Impact of climate change on photovoltaic performance

EUPVSEC 2023

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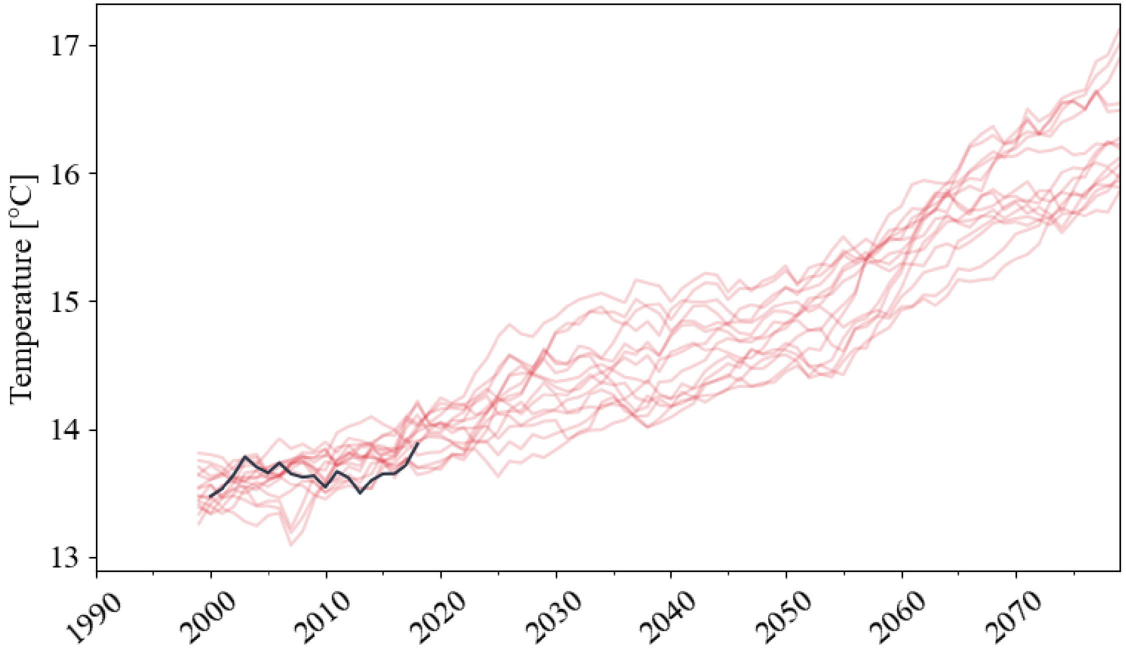
Introduction
Research Question
Methodology
Results
Conclusion

Introduction

Due to climate change, environmental variables are inevitably going to change…

Yearly average temperature projections according to RCP8.5 at Bordeaux



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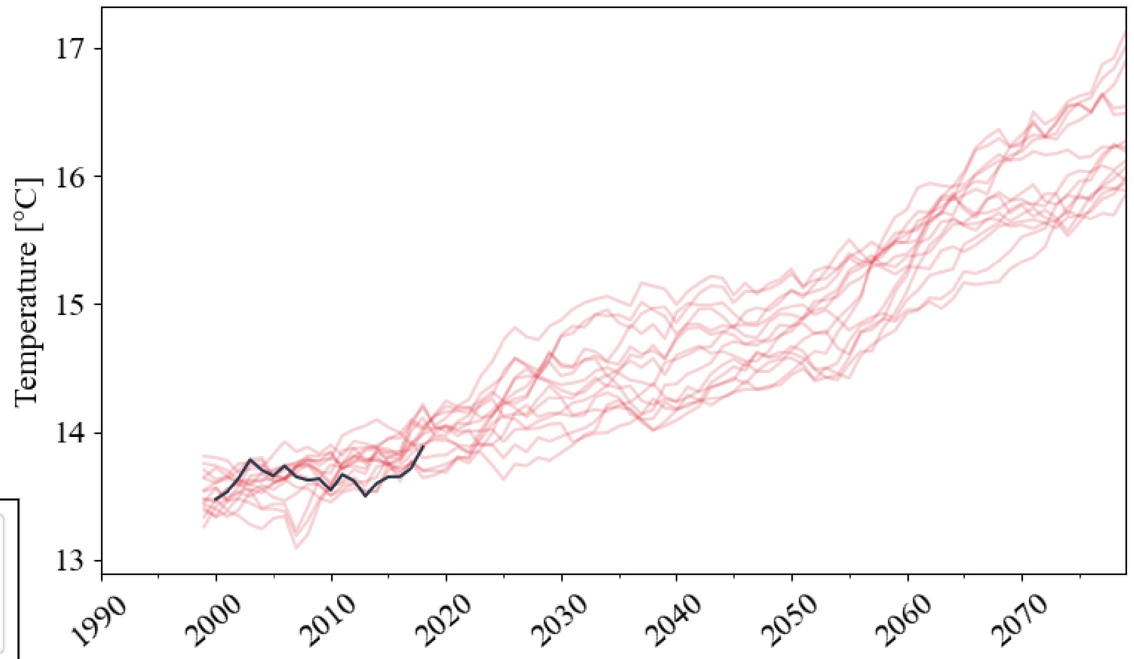
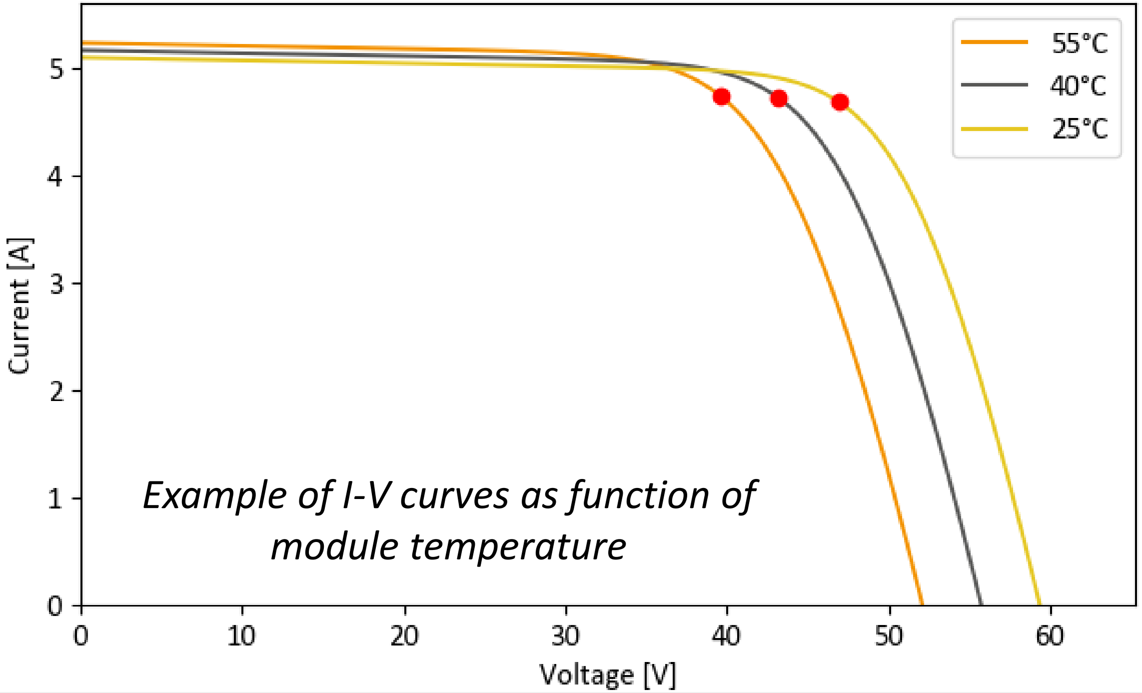


… and will result in different PV operating conditions such as, for instance, more temperature losses



Example of I-V curves as function of module temperature

Research question

How do climate projections translate to PV performance losses ?

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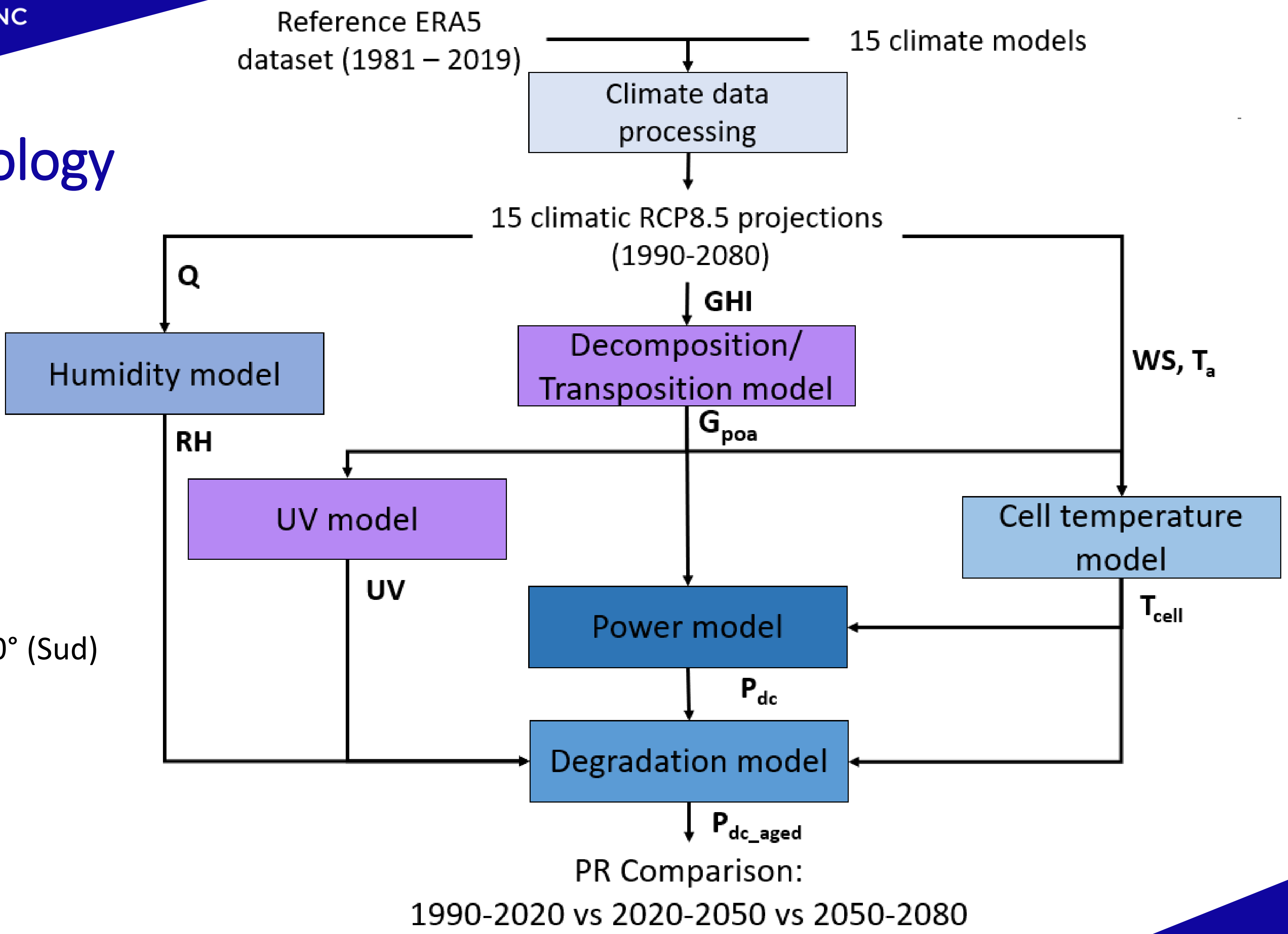
Methodology



PV installation
- Azimuth = 180° (Sud)
- Tilt = 30°

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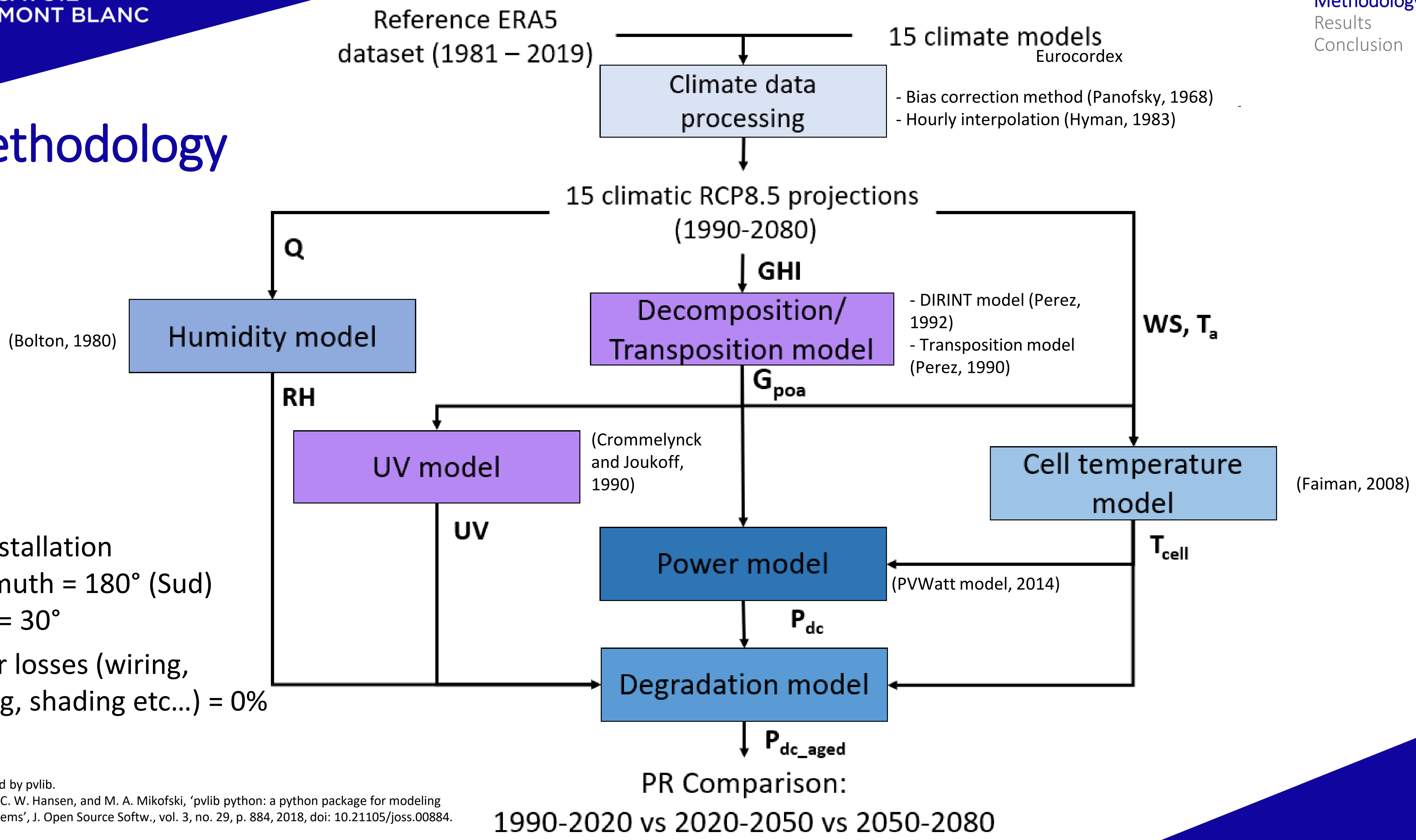
Methodology



PV installation
- Azimuth = 180° (Sud)
- Tilt = 30°

Other losses (wiring, soiling, shading etc…) = 0%

Mainly supported by pvlib.
W. F. Holmgren, C. W. Hansen, and M. A. Mikofski, 'pvlib python: a python package for modeling solar energy systems', J. Open Source Softw., vol. 3, no. 29, p. 884, 2018, doi: 10.21105/joss.00884.

Methodology, natural ageing

Kaaya's model*

$$\eta_{ageing}(y) = 1 - \exp(-\left(\frac{\Gamma}{k(y) \cdot (y - y_0)}\right)^{\mu})$$

with:

- y_0 the installation year
- (Γ, μ) empirical constants
- $k(y)$ the total degradation rate

* Ismail, Kaaya & Köhl, Michael & Mehilli, Amantin - Panos & Sidrach-de-Cardona, M. & Weiss, Karl. (2019). Modeling Outdoor Service Lifetime Prediction of PV Modules: Effects of Combined Climatic Stressors on PV Module Power Degradation. IEEE Journal of Photovoltaics. PP. 1-8. 10.1109/JPHOTOV.2019.2916197.

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Actually, **k(y)** depends on environmental variables

$$k(y) = f(k_H(y), k_P(y), k_{Tm}(y))$$

Hydrolysis-driven degradation

- $k_H(y) = A_H \cdot RH(y)^n \cdot exp\left(-\frac{E_{ah}}{k_B \cdot T_{mod}(y)}\right)$

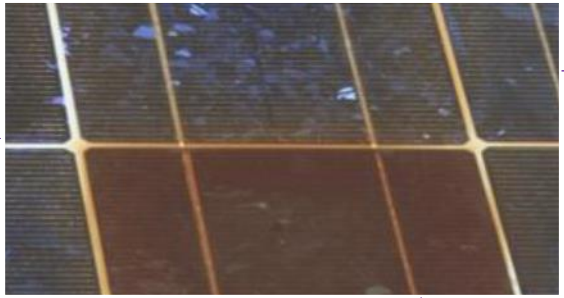
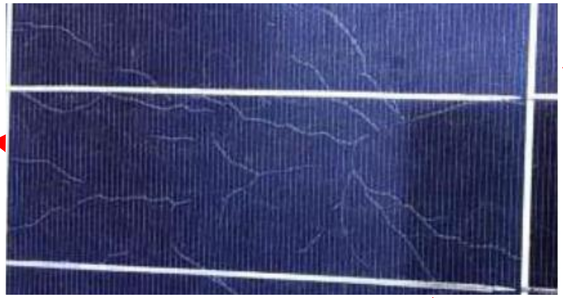


Photo-degradation

- $k_P(y) = A_p \cdot UV(y)^x \cdot (1 + RH(y)^n) \cdot exp\left(-\frac{E_{ap}}{k_B \cdot T_{mod}(y)}\right)$



Thermo-mechanical degradation

- $k_{T_m}(y) = A_t \cdot C_N \cdot (273 + \Delta T(y))^{\theta} \cdot exp\left(-\frac{E_{at}}{k_B \cdot T_{max}(y)}\right)$

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** Pictures: Cécile Miquel et al. Dysfonctionnement électriques des installations photovoltaïques: points de vigilance. PTVIGI1801. AQC - HESPUL, Oct. 1, 2018 et Marc Köntges et al. Review of Failures of Photovoltaic Modules. IEA-PVPS T13-01:2014. IEA PVPS T13, 2014.

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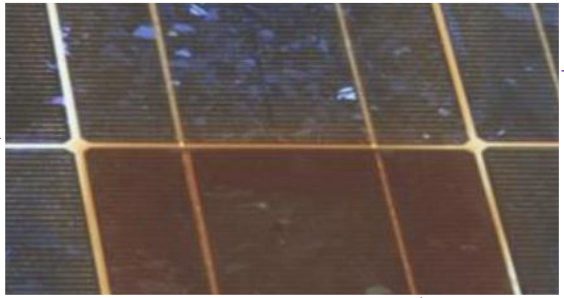

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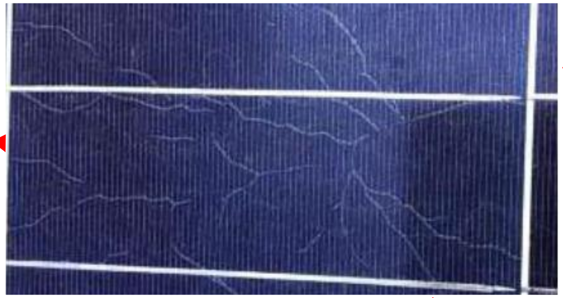

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Parameters extracted from Kaaya's study 2019*, on an open rack installation, mc-Si, with polymer backsheet and aluminium frame

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Methodology, PR

$$PR\,(y) = \eta_{power}(y) \cdot n_{ageing}(y)$$

Methodology, PR

$$\boldsymbol{PR\ (y) = \eta_{power}(y) \cdot n_{ageing}(y)}$$

$$\eta_{power}(y) = \frac{\int_{y} P_{out}(t)\,dt \;/\; \int_{y} G_{POA}(t)\,\mathrm{dt}}{P_0 \;/\; G_{ref}}$$

$P_{out}(t)$ computed with PVWatts Model*

$$\eta_{ageing}(y) = 1 - \exp\left(-\left(\frac{\Gamma}{k(y)\cdot(y - y_0)}\right)^{\mu}\right)$$

Kaaya's Model**

*Aron P. Dobos. PVWatts Version 5 Manual. Sept. 4, 2014
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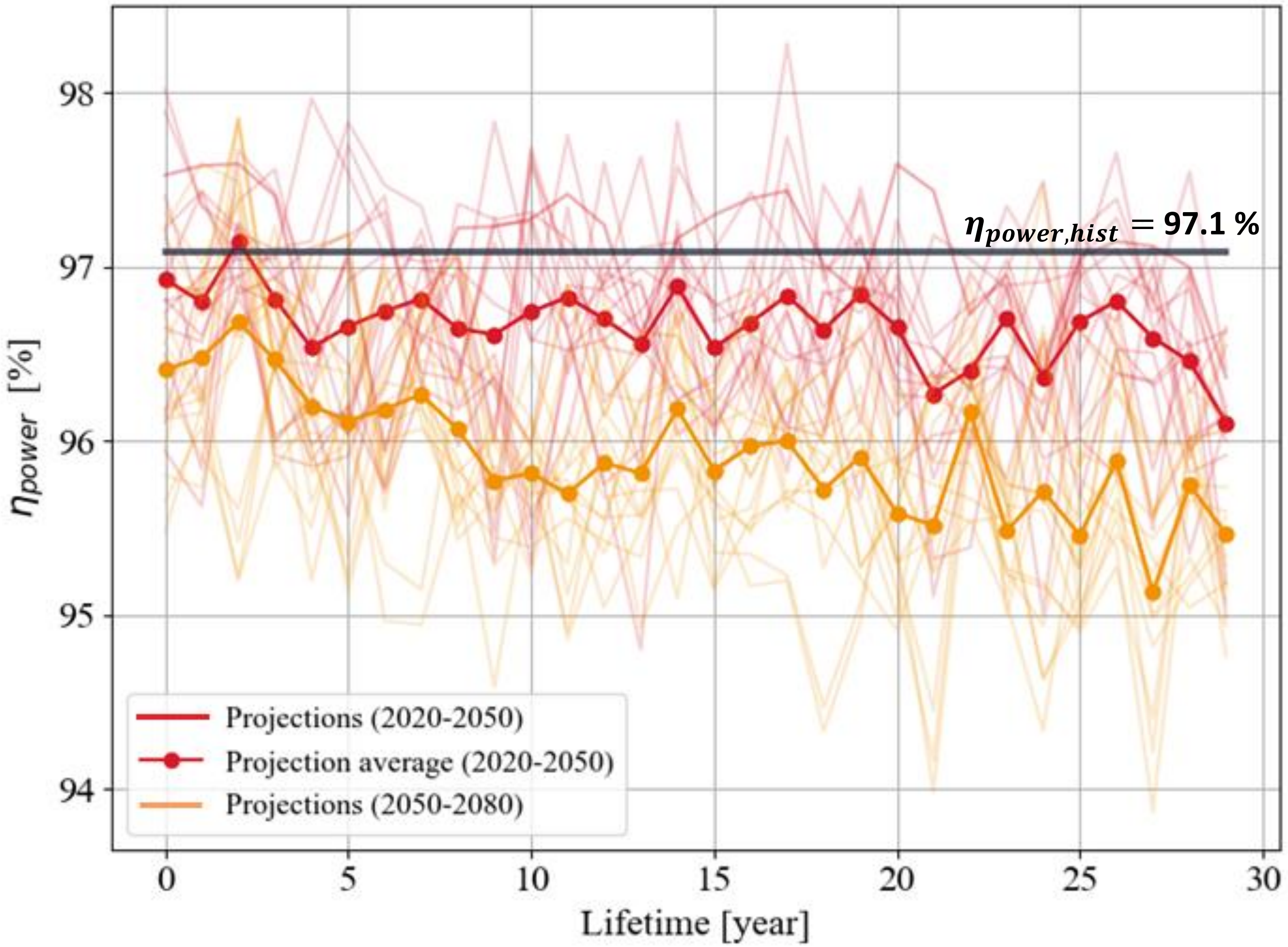
Results, Bordeaux case study

$$PR(y) = \boldsymbol{\eta_{power}(y)} \cdot \eta_{ageing}(y)$$

η_{power} over time of 15 climate projections on 2020-2050 and 2050-2080 at Bordeaux



η_{power} trend over time:

- Overall decrease
- More volatile

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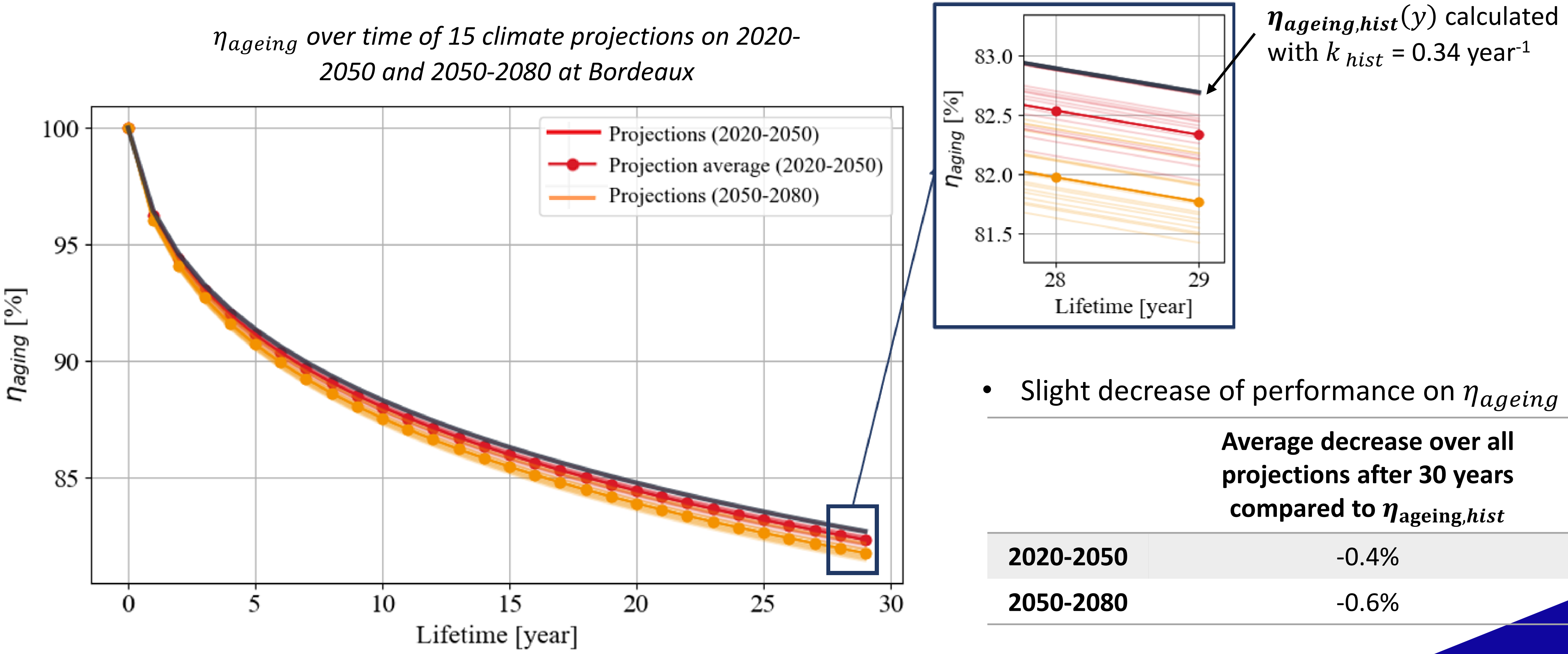
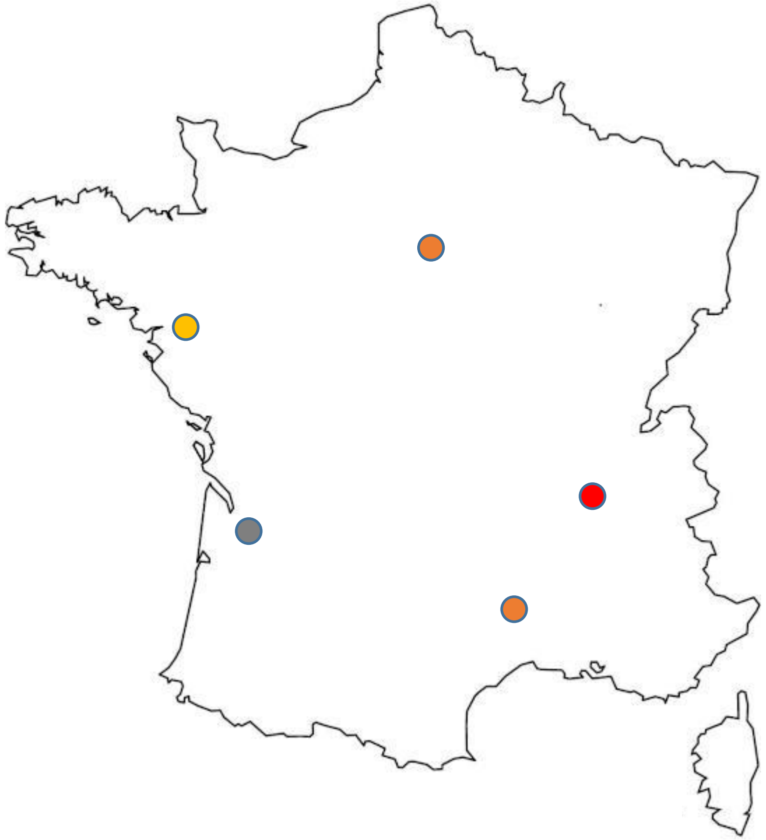


- Slight decrease of performance on η_{ageing}

	Average decrease over all projections after 30 years compared to $\boldsymbol{\eta_{\text{ageing},hist}}$
2020-2050	-0.4%
2050-2080	-0.6%

Results, other French cities



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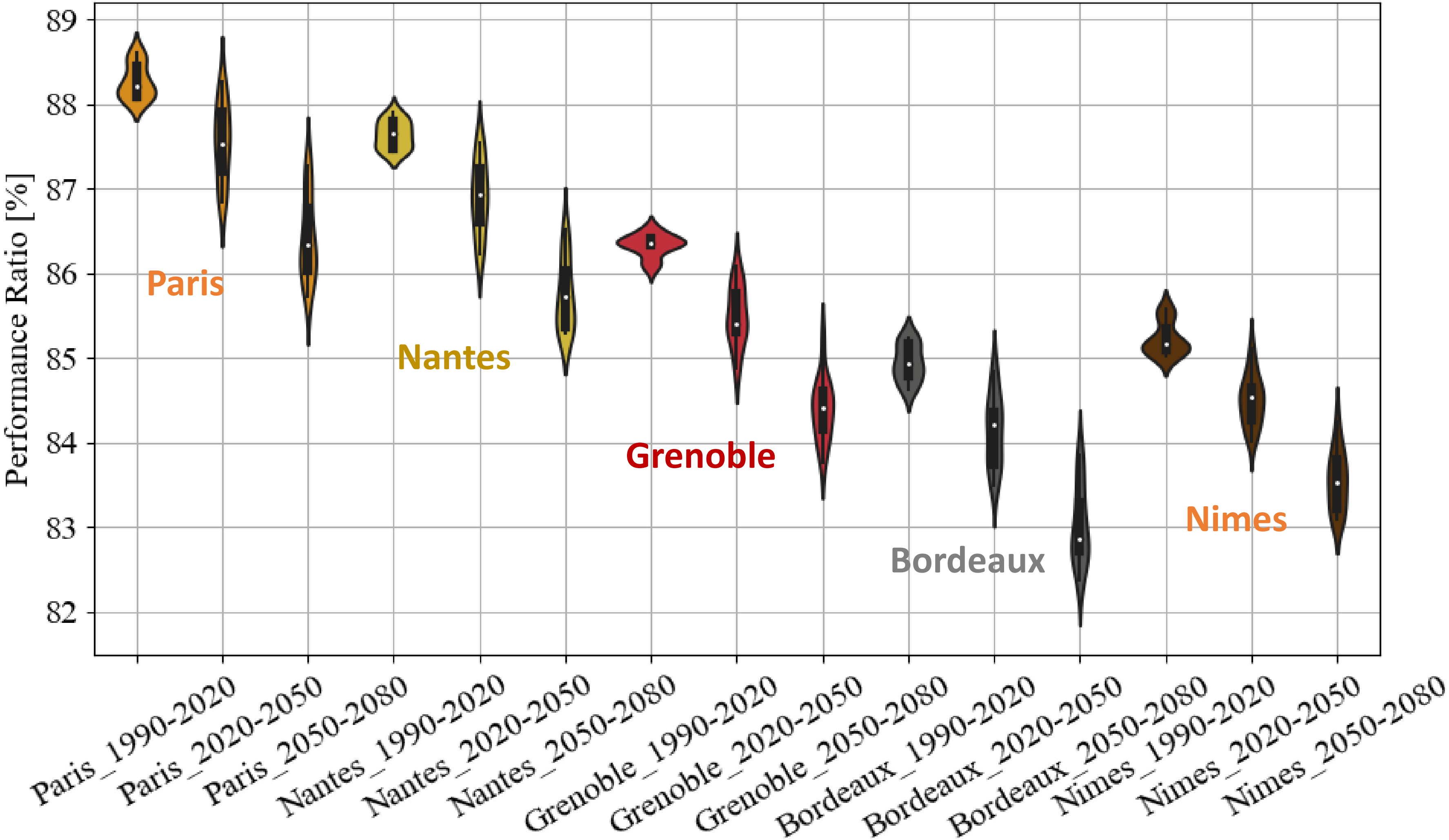
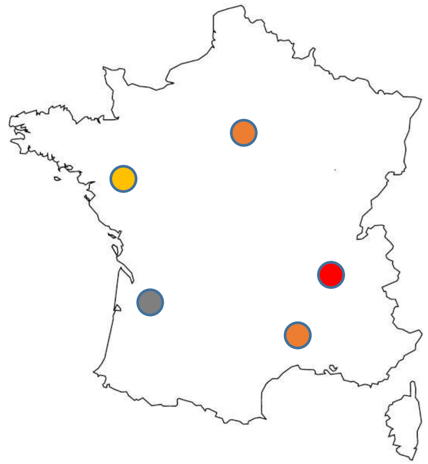
Results, other French cities

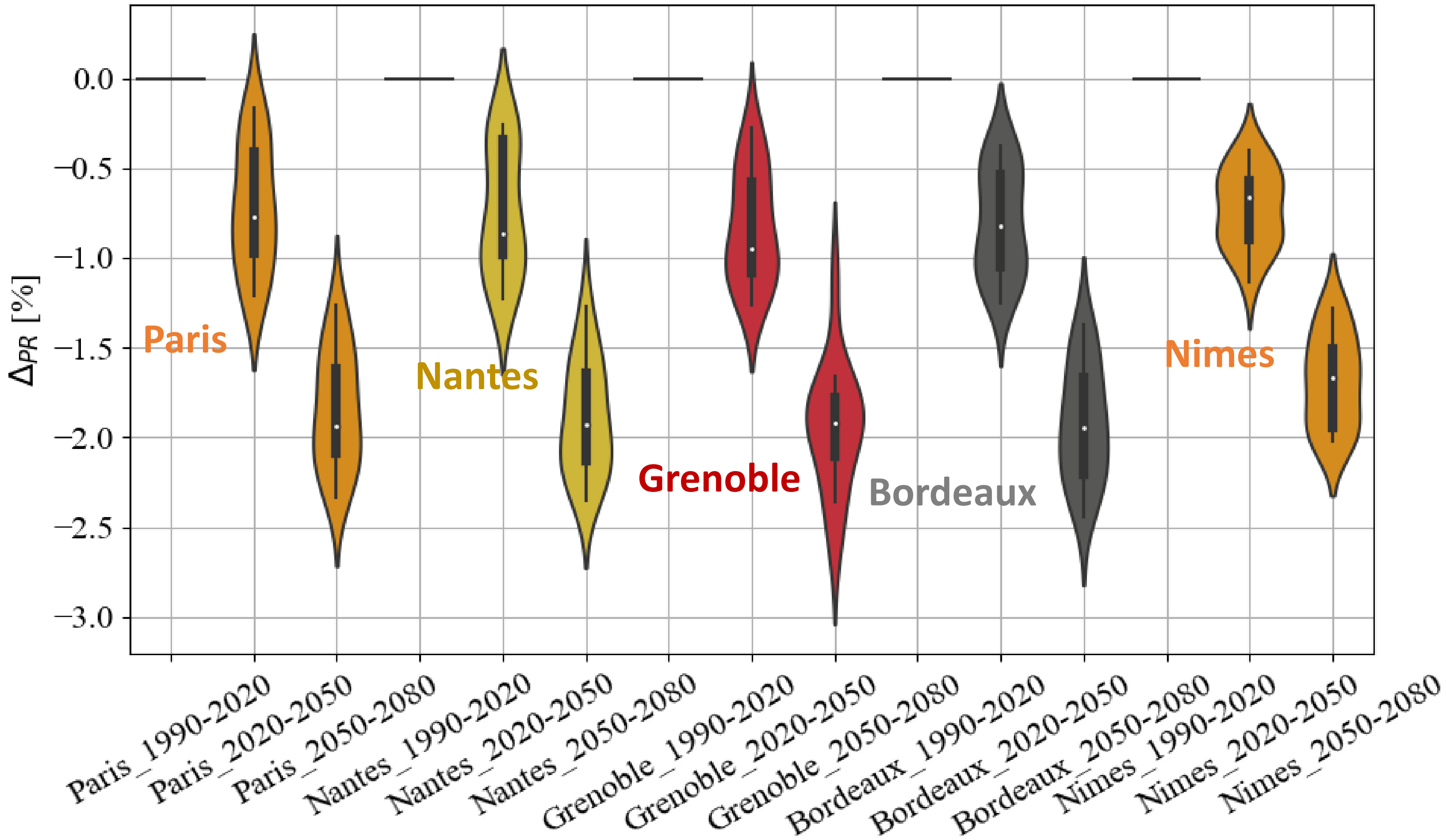
PR on 15 climate projections for different cities for a 30-year lifetime installation

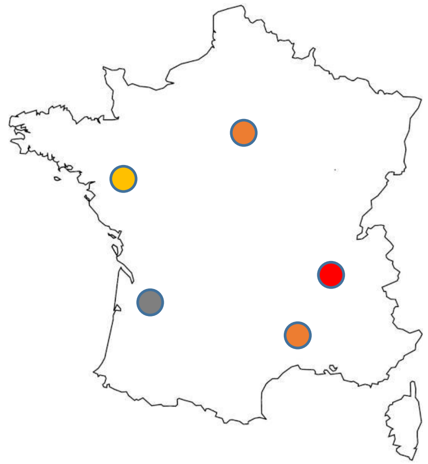




Results, other French cities

Δ_{PR} on 15 climate projections on different cities for different climate periods compared to 1990-2020 for a 30-year lifetime installation





Very similar trends are observed for all cities with a PR median decreasing by:
- 0.5-1% on 2020-2050 vs 1990-2020
- 1.5-2% on 2050-2080 vs 1990-2020

Conclusion

In this study, a **modeling chain quantifies** the impact of climate change.

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The impact on PV goes through **two** factors:

- **Decrease in instantaneous power**
- **Accelerated aging**

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The impact on PV goes through **two** factors:

- **Decrease in instantaneous power**
- **Accelerated aging**

In the case studies, the impact of the **RCP8.5** future projections has repercussions **under 3% on the Performance Ratio.**

Questions / Comments

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Backup slides

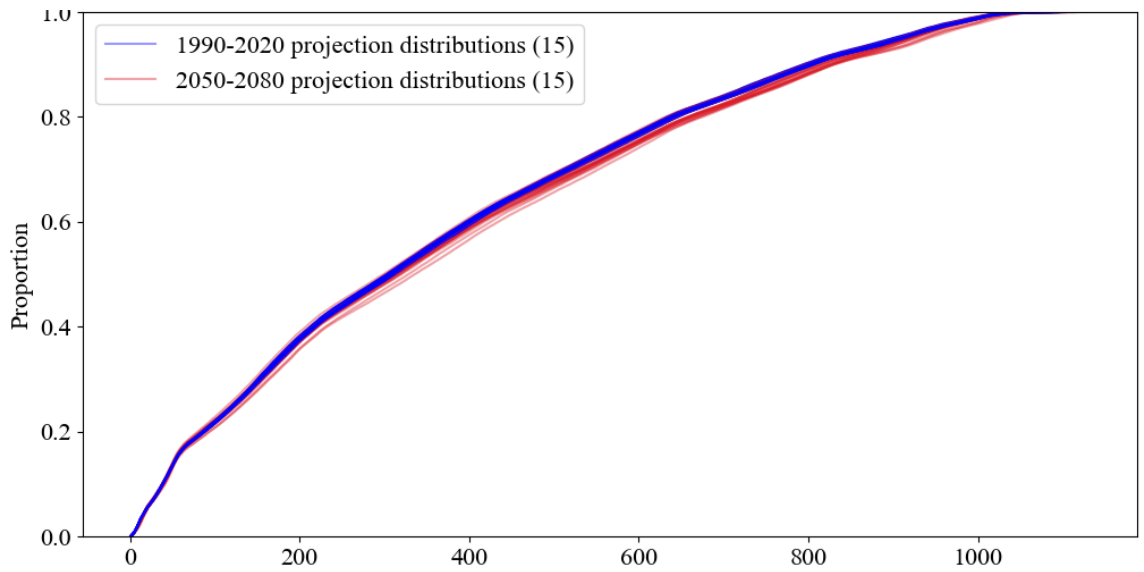
Results, Bordeaux study case

Environmental variables

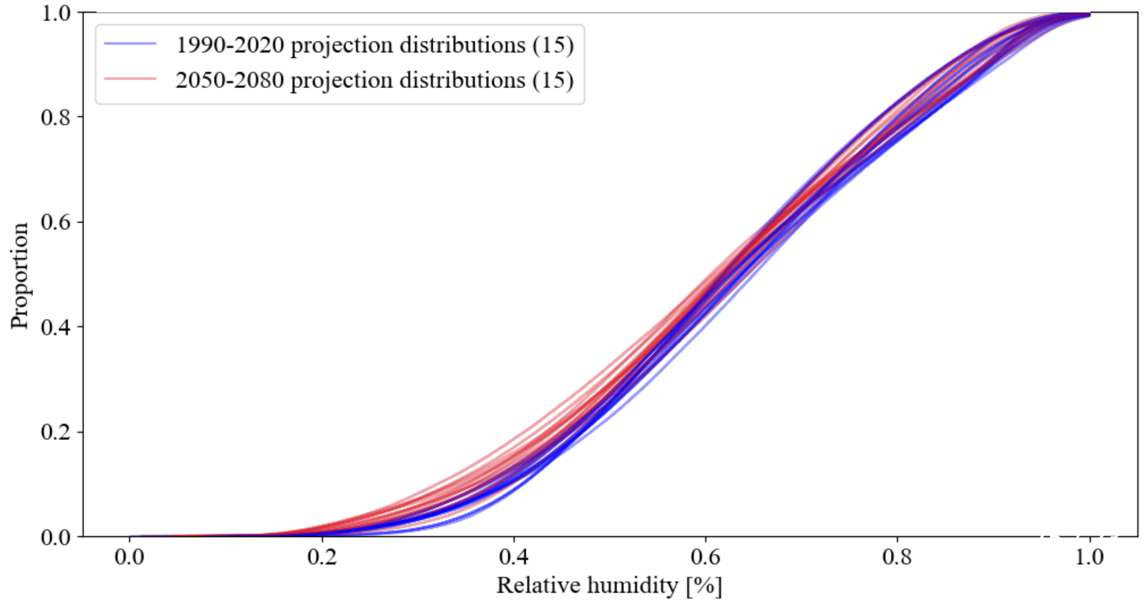
2050-2080 vs 1990-2020 (during daytime)

- Irradiation: Slight increase with +28 kWh/m2/year on average at most for all projections
- Relative humidity: Slight decrease with -1.1% on average at most for all projections

The cumulative distribution function of the hourly irradiance [W/m²] during daytime



The cumulative distribution function of the hourly relative humidity [%] during daytime



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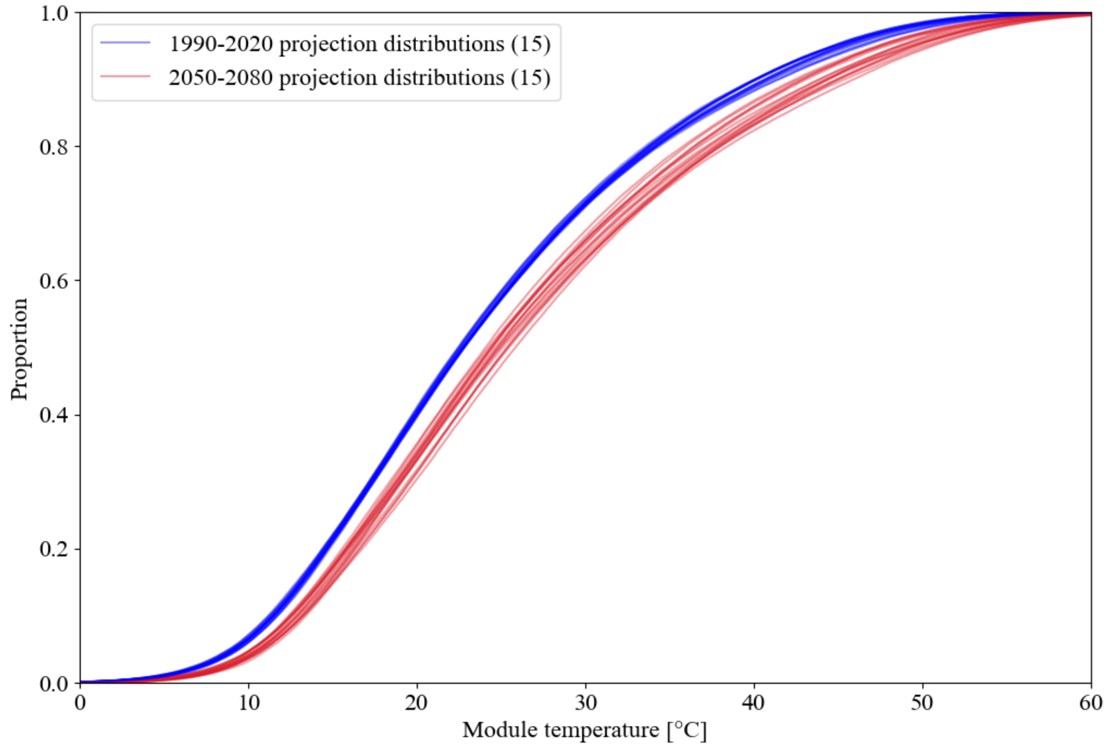
- Relative humidity: Slight decrease with -1.1% on average at most for all projections
- Module Temperature:
  - Quantile 5%: 1.5°C
  - Average: +2°C
  - Quantile 95%: +3.5°C

The cumulative distribution function of the hourly module temperature [°C] during daytime



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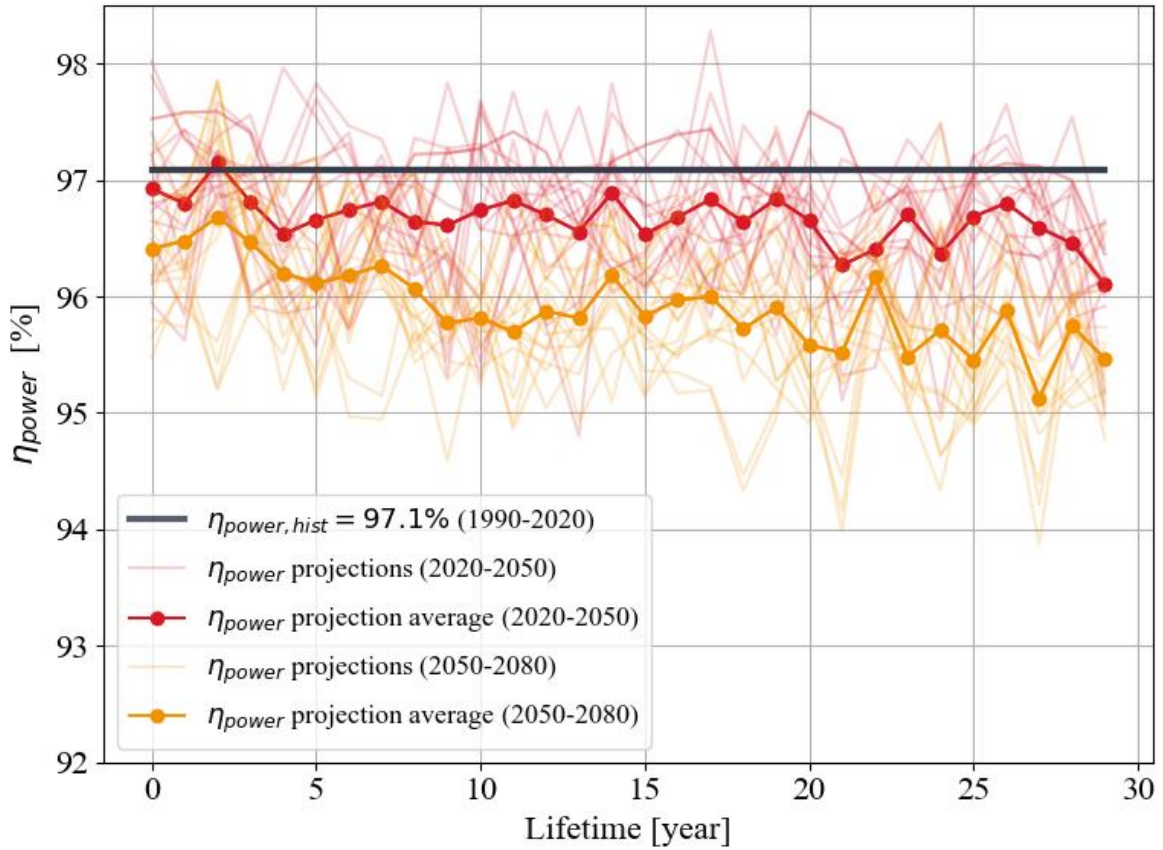

Historical $\eta_{power,hist}$ (1990-2020) = 97.1 %

η_{power} tendencies over time:

- Overall decrease
- More volatile

	Standard deviation
1990-2020 (ERA5 dataset)	0.43 %
2020-2050	0.49% (median) [0.37%, 60%]
2050-2080	0.59% (median) [0.41%, 0.67%]