 0.2% of nuclear electricity generated each year globally**

Source: IAEA (Forthcoming) *Nuclear Energy's Contribution to a Net-Zero World* based on IAEA Power Reactor Information System (PRIS) database

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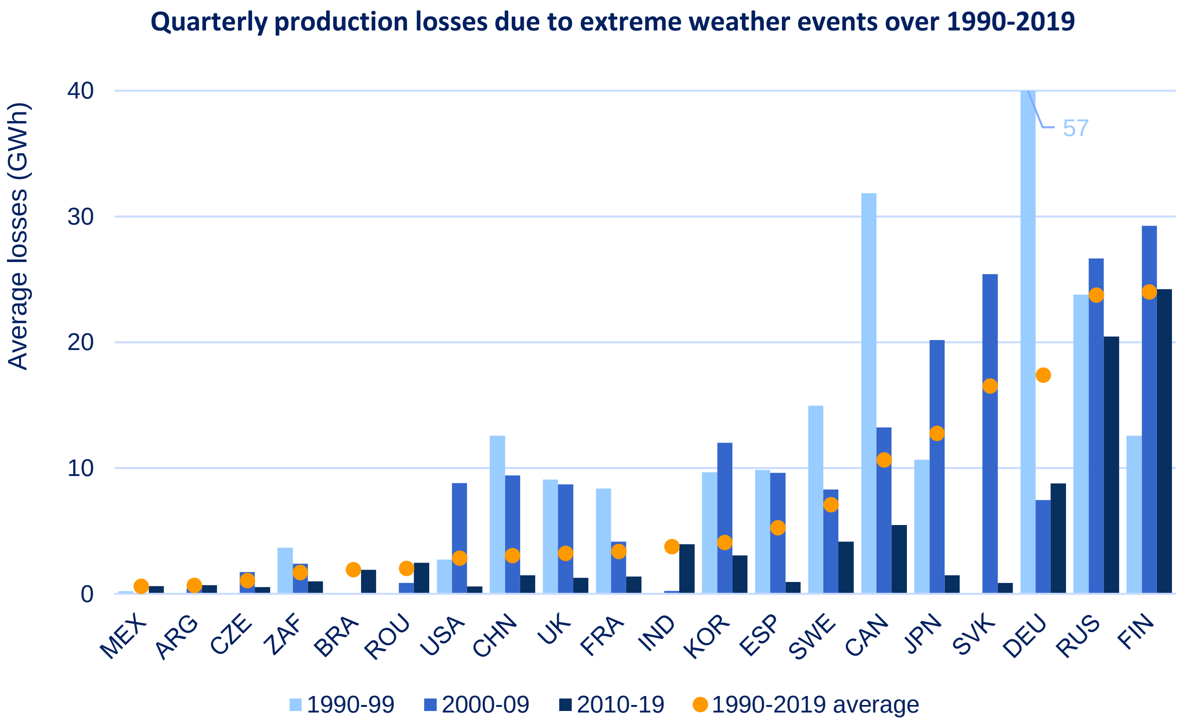
Stable production foregone since 1990 due to extreme weather conditions



Limited forced outages on record

- thanks in particular to **facility design** and **limited reliance** on **fuel supply chains**
- Production losses per event often **lower than 5 GWh** (equivalent of five hours of production for a 1GW nuclear plant operating at full capacity)
- Nuclear power plants located in **colder climates**, including in Finland, Russia and Canada **disproportionately affected**

Regular nuclear power plant upgrades:

- **enhance overall resilience** of energy infrastructures
- **improve reliability of energy services** in the future

Source: IAEA (Forthcoming) *Nuclear Energy's Contribution to a Net-Zero World* based on IAEA Power Reactor Information System (PRIS) database

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FACTORING CLIMATE RESILIENCE INTO THE DESIGN OF CLEAN POWER INFRASTRUCTURES

Speakers

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International Atomic Energy Agency

Climate Science Basis for Resilience and Decision Making

Roberta Boscolo
Climate and Energy Scientific Officer, WMO
IAEA Climate Resilience Webinar
Tuesday, 08 June 2021

Acknowledgement:
Hamid Bastani
Omar Baddur
Wilfran Moufouma

Content

State of the global climate in 2020 and climate indicators

Climate risks and opportunities in the energy sector

Climate services for the energy sector

State of the global climate in 2020 and climate indicators

GHG continued to increase – temporary reduction related to COVID-19

one of the three warmest years on record

The trend in sea-level rise is accelerating

The Arctic minimum sea-ice extent in September 2020 was the second lowest on record

The Antarctic mass loss trend accelerated around 2005, and currently, Antarctica loses approximately 175 to 225 Gt of ice per year.

North Atlantic hurricane season was exceptionally active

Some 9.8 million displacements

Disruptions to the agriculture sector

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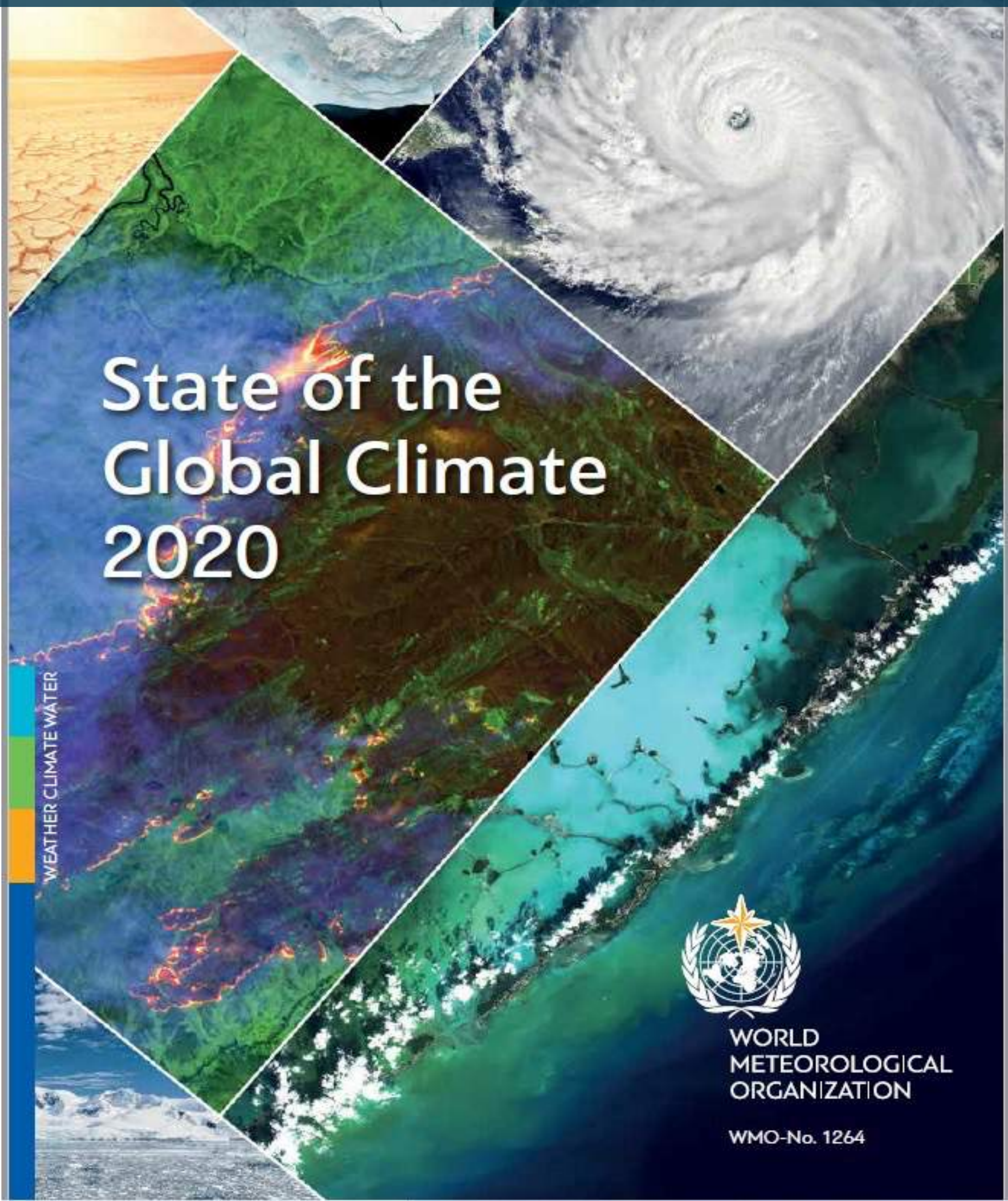
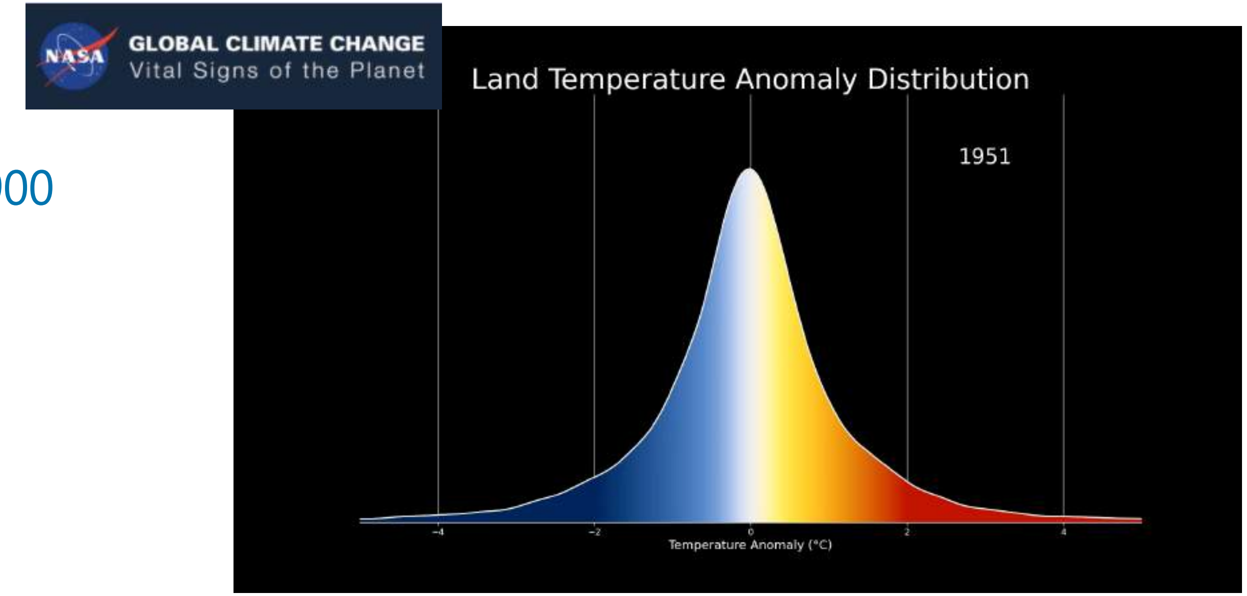
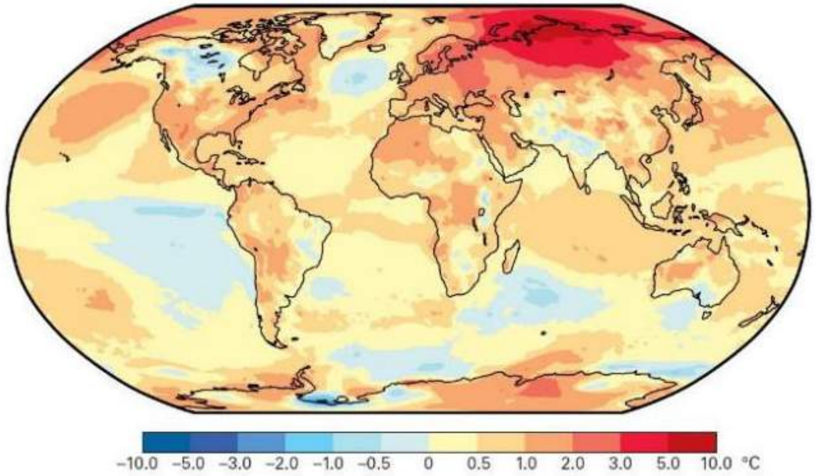


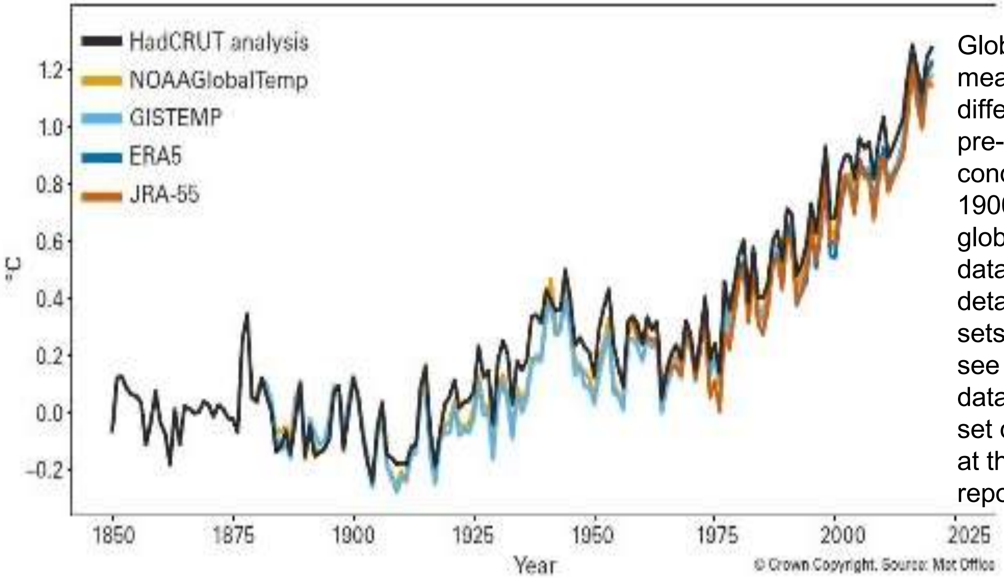
TEMPERATURE

- For global mean temperature, the baseline is 1850–1900 from pre-industrial condition (IPCC).
- Paris Agreement aims to hold the global average temperature to well below 2 °C above pre-industrial levels and to limit the temperature increase to 1.5 °C.
- 2016 was the warmest year and 2020 was one of the three warmest years on record.



Temperature anomalies relative to the 1981–2010 long-term average from the ERA5 reanalysis for 2020. Source: Copernicus Climate Change Service, European Centre for Medium-Range Weather Forecasts (ECMWF)

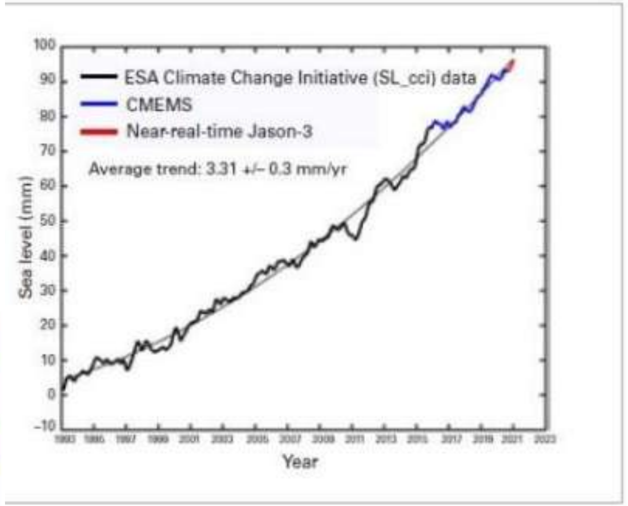


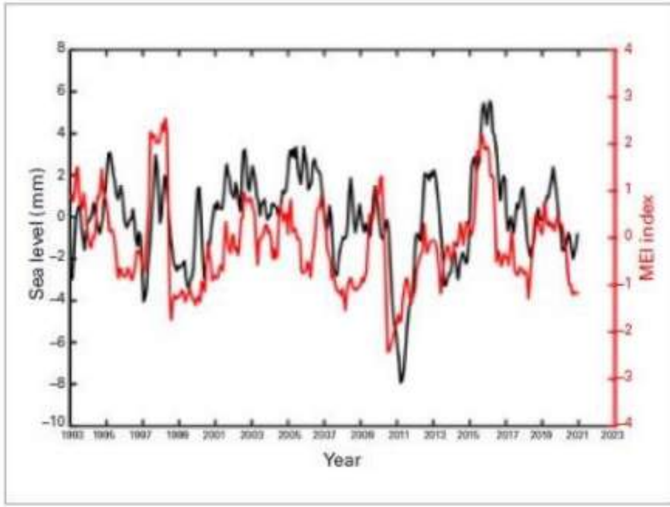


Global annual mean temperature difference from pre-industrial conditions (1850–1900) for five global temperature data sets. For details of the data sets and plotting, see Temperature data in the Data set details section at the end of this report.

SEA-LEVEAL RISE

- On average, since early 1993, the altimetry-based global mean rate of sea-level rise has amounted to 3.3 ± 0.3 mm/yr.s are a great tool.
- At the regional scale, sea level continues to rise non-uniformly The strongest regional trends over the period from January 1993 to June 2020 were seen in the southern hemisphere:





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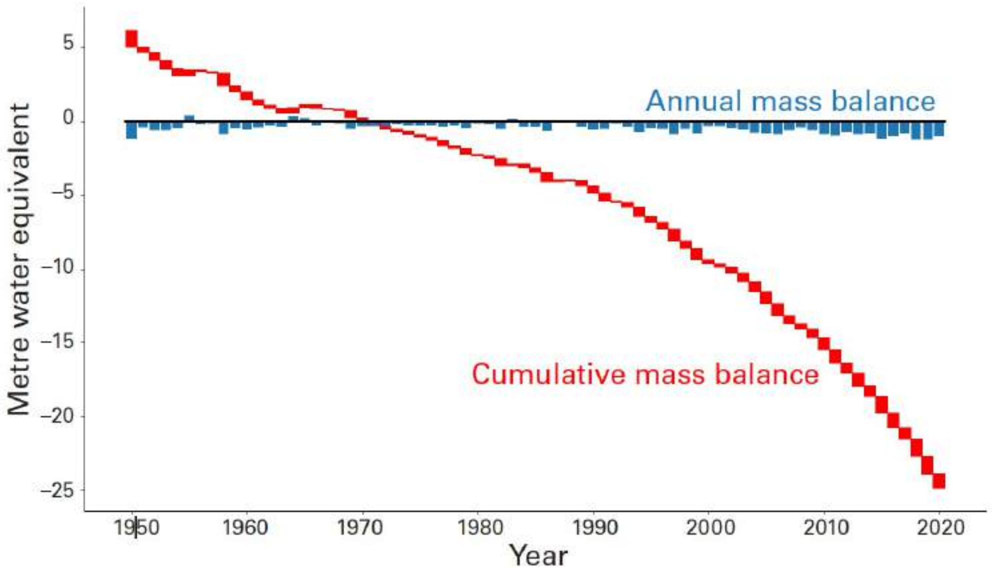
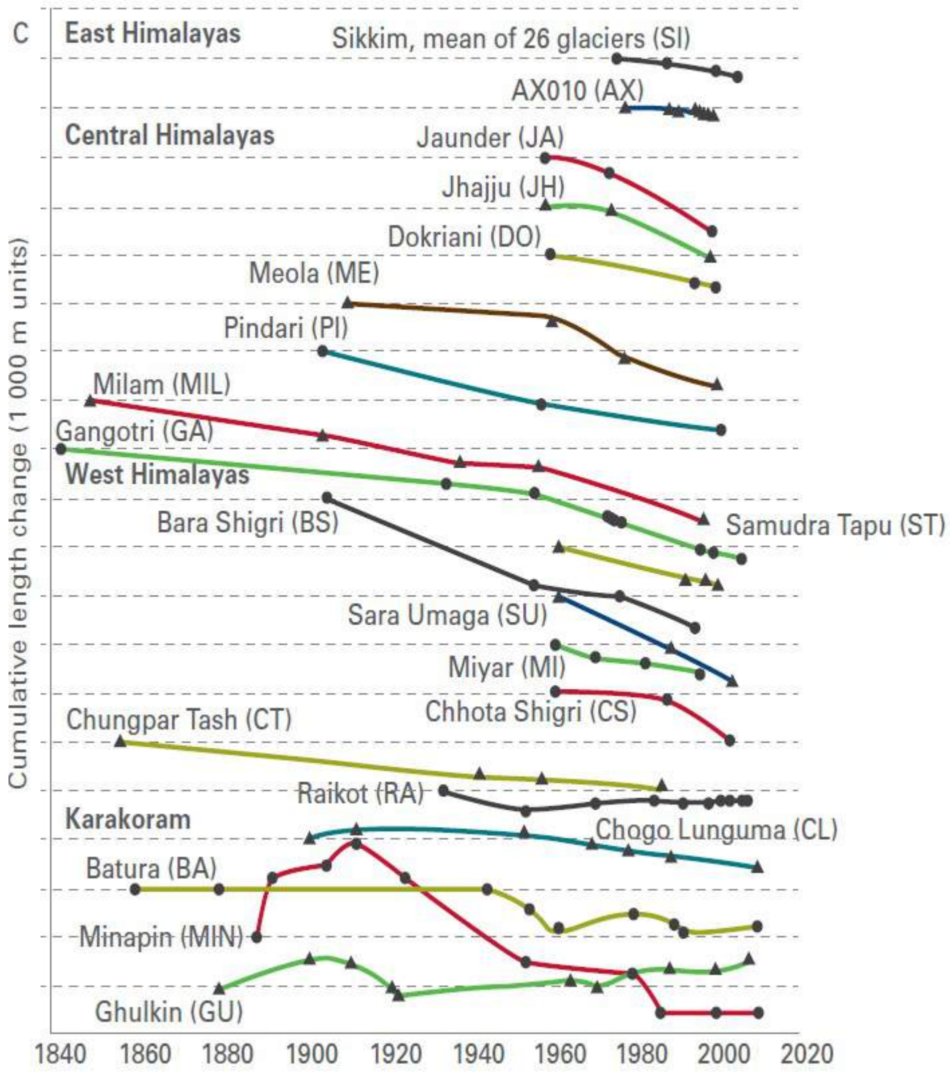
Global mean sea level continued to rise in 2020 (Fig. left). Interannual changes of global mean sea level are correlated with El Niño Southern Oscillation (Fig. right). multivariate ENSO index (MEI) (red curve and right axis).

Cryosphere - Glaciers

- 40 Glaciers with long-term observations experienced an ice loss of 1.18 meter water equivalent in 2018/19 and 0.98 in 2019/20.
- Eight out of the ten most negative mass balance years have been recorded since 2010



World Glaciers Monitoring Services, 2021, updated



Measured rates of change in glacier cumulative length measurements. The glacier retreat since the mid-19th century is obvious in the Himalayas, with the exception of the glaciers at Nanga Parbat in the northwest (RA, CL). Glaciers in the Karakoram show complex behaviour (Source: T. Bolch et al., 2012).

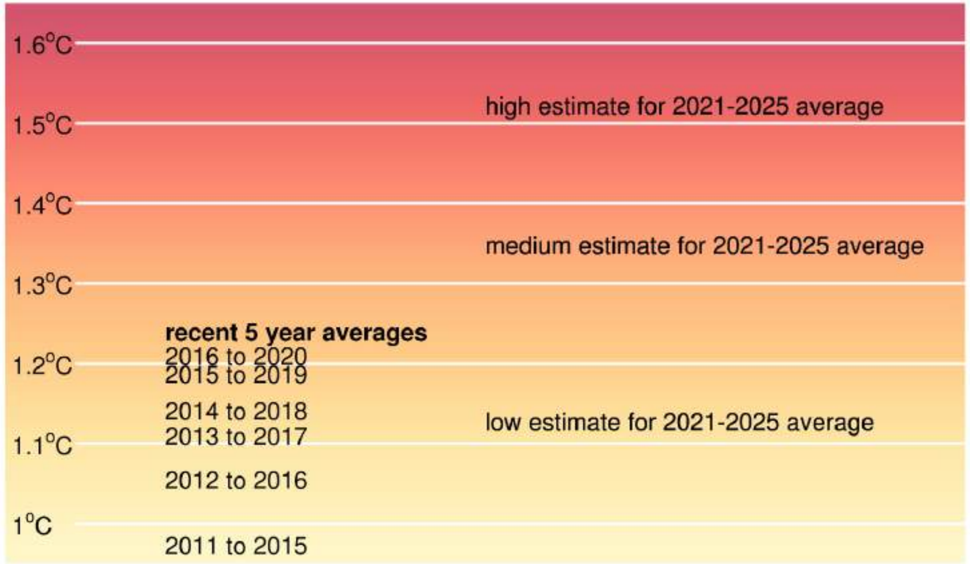
Regional Predictions for 2021-2025

- There is more than a 40% chances that the annual average global temperature in at least one of the next five years will temporarily reach 1.5ºC above pre-industrial level. These odds are increasing with time.

Met Office

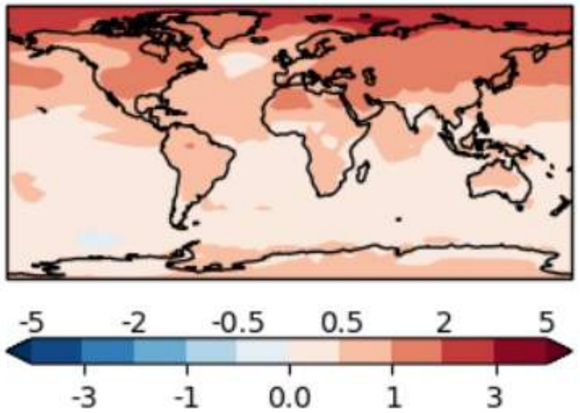
WORLD METEOROLOGICAL ORGANIZATION

Five year climate forecast



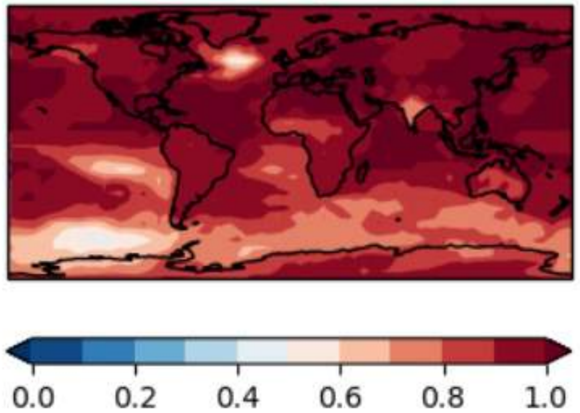
Distribution of predicted global five-year-mean near-surface temperature for 2021-2025 (compared to pre-industrial average temperature)

Ensemble mean forecast for 2021-2025 surface temperature



Anomalies from 1981-2010 (°C)

Probability of above average surface temperature



Predictions for 2021-2025 temperature anomalies relative to 1981-2010

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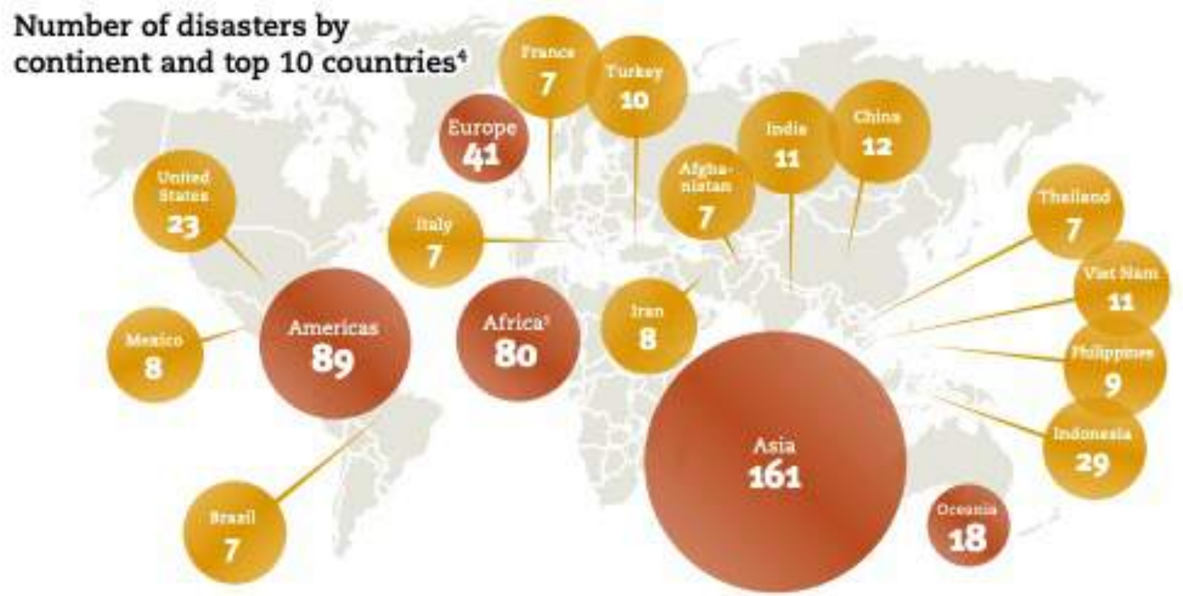
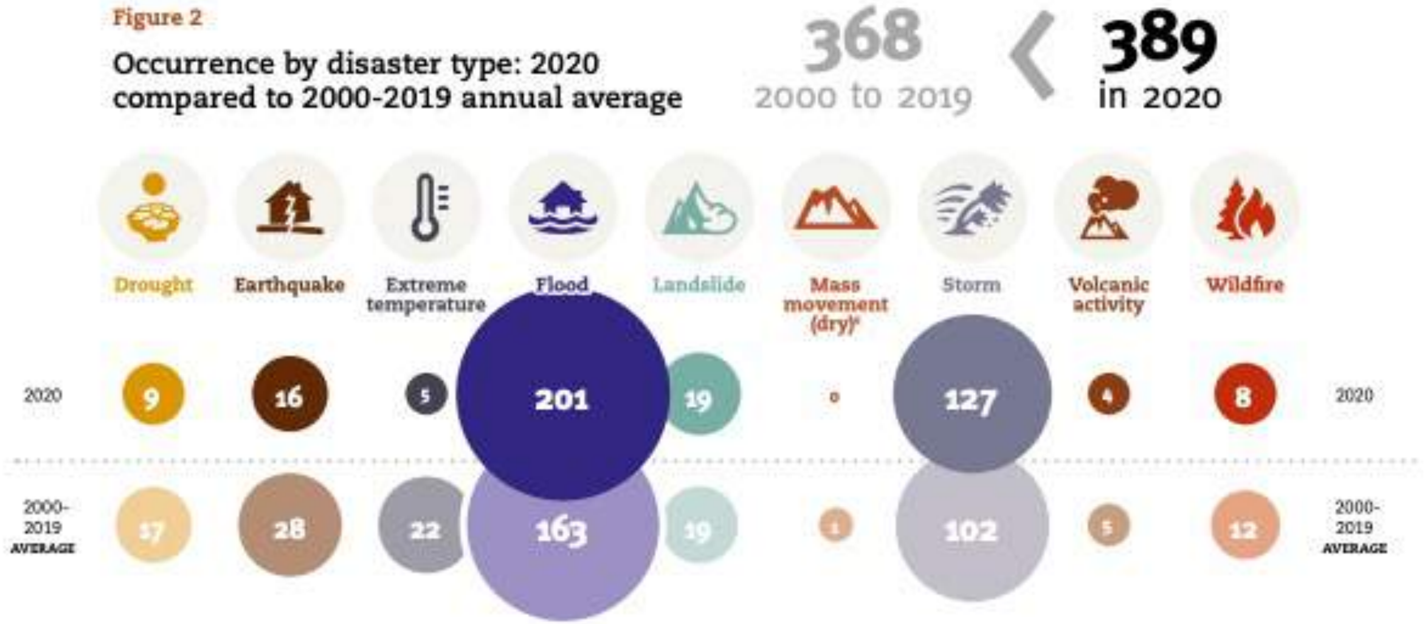
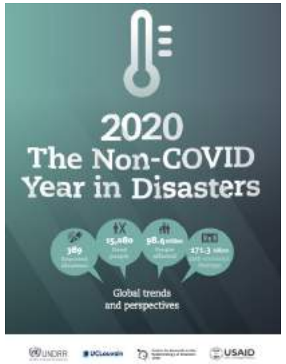
Not-only COVID

Most notable features:

- Floods events across East Africa, South Asia and China
- A record year of in the number of storms in the Americas
- A series of storms in quick succession to strike South-East Asia
- Summer heatwaves across Europe







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From EM-DAT databased, CRED, UClouvain

CLIMATE CHANGE IMPACTS ON THE ENERGY SECTOR

- The electricity system is witnessing increasing pressure from climate change.
- The effect even get worsen accompanies with power outage.
- A climate-resilient electricity system, which has the ability to anticipate, absorb, accommodate and recover from adverse climate impacts, brings multiple benefits to electricity security.

Climate impact	Generation	Transmission and distribution	Demand
Rising global temperatures	• Efficiency • 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

Overview of main potential impacts on the electricity system due to climate change. Source: IEA, climate resilience, 2021

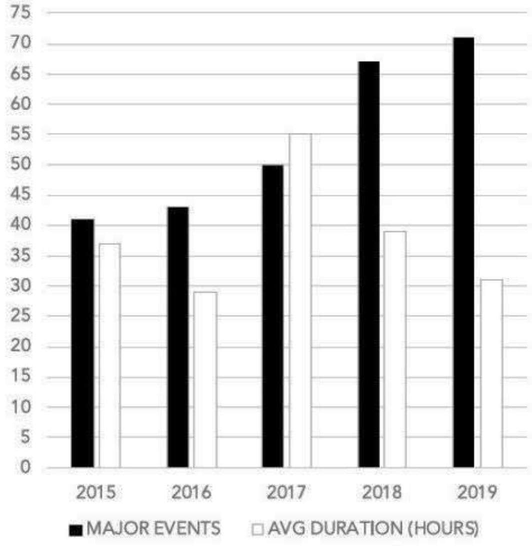


Figure 1. Total number of major electrical grid failure events and average event duration (hours) for U.S. power utilities (2015–2019).[4]

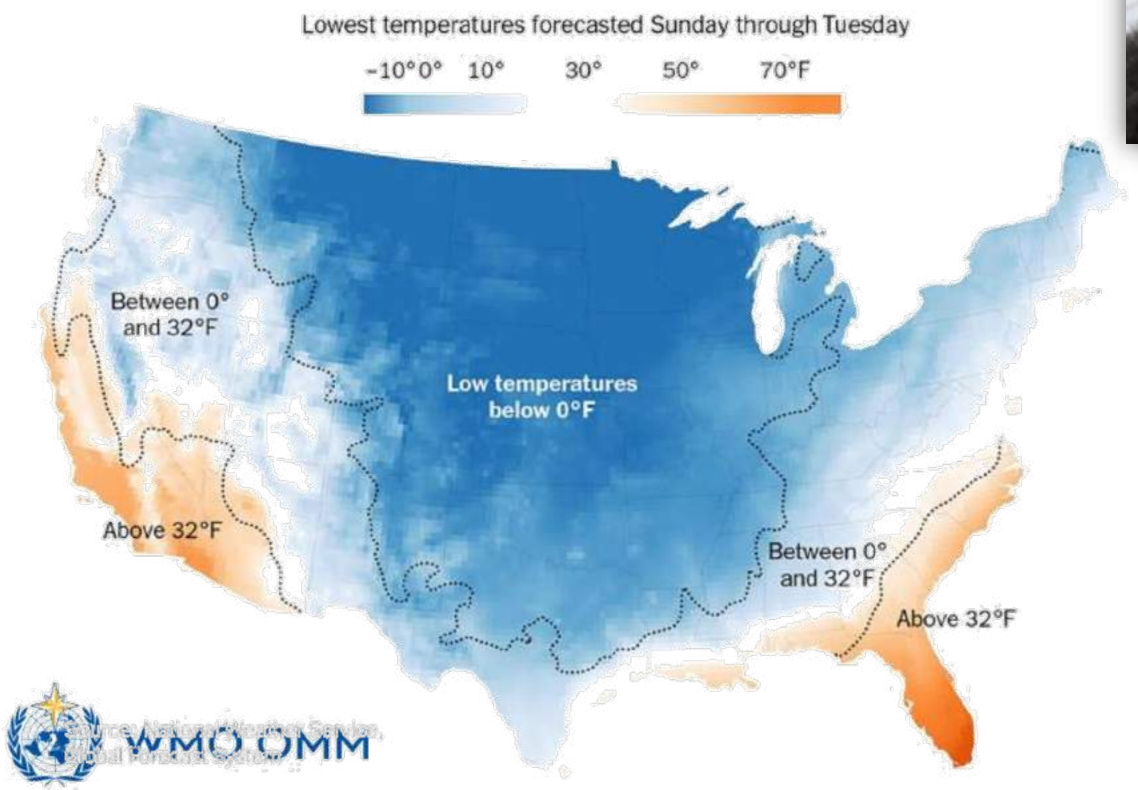
Brian Stone et al. (2021), Compound Climate and Infrastructure Events: How Electrical Grid Failure Alters Heat Wave Risk, Environ. Sci. Technol. 2021, 55, 6957−6964, Doi: 10.1021/acs.est.1c00024

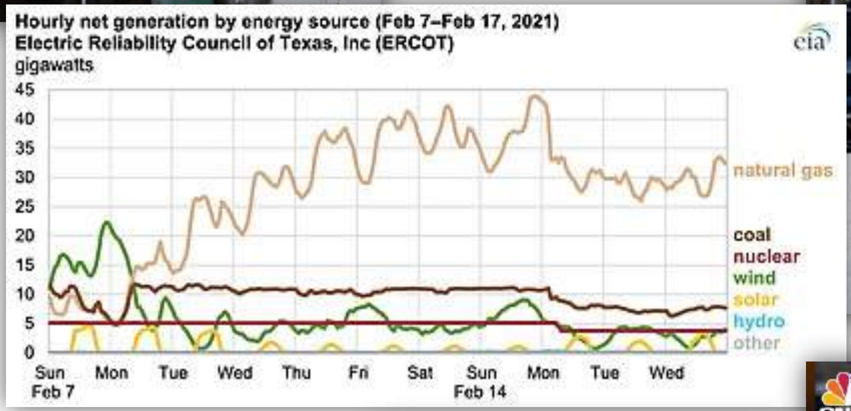
Climate Variable	Physical Components	Key Impacts	Adaptation Options
• Precipitation • Changed river flows • Higher air temperature	• Cooling system • Turbine/ generator • Spent fuel storage	• Insufficient cooling water (drought, temperature, competing uses) particularly for inland plants • Decreased generation efficiency (temperature rise) for inland plants • Loss of on-site power, leading to severe interruptions to safety and operations for inland and coastal plants	• Formulate long-term strategies to respond to climate-related disruptions. • Install additional cooling towers and modify cooling water inlets at coastal locations. • Use dry or hybrid cooling systems with lower water requirements. • Develop more efficient pumps and heat exchangers.
• Sea level rise • Floods • Extreme or multiple events	• Cooling system • Turbine/ generator • Spent fuel storage • Emission control system	• Flooding from heavy rainfall, storm surges, or sea level rise • Catastrophic failure with radioactive leaks and widespread evacuations of population, particularly for coastal locations	• Require more stringent safety investments. • Incorporate gradual sea level rise, increased storm events, and associated tidal surges into design criteria. • Formulate long-term strategies to respond to climate-related disruptions.

Key climate change impacts and adaptation- Nuclear power

COLD WAVE WITH POWER OUTAGE

- **Temperatures fell as much as 14-28 °C below average as far south as the Gulf coast.**
- **over 5 million people in Texas were without power, some for more than 3 days.**





HEAT WAVE WITH POWER OUTAGE

Study applied to three large U.S. cities, combined blackout and heat wave would expose at least two-thirds of residents in those cities to heat exhaustion or heat stroke.

Brian Stone et al. (2021), Compound Climate and Infrastructure Events: How Electrical Grid Failure Alters Heat Wave Risk, Environ. Sci. Technol. 2021, 55, 6957−6964, Doi: 10.1021/acs.est.1c00024

HEAT INDEX CLASS	EXPOSURE RISK
NO RISK (< 27°C)	NONE
CAUTION (27 - 32°C)	FATIGUE
EXTREME CAUTION (32 - 41°C)	HEAT EXHAUSTION POSSIBLE, HEAT STROKE POSSIBLE
DANGER (41 - 54°C)	HEAT EXHAUSTION LIKELY, HEAT STROKE POSSIBLE
EXTREME DANGER (> 54°C)	HEAT STROKE LIKELY

Figure 2. U.S. National Weather Service heat index classification framework.[33]

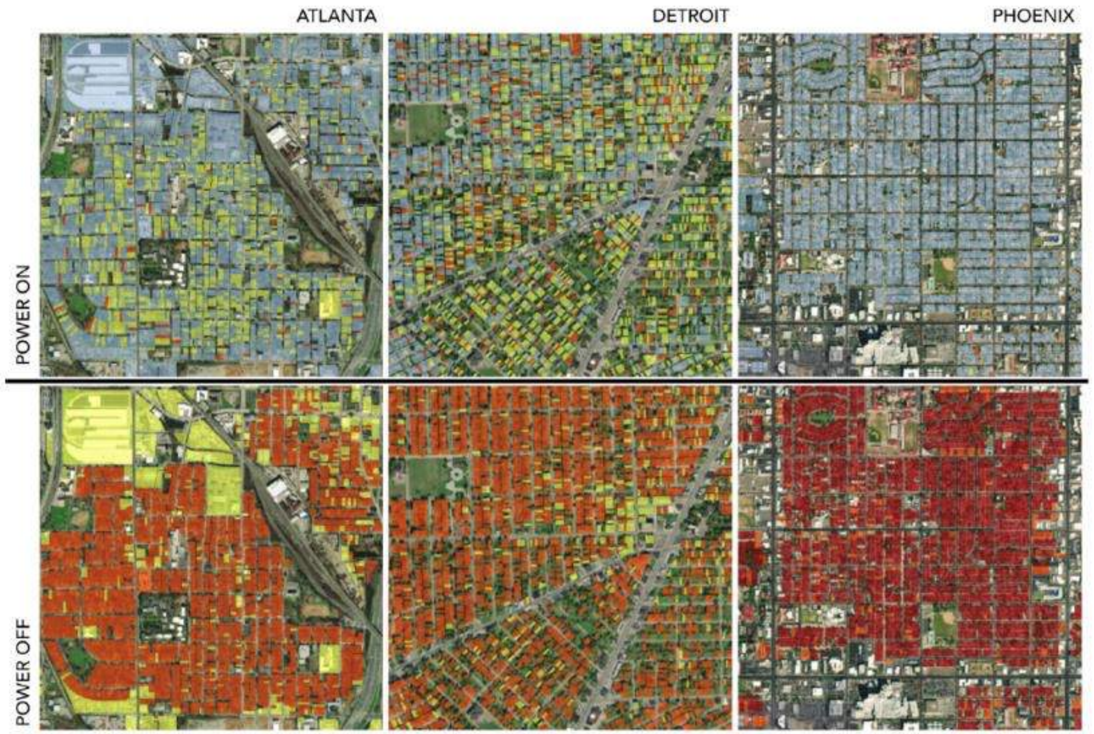


Figure 3. Example building-interior heat index classes for 5-day average maximum heat index values under historic heat wave conditions and in response to normal electrical grid operation (power on) and electrical grid failure scenarios (power off). Heat index classes as follows: No Risk (blue), Caution (yellow), Extreme Caution (orange), Danger (red).

Figure 4. Boxplots for 5-day average maximum building-interior heat index values (°C) during a concurrent heat wave and electrical grid failure event. Mean values denoted with "X" and outliers included.

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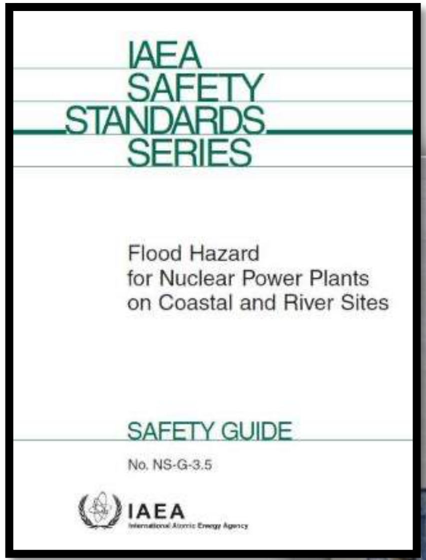
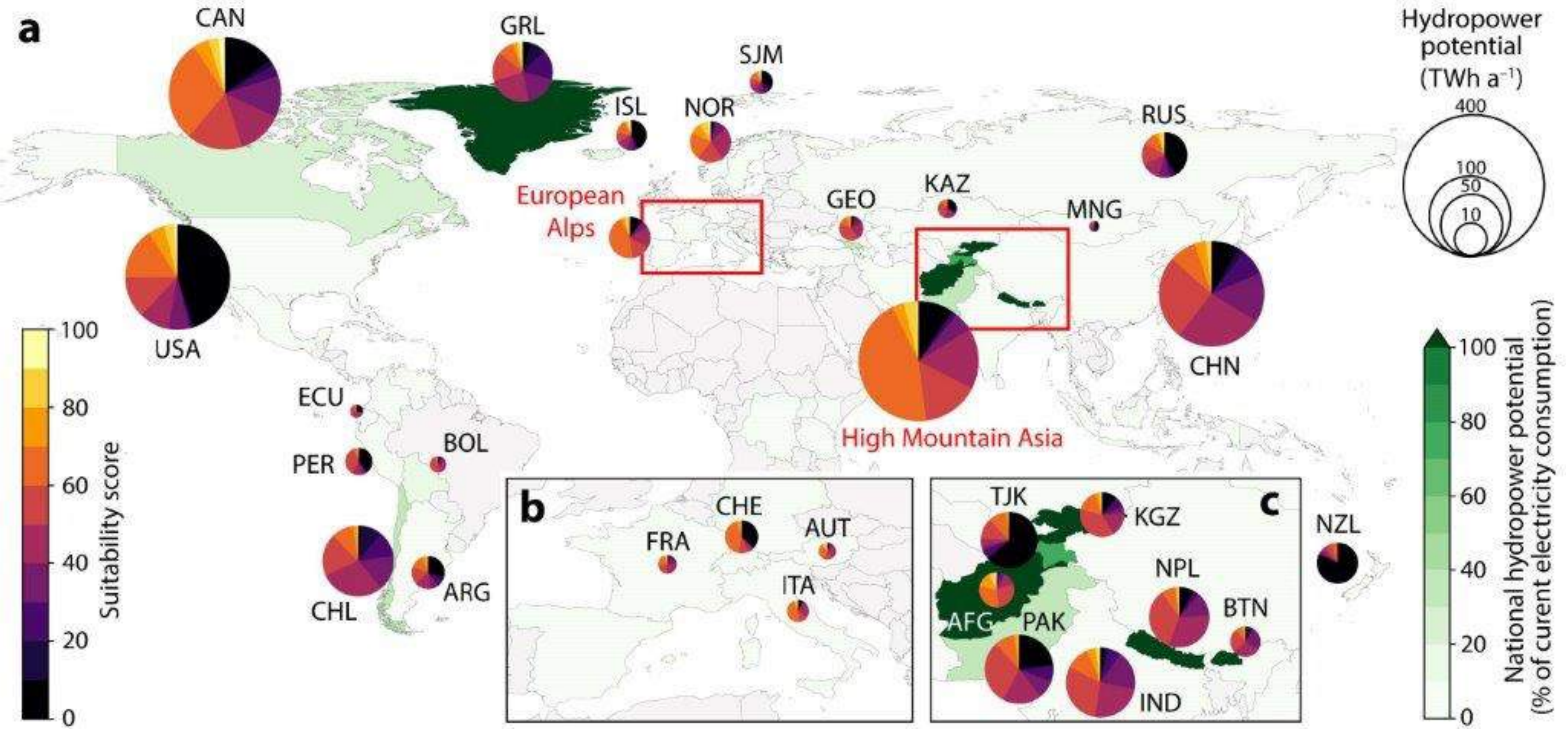
FLOODING



SEA-LEVEL RISE

Florida's Turkey Point nuclear plant, which sits right at sea level, will be threatened in the coming decades. Photo: Florida Power & Light

Hydropower potential from deglacierizing areas



Farinotti et al, 2021

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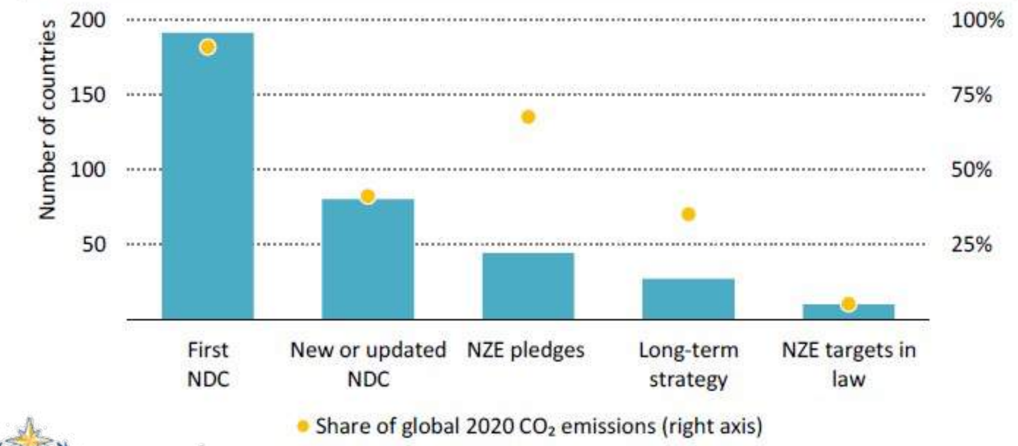
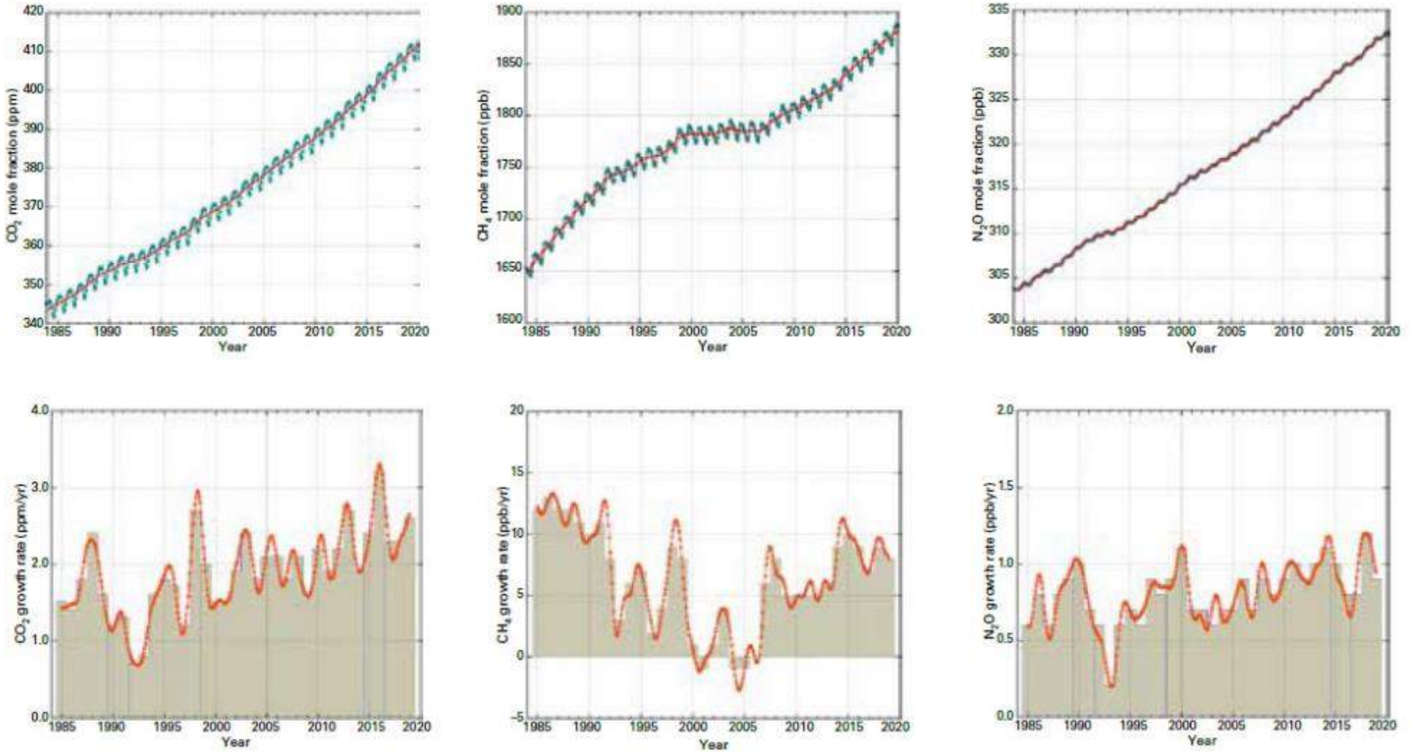
Green House Gases (GHG)

- For greenhouse gases, pre-industrial concentrations estimated from ice cores for the year 1750 are used as baselines.
- Limiting warming to 1.5°C implies reaching net zero CO2 emissions globally around 2050 and concurrent deep educations in emissions of non-CO2 forcers, particularly methane (IPCC Special Report on Global Warming of 1.5 °C)

Figure 1.1 ▷ Number of countries with NDCs, long-term strategies and net zero pledges, and their shares of 2020 global CO_2 emissions



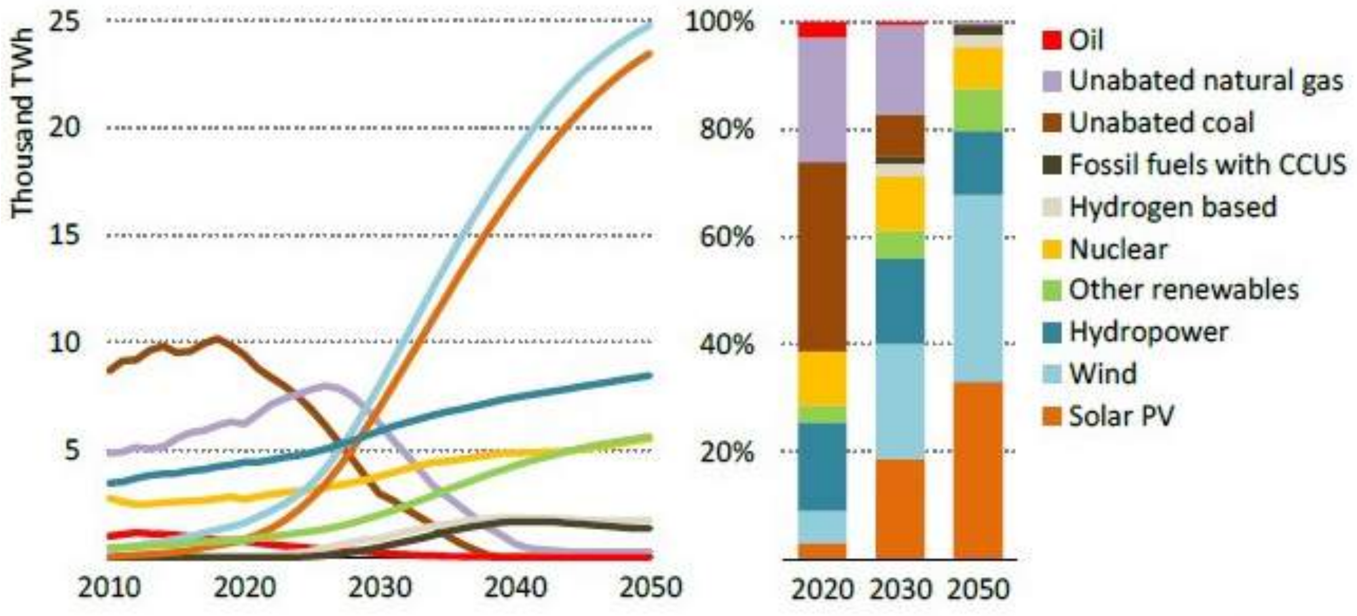
Source: IAE, Net Zero by 2050 A Roadmap for the Global Energy Sector



Source: WMO Global Atmosphere Watch

NET ZERO EMISSIONS from ENERGY SECTOR

- Rapid scaling up of solar and wind by 2030, annual addition of four-times the record levels set in 2020.
- Governments face several key decisions in the electricity sector if they are to follow the pathway to net-zero emissions by 2050 envisioned in the NZE



Global electricity generation by source in the NZE, source: IAE

WMO CLIMATE SCIENCE BASIS FOR CLIMATE ACTION

Tools & data sources

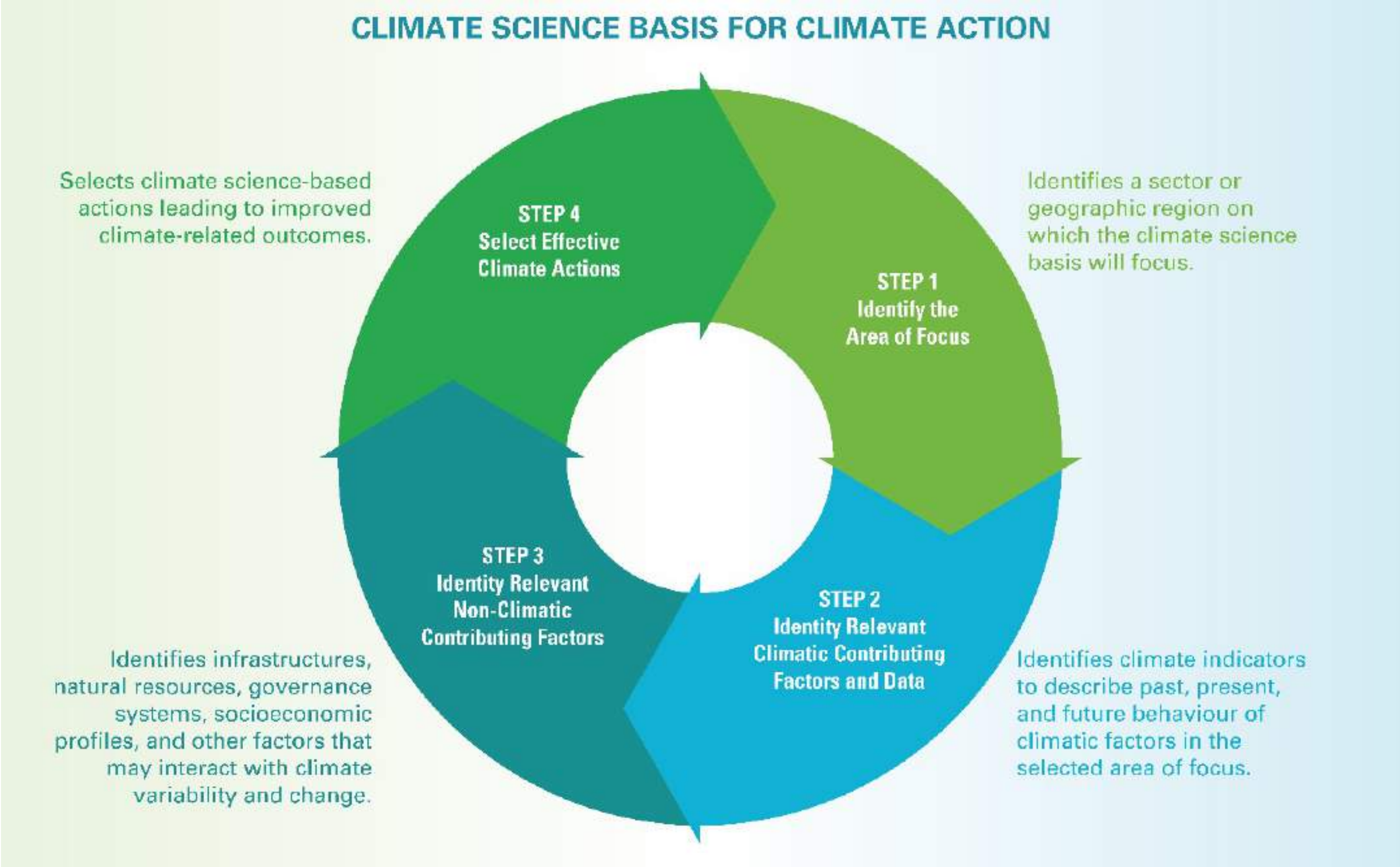
Climate Information Platform (CIP)

A web-based data access platform – providing access to CMIP and CORDEX projections and indicators worldwide.

Climpact

A software package to calculate over 70 climate indices from historical daily temperature and precipitation relevant for the energy sector as well as other climate-sensitive sectors.

www.climateinformation.org



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WMO CLIMATE SCIENCE BASIS FOR CLIMATE ACTION

Area of focus

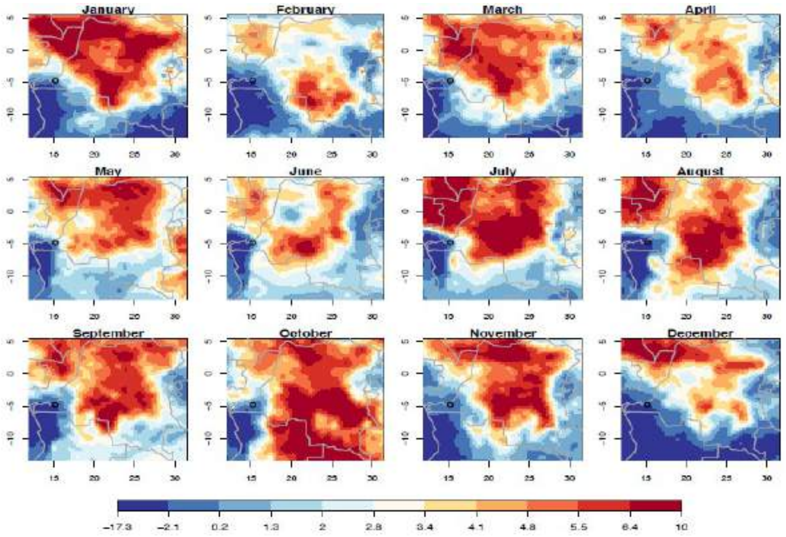
- Clean energy production is supported by natural elements such as wind, sun and sea waves as well as the resiliency of energy platforms

Non-climatic contributing factors

- Energy access and demand
- Transport systems
- Energy storage structures

Climatic contributing factors

- Solar irradiance and cloud properties
- Land cover
- Wind speed and direction
- Wave height
- Air temperature



Right-hand figure: In DRC, ERA5 re-analysis technique shows a trend of Solar Radiation based on the period 1979-2019. Solar radiation displays some interannual variability, of the order of 5-10%, which should to be an important consideration when planning solar power farms. The ERA5 temperature in Kinshasa has been increasing by a considerable amount, 0.3°C per decade, whereas annual wind speed has remained flat and at low values over the entire ca. 40-year record.

Evidence-based actions

- Appropriate renewable energy mix based on the energy potential
- Promotion of solar pumping in agriculture
- Micro grids of renewable energy

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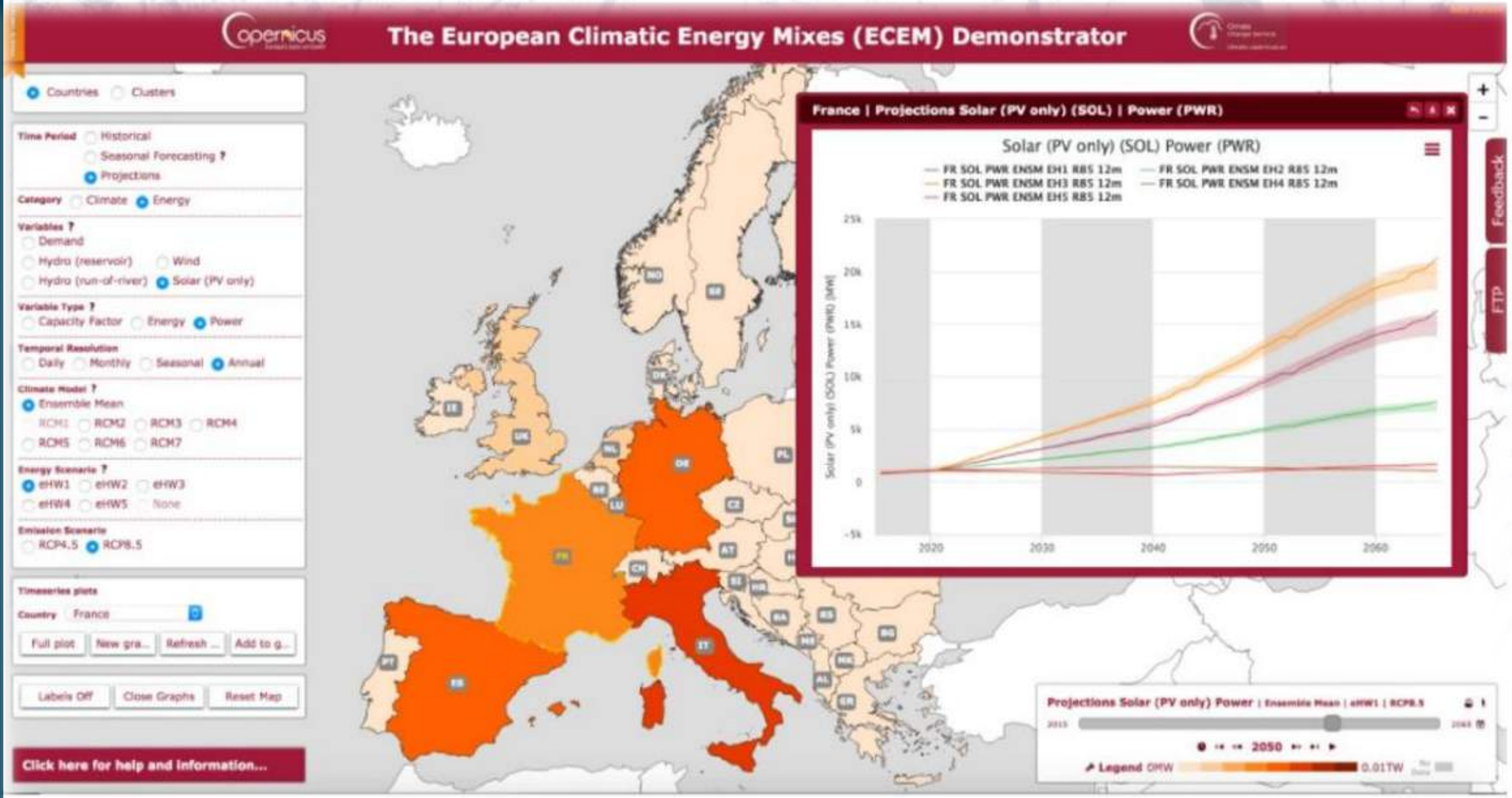
COPERNICUS OPERATIONAL SERVICE FOR THE ENERGY SECTOR

- Climate and Energy Indicators for Europe:
  - Air Temperature
  - Precipitation
  - Incoming solar radiation
  - Wind speed at 10m and 100m
  - Mean sea-level air pressure
  - Electricity demand
  - Wind, solar, hydro- power
- Historical (1979-present)
- Seasonal forecast
- Climate projections (2005-2100)



An example of how solar power scenarios for the next decades are represented within the C3S Energy pre-operational Demonstrator.

https://climate.copernicus.eu/3rd-copernicus-climate-change-service-symposium-energy-sector

Climate services for the energy sector

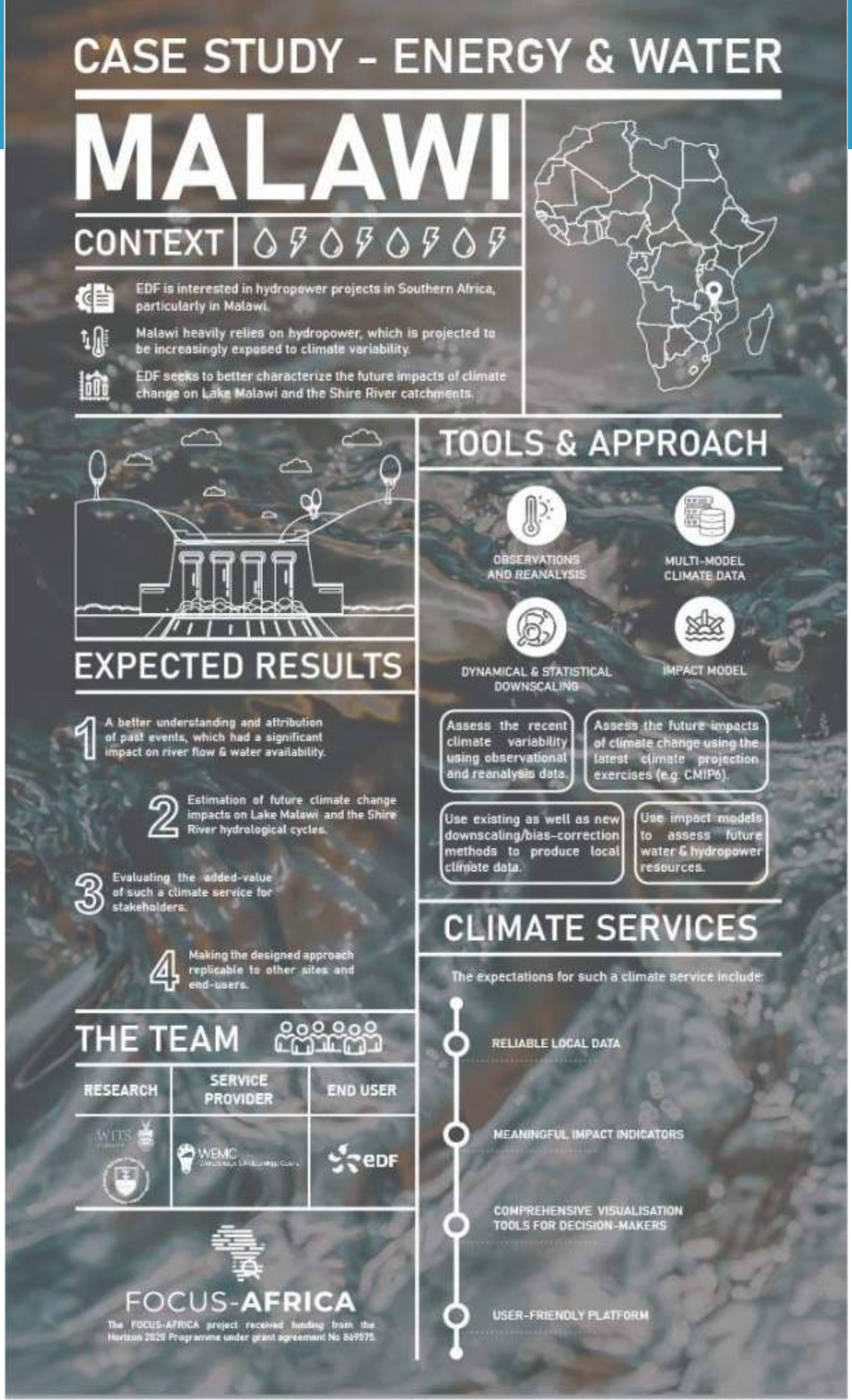
WMO STUDY GROUP ON INTEGRATED ENERGY SERVICES (SG-ENE)

ABOUT, MISSION

The SG-ENE is A group of technical experts from all over the world, working on a range of activities in the climate-energy sector.

PROJECTS:

FOCUS-Africa, ENANDES



WEBPAGE


THANK YOU!
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The growing need for climate resilient electricity systems

Craig Hart, Renewable Integration & Secure Electricity Unit, IEA

IAEA Webinar – “Factoring climate resilience into the design of clean power infrastructures”

8 June 2021

Climate change poses an increasing threat to electricity security

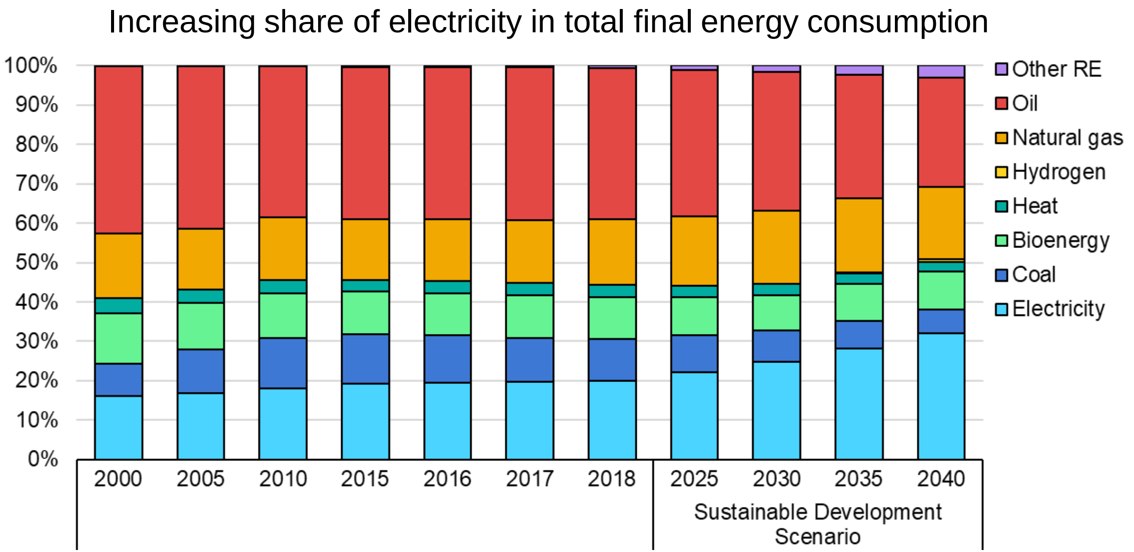
- The electricity system is witnessing increasing pressure from climate change

- **Climate change directly affects every segment of the electricity system**

Overview of main potential impacts on the electricity system due to climate change

Climate impact	Generation	Transmission and distribution	Demand
Rising global temperatures	• Efficiency • 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

The role of electricity security in modern power systems



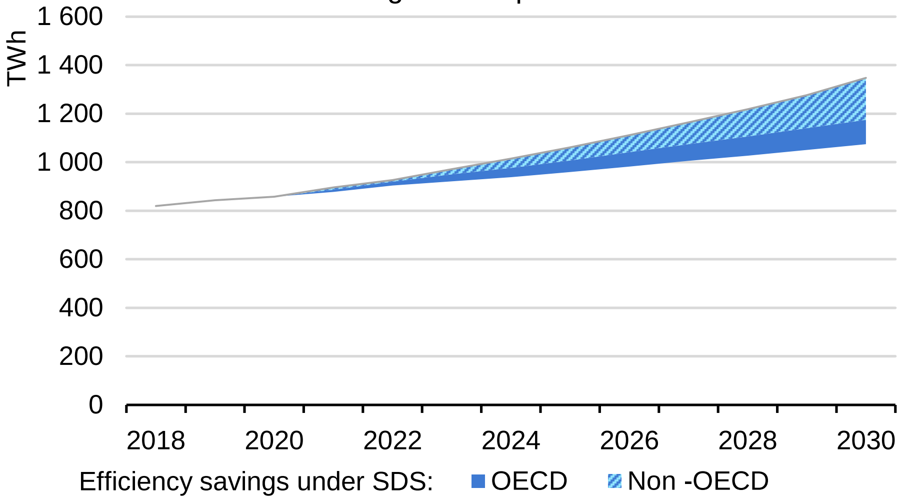
- Electricity security is the power system's capability to ensure uninterrupted availability of electricity by withstanding and recovering from disturbances and contingencies.
- Three main blocks: Adequacy, operational security, resilience
- Covered in a new IEA flagship report (Electricity Security 2021)

Impacts on electricity systems: Global warming

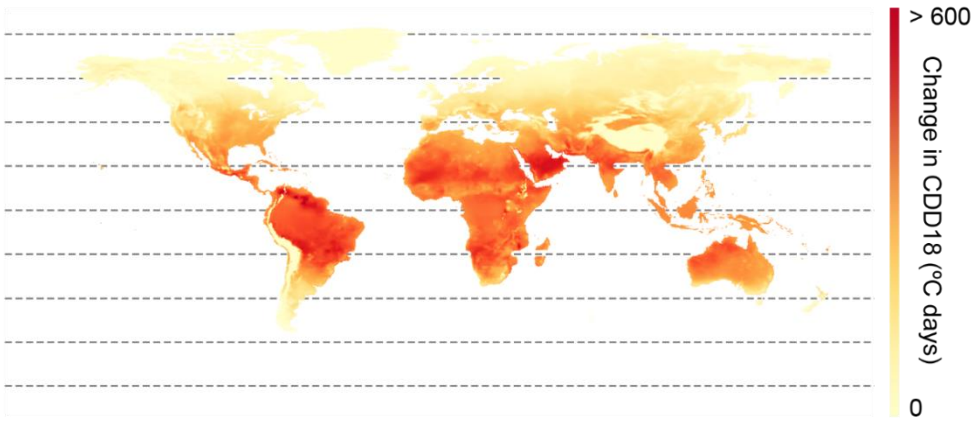
- Increasing temperatures will have an impact on the entire electricity value chain, e.g.:

- **Generation**: decreased efficiency of plants, **T&D**: thermal derating of lines, transformers and other components, **Demand:** increased cooling and refrigeration demand

Residential cooling consumption under STEPS & SDS



Change in CDDs (2019 – 2070) under RCP4.5



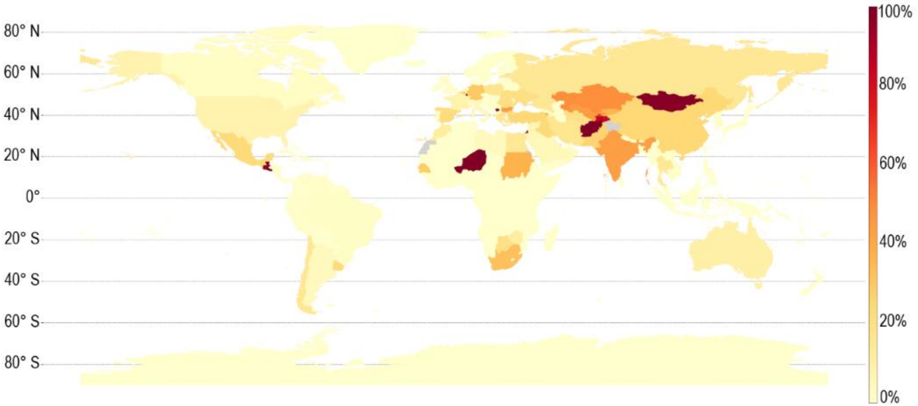
Impacts on electricity systems: Changing precipitation patterns

- Changing precipitation patterns will have an impact on water availability at both **seasonal** and **geographical** level

- Notable impact on hydropower and risks to security of supply from thermal plants

National share of thermal plants using freshwater cooling

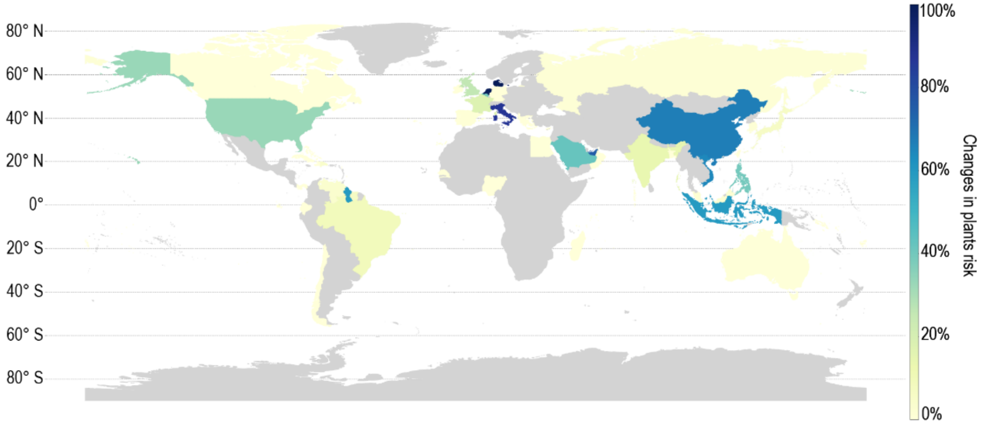
Share of existing thermal plants which use freshwater cooling and are in regions of high water stress



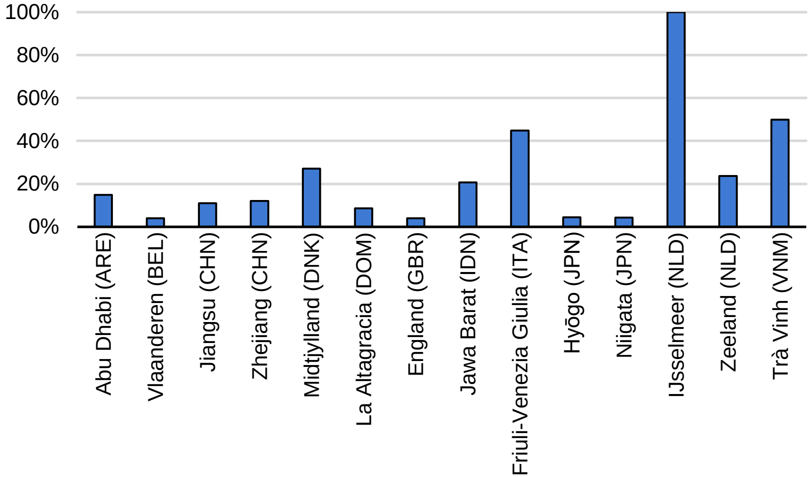
Impacts on electricity systems: Sea level rise

- This affects generation assets, transmission and distribution lines and substations located near the coast.
- Analysis shows the risk of sea level rise is highly disparate, affecting only countries with particular geographies (coastal, low-lying).

Share of plants at risk of 1-in-100 year floods (1.1m SLR)



Regions with >1% generation capacity newly at risk (1.1m SLR)

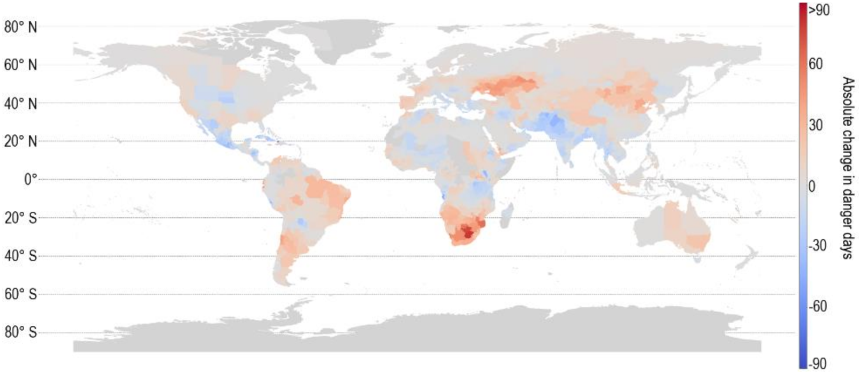


Impacts on electricity systems: Extreme weather events

- Extreme weather events provide **immediate shocks** to the system with **multiple impacts over large geographies**

- Impacts can be severe and span the entire electricity value chain, e.g.:
  - Cold spells, heatwaves and droughts (increased demand, generation availability)
  - Cyclones and floods (damaged T&D equipment)
  - Wildfires (damaged T&D equipment, multiple simultaneous faults, de-energised lines)

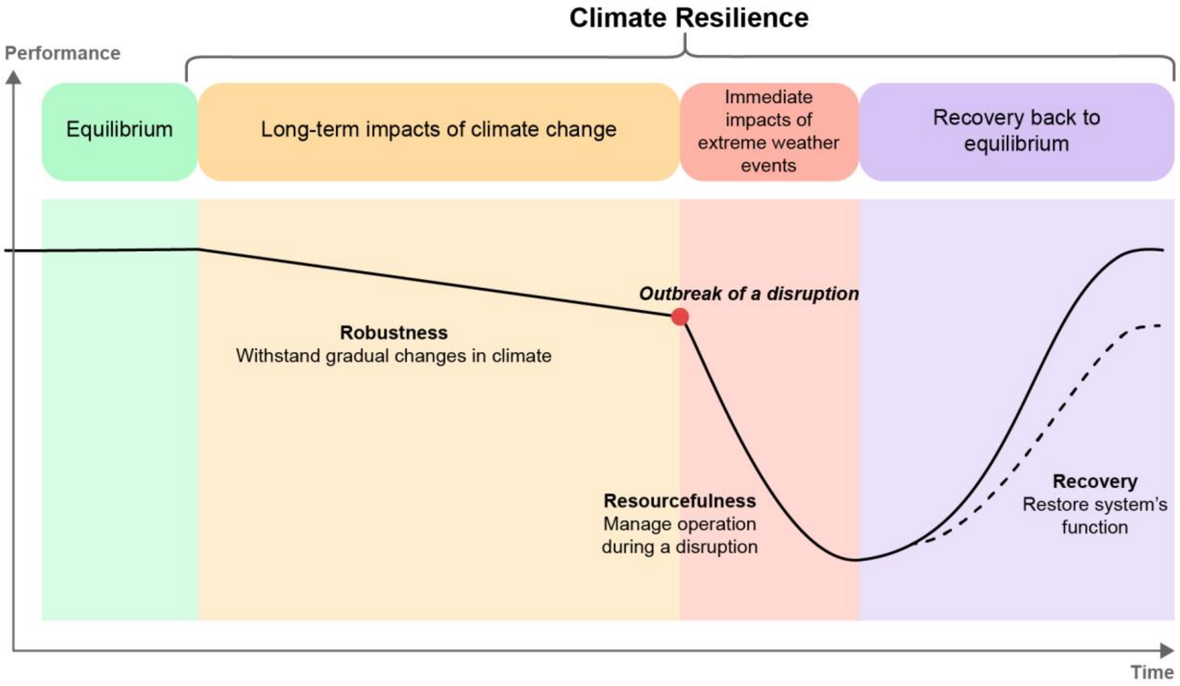
Absolute change in the distribution network-weighted average of fire danger days by subnational region from 1999-2004 to 2015-2019



Share of distribution networks at very high risk (1-in-50 years) of destructive cyclone winds

Conceptual framework for climate resilience

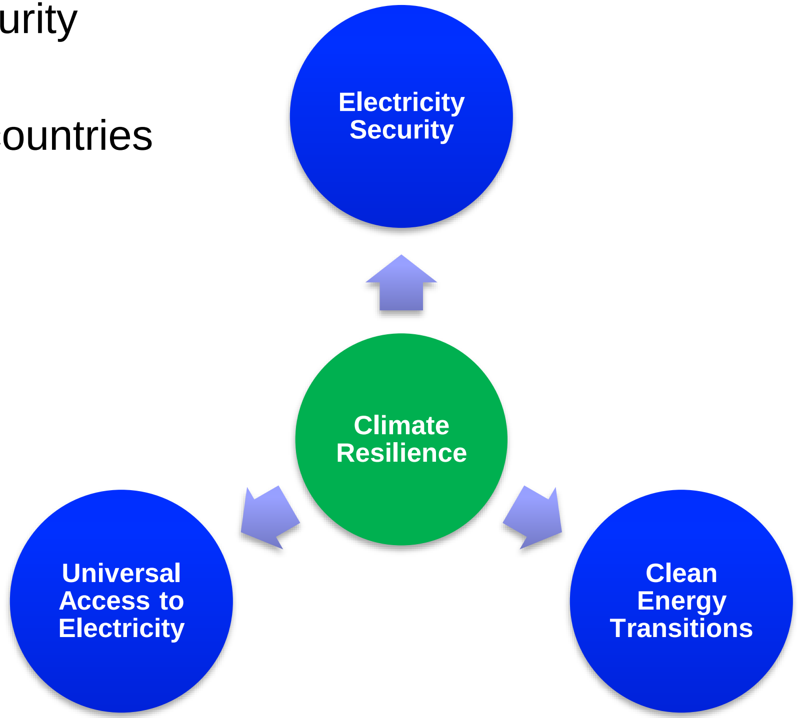
Conceptual framework for climate resilience of the electricity system



Climate resilience is the ability to anticipate, absorb, accommodate and recover from adverse climate impacts.

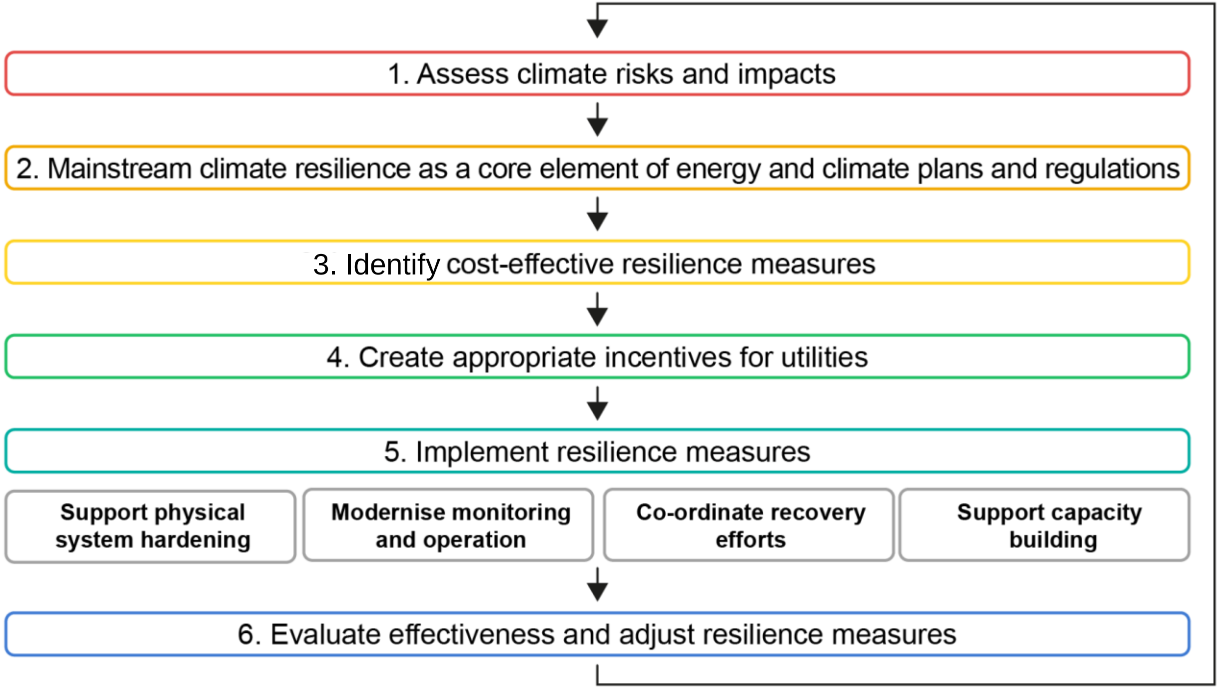
Multiple benefits of climate resilience

- Provide a cost-effective solution for electricity security
- Enable universal electricity access in vulnerable countries
- Support clean energy transitions



Measures for climate resilience

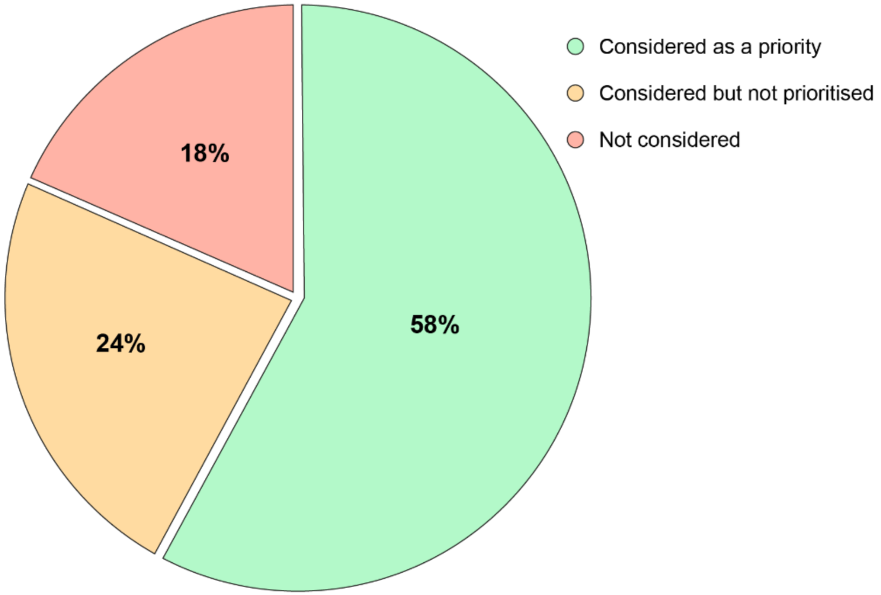
Sequential application of measures for climate resilience



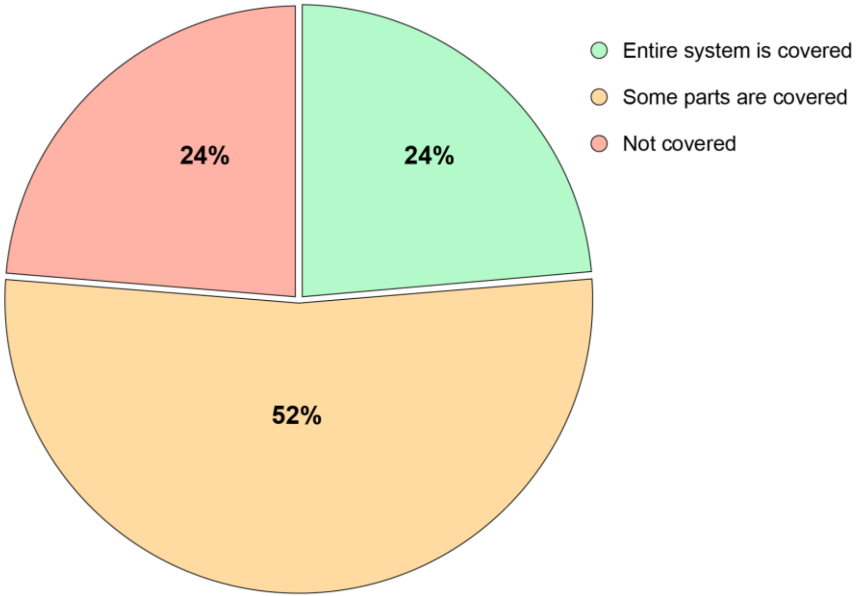
Effective policy measures and co-ordinated action among key actors can build up climate resilience.

Climate resilience as a core element of energy and climate plans

Energy sector in national adaptation strategies and plans



Coverage of climate resilience of electricity systems



National plans and strategies that explicitly include climate resilience as a core element send a strong signal to utilities and investors to strengthen the resilience of electricity systems.

The IEA's participation in this event was made possible through the Clean Energy Transitions in Emerging Economies programme has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952363.

Integrated Climate Resilience for a Decarbonized Future

EPRI research approach

Delavane Diaz, Principal Project Manager
EPRI Energy Systems and Climate Analysis

IAEA Webinar
Factoring climate resilience into the design of clean power infrastructures
June 8, 2021

Motivation: Extreme weather and climate resiliency affect the electric system via multiple pathways and at various scales

	Vulnerability	Driver	Risk
Supply and Distribution	Thermoelectric units	air temperature	Reduced efficiency of combustion
	Water-cooled units	water temperature	Reduced cooling efficiency, reduced availability (temp of intake and discharge, water permit violations)
	Hydropower	precipitation, snowmelt, runoff	Reduced hydropower resource availability
	Power plants near water	sea level rise, precipitation	Flood risk in low-lying coastal and riverine areas
	Wind and solar	wind speed, temperature, clouds	Availability / predictability of renewable power
	T&D lines	air temperature	Line ratings, efficiency, sagging lines
	Utility assets	extreme weather, storms	Power outages, infrastructure damage
Demand	Total consumption	air temperature, extreme weather	Changes in HDDs / CDDs Changes in demand shapes and regional patterns
	Peak demand	air temp, humidity, extreme weather	Increase in summer peak load, power outages

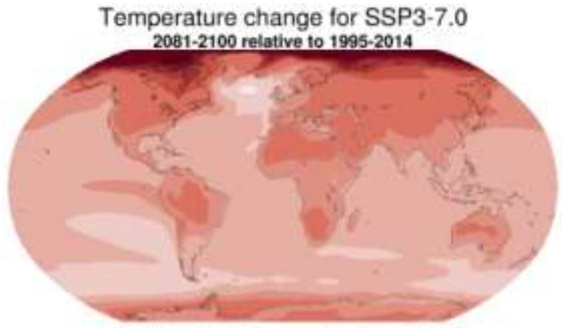
Adapted from NYSERDA (2011)

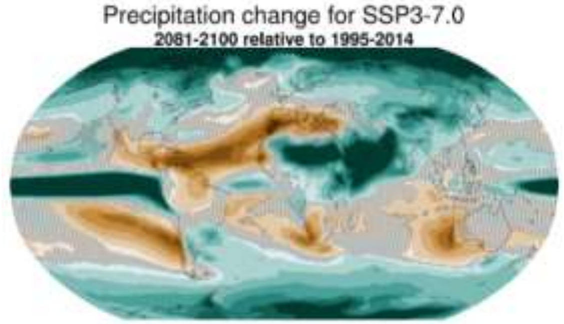
What are the potential costs of these impacts?

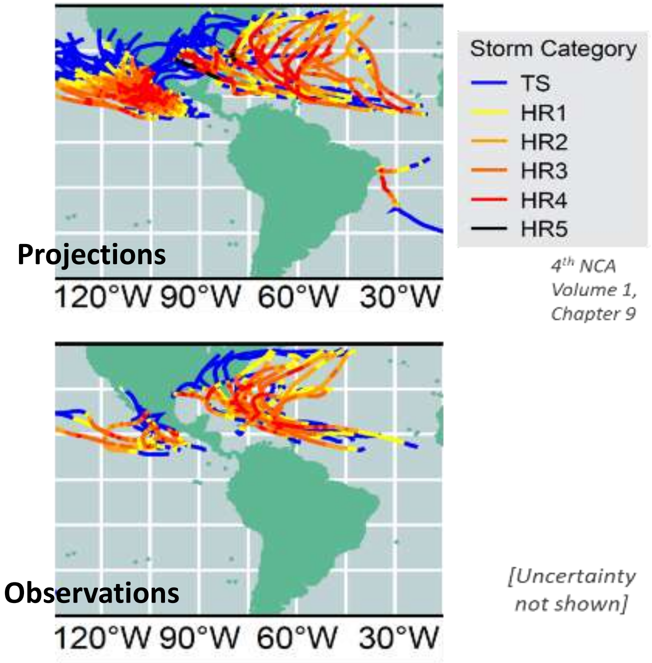
What is the benefit of proactive adaptation planning?

EPRI's climate resilience research is founded on assessing both the hazard and the consequence

Future climate changes are committed, extreme weather events are expected: More extreme heat, heavy precipitation, intense storms



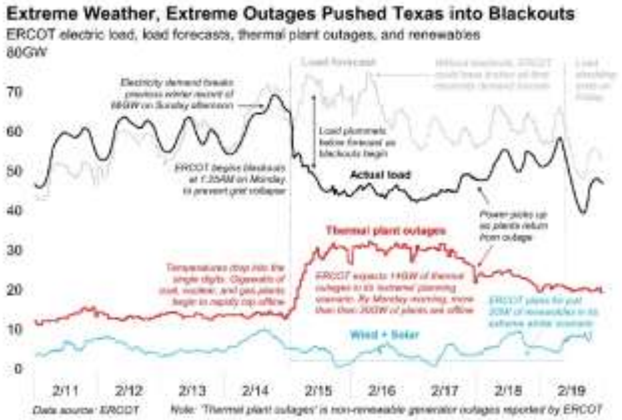




4th NCA Volume 1, Chapter 9

[Uncertainty not shown]

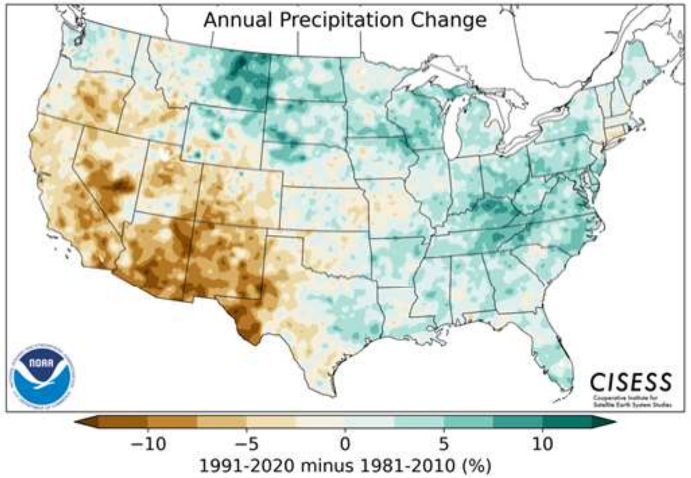
EPRI research exploring climate hazards: Evaluate electrical consequence and develop adaptation strategies and responses



Figures: Tebaldi et al (2021), NCA4 (2018)

ERCOT figure source: Brian Bartholomew, energy analyst, https://twitter.com/BPBartholomew

EPRI's approach to systematically examining potential climate impacts and responses for utility operations and planning



Relevant Physical Climate Variables

- Identification of climate variables
- Trends and projections
- State of science

Energy System Relevance

- Components affected
- System effects (e.g., damage, outages, performance, siting)

Potential Responses

- Potential risk mitigation options (i.e., potential adaptation strategies)

Research Priorities

- Energy technologies
- System operations
- Climate data needs
- Scenarios

Source: https://www.ncei.noaa.gov/products/us-climate-normals

Identifying considerations for electric sector resilience to climate impacts

EPRI's US-REGEN integrated electric sector and end-use model can be used for long-term system-level climate assessment

US-REGEN Climate Inputs: temperature, precipitation, water availability, humidity*

Shifted distribution of gridded hourly air temperature
Increased cooling degree days
Decreased heating degree days

Decreased efficiency of thermal generators
Changes in seasonal water availability for hydro generators
Reduced transmission line carrying capacity

US-REGEN Energy Use

- Climate zones and hourly temperature
- Building types and equipment stock
- Household and vehicle characteristics
- Industrial mix
- End-use technology decisions

SYNCHRONIZED

Hourly Load, Renewables & Prices

Model Outputs:

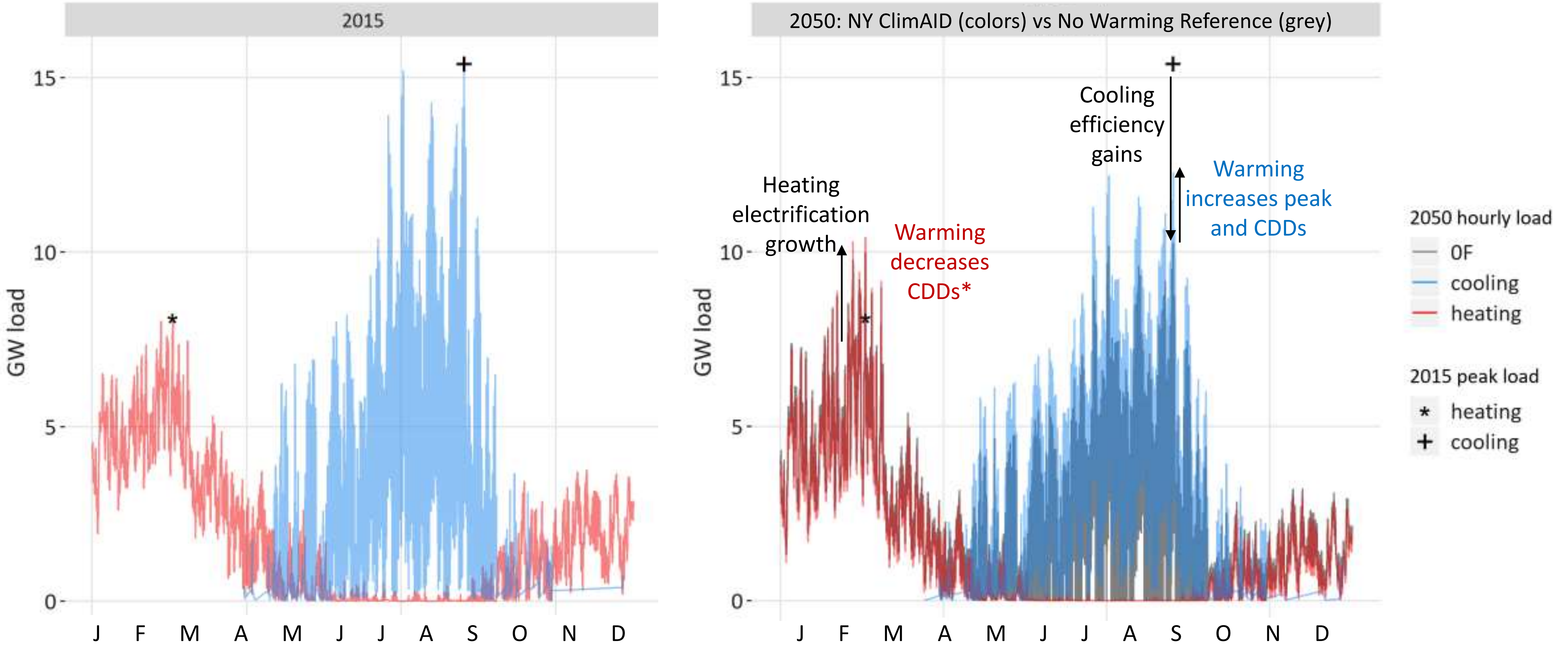
- Least cost generation, capacity, and end-use mix
- Emissions and environmental outcomes

US-REGEN Electric Sector

- Investment and dispatch
- Transmission and interchange
- Integration of variable renewables
- Energy and capacity requirements
- Regional policies and constraints

**humidity under development*

Electrification + efficiency drive evolution of electricity demand in 0°F reference case – climate warming has an offsetting effect



*Warming increases 2050 peak – compound impact of less extreme cold plus additional electric heat pumps requiring back-up electric resistance heating in coldest hours

Operational models for transmission resiliency can be used to assess potential extreme events

Step 1: Map Climate Impacts Geographically to Utility Assets

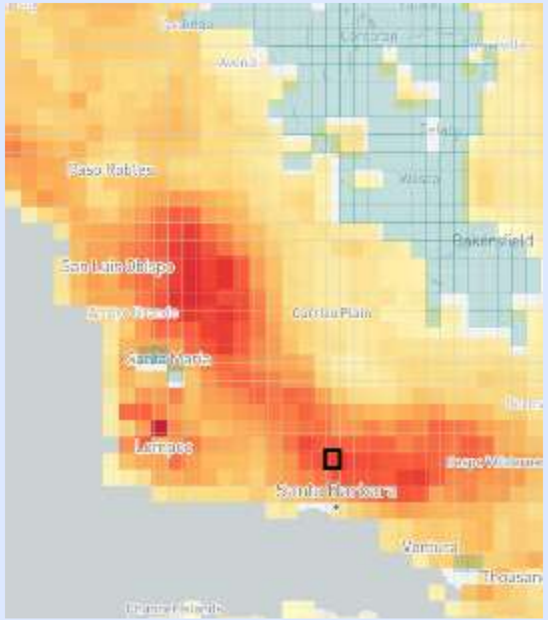
Apply detailed climate datasets to assess location-specific variables of interest

Step 2: Identify Equipment Impacts and System Contingencies

Electrical consequences of extreme events used to define contingencies

Step 3: Assess Grid Risk and Identify New Transmission to Mitigate Risk

Use resiliency risk analysis to assess risk with and without upgrades



Source: Cal-Adapt, RCP8.5 multimodel mean

Wildfire Example North of Santa Barbara, CA

Timeframe: 2010 – 2040

- Projected Increase in Area Burned = 21%
- Slight Increase in Fire Prob = 23% to 25%

```
CONTINGENCY '2 STATION WILDFIRE OUTAGE'
DISCONNECT BUS FROM BUS 12345
DISCONNECT BUS FROM BUS 23456
END
CONTINGENCY '3 STATION WILDFIRE OUTAGE'
DISCONNECT BUS FROM BUS 34567
DISCONNECT BUS FROM BUS 45678
DISCONNECT BUS FROM BUS 57890
END
END
```

Define extreme event contingencies based on electrical consequences of projected climate extremes

Resilient System Investment Framework (RSIF)

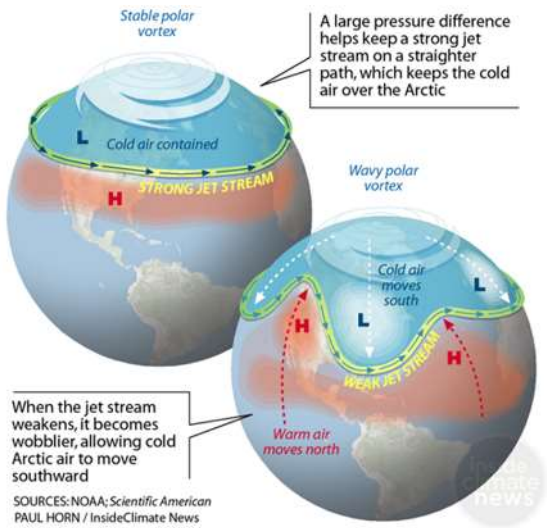
Initiating HILF Events

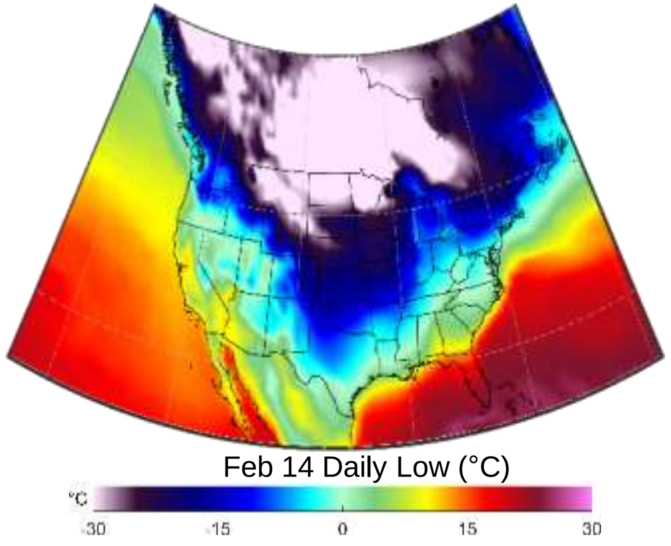
Possible Network Topologies

Probabilistic Cascading and Risk Assessment

Cost/Benefit Assessment Across Alternatives

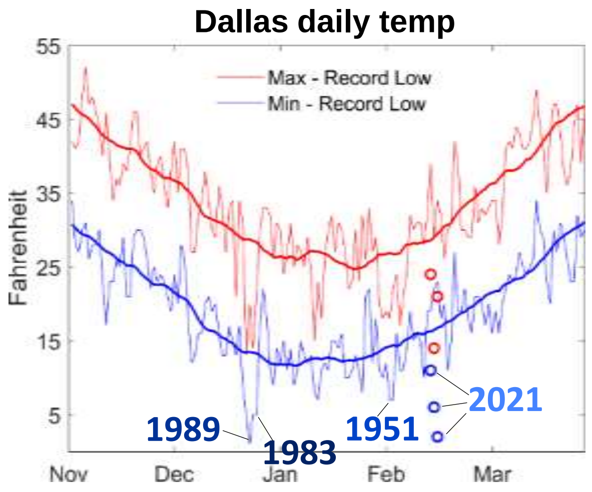
February polar vortex highlights resource adequacy research needs

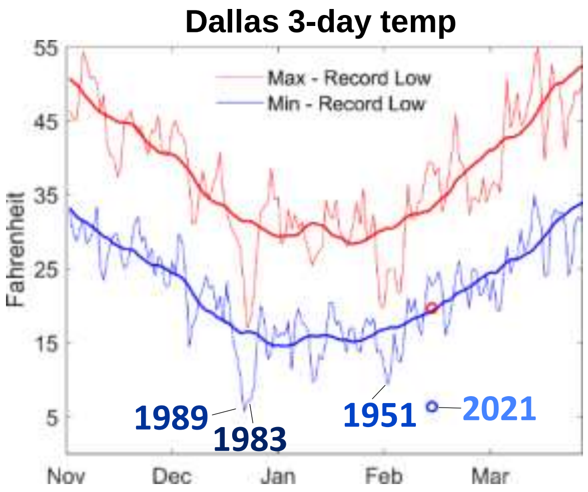


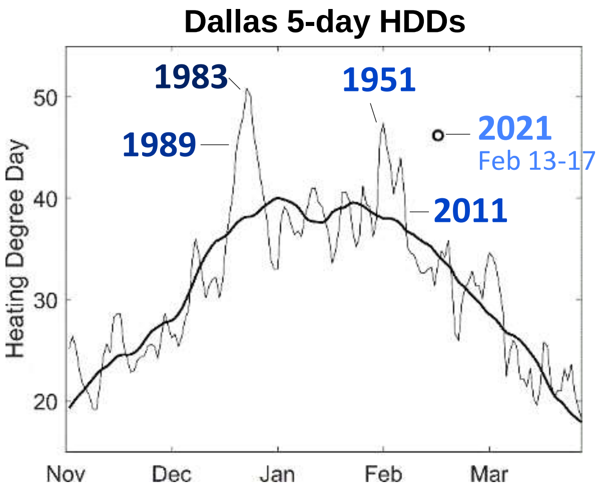


Figures: Erik Smith, MRCC Dallas airport data 1950-2020

- Strong polar vortex keeps Arctic cold air contained; sudden stratospheric warming (SSW) can weaken circulation, enabling cold air outbreaks (CAOs) to southern latitudes
- February 2021 TX temperatures were extremely cold, but spatial and temporal extent not outside historical record (e.g., 1951, 1983, 1989, 2011)



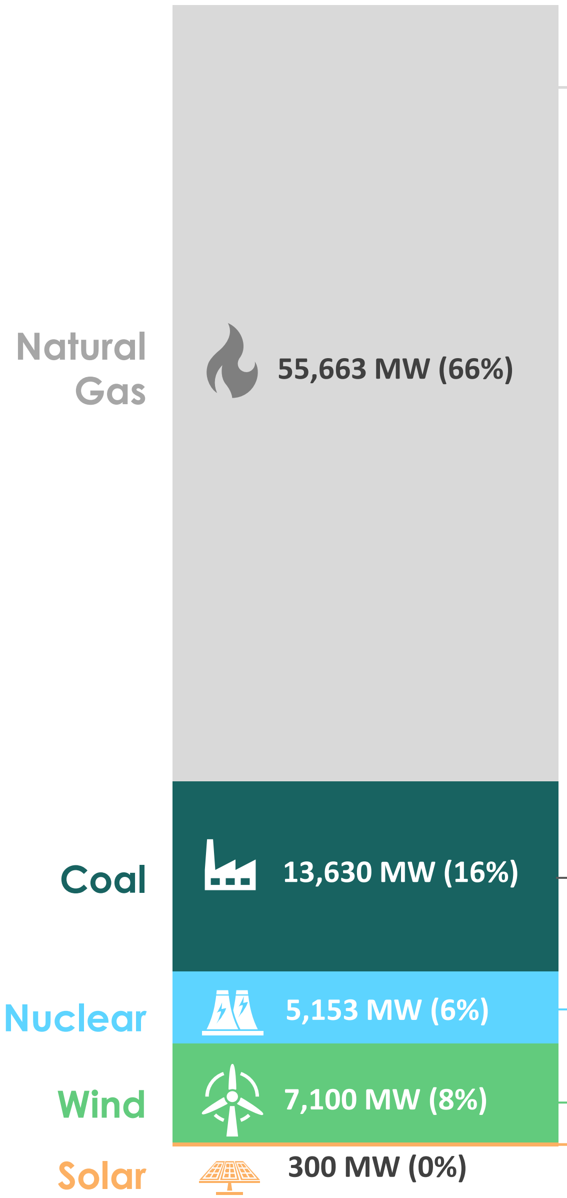


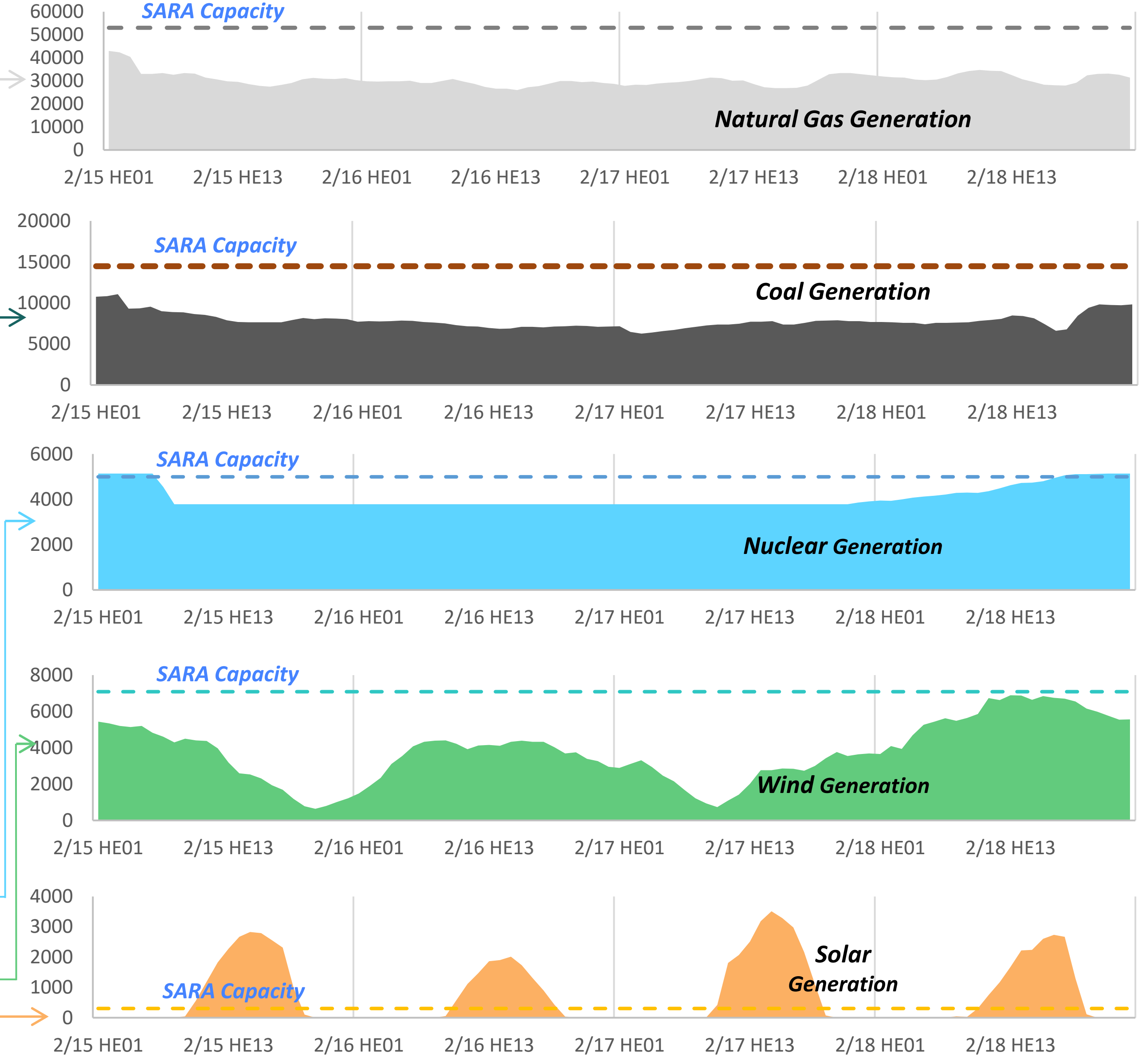


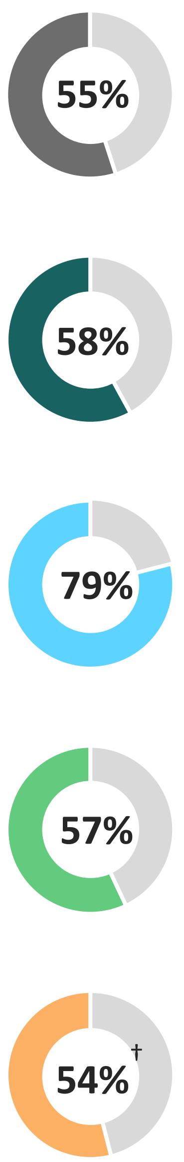
Historical profiles + understanding of climate changes needed to develop weather scenarios that inform resource adequacy and company planning

ERCOT Electricity Generation vs. Seasonal Expected Availability
Feb. 15-18

2021 Winter SARA	Seasonal Assessment of Resource Adequacy* (SARA) vs. Actual Generation	Performance vs. SARA







** ERCOT's Seasonal Assessment of Resource Adequacy (SARA) attributes an expected available capacity to each generation type, considering seasonal factors.*

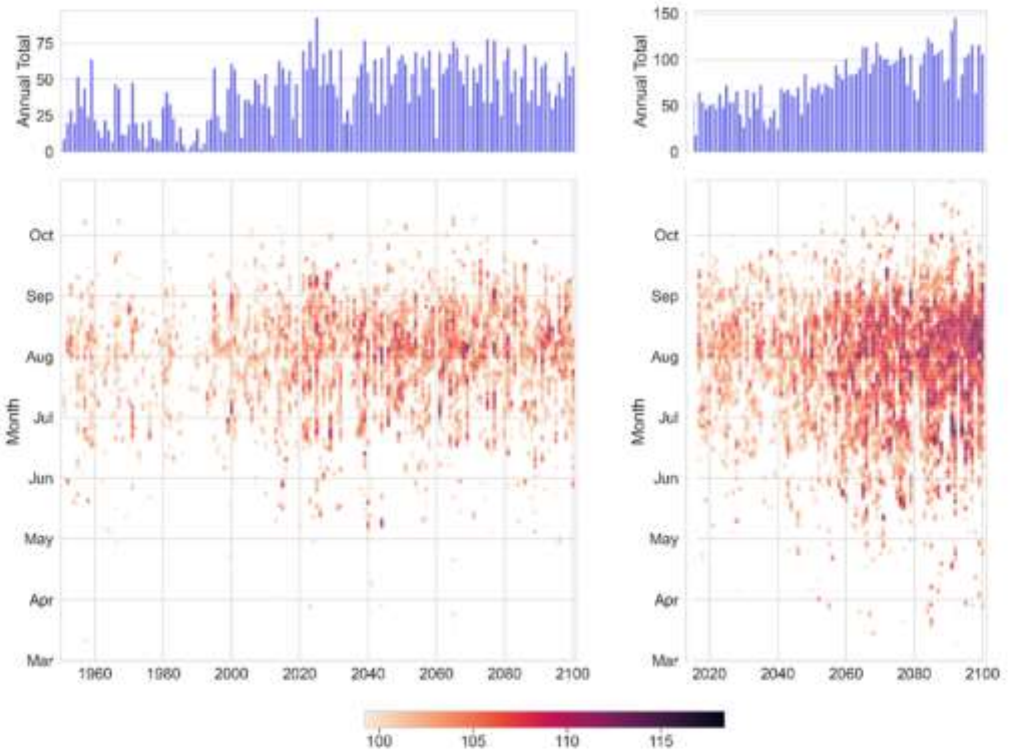
Data Sources:
Winter '21 SARA
Daily Balancing Authority Report

†During peak demand (18-23h)
Over all hours: 259%

Climate projections provide locationally-specific information that can provide insight into how climate trends are changing

- Figure shows **number of days per year where temperature exceeds 100°F** for an ensemble of CMIP6 climate models for two emissions scenarios
- Data shown for a grid cell in **north central Texas** but can be reproduced for other areas of the United States
- Data indicate not only an **increase in the number of extreme heat days annually**, but also an **extension in the occurrence** of these days into the shoulder seasons

Days over 100°F



Extreme heat threshold defined at 100°F. Data shown for a grid cell in north central Texas.

Climate change is expected to alter the statistical properties (frequency, magnitude, duration, and intensity) of extreme events that impact the power system as well as the chronic conditions under which it operates.

Electric Sector Resiliency is Required for a Clean Energy Future

2050: 2X Electricity Share of Final Energy

A greater portion of societal needs will be dependent on the reliable supply of electricity.

2050: >4X Renewables Capacity

The resource mix will have significantly different performance characteristics and the grid must adapt.

2050: The Unpredictable

Changing climate, technology, policy, and societal trends must be integrated into scenario planning.

Grid planning and operational practices must evolve.

The biggest challenge electric sector decarbonization and achieving net zero may be ensuring the resiliency of energy supply and the electric grid.

Together…Shaping the Future of Electricity

Impacts of climate change on the energy system

IAEA webinar, June 8th 2021

Thomas Unger

- Profu is an independent research and consulting company within energy, waste and transport systems analysis
- Established in 1987. Currently some 20 employees
- Offices in Mölndal and Stockholm

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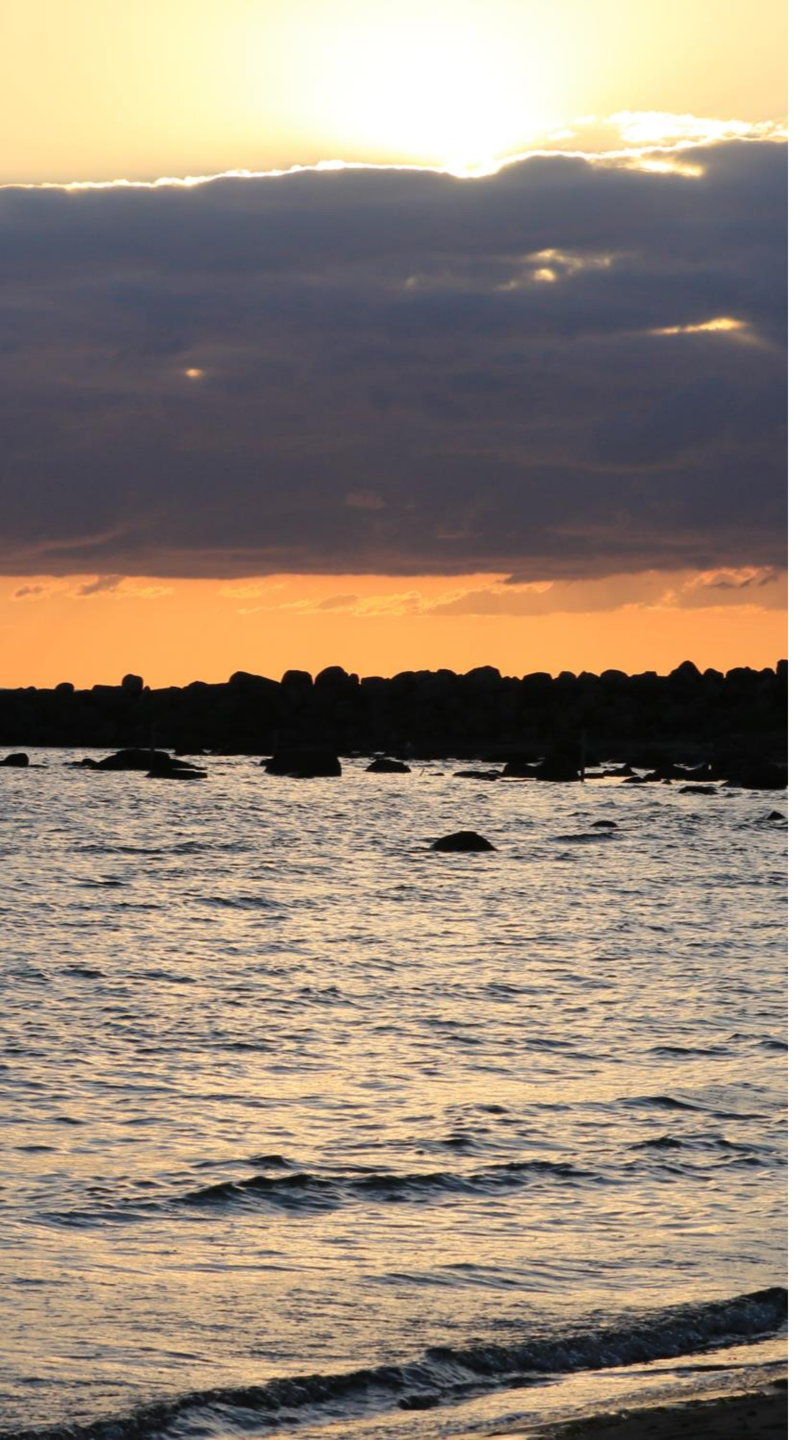

The research project: Impact of climate change on the energy system

- Research project during 2019-2021, (see https://energiforsk.se/program/klimatforandringarnas-konsekvenser-for-energisystemet/ for more info)
- Financed by energy sector and authorities in Sweden
- Assessing regional (Sweden) climate change impacts based primarily on climate model runs
- Assessing impacts on the overall energy system with special emphasis on key sources of energy (biomass, hydro power, wind power, nuclear power, district heating/cooling, electricity grids)

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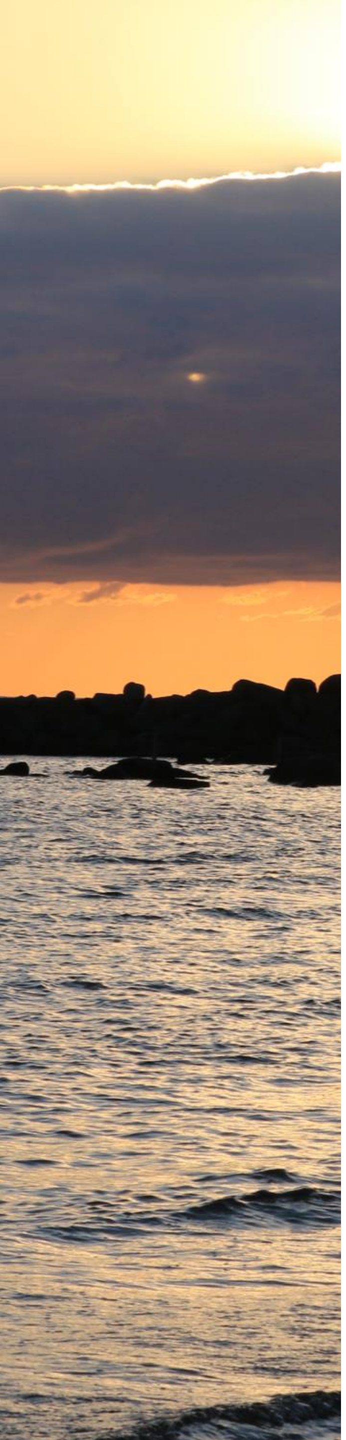
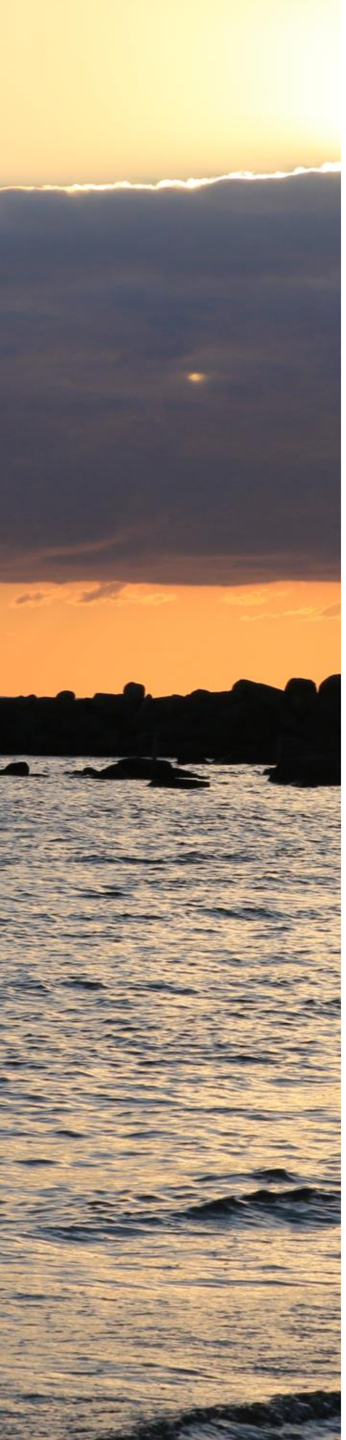


Overall main findings

- Manageable impacts for the energy system to around 2040
- But important to prepare for climate change in coming investments
- Weather-initiated (due to climate change) impacts on energy supply and use will increase and are largely negative to the energy system
- Significant differences between different sources of energy



The significance of climate change growths with time

- We need to understand the energy system of the future
- Significance of climate impact on a certain source of energy within a system context depends on the future role of that source
- The energy system develops as a response to many external conditions
- Currently the energy system develops largely as a response to *climate mitigation* and not to *climate adaptation*

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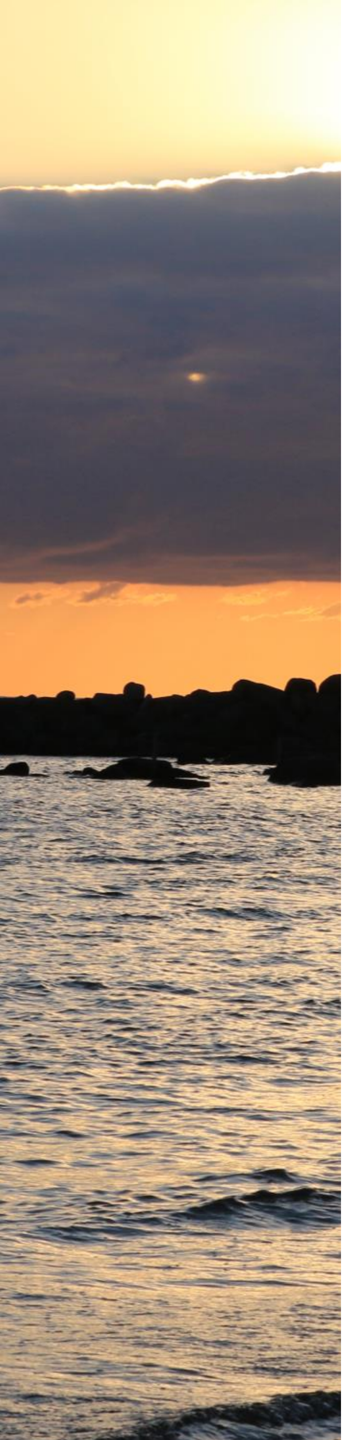

Measures and possibilities to prepare and adapt to climate change

- Differ between different sources of energy
- Include an array of measures, e.g. investments in protective measures, improved forecasting and planning, investments in storage capability, and changes in technical design criteria

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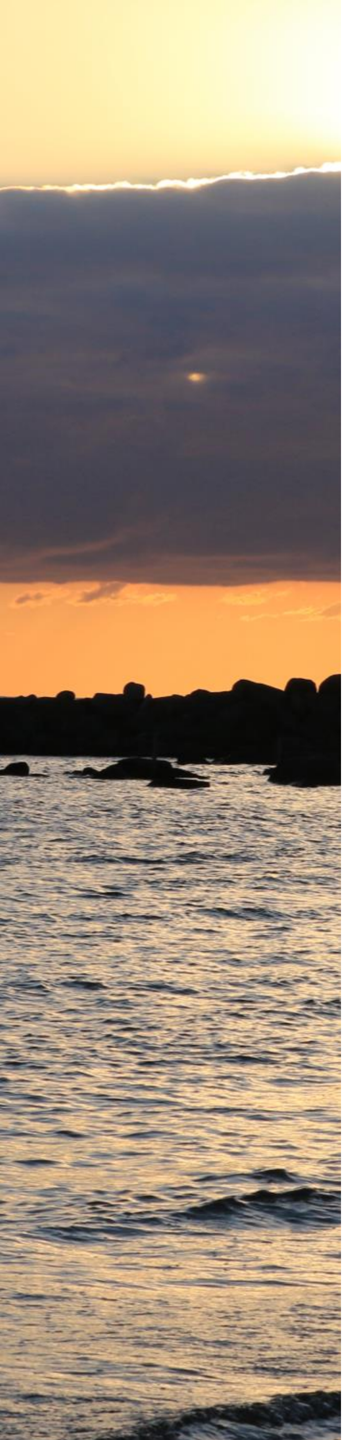

Other external factors than CC impact often more crucial

	Impacts of climate change to ca 2040	Other external factors
Hydro power	Medium → large	Future electricity system and demand, environmental requirements and legislation
Wind power	Small (uncertainties)	Massive expansion, acceptance, permit processes
Nuclear power	Small	Politics, technical development, acceptance
Bioenergy	Medium	Competition for biomass, sustainability aspects
District heating/ cooling	Large	Population development, energy efficiency improvement, competition
Electricity grids	Medium → large	Increased electricity demand → need for new investments

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CC and nuclear power: *Main findings*

- In general, NP is a climate-robust source of energy
- Due to extremely high safety standards and high margins against operational disturbances …
  - Design and planning with respect to extreme events is ”normal business”
  - Continous improvements in safety and operational performance
- … but also since some climate-change impact of more significance to NP still lies relatively far in the future
- Weather-related (operational) disturbances have occured (yet to a limited extent) and are likely to increase in the future
- Climate-change impact on NP is primarily a matter of increased risk of operational disturbances (unplanned outages) …
- … and not a concern for safety

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CC and nuclear power: *Main findings (cont.)*

- Measures are at hand and additionally available if considered necessary
- Ultimately a question of finding the balance between addional costs and benefits
- There are, however , remaining (large) uncertainties as regards e.g. frequency and amplitude of certain relevant weather events …
  - e.g. extreme events (e.g. thunderstorms) and compound events,
- …why the NP sector needs to continue to monitor climate-change research
  - PSRs typically every 10 years
  - Event classification of extreme weather events

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