4th CIGRE SEERC Grid Resilience Workshop
Enhancing Power Grid Resilience: Operational & Planning Experiences in Transmission & Distribution Grids and Generation Facilities

South East European Regional Council
Forum for power system expertise

Power System Resilience: Challenges and Strategies in Greece at Distribution, Transmission and Regional level

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[*] **CIGRE Greece National Committee**

Faculty of Engineering - University of Roma "La Sapienza", 23 January 2024, Roma, Italy

Understanding Climate Crisis

Extreme Weather Events of
Low Frequency BUT High Impact

Low Frequency/Probability BUT High Impact Extreme Events

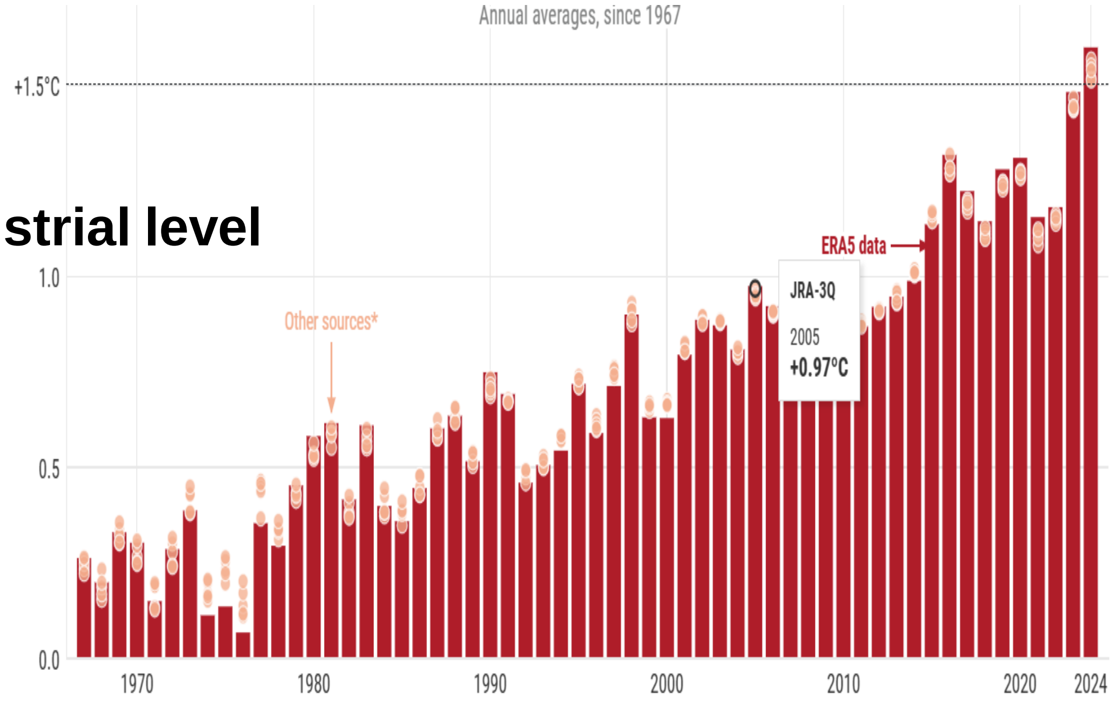
- Increased frequency, intensity, duration and extent of heatwaves;
- Longer fire season with more extreme fire danger days;
- More time spent in drought and hotter droughts
- Greater possibility of floods due to heavy rainfall events
- Increased frequency of coastal inundation and recession
- Prolonged high ocean temperatures

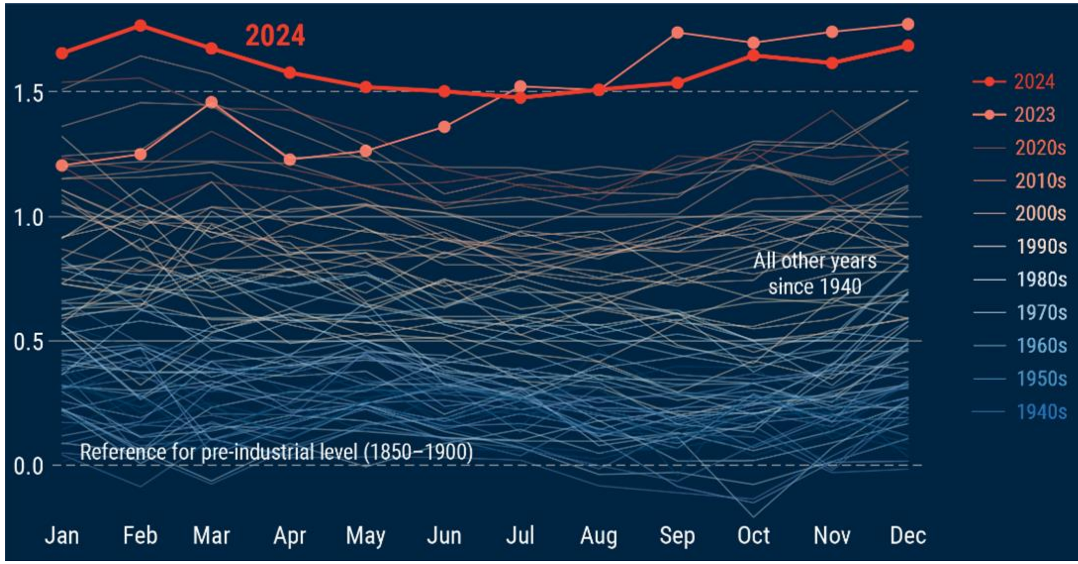
Global Climate Highlights 2024

2024 is the first year to exceed 1.5°C above pre-industrial level

- 2024 was the warmest year in global temperature records going back to 1850.
- 2024 is the first calendar year that has reached more than 1.5°C above the pre-industrial level.
- Each of the past 10 years (2015–2024) was one of the 10 warmest years on record.
- 2024 saw three record-warm seasons for the corresponding time of the year: boreal winter (December 2023-February 2024), boreal spring (March-May) and boreal summer (June-August) at 0.78°C, 0.68°C and 0.69°C respectively above the 1991-2020 average.
- Each month from January to June 2024 was warmer than the corresponding month in any previous year on record.

Region	Anomaly (vs 1991–2020)	Actual temperature	Rank (out of 85 years)
Globe	+0.72°C (+1.60°C vs pre-industrial)	15.10°C	1st highest 2nd - 2023
Europe	+1.47°C	10.69°C	1st highest 2nd - 2020
Arctic	+1.34°C	-11.37°C	4th highest 1st - 2016
Extra-polar ocean	+0.51°C	20.87°C	1st highest 2nd - 2023



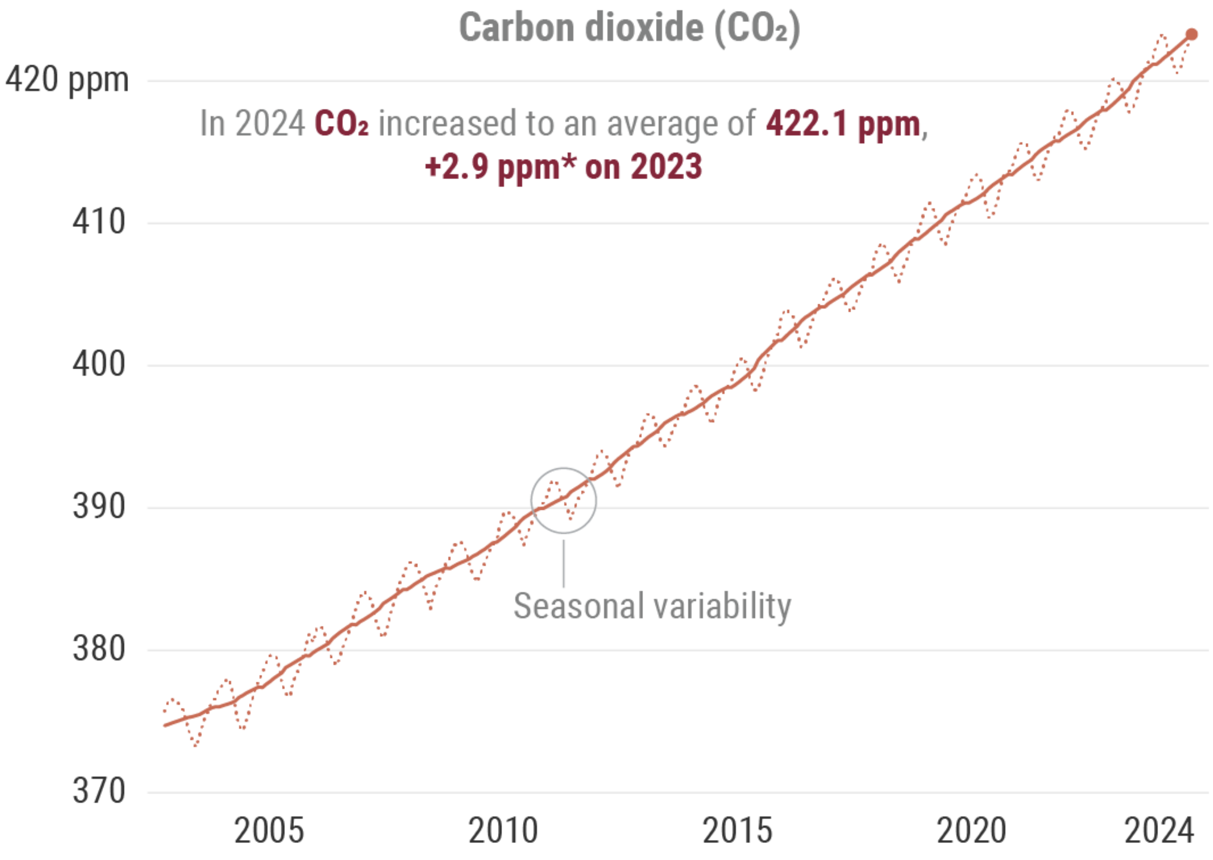


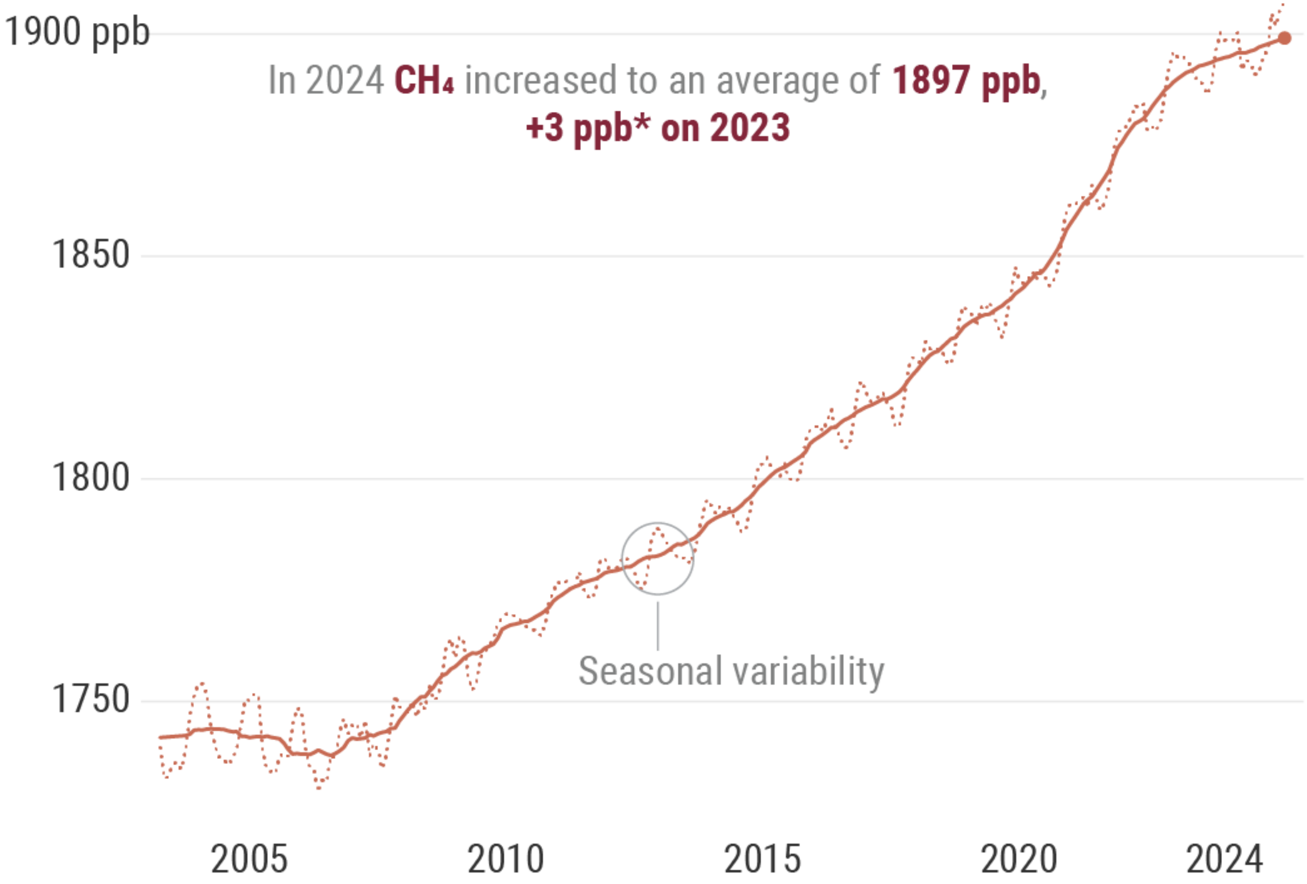
Data from ECMWF as part of The Copernicus Programme https://climate.copernicus.eu/

Greenhouse gases (GHGs)

Global atmospheric concentration of Carbon Dioxide (CO_2) and Methane (CH_4)

In 2024, atmospheric GHG reached the highest annual levels ever recorded in the atmosphere. CO_2 concentrations in 2024 were 2.9 ppm higher than in 2023 and methane concentrations were 3 ppb higher. This increase has brought the annual estimate of the atmospheric concentration of CO_2 to 422 ppm, and of methane to 1897 ppb. This points clearly to a steady global increase of GHGs emissions, and these remain the main agent of Climate Change.

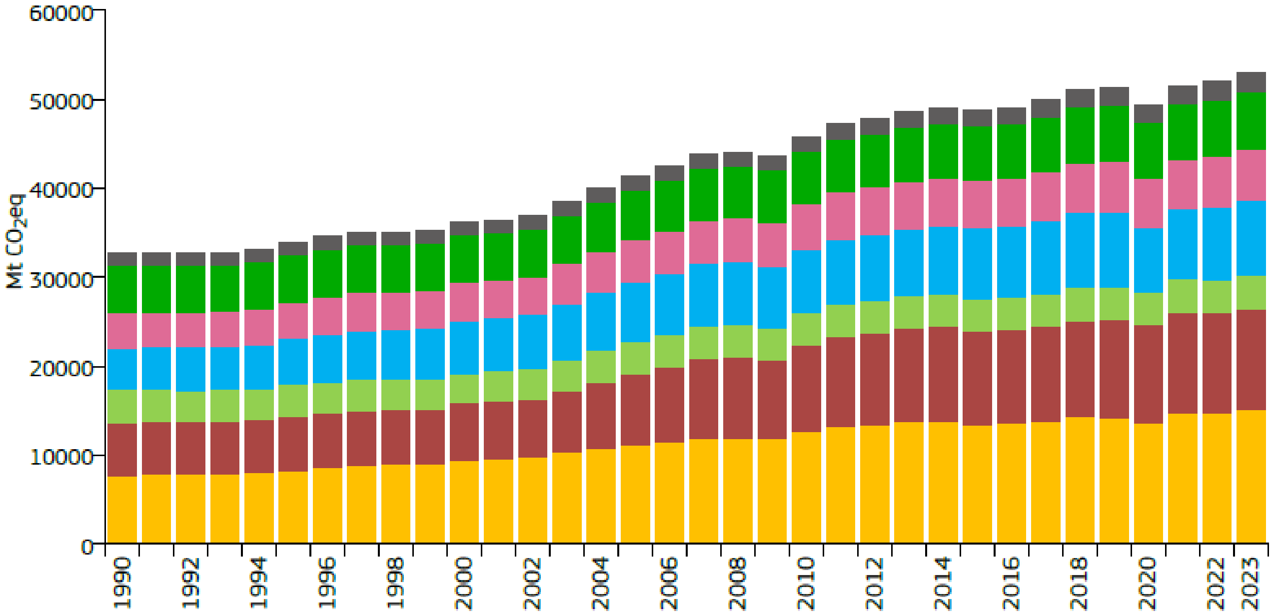


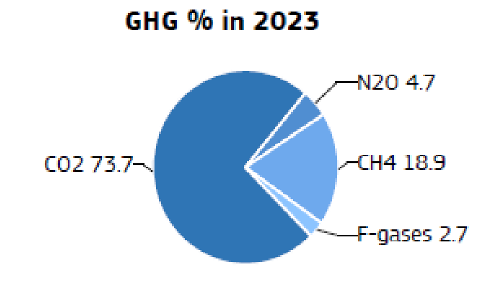


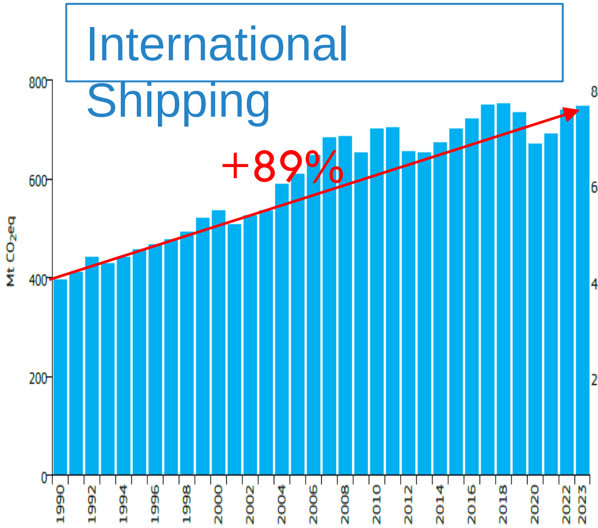
Data from ECMWF as part of The Copernicus Programme https://climate.copernicus.eu/

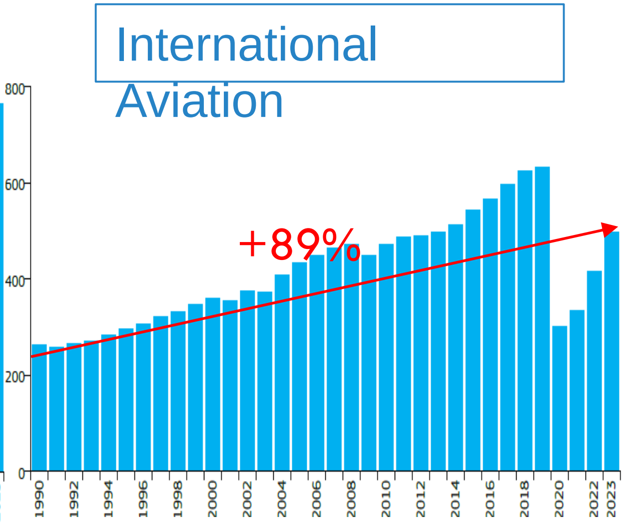
World GHG emissions

WORLD









Year	GHG emissions Mt CO_2eq/yr	GHG emissions per capita t CO_2eq/cap/yr	GHG emissions per unit of GDP PPP t CO_2eq/kUSD/yr	Population
2023	52962.901	6.594	0.320	8.032G
2015	48808.767	6.613	0.369	7.381G
2005	41296.885	6.314	0.437	6.540G
1990	32726.228	6.140	0.543	5.330G

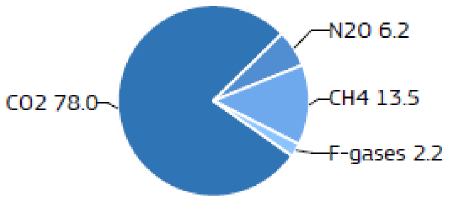
	2023 vs 1990	2023 vs 2005	2023 vs 2022
Power Industry	+96%	+36%	+2%
Industrial Combustion and Processes	+91%	+41%	+2%
Buildings	+1%	+3%	+1%
Transport	+78%	+26%	+4%
Fuel Exploitation	+48%	+23%	+2%
Agriculture	+20%	+15%	0%
Waste	+56%	+37%	+2%
All sectors	+62%	+28%	+2%

JRC, EDGAR, "GHG emissions of all world countries", 2024 Report.

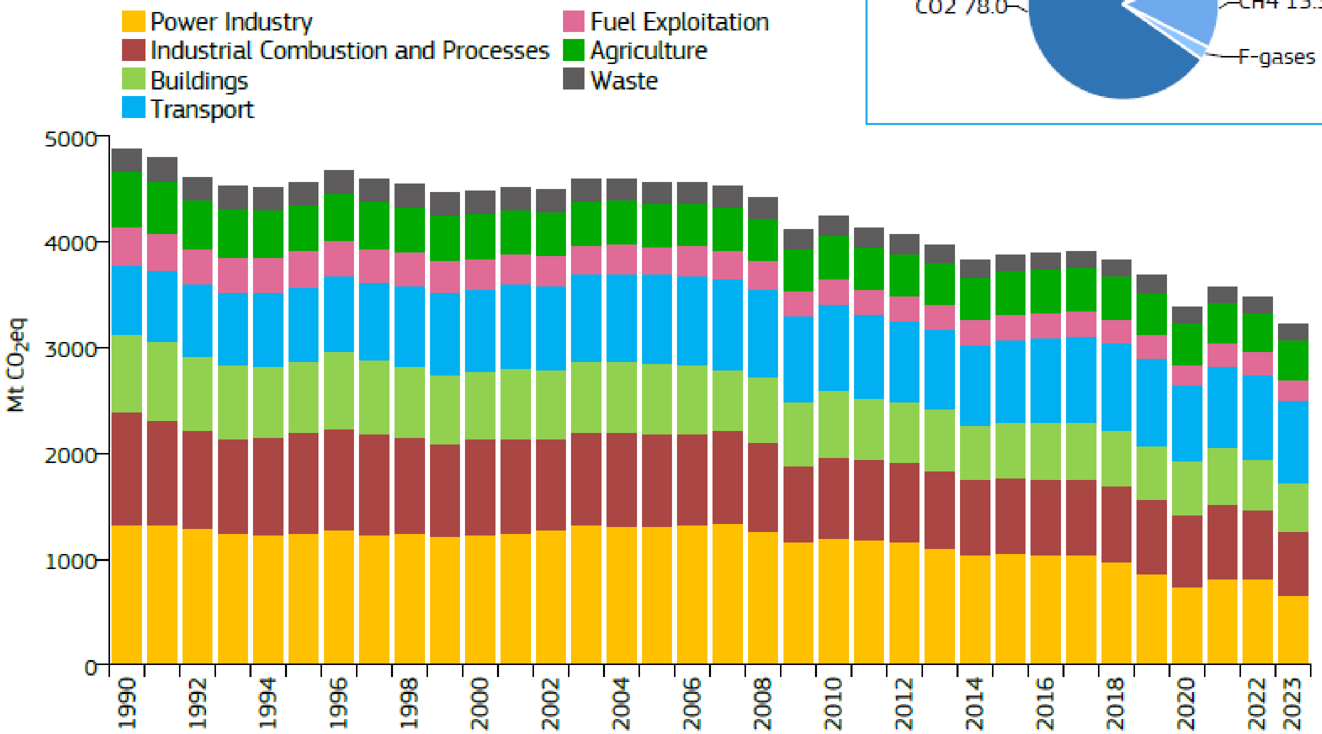
EU27 GHG emissions

EU27

GHG % in 2023



GHG emissions by sector



Year	GHG emissions Mt CO_2eq/yr	GHG emissions per capita t CO_2eq/cap/yr	GHG emissions per unit of GDP PPP t CO_2eq/kUSD/yr	Population
2023	3221.795	7.264	0.133	443.523M
2015	3879.729	8.776	0.183	442.095M
2005	4553.562	10.464	0.239	435.163M
1990	4877.284	11.607	0.343	420.198M

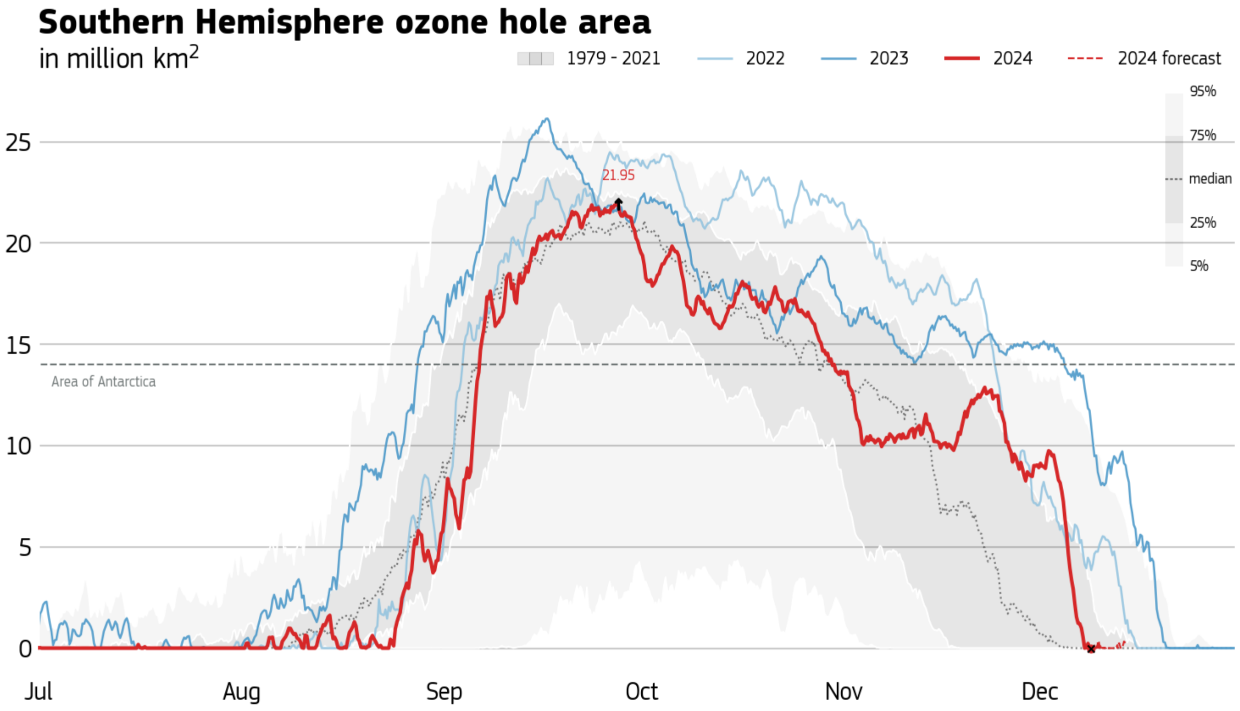
Legend of the sectors:

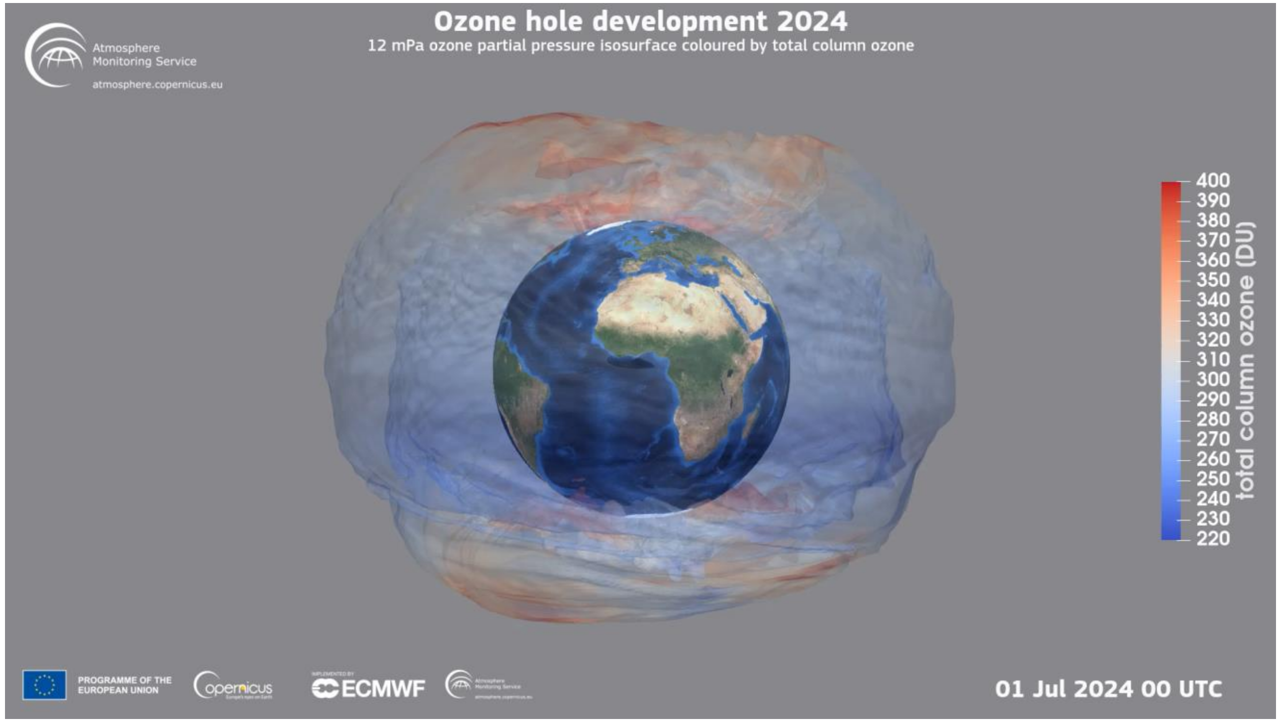
- Power Industry - Power and heat generation plants (public & autoproducers)
- Industrial Combustion and Processes - Combustion for industrial manufacturing and processes
- Buildings – Small scale non-industrial stationary combustion
- Transport – Mobile combustion (road & rail & ship & aviation)
- Fuel Exploitation – Fuel extraction, transformation and refinieries
- Agriculture – Agricultural soils, livestock, field burning of agricultural residues, indirect N_2O emissions from agriculture
- Waste – Solid waste disposal and waste water treatment
- All sectors – Sum of all sectors. The pie chart represents the GHG sectorial share in 2023.

	2023 vs 1990	2023 vs 2005	2023 vs 2022
Power Industry	-51%	-50%	-20%
Industrial Combustion and Processes	-42%	-30%	-6%
Buildings	-37%	-31%	-6%
Transport	+19%	-6%	-2%
Fuel Exploitation	-46%	-27%	-6%
Agriculture	-27%	-6%	0%
Waste	-35%	-26%	-2%
All sectors	-34%	-29%	-7%

Ozone hole/hope 2024?

- One of the smallest ozone holes in recent years closes

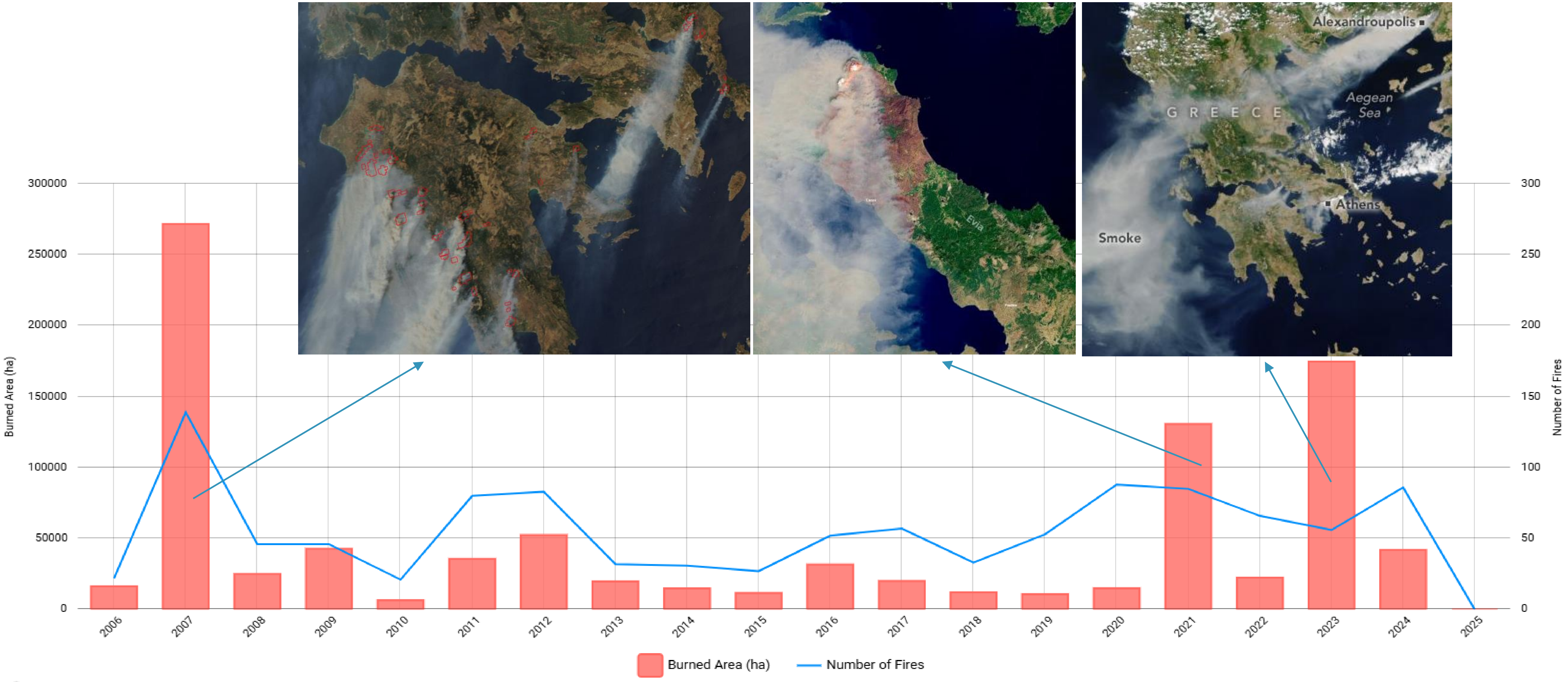




The ozone layer protects life on Earth from harmful solar ultraviolet (UV) radiation. In the late 20th century, human emissions of chemicals known as ozone-depleting substances (ODSs), in particular halocarbons, adversely affected the amount of ozone molecules in the atmosphere, most notably resulting in the dramatic annual ozone hole over the Antarctic region. The Montreal Protocol, which was signed in 1987 and came into force in 1989, has curbed the amount of ODSs in the atmosphere, resulting in the slow recovery of the ozone layer.

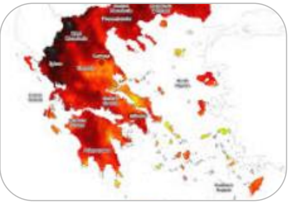
Monitoring of the ozone layer
https://atmosphere.copernicus.eu/monitoring-ozone-layer

Wildfires and Megafires in Greece



Main Risks for Grids

- The increase in the frequency and intensity of extreme weather events in recent years is a major challenge for System and Network Operators.
- Risks from climate change can be divided into short-term events (capable of causing shocks to equipment) and long-term stresses.
  - ✓ **Shocks:** floods, fires, storms, heat waves, strong winds, snowfall, frost.
  - ✓ **Stresses:** humidity, increased temperature, drought, landslides, sea level rise and coastal pollution.



Extreme Heat

Wildfires

Snowstorms

Floods

	Natural Disasters						Long-term stresses				
Climatic Risks	Floods	Wild-fires	Strong winds	Storms (thunder, heavy rainfall, hailstorm	Snow-storms, frost	Heat-waves	Increased Temper-ature	Humidity	Drought	Soil instability, landslides, subsidence	Sea level rise, marine pollution, salinization
Equipment											
Outdoor substations	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Indoor substations	✓	✓						✓			
Overhead line network (poles, conductors, insulators)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Switches/ disconnectors	✓	✓		✓	✓		✓	✓			
Transformers (MV/LV)	✓	✓	✓				✓	✓	✓		
Underground cable network				✓			✓			✓	✓
Comm-unications		✓	✓	✓						✓	

Most vulnerable equipment to climate change risks

Heatwaves and Power Grids

Characteristics of the phenomenon

- Extreme temperatures, with values much higher than season normal (>40ºC)
- Extremely high minimum temperature values (>28ºC)
- Long duration (>10 days in a row)
- Very often accompanied by African dust storms
- Combined with wildfires turns into a complex crisis

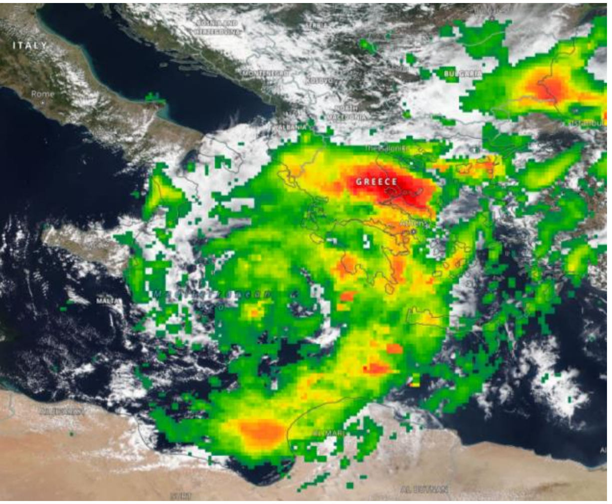
Most affected assets of the distribution network

- Underground cable network
- Outdoor and indoor substations
- Overload due to high demand and reduced heat dissipation cause more frequent faults in the equipment during the heatwaves
- Overhead line network
- The African dust creates surface pollution and causes insulator leakage, wear and

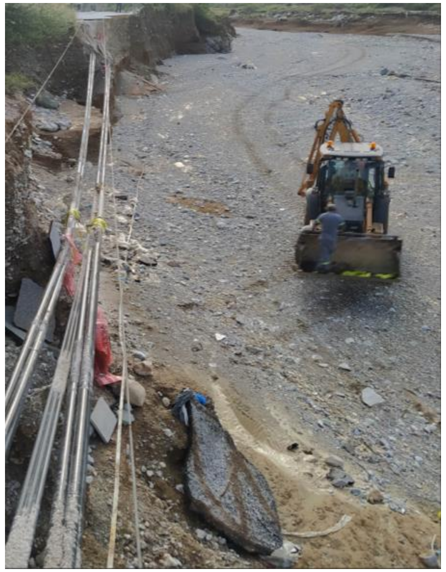
Wildfires and Power Grids

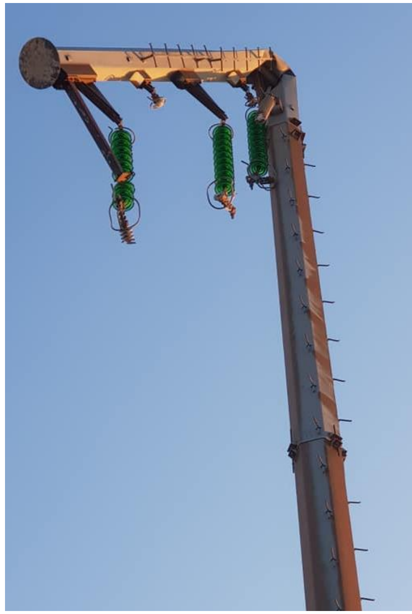
Floods

- Coastal regions faced the fury of supercharged hurricanes and cyclones in 2023.
- Warmer ocean temperatures provided the energy needed for these storms to intensify rapidly, leading to stronger winds, heavier rainfall, and more destructive storm surges.
- The deadliest-ever Mediterranean cyclone Daniel dropped record rainfall in Libya, overwhelming dams and causing catastrophic flooding.
- Storm Daniel, also affecting Greece, Turkey, and Bulgaria, became the costliest tropical cyclone outside of the north Atlantic Ocean.



Flooding and Grids

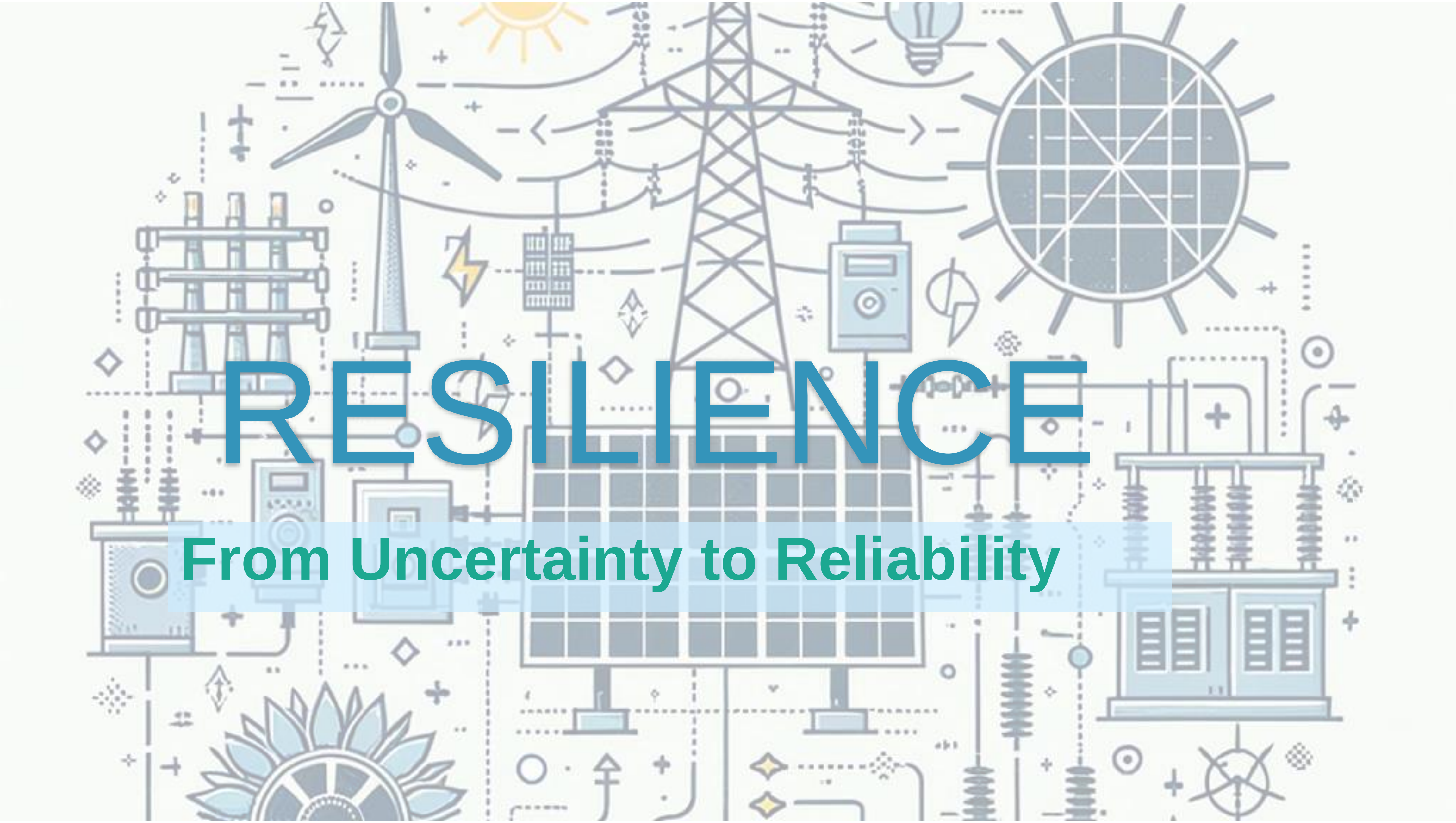




Snowstorms





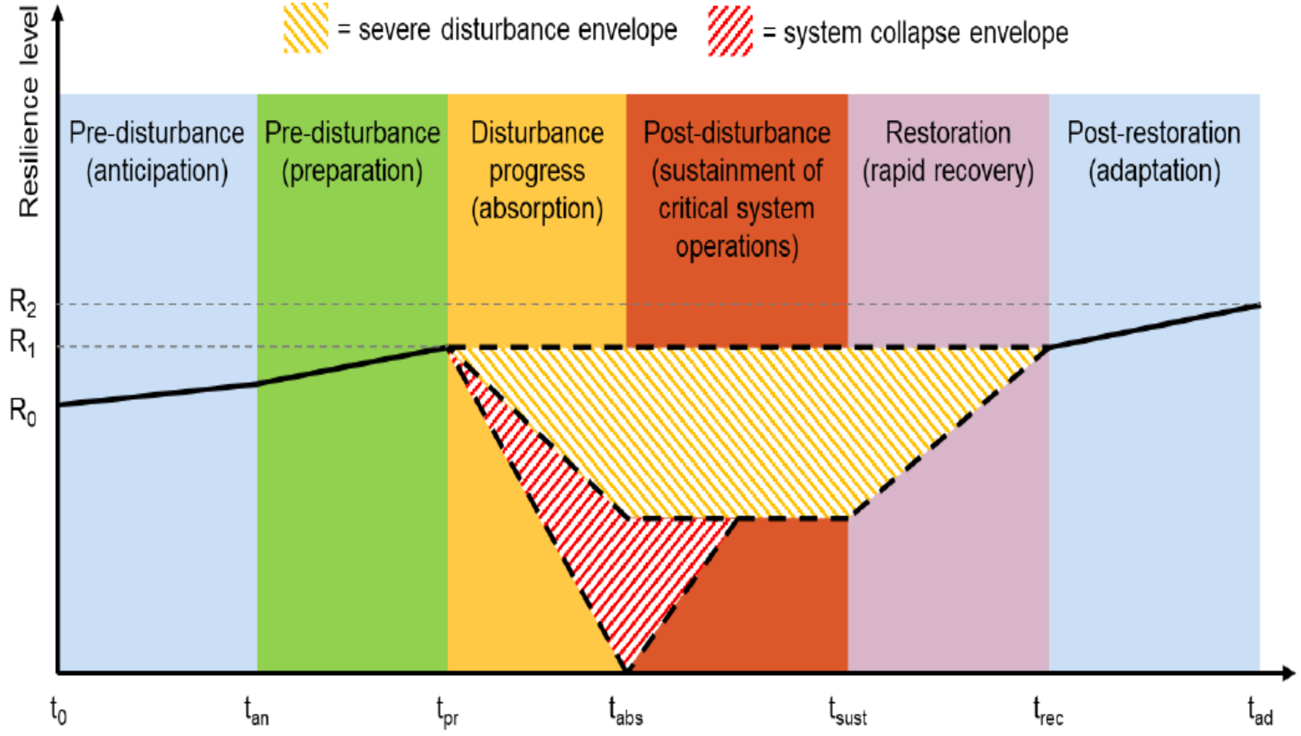
RESILIENCE

From Uncertainty to Reliability

Learning Resilience in Power System and Electricity

Power system resilience **is defined by CIGRE Working Group SC C4.47 as**

- *the ability to limit the extent, severity, and duration of system degradation following an extreme event.*
- *it is achieved through a set of key actionable measures to be taken before, during, and after extreme events, such as:*
  - ✓ *anticipation*
  - ✓ *preparation*
  - ✓ *absorption*
  - ✓ *sustainment of critical system operations*
  - ✓ *rapid recovery; and*
  - ✓ *adaptation including the application of lessons learnt.*



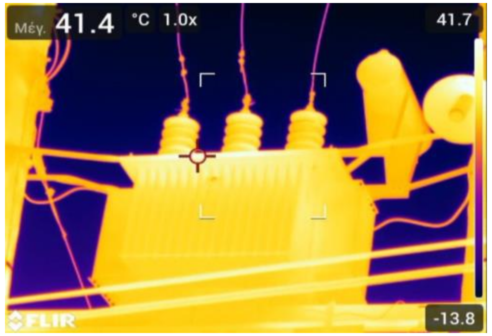
Resilience Improvement and Asset Performance Management

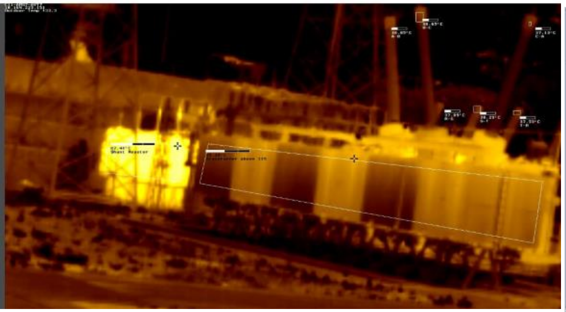
On-Line Monitoring Systems (OLMS)

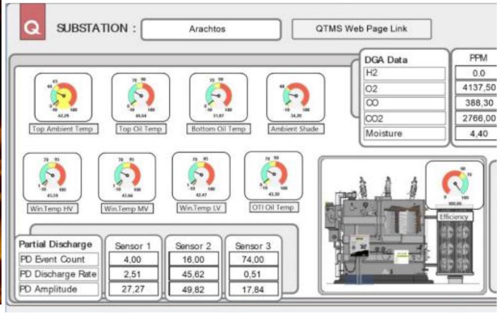
- Autotransformers (ATFs), 400/150/30 kV
- Circuit Breakers (CBs) 400 kV
- Reactors 150kV
- Battery Packs
- Underground and Submarine Cable Lines
- Gas Insulated Switchgear (GIS) bays
- Equipment surveillance with thermal/infrared

Asset Performance Management System (APMS) software for the utilization of all data collected by the distributed OLMS with Artificial Intelligence (AI) and Machine Learning (ML) tools will calculate and analyze:

- Asset Health Index (AHI) and Probability of Failure (PoF)
- Asset Criticality
- Asset Life Cycle Analysis (Lifecycle Cost Analysis)
- Diagnostics Evolution & Predictive Evolution

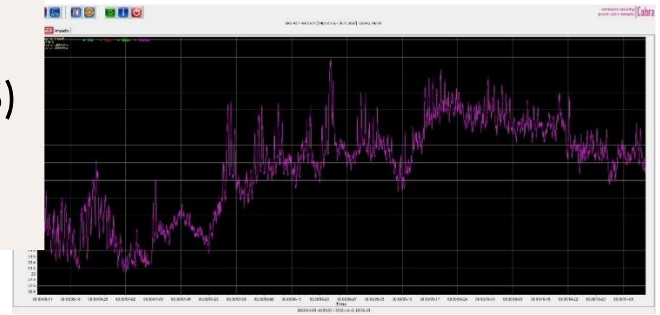


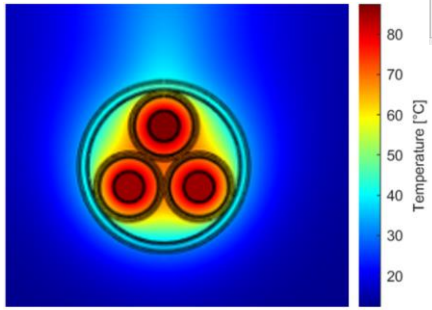


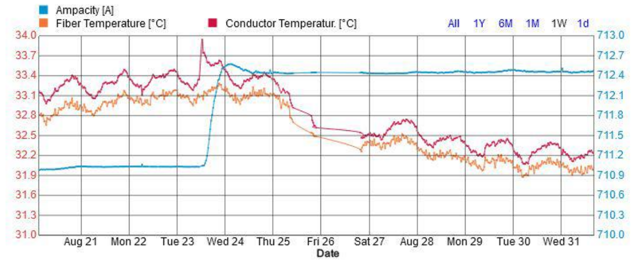


OLMS for Power Cables

- Distributed Temperature Sensing (DTS)
- Real Time Thermal Rating (RTTR)
- Dynamic Cable Rating (DCR)

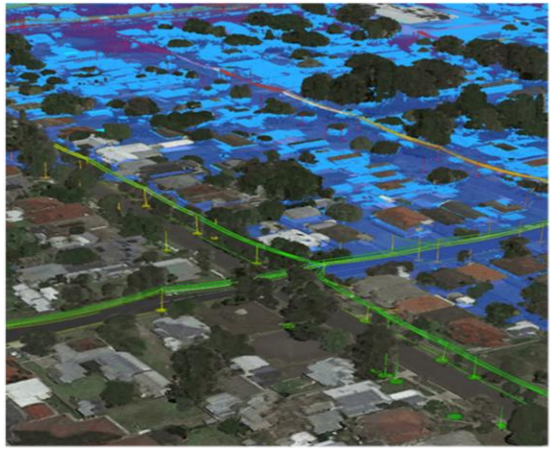


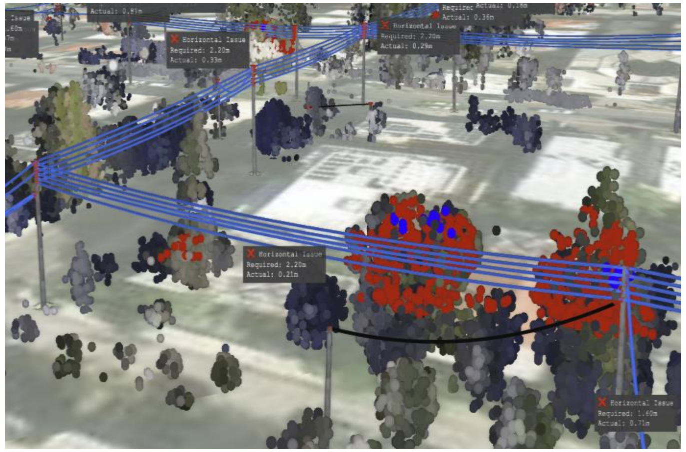




Resilience Improvement: Vegetation Management

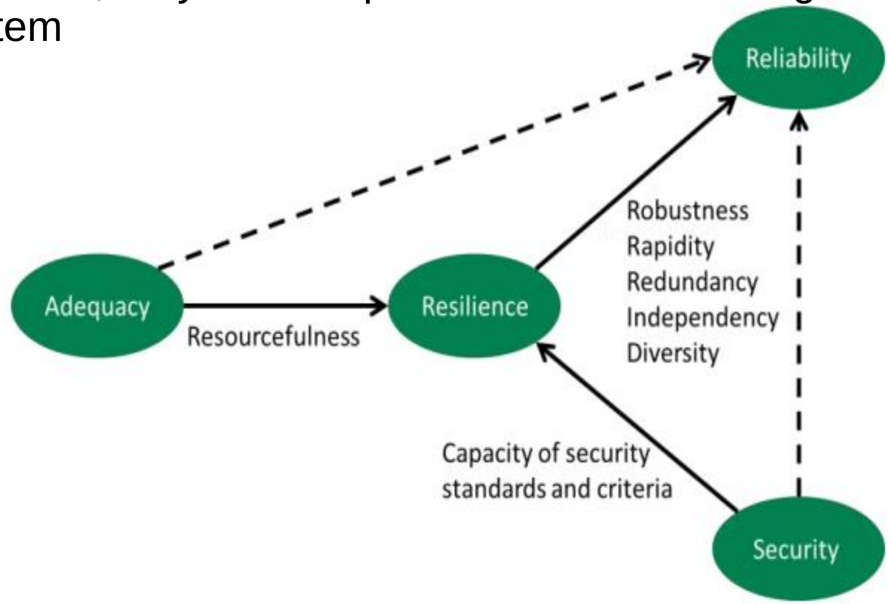
- There are intensive inspection of the crucial OHL in cooperation with Public Authorities
- there is a special Vegetation/Trees Management and cleanliness along the ROW to protect the TL operation
- The ROWs can also be used as Firewalls/Firebreaks and forest access
- Monitoring cameras are used
- All Substations and OHL squares are cleaned → **FIREWALLS**





Resilience Improvement: Operational Resilience

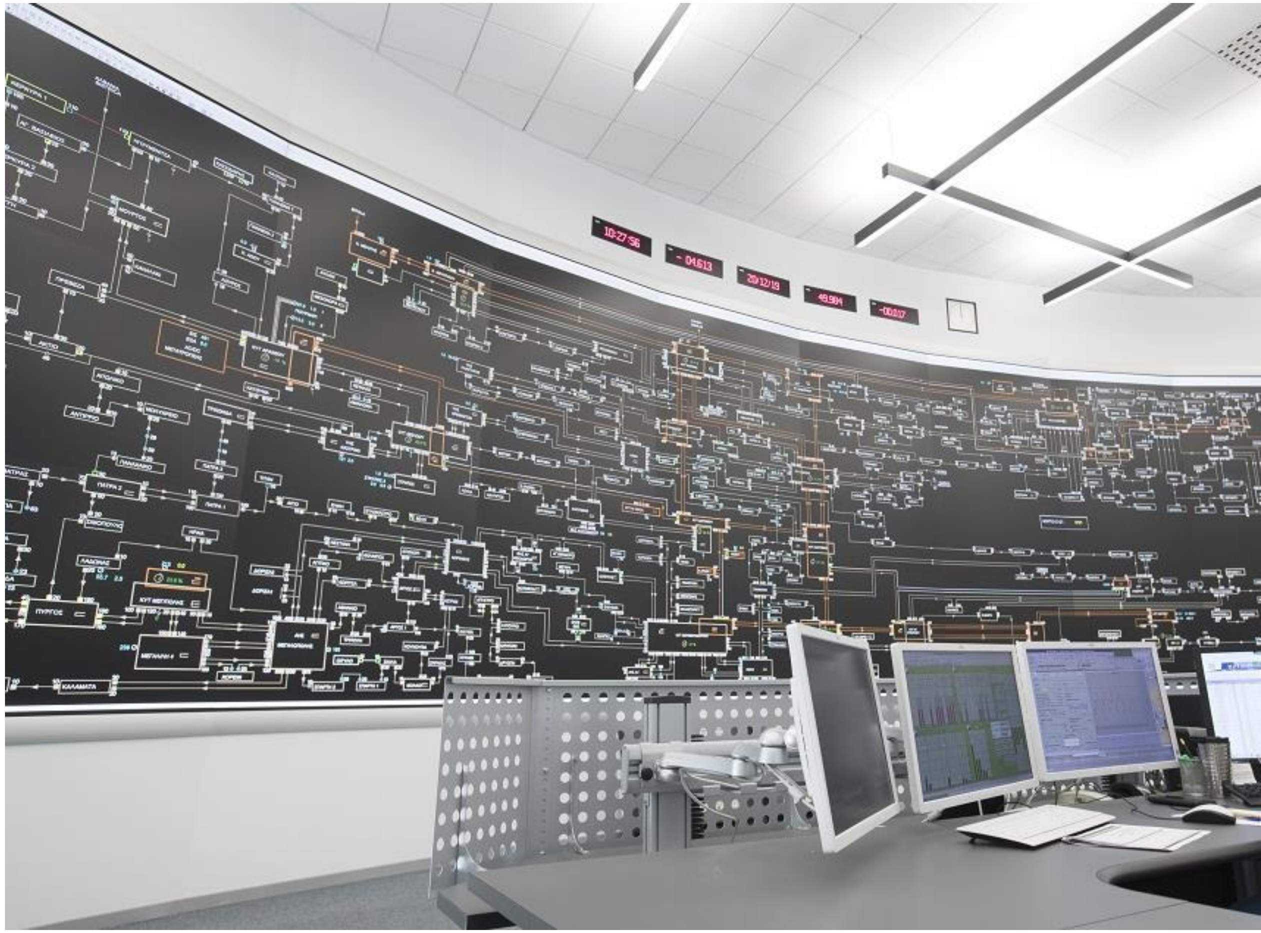
- **Adequacy** provides the guarantee that the basic resources for system operation
(including operational margins) will be provided
- **Security**: Management security, Operational security, Physical and cyber security
- **Resourcefulness**: the non-accountable power and energy resources in system adequacy can be used in emergency and restoration procedures under specific conditions.
- **Robustness** of the electrical systems, particularly for grid protections (e.g. special protection schemes) and communications and for grid-facility interfaces shall be developed by maintaining through quality in design, operation, maintenance and testing.
- **Rapidity** is crucial in absorption, adaptation and recovery phases. Rapidity also covers the process of understanding the system degradations, the decision process when mitigating the consequences of the event and the communication process when it is time to restore power.
- **Redundancy**: The resilience can be improved by identifying and using redundancies that appear in some degraded situations.
- **Independence**: The design of equipment shall take due account of the potential for common cause failures of items important to absorption, adaptation and recovery, to determine how the concepts of physical/electrical separation and functional independence have to be applied to achieve the necessary resilience.
- **Diversity** improves the reliability of the system but also contributes to resilience. The diversity of power supply sources for critical loads, for example emergency communication systems, controls contributing to Defence Plan etc., may often improve the resilience degree of the system



Digital Resilience and Cyber-Security

Wide-Area Monitoring, Protection, and Control (WAMPAC)

- SCADA Upgrade to Energy Control Centers following the new Std's.
- Interconnection of all Regional Control Centers for System Operational Security and Reserve (Business Continuity Plan, Backup, Cyber Security)
- New SCADA to Substations and Power Plants compatible to new IT Stds.
- Data collection and Condition Information for efficient management and maintenance of the equipment
- Assurance of independent, secured and reliable private telephony network
- Secure interconnection of the Control Center with the ENTSO-e for huge data volume exchange with security, reliability and broadband transmission
- Integration of all the Substations to the fiber-optic telecommunication network (OPGW)



Resilience Improvement: Research and Innovation

- Contribution to EU R&D RAIN Project 2014-2017
  Risk Analysis of Infrastructure Networks in Response to Extreme Weather
  - ✓ **Consequences of past extreme weather events,**
  - ✓ **State-of-the-art Early Warning Systems**
  - ✓ **How to monitor, forecast and study hazards on a European level**
  - ✓ **Measures, including physical adaptations and changes to management strategies, to increase the level of redundancy and mitigate the consequences of cascading effects.**
- Contribution to FARCROSS Project *"Building a Low Carbon, Climate Resilient Future: Secure, Clean and Efficient Energy"*
- *New projects related on RT Data Analytics and Resilience*
- *Extensive use of Drones and News technologies for inspections and grids monitoring*

RAIN PROJECT

Increased cross border power transfers and RES penetration in SE Europe through a rapidly deployable Modular Power Flow Control (MPFC) solution


Regional Coordination of Grids

Common grid model (CGM)

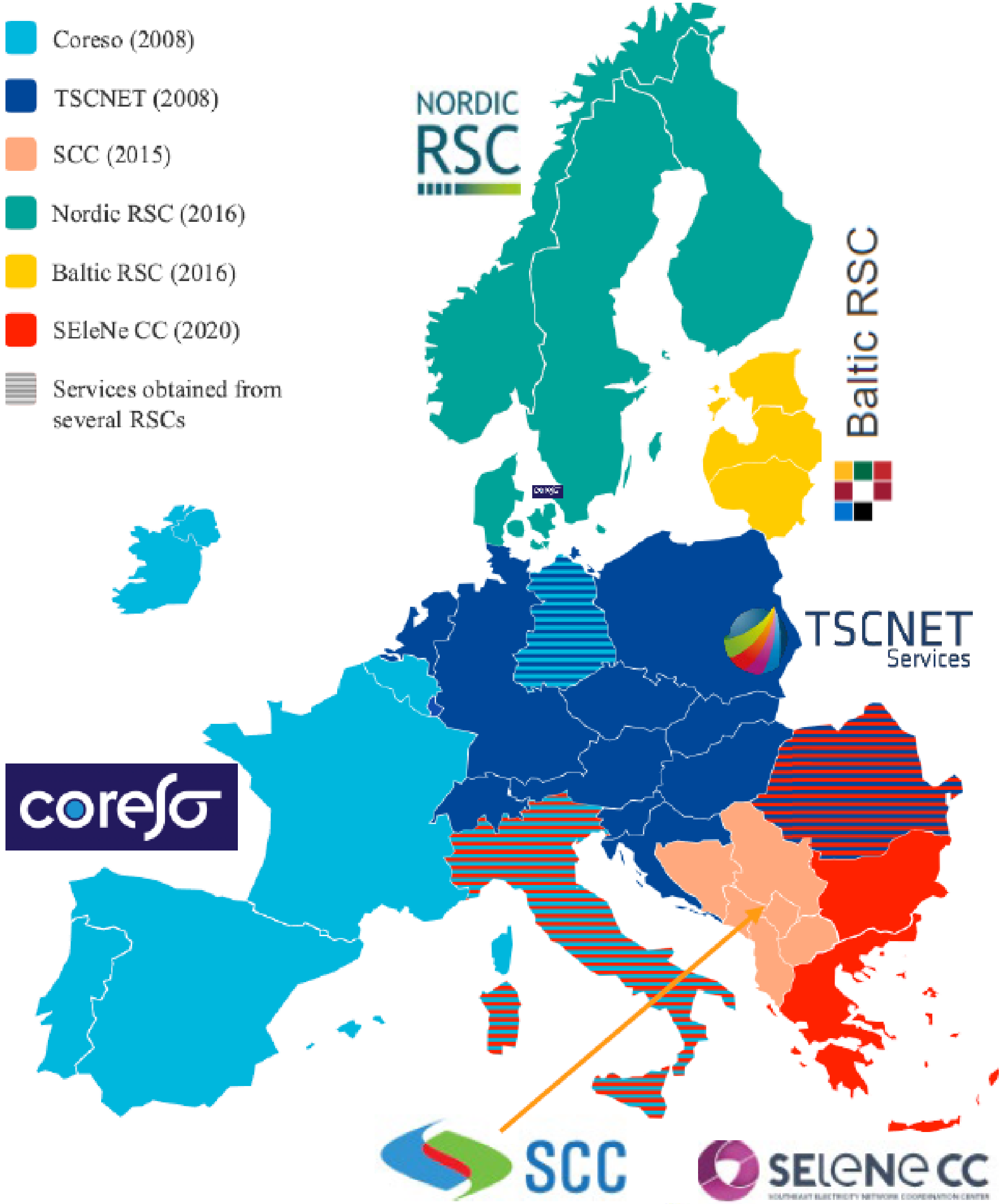
Coordinated capacity calculation (CCC)

Short-term Adequacy Forecasting (SAT)

Coordinated security analysis (CSA)

Outage planning coordination (OPC)

Critical Grid Situation (CGS)



MED POWER 24
3-6 November 2024 Athens, Greece

With the support of CIGRE Greece

Resilience Against Natural Disasters and Extreme Weather

Innovations, Applications and Policies in Power Systems

- "Introduction and the R2D2 project" by Mathaios Panteli, University of Cyprus
- "Key challenges for operating future grids under a carbon-neutral Europe" by Nuno de Souza e Silva, R&D Nester, Portugal
- "HEDNO: Climate Resilience Strategy" by George Andreakos, HEDNO
- "Building Machine Learning Supported Resilient Power Grids" by Jin Zhao, Trinity College Dublin, Ireland
- "Resilient, reliable and secure power systems: the eFORT project" by Maria Fotopoulou, CERTH, Greece
- "Operational and Infrastructure Planning to Enhance Resilience" by Dimitris N. Trakas, SMPnet, UK
- "Regulatory Frameworks and Standards for Resilient Power Systems" by Aleksandra Krkoleva Mateska, UKIM/FEIT, Ss Cyril and Methodius University in Skopje

PYLONs

The Online Magazine of CIGRE Greece

- In the 2nd Issue the special theme is Uncertainty, Security, Resilience.
- It starts with an introduction on the **Challenges in the time of Energy Transition** where **C. Vournas** introduces Resilience in Electrical Power Systems and discusses ways to Counter Uncertainty and Ensure Resilience during Energy Transition.
- **About Resilience in Power Systems**, by A. Koronides, G. Georgantzis and M. Champakis
- **Coping with uncertainties and assurance resilience of Power Systems on the way to Energy Transition**, by M.Karystianos and Y. Kampouris

More specific topics are explored in the invited articles

- **Towards cyber-physical security for the electric power system** by E. Karangelos and L. Wehenkel of the University of Liege
- **Enhancing Resilience against Fires** by N.Hatziargyriou,
- **Anti-icing and De-icing in Transmission lines** by K.Papailiou.

CONCLUSIONS

SI VIS STABILITÀ E SICUREZZA, PARA RESILIENZA!

SI VIS TRANSIZIONE ENERGETICA, RES NO VERBA!

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CIGRE Greece