Simulation of long term solar power feed-in and solar balancing potential in European countries

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Outline

- Brief overview on the project
- Description of data sources & methodology
- Evaluation of regional power timeseries
- Analysis of fluctuations of intermittent renewables
- Impact of module configurations on fluctuations
- Summary & outlook
Project RESTORE 2050

- Investigates European energy system in 2050 with ~ 100% renewables
- Analysis of fluctuations of intermittent renewables
- Estimation of storage needs

Here focus will be on solar energy & its fluctuations

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1Kies et al, Investigation of balancing effects in long term renewable energy feed-in with respect to the transmission grid , EMS2014-331
Data sources & models

- Irradiance calculated using *Heliosat*\(^1\) method
- Meteosat 1\(^{st}\) & 2\(^{nd}\) generation satellites
  - regridded to 7\(km \times 7\)\(km\)
  - temporal resolution: 1 hour
- Projected country-level installed power from Energy scenario of Fraunhofer ISI
- Ambient temperature and Wind: downscaled from Merra Reanalysis
- Load: estimated from Entso-E data

Model domain: EU-28, Norway, Switzerland and Balkan countries
Simulation performed for 10 years (2003-2012)

Methodology

- Meteosat Satellite Images
- Cloudindex calculation
- Atmospheric Turbidity
- Irradiance on Horizontal surfaces
- Klucher Model
- Irradiance on Inclined surfaces
- Temperature
- PV Module Efficiency
- PV Power calculation

Germany 2012
Resource-dependent Capacity distribution

Data sources and methodology
Evaluation of regional power timeseries

Timeseries of PV power feed-in in Germany are provided by the 4 transmission system operators:

- 50 Hertz
- amprion
- tennet
- transnet-bw

The data is upscaled from a number of measurement sites.
Average of normalised power $P/P_{\text{nom}}, P_{\text{nom}}$: installed nominal power $Estimated = 0.1112$ & $Simulated = 0.1130$
Comparison of incremental timeseries

Analysis of fluctuations: cumulated frequency distribution of increment timeseries

![Graph showing cumulated frequency distribution for Germany, 2012, comparing upscaled measurements and simulation. The graph shows good agreement between the two.

Good agreement of simulation with upscaled measurements.
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Estimation of fluctuations of intermittent renewables

Incremental timeseries of PV & offshore wind

Due to its diurnal pattern, PV shows higher fluctuations than Wind
Solar fluctuations on hourly scale

![Solar fluctuations on hourly scale](image_url)
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Estimation of fluctuations of intermittent renewables

Incremental timeseries of PV & offshore Wind

Daily incremental timeseries for both technologies mainly determined by meteorological factors, wind shows higher fluctuations than PV.
Effects of regional averaging on fluctuations

Hourly timeseries remains almost unaffected to regional averaging
On daily scale, PV fluctuations decrease on regional averaging
Analysis of fluctuations for changed module configurations

- Reference configuration from Energy scenario, Fraunhofer ISI
- Compared with South-East & South-West oriented modules
- Steeper inclination applied to increase annual production
Results: fluctuations for changed PV module configuration

Standard deviation of daily $P/P_{nom}$ is decreased by $\sim 11\%$
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Estimation of fluctuations of intermittent renewables

Results: fluctuations for changed PV module configuration

\[ \mu_{rel} = \left( \frac{\langle P_{adj} \rangle - \langle P_{orig} \rangle}{\langle P_{orig} \rangle} \right) \times 100 \]

\[ \sigma_{rel} = \left( \frac{\sigma_{adj} - \sigma_{orig}}{\sigma_{orig}} \right) \times 100 \]
Summary

▶ Feed-in timeseries for fluctuating renewables produced
▶ Solar PV shows good agreement with upscaled measurements
▶ PV power shows higher fluctuations than wind on hourly scale and less fluctuations on the daily scale
▶ Module configurations adjusted to reduce fluctuations to \(\sim 11\%\) with a compromise to \(\sim 8\%\) decrease in power production & can be mitigated by adequate storage, proper DSM etc

Outlook

▶ Incorporate adequate storage for different technologies
▶ System behavior under extreme events
▶ For CSP, power import from Sahara
Thank you for your attention!!!

Questions & Comments are welcome

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- NEXT ENERGY, Oldenburg, Germany

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Thank You for your Attention!!!