Does the spatial layout of variable renewable energy capacity matter?

- A quantitative study of its influence on variability characteristics of the EU-aggregated power output

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Introduction

- Energy from wind and solar photovoltaics (PV) is expected to greatly increase its share of the sourced energy in the EU power systems. At the same time, unfortunately, the temporal variability of these resources greatly increases the need for system flexibility and back-up capacity.
- Demand-side management and improved energy storage may mitigate this, but so may an efficient use of resource mixes and spatial capacity layouts within a sufficiently large interconnected area. However, little is known about the spatiotemporal variability of wind and solar in Europe, and particularly how a joint EU approach to wind and solar PV deployment can be optimised.

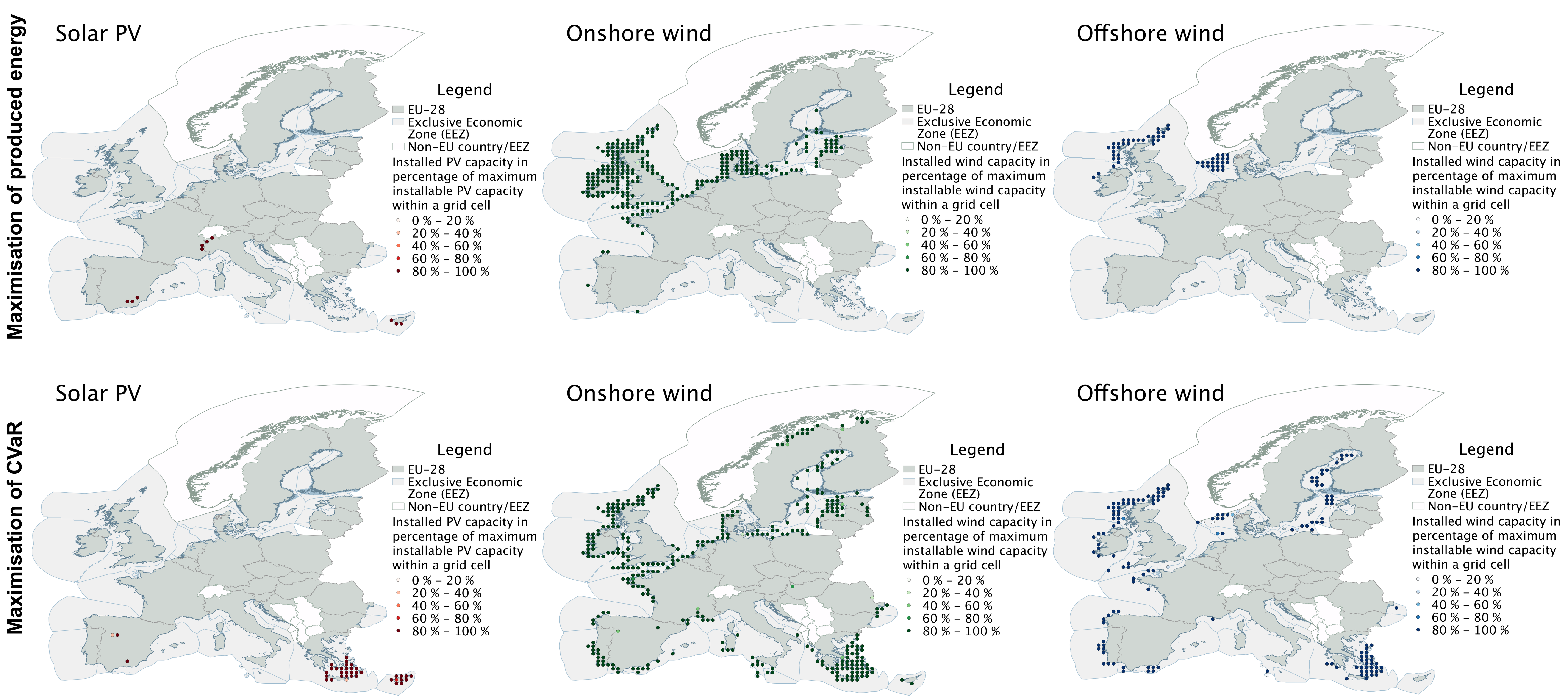
➡ **What is the benefit of an EU-scale spatial optimisation of capacity compared to single country-scale optimisations in terms of the variability of the combined wind and solar PV power output across EU at the daily time scale for one indicator of variability, the conditional value-at-risk (CVaR)? How does it compare to similar spatial optimisations of capacity based on a maximised energy production?**

Data and Methods

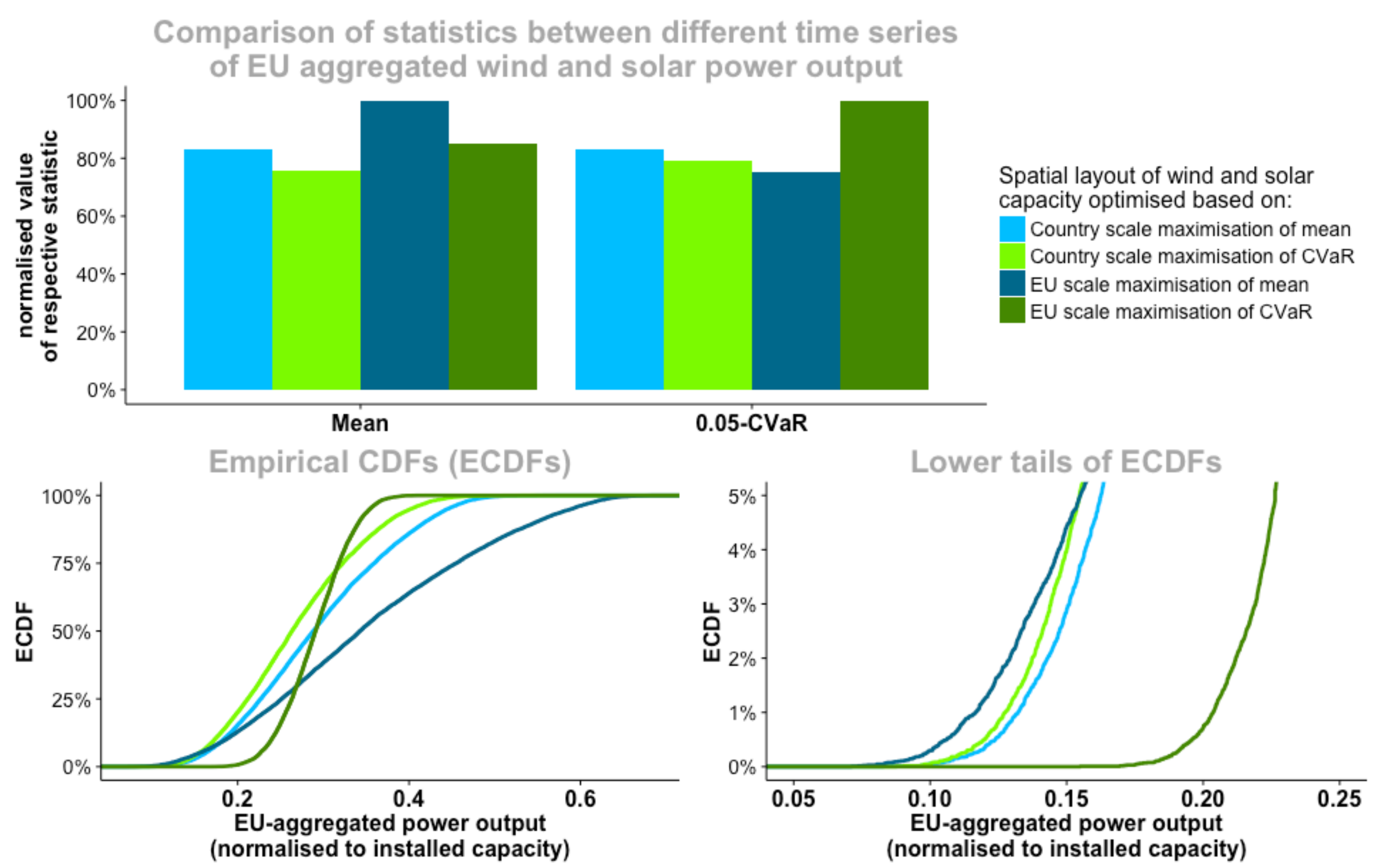
- We obtain time series for solar PV, onshore and offshore wind power output per installed power device per MERRA grid cell by applying physically motivated, or commonly used, models to MERRA reanalysis data[1] for Europe over 36 years (1979-2014) with a resolution of hours and 0.5º × 0.67º.
- Resource mix and installed capacity according to the National Renewable Energy Action Plans (NREAPs) for 2020 are used: in total 169 GW onshore wind, 44.4 GW offshore wind and 84.4 GW solar PV.
- We optimise the spatial distribution of capacity based on two different criteria: 1) maximise CVaR, and 2) maximise produced energy. The latter is the same as maximising the mean of the power output.
  - CVaR is defined as the mean value of the power output at and below the 5th percentile of the spatially aggregated combined wind and solar PV power output distribution. We use the linear optimisation formulation of CVaR outlined in Rockafellar and Uryasev[2] (2000). This optimisation is done simultaneously for all three resources, i.e. not separately for each resource.
- Each optimisation criteria (1 and 2) is optimised at two spatial scales: A) at the country-scale, where each optimisation takes place separately within each country, and B) at the EU-scale, with the optimisation taking place at the EU-level, i.e. without considering country borders.
- Capacity deployment constraints per resource per grid cell are determined by calculating the land area respectively the offshore area with a sea depth less than 50 m for each grid cell using GEBCO bathymetry data[3] and then applying a simple assumption of 10% area availability for each resource.
- The optimisations are based on the full 36-year time series and performed at the same spatial resolution as the MERRA grid cells, but at a daily time scale. As solver, CPLEX is used.
- Finally, the values of the CVaR and the mean of the resulting EU-aggregated combined wind and solar PV power outputs for each optimised capacity layout are compared.

Preliminary results

Resulting capacity layouts for EU-scale optimisations



CVaR significantly improved by EU-scale optimisation



Conclusions and Future Directions

- For EU-scale optimisations, the value of CVaR is significantly higher (33%) when the capacity layout has been optimised based on this criteria compared to energy production. It is also significantly higher (21-26%) than the resulting EU-aggregated CVaR for country-internal maximisations of CVaR and energy production.
- These results imply that the spatial layout of variable renewable energy installations has a significant impact on the variability of the power output at the EU-scale and should be considered in planning scenarios.
- Additional dimensions to study are different temporal scales, variability indicators (also including temporal variability of demand), resource mixes and amounts of total installed capacity, but also other spatial capacity distribution criteria, such as proximity to demand centres. In the future, other data sources, including higher spatially resolved wind data, should be investigated.

Acknowledgments

This work was funded by Good Energy

References:

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(2) Rockafellar, R.T., and S. Uryasev. "Optimization of Conditional Value-at-Risk." *The Journal of Risk* 2, no. 3 (2000): 21–41.
(3) "GEBCO 30 Arc-Second Grid." *GEBCO*. Accessed October 28, 2015. http://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_30_second_grid/.