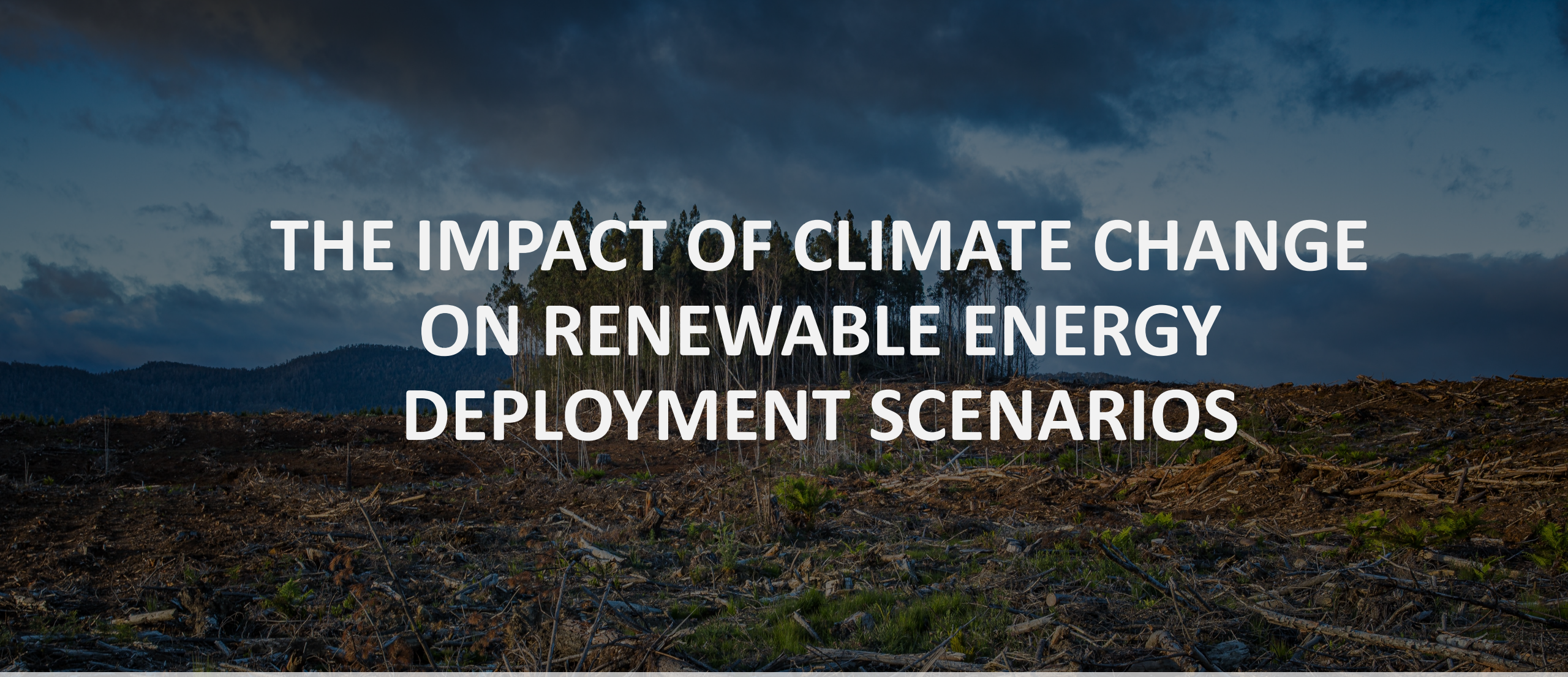


THE IMPACT OF CLIMATE CHANGE ON RENEWABLE ENERGY DEPLOYMENT SCENARIOS

Universitat de les Illes Balears

Grup de Meteorologia

Aina Maimó Far

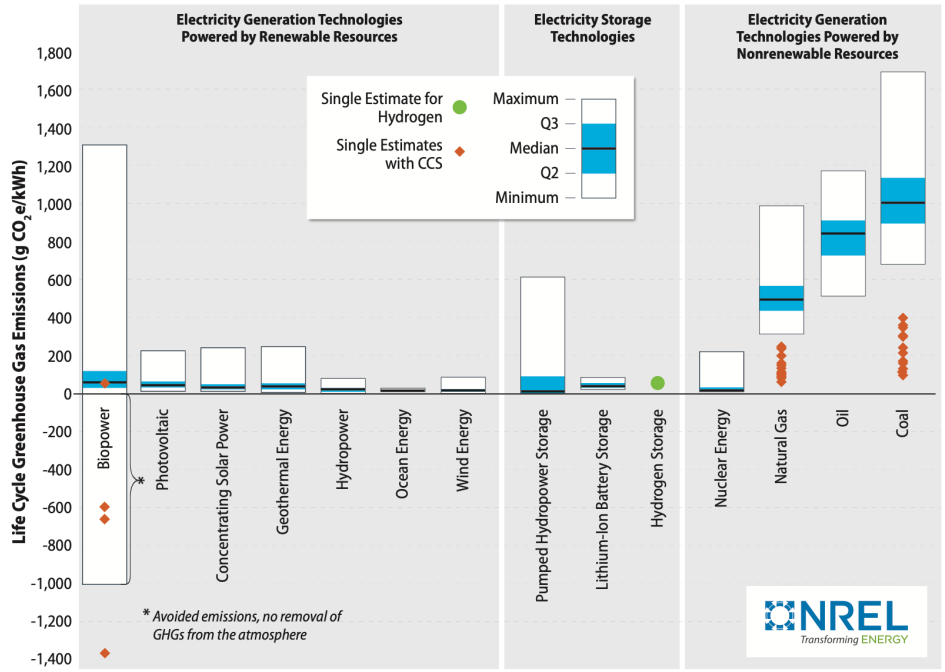
2nd TRAMPAS meeting
24/10/2023

Why renewable energy? – Global perspective

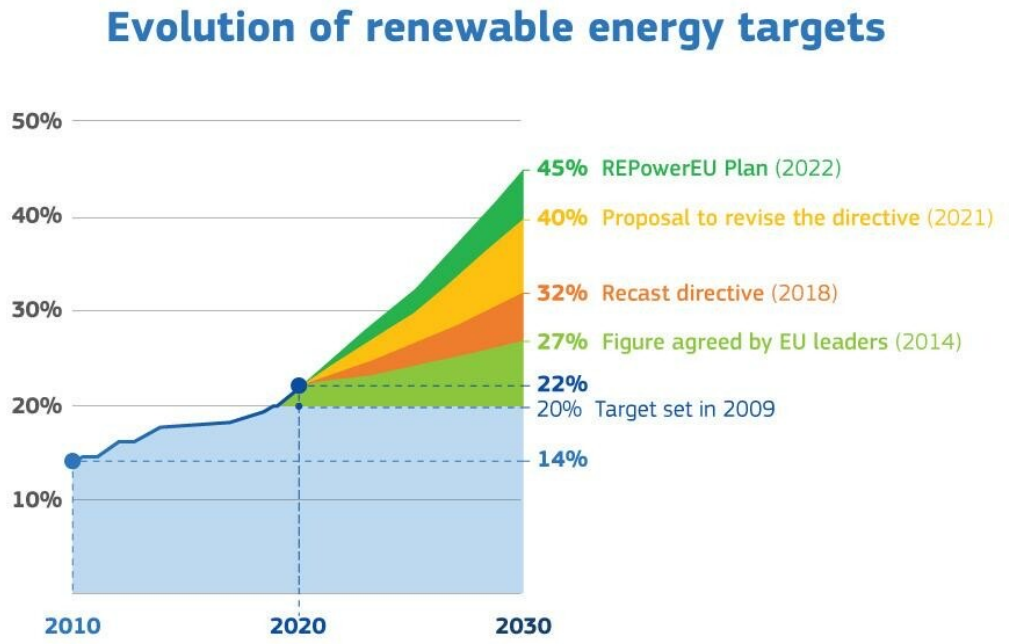
PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

Limit global warming by 1.5 °C by the end of the century

Figure 2. Life cycle greenhouse gas emission estimates for selected electricity generation and storage technologies, and some technologies integrated with carbon capture and storage (CCS).



Estimates	276 (+4)	46	36	35	149	10	186	16	29	1	99	80 (+13)	24	164 (+11)
References	57 (+2)	17	10	15	22	5	69	4	3	1	27	47 (+11)	10	53 (+9)



Source: EU

Why renewable energy? – National perspective

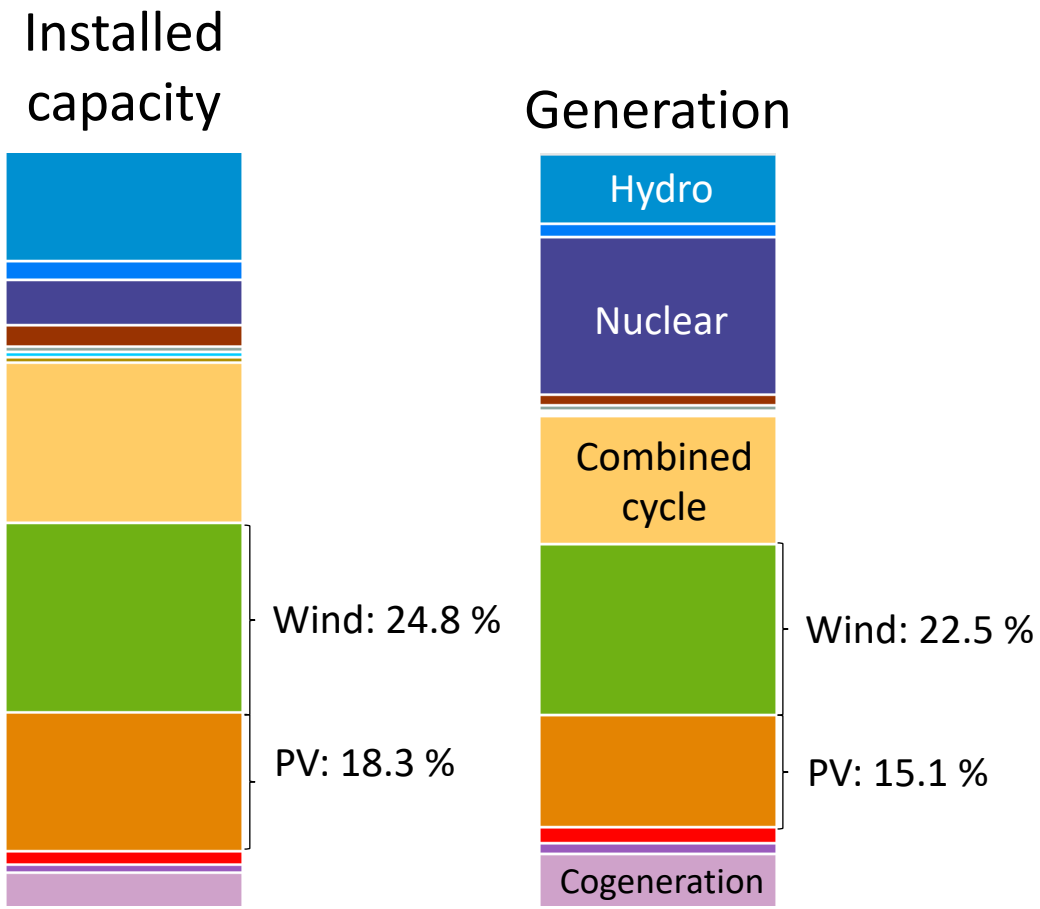
GOBIERNO DE ESPAÑA

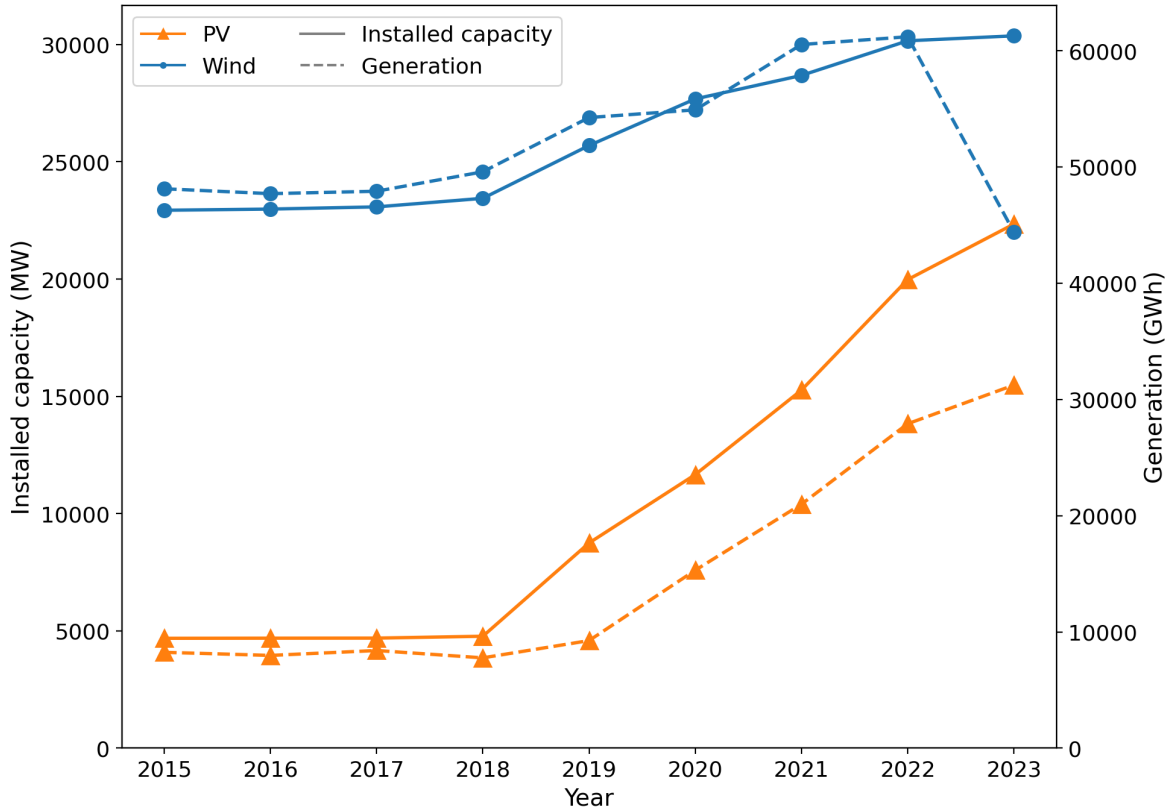
MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO

+ RED ELÉCTRICA DE ESPAÑA

Why consider climate?

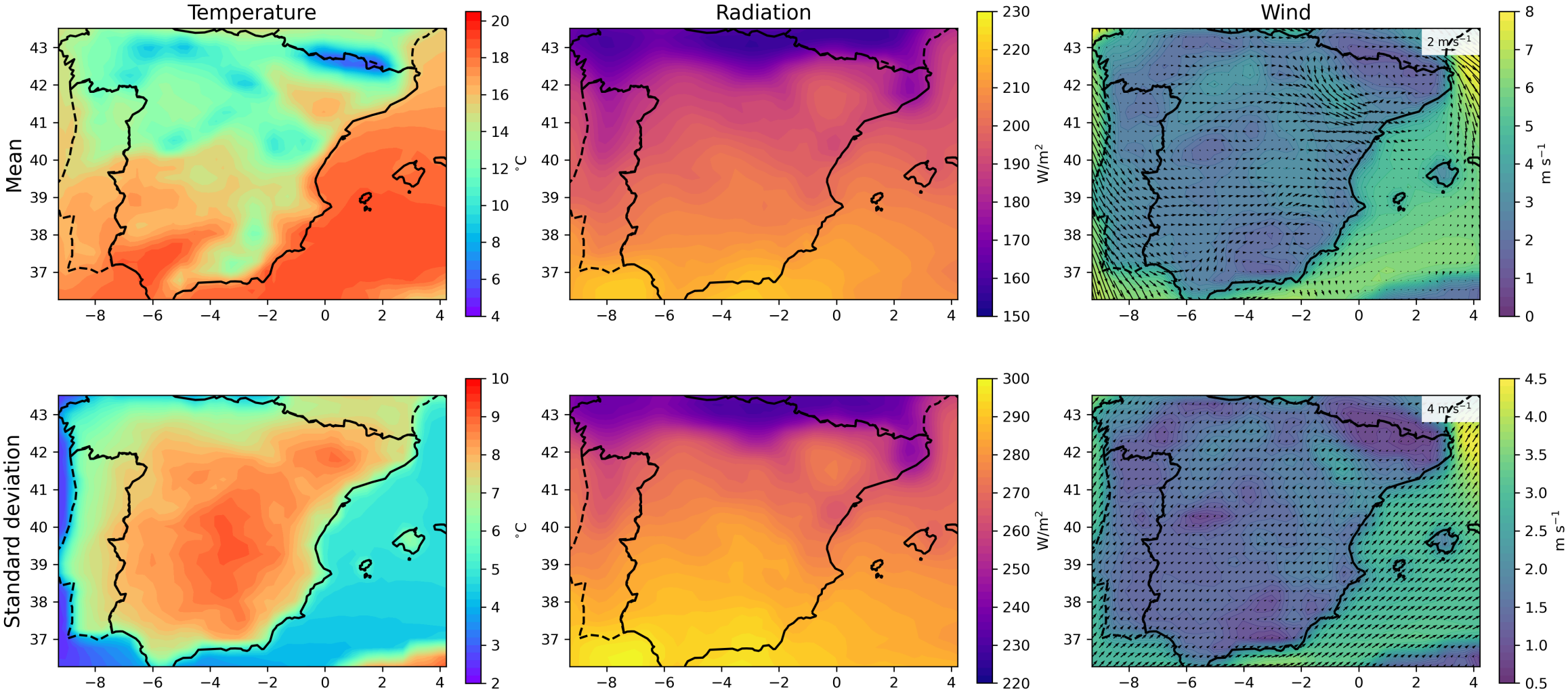
2023 data (in %)



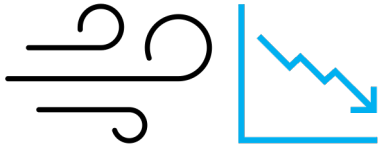


National data from REE. 2023 data as of October 4th

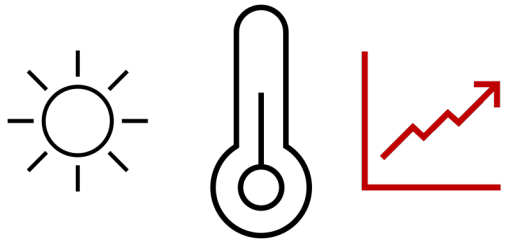
Present climate: 1985-2020 ERA5



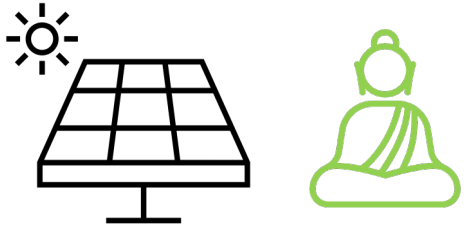
Expected climate changes in Spain



Wind magnitude tendencies show a generalized decrease



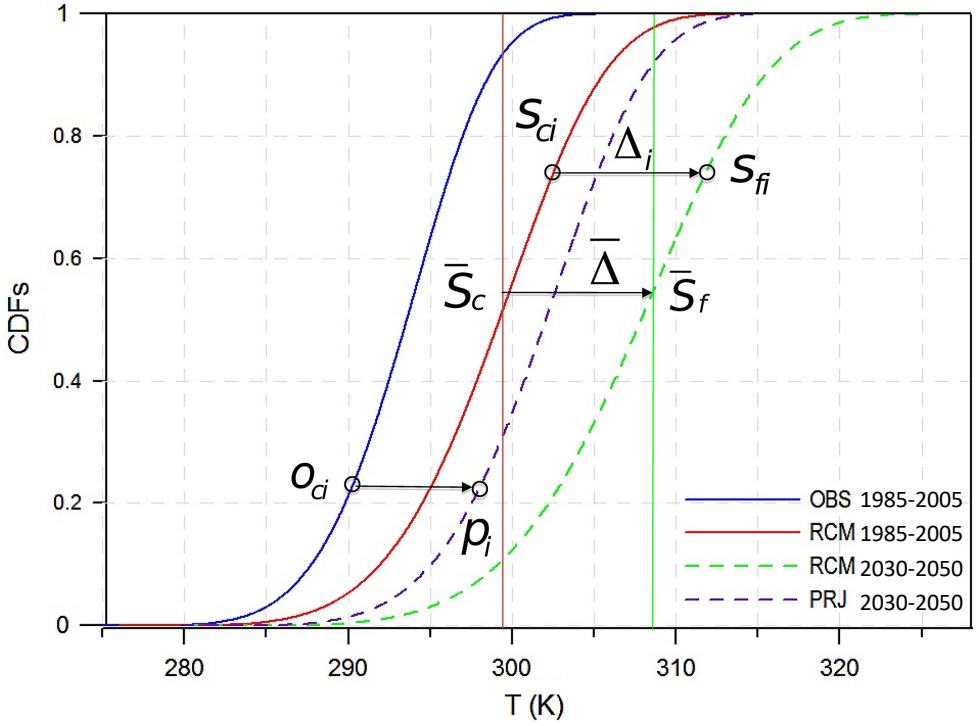
Solar radiation and temperature are expected to increase in the coming years



Climate change is projected to have a weak impact on PV generation

Methods to quantify future climate projections

Temperature and pressure:
Quantile-Quantile adjustment



Source: Cardell et al., 2019

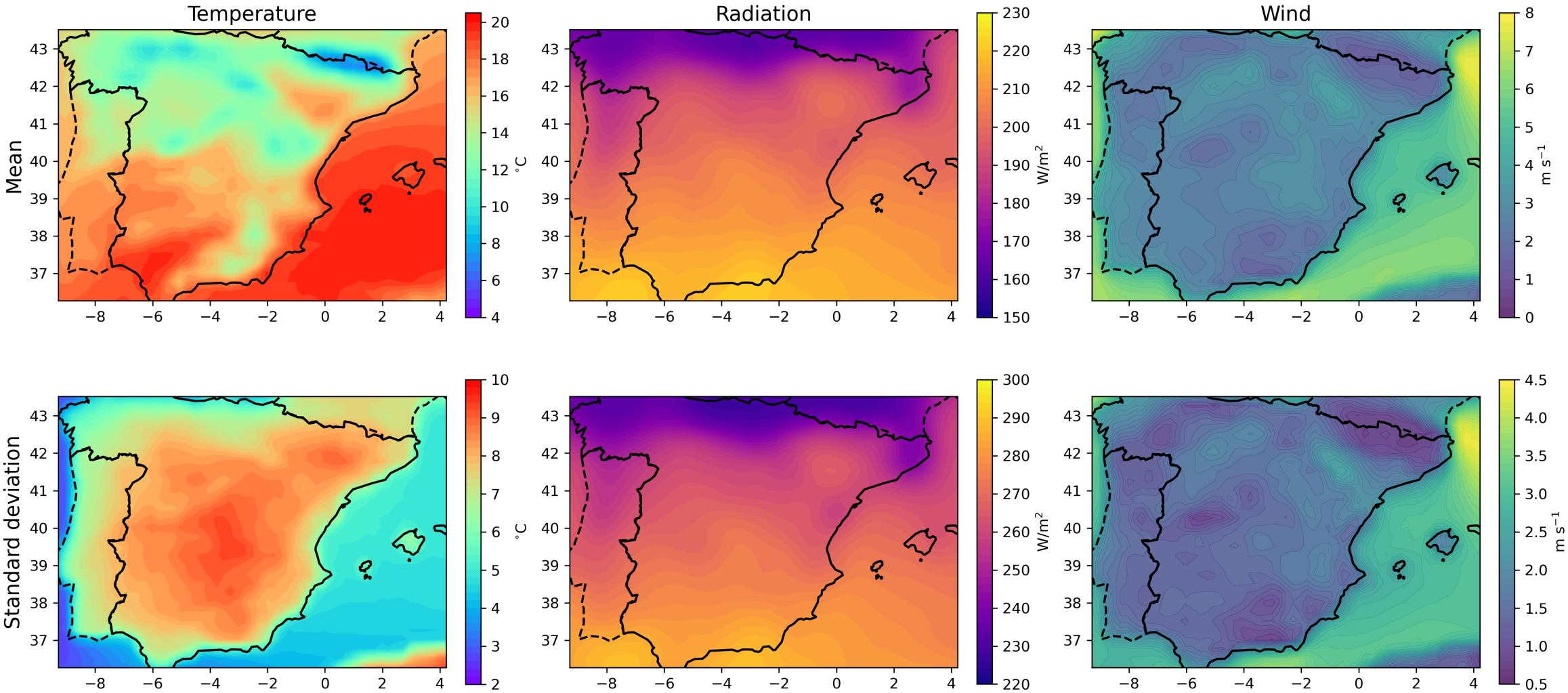
Wind:
Scaling

$$p_t = o_t \frac{\bar{S}_f}{\bar{S}_c} \quad ; \quad p_t \geq 0$$

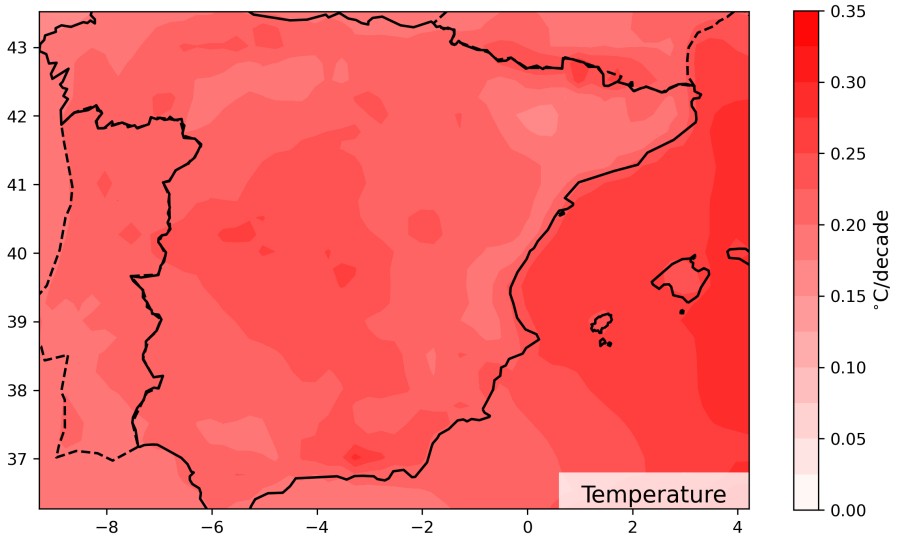
Radiation:
Energy scaling maintaining physical limits

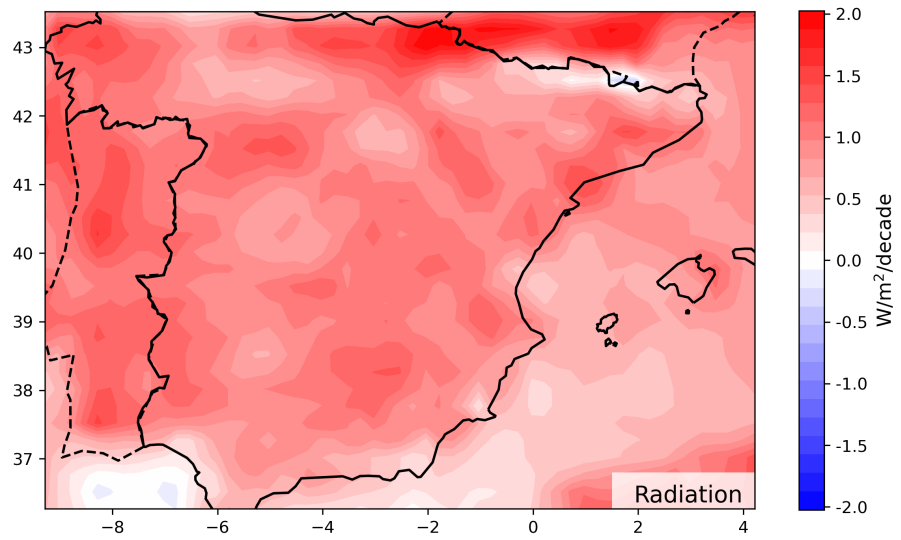
$$\frac{\sum_t p_t^2}{\sum_t o_t^2} = \frac{\sum_t s_{ft}^2}{\sum_t s_{ct}^2} \quad ; \quad 0 \leq p_t \leq \mathrm{CS}_t$$

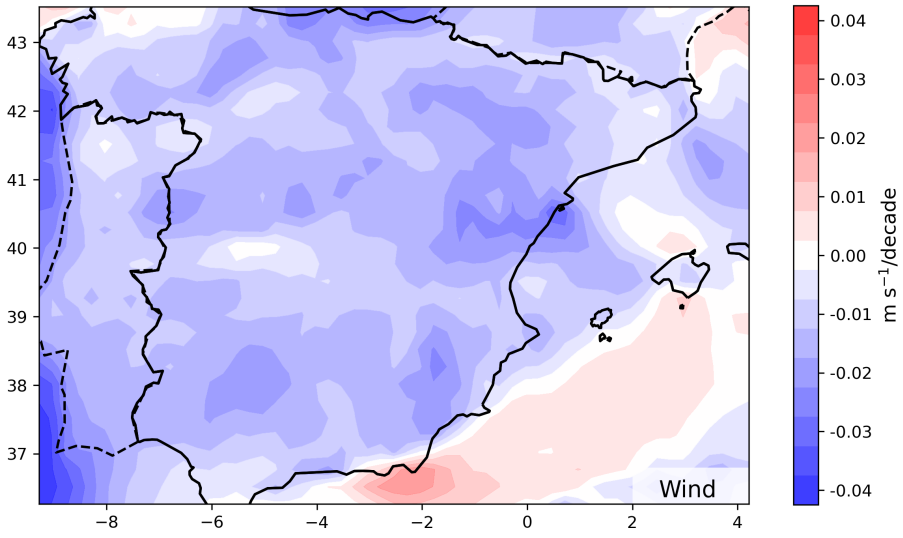
Calibrated projected future climate: 2030-2050



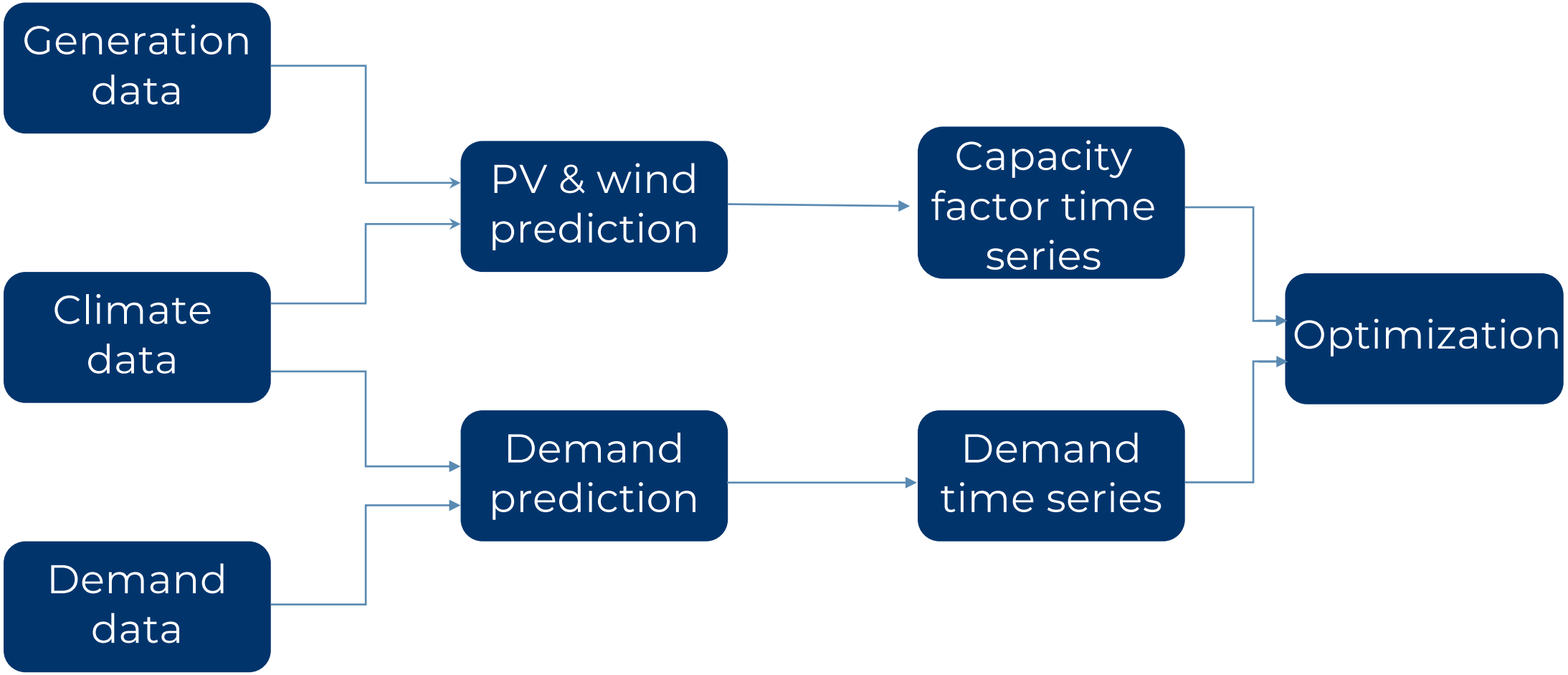
Average projected future changes in climate







Methodology: the e4clim model



Methodology: system total cost minimization

$$\mathrm{STC}_\alpha = T_0 \sum_k \omega_k \mathrm{hRC}_k + \alpha \sum_t q^2(t)$$

$$\min_{G_{\mathrm{Di}}(t,\omega)} \mathrm{STC}(\omega, G_{\mathrm{Di}}(t,\omega))$$

$$G_{\mathrm{Di}}(t,\omega) + Q(t,\omega) \geq L(t,\omega)$$

$$0 \leq G_{\mathrm{Di}} \leq \omega_{\mathrm{Di}}$$

$$\min_{\omega} \mathbb{E}(\overline{\mathrm{STC}}(\omega))$$

$$0 \leq \omega_k \leq \omega_k^{max}$$

The cost of variable renewable energy sources: economic cost

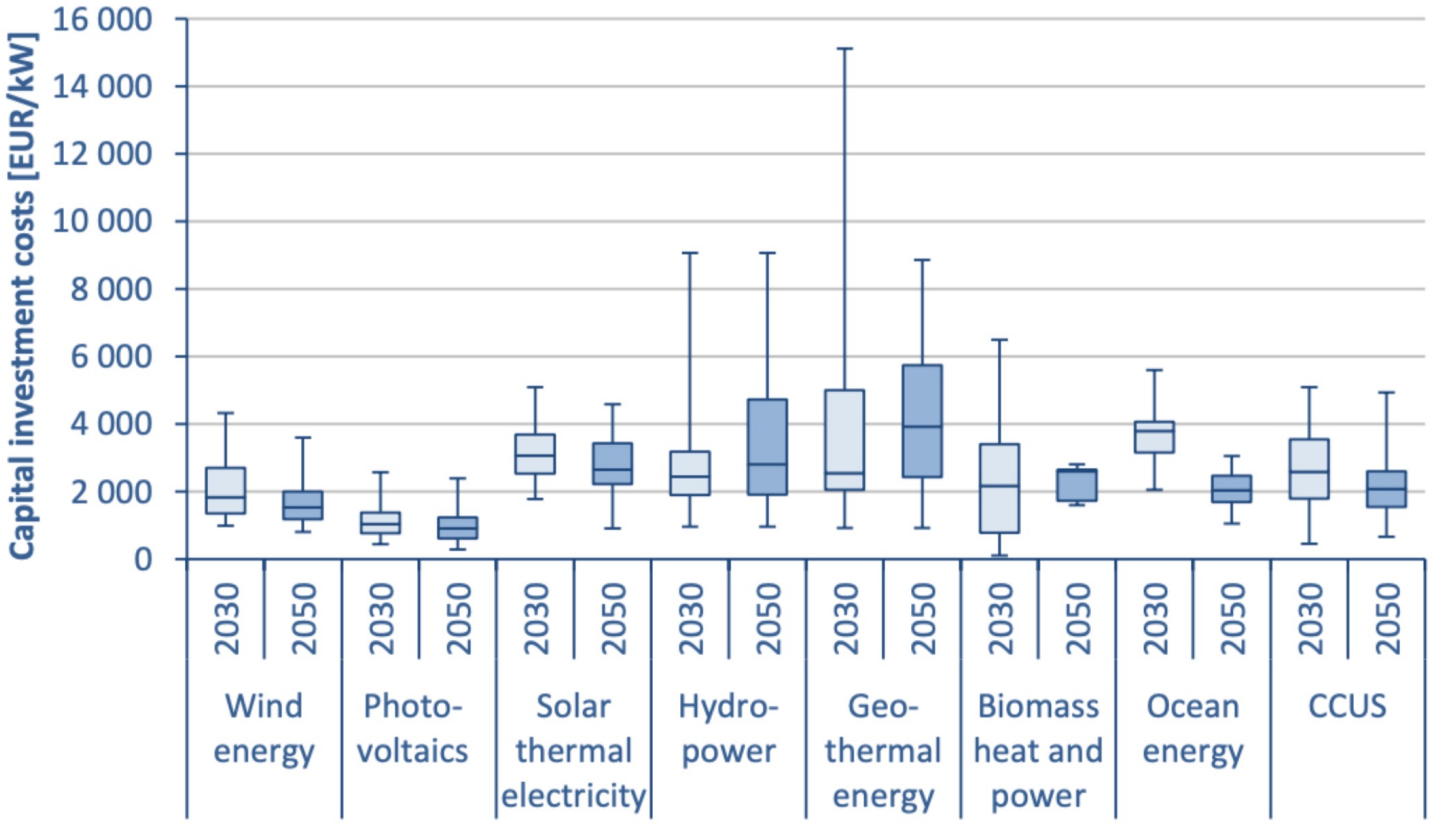


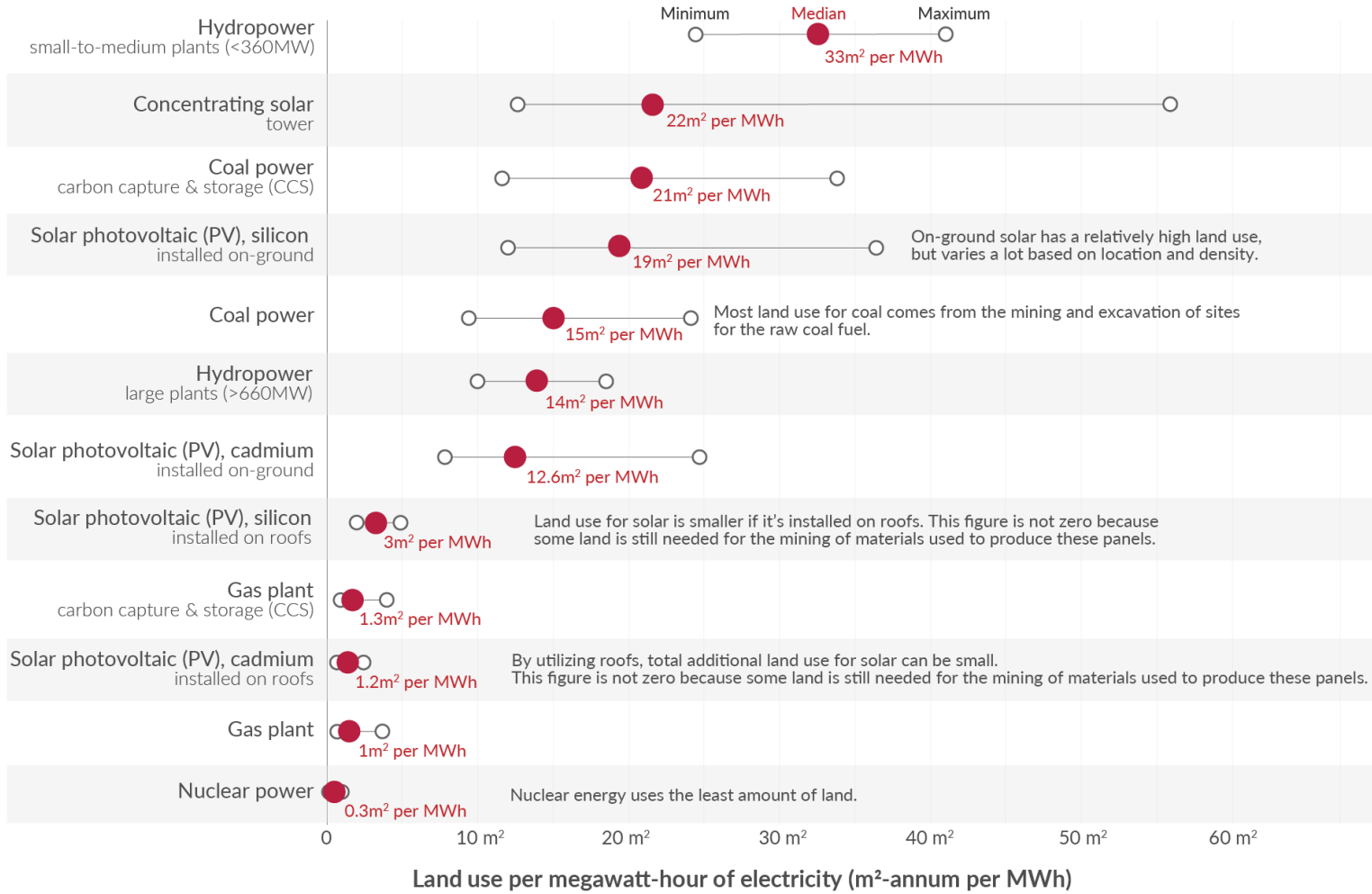
Figure 1 Investment costs of low carbon energy technologies according to literature

Source: Cost development of low carbon energy technologies – Scenario-based cost trajectories to 2050 (2017)

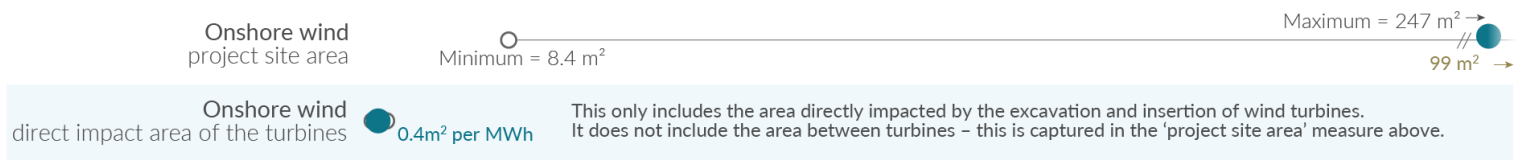
Land use of energy sources per unit of electricity

Land use is based on life-cycle assessment; this means it does not only account for the land of the energy plant itself but also land used for the mining of materials used for its construction, fuel inputs, decommissioning, and the handling of waste.

Our World in Data



The land use of onshore wind can be measured in several ways, and is distinctly different from land use of other energy technologies. Land between wind turbines can be used for other purposes (such as farming), which is not the case for other energy sources. The spacing of turbines, and the context of the site means land use is highly variable.



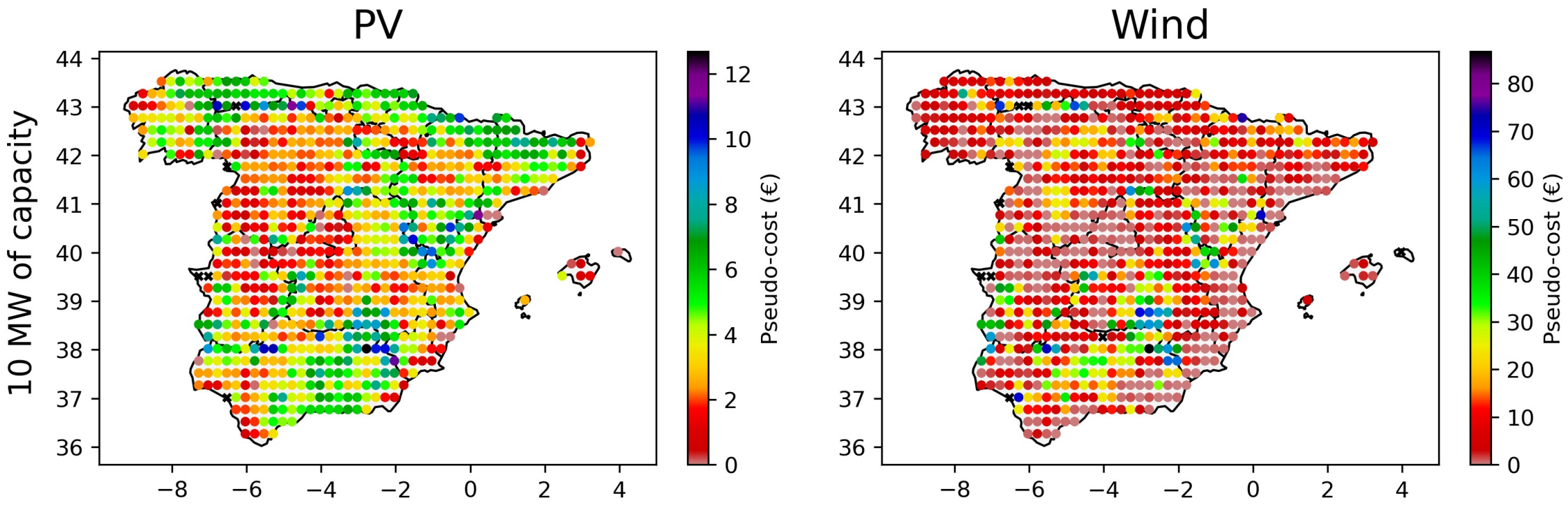
Note Capacity factors are taken into account for each technology which adjusts for intermittency. Land use of energy storage is not included since the quantity of storage depends on the composition of the electricity mix.

Source: UNECE (2021). Lifecycle Assessment of Electricity Generation Options. *United Nations Economic Commission for Europe* for all data except wind. Wind land use calculcated by the author.

See OurWorldinData.org/land-use-per-energy-source for more research on this topic.

Source: How does the land use of different electricity sources compare? – Our World in Data (2022)

Introducing suitability cost



Model framework

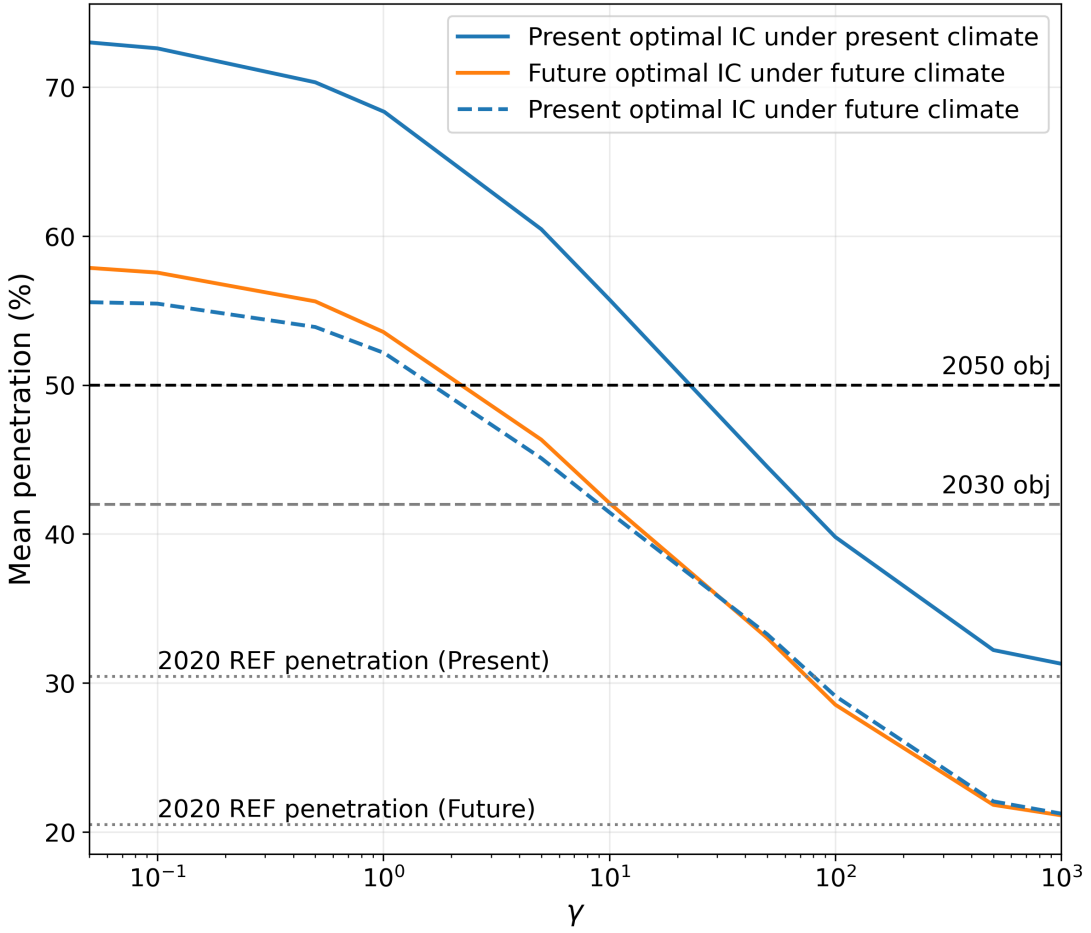
$$STC = T_0 \sum_i x_i hRC_i + \alpha \sum_t q_t^2 + \gamma T_0 \sum_i \left[a_i \Delta x_i^4 + b_i \Delta x_i^3 + c_i \Delta x_i^2 + d_i \Delta x_i \right]$$

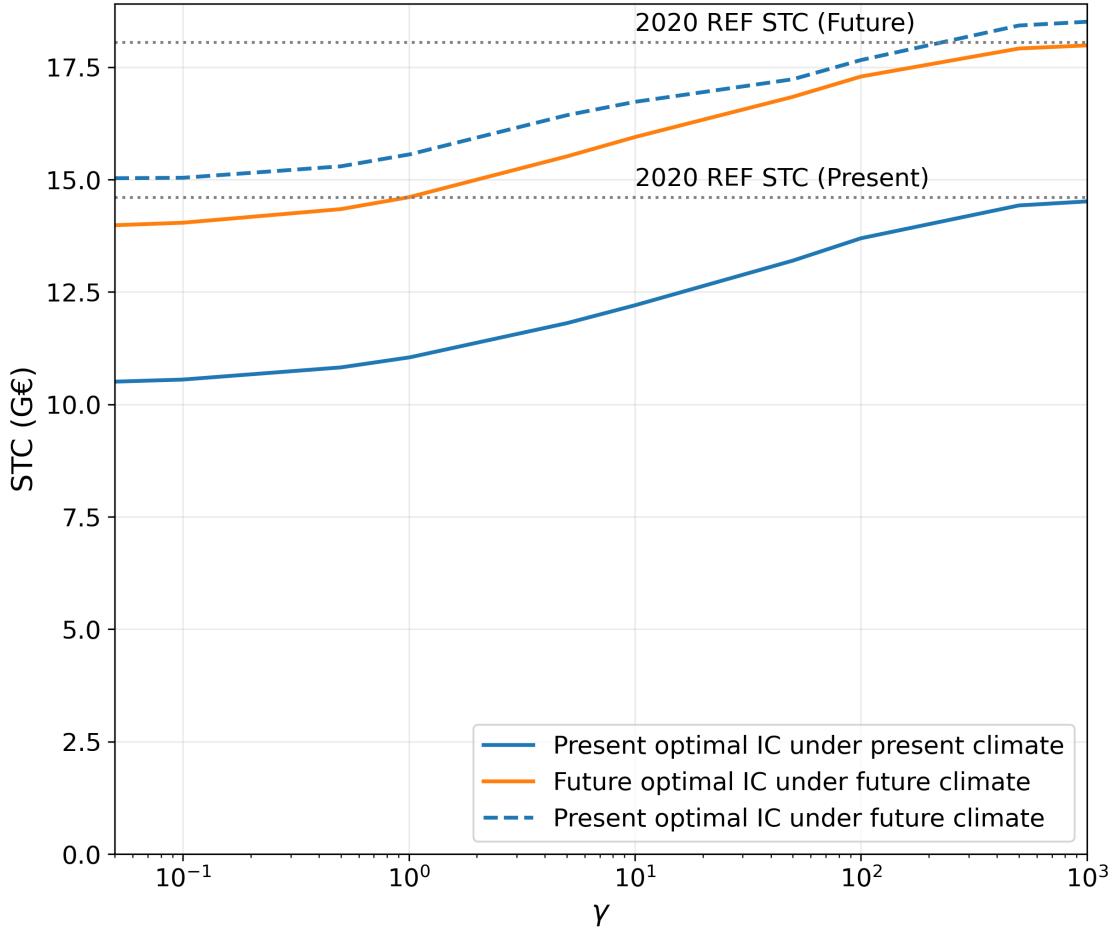
$$\Delta x_i = x_i - x_i^{min}$$

$$x_i^{min} \leq x_i$$

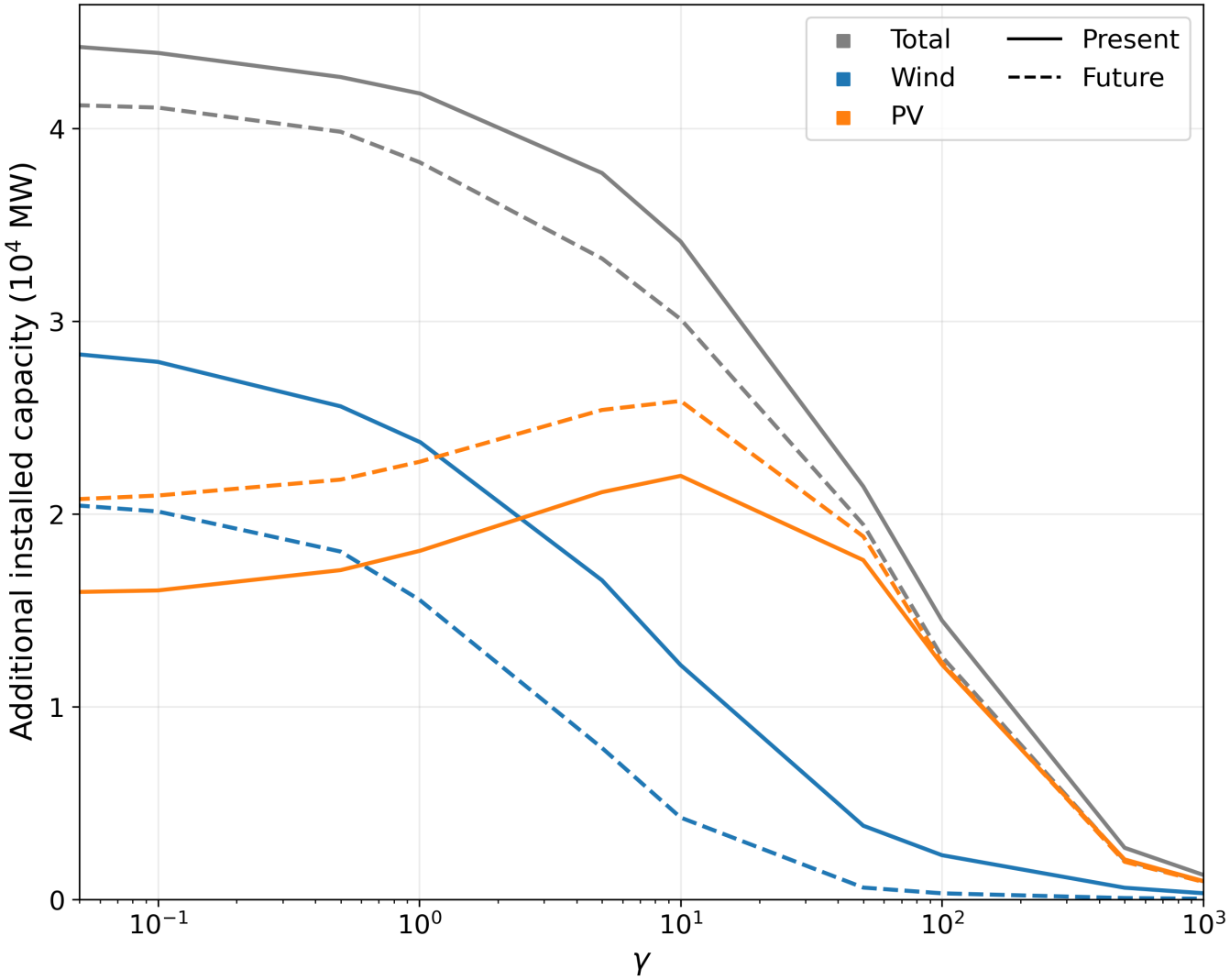
$$x_{r,PV} \frac{1}{\rho_{PV}} + x_{r,W} \frac{1}{\rho_W} \leq A_r$$

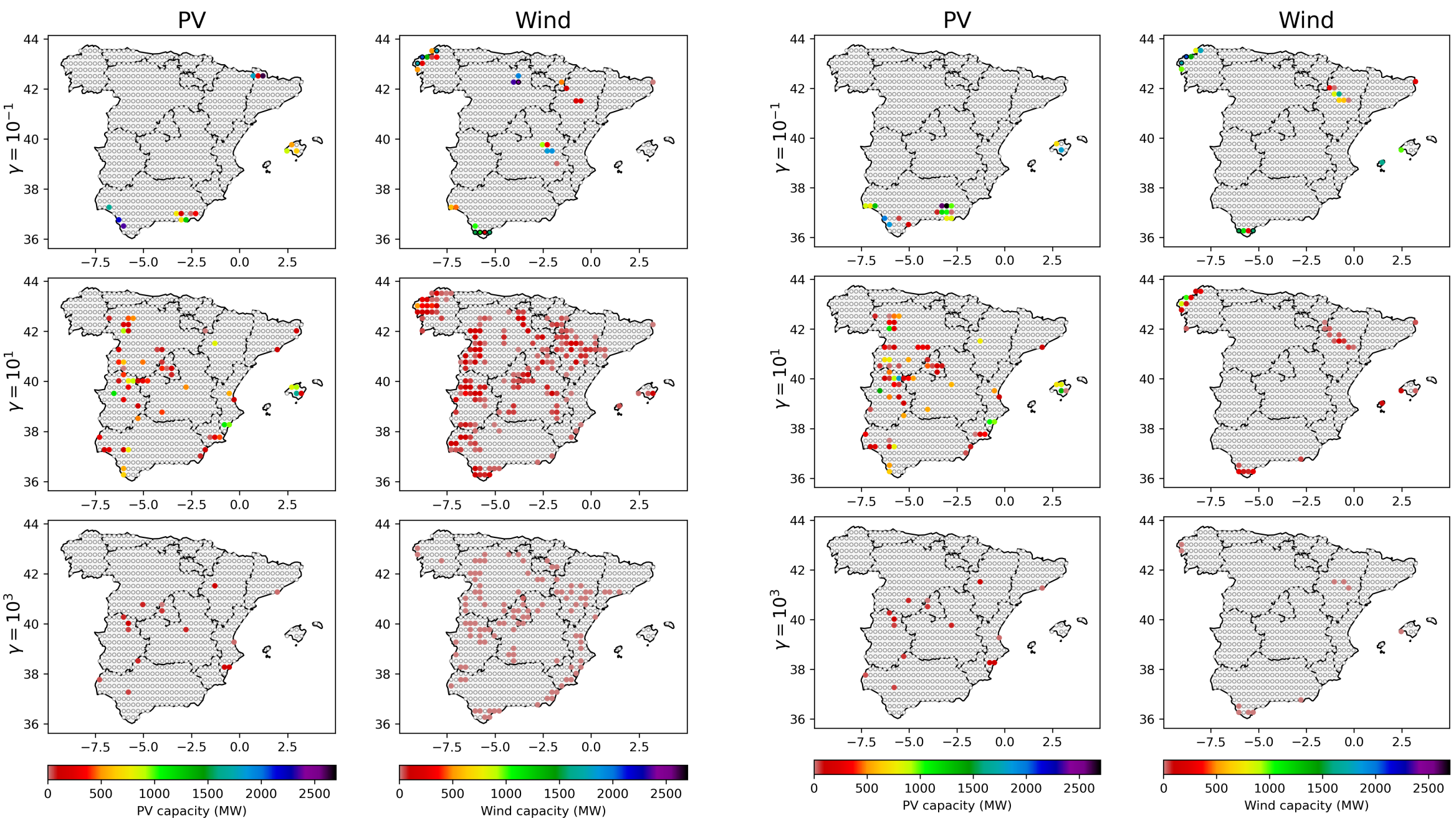
Impact on mean penetration and system total cost

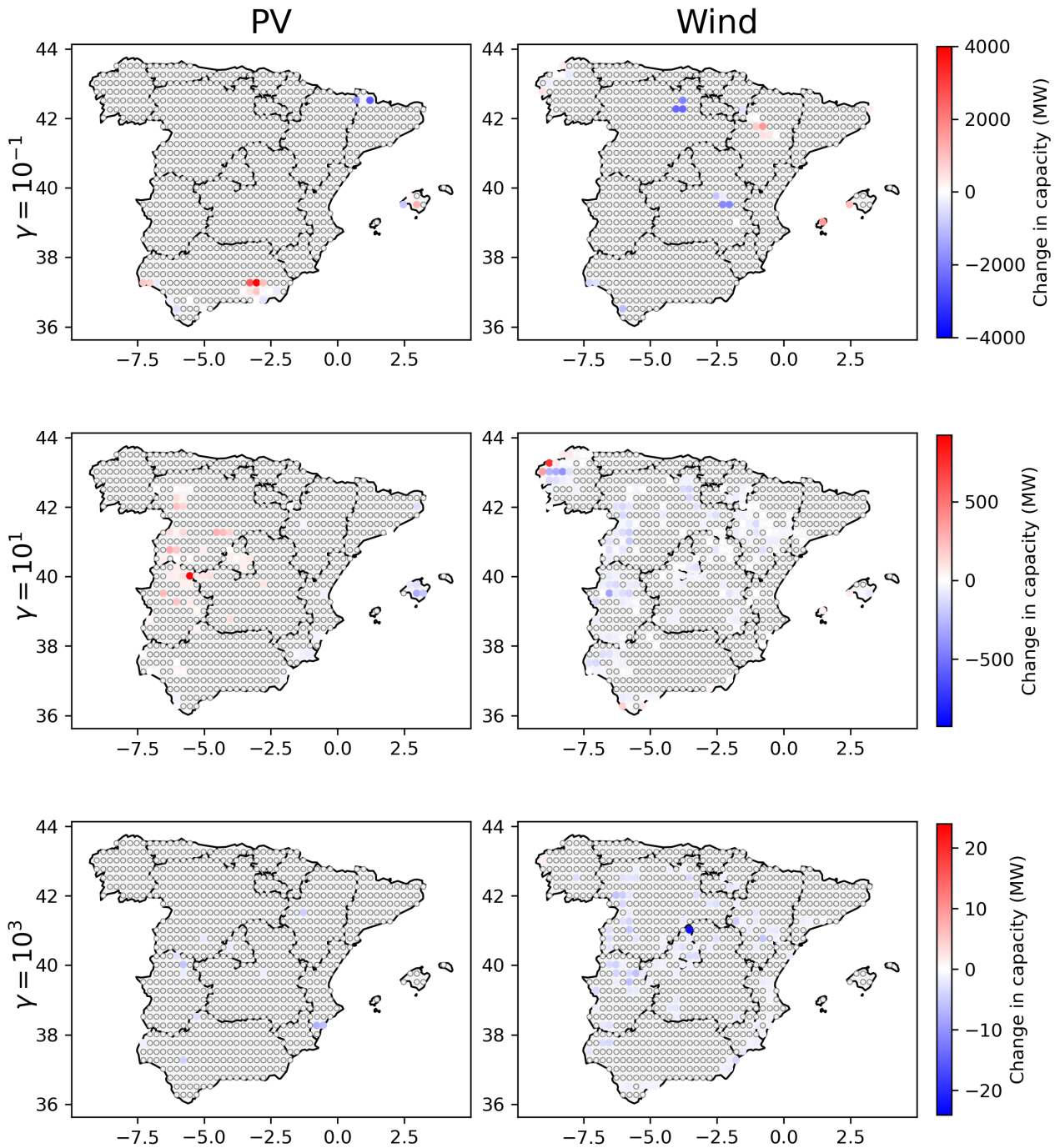




Impact on total installed capacity

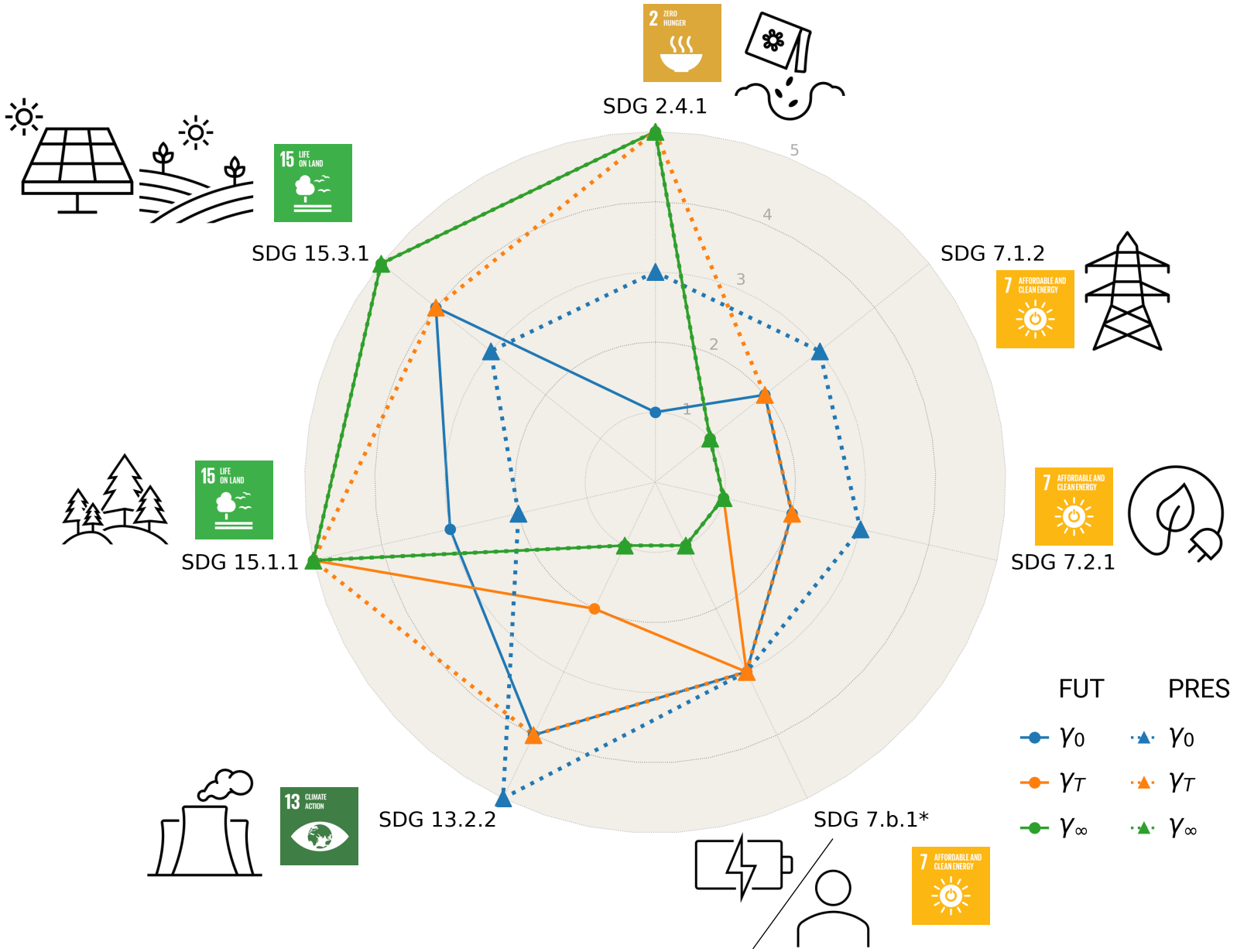



Present climate
Projected future climate
PV
Wind
PV
Wind
$\gamma = 10^{-1}$
$\gamma = 10^{1}$
$\gamma = 10^{3}$
44
42
40
38
36
−7.5
−5.0
−2.5
0.0
2.5
0
500
1000
1500
2000
2500
PV capacity (MW)
Wind capacity (MW)


PV
Wind
$\gamma = 10^{-1}$
$\gamma = 10^{1}$
$\gamma = 10^{3}$
Change in capacity (MW)
4000
2000
0
−2000
−4000
500
−500
20
10
−10
−20
44
42
40
38
36
−7.5
−5.0
−2.5
0.0
2.5

Source: United Nations

Impact on the contribution to SDGs



Impact on the contribution to sustainable development goals

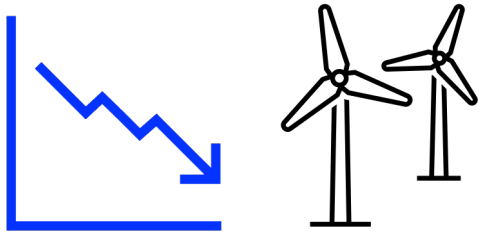
Projected future climate

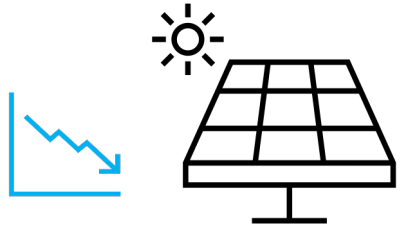
	γ_0	γ_T	γ_∞
SDG 2	1	5	5
SDG 7	2.2	1.4	1
SDG 13	4	2	1
SDG 15	3.5	5	5
Nexus index	**2.675**	**3.35**	**3**

Differences

	γ_0	γ_T	γ_∞
SDG 2	-0.67	-	-
SDG 7	-0.27	-0.36	-
SDG 13	-0.2	-0.5	-
SDG 15	+0.4	+0.11	-
Nexus index	**-0.21**	**-0.15**	**-**

Conclusions

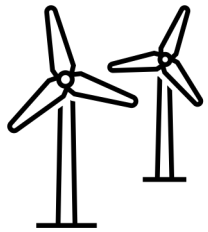


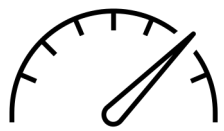


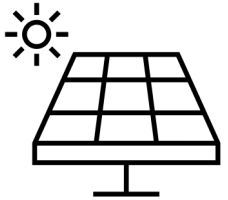
Mean renewable penetration

System total cost

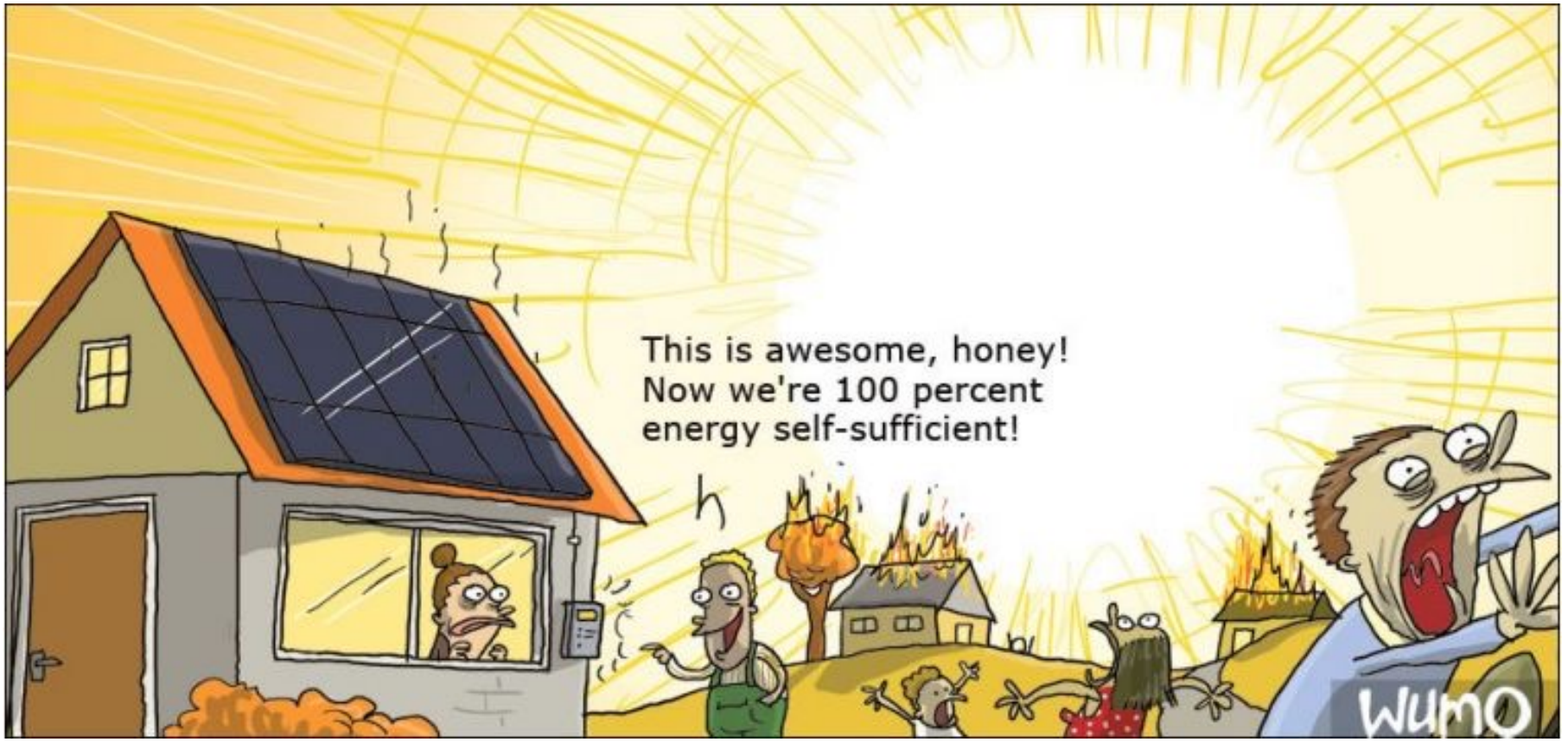
Shift







Midway γ approach for ↑ sustainability



Acknowledgements

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FPU 18/00520