and monthly). Many different statistical measures are applied here to interprete various aspects of renewable fluctuations. These include:

1. interannual variations of capacity factors and standard deviations of different technologies at different temporal resolutions
2. Kolmogorov-Smirnov Integral (KSI), a statistical approach to quantify how closely individual years follow the reference time-series
3. incremental time-series are analysed to better understand the corresponding changes from one time step to the next
4. the range and the frequency of occurence of values of generated power under different meteorological conditions is studied using cumulated distribution functions and histograms
5. finally, a statistical hypothesis testing is applied to find the most suitable representative year from 2003-2012

### 3.2.1. Interannual variation of capacity factor

Interannual variations of capacity factors of different technologies are compared against the capacity factor of the reference time-series, Fig. 18. In terms of average generation, the years 2004, 2006, 2009 and 2011 show close proximity to the reference year. 2010 is found to be furthest away from the reference time-series for all technologies.

### 3.2.2. Interannual fluctuation of standard deviations

In this section, variability is analysed over ten years with respect to the reference time-series. For each technology, the standard deviation from individual years is normalised to the standard deviation of the reference time-series:

$$normalised\_std = \frac{std(P)}{std(P_{ref})}$$

Values close to 1 indicate that the particular year has fluctuation comparable to the reference time-series. It is to be noted that for PV and CSP, night-time values are filtered out from the hourly time-series to remove the effects of strong deterministic course of the diurnal solar variability.

The variation of the ratio of standard deviation of a particular year to the standard deviation of the reference time-series is shown in Fig. 19 for different temporal resolutions. For onshore and offshore wind 2003, 2006, 2007, 2008 and 2011 have standard deviations higher than the reference time-series for all temporal resolutions. On the other hand, 2009, 2010 and 2012 have lower standard deviations of wind compared to the reference time-series. The interannual variations for solar technologies are primarily visible over daily, weekly and monthly time scales. Fig. 19 shows that for 2003, PV and CSP have values greater than 1 for all temporal resolutions considered here. Apart from

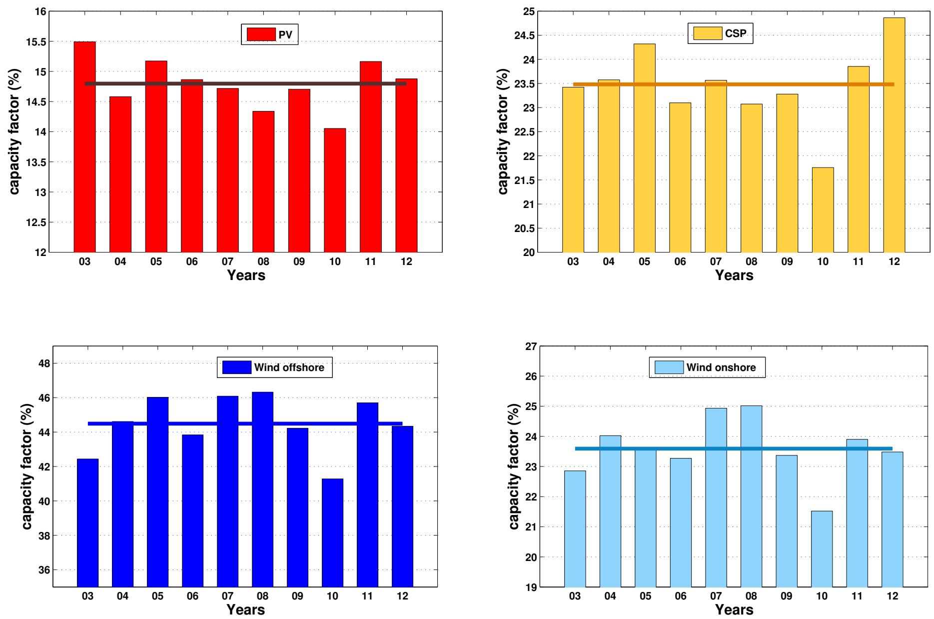


Figure 18: Interannual variations of Europe's capacity factors for different renewable resources.

2003, other years also show similar behaviour, like 2011 and 2012 on the hourly scale and 2009 and 2010 on daily, weekly and monthly scales. 2006, 2007 and 2008 have lower standard deviations than the reference time-series for solar technologies on all temporal resolutions. Additionally, Fig. 19 shows that 2010 and 2005 have values lower than 1 on the hourly and the other resolutions, respectively. Since we are not looking for years that have higher or lower variations, rather for years with variations comparable to the reference time-series, we see only 2004 and 2011 have values close to 1 for most technologies and for all resolutions.

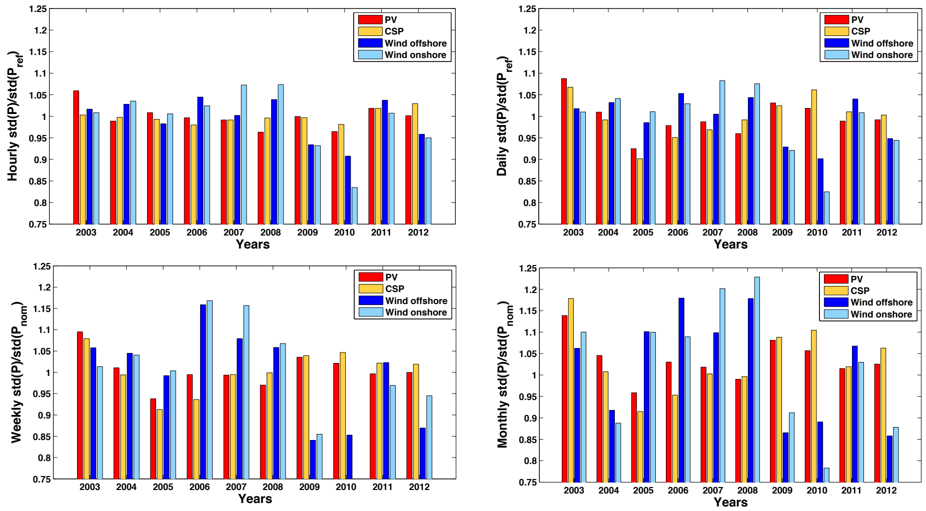


Figure 19: Ratio of standard deviation of power to the standard deviation of the reference time-series for different technologies in Europe.

### 3.2.3. Application of Kolmogorov-Smirnov integral (KSI)

We have applied the Kolmogorov-Smirnov integral (KSI) as a measure of quantifying how well the time-series of a particular year can reproduce the features of the reference time-series. A detailed description of the KSI measure is given in Appendix A.1. When using it to determine a representative year, a lower KSI value indicates better match with the reference time-series. A comparison of KSI for different technologies during the ten year period is carried out for different temporal resolutions, Fig. 20. In general, 2004, 2006, 2009, 2011 show lower KSI values at all temporal resolutions compared to the other years. However, offshore wind shows comparatively higher KSI magnitudes for 2006 and 2009 (above 0.015), specially on weekly and monthly scales. Hence, we conclude that the remaining two years (2004 and 2011) are most suitable to function as the representative year. This result using the KSI measure is in good agreement with the findings from Sec.3.2.2. The rest of the years, specially 2003 and 2010, have quite high KSI values on all resolutions.

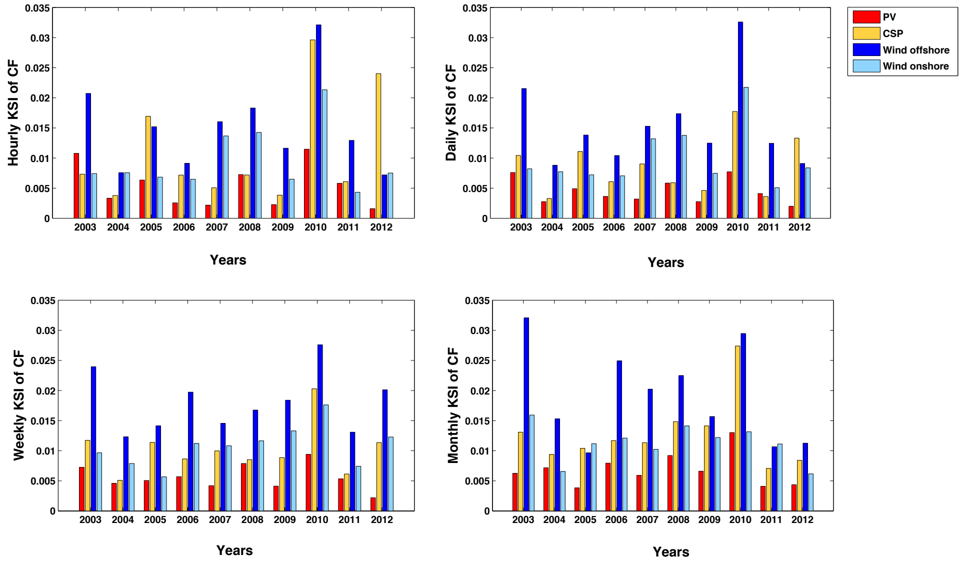


Figure 20: Interannual variation of KSI at different temporal resolutions. Distance between the distribution of annual power generation and the ten years reference time-series is expressed as the KSI values.

### 3.2.4. Analysis of incremental power time-series

Low gradients in power generation on all time scales are desirable, thus a representative year shall have the same gradients as the ten years time-series. In this section, the distribution of increments for each year is analysed and compared with the distribution of increments of the ten years reference time-series. Since changes in wind speed are usually not very large from one hour to the next when averaged over the large domain of Europe, the yearly distribution of on/offshore wind is closer to the reference distribution in all years. The much stronger diurnal variation for solar technologies show high hourly power gradients, even after filtering out the night time values (Fig. 21). The substantial higher increments for solar arise from the very strong gradient in the diurnal cycle (Fig. 22). For the other temporal resolutions in Fig. 21, solar show lower KSI values compared to wind for all years.

### 3.2.5. Application of hypothesis testing

The statistical measure of KSI is extended to the KSI hypothesis test which is discussed in details in Appendix A.2. The results from hypothesis testing are discussed on hourly and daily scales and only for 2004 and 2011, as these two years are found to be best suited as the representative year from the previous analysis. Fig. 23 shows that for

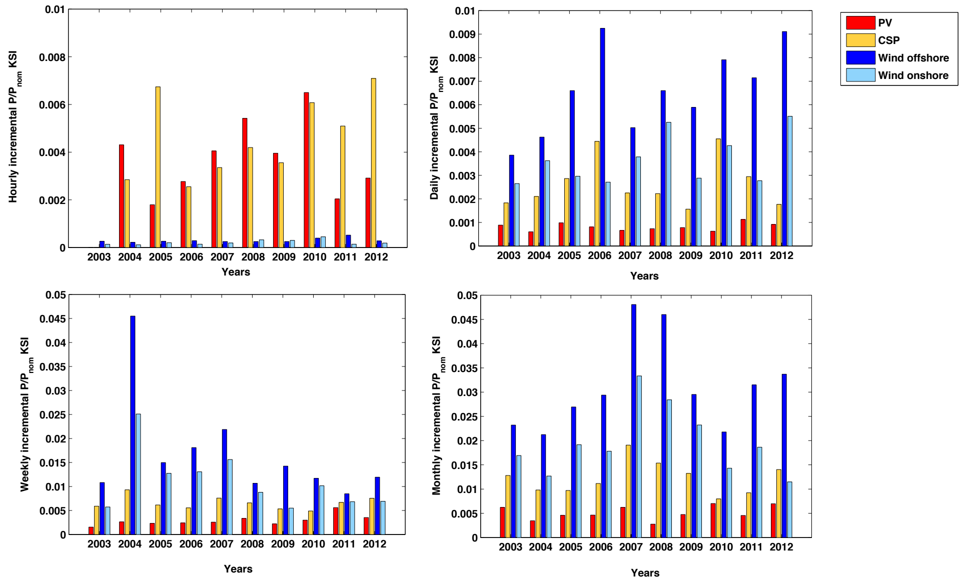


Figure 21: Distribution of the increments of power in relation to the increments of the ten years reference time-series expressed as the KSI to analyse interannual variations of KSI at different temporal resolutions.

both years, onshore and offshore wind rejects the null hypothesis on the hourly scale but retains it on the daily scale, although the value for daily offshore wind for 2011 is found to be very close to the critical line of 95% confidence level. As for the solar PV, the null hypothesis on 95% confidence level is retained for 2004 and rejected for 2011 on both temporal scales. For CSP, however, it is retained through both years in both resolutions. At weekly and monthly resolutions, all technologies are found to retain the null hypothesis and hence not shown explicitly.

With the careful analysis from the previous sections, we select 2004 as the representative year. However, it should be noted that 2011 also has quite the potential to reproduce most features of the reference time-series, and in certain cases, even better than 2004 (for example, weekly KSI values of incremental capacity factors). So, although a suggestion has been made here, we request the readers to carefully go through the examples cited above and to adapt the year that is most reasonable for their particular analysis on desired resolution.

### 3.3. Spatio-temporal variability analysis

In this section, we discuss the spatial distributions and interannual variations of renewable resources. The feed-in profiles of different renewables are analysed in different

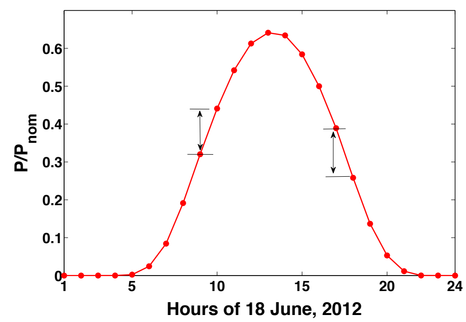


Figure 22: The strong deterministic effect of the sharp gradient associated with diurnal solar course

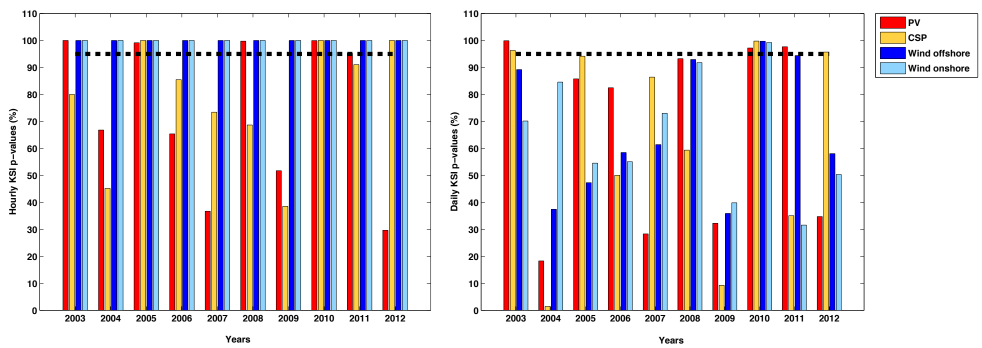


Figure 23: KSI test results for hourly and daily normalised power time-series at 95% confidence level

temporal resolutions to better understand their characteristics.

The mean and standard deviation maps of PV capacity factors in Europe, calculated over ten years (2003-2012) are shown in Fig. 24. The spatial distribution of PV capacity factor strongly resembles the irradiance distribution, with higher values in southern Europe and gradually decreasing towards north. However, this change in irradiance gradient is not uniform, as it depends on multiple factors like meteorology, frequency of cloud cover, local atmospheric conditions, aerosol and water vapor content etc. The interannual variations of PV capacity factors is expressed as standard deviation (Fig. 24). The values are relatively low throughout Europe ($\sim 0.5\%$), with maximas ($\sim 1-2\%$) in central Europe, the hilly region with highest orographic elevations. This effect is also visible for Norway and north-west of Romania. Countries with zero installed PV capacities (according to the meta-studies [17], [9]) are left blank in Fig. 24.

The advantage of analysing long-term data is the ability to quantify inter- and intra-annual fluctuations. Different technologies, like solar PV and wind, have a different