CLIM4ENERGY TECHNICAL NOTE NO.1: COMPUTING CAPACITY FACTOR

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Contents

Index of figures

Index of tables

1. Computing capacity factor indicator

The typical way of computing capacity factor is using manufacturer-provided power curves that relate power output to steady 10-minute winds blowing at hub height. Capacity factor can be derived from power curve values easily, dividing power output by the nominal capacity of the turbine.

There are in the market several manufacturers offering a wide range of turbines, and each of them is suited for maximum efficiency at specific wind conditions. The international standard IEC-61400-1[1], published by the International Electrotechnical Commission, defines 4 classes of turbines suited for an average annual wind speed of 10, 8.5, 7.5 and 6 m/s at hub height respectively.

Table 1. *IEC-61400-1 turbine classes.*

Class	Description	Annual average wind speed (m/s)	Turbulence intensity	Extreme 50-year gust (m/s)
Ia	high wind & high turbulence	10.0	18%	70
Ib	high wind & low turbulence	10.0	16%	70
IIa	medium wind & high turbulence	8.5	18%	59.5
IIb	medium wind & low turbulence	8.5	16%	59.5
IIIa	low wind & high turbulence	7.5	18%	52.5
IIIb	low wind & low turbulence	7.5	16%	52.5
IV	very low wind	6.0	-	42.0
S	special	-	-	-

As the capacity factor is related not only to the wind resource available but also to the ability of the turbine to extract its power, it will be important to assess differences in capacity factor due to turbine models.

[1] International Electrotechnical Committee IEC 61400-1: Wind turbines Part 1: Design Requirements; 3rd ed.; IEC: Geneva, Switzerland, 2005.

2. Selection of turbines

From a sample of more than two-hundred turbine models, five have been selected for testing sensitivity of the capacity factor indicator to the selected power curve. A first screening was carried out to select the most representative technologies. Several conditions were imposed:

- consider only pitch-regulated turbines,
- with nominal capacities around 2 MW,
- available for installation at 100 m hub height (or 95 m or 105 m),
- from the manufacturers with highest market shares in Europe: Vestas, Enercon and Gamesa.

After this first screening, five turbines representing the whole range of IEC Classes was selected. Class IV is barely used in the industry, and Class S is for special designs not fitting any other class, so they were discarded. Note that some turbines can be certified as Class I and II or II and III at the same time.

Table 2. Main features of the selected turbines.

IEC Class	Turbine name	Rotor diameter (m)	Rated power (MW)	Cut-in speed (m/s)	Rated speed (m/s)	Cut-out speed (m/s)
Class I	Enercon E70_2.3MW	70	2.3	2.0	16.0	25.0
Class I/II	Gamesa G80_2.0MW	80	2.0	4.0	17.0	25.0
Class II	Gamesa G87_2.0MW	87	2.0	4.0	16.0	25.0
Class II/III	Vestas V100_2.0MW	100	2.0	3.0	15.0	20.0
Class III	Vestas V110_2.0MW	110	2.0	3.0	11.5	20.0

Looking at the power curves in Figure 1 below we can see they are quite evenly spaced. Notice also how using the cut-in and rated speed values to select the turbines would not have been a good way to select the power curves. Cut-out values are very important for sensitivity because small variations of wind produce ramps in capacity factor between 0 and 1.

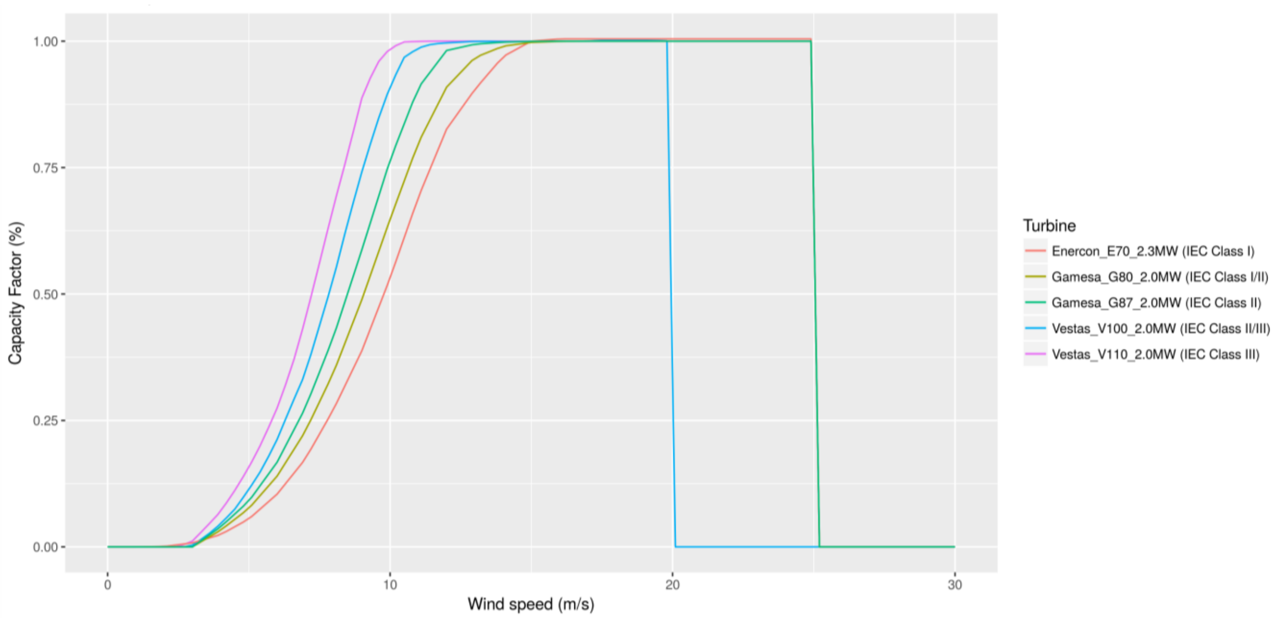

Figure 1. *Capacity factor curves for the selected turbines.*

3. Sensitivity to power curve

The five selected power curves have been used to analyse differences in capacity factor. We used 6-hourly ERA-Interim surface winds to compute capacity factors for those turbines. But surface wind needs to be adjusted to represent wind at hub height, which typically is between 80 and 120 m in modern turbines. For this we used a power law and assume a hub height of 100 m and a constant shearing exponent of 0.143:

$$WSPD100 = WSPD10 * (\frac{100}{10})^{0.143} \approx 1.39 * WSPD10$$

We also corrected the ERA-Interim winds using DTU's Global Wind Atlas mean annual wind speeds.

The capacity factor was computed using 6-hourly temporal resolution but then averaged over seasons.

In Figure 2 you can see the capacity factor values over Europe for several DJF seasons, whereas in Figure 3 you can see the anomalies. Although absolute values differ quite a lot amongst different turbines, anomalies look like very similar in general.

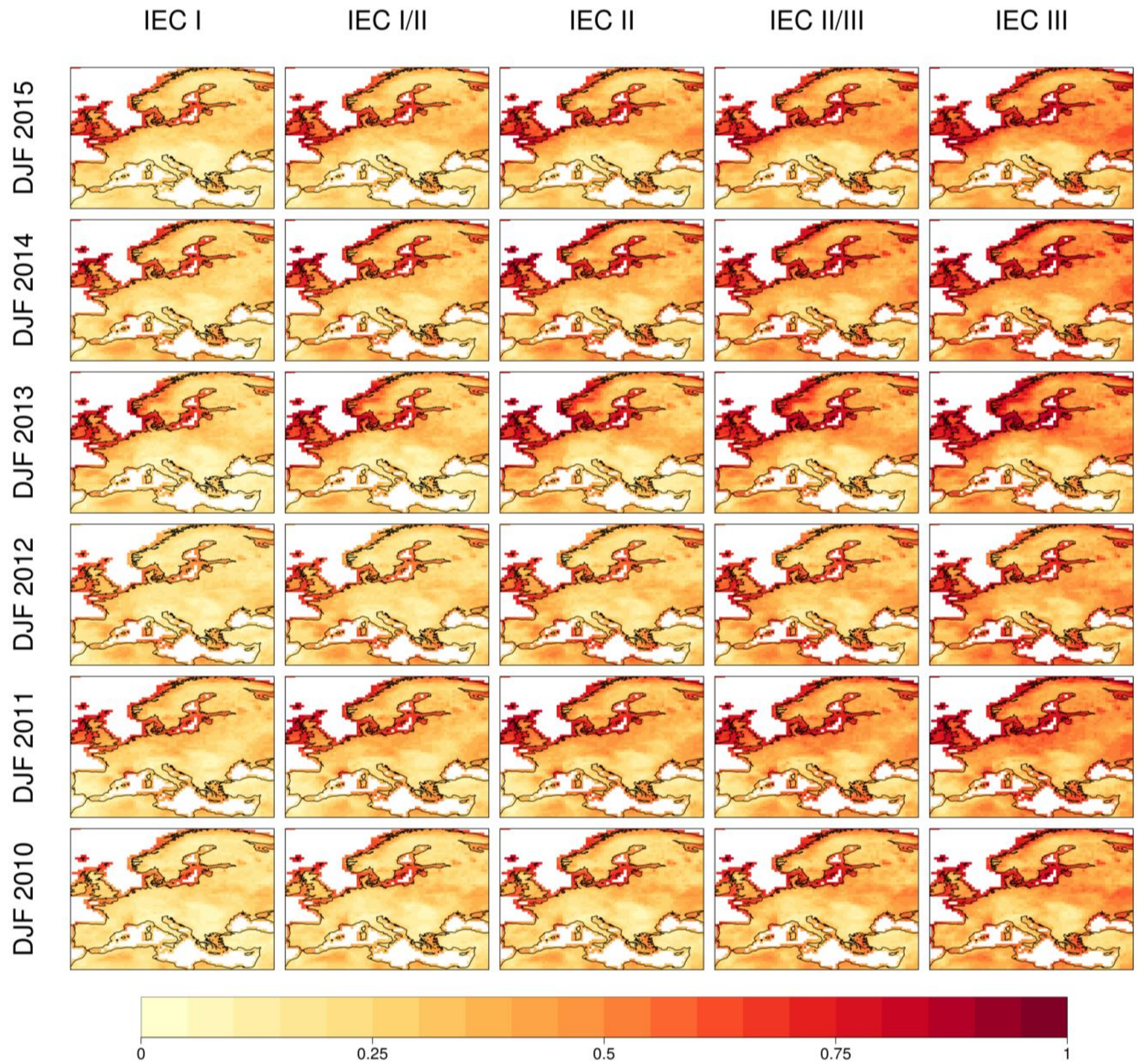

Figure 2. *Capacity factor for 2010-2015 DJF season, computed from ERA-interim, for five turbines representing the different IEC classes.*

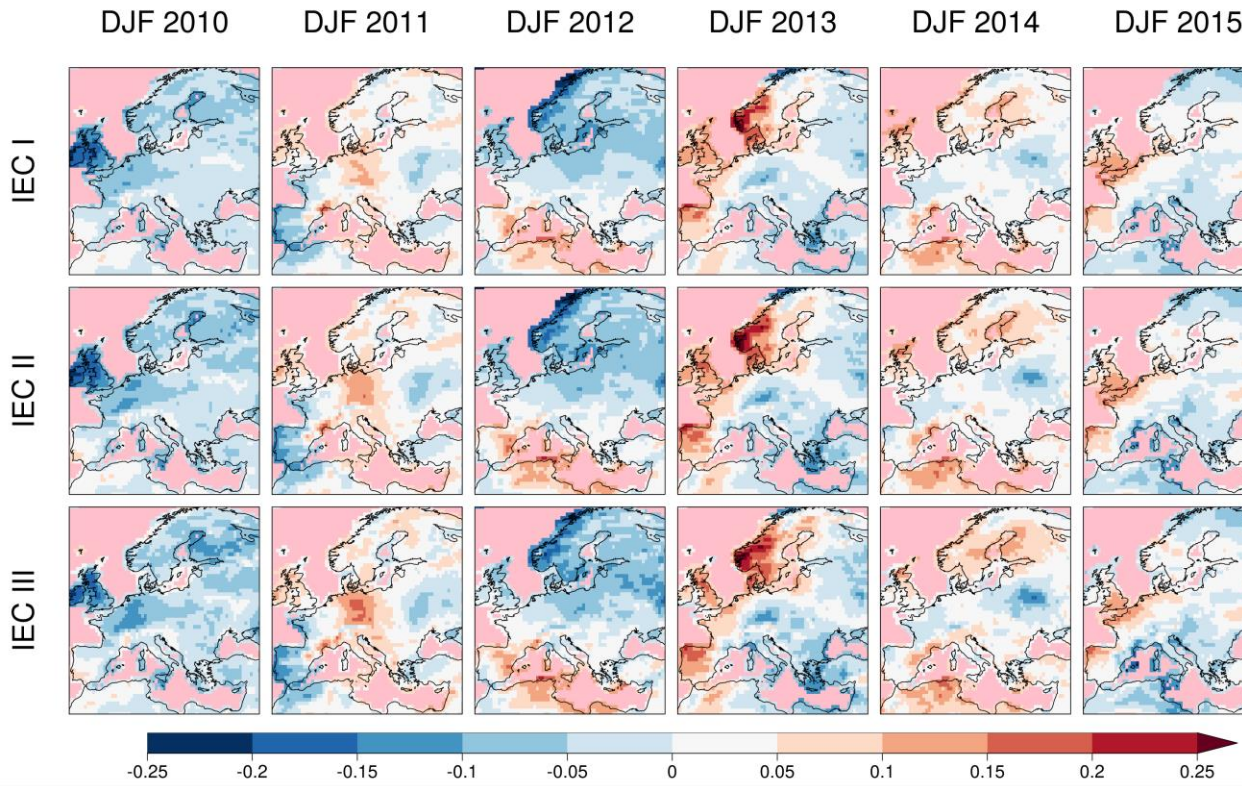

***Figure 3**. Capacity factor anomalies over Europe for 2010-2015 DJF season.*

4. Error metrics

Finally, we have computed the root mean squared differences and R^2 between the different seasonal capacity factors to have an estimate of the errors we can expect when using different turbines than the selected ones here. In Figure 4 you can see that RMSD are higher in offshore areas, where high wind speeds might reach the cut-off value more often. The RMSD are bigger between Class II and III than for Class I and II, for the same reason: class III turbines have lower cut-off speeds, that are more often reached. In Figure 5 we show how R^2 values are very high, enforcing the message that capacity factor anomalies are not very different amongst selected turbines.

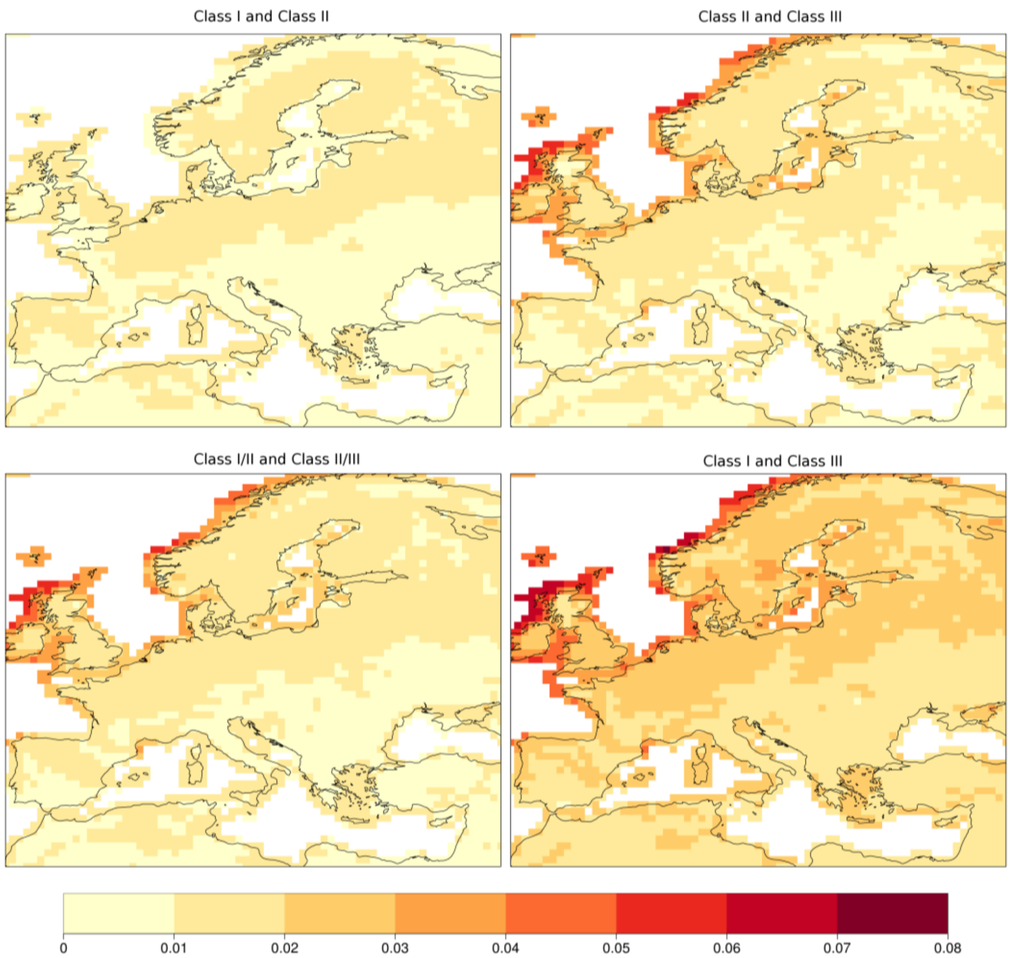

Figure 4*. Root mean squared differences between the different capacity factors.*

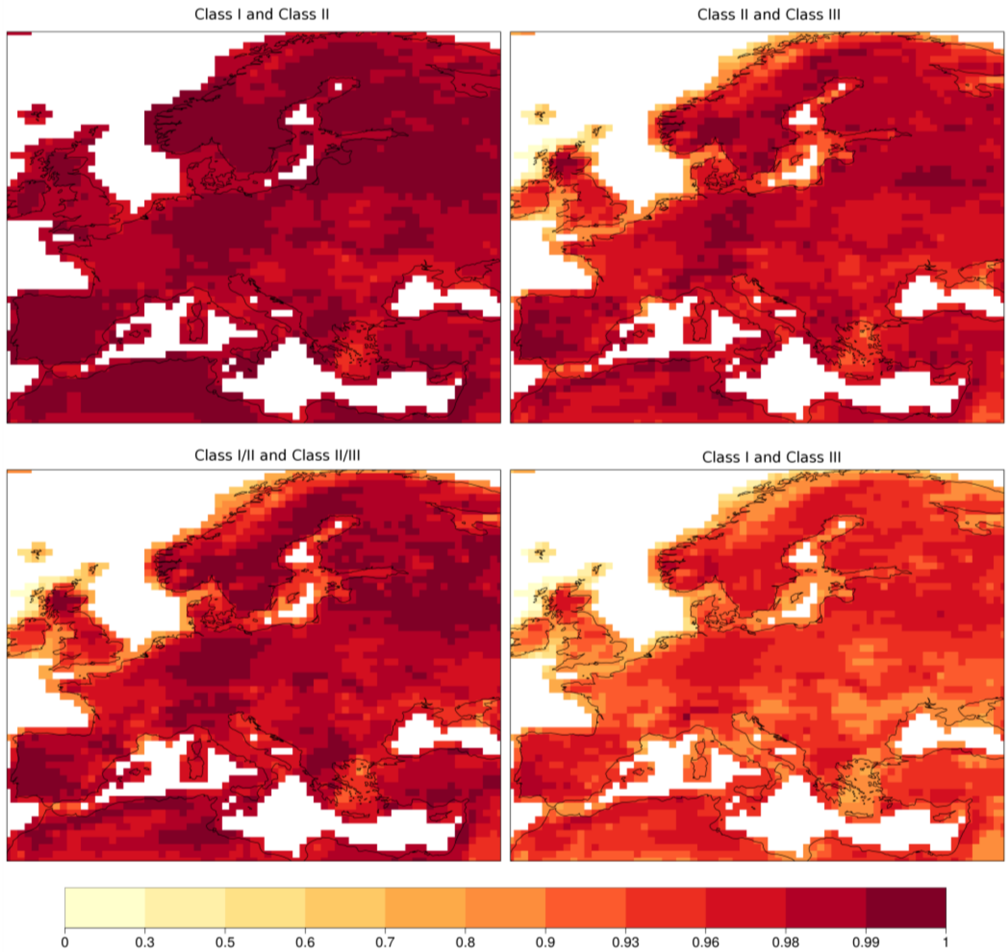

Figure 5. *R^2 between the different capacity factors.*