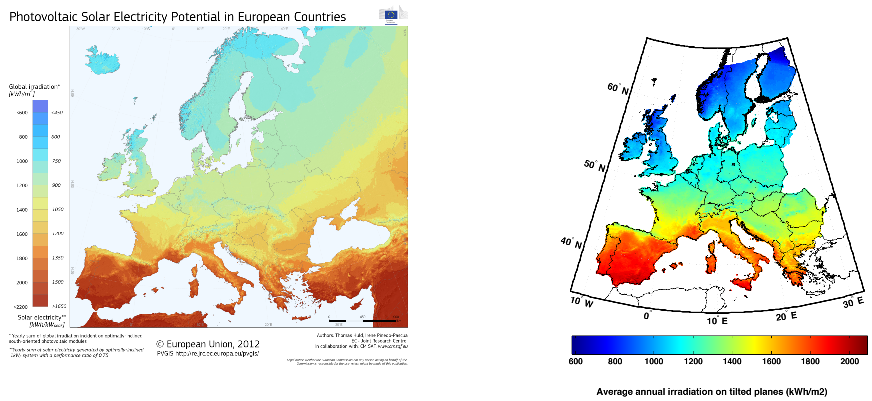


Figure 14: European map of average annual sum (April, 2004 - March, 2010) of global irradiance on inclined surfaces from European Union Joint Research Centre (EU-JRC) (left) (PVGIS ©European Union, 2001-2012) and our simulation (right)

CSP plants. Hence, DNI data is used as an indirect measure of solar thermal power. Fig.15 shows a qualitative comparison of DNI map of Spain from SolarGIS database and our simulations. The results from GeoModel SolarGIS are mainly satellite-derived and combined with informations from meteorological stations. Fig.15 shows that our model can potentially capture the spatial distribution of DNI simulated over a long time-period. It is worth to be noted that the DNI map from SolarGIS shows annual average from 1994-2010 while ours is from 2003-2012.

SolarGIS also provides hourly irradiance time-series for one station in Almeria, Spain (37.09°N, 2.36°W) from January, 1994 to June, 2012. To make a reasonable comparison with this data, we calculated irradince time-series at the nearest available grid point in our model domain (37.09°N, 2.45°W). Fig.16 shows the daily GHI and DNI time-series from SolarGIS database of Almeria and our simulation for 2006. The results are in good agreement with each other and nicely captures the fluctuations throughout the year. The annual course of SolarGIS time-series, however, show higher fluctuations than our simulated irradiance time-series. The differences are more prominent for DNI than GHI as DNI is more sensitive to atmospheric turbidity and the presence of clouds. As mentioned in Sec. 3.1.1, our results may differ from SolarGIS data due to the differences in modeling details including model resolutions, different parameterizations and different sources of input data. A combined effect of all these factors explains the existing differences between the irradiance time-series from SolarGIS and our simulations.

Some dispersed information on power production is collected from some CSP plants

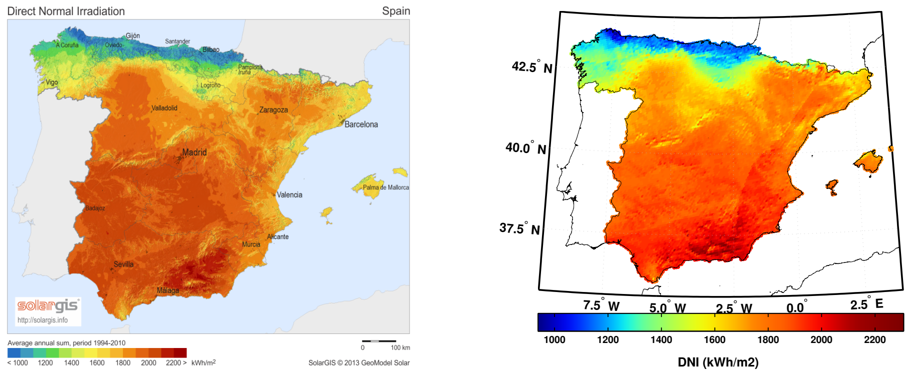
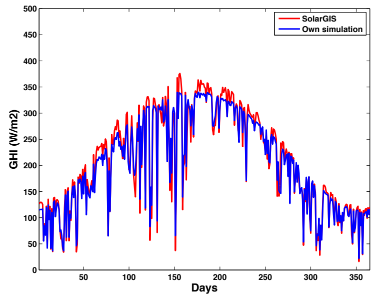


Figure 15: Average annual sum of DNI in Spain from SolarGIS database (left) (SolarGIS©2013 GeoModel Solar) and our simulation (right)

in Spain. Table 6 shows the relative comparisons of CSP power from these data and our simulations. The Valle Solar Power Station is a two adjacent twin 50 MW solar thermal power plants. Valle 1 and Valle 2 are expected to produce a combined 320 GWh of energy per year. Andasol, on the other hand, combines three separate power plants each with a nameplate capacity of 50 MW and are expected to generate a combined 495 GWh energy per year. We simulated CSP power for 2012 at the nearest model grid points for Andasol and Valle each with the capacity of 100 MW. Each plant of Valle and Andasol is equipped with a heat storage system of 7.5 hours while our simulations so far do not include any thermal storage system. Additionally, we have used a solar field area of 68.6 ha in our model. The Valle 1 and 2 plants employ a solar field on a surface area of 460 ha while for Andasol, the power plants each cover an area of 195 ha. The lack of thermal storage and the low solar field area used in our model results in low capacity factor from our simulation compared to the measured ones (Table 6). Although these dispersed data are not very precise and are not quite standardised, nevertheless they give a rough idea on the performance of the power plants.



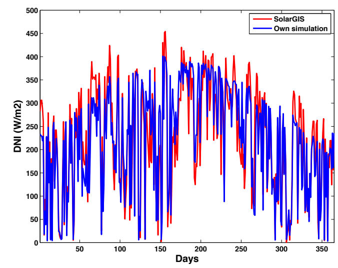


Figure 16: Comparison of daily GHI (left) and daily DNI (right) time-series of 2006 in Almeria, Spain from SolarGIS database and our simulation

		latitude (N)	longitude (W)	capacity (MW_p)	annual generation (GW_h)	CF (%)
Andasol	measurement	37.23	3.06	150	495	41.0
	simulation	37.27	3.03	100	240	27.3
Valle	measurement	36.65	5.83	100	320	37.0
	simulation	36.69	5.85	100	221	25.1

Table 6: Overview of Andasol and Vally CSP power plants' performances and comparison with our simulations for 2012 at nearest grid point of the model domain

3.1.3. Validation of Hydro inflow

For hydro power, generation is controllable (Apart from Run-of-River technologies). Therefore, the quantity that demands verification, is the inflow instead of the generation. The inflow is the amount of energy that enters reservoir storages and is again made of an controllable part (Pumped hydro storages) and a part coming from natural the natural runoff (For example in dams). Data on this inflow is rare for most countries. However, Norway provides weekly data on the inflow into hydro power plants. The monthly data of this calculation in comparison to measurements provided by the Norwegian Energy and Resources Directorate can be seen in Fig. 17. The seasonal cycle is generally well caught, while there seems to be an offset in some years. However, it is unclear how exactly the measurements of the inflow were performed.

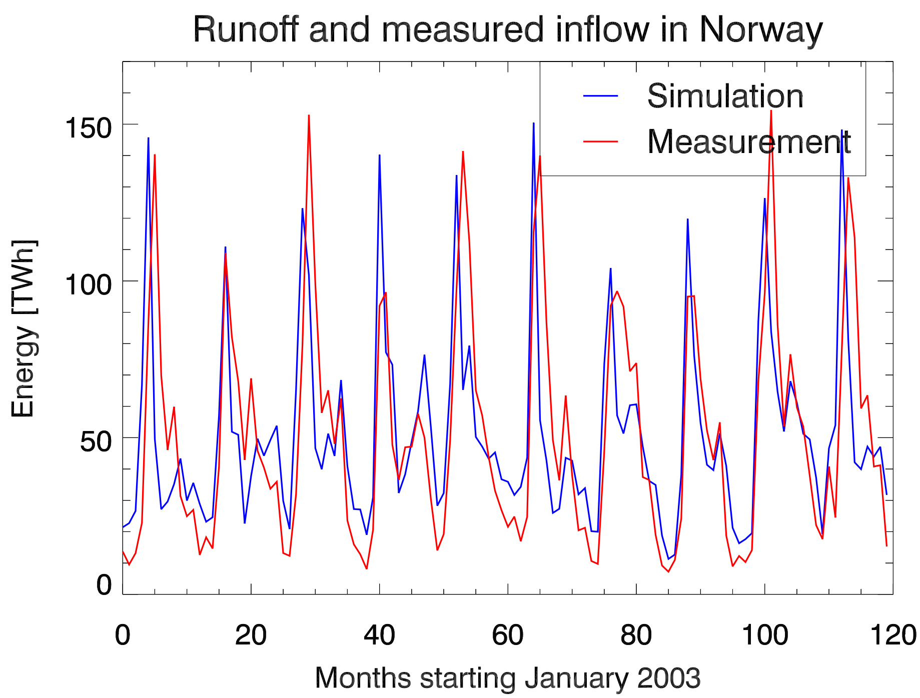


Figure 17: Monthly measured inflow of energy into hydro power plants and simulated inflow from reanalysis data for Norway.

3.2. Representative year analysis

The 10 years time-series (2003-2012) for different technologies have been thoroughly analysed. The objective of this section is to determine a representative year that can reproduce the major aspects of the ten years. The characteristic features of variations are analysed here for the most fluctuating renewables: solar and wind. All calculations included of this section use time-series of Europe, instead of individual countries. It should be noted that finding a representative year is based on the ten years time-series, here after refered to as the reference time-series. Hence, it contains the characteristic features of all ten years.

Different statistical measures are applied to cover a wide range of attributes of renewable fluctuations. Since different types of technologies are compared, generated power is best expressed when normalised to respective installed capacities. The analysis is also extended to include comparison between different temporal scales (hourly, daily, weekly