PAUL SCHERRER INSTITUT

PSI

Martin Densing, Yi Wan, Russell McKenna; Energy Economics Group, Paul Scherrer Institute, Switzerland

Low-dimensional scenario generation method of solar and wind availability for representative days in energy modeling

IEA Wind TEM# 113, Dublin, 8. April 2024

Integrated Energy Systems Analysis at PSI and ETH

PSI

Technology Assessment

Dr. P. Burgherr

14 scientists, Postdocs, PhDs

- LCA
- Sustainability analysis
- MCDA
- External costs
- Health impacts

Energy Economics

Vacant

12 scientists, Postdocs, PhDs

- Scenario analysis
- Policies strategies for sustainable energy systems

Risk/Human reliability

Dr. V. N. Dang

3 Scientists

- Human Reliability analysis
- Critical infrastructure and resilience

ETH

Energy Systems Analysis

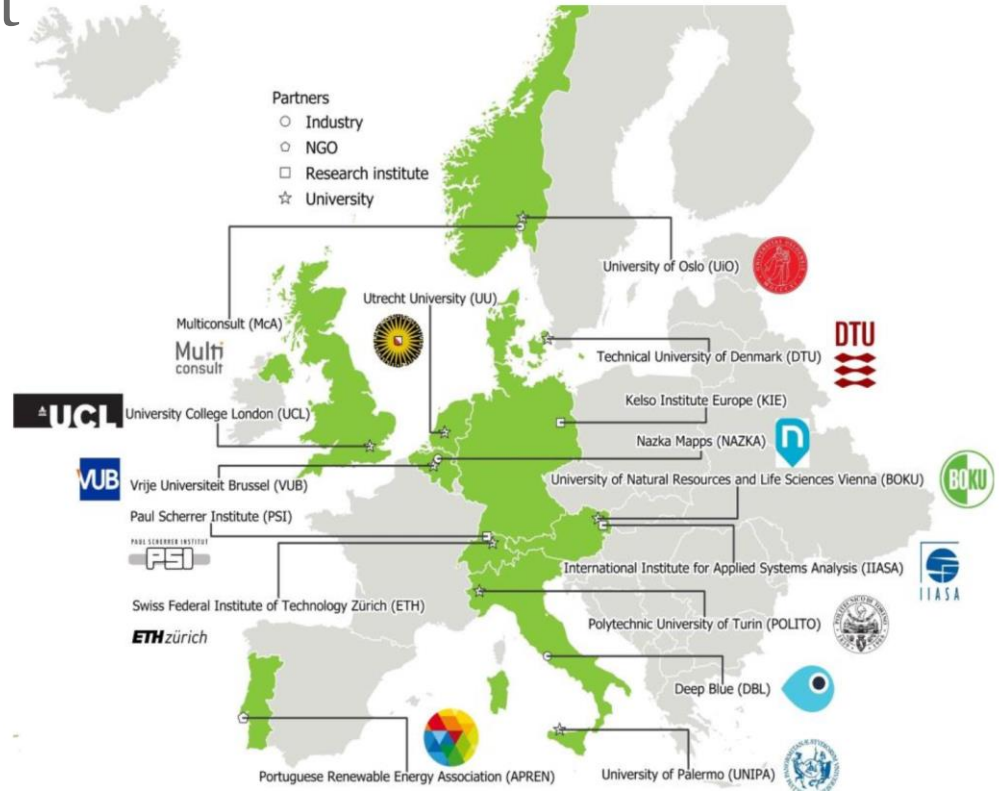
Prof. Russell McKenna

10 Postdocs & PhDs

- Decentralised energy systems
- Energy demand
- Resource assessment
- Sector coupling

WIMBY Project

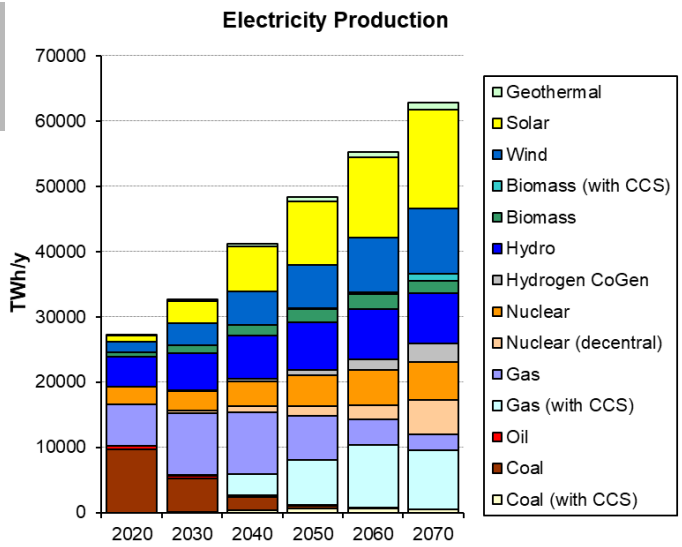
- EC Topic: Wind energy in the natural and social environment: **Deepen knowledge of barriers for social acceptance** and **develop guidelines to raise public understanding and engagement** with wind power.



- 16 Partners; Start: Jan 2023
- Budget: 3.3 Million € + CH + UK
- https://www.wimby.eu/

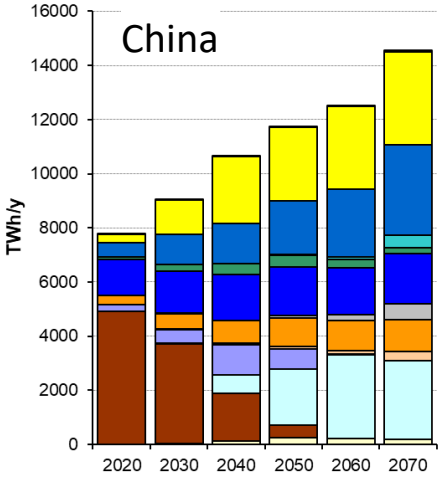
Wind in PSI's global (full) energy system model

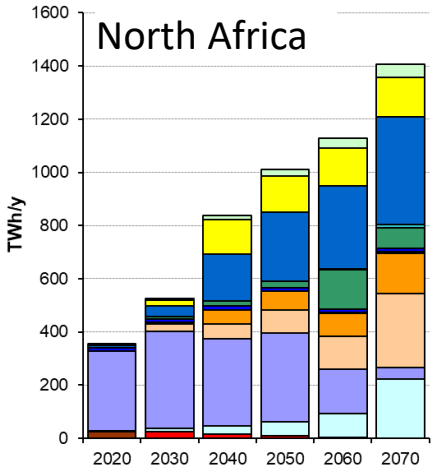
Example: Scenario «Harmony» (Converging, relatively high CO2 prices)

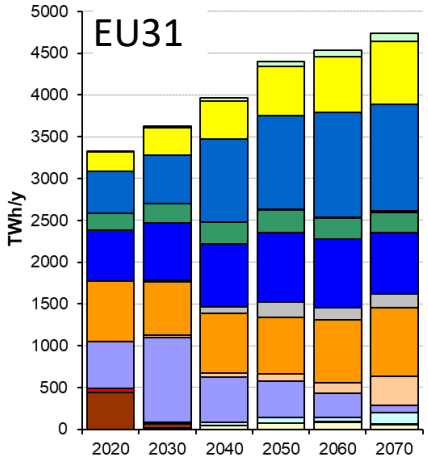


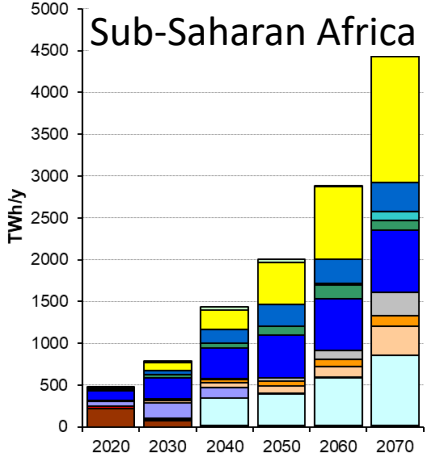
Standard approach to model wind in large-scale energy system models:

- **Time-slices:** Seasons & day/night
- **Availability factor** (per season and region)
- Wind cannot contribute to **«peak equation»** (dispatchable supply can)

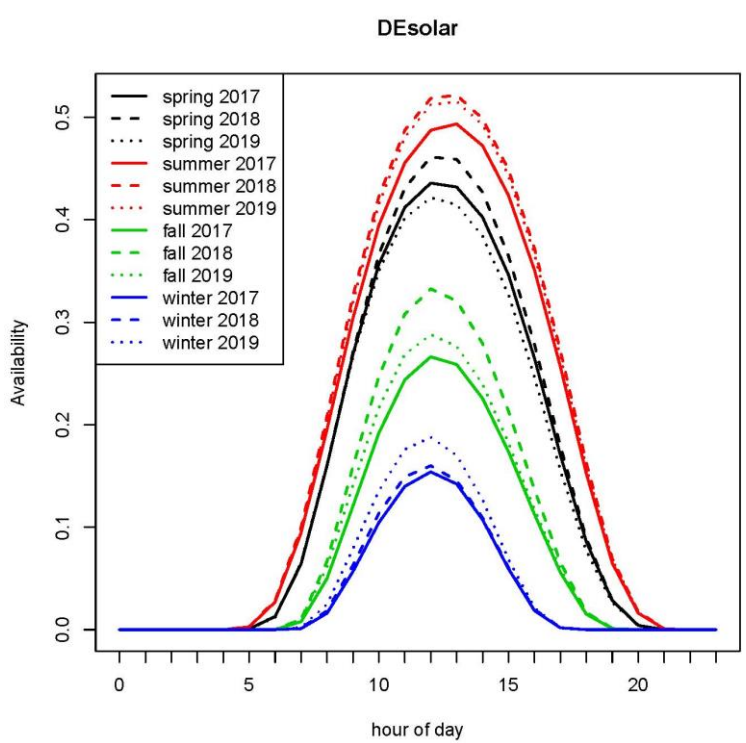


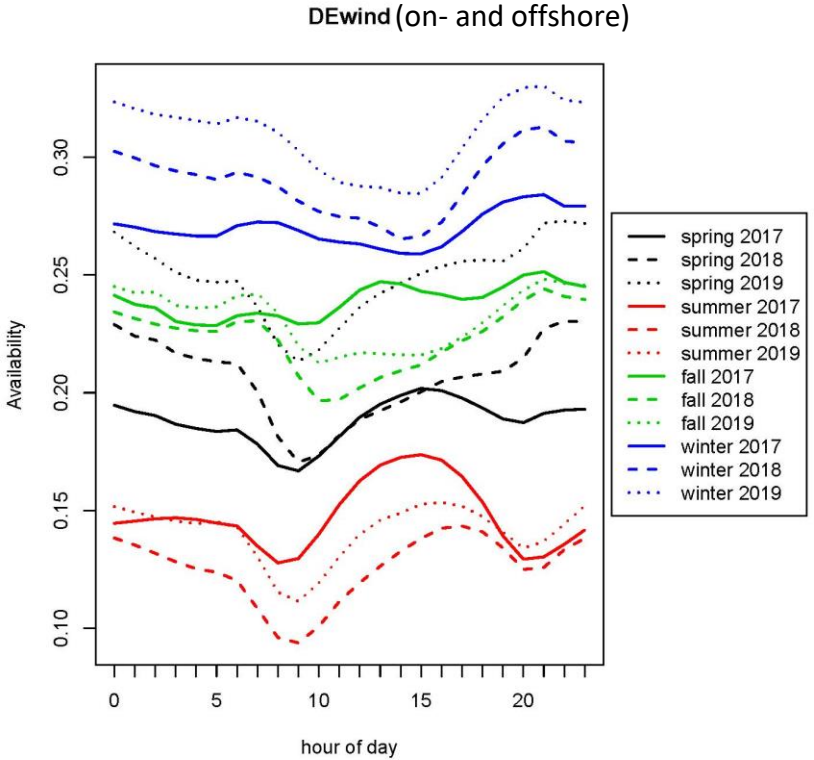






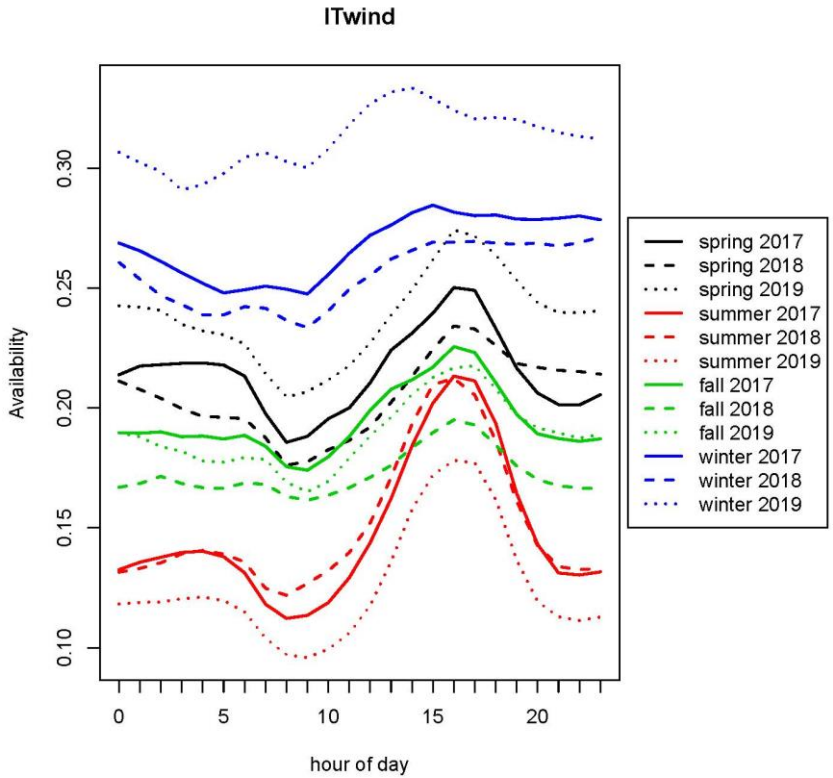
Wind & solar availability: Average days per season





- What about the correlations between hours of day ?
- **Goal: Capturing correlations of wind & solar availability per seasons**

Different wind pattern: Example Italy



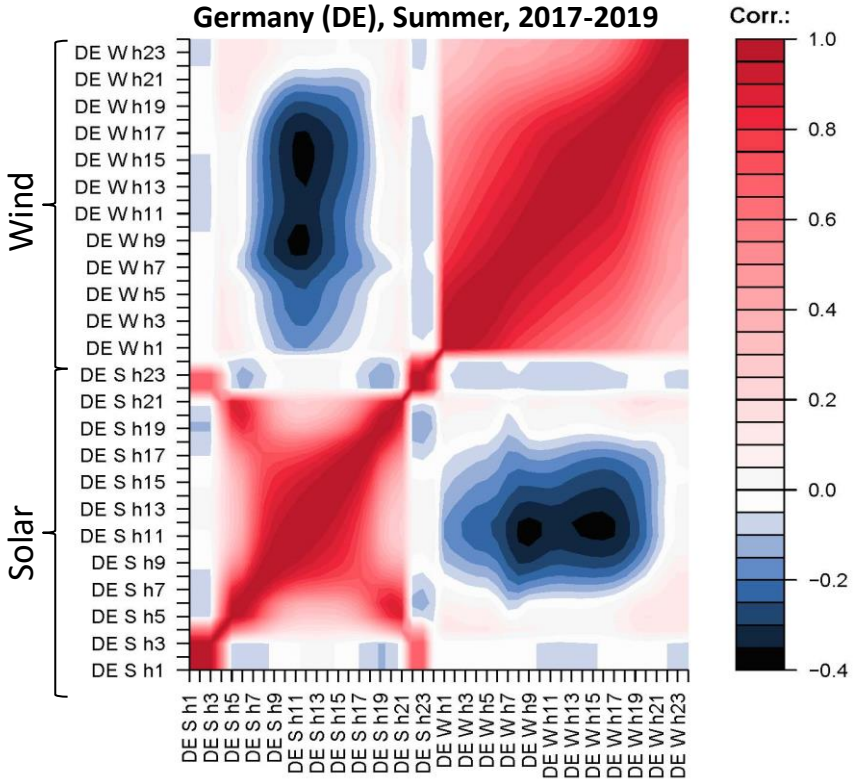
Correlation: Hourly wind & solar PV availability

Correlation wind vs. solar over all hours a year

Region	2017	2018	2019
Austria	-0.12	-0.14	-0.17
Switzerland	-0.16	-0.05	-0.12
Germany (on- and offshore)	-0.17	-0.24	-0.22
Germany offshore	-0.15	-0.21	-0.16
France	-0.15	-0.21	-0.16
Italy	-0.07	-0.09	-0.10

- Negative correlation can be higher in certain hours, up to: -0.4
- Positive correlation at
  - late-evening solar
  - late-evening wind

Correlation for each hour

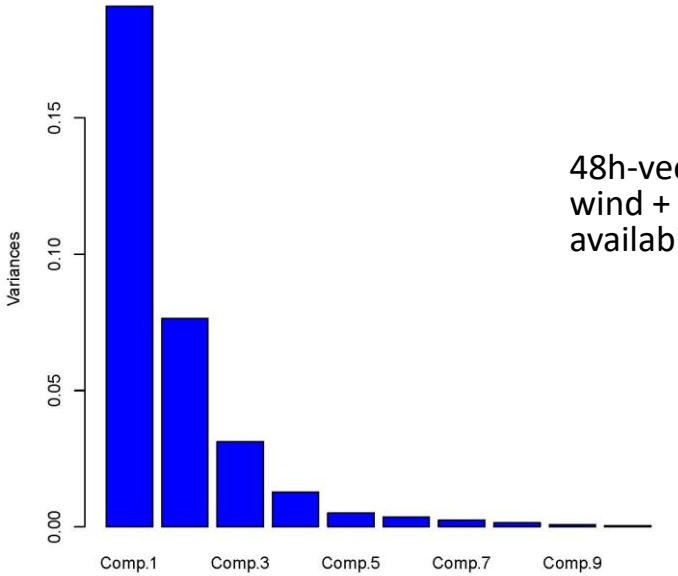


(wind: on + offshore)

Principal Component Analysis (PCA)

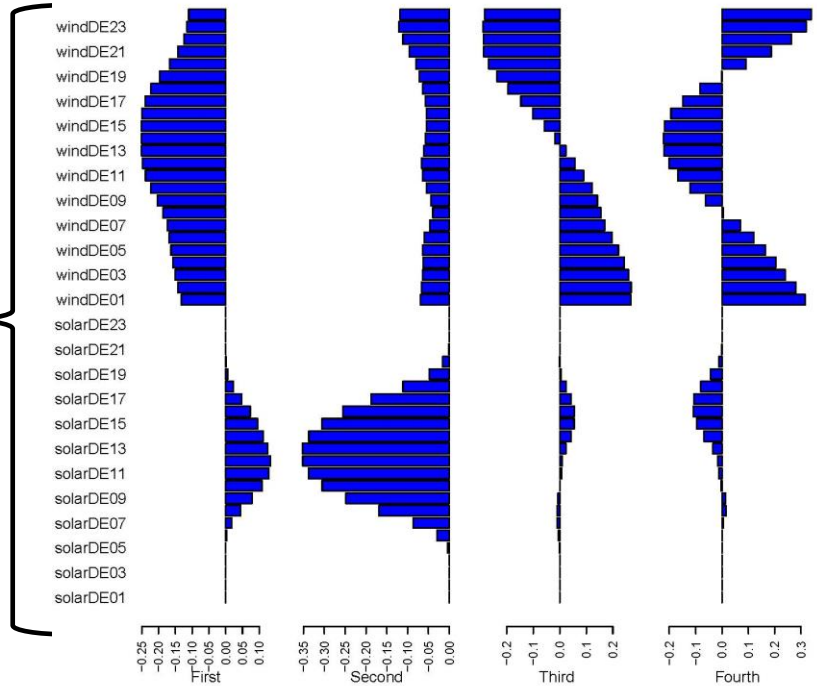
- Based on covariances, PCA yields uncorrelated loadings

Example: Germany, summer, 2017-19



Variance of PCs ordered by variance

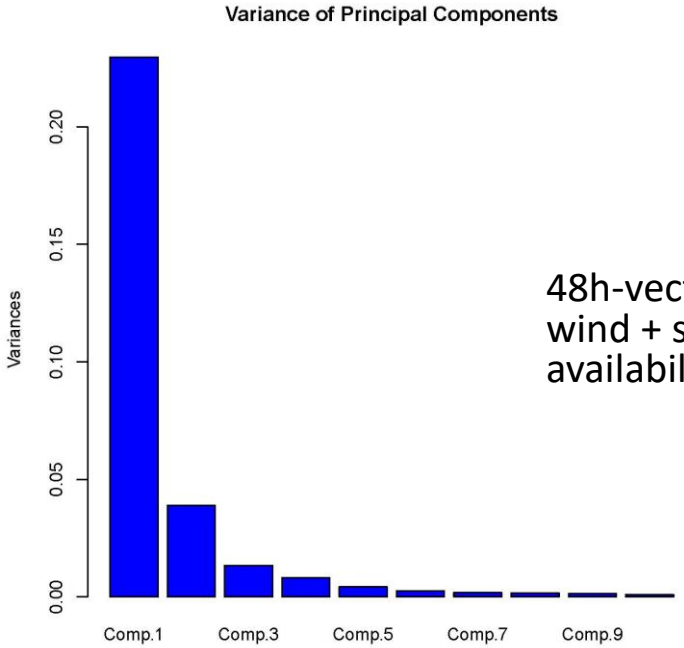
48h-vector wind + solar availability



Loadings of the ordered PCs

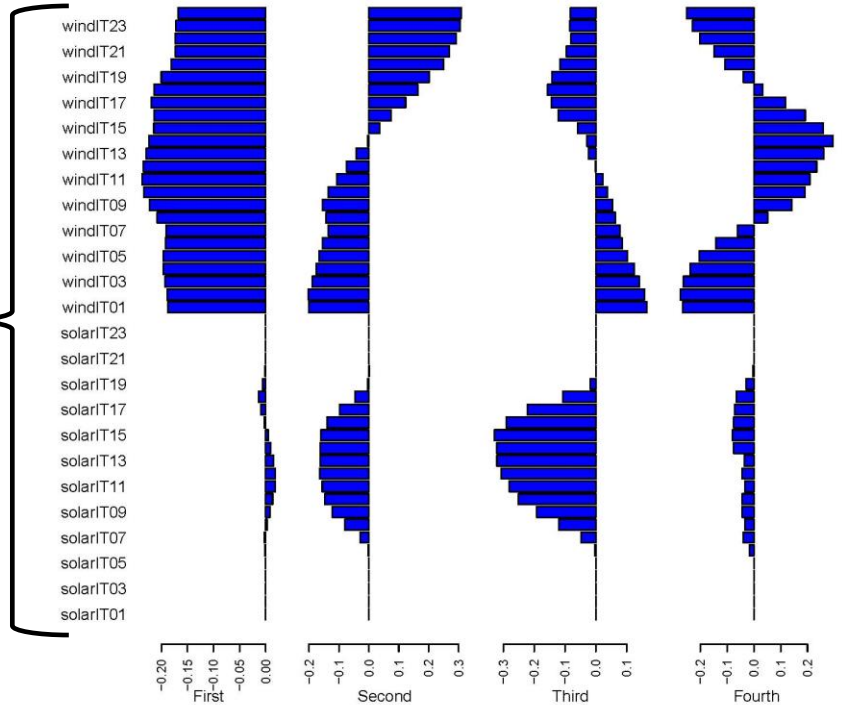
Italy: PCA of hourly wind & solar

Again: Summer, 2017-19



Variance of PCs ordered by variance

48h-vector wind + solar availability



Loadings of the ordered PCs

Scenario generation: Factor model given by PCA

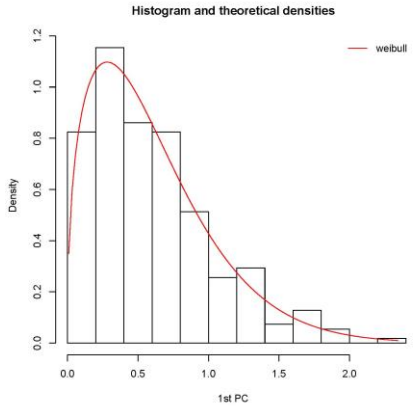
- PCA approximates covariance matrix of *X* by sum of uncorrelated loadings:

$$X \approx \sum_{i=1}^{k} P_i u_i, \qquad k < n$$

  - $X \in \mathbb{R}^n$: original random vector with values in n-dimensional space (n = 48),
  - $P_i \in \mathbb{R}$: random variable, i^{th} PC,
  - $u_i \in \mathbb{R}^n$: loadings of PC (deterministic vector)

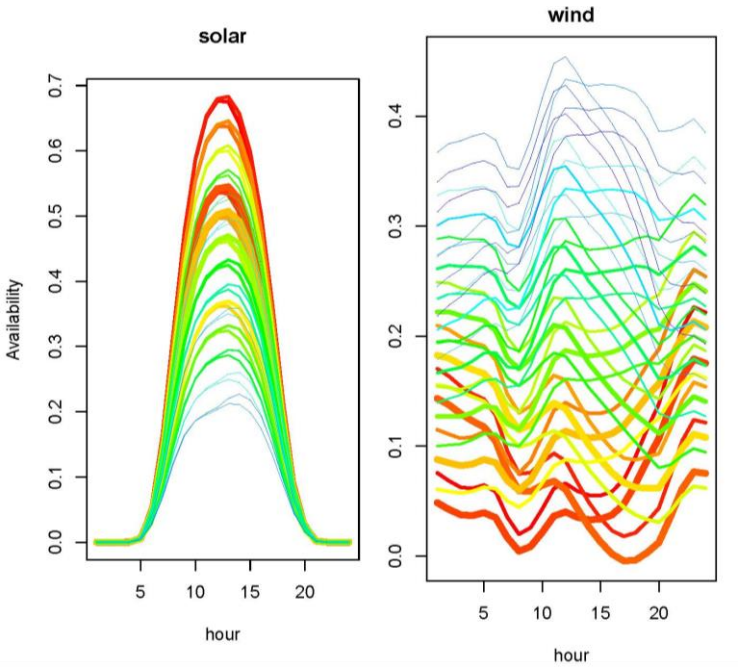
- **Factor model:** $X = UF + \varepsilon$
  - $F = (P_1, \dots, P_k)^T \in \mathbb{R}^k$: lower-dimensional factor,
  - $U = (u_1, \dots, u_n)$
  - Distribution of factors P_i are fitted by continuous distributions and then discretized:

Example: Germany, summer, P_1



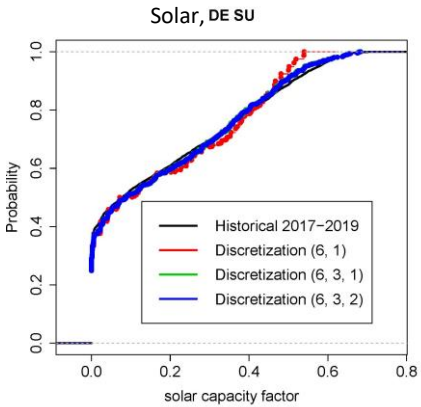
Scenarios; Quality

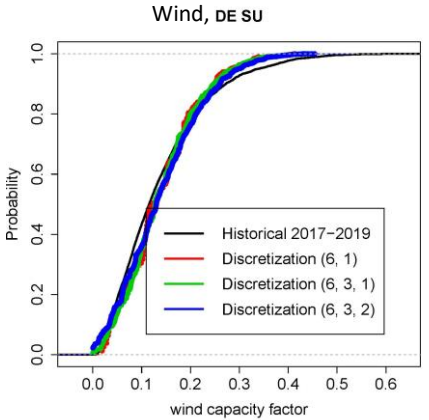
Example: Germany, summer; 36 scenarios;
line width = probability weight



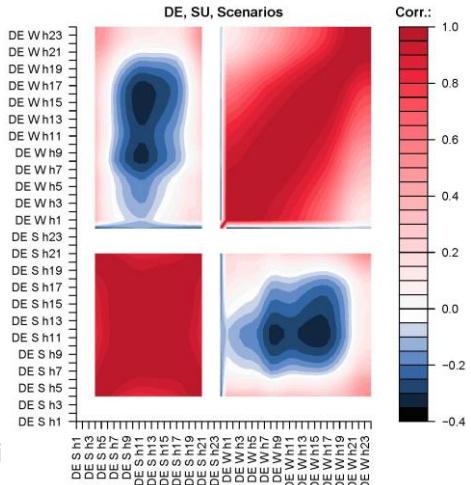
- number of components and discretizations:
  1st, 2nd, 3rd PC = 6, 3, 2

Duration curves

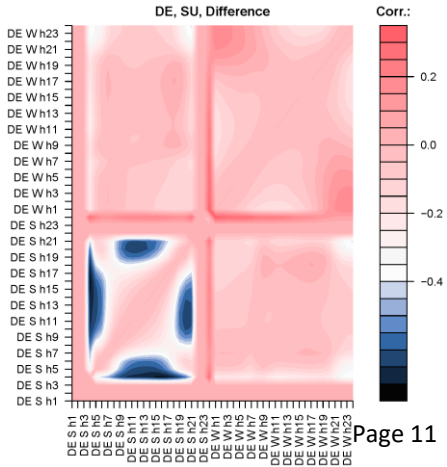




Correlation of scenarios

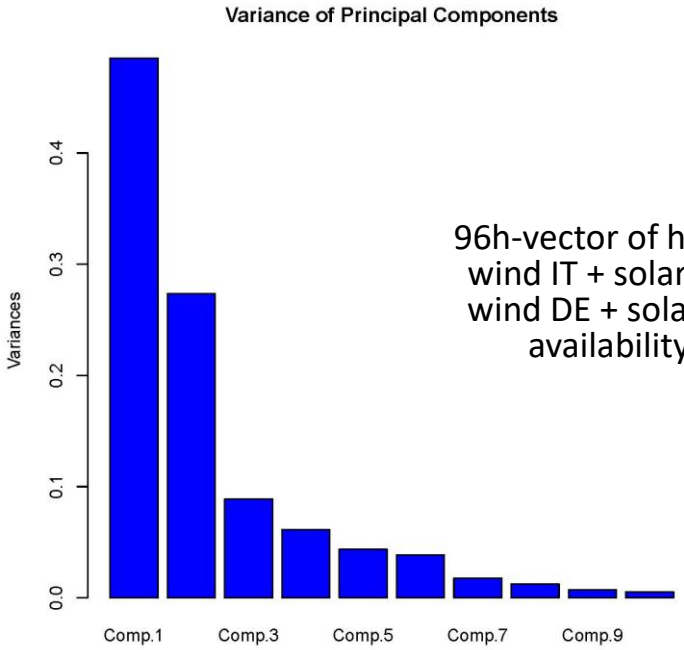


Correlation: error

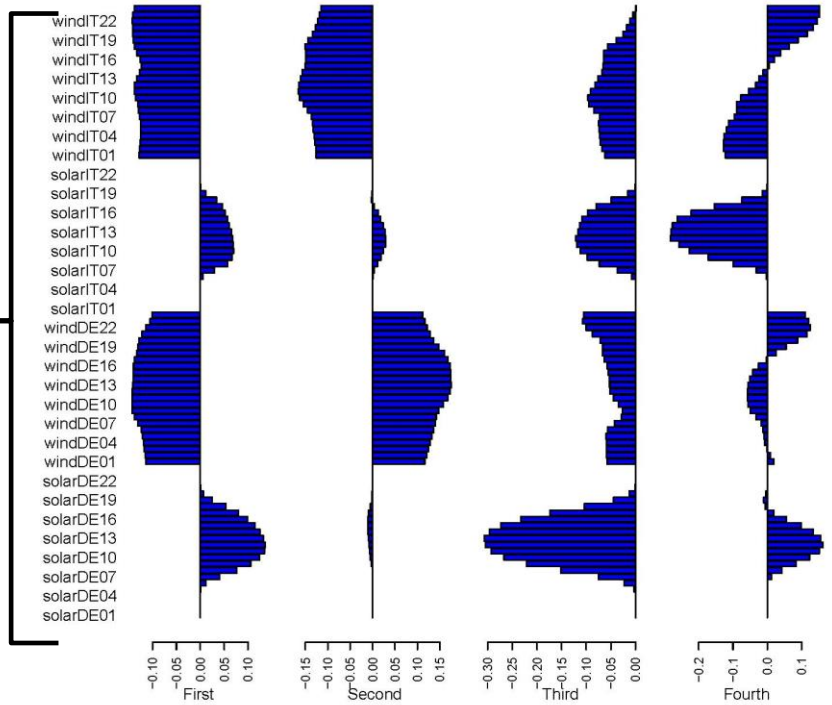


Several countries: PCA over two countries?

Example: Italy + Germany



96h-vector of hourly wind IT + solar IT + wind DE + solar DE availability



Variance of the PCs having highest variance

Loadings of the ordered PCs

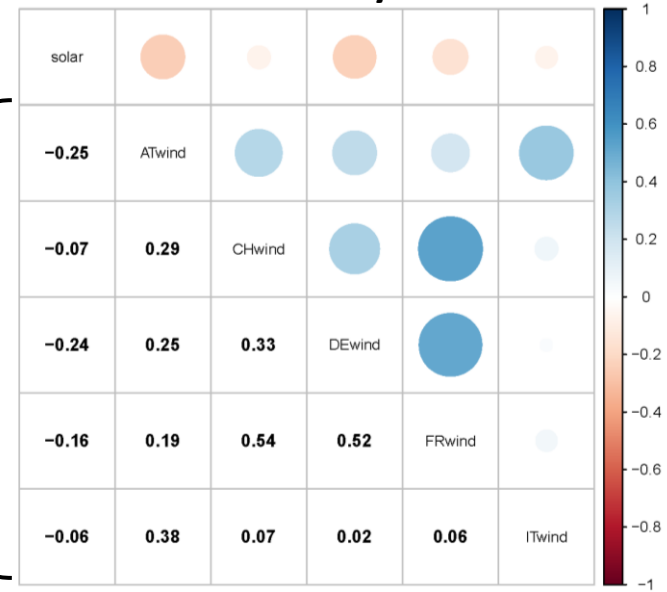
Across regions: **Daily** wind & solar availability

- **Regions:** Switzerland, Austria, Germany, France, Italy (CH, AT, DE, FR, IT)
- **Keep dimension low:** Cross-regional correlation between daily availability (avg. of hourly)

Correlation matrix daily wind and solar

solar PV (all countries)→

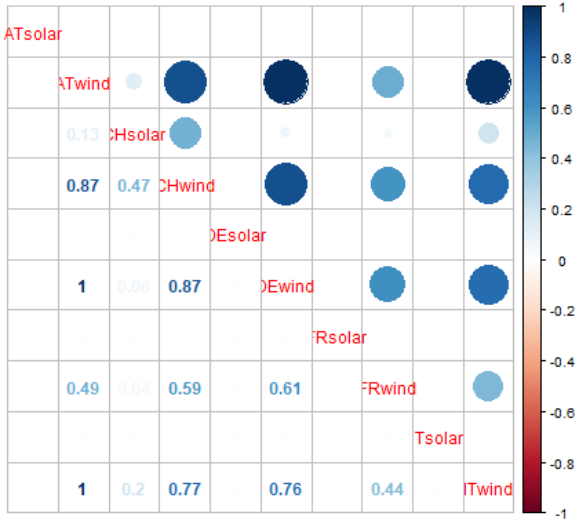
wind: AT, CH, DE, FR, IT



← **Keep dimension low:** By statistical analysis: If sun is shining, then usually in all the considered countries

Tail-dependence of wind & solar across regions

- **Tail dependence := Probability of joint, extremely-high values (or extremely low values)**
- Daily wind & solar availability across regions: <u>High tail-dependence</u> = 0;
  <u>Low tail-dependence</u> =



Within a day:

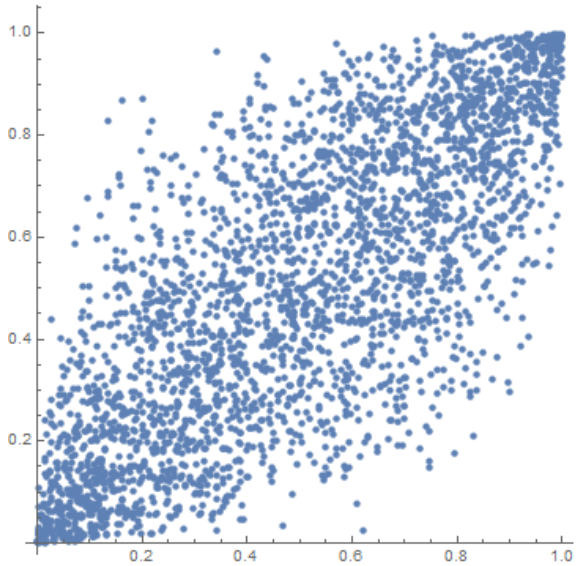
- **Likely: Joint calms across regions**
- **Unlikely: Joint storms, or dark- & calmness**

- <u>Scenario generation:</u> Random sampling from multivariate distribution of the variables
- Estimation of distribution? Gaussian has tail-dependences = 0. We use: <u>t-distribution</u>

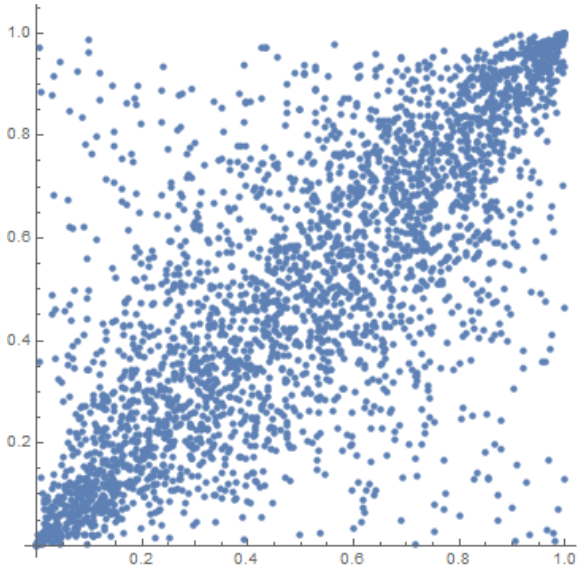
Correlation is not enough

Copula: Multivariate random variable, values in [0,1], to capture only interdependencies

Random samples of
Bivariate **Gaussian (normal) copula**,
corr = 80%

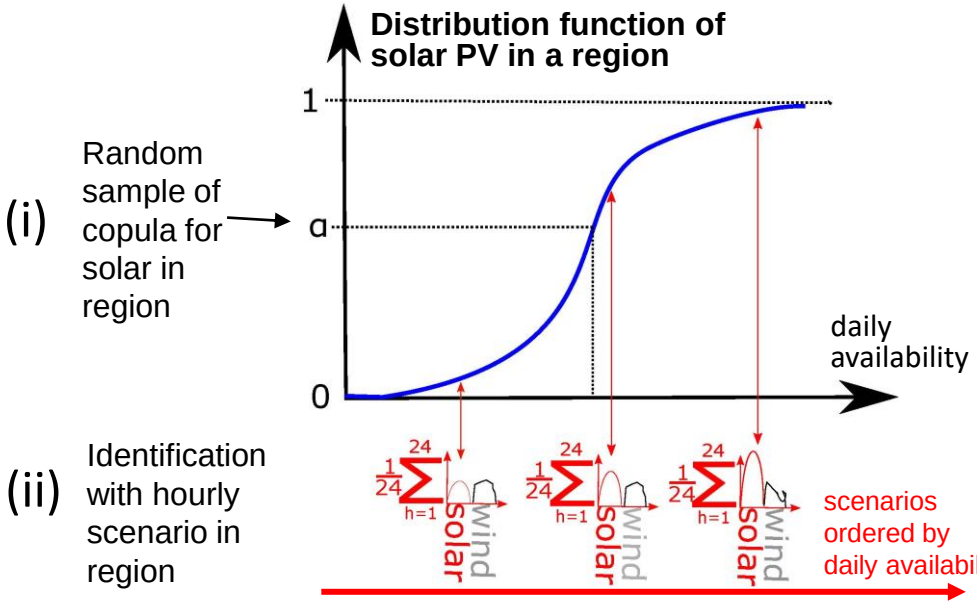


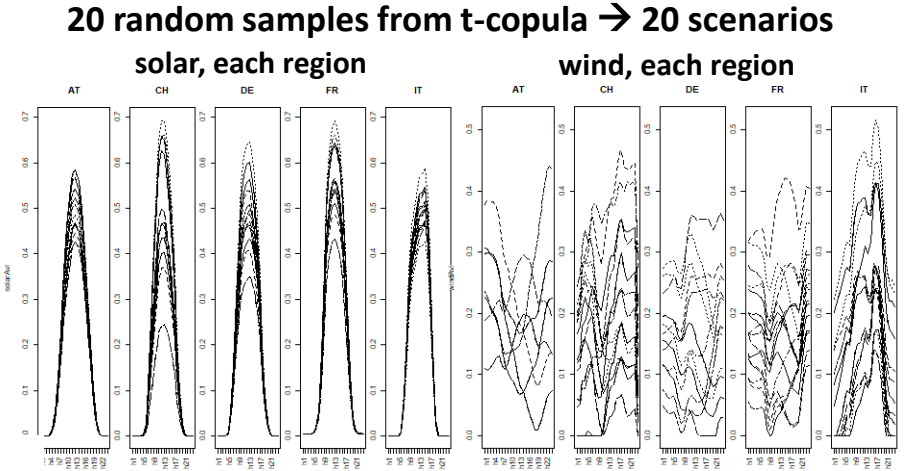
Random samples of
Bivariate **t-copula**
corr=80%



Random sampling of copula of t-distribution

- Copulas in spatial energy time series: see e.g. Zhan et al. (2019), Camal et al. (2019)
- A random sample of a copula are quantiles of its marginal distributions. Two steps:
  (i) Sample quantile α for daily wind, solar, for each region (-> daily values across regions)
  (ii) Identify with hourly scenario having closest quantile α (ordered by daily values)

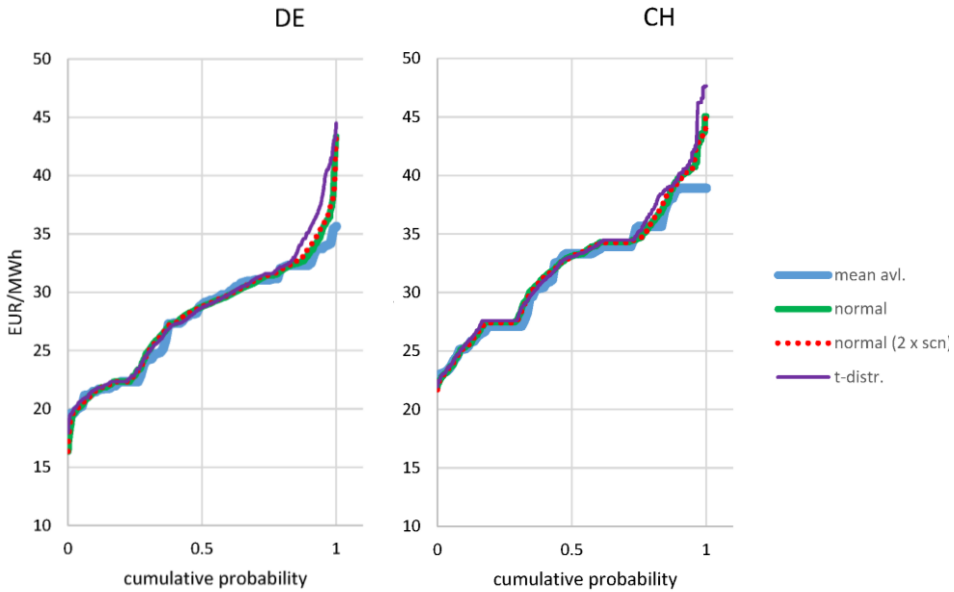




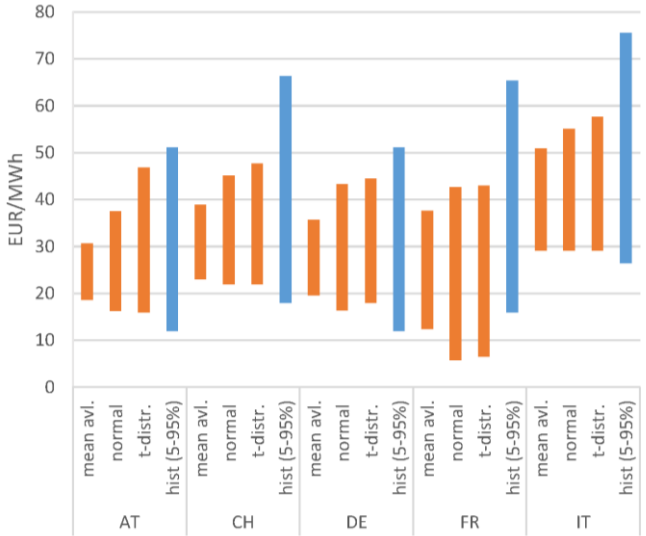
Results in an electricity market model

- BEM: Cross-border electricity market model: Switzerland and surrounding countries (Panos & Densing, 2019)
- BEM is run for this work in “basic” marginal-cost mode (price-peaks in model too low)

Price duration curves



Price ranges



Conclusions

- **Considerations for wind modelling in energy system models:**
  - Different regions have different wind patterns (also: different wind & solar dependencies)
  - Across regions, extreme joint calmness events should be considered
  - Interdependence with solar: (Linear) correlation seems to be sufficient

→ **A simple way-out for wind & solar modeling:** Hourly (8760h) modelling, with sufficient spatial resolution (if numerical model can be solved).
  - Dependencies are trivially captured
  - Energy modelers are not meteorologists

- Densing & Wan, 2022. Low-dimensional scenario... *Applied Energy*. 10.1016/j.apenergy.2021.118075
- R-package: https://gitlab.psi.ch/energy-economics-group/representative-days.