Impact of climate change on a future highly renewable European power system

Strommarkttreffen
17.11.17

Markus Schlott[a], **Alexander Kies**[a], Tom Brown[a], Stefan Schramm[a], Martin Greiner[b]

October 2017

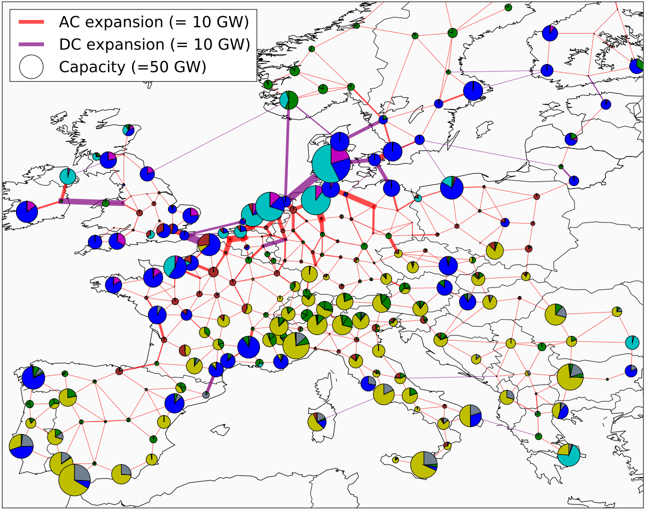
Frankfurt Institute of Advanced Studies (FIAS), Goethe University Frankfurt[a]
Department of Engineering, Aarhus University[b]

Background

Optimal future highly renewable European power system?

Background

Using historic data, maybe like that



Background

- Power systems around the world are transforming to mitigate climate change
- Climate gas emissions of power systems have effect on weather patterns
- Weather patterns influence power systems based on renewable sources
- **Here: Investigate the effect of climate change on renewable resources and consequently a highly renewable European power system**

Climate affected weather data

- Weather data of the EURO-Cordex initiative (euro-cordex.net)
- 5 ensembles (different GCM, same RCM) which provide (among other variables) 10 m wind speeds, temperatures, irradiation and surface runoff at a spatial resolution of 0.11 degrees and 3 hourly temporal resolution
- Convert this weather data to power data using the Aarhus Renewable Atlas
- We use data under emission pathway RCP (representative concentration pathway) 8.5 (associated with a temperature increase of 2.6 to 4.8 degrees Celsius until the end of the century compared to pre-industrial values) until 2100

Periods considered

We study two quantities, mean and correlation length for renewable resources and the following periods

notation	years covered
historical (Hist.)	1970 - 2005
beginning of century (BOC)	2006 - 2037
middle of century (MOC)	2038 - 2069
end of century (EOC)	2070 - 2100

Table 1: Time periods considered.

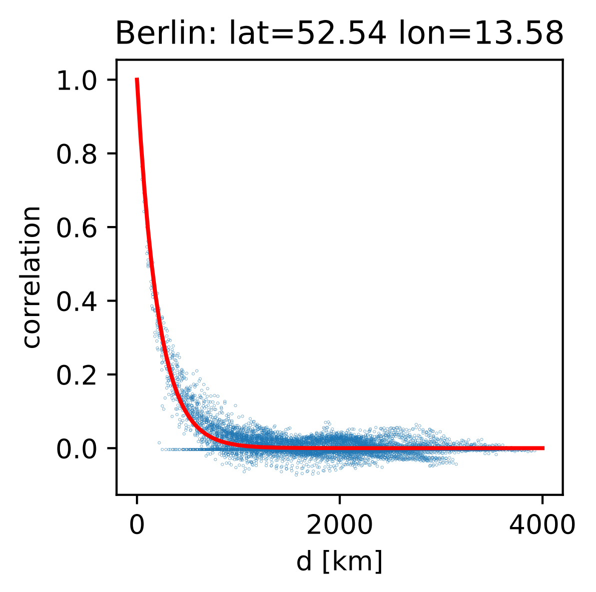
For correlation lengths, we compute pairwise

$$\rho^\tau(x_i, x_j) = \frac{cov(\tau(x_i), \tau(x_j))}{\sigma_{\tau(x_i)}\sigma_{\tau(x_j)}}, \tag{1}$$

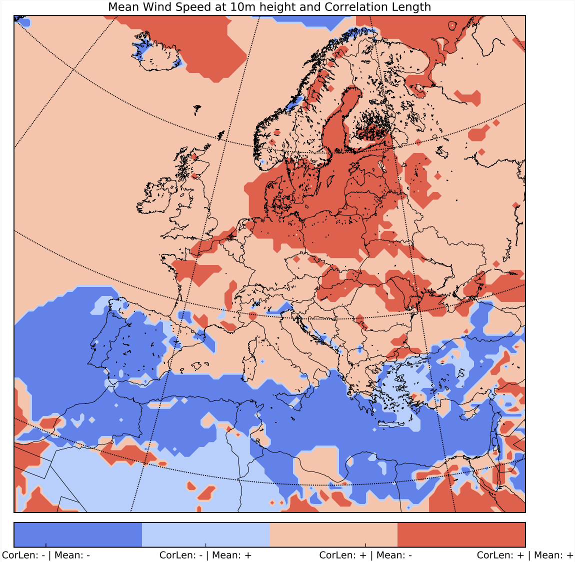
and fit it to

$$\rho^\tau(x_i, x_j) = \exp\left(-a_i^\tau d\left(x_i, x_j\right)\right) + \epsilon, \tag{2}$$

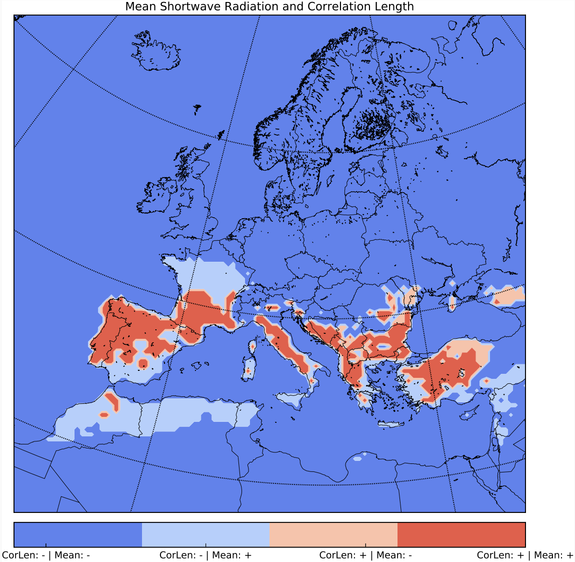
Correlation length



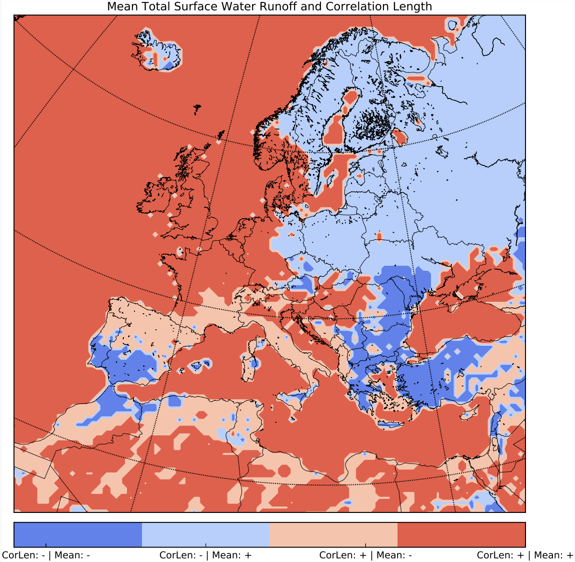
Renewable energy resources - wind



Renewable energy resources - solar

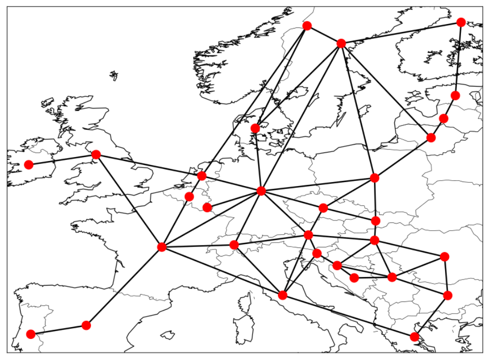


Renewable energy resources - hydro



Impact on optimal power system

We calculate the cost-optimal power system (generation, transmission, storage) represented by one node per country for historic weather data from 1970 climate change-affected EOC weather data for 2100 in 5-6 year blocks



Linear optimisation of annual system costs

Given a desired CO_2 reduction, what is the most cost-effective energy system?

$$\text{Minimise} \begin{pmatrix}\text{Yearly system}\\ \text{costs}\end{pmatrix} = \sum_n \begin{pmatrix}\text{Annualised}\\ \text{capital costs}\end{pmatrix} + \sum_{n,t} (\text{Marginal costs})$$

subject to

- meeting energy demand at each node n (e.g. countries) and time t (e.g. hours of year)
- wind, solar, hydro (variable renewables) availability $\forall\, n, t$
- electricity transmission constraints between nodes
- (installed capacity) $\leq$ (geographical potential for renewables)
- CO_2 constraint (95% reduction compared to 1990)
- Flexibility from gas plants, battery storage networks

Cost assumptions

technology	investment cost [Euro/kW]	operational cost [Euro/kW/a]	marginal cost [Euro/MWh]	lifetime [a]	efficiency	capital cost energy storage [Euro/kWh]
onshore wind	1182	35	0.015	25	1	
offshore wind	2506	80	0.02	25	1	
solar PV	600	25	0.01	25	1	
OCGT	400	15	58.4	30	0.39	
hydrogen storage	555	9.2	0	20	$0.75 \cdot 0.58$	8.4
battery	310	9.3	0	20	$0.9 \cdot 0.9$	144.6
transmission	400 Euro /MWkm	2%	0	40	1	
PHS	2000	20	0	80	0.75	N/A
hydro reservoir	2000	20	0	80	0.9	N/A
run-of-river	3000	60	0	80	0.9	

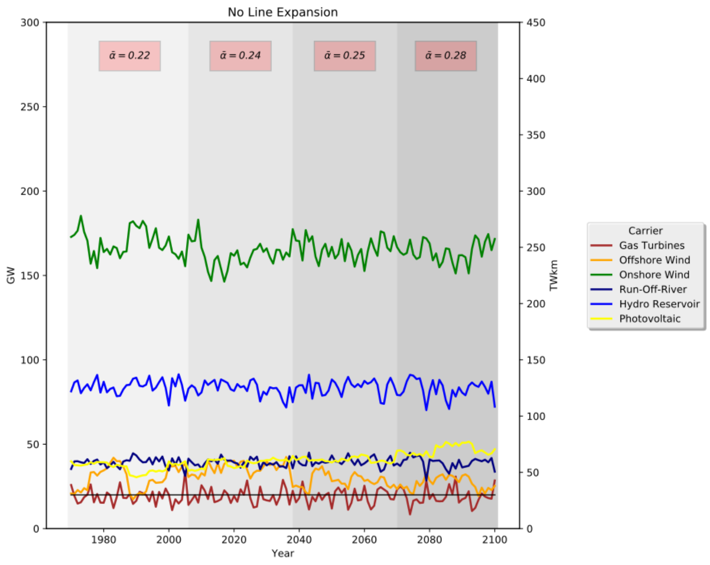
Table 2: Cost assumptions for generation technologies originally based on 2030 value estimates from Schroeder et al..

Results

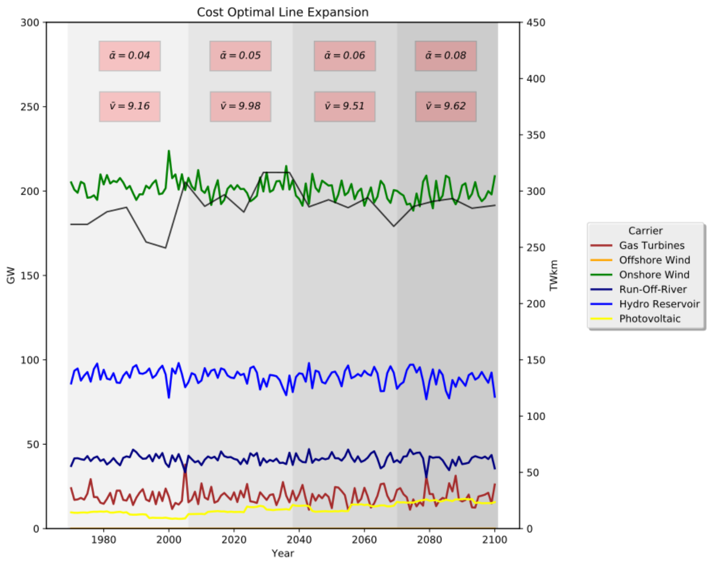
Results for the MPI-ESM-LR ensemble member

- Two (of four) scenarios: with storage and with/without transmission capacity expansion
- Additional results can be found in upcoming paper.

Results - Optimisation with Transmission Cap



Results - Optimisation no Transmission Cap



Results - Optimisation with Transmission Cap

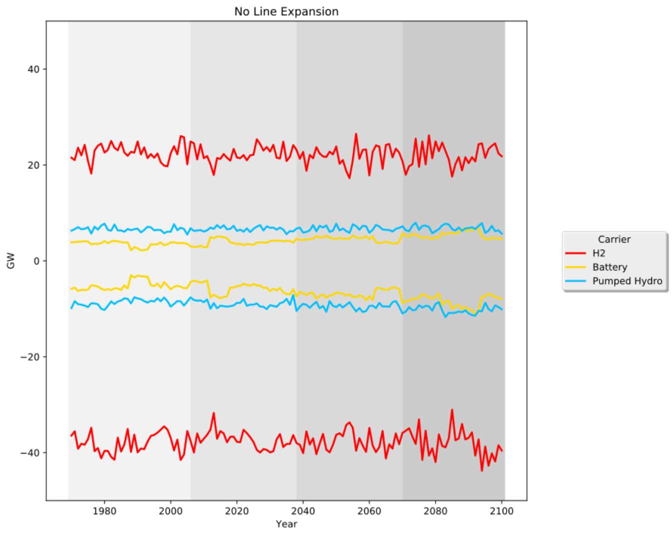


Figure 1: Average hourly charging (negative axis) and discharging (positive

Results - Optimisation no Transmission Cap

Results - Optimisation with Transmission Cap = today

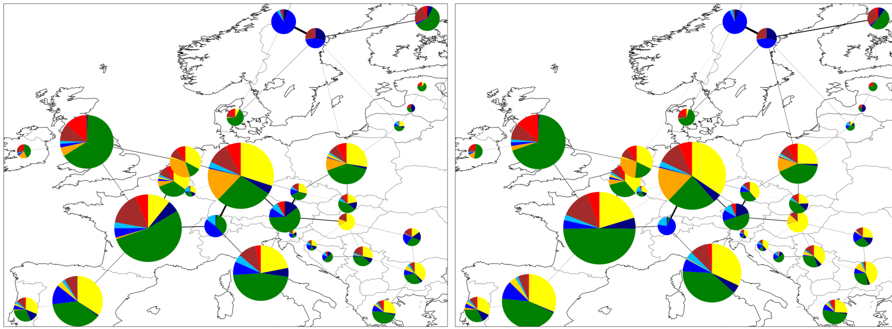


Figure 3: Yellow is solar power, green is onshore, orange offshore wind, gas turbines are red, light blue are hydro reservoirs and dark blue is run of river. The left figure is based on historical weather data, whereas the right figure is based on EOC data.

Results - Optimisation with Transmission Cap = 5 today

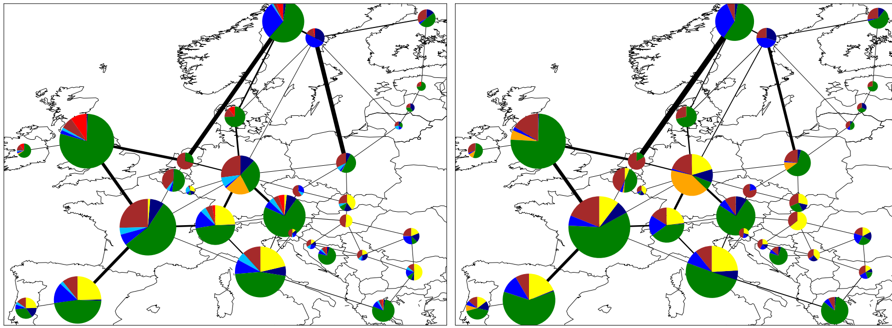


Figure 4: Yellow is solar power, green is onshore, orange offshore wind, gas turbines are red, light blue are hydro reservoirs and dark blue is run of river. The left figure is based on historical weather data, whereas the right figure is based on EOC data.

Results - Optimisation no Transmission Cap

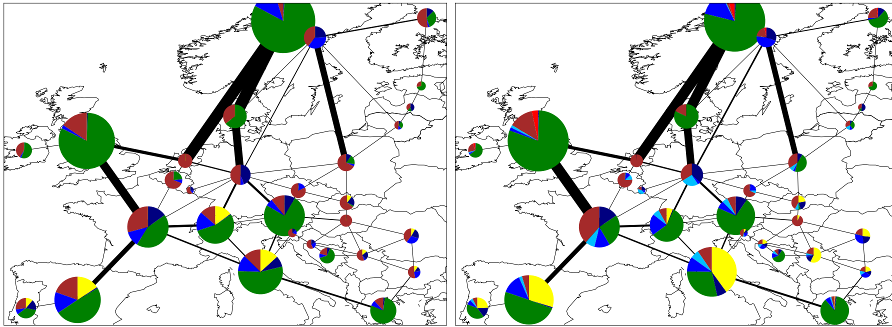


Figure 5: Yellow is solar power, green is onshore, orange offshore wind, gas turbines are red, light blue are hydro reservoirs and dark blue is run of river. The left figure is based on historical weather data, whereas the right figure is based on EOC data.

Conclusions

- Wind, solar and hydro resources are affected by global warming, but consequences for European countries differ.
- Changing renewable resources lead to small changes in the cost-optimal European power system infrastructure. For all scenarios with/without storage/transmission grid expansion, the share of solar power rose considerably if the end of the century is compared with historical years.
- The cost-optimal European power system requires an extension of today's inter-connecting transmission capacities, in all scenarios, the need for inter-connecting transmission capacity expansion grows as the effect of climate change on weather data grows.
- All scenarios were dominated by generation from wind onshore.

Outlook

- All scenarios were dominated by generation from wind onshore and contained no or only minor shares of offshore wind energy. However, wind offshore costs have fallen in recent years much faster than earlier projected and this might not be adequately reflected by the cost assumptions.
- It has not been fully understood (yet) how significant the effect of the changes in power system infrastructure induced by climate affected weather on overall system cost is, e.g., the structure of the solution at the optimum point must be analysed.
- It is planned to incorporate a scenario with climate change affected demand, as well.

Final Slide

Thank you for your attention.
Questions?

FIAS Frankfurt Institute for Advanced Studies

Stiftung Polytechnische Gesellschaft Frankfurt am Main

openmod open energy modelling initiative