EUMETSAT CM SAF CLIMATE MONITORING

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Climatological Analysis of the Solar and Wind Energy Potential in Germany

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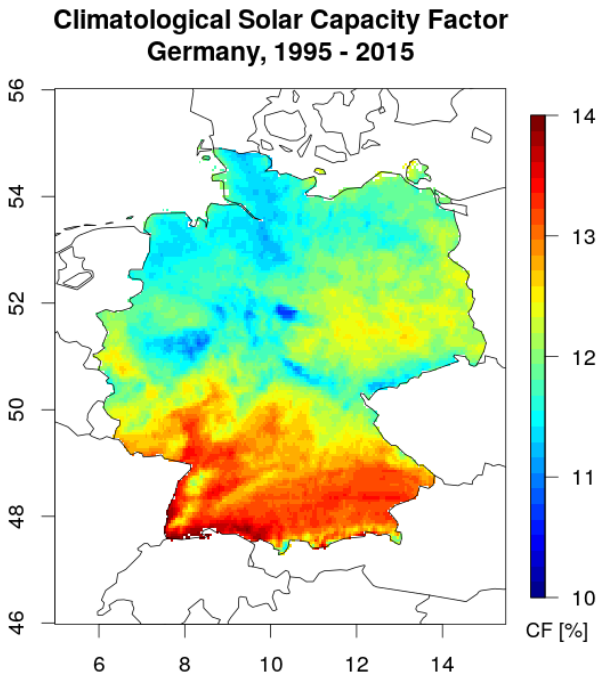
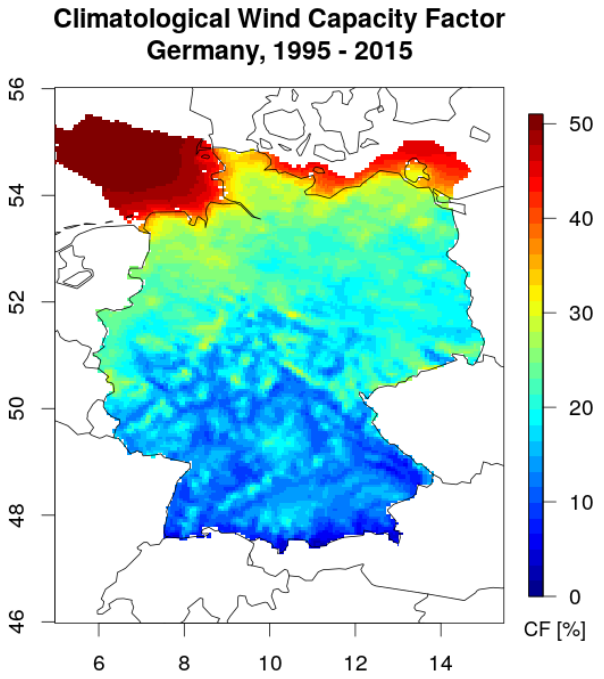




Motivation of this study

- Increased share of solar and wind energy in European energy production
- Solar radiation and wind depending on weather and are highly variable
- Analysis of the variability of produced energy by calculating capacity factors for Germany

$$CF = \frac{produced\ energy}{installed\ capacity}$$

  - Particularly the very low energy production events, so-called shortfall events are problematic
    - how often?
  - Occurrence at which Großwetterlage (GWL)?
  - Balancing effects in Europe?

Data

Solar Capacity Factor

Data

based on CM SAF SARAH-2 data record

- global / direct radiation

Resolution

Temporal: 30 minutes

Spatial: 5 km x 5 km

Coverage

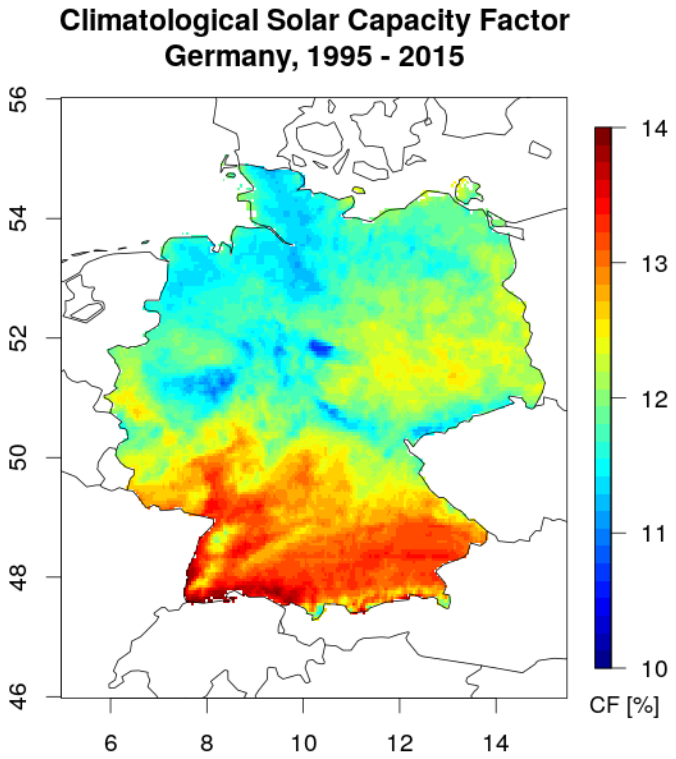
Germany, 1995 - 2015

Auxillary Data

2m-temperature (COSMO-REA6)

Assumption tilt angle: angle distribution*

- centered: 20° inclination angle,
  southward azimuth angle



Solar Capacity Factor - Methods

Calculating radiation on tilted surface

R-package "solaR" (Lamiguerio, 2016)

Modelled PV-modules

Standard Test Conditions

(Huld und Gracia Amillo, 2015)

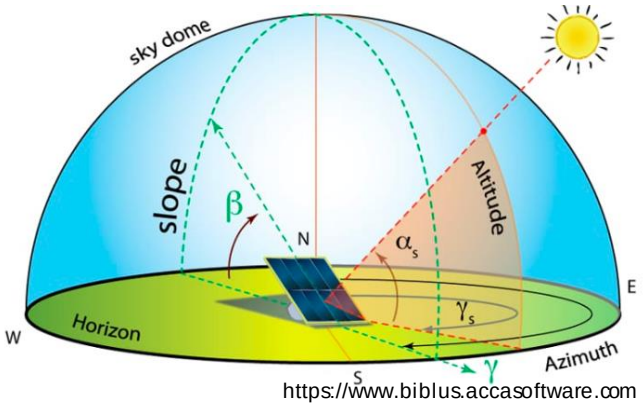
Sensitivity Studies

Optimum Inclination and Azimuth Angle

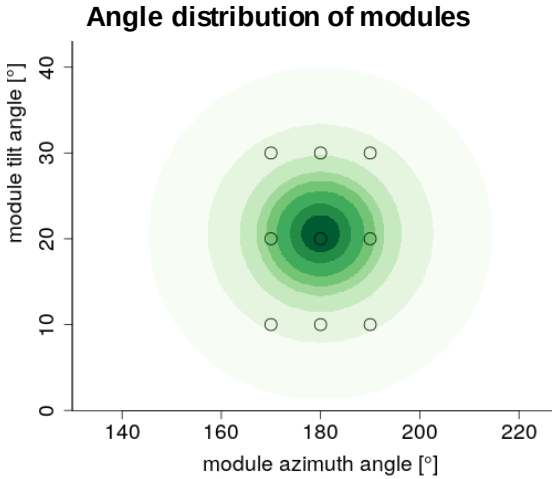
Assumption tilt angle

Frequency distribution

(Saint-Drenan et al. 2018)



https://www.biblus.accasoftware.com



Y.-M. Saint-Drenan et al. 2018, Adv. Sci. Res.,15, 51-62, doi:10.5194/asr-15-51-2018

Huld, T. and Gracia Amillo A.M., Energies 2015, 8, 5159-5181; doi:10.3390/en8065159

Lamiguerio, 2016, R-Package solaR, version 0.44, 2016-04-16

Wind Capacity Factor

Data

Based on regional reanalysis COSMO REA6

- 100m-wind speed

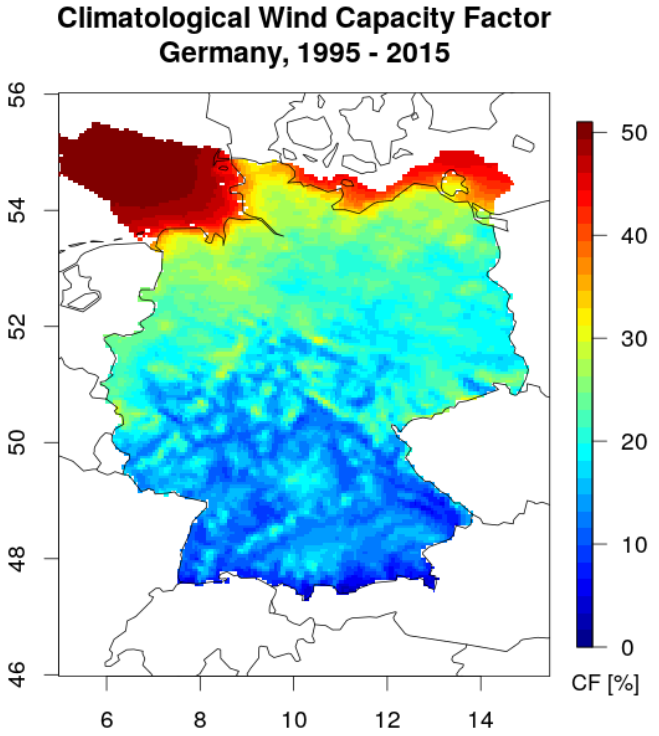
Resolution

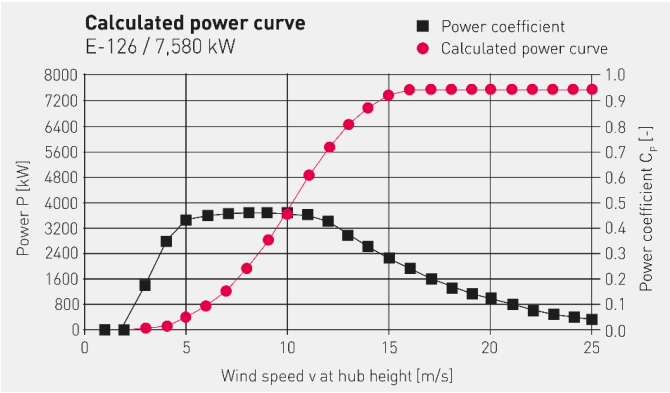
Temporal: hourly

Spatial: 5 km x 5 km

Coverage

Germany, 1995 - 2015





Assumption

Power Curve* of a modern wind turbine (116m height);

Implementation in R package "bReeze"

*https://www.enercon.de/en/products/ep-8/e-126/

Graul and Poppinga, 2018, R-Package bReeze, version 0.4-2, 2018-01-05

Open Power System Data

web platform with energy data

https://open-power-system-data.org/

Data

Collection of publicly available data

- Quality-checked, processed and documented

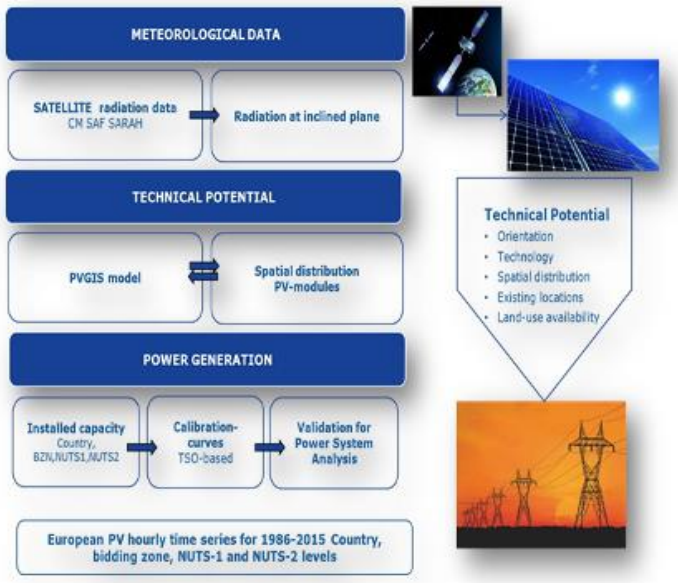
Content

- Time series data of installed capacity
- Actual power generation
- Individual power plants

EMHIRES Data Set

web platform with European CF

https://setis.ec.europa.eu/EMHIRES-datasets



Data

- Collection of publicly available data
- Solar CF based on CM SAF SARAH
- Wind CF based on MERRA

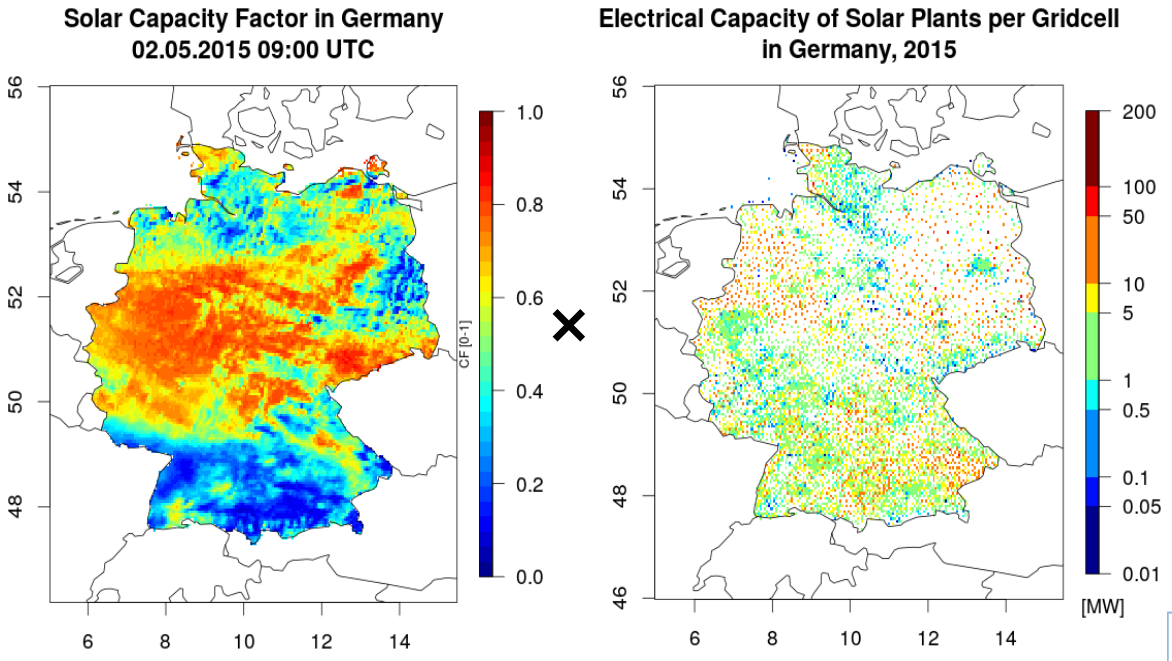
Content

- Time series data of 28 European countries from 1986 - 2015
- Actual power generation

Methods

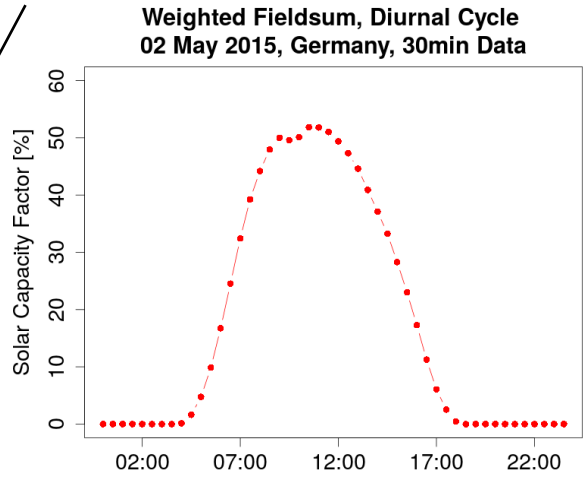
Data Processing – Time Series

Example SOLAR



Consider locations and installed capacity from 2015

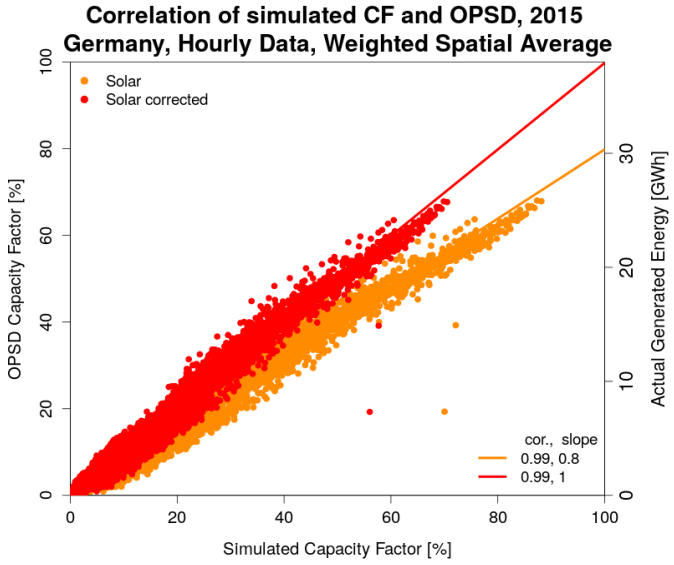
Spatial Sum for Germany

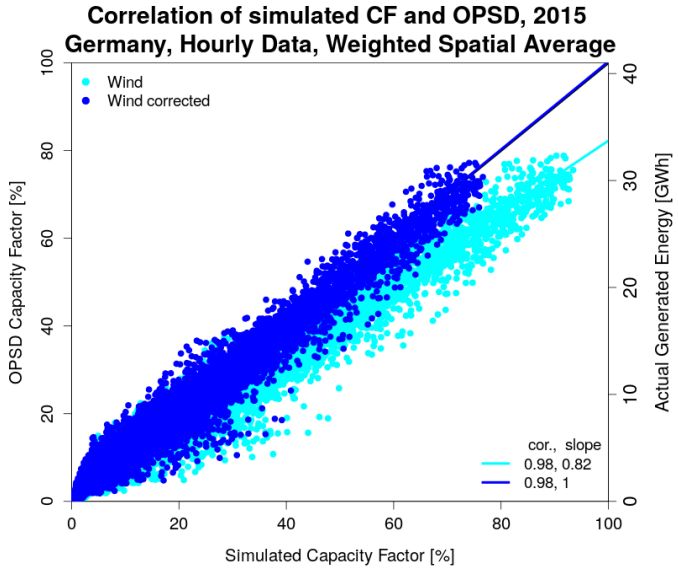


÷ mean installed capacity 2015

Calibration of the simulated Capacity Factor

- Measurement data based on Open Power System Data (OPSD)
  - Temporal resolution: hourly
- Simulated CF are calibrated with linear fit (normalised at 2015)
- High correlation between simulated solar and wind CF and the CF from measurement data



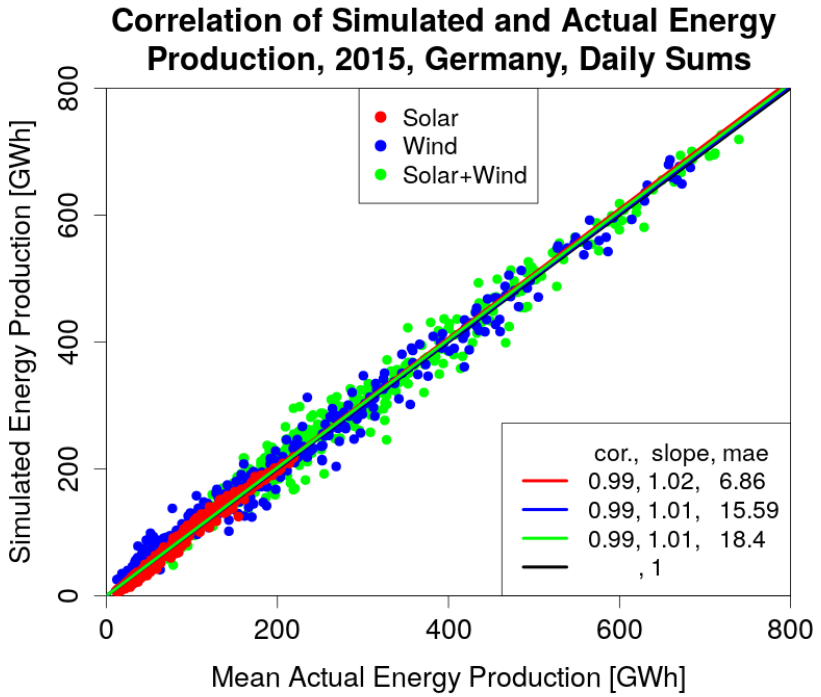


Simulated Generated Power

Conversion of CF in produced energy

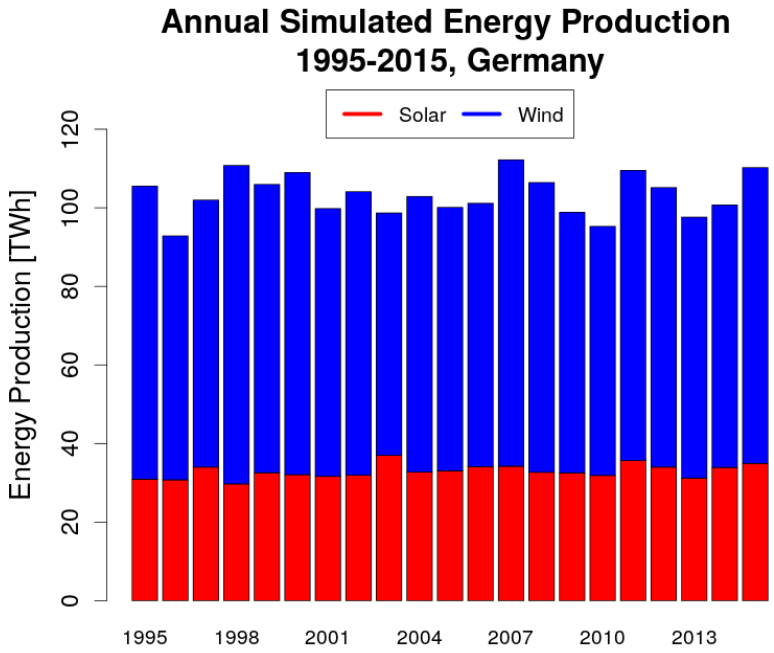
- Mean installed Capacity 2015:
  - 38 GW Solar
  - 40 GW Wind
- Produced Energy 2015:
  - 35 TWh Solar
  - 75 TWh Wind

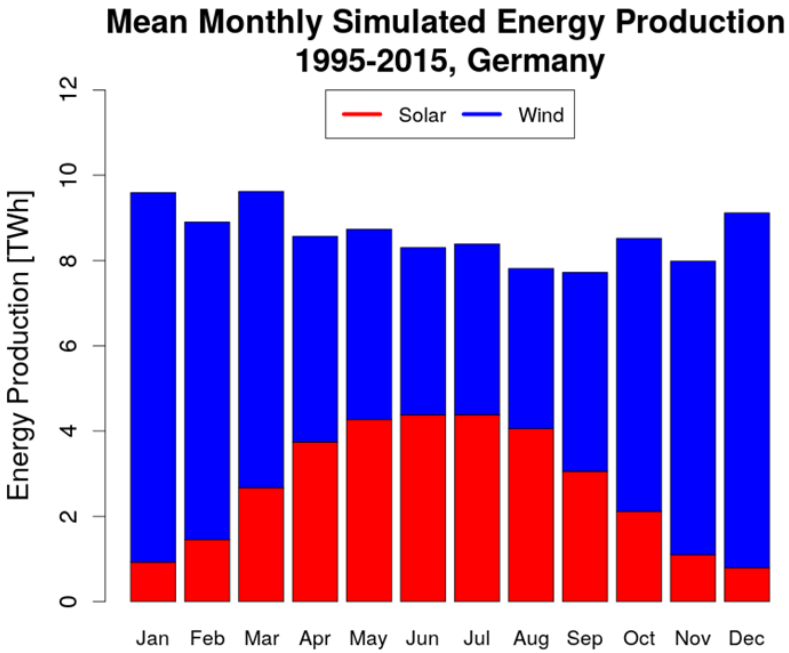
⇨ 110 TWh Sum



Results

Annual Sum / Mean Monthly Sum 1995 - 2015

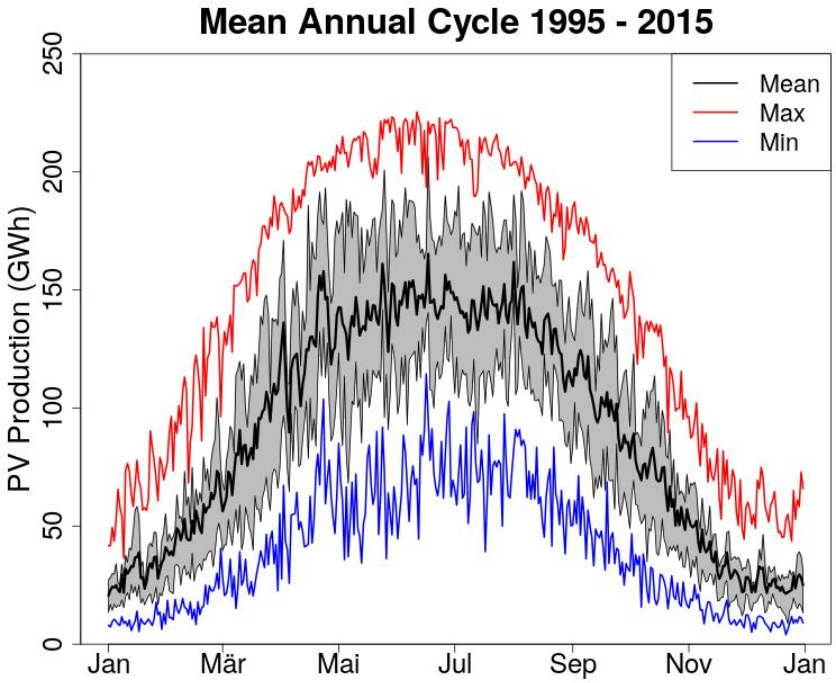


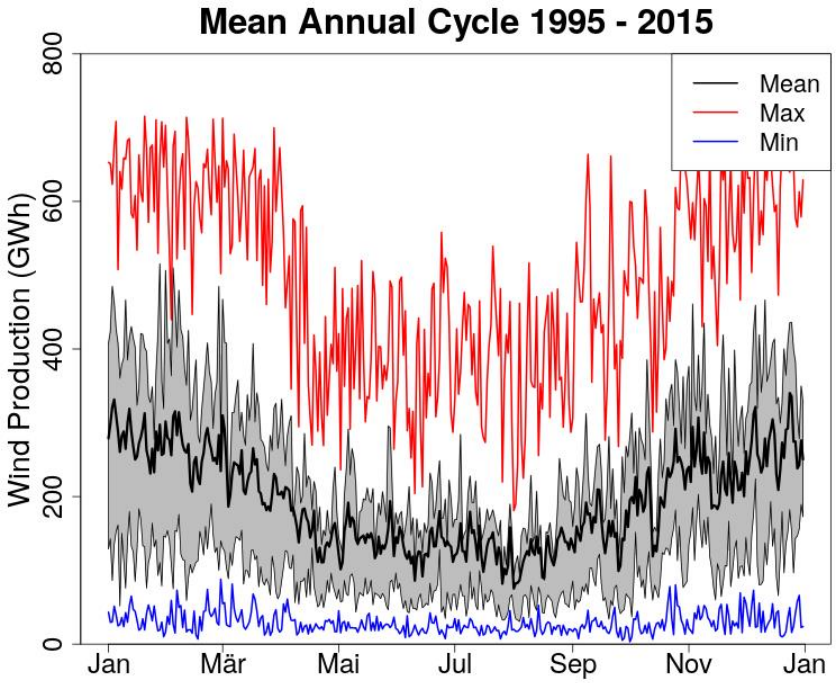


- ~ 102 TWh mean yearly production due to solar and wind energy*
- Wind energy dominates in fall / winter
- Solar and wind energy have an equal share in summer

*Assumption: installed capacity normalised to 2015 for all years

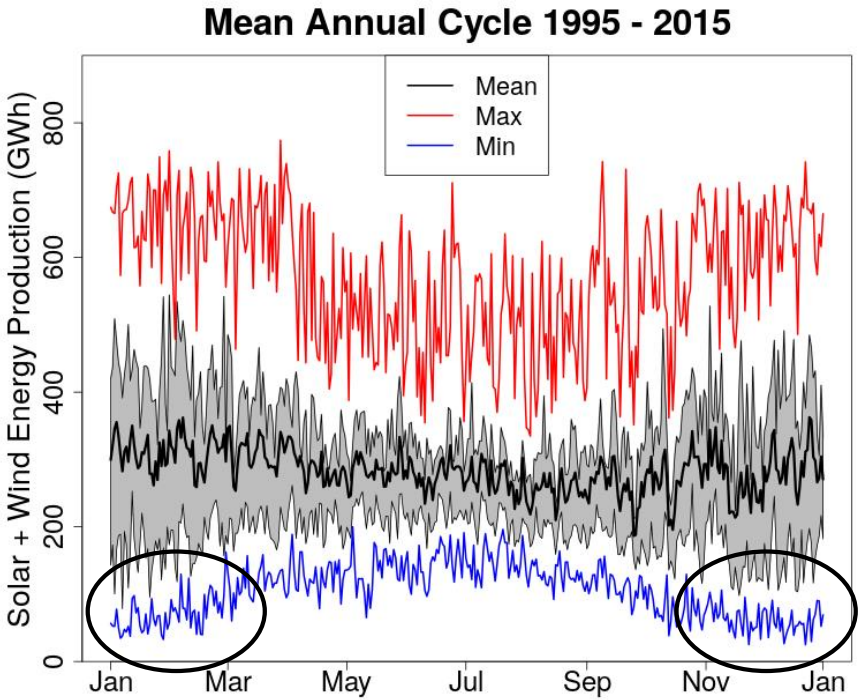
Mean Annual Cycle 1995 - 2015





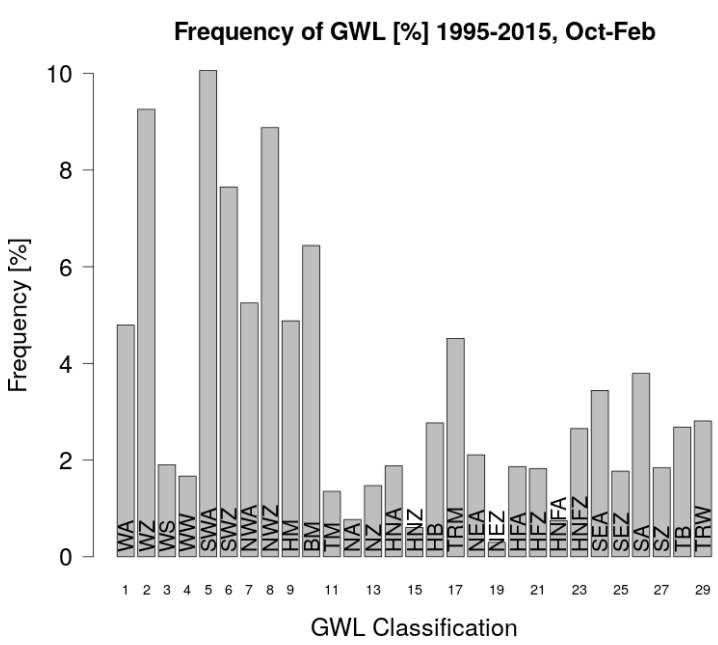
- More energy production due to wind energy in principle, but therefore higher variability than solar energy

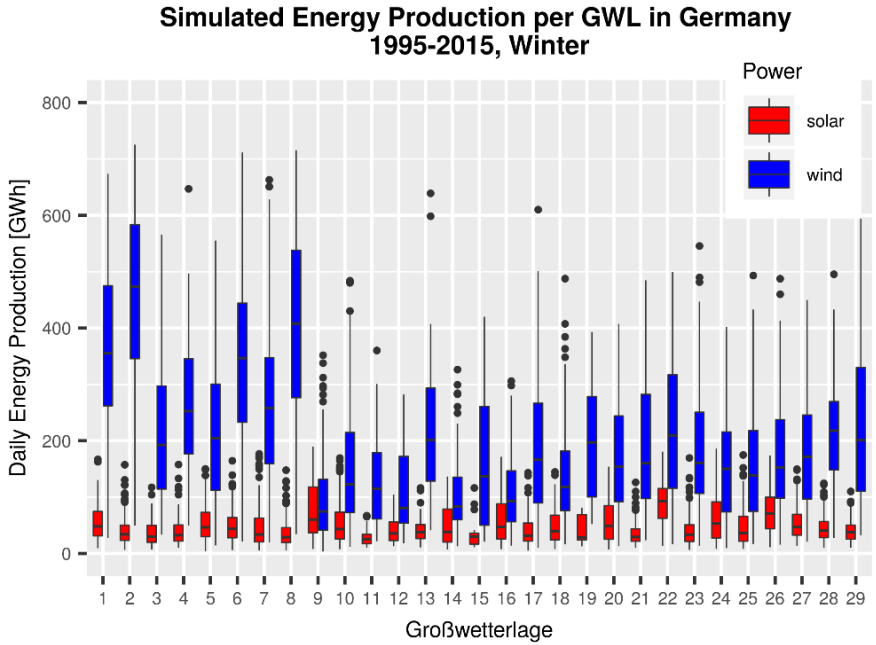
Mean Annual Cycle 1995 - 2015



- Relatively constant energy production throughout the year
- All low energy production events occur in fall / winter

Impact of „Grosswetterlagen“ (GWL)





- Using GWL classification of James, P.M., 2007
- Clear dependency of wind / solar CF on weather regimes

James, P.M., 2007, An objective classification method of Hess and Brezowsky Grosswetterlagen over Europe, *Theoretical and applied Climatology*, 88, 17-42

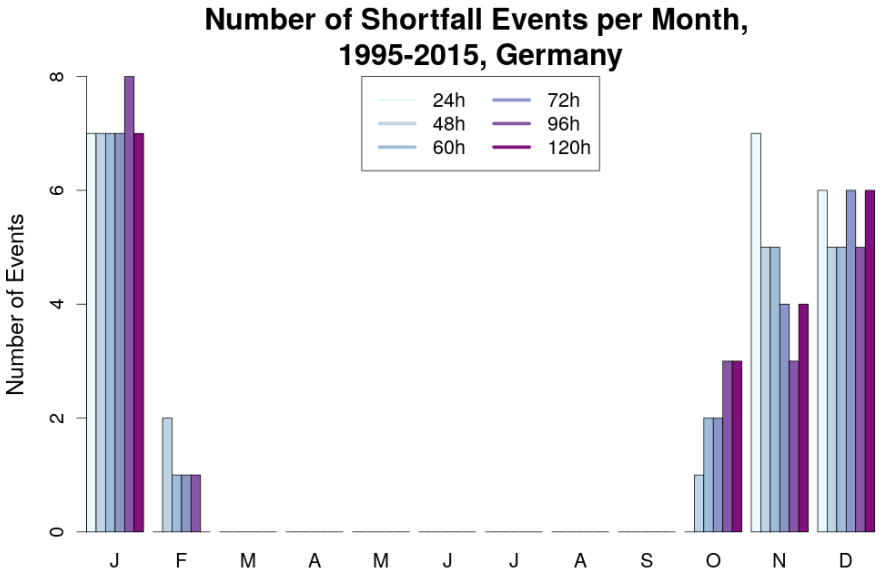
Shortfall Events

Def.: Shortfall Events

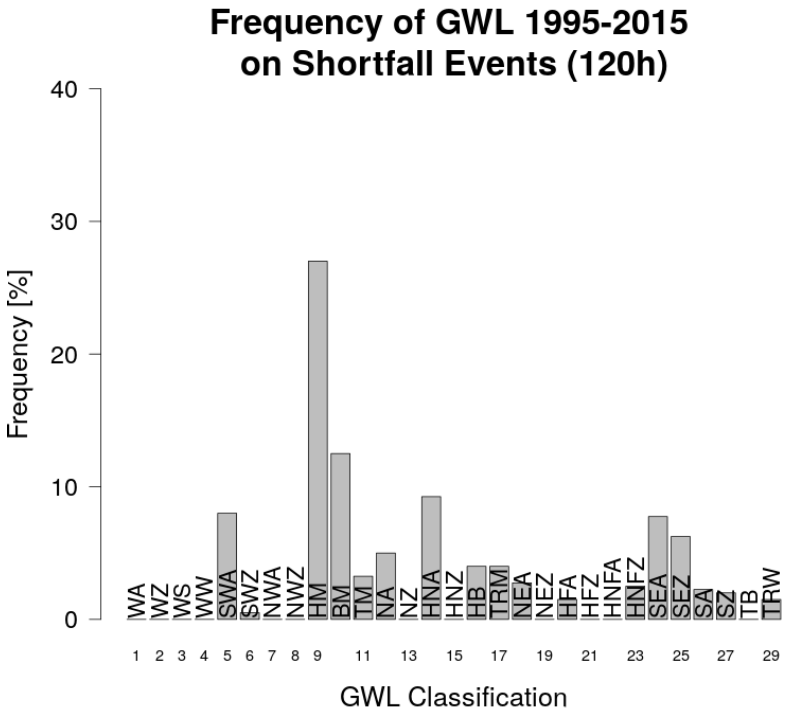
- Specific period of time, where low energy production occur due to sun and wind

Occurence of Shortfall Events

- Considering 20 lowest energy production events
- All shortfall events occur in fall / winter independent on event length



Shortfall Events



Length of shortfall events for further analysis

- 120h; taking the 20 lowest events
- GWL „9" (High over Central Europe) is the most frequent GWL at shortfall events

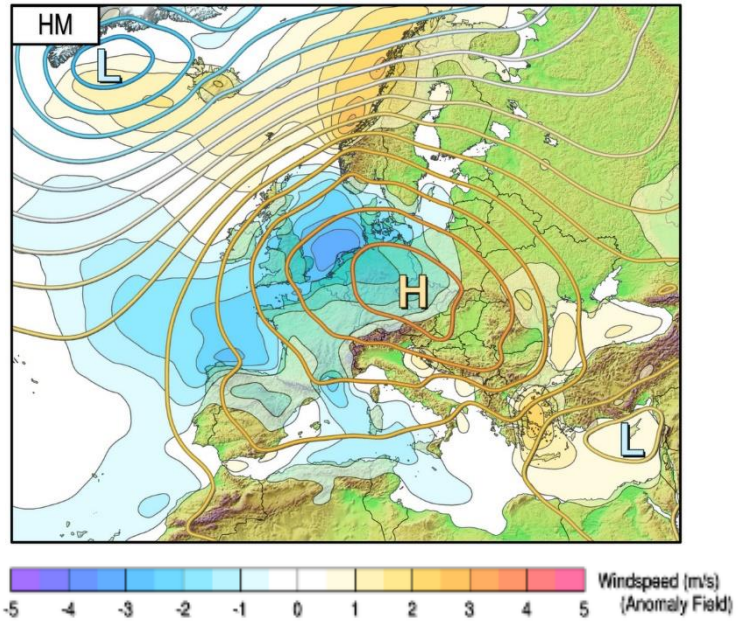
Shortfall Events (120h) 1995 - 2015

			Event (Daily Mean) Produced Energy [GWh]		
Event Start	**Event End**	**GWL**	**Solar+Wind**	**Solar**	**Wind**
05.01.1997 08:00	10.01.1997 07:00	HB (16) HNA (14)	295 (59)	69 (14)	226 (45)
22.12.2006 14:00	27.12.2006 13:00	HM (9)	300 (60)	135 (27)	165 (33)
1995 - 2015			1415 (283)	455 (91)	965 (193)

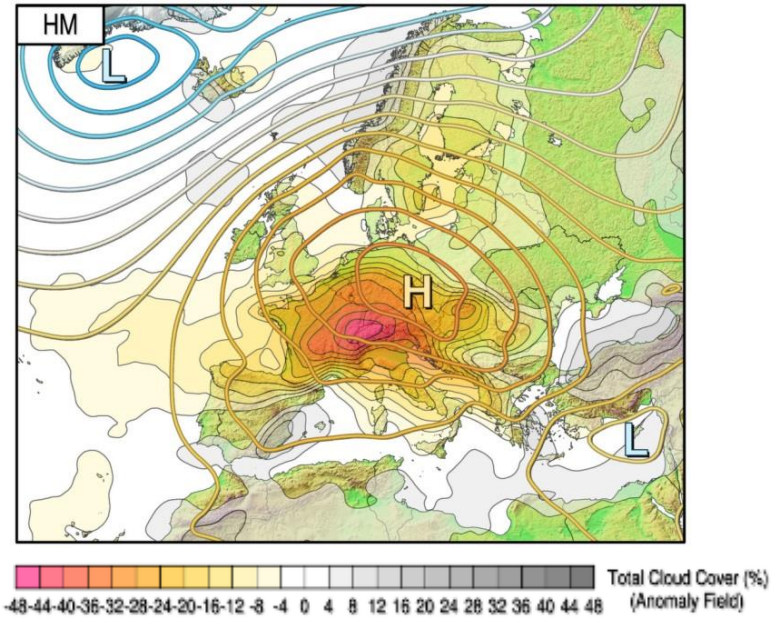
- During the shortfall event (120h) only 10% of the daily mean is produced

Analysis of Shortfall Event 22. - 27.12.2006 (GWL 9)

Wind speed anomaly [m/s]

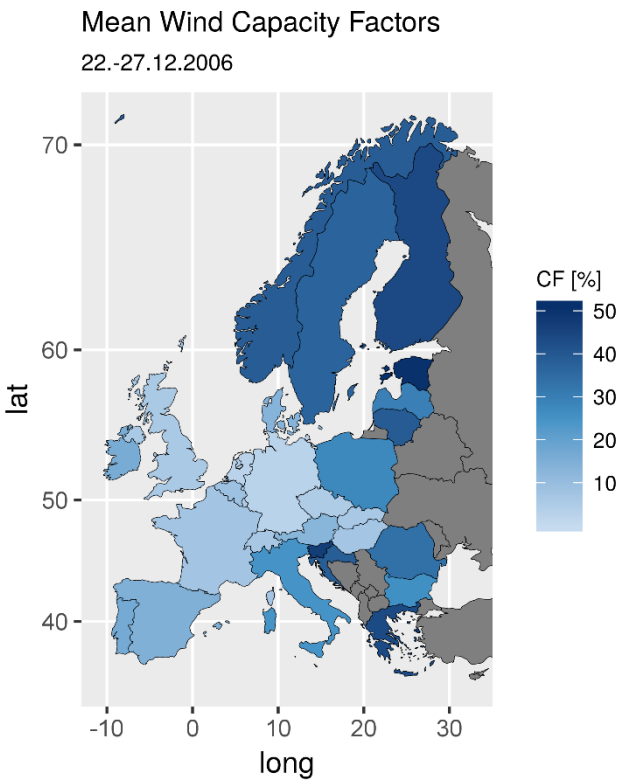


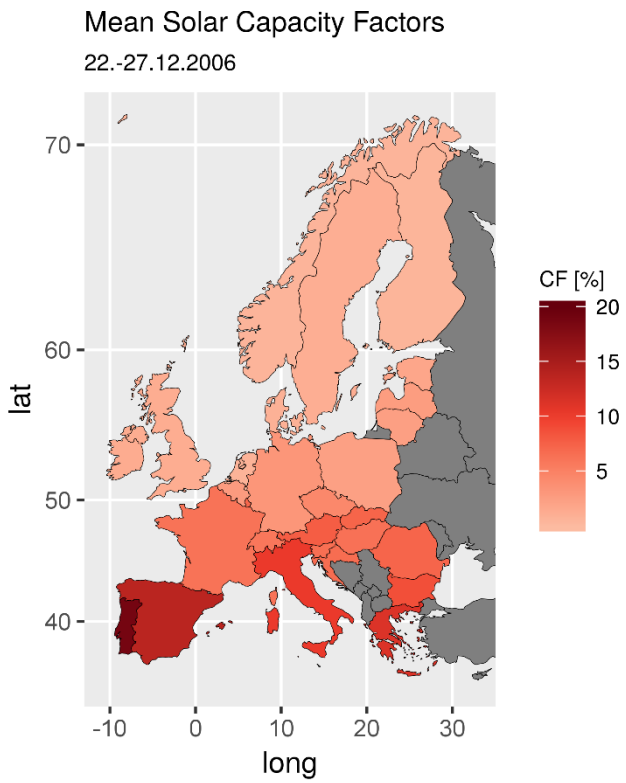
Cloud cover anomaly [%]



- Negative wind speed anomaly in Germany leads to low wind energy production at this event (17 % of daily mean)
- Negative cloud fraction anomaly over Germany during GWL 9 in winter; individual events related to fog / low clouds possible

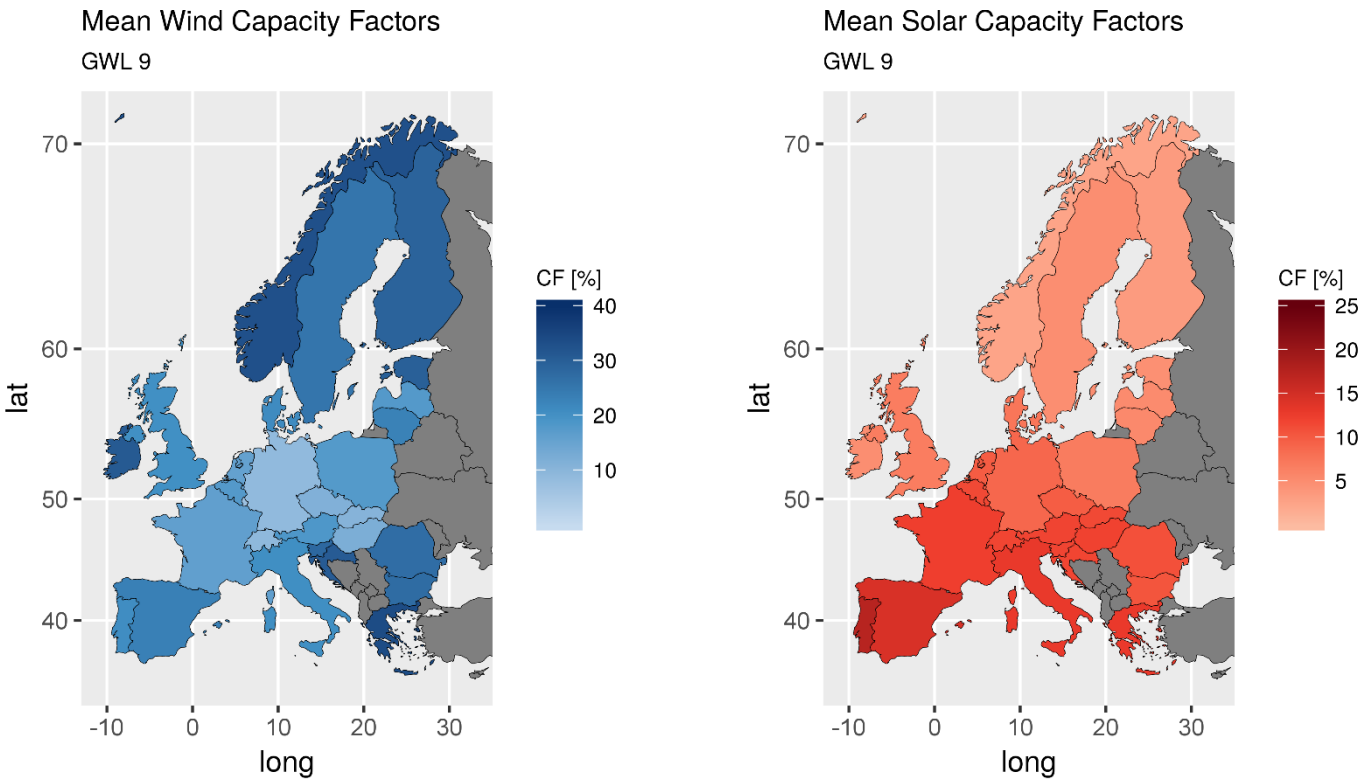
Analysis of Shortfall Event 22. - 27.12.2006 (GWL 9)





High wind CF in Scandinavia (29 %), Croatia (31 %) and Slovenia (28 %) allow the balancing of the low wind CF (9 %) in Germany at this event

Mean Wind CF / Mean Solar CF in Winter at GWL 9*



European wind CF / solar CF distribution at the low production event is similar to the general wind CF / solar CF distribution at GWL 9

*All GWL 9 events from 1995 to 2015 (Winter) included

Summary

- Successfully **simulate Capacity Factors (CF)** based on satellite data (solar) and reanalysis data (wind)
- Validation and conversion of CF in **produced energy** (GWh) with Open Power System Data
- Clear **dependency** of wind / solar power generation **on weather regimes** (GWL)
- Identifying low energy production events **(shortfall events)** with event length of 120h from 1995 to 2015
- **Balancing effects** for Germany with Scandinavia, Croatia or Slovenia possible