Assessing the impacts of extreme temperature events on energy systems in France

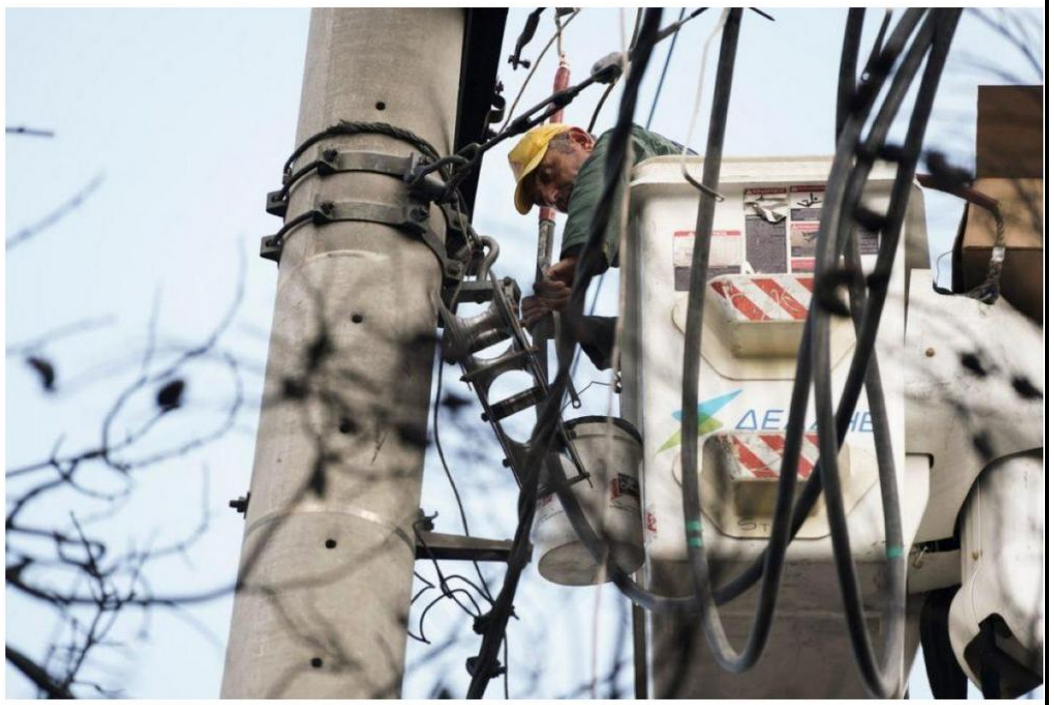
Monday 29th September 2025

Anastasia Akakpo – Numado, G. Cazzaniga, A. Burq, M. Vrac, D. Faranda

Laboratoire des Sciences du Climat et de l'Environnement (LSCE)
University of Paris Saclay

Extreme temperatures & Power systems

Greece's Power Grid Under Strain Amid Heatwave



Power grid outage in Greece: high-voltage transmission system at fault, Jul. 2025

Outage in Toulouse, Jul. 2019, FR

Toulouse. Plus d'un millier de clients privés d'électricité pendant plusieurs heures

Lundi 22 juillet 2019, en fin de journée, deux coupures ont eu lieu à Toulouse privant d'électricité de nombreux clients dans le quartier de la Reynerie. En voici les raisons.

Extreme temperature & Power systems

Greece's Power Grid Unde

Power grid outa
high-voltage tra
system at fault.

ÉNERGIES • NUCLÉAIRE

Canicule : EDF doit mettre à l'arrêt deux réacteurs nucléaires

La vague de chaleur qui s'abat sur la France risque de conduire à des baisses de production, voire à d'autres arrêts de réacteurs, notamment en bordure du Rhône.

Par Nabil Wakim

Publié le 22 juillet 2019 à 18h45, modifié le 23 juillet 2019 à 10h24 · Lecture 3 min.

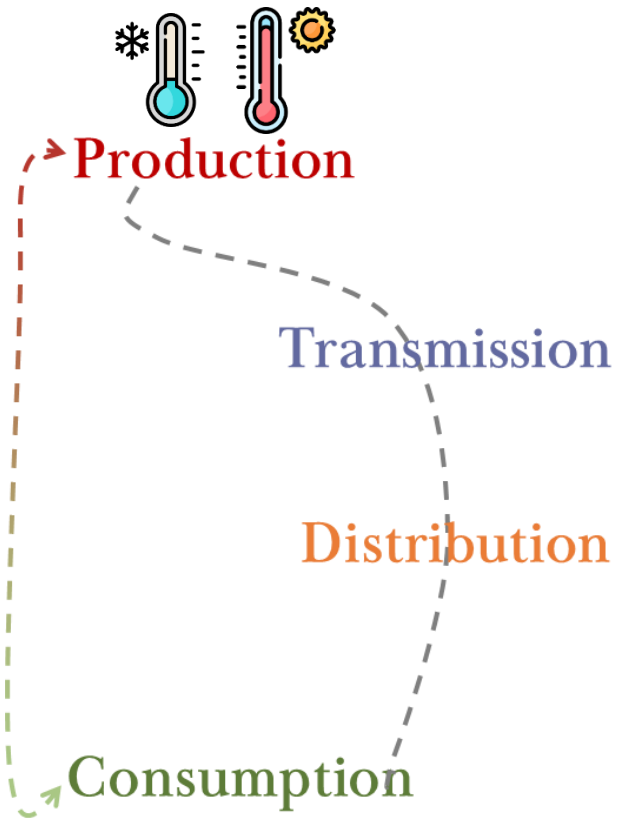
La centrale de Golfech (Tarn-et-Garonne), le 19 juillet, pourrait être mise à l'arrêt au moins pour une journée, en raison de la vague de chaleur. REGIS DUVIGNAU / REUTERS

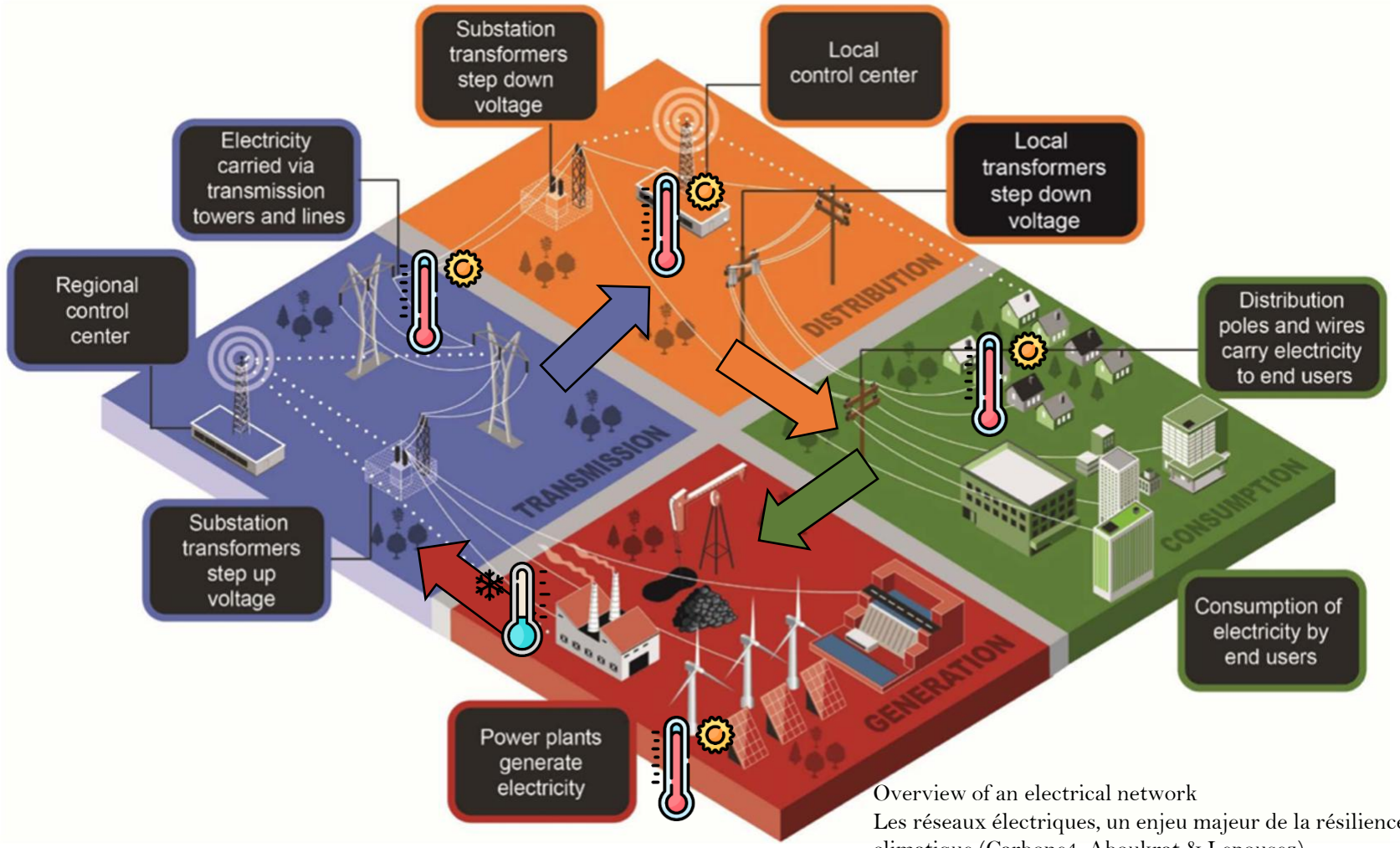
Toulouse, FR

millier de clients privés
plusieurs heures

, deux coupures ont eu lieu à Toulouse privant
le quartier de la Reynerie. En voici les raisons.

Extreme temperatures & Power systems





Overview of an electrical network
Les réseaux électriques, un enjeu majeur de la résilience climatique (Carbone4, Aboukrat & Lepousez)

Attribution science

The process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence.

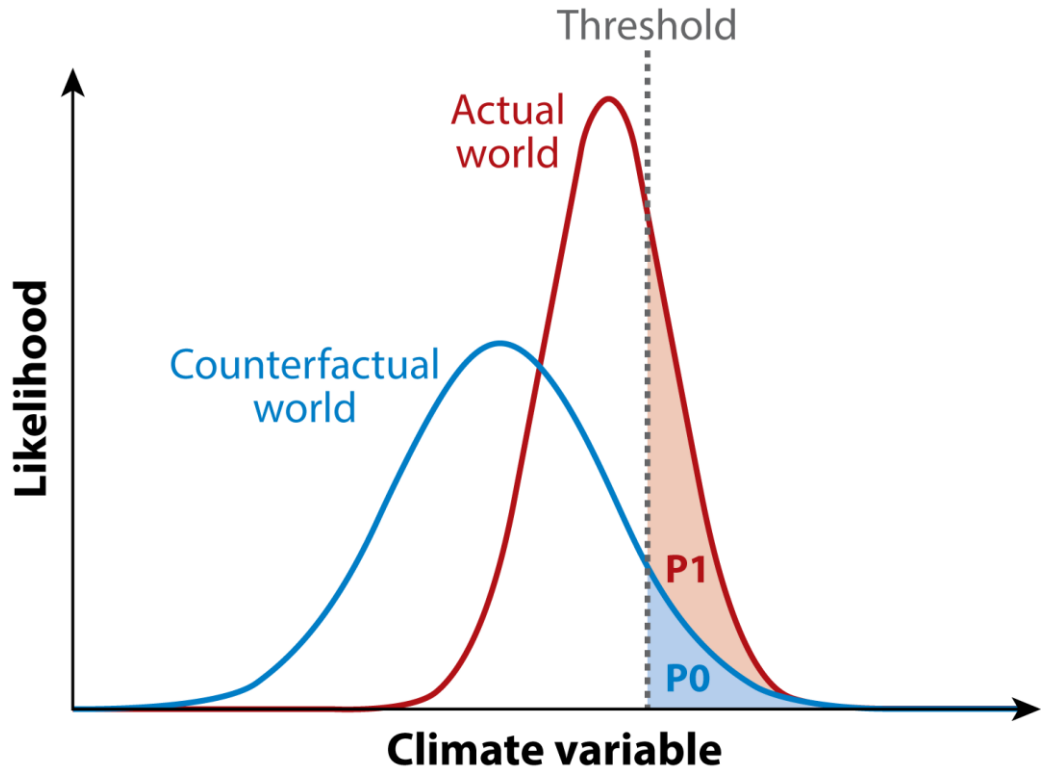
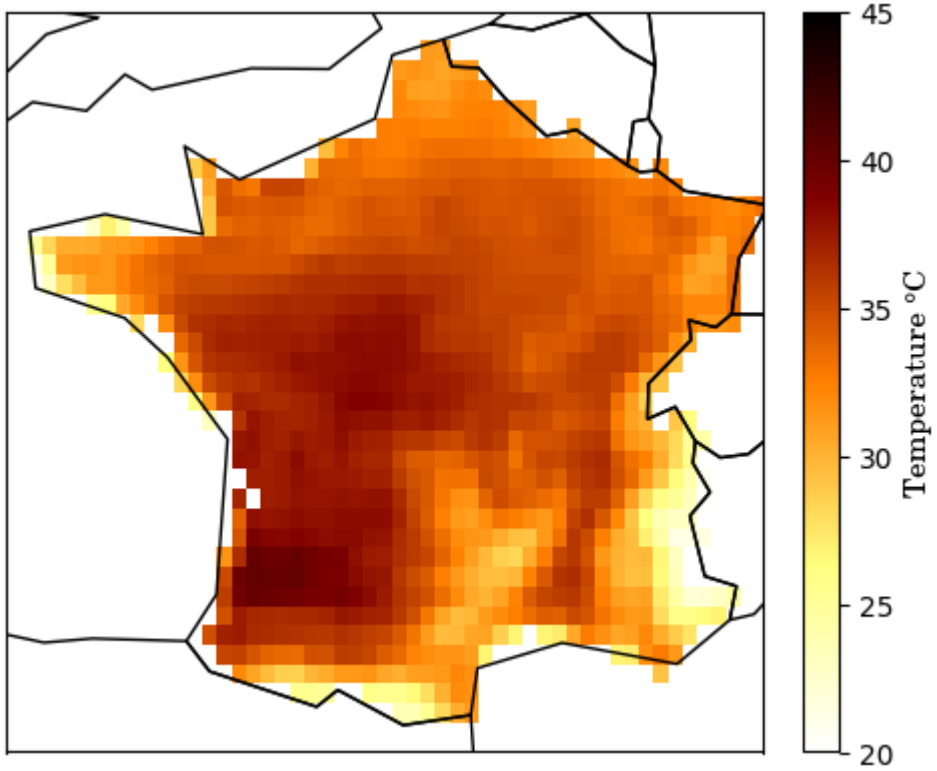


Figure from Otto FEL. 2017,. Annu.Rev.Environ.Resour

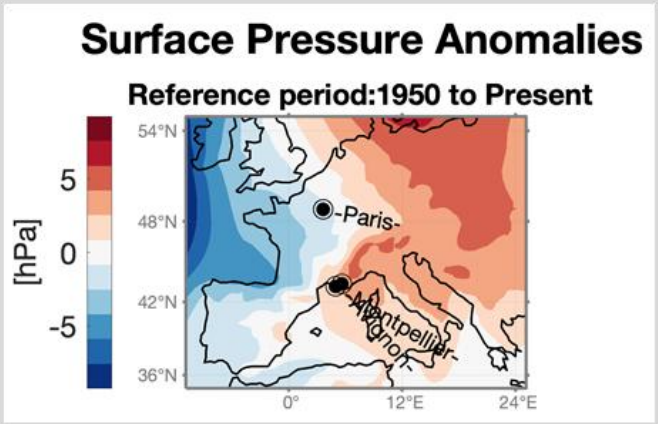


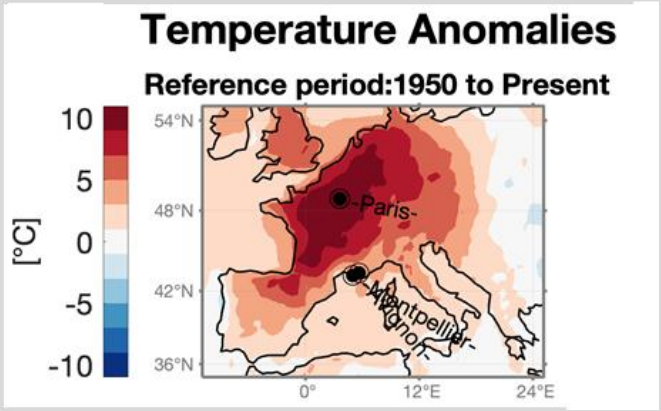
Temperature of 23th July 2019 – 1pm
ERA5 reanalyzed gridded data

Conditional attribution

Dates of weather analogs

Analyse of the climatic event





🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)

🌀 **Event Definition**:
- Time averaged Surface Pressure Anomalies map in a lon-lat box

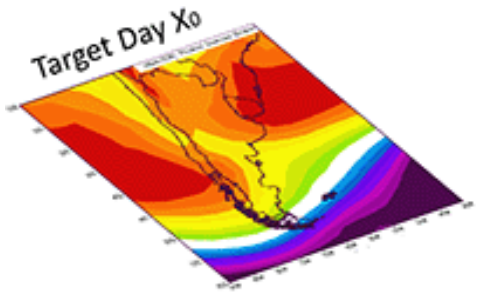
🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

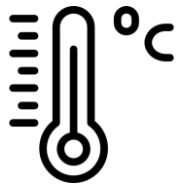
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:** 🌀 🌡️ ☂️ 🌬️
- Pressure, Temperature, Precipitation, Winds

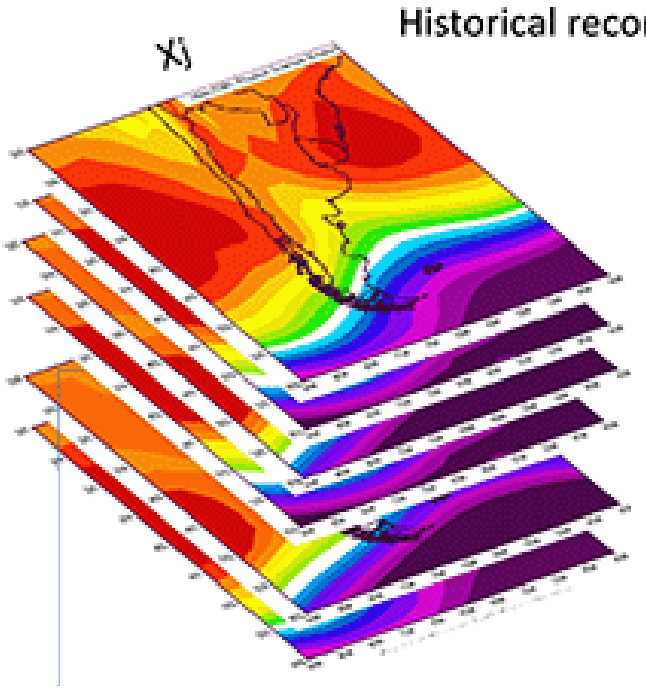
🌍 **Natural Variability Modes Change of phase in analogues:**
- ENSO, AMO, PDO

Weather analogs





Euclidiens distances



Past

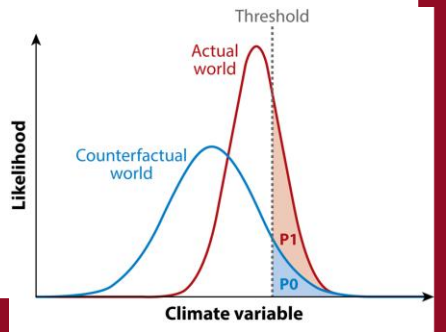
Present

time

Temporal mean of the variable

Counter factual world

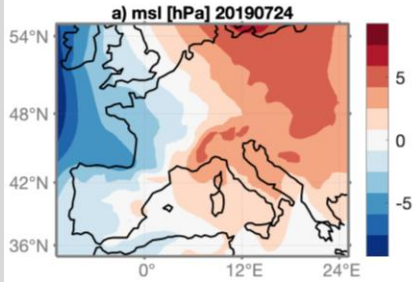
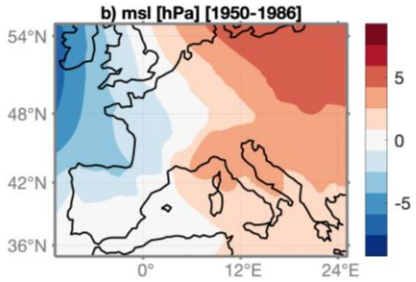
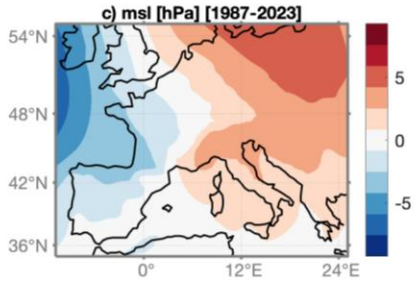
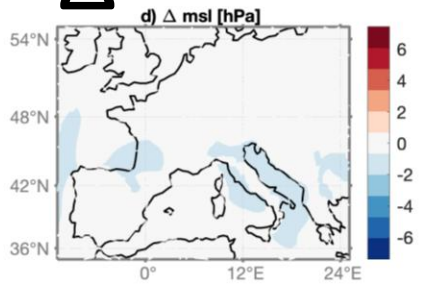
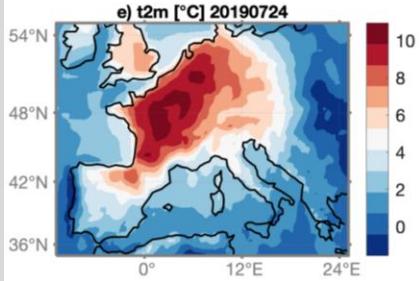
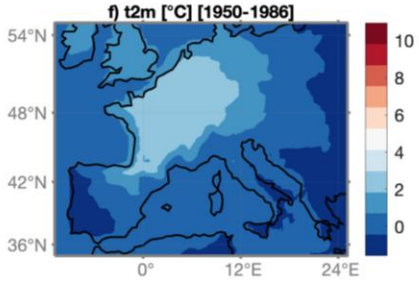
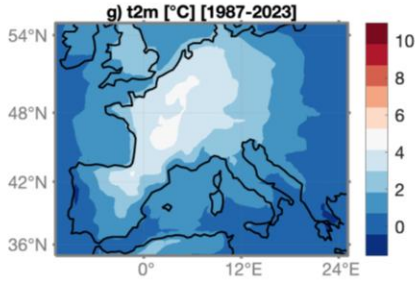
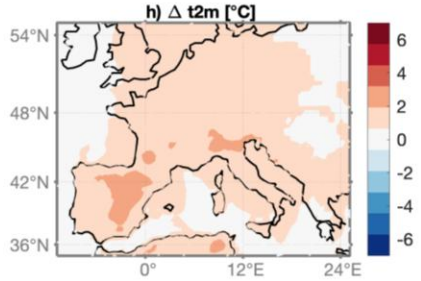
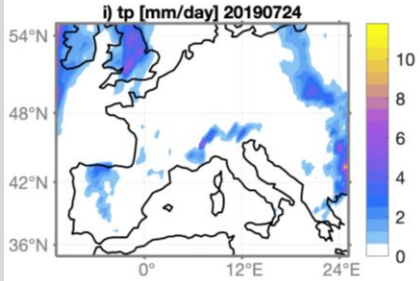
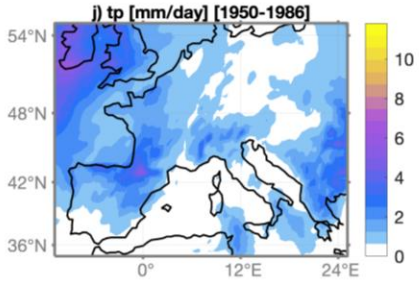
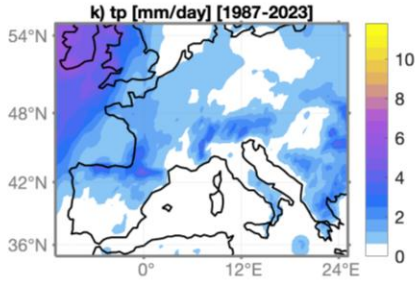
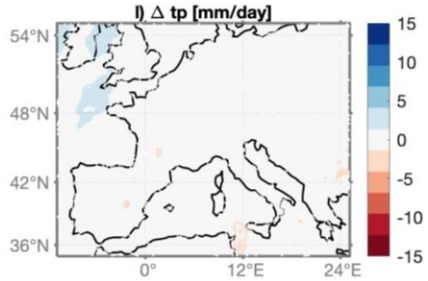
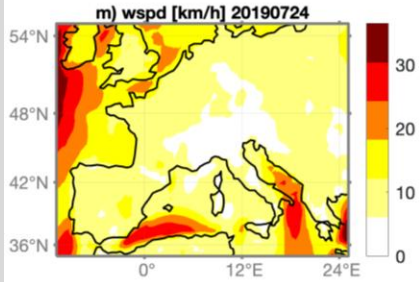
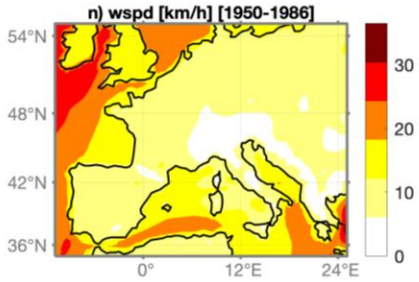
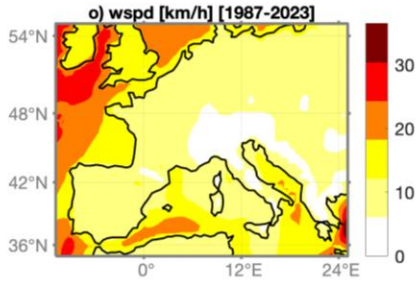
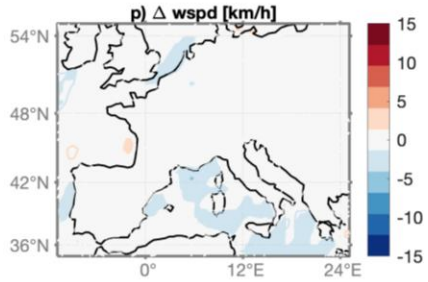
Factual world



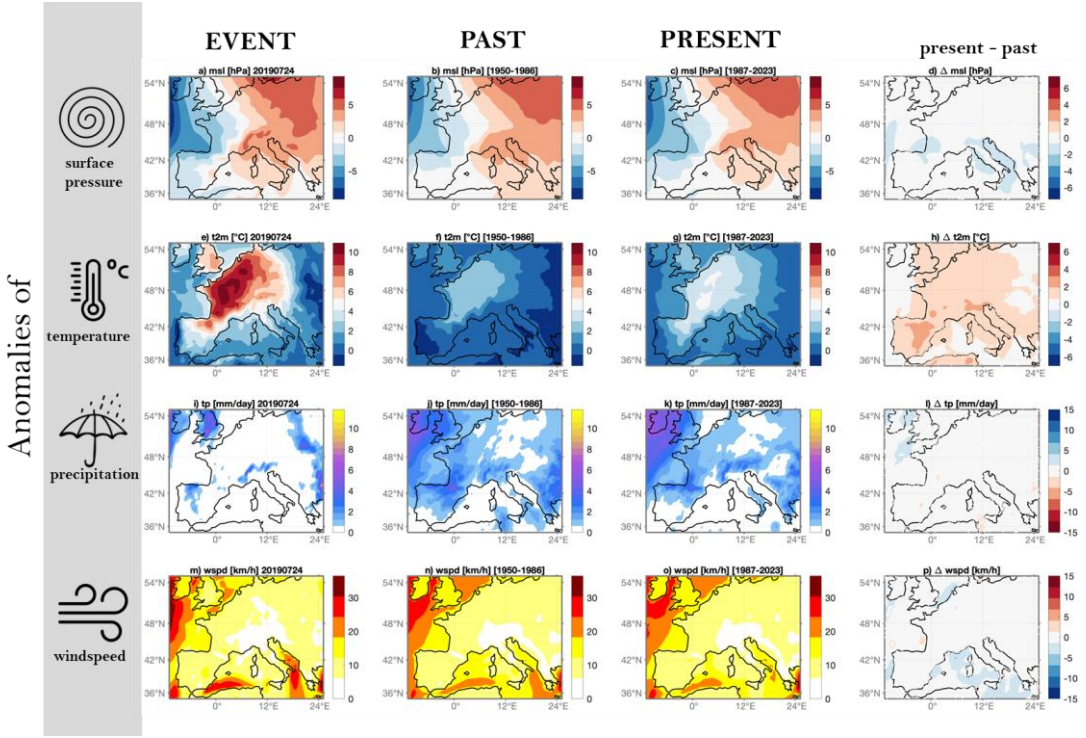
Figures from : María Laura Bettolli, Analog Models for Empirical-Statistical Downscaling

Figure from Otto FEL. 2017. Annu Rev Environ Resour

Anomalies of

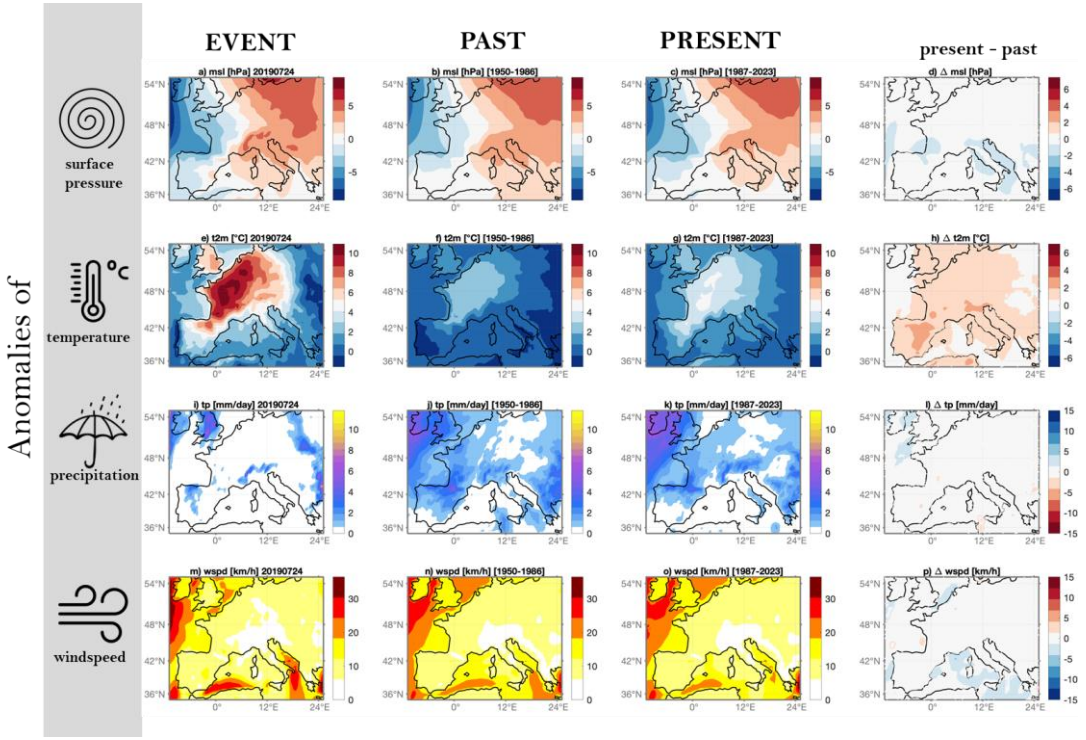
	EVENT	PAST	PRESENT	Δ present - past
surface pressure				
temperature				
precipitation				
windspeed				

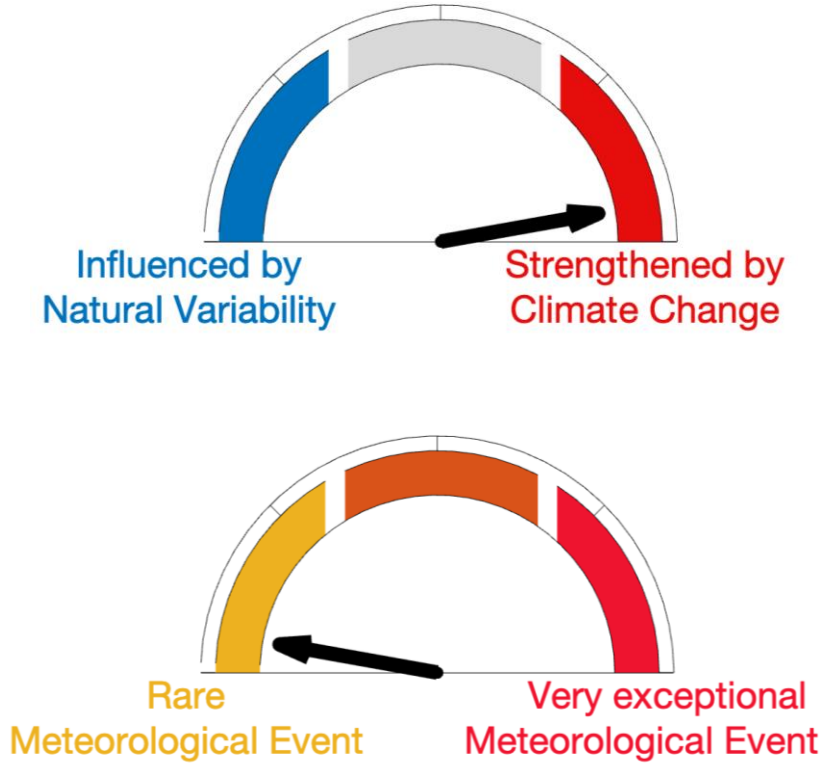
Heatwave of 23-24 July 2019



ClimaMeter analysis

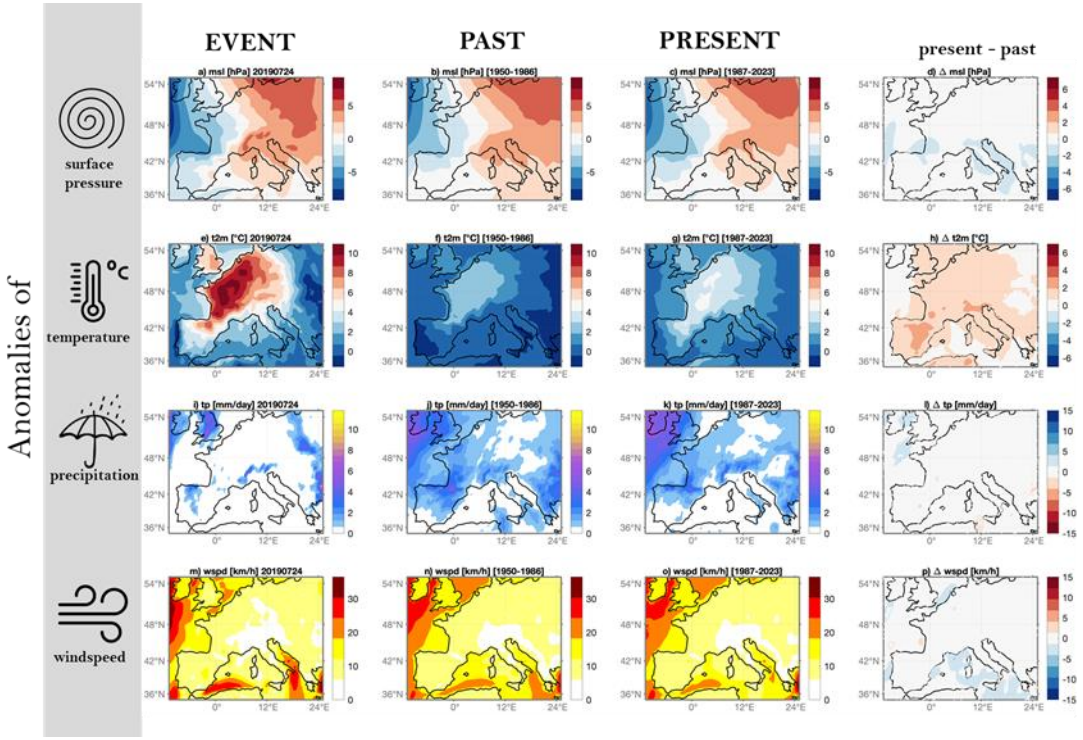
Climate variability



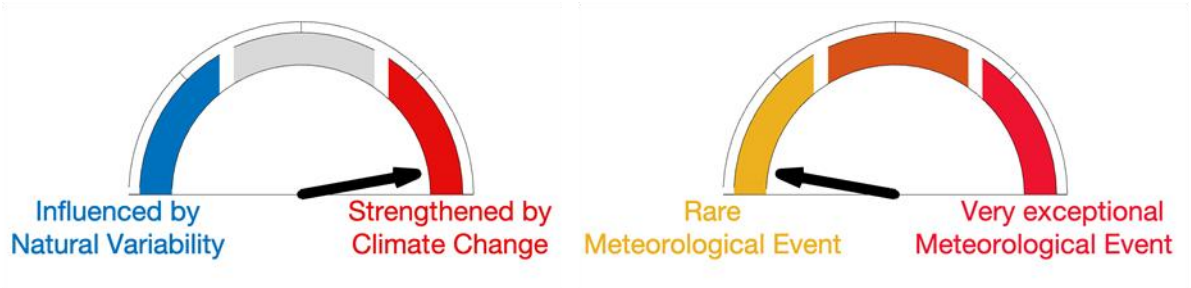


ClimaMeter analysis

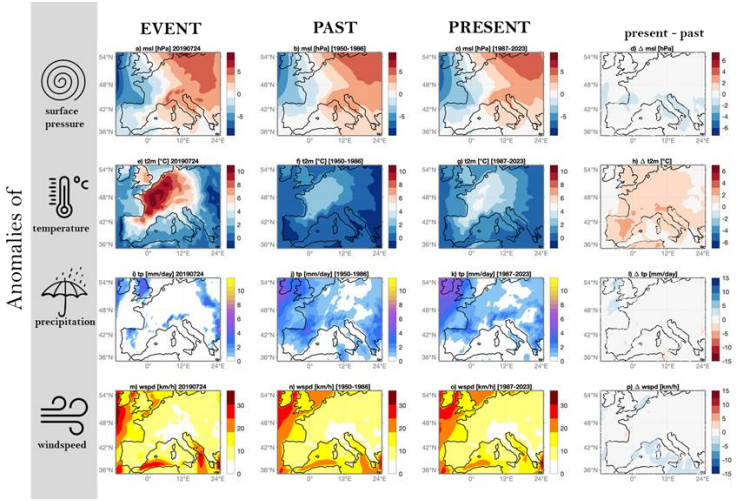
Heatwave of 23-24 July 2019

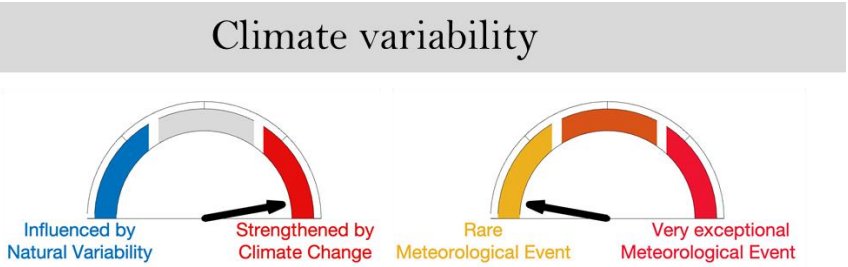


Climate variability



Conditional attribution

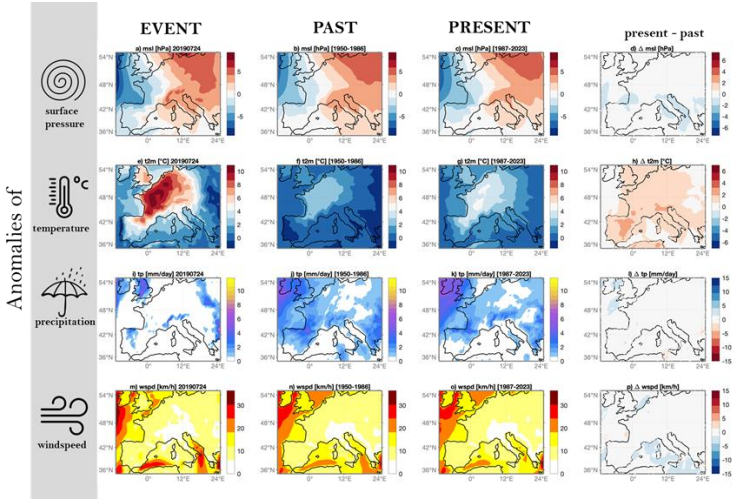


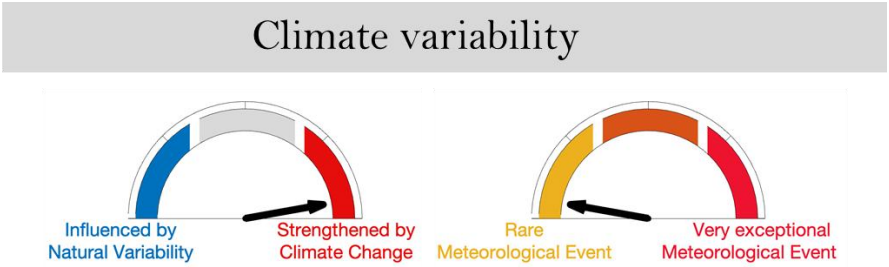


How can the influence of climate change on societies and ecosystems – the real observed consequences faced by populations – be assessed?

From climate event attribution to impact attribution: what is the next step?

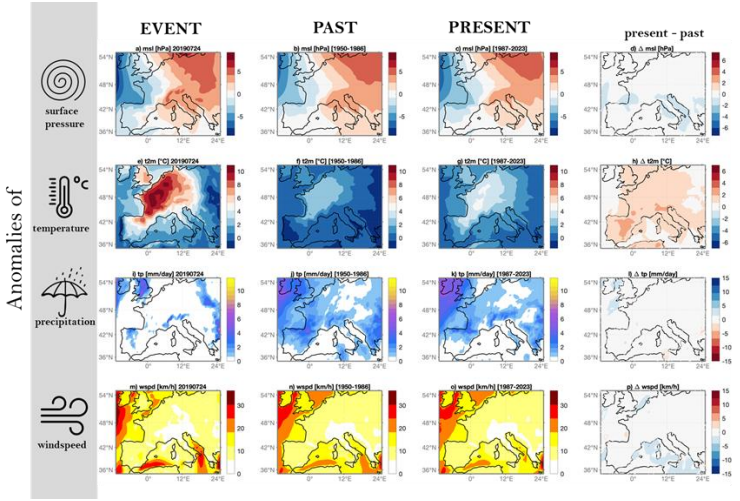
Conditional attribution

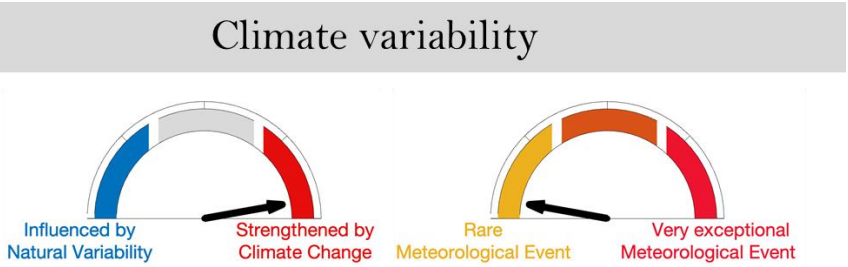




From climate event attribution to impact attribution: what is the next step?

Conditional attribution





From climate event attribution to impact attribution: **what is the next step?**

Focus on the energy system:

How can we assess the impact of extreme temperatures on the power system ?

1st approach:

Attribution of renewable energy production: a case study

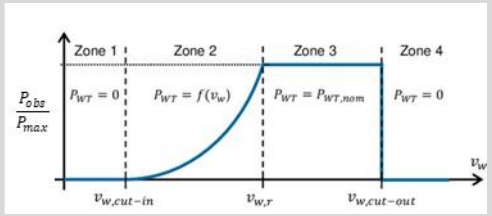
Modeling the impact on renewable production

Method

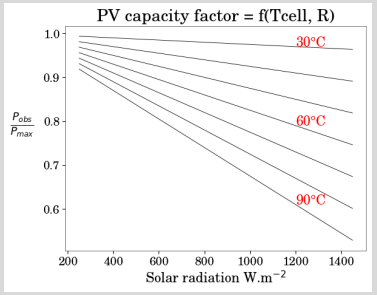
Spatial distribution of renewable production under current capacity

Model potentiel & production

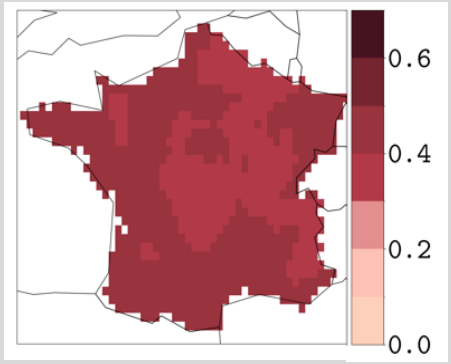
Wind turbine



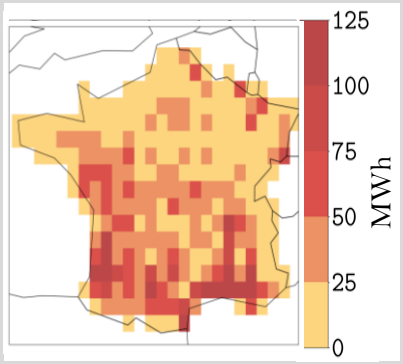
PV panel



Potential map



Production map



🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

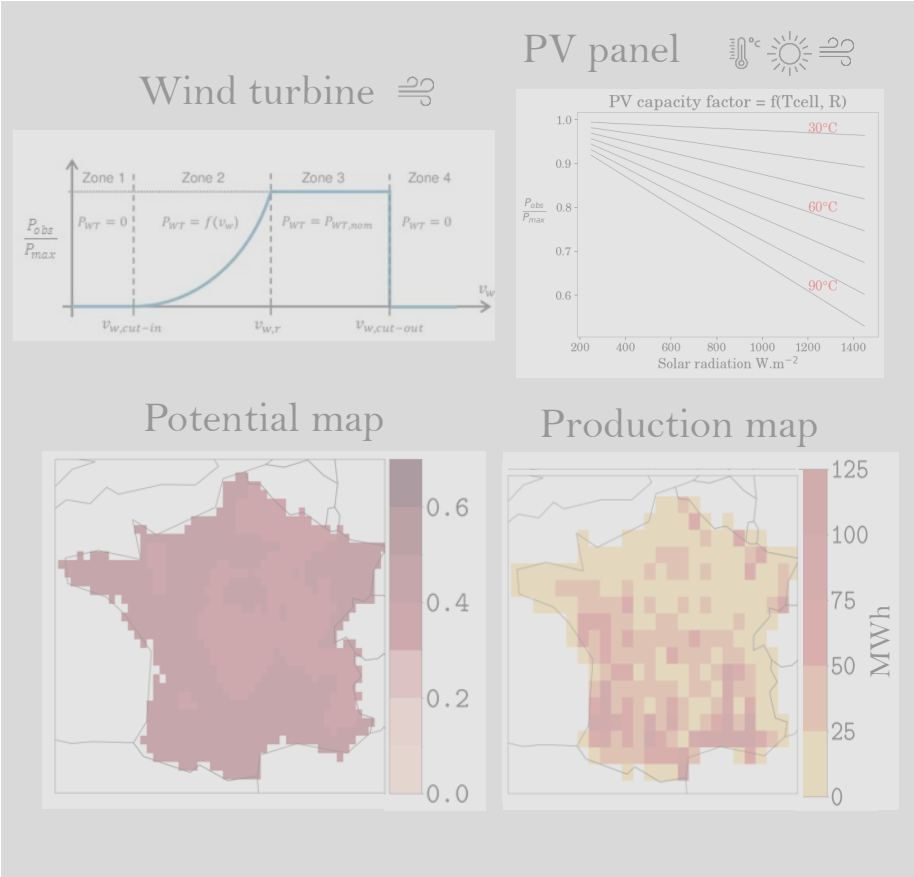
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Model potentiel & production



Spatial distribution of renewable production under current capacity

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

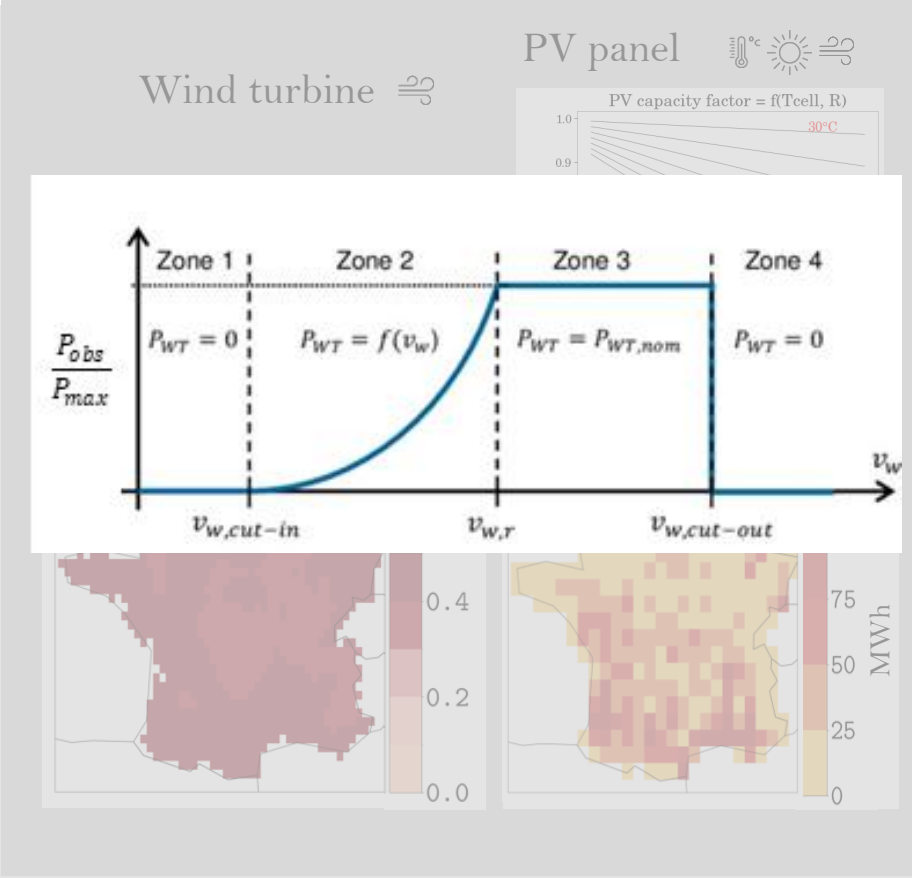
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Model potentiel & production



Spatial distribution of renewable production under current capacity

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

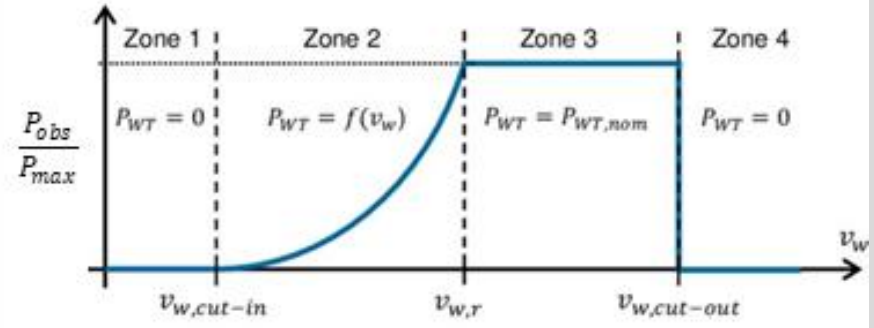
Modeling the impact on renewable production

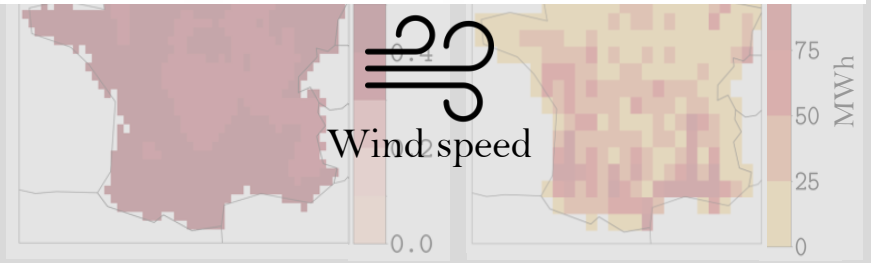
Method

Model potentiel & production

PV panel

Potential of production of a wind turbine in relation to **wind speed**





Spatial distribution of renewable production under current capacity

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

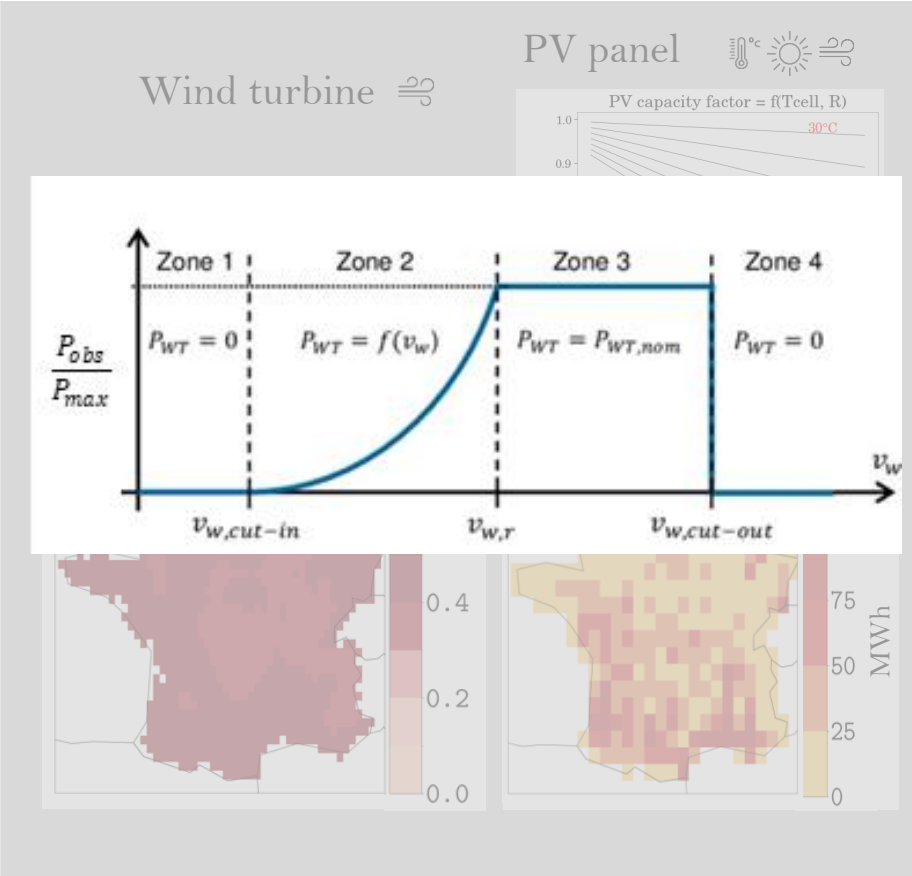
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Model potentiel & production



Spatial distribution of renewable production under current capacity

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

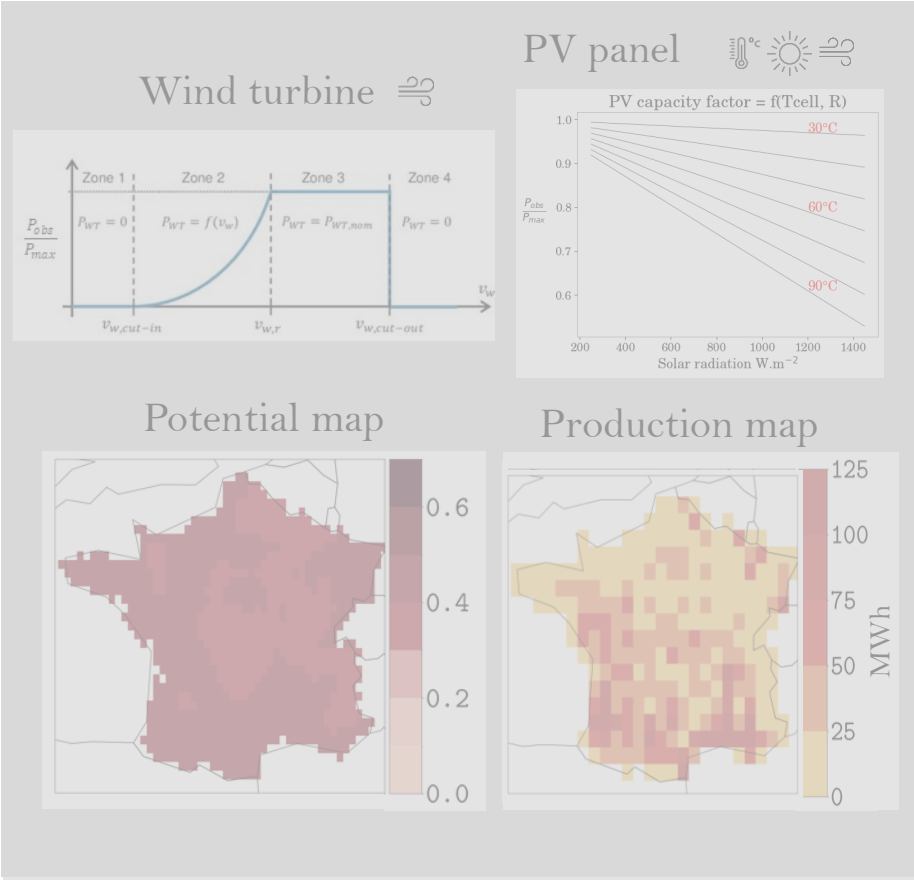
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Model potentiel & production



Spatial distribution of renewable production under current capacity

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

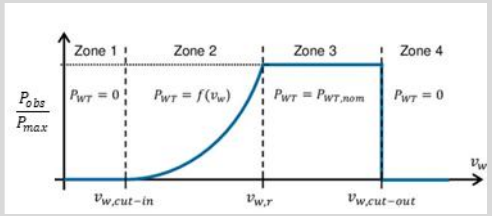
Modeling the impact on renewable production

Method

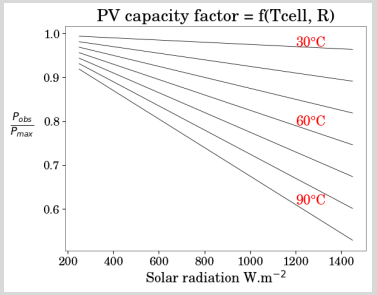
Spatial distribution of renewable production under current capacity

Model potentiel & production

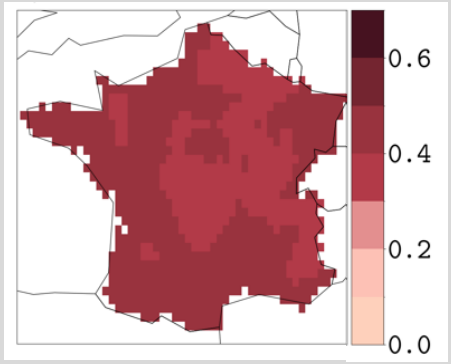
Wind turbine



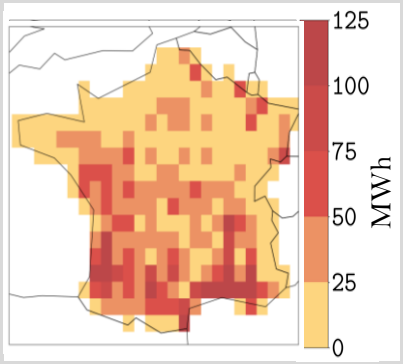
PV panel



Potential map



Production map



🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

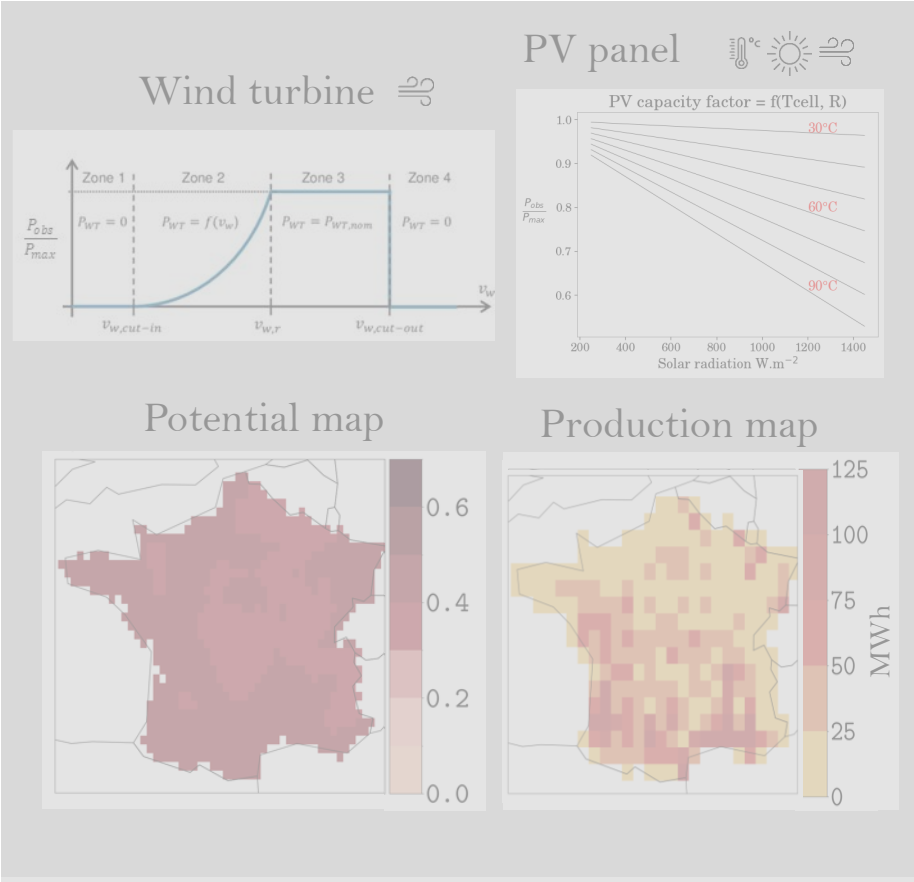
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Model potentiel & production



Spatial distribution of renewable production under current capacity

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

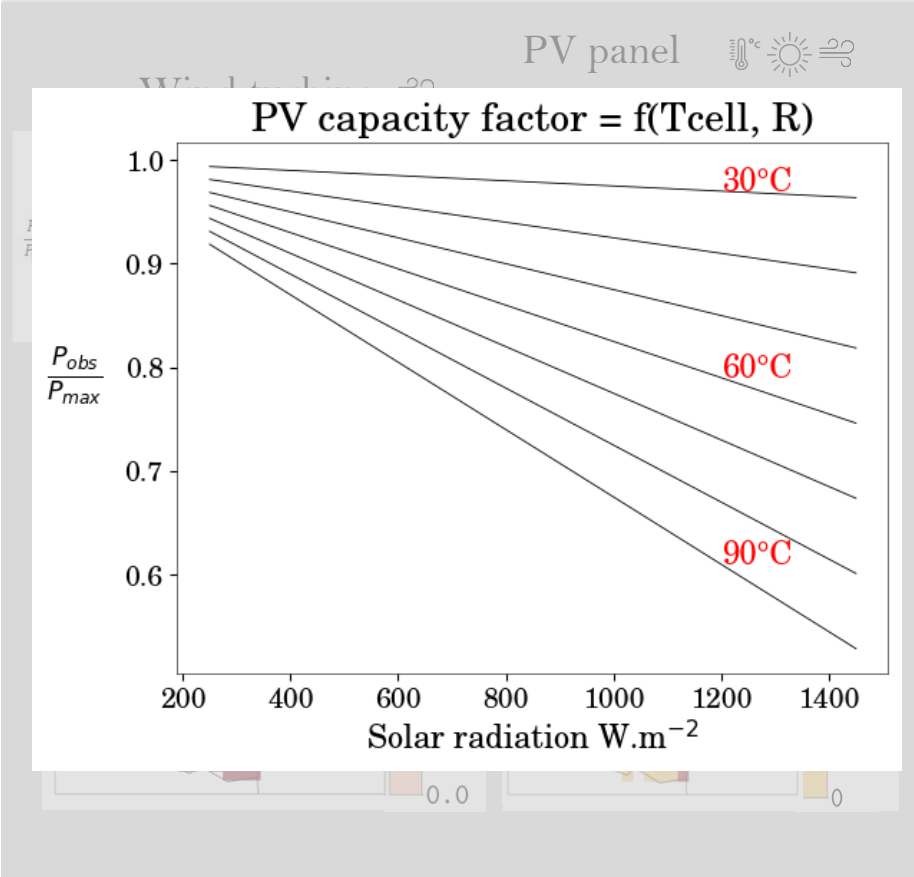
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Model potentiel & production



Spatial distribution of renewable production under current capacity

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

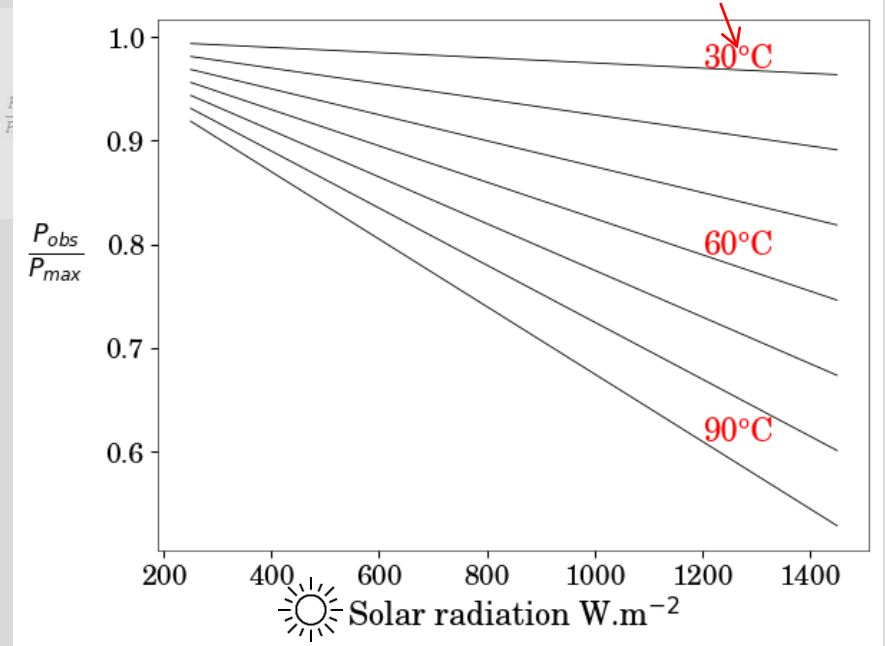
📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Model potentiel & production

Potential of production of a PV panel in relation to **solar radiation & T cell**



T° PV cell = f(🌡️;☀️,🌬️)

Spatial distribution of renewable production under current capacity

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

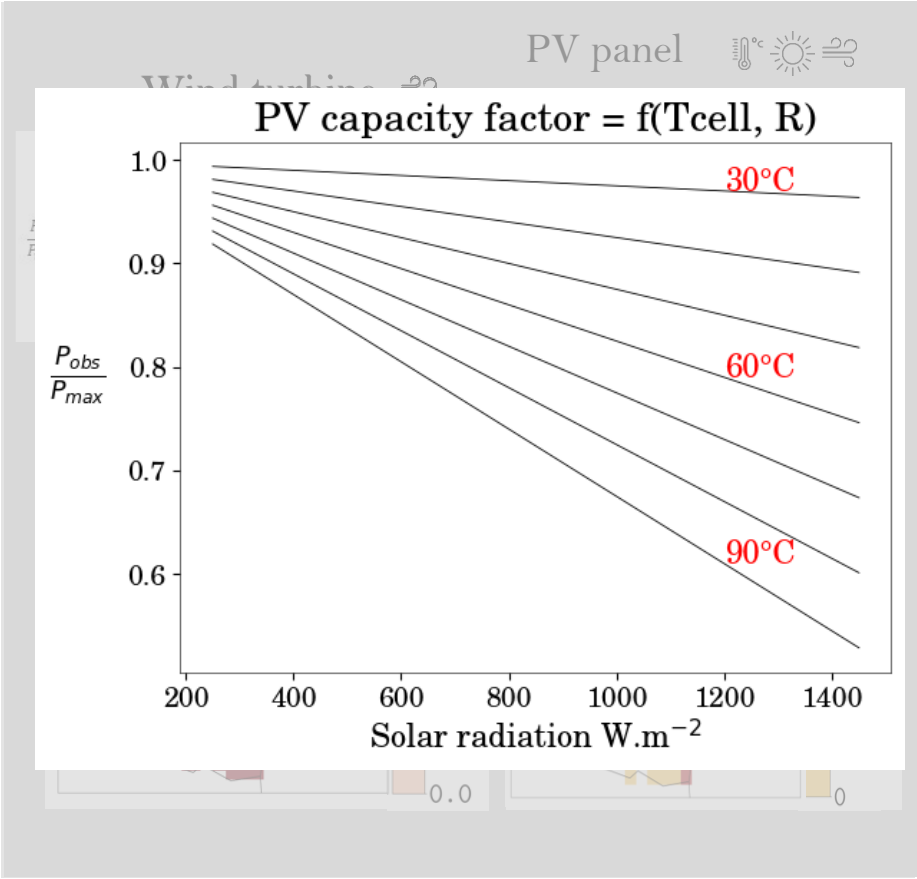
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Model potentiel & production



Spatial distribution of renewable production under current capacity

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

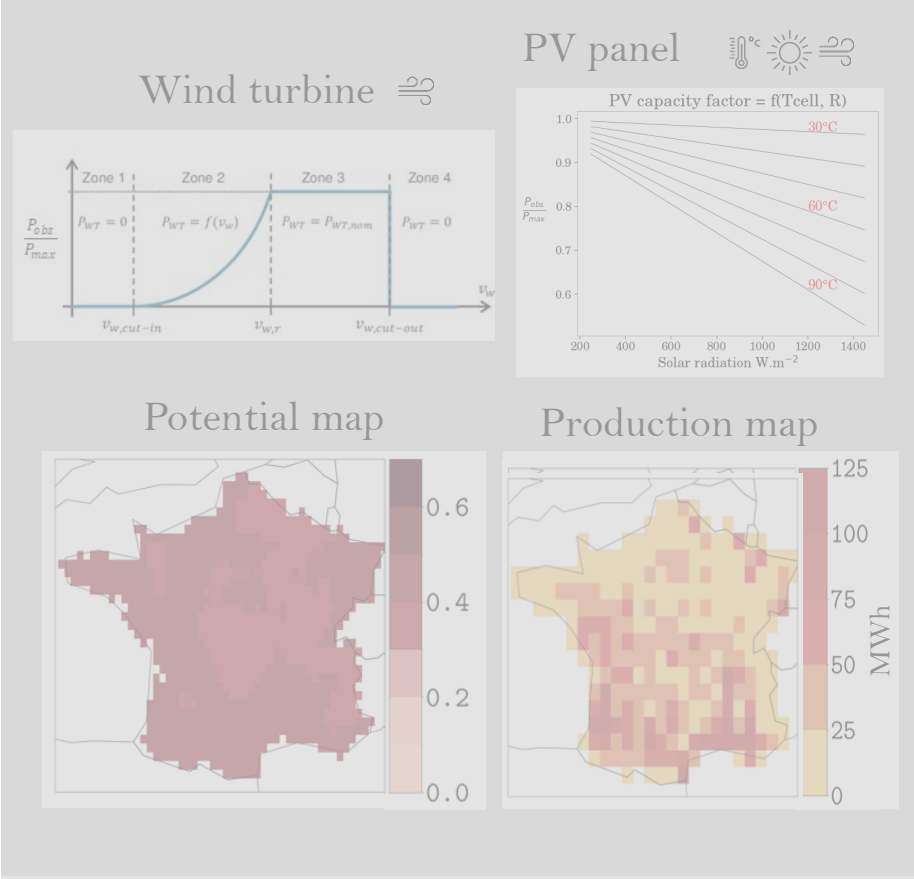
📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Spatial distribution of renewable production under current capacity

Model potentiel & production



🌐 **Data**:

- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:

- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**

- Assess differences in Present vs. Past Analogues

⏰ **Periods**:

- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**

- Capacity factors, production of PV panel, windfarms

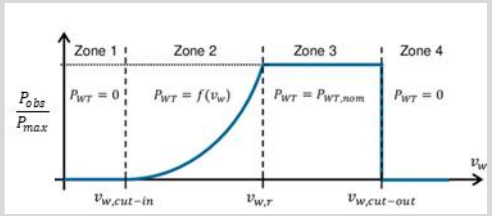
Modeling the impact on renewable production

Method

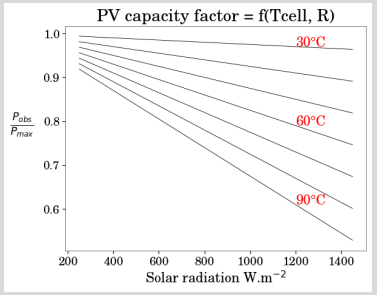
Spatial distribution of renewable production under current capacity

Model potentiel & production

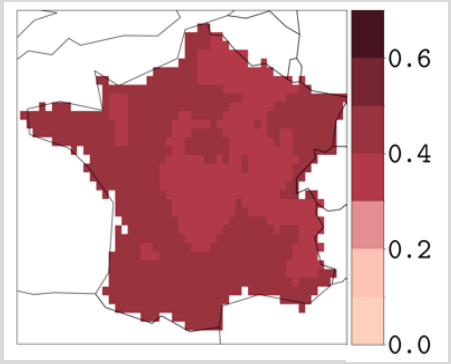
Wind turbine



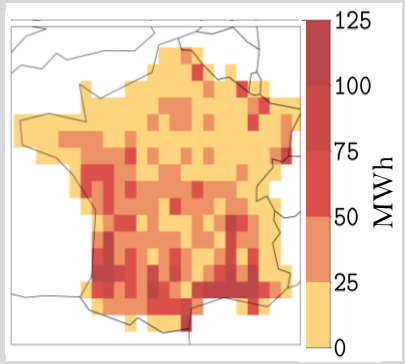
PV panel



Potential map



Production map



🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

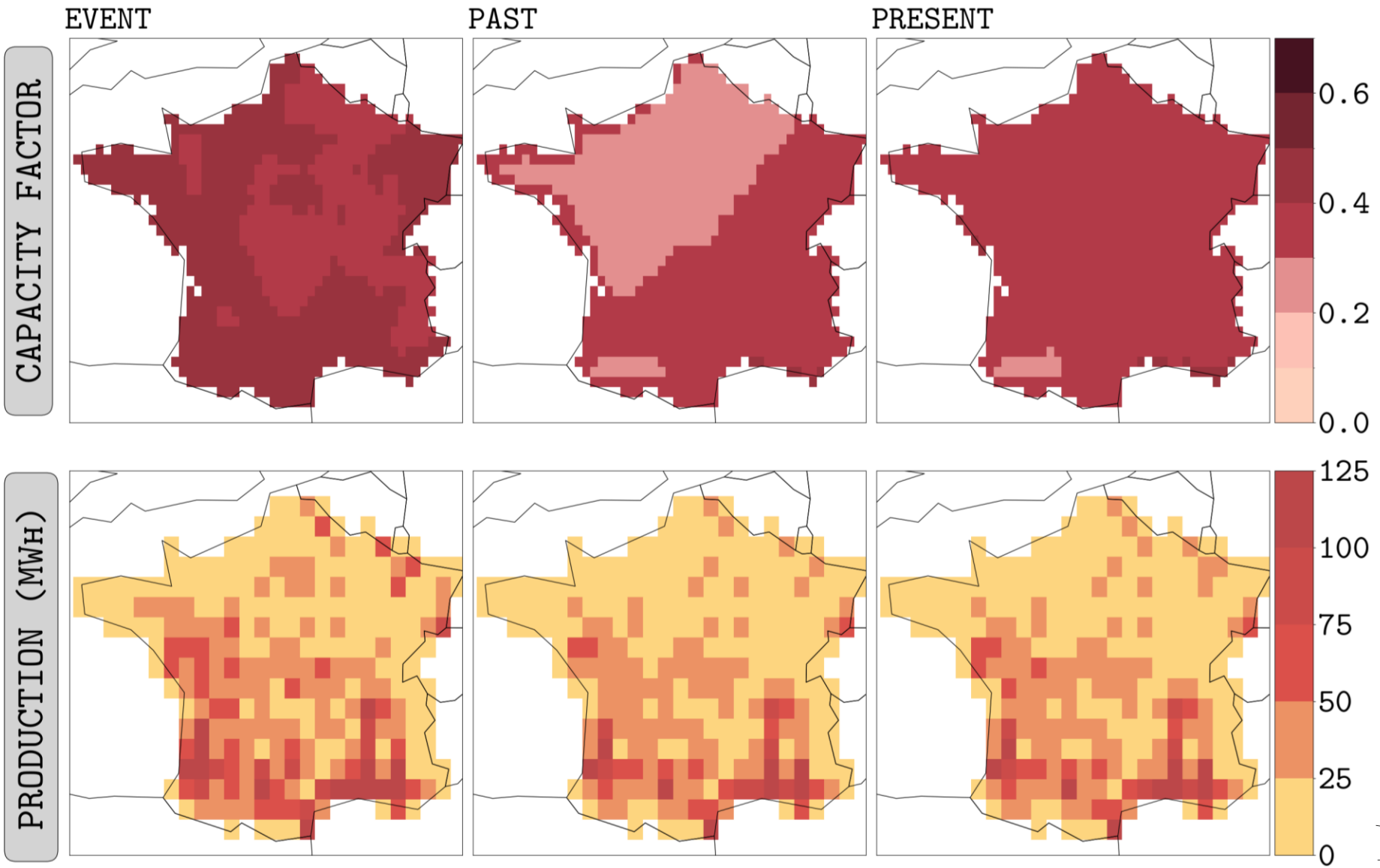
🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

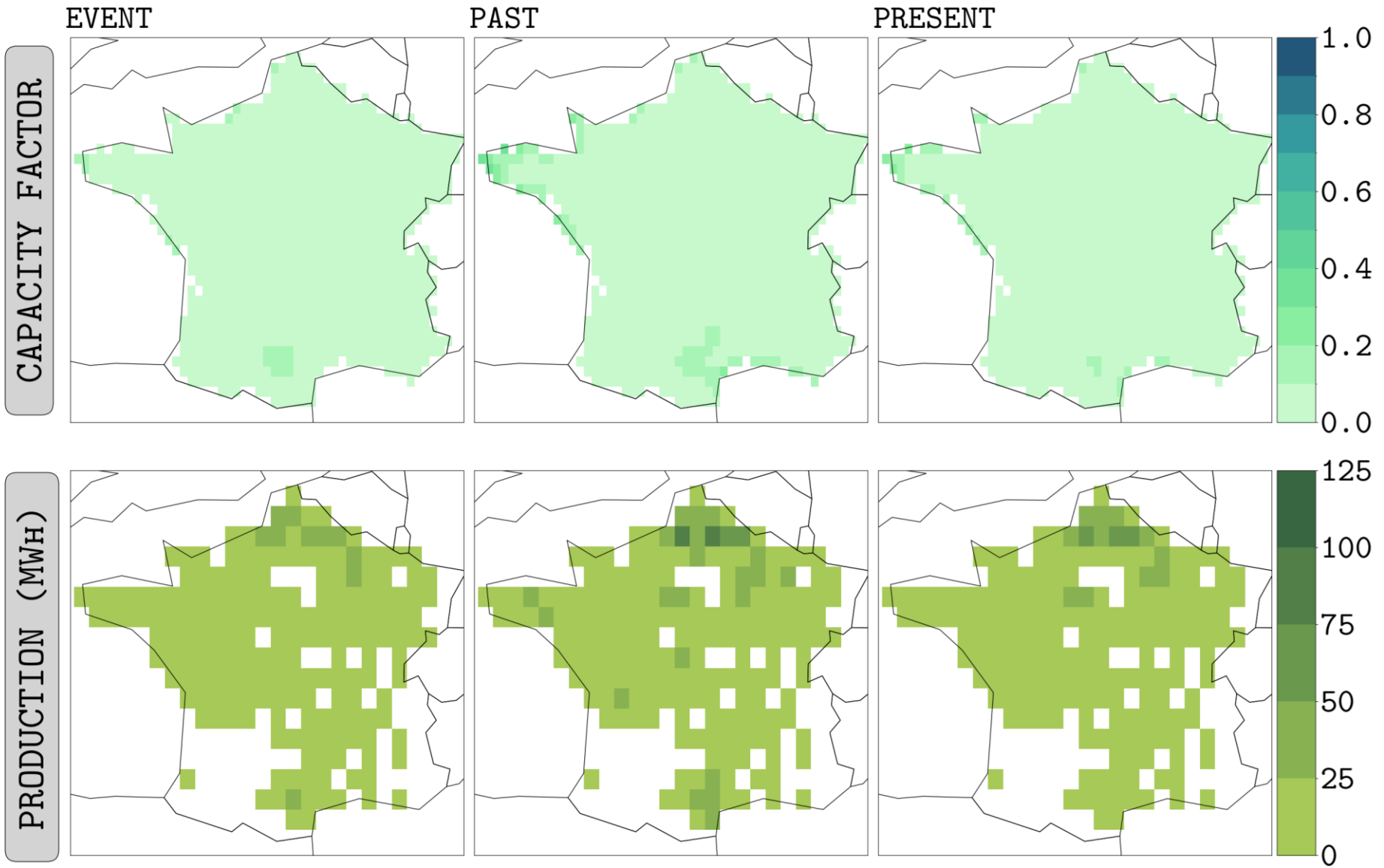
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

PV PANEL ANALYSIS



WIND FARMS ANALYSIS

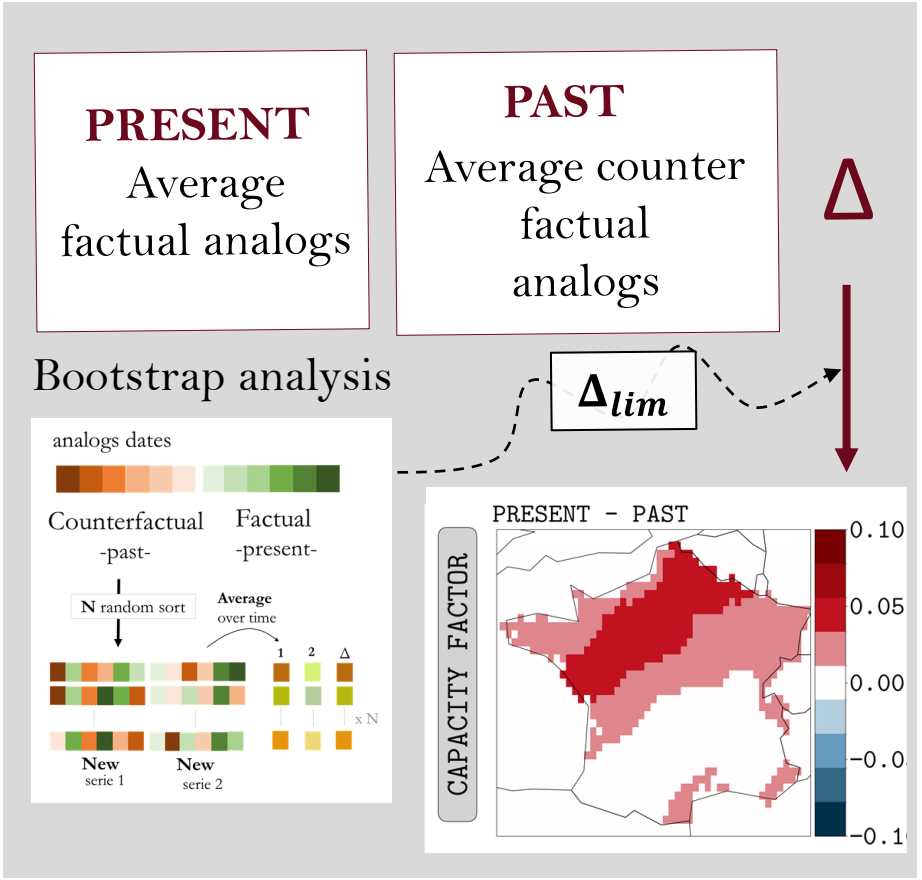


Modeling the impact on renewable production

Method

Statistically significant difference

Increase or decrease in production, Spatial mapping



🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

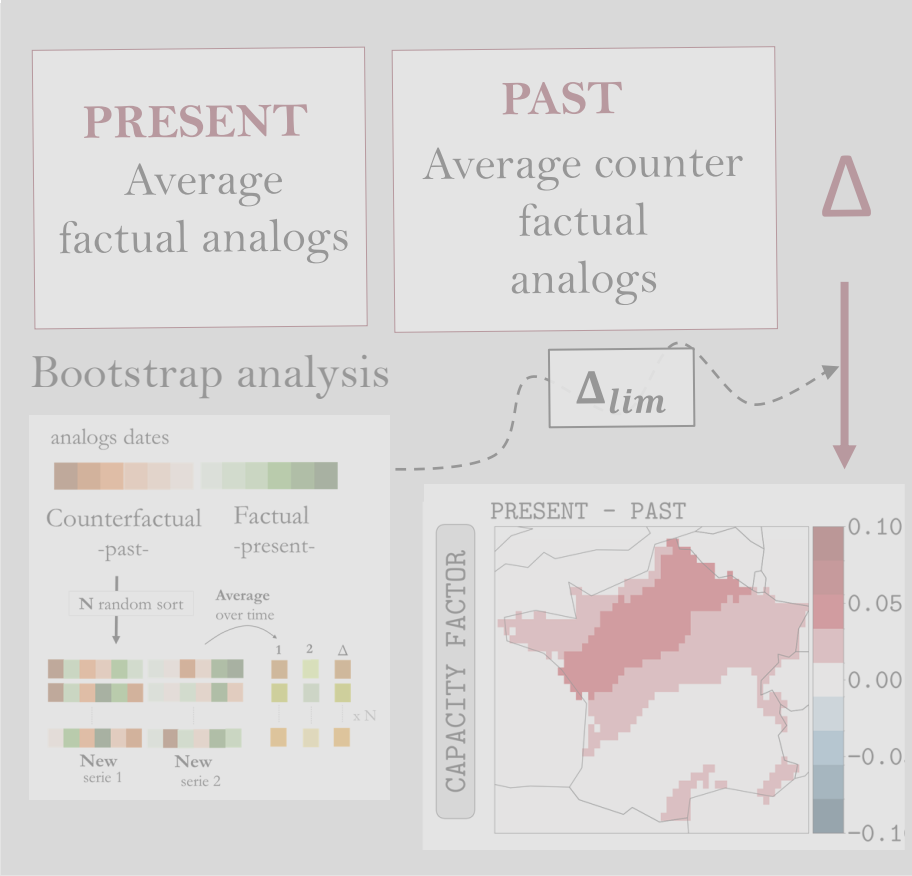
⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes**:
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Statistically significant difference



Increase or decrease in production, Spatial mapping

🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

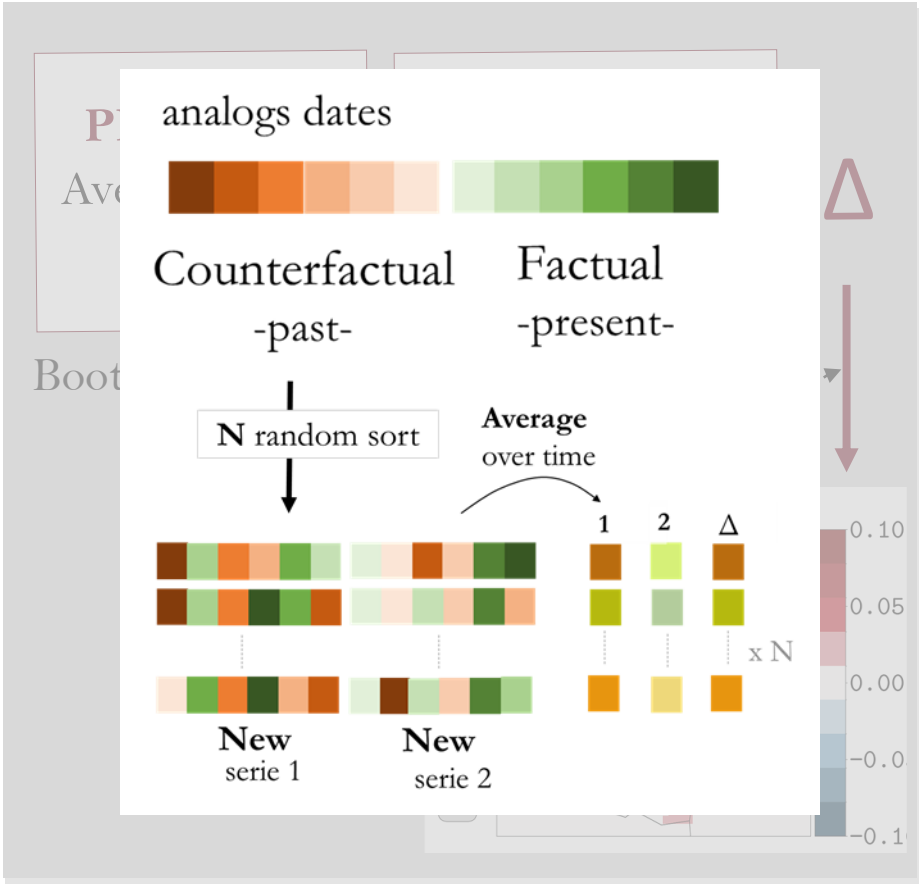
📊 **Diagnosed Changes**:
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Statistically significant difference

Increase or decrease in production, Spatial mapping



🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

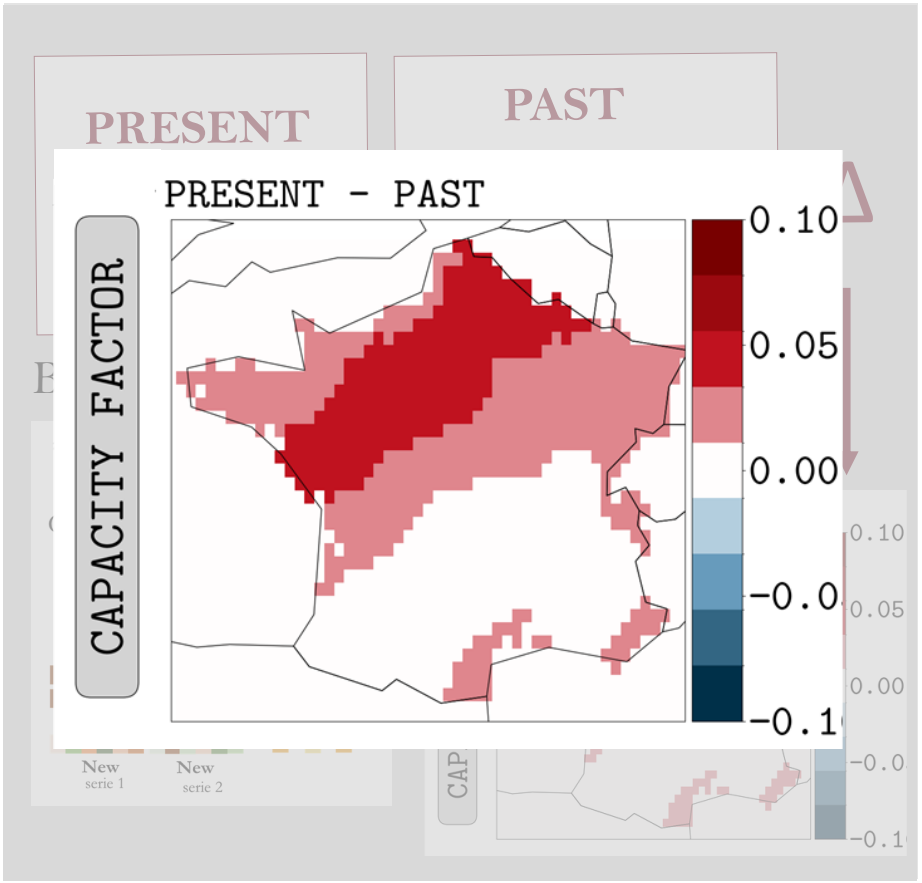
📊 **Diagnosed Changes**:
- Capacity factors, production of PV panel, windfarms

Modeling the impact on renewable production

Method

Statistically significant difference

Increase or decrease in production, Spatial mapping



🌐 **Data**:
- gridded data from reanalyses based on ERA5 (1950 to Present)
- gridded installed renewable power in France in 2022 (FR open data)

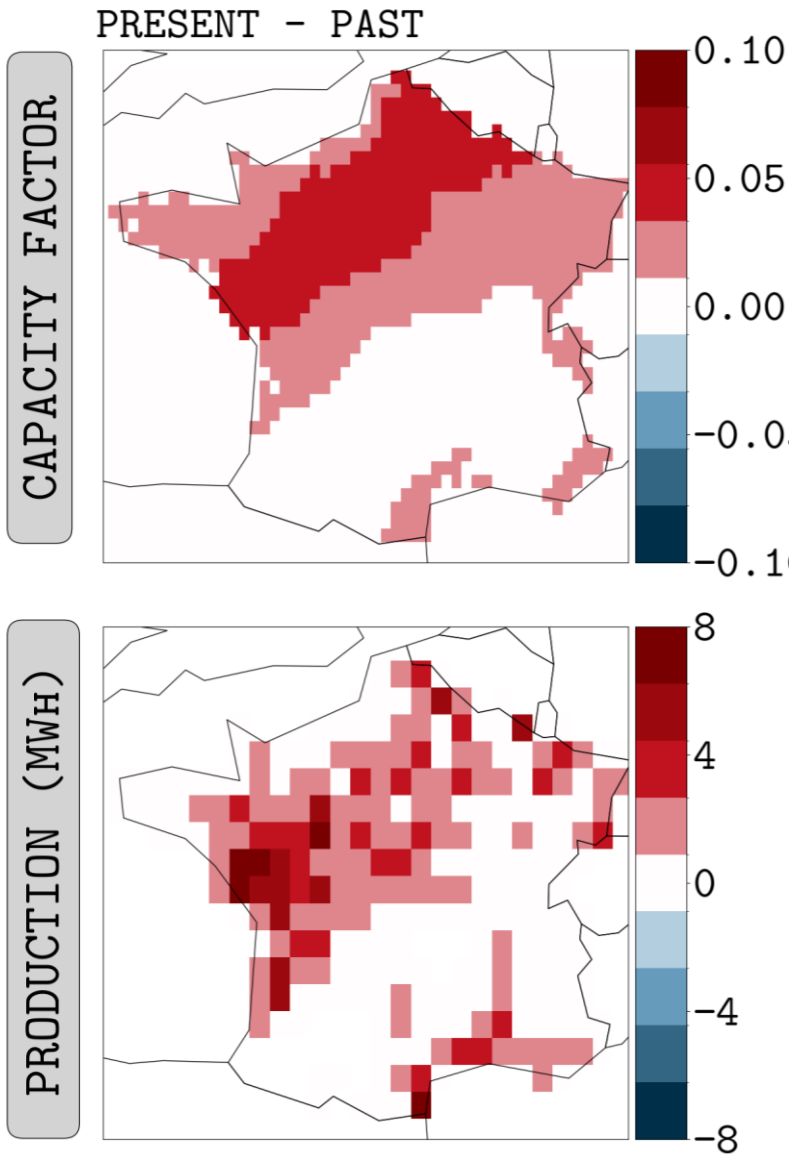
🌀 **Capacity factor definition**:
- Ratio of actual production to maximum possible output, calibrated to current system performance

🔍 **Analogues Analysis**
- Assess differences in Present vs. Past Analogues

⏰ **Periods**:
- Split into two periods (1950 - 1980 | 1980 – 2024)

📊 **Diagnosed Changes:**
- Capacity factors, production of PV panel, windfarms

PV PANEL ANALYSIS



Fixed threshold : 90th percentile

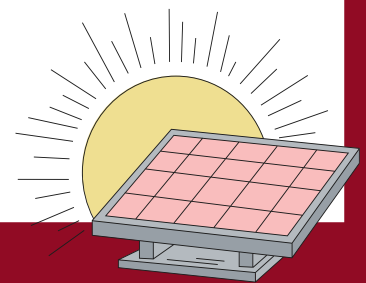
CAPACITY FACTOR

Average increase : + 0.01

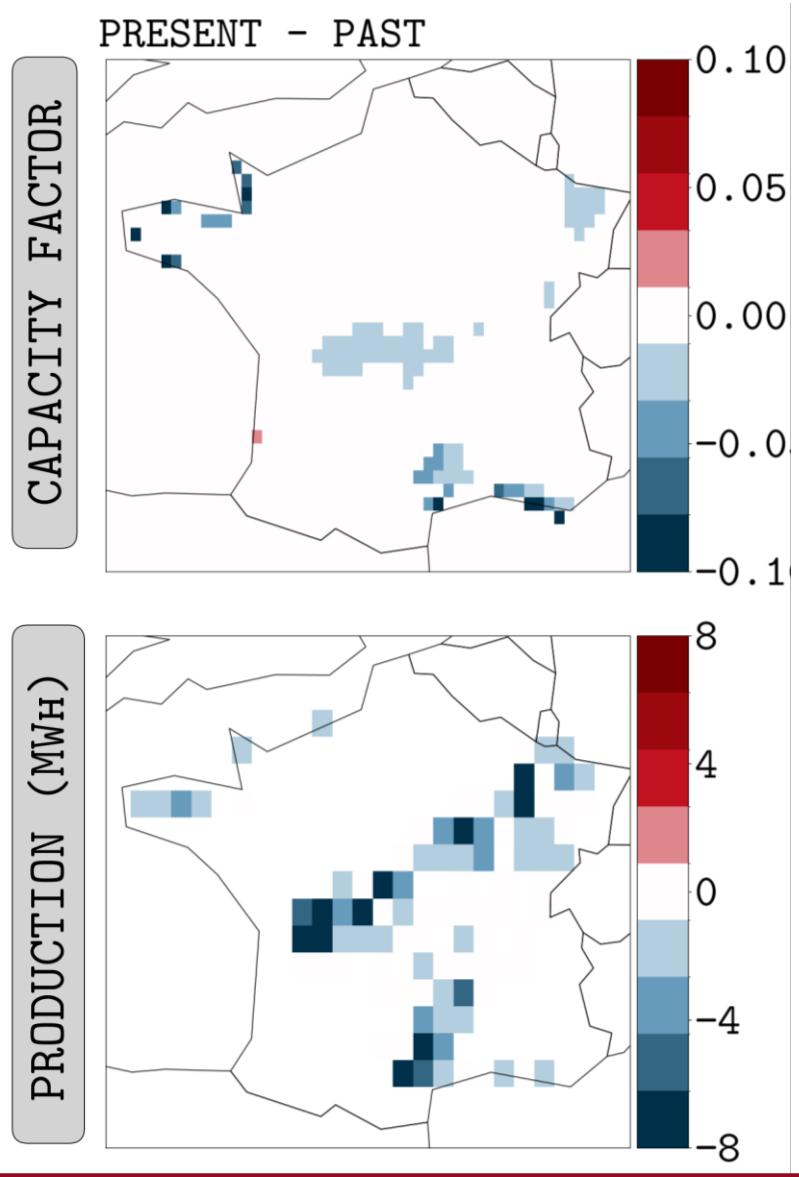
Max increase : + 0.05

PRODUCTION

Total increase : **+ 375 MWh**



WIND FARMS ANALYSIS



Fixed threshold : 90th percentile

CAPACITY FACTOR

Average decrease : - 0.01

Max decrease : - 0.09

PRODUCTION

Total increase : **- 195 MWh**

Conclusion

Extreme events attribution → Impacts of extreme temperatures on renewable energy production

A ClimaMeter approach applied to energy production :

- Production potential modeled from weather variables ;
- Estimated production based on 2022 installed capacity ;
- Spatial mapping of gains and losses ;
- Identification of statistically significant variations.

Perspectives

EnergyMeter : A methodological framework to assess the impacts of extreme temperatures on the power systems

- Integration of additional production source (thermal, hydro) ;
- Evaluation of energy demand sensitivity to temperature extremes ;
- Analysis of vulnerabilities in transmission and distribution networks ;
- Additional case studies focused on the Mediterranean Basin.

Thank you !

Thank you !

Questions ?