Impact of power production from different module configurations on PV fluctuations and storage requirements

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Overview

- A numerical model of European power system is developed as part of the project RESTORE-2050
- Long term timeseries (2003-2012) of different renewable sources is created using weather data from NWP models and satellite observations
- This presentation focuses on the solar PV component of the model and deduces the impact of different module configurations on PV fluctuations and storage needs
- PV fluctuations are studied in different temporal scales (hourly, daily, weekly, monthly)
- The study is also extended to include storage needs for different module configurations for different countries with substantially different meteorological conditions

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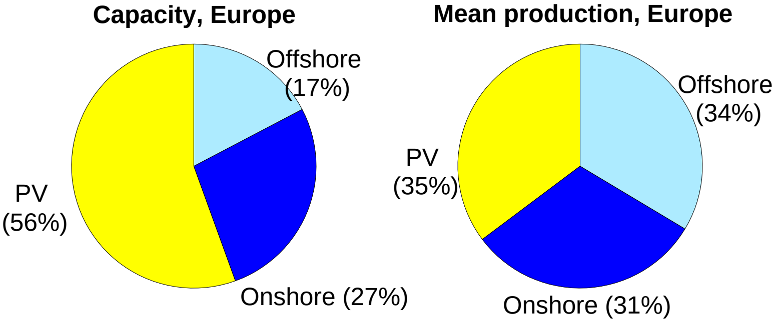
- An extension of work done in project RESTORE-2050
- Baseline scenario is adopted from: meta-study ISI (Fraunhofer report, 2011) and EREC (Greenpeace report, 2012)
- Country level installed capacities taken from meta-study EREC
- Share of different module configurations taken from meta-study ISI
- The optimum module inclinations for each country are based on the work of Huld et al, 2008



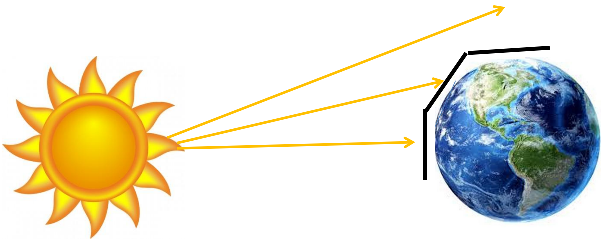
Overview of chosen EREC scenario for Europe with large PV share

Motivation

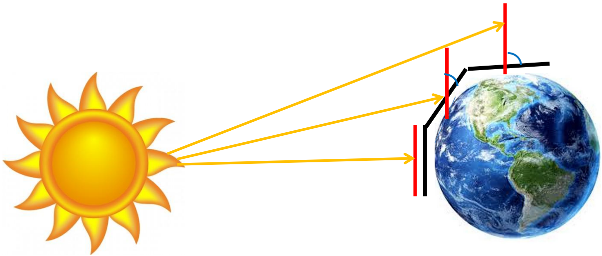
There are two effects in determining module inclinations with respect to maximum production:

- with increasing latitudes, higher inclinations seem effective (for clear-sky conditions)
- for cloudy conditions, lower inclinations are prefered as it can utilise more of the diffused radiation which is otherwise lost behind modules

Module inclinations

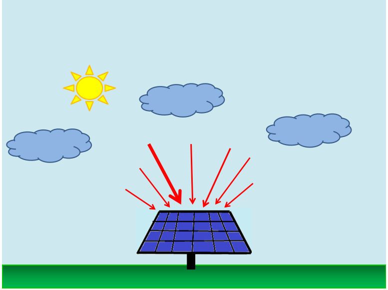


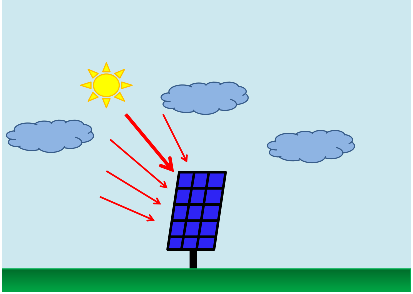
Horizontal PV modules can receive most radiation near the equator and least radiation around the poles.



Usually, steeper module inclinations are favored as moving from equatorial to high latitude regions

Module orientations





Under cloudy conditions, steeper modules are usually less favored as they tend to lose substantial diffuse radiation behind the module.

- Depending on location and seasonality, solar elevation can be different
- Winter: low solar elevation and steeper PV modules are more favorable
- Summer: high solar elevation and less inclined modules are prefered

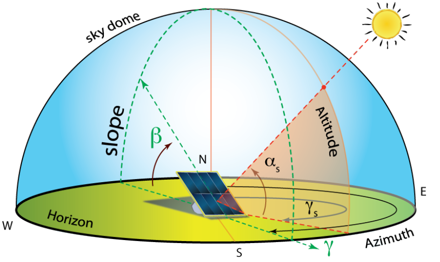
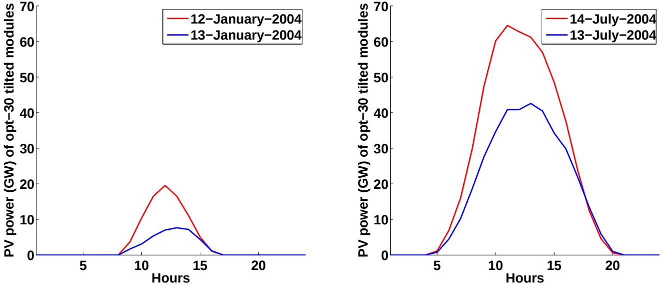
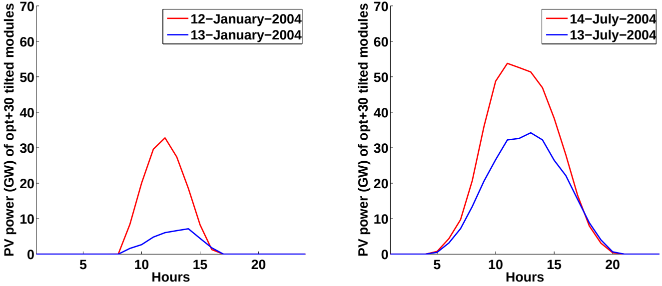


Image courtesy: Jeffrey Brownson



PV power production in different sky conditions and different seasons for Germany: power computed for south-facing modules inclined in opt-30°



PV power production in different sky conditions and different seasons for Germany: power computed for south-facing modules inclined in opt+30°

Existing studies have optimal module inclinations for best PV power production.

We extended this to quantify PV fluctuations on different module configurations.

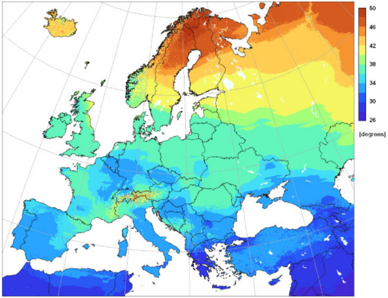


Image courtesy: Huld et al, 2008

A proper assessment of modules with different inclinations and orientations is essential to understand their characteristic behavior for different locations

This is not an optimisation, rather a sensitivity study

It aims to:

- quatify PV fluctuations on different temporal scales
- understand behavior of different module configurations in different sky conditions
- compare storage needs for different configurations and different geographic locations

Our model uses:

- 45(+15) module configurations for European countries
- a simple balancing model with 'no tranmission scenario'

Module configurations:

Primarily 45 configurations are analysed:

- five orientations (East, South-East, South, South-West, West)
- nine inclinations for each orientations

Orientations	**Inclinations**				
East	Opt$\pm 20^\circ$	Opt$\pm 15^\circ$	Opt$\pm 10^\circ$	Opt$\pm 5^\circ$	Optimal
South-East	Opt$\pm 20^\circ$	Opt$\pm 15^\circ$	Opt$\pm 10^\circ$	Opt$\pm 5^\circ$	Optimal
South	Opt$\pm 20^\circ$	Opt$\pm 15^\circ$	Opt$\pm 10^\circ$	Opt$\pm 5^\circ$	Optimal
South-West	Opt$\pm 20^\circ$	Opt$\pm 15^\circ$	Opt$\pm 10^\circ$	Opt$\pm 5^\circ$	Optimal
West	Opt$\pm 20^\circ$	Opt$\pm 15^\circ$	Opt$\pm 10^\circ$	Opt$\pm 5^\circ$	Optimal

Module configurations:

Additionally, 15 extreme configurations are analysed (only for Germany and Spain):

- five orientations (East, South-East, South, South-West, West)
- three inclinations for each orientations

Orientations	Inclinations		
East	Opt±30°	90°	0°
South-East	Opt±30°	90°	0°
South	Opt±30°	90°	0°
South-West	Opt±30°	90°	0°
West	Opt±30°	90°	0°
	Opt±30°	90°	0°

Some important terminologies used:

$$Generation(t) = PV(t) + Onshorewind(t) + Offshorewind(t)$$

$$Installation\_factor(\alpha) = \frac{< Generation(t) >}{< Load(t) >}$$

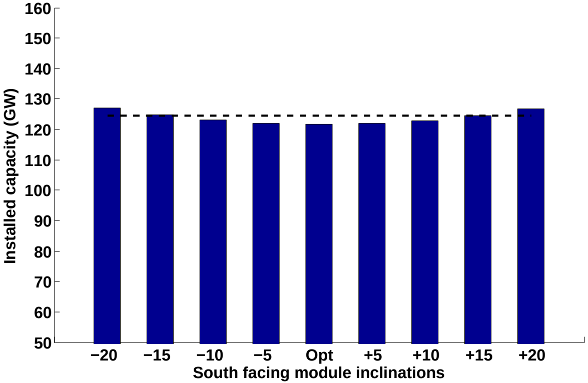
$$mismatch(t) = Generation(t) - \alpha \times Load(t)$$

Adjusting capacity

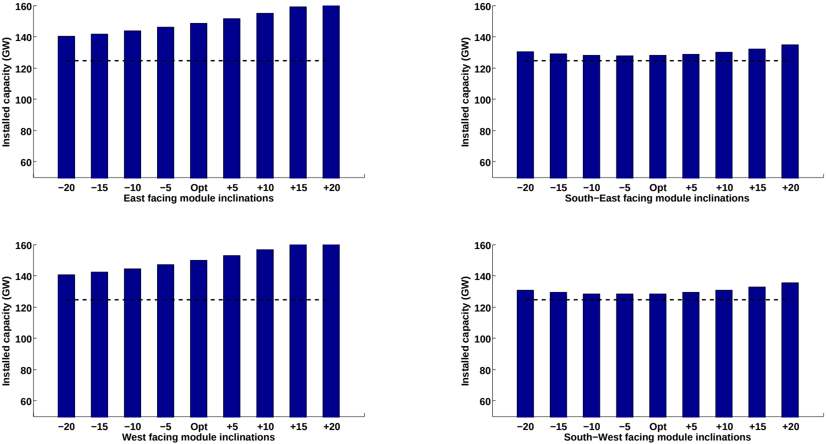
The mean power production (calculated from 2003-2012) is kept the same by adjusting the installed capacities for each configuration.

Certain module configurations can produce more PV power than the other, so a levelised PV production from each module configuration is necessary to keep the average share of PV and wind same throughout.

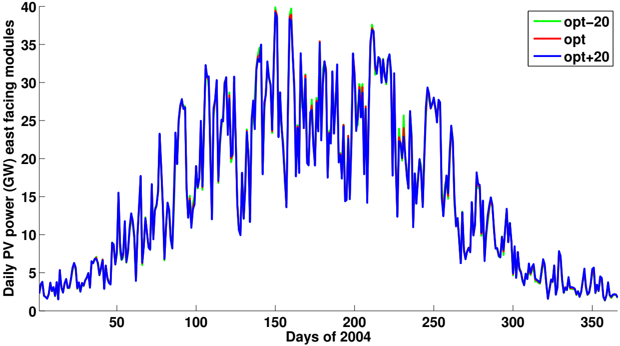
Adjusting capacity:



Adjusting capacity:

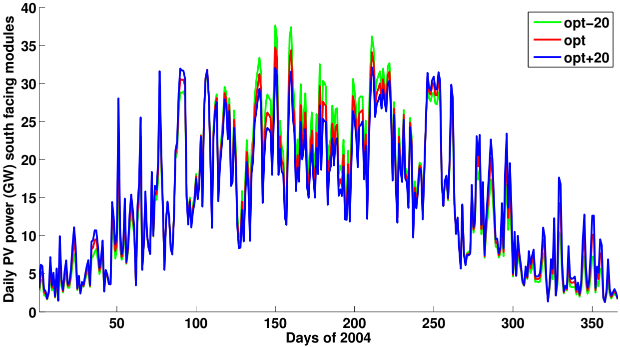


PV production: Germany



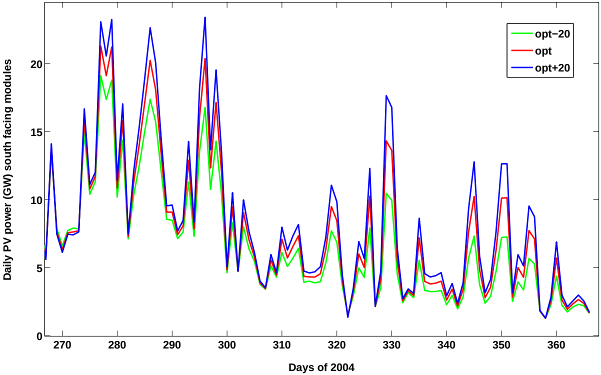
Daily PV power over Germany during 2004 from east-facing modules

PV production: Germany



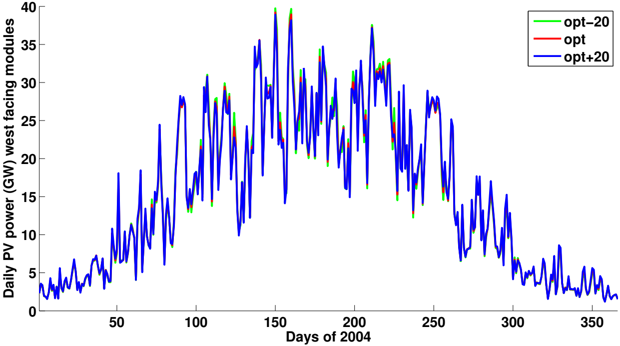
Daily PV power over Germany during 2004 from south-facing modules

PV production: Germany



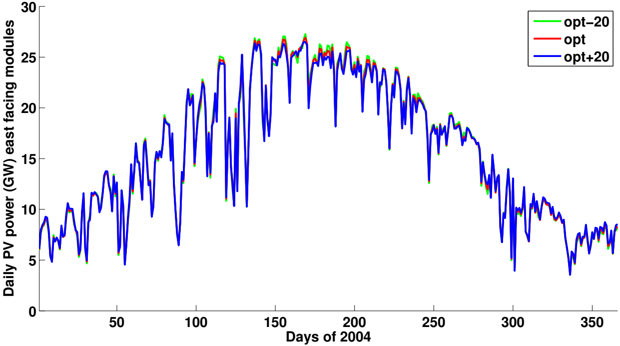
Daily PV power zoom-in for winter in Germany during 2004 from south-facing modules

PV production: Germany



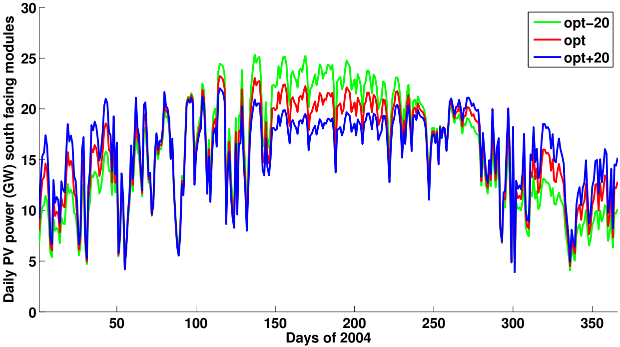
Daily PV power over Germany during 2004 from west-facing modules

PV production: Spain



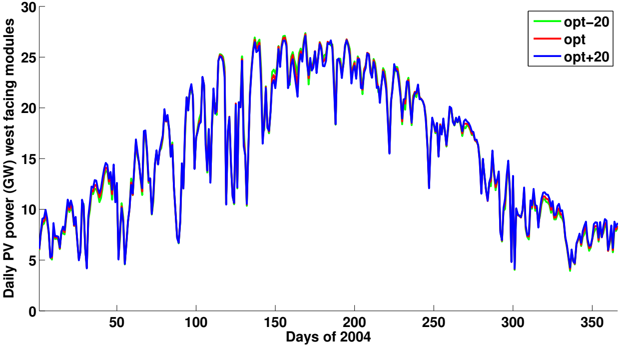
Daily PV power over Spain during 2004 from east-facing modules

PV production: Spain



Daily PV power over Spain during 2004 from south-facing modules

PV production: Spain



Daily PV power over Spain during 2004 from west-facing modules

Hourly deviation

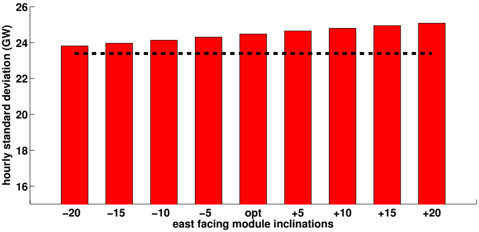


Figure: hourly deviation (GW)

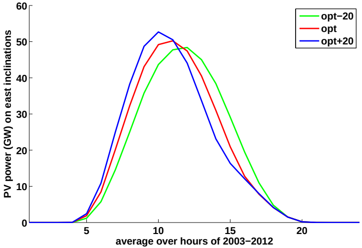


Figure: diurnal variation

PV variation from east-facing modules computed over 2003-2012

Hourly deviation

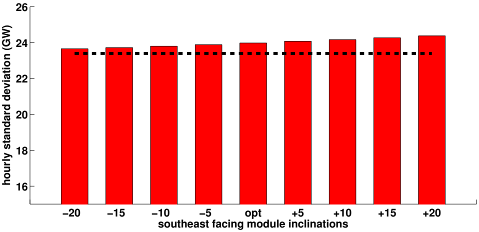


Figure: hourly deviation (GW)

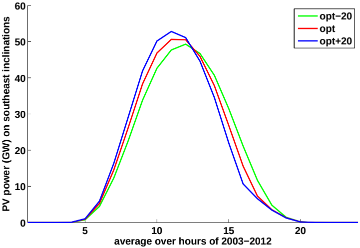


Figure: diurnal variation

PV variation from south-east-facing modules computed over 2003-2012

Hourly deviation

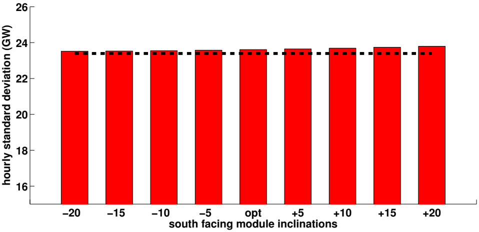


Figure: hourly deviation (GW)

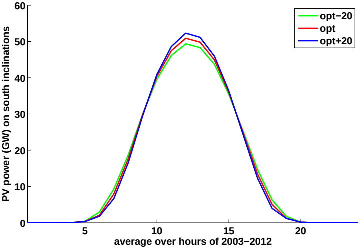


Figure: diurnal variation

PV variation from south-facing modules computed over 2003-2012

Hourly deviation

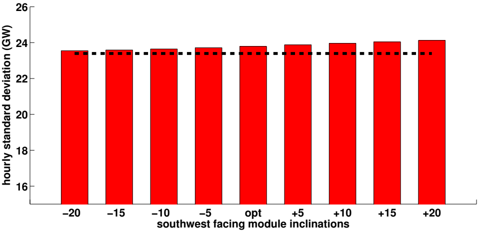


Figure: hourly deviation (GW)

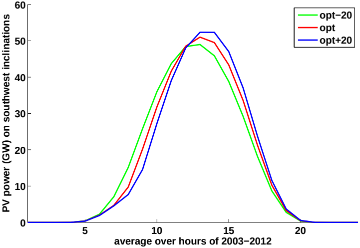


Figure: diurnal variation

PV variation from south-west-facing modules computed over 2003-2012

Hourly deviation

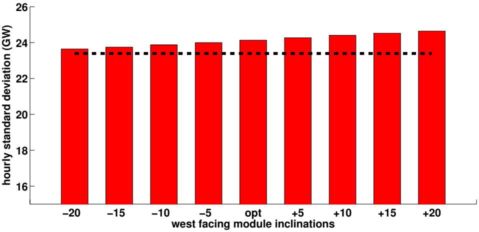


Figure: hourly deviation (GW)

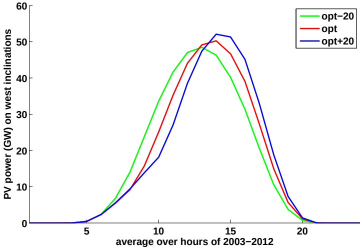


Figure: diurnal variation

PV variation from west-facing modules computed over 2003-2012

Daily deviation

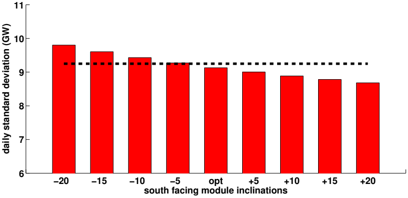


Figure: daily deviation (GW)

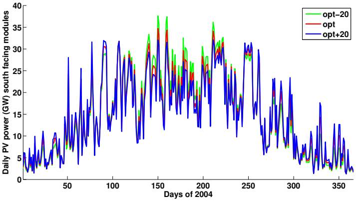


Figure: annual variation

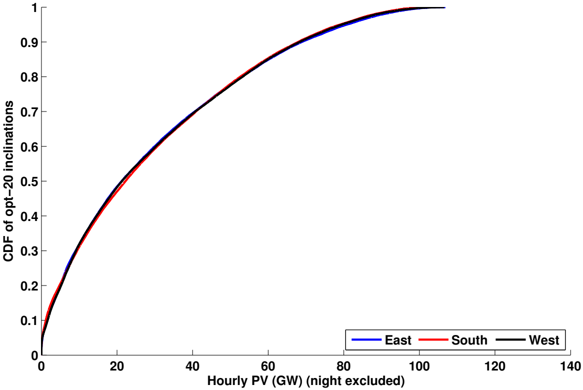
Daily fluctuation of PV from south-facing modules for Germany

Cumulated distribution

To analyse the frequency distribution of levelised PV production from these modules, their cumulated distributions are compared.

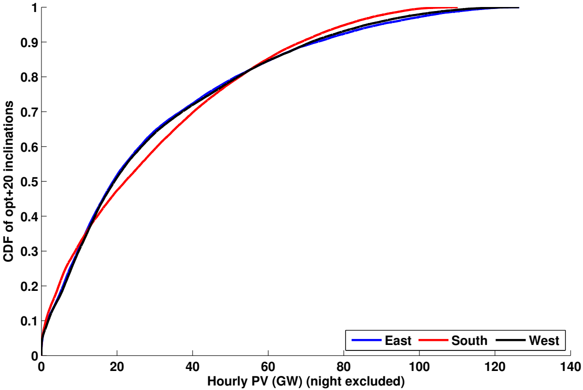
We also analyse the incremental cumulated distributions to understand their relative changes from one time step to another

Hourly CDF

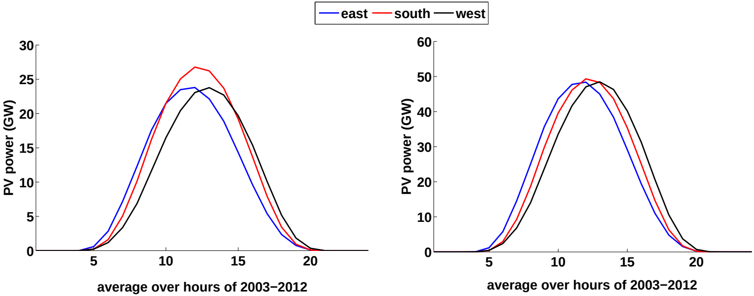


CDF of PV power (GW) from modules with inclination of optimal−20° for Germany

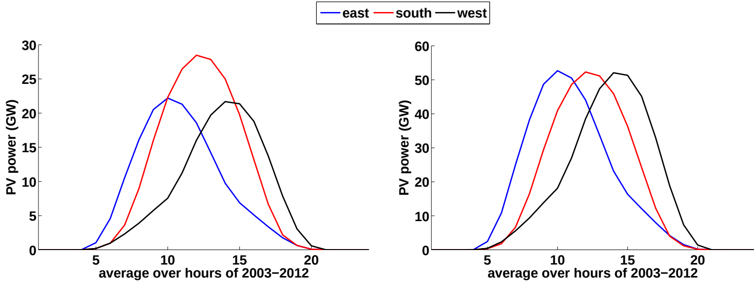
Hourly CDF



CDF of PV power (GW) from modules with inclination of optimal$+20^\circ$ for Germany

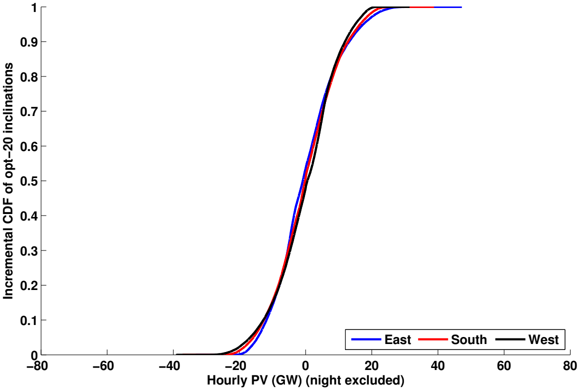


Averaged PV power from optimal−20° module inclination for Germany: (a) without capacity adjustment (left) and (b) with capacity adjustment for levelised production (right)



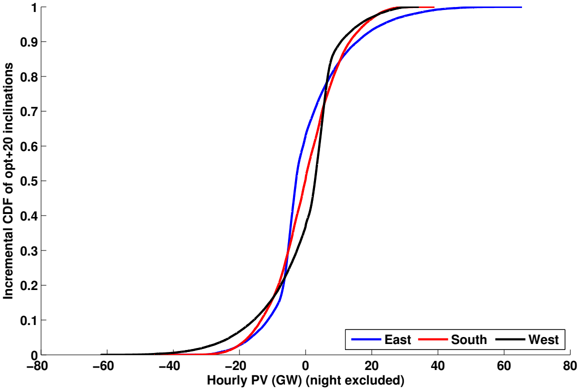
Averaged PV power from optimal+20° module inclination for Germany: (a) without capacity adjustment (left) and (b) with capacity adjustment for levelised production (right)

Incremental CDF



Hourly incremental CDF from modules with inclination of optimal-20° for Germany

Incremental CDF



Hourly incremental CDF from modules with inclination of optimal$+20^\circ$ for Germany

We define *residual_load* as the negative parts of overall mismatch, i,e, situations when demand surpluses generation:

$$residual\_load(t) := (mismatch(t) < 0)$$

Storage energy is computed using:

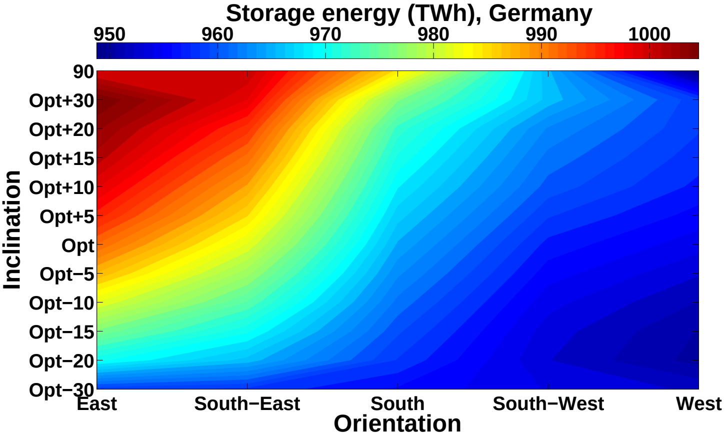
$$\boxed{storage\_energy = \int_t residual\_load(t)dt}$$

Storage filling is computed using:

$$storage\_filling = \int_t mismatch(t)dt$$

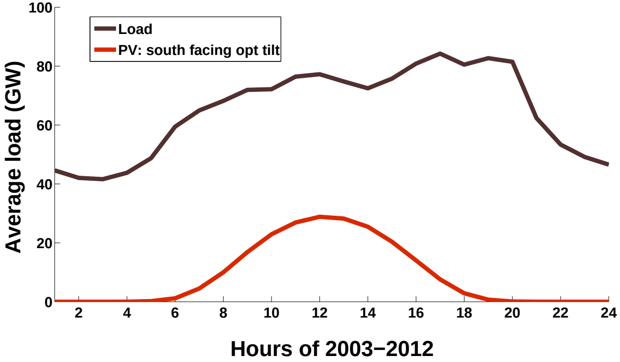
For simplification, no storage loss is calculated for now!

Storage energy



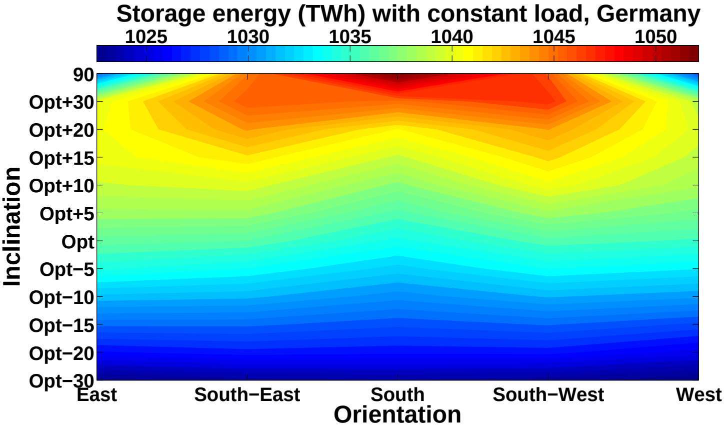
Storage energy for different module configurations for Germany

Average load

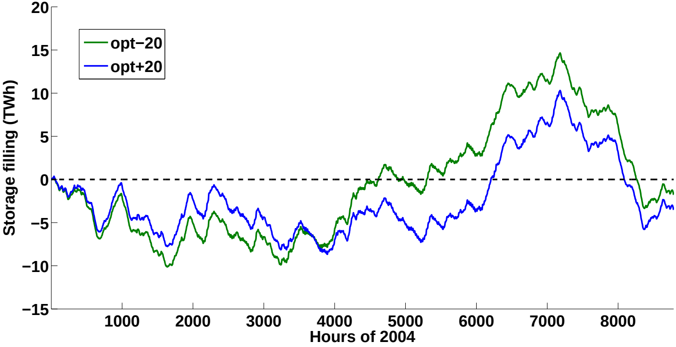


Annual average of hourly load and PV power from south-facing optimally tilted modules for Germany

Storage energy

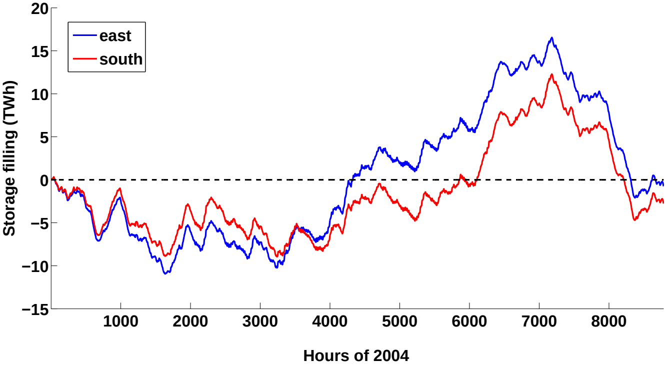


Storage energy for different module configurations for Germany calculated with a constant load



Hourly storage filling for Germany, 2004 for south facing modules with different inclinations (opt-20°,opt+20°)

Storage filling



Hourly storage filling for Germany, 2004 for optimally inclined modules with different orientations (east, south)

Storage capacity

We define storage capacity as:

$$storage\_capacity = max(storage\_filling) - min(storage\_filling)$$

For Germany it is 24.79 TW for south facing modules in opt-20° inclinations and 18.98 TW for opt+20° inclinations.

For optimally inclined east facing modules, storage capacity is 18.03 TW in Germany while for optimally inclined south facing modules, it is 9.13 TW.

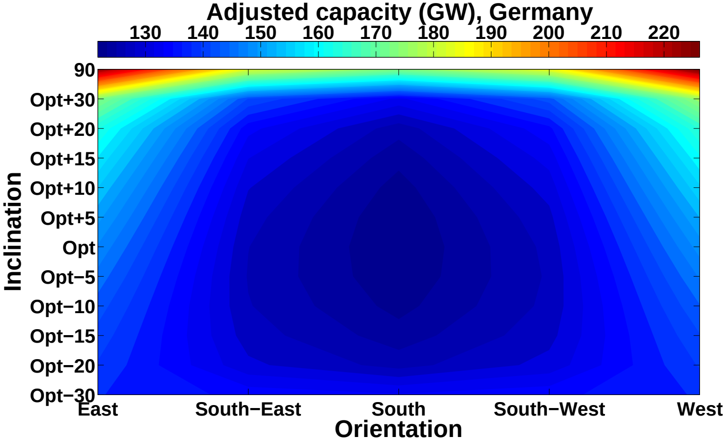
Summary

We summarise the presentation with a quick look back on:

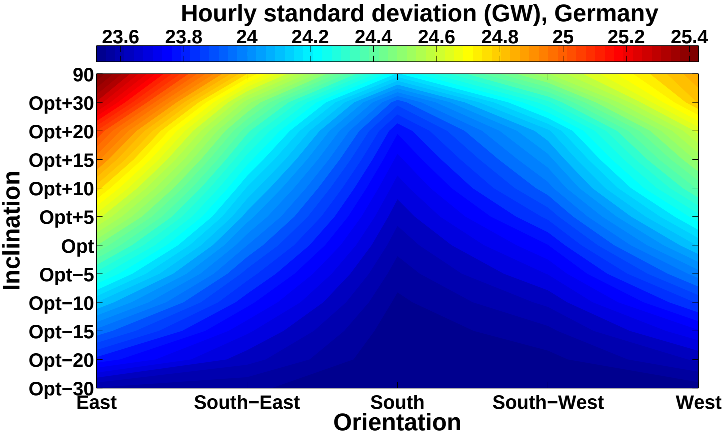
- capacity adjustment
- calculating fluctuations
- calculating storage energy
- calculating storage requirement

for different module configurations and for different countries

Capacity adjust

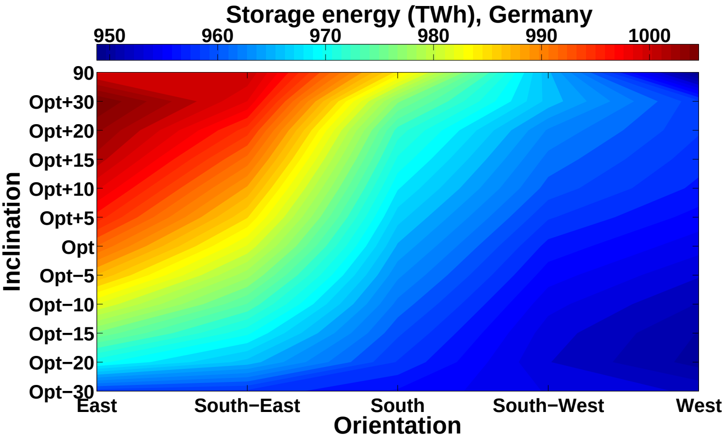


Optimum comes around optimally tilted south-facing modules

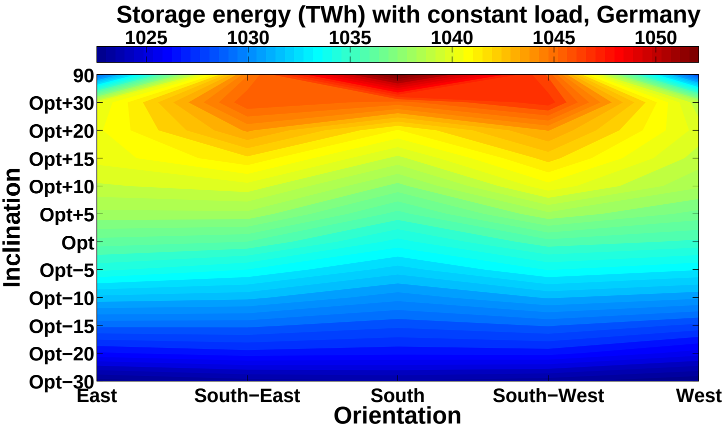


Optimum comes for low inclined modules, with some preferences towards west

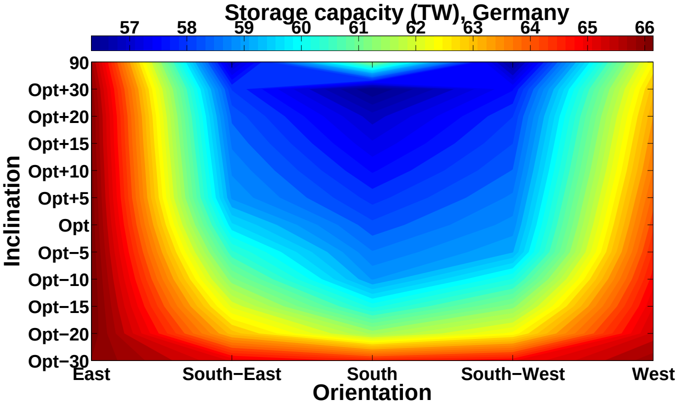
Storage energy



Optimum comes around low inclined west facing modules



Optimum comes around low inclined modules



Optimum comes for south facing high inclined modules

Summary

We summarise the location of optimum for different categories:

- capacity adjustment: optimally tilted south-facing modules
- fluctuations: low inclined south or south-west facing modules
- storage energy: low inclined west facing modules
- storage energy with constant load:low inclined modules
- storage requirement: south facing high inclined modules

Outlook

- Extend the analysis to other European countries
- Include storage loss in calculation
- Analyse the fluctuations from east-west mixed timeseries at different temporal resolutions
- Include hydro power in the model
- Modify the existing code to allow power transmission across Europe

Thank You for your Attention!

Questions?