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Impact of climate change on long-term planning of electrical systems based on renewable sources in Europe

Roberto Bricalli
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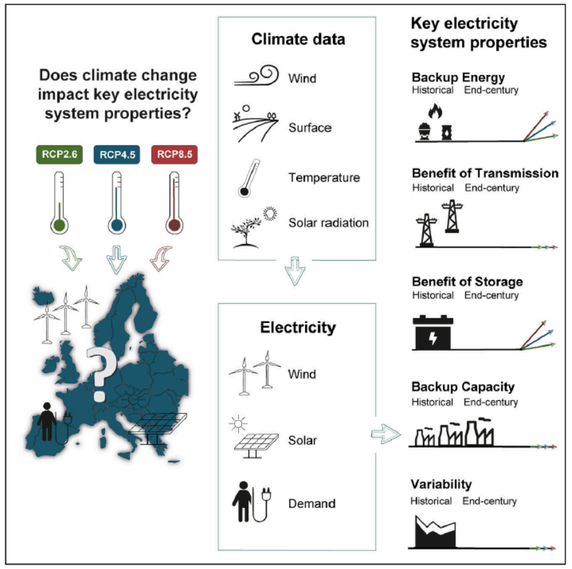
Gorm Bruun Andresen

Joule

CellPress

Article

21st Century Climate Change Impacts on Key Properties of a Large-Scale Renewable-Based Electricity System



Wind and solar sources currently drive an increased weather-dependent electricity production because of decreasing costs and efforts to mitigate climate change. Unfortunately, some degree of climate change appears to be unavoidable. We use different projections of climatic outcomes over the 21st century to assess how important key metrics of a highly renewable electricity system are affected by climate change.

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HIGHLIGHTS

Climate change shows impacts on large-scale metrics of a European electricity system

Largest climate impacts are observed within fully wind-dominated electricity systems

6 high-resolution CMIP5 GCMs under the forcing of three IPCC RCPs have been used

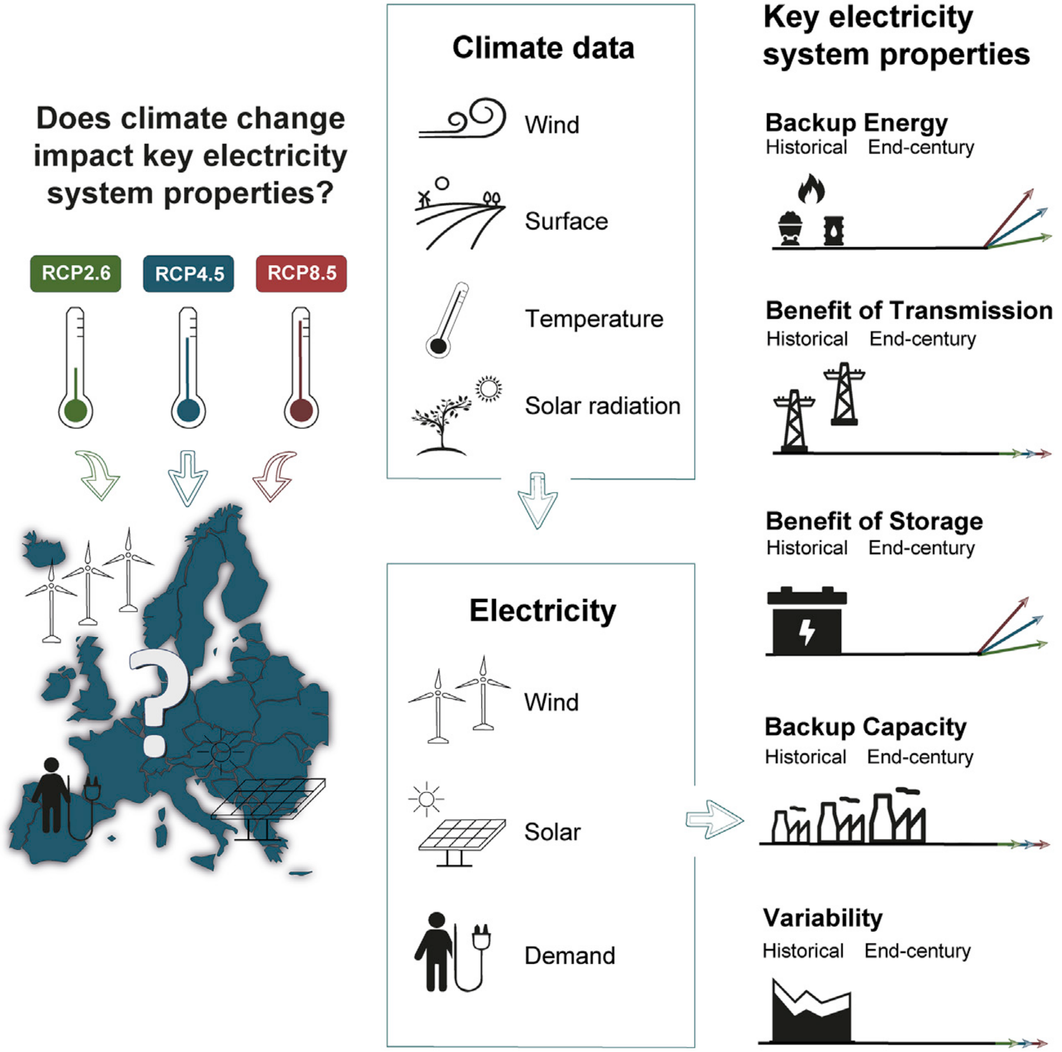
State-of-the-art wind and solar capacity factors and electricity demand data were used

Kozarcanin et al., Joule 3, 1–14
April 17, 2019
https://doi.org/10.1016/j.joule.2019.02.001

Goals

- Understand how the temperature increase will affect the European electric system
- Make the previous study more robust:
  - From 6 to 9 models
- Focus on the differences between model results

Yearly averaged and smoothed (10 years) temperatures from the regional model HIRAM5 for the 3 IPCC scenarios, RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red) and the historical period (black)



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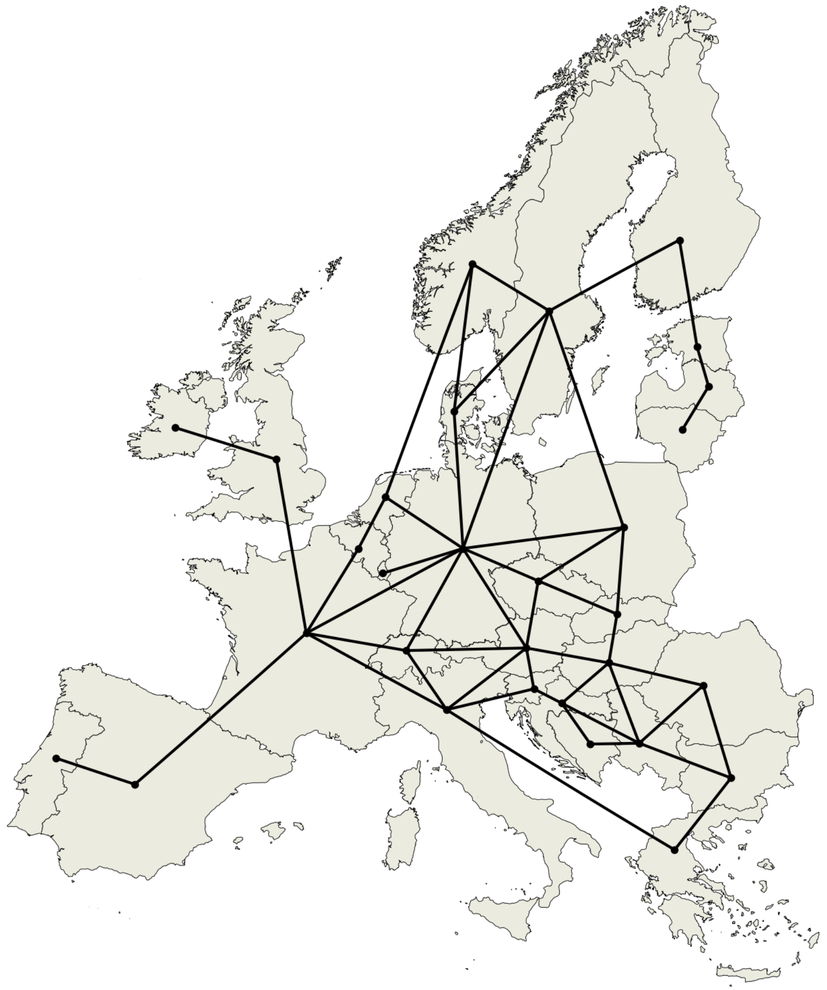
Methodology

- Creating a network connecting 30 European countries
- Assuming 100% renewable generation as solar and wind power
- Basing the load on the current electricity consumption
- Forecasting the future temperature, wind speed and solar radiation in Europe
- Forcing 3 IPCC scenarios on global models and downscaling them on regional models (EURO-CORDEX)



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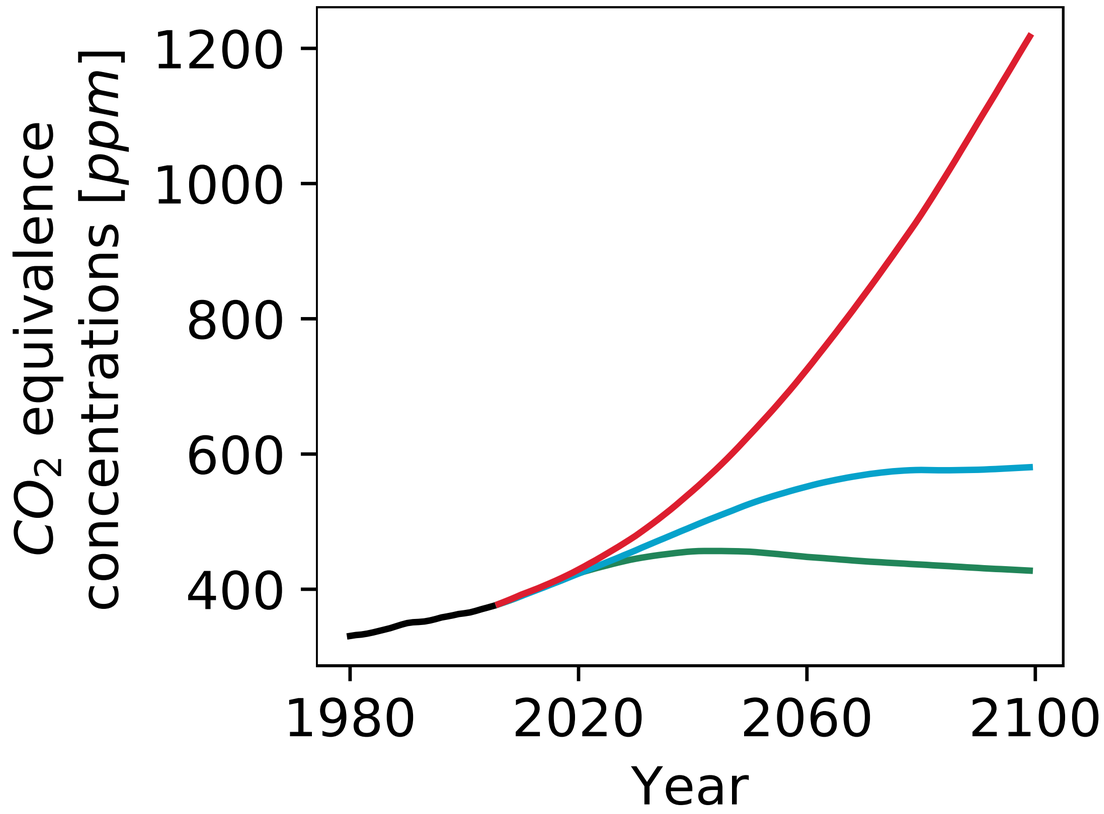

Forecast of CO_2 concentration from the 3 IPCC scenarios, RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red) and the historical period (black)

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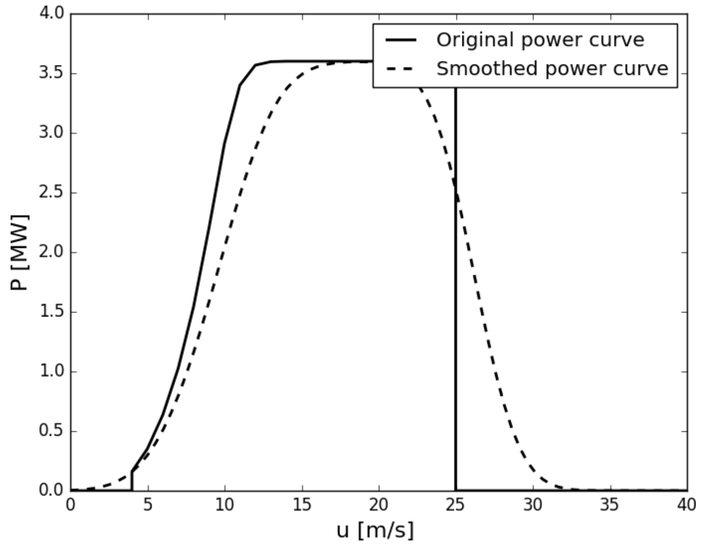
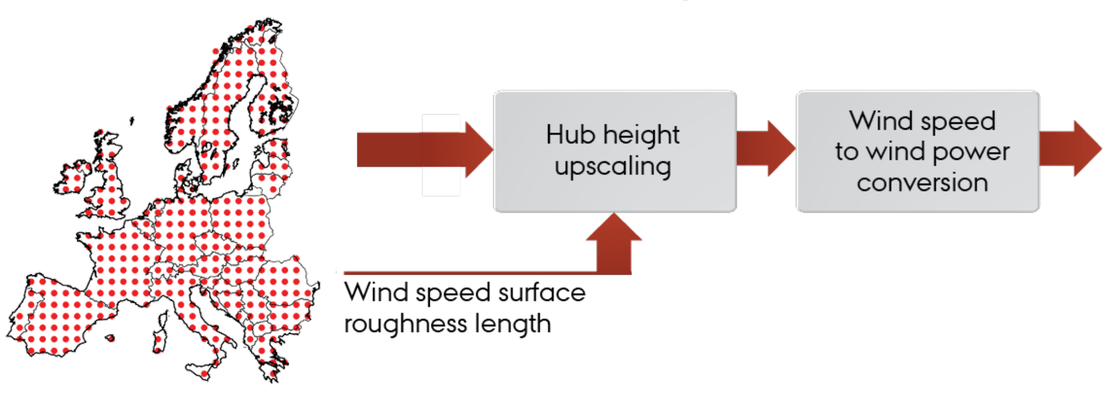
Data treatment

- Spatial resolution of 12x12 km
- Temporal resolution of 3 hours
- Conversion of data into power:
  - Wind speed —> Wind power
  - Solar radiation —> Solar power





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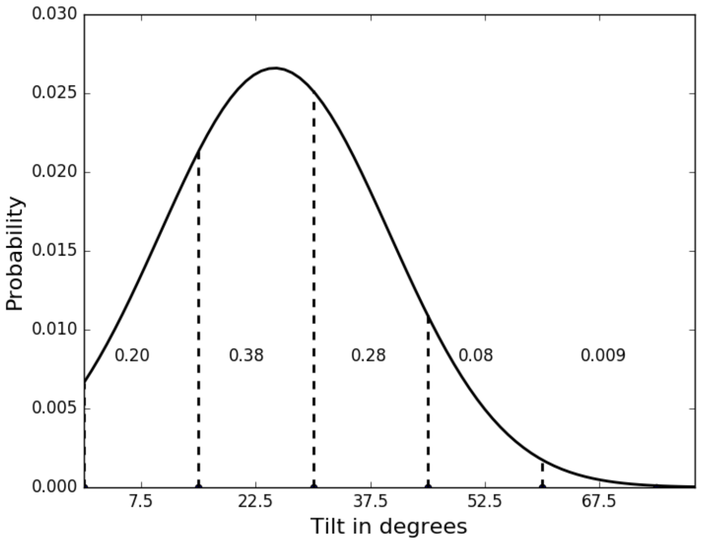

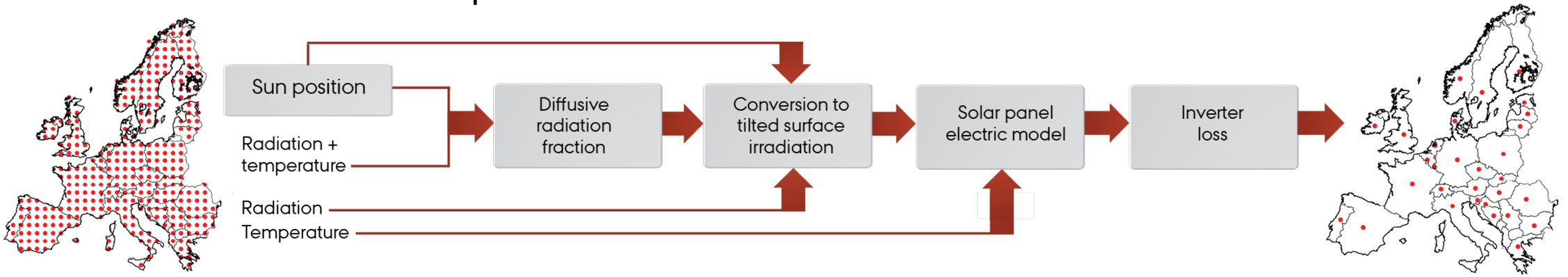

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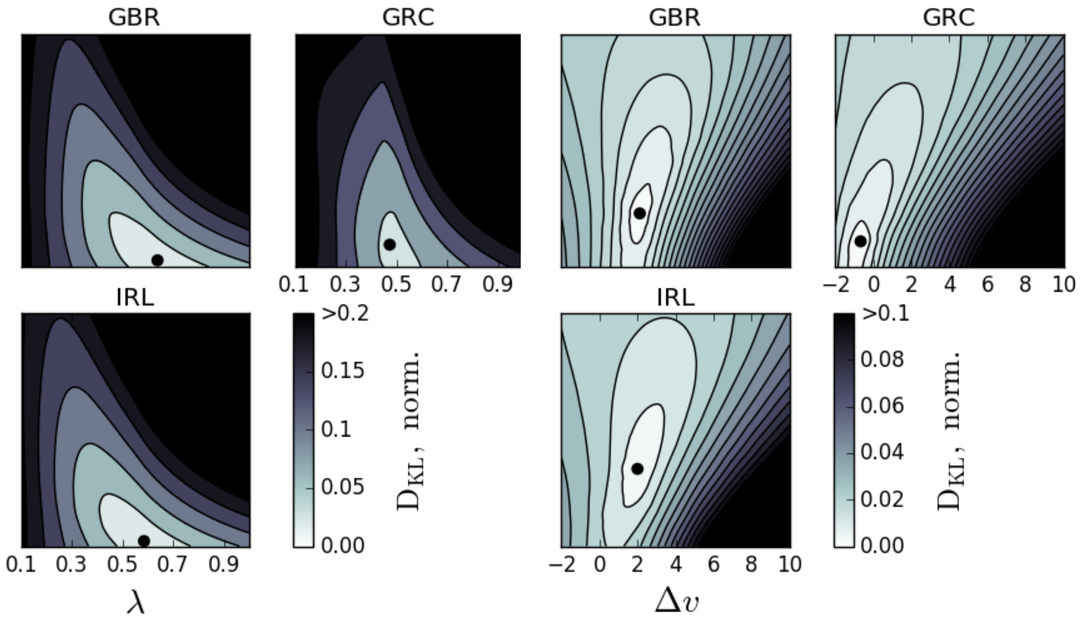
- Balancing equation of the network



Heat maps of the resulting Kullback-Leibler divergence, D_{KL}, for United Kingdom, Greece and Ireland in the climate model CCLM4-MPI-ESM-LR for solar (left) and wind (right) power. The black dots indicate the optimal values

$$D_{kl} = \sum_{q} CF_{R,q}^{W} \ln\left(\frac{CF_{R,q}^{W}}{CF_{C,q}^{W}(\sigma_0, \Delta v)}\right)$$

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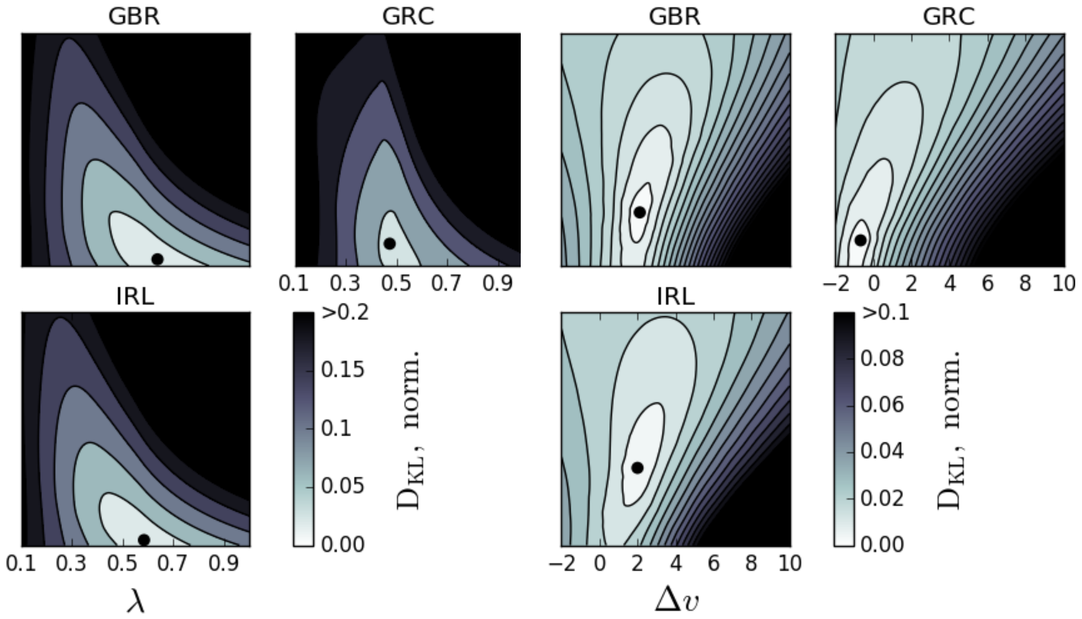

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$$G_n^R(t) - L_n(t) = B_n(t) + P_n(t)$$

$$G_n^R(t) = G_n^W(t) + G_n^S(t)$$

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Key metrics

Dispatchable electricity

Necessary non-renewable energy

$$G_n^B(t) = -\min(B_n(t),0)$$

Benefit of transmission

Change in dispatchable electricity in case of zero and infinitive transmission

Benefit of storage

Change in dispatchable electricity in case of smooth and not smooth load

Dispatchable Capacity

Non-renewable capacity necessary to generate 99% of the necessary power

Short-term variability

Average fluctuation of the non-renewable electricity for continuous time steps

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$$0.99 = \int_0^{k_n^B} p_n(G_n^B) dG_n^B$$

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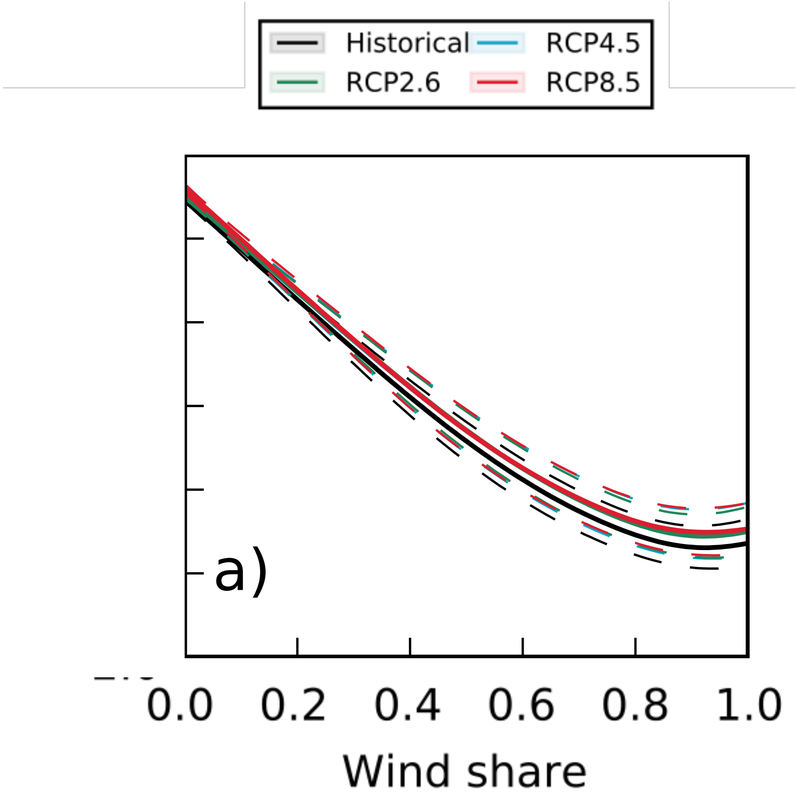
$$\sum_n std_t(G_n^B(t) - G_n^B(t+1))/K^{W+S}$$

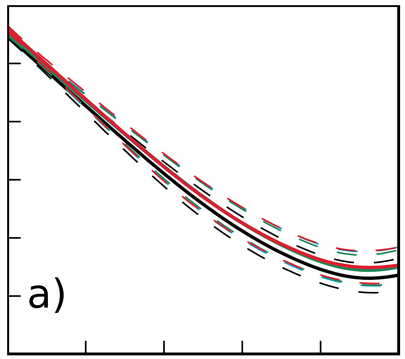
Analysis

- Impact of wind penetration at the end of the century
  - Models average
  - Time average of the end of the century 2080-2100
- Accordance between models



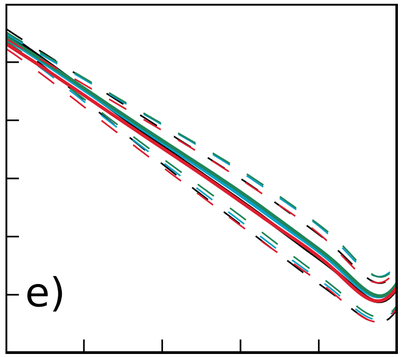
Model ensemble average trend of the Dispatchable Electricity metric as a function of the renewable power mix (solar-wind) for the historical period 1996-2006 (black), and predicted period 2080-2100

Results



patchable Capacity

d)



Trend of the 5 Key Metrics as a function of the renewable power mix (solar-wind) of the ensemble average over all the models for the historical period 1996-2006 (black), and predicted period 2080-2100 under the 3 ICPP pathways RCP2.6, RCP4.5 and RCP8.5, green, blue and red respectively.

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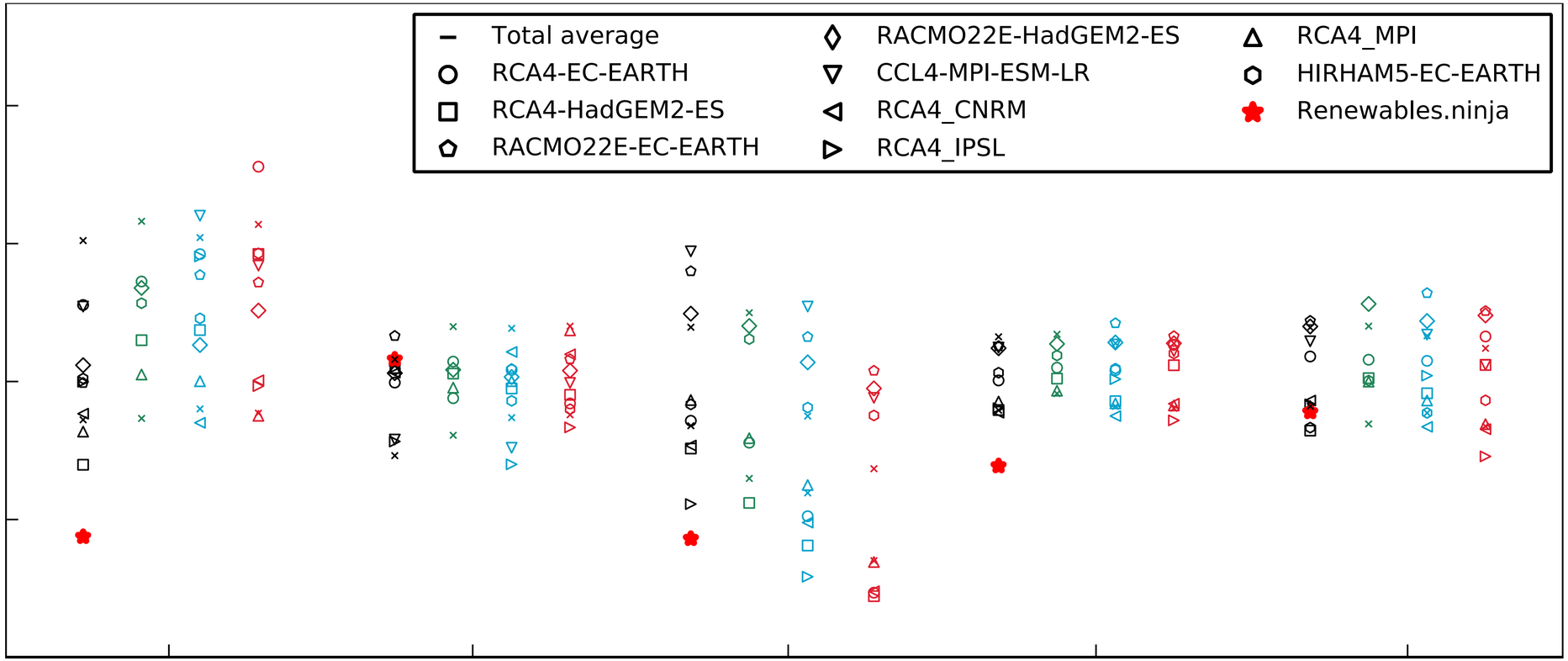
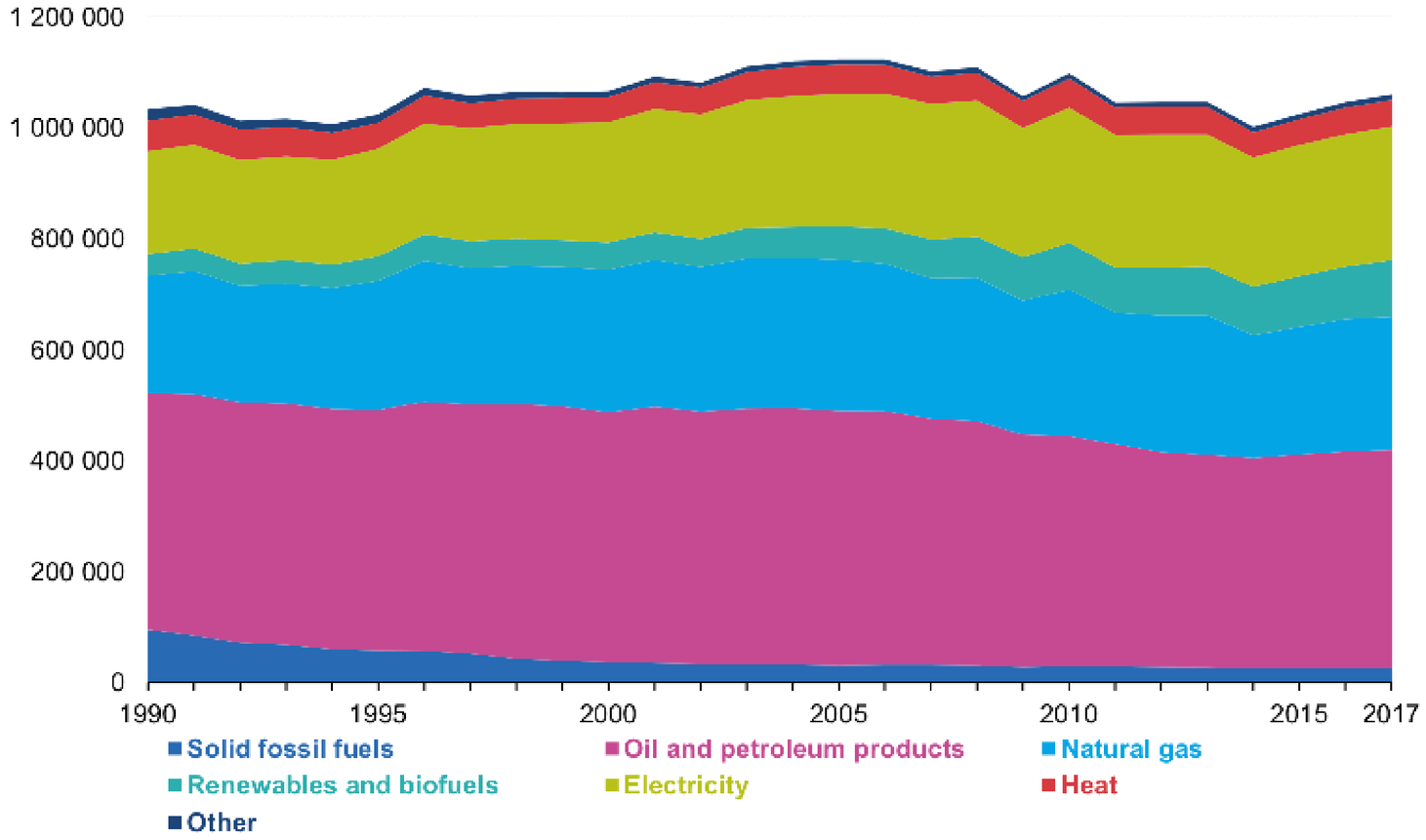
Results



Time average comparison between all the models for the 5 Key Metrics. The colours black, green, blue and red represent historical period (1996-2006), RCP2.6, RCP4.5 and RCP8.5 pathways for the end of the century 2080-2100 respectively.

How can we improve?



Historical trend of final energy consumption by fuel in the EU in [ktoe]
Source: Energy balance sheet - Data 2017 - Edition 2019

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Summary

- Goals
  - Understand how the temperature increase will affect the European electric system
  - Support the results of the already published paper
- Results
  - General impact of climate change lower than annual variation
  - Storage metric effected in the case of high solar penetration and high CO_2 emissions
  - All the 9 models agree on the results and validate the conclusions of the main paper