UK Photovoltaic Yield Estimate 2013

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Directive

Using data from the Microgen Database (MgDB) ensemble [1], this report details the annual yield and annual capacity of solar PV across the UK, which is divided into regions as defined by SAP2012 [2]. The key stakeholders in this study are PV investors, installers and regulators, though the results are also relevant to anyone concerned with distributed PV generation.

MgDB Ensemble

The MgDB dataset comprises PV generation data of varying resolution from across the UK, with historic data spanning up to seven years. The dataset is supplied by a combination of homeowners and commercial sources and includes both domestic and commercial scale installations with a wide range of azimuth and elevation angles. Details of the system parameters for the ensemble can be seen in Figure 5 of the Appendix.

Annual Yield and Capacity

The annual yield of a system is defined as the total annual generation divided by the system size (kWp). The annual capacity is calculated for each region as the mean annual yield multiplied by the total installed capacity of the region at the end of 2013 according to Ofgem [3].

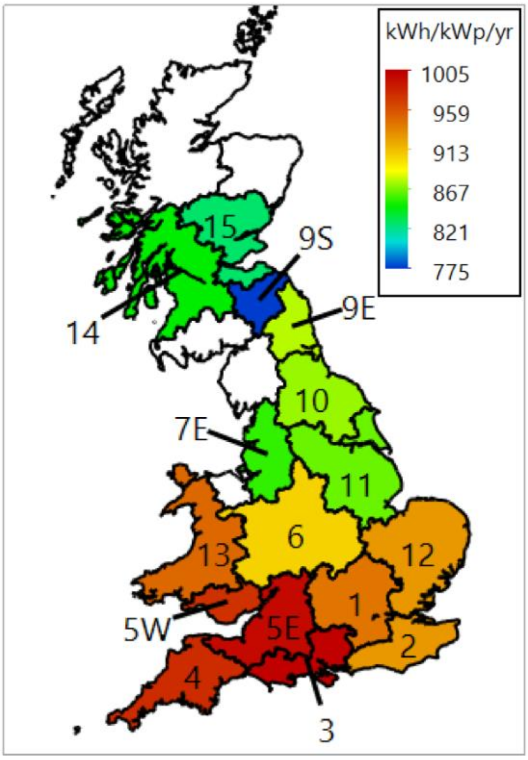

Figure 1; SAP2012 regions coloured by mean annual yield measured from the MgDB ensemble. Regions with less than 5 systems are excluded and left blank.

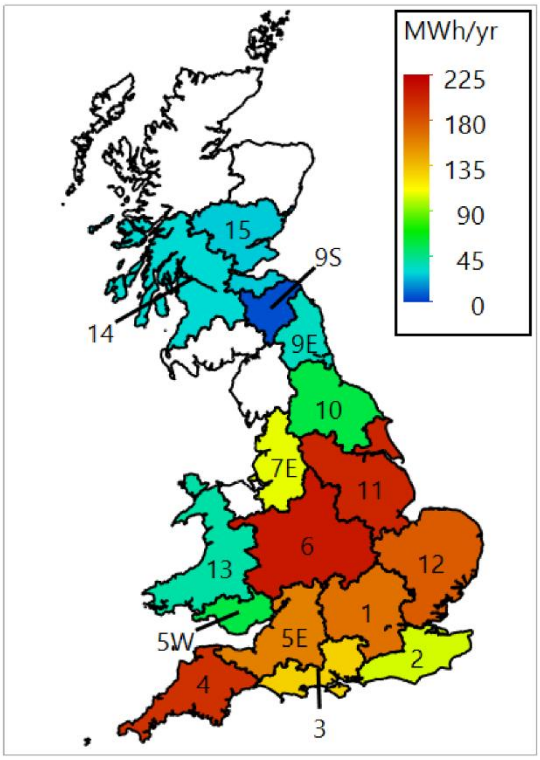

Figure 2; SAP2012 regions coloured by annual capacity for all systems less than 5 MWp.

Figure 1 illustrates the relative performance of the regions in 2013, whilst Figure 2 gives insight into how much electricity is actually being generated in each region. This first result is highly relevant to the decision making process of PV investors, particularly those investing in systems that are not geographically restricted. The latter result is crucial in understanding the impact PV will have on the UK's electricity infrastructure, particularly so since the performance and installation density are not well correlated geographically, as can be seen by comparing Figures 1, 2 and 5. Figure 6 also gives some insight into the level of market saturation for PV in each region, although one would also need to factor in various other parameters such as the population density and average income of each region to get the full picture.

Comparison with PVGIS and MCS

The widely used PVGIS† [4] prediction tool can provide an estimate of the expected annual yield for a PV system, and is used here to benchmark the figures calculated from real systems in the MgDB ensemble. Since the regions contain multiple systems, there are two ways to retrieve a PVGIS prediction which is representative of each region. Firstly, as is the case in the *PVGIS-CMSAF (1)* column of Figure 3, one can consider the individual prediction for each system within a region and then take the mean value. Alternatively, as is the case in the *PVGIS-CMSAF (2)* column of Figure 3, one could retrieve a prediction using the mean azimuth and elevation of the MgDB systems within the region with the representative latitude and longitude of each region (see Figure 7). Both of these predictions are dependent on the four key parameters, namely azimuth, elevation, latitude and longitude, but the difference between the two will mostly be a function of the geographic skew of the MgDB systems. Therefore, the relative difference between these two prediction methods gives an approximation as to the relative uncertainty of the MgDB mean annual yield calculations due to the geospatial skew of the MgDB systems within the region.

MCS provide an alternative prediction methodology which must be used by PV installers and submitted when applying for certification [5]. The methodology is a simplified version of PVGIS-CMSAF whereby the geospatial dependence of predictions is accounted for using the same region definitions as SAP2012. In order to achieve this, MCS defines representative latitudes for each region, which are listed in Figure 7. As such, the MCS prediction can be used here to explore the uncertainties associated with the other response variables, namely azimuth and elevation.

A second uncertainty in the calculation of regional mean annual yield from the MgDB dataset derives from the fact that whilst the nationwide distribution of azimuths and elevations in the MgDB ensemble can be considered representative of the true distribution across all sub 5 MWp PV in the country, the same cannot be said for the equivalent distribution within each region. Since the MCS prediction is a function of SAP2012 region as opposed to the specific location of systems withih the regions, the difference between these two predictions will effectively be a function of the azimuth and elevation skew of the MgDB systems away from the representative mean values. Therefore, to estimate this uncertainty, we consider the relative difference between the mean MCS prediction for systems in each region, *MCS (1)*, and the MCS prediction with the mean azimuth and elevation for the ensemble as a whole, *MCS (2)* (see Figure 5).

The MCS prediction includes a 'shading factor' which is ideally estimated from a sunpath diagram. Since the MgDB ensemble contains no data on the shading factors for each system and the average/representative shading factor is not known for either the regions nor the UK as a whole, shading is ignored in the MCS predictions in this report i.e. the shading factor is

† Photovoltaic Geographical Information System

set to 1. This will introduce a systematic error on direct comparisons between the MCS prediction and the measured annual yield for each region, but has little effect on the uncertainty estimate for skew in azimuth and elevation since we assume the average shading factor will be close to 1 in the UK.

How these uncertainties should be interpreted depends on the purpose for which the mean annual yield values are being used. If one requires a predicted annual yield that is representative of a region, then both uncertainties need to be totalled to give the final uncertainty. However, if one was interested in the annual yield for a typical installation in the region, and we were to postulate that the MgDB ensemble is representative of the geospatial spread of PV systems in the UK, it is no longer necessary to consider the uncertainty due to geographic skew and as such the uncertainty is reduced dramatically for most regions.

Region	System Count	MCS (1) (kWh/kWp/yr)	MCS (2) (kWh/kWp/yr)	PVGIS-CMSAF (1) (kWh/kWp/yr)	PVGIS-CMSAF (2) (kWh/kWp/yr)	Mean Annual Yield 2013 (kWh/kWp/yr)	Mean Annual Yield Any Year (kWh/kWp/yr)	Estimated Uncertainty (± kWh/kWp/yr)		
								Geographic	Az/El	Inter-annual Irradiance
3	38	998 ▬	1008 ▬	1012 ▬	1007 ▬	1004	964	5	10	40
5E	84	945 ▼	959 ▼	950 ▼	951 ▼	1000	960	1	14	39
4	412	1066 ▲	1077 ▲	984 ▬	937 ▼	980	941	47	10	39
5W	7	923 ▼	937 ▼	972 ▬	1010 ▲	977	938	36	14	38
13	7	909 ▼	912 ▼	963 ▬	770 ▼	951	913	228	3	37
1	44	961 ▬	971 ▲	947 ▬	970 ▲	945	907	21	10	37
12	240	941 ▬	949 ▬	969 ▲	971 ▲	930	893	3	7	37
2	16	1052 ▲	1115 ▲	958 ▲	986 ▲	930	893	26	50	37
6	848	918 ▬	924 ▬	885 ▼	928 ▲	907	870	40	5	36
9E	1490	876 ▬	891 ▬	920 ▲	877 ▬	879	844	42	14	35
10	31	894 ▲	901 ▲	883 ▬	893 ▲	874	839	9	7	34
11	874	857 ▬	881 ▬	884 ▲	931 ▲	866	832	42	23	34
7E	19	830 ▼	855 ▬	839 ▼	873 ▬	857	822	32	24	34
14	6	787 ▼	823 ▼	803 ▼	855 ▬	848	814	50	35	33
15	6	926 ▲	925 ▲	896 ▲	915 ▲	829	796	17	2	33
9S	5	839 ▲	889 ▲	779 ▬	749 ▼	777	746	30	42	31
Mean		920	939	915	914	910	873	39	17	36

Figure 3; Table of results by region. "The Mean Annual Yield" is measured from the MgDB ensemble. PVGIS predictions use the (default) values of 'Estimated system losses' and 'PV technology' which are 14% and 'Crystalline Silicon' respectively. MCS predictions use a shade factor of 1 i.e. zero shading. The symbols next to PVGIS and MCS predictions show the shift with respect to the "Mean Annual Yield 2013".

In Figure 3 we see that the geographic error associated with region 13 is extremely high relative to the other regions. This is caused by a very high geospatial sensitivity of the PVGIS predictions in Wales, coupled with the fact that 6 of the 7 systems in the region are coastal whereas the representative latitude and longitude of the region is very much inland. To an extent the high sensitivity of the PVGIS predictions in Wales is justified since the irradiance levels and sunshine hours are known to vary significantly across the region [6] [7]. It is also apparent that coastal microclimates can indeed have an adverse effect on irradiance and temperature levels, which are critical variables in PV generation [8].

Interannual Variability

Before extrapolating the results presented here to years other than 2013, it's important to understand the variability of annual irradiance in the UK, not just as a function of geography but also inter-annual weather variability.

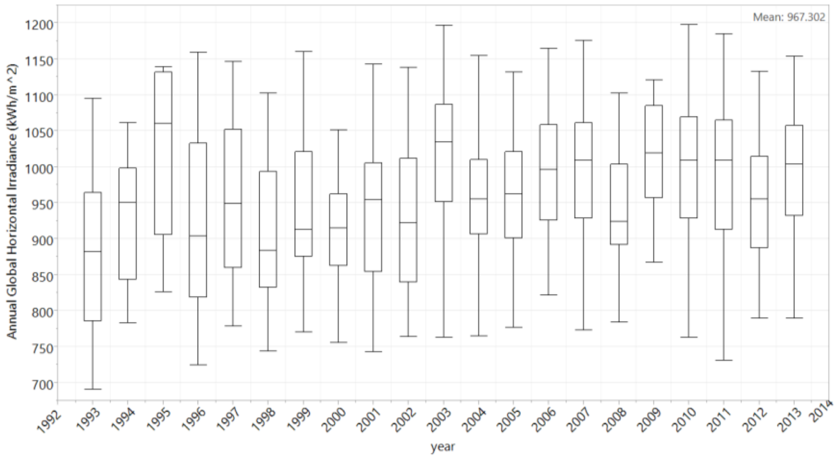

Figure 4; Boxplots showing variability of annual global horizontal irradiance according to the met office's ground based pyranometers (MIDAS). Annual variability (individual boxplots) is caused by the geospatial distribution of MIDAS stations whilst inter-annual variation is caused by phenomena such as solar cycles and the North Atlantic oscillation.

In Figure 4 we see that the mean annual irradiance shifts by up to 8% from the 20 year mean of 959 $kWh/m^2/yr$, with a standard deviation of 39 $kWh/m^2/yr$ (4.1%). For comparison, the mean annual irradiance for 2013 is 997 $kWh/m^2/yr$, revealing that 2013 saw higher than usual irradiance levels. When considering years other than 2013, this systematic error can be corrected by scaling the 2013 mean annual yield according to the ratio of the 2013 mean annual irradiance and the 20 year mean annual irradiance i.e. a scaling factor of 0.96. An uncertainty of 4.1% should then be factored into the total uncertainty to account for inter-annual variability in irradiance. The scaled annual yield and associated uncertainty for each region are shown in Figure 3.

Summary

This report has demonstrated the use of measured PV generation data in calculating the annual yield estimate for a typical PV system in regions across the UK along with a corresponding uncertainty. Regions with the highest confidence are those with the greatest number of systems in the MgDB ensemble. The estimated annual yield in any given year in the Midlands (region 6) for a typical[‡] PV system is 870 ± 36[§] $kWh/kWp/yr$. Similarly, the estimated annual yield for the East Pennines (region 11) is 832 ± 41 $kWh/kWp/yr$ and for South West England (region 4) is 941 ± 40 $kWh/kWp/yr$.

References

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‡ Uncertainty due to geographic skew is ignored when considering a "typical" system.
§ Uncertainties are propagated in quadrature since the two sources are independent of one another.

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Appendix

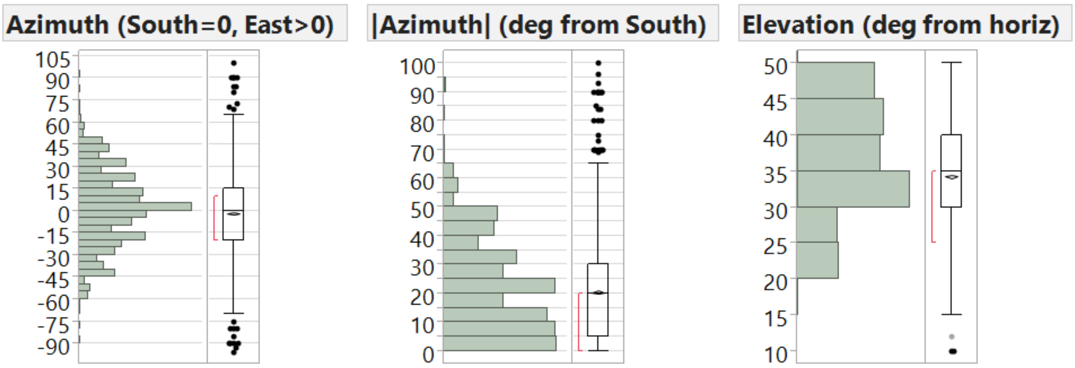

Figure 5; Distribution of system parameters for the MgDB systems used. The mean |Azimuth| is 20.5° and the mean elevation is 34.3°. The mean system size for the sample is 2.48 kWp, with a maximum size of 69 kWp, although the vast majority (99.4%) are under 4 kWp (i.e. “domestic” systems). Of the 4139 systems, according to the Photon Database [3], 4031 (97.4%) use mono-crystalline or multi-crystalline silicon cells, 42 (1.0%) use HIT (Heterojunction with Intrinsic Thin layer) cells, 38 (0.9%) use poly-crystalline silicon cells and the remaining 28 (0.7%) are unknown.

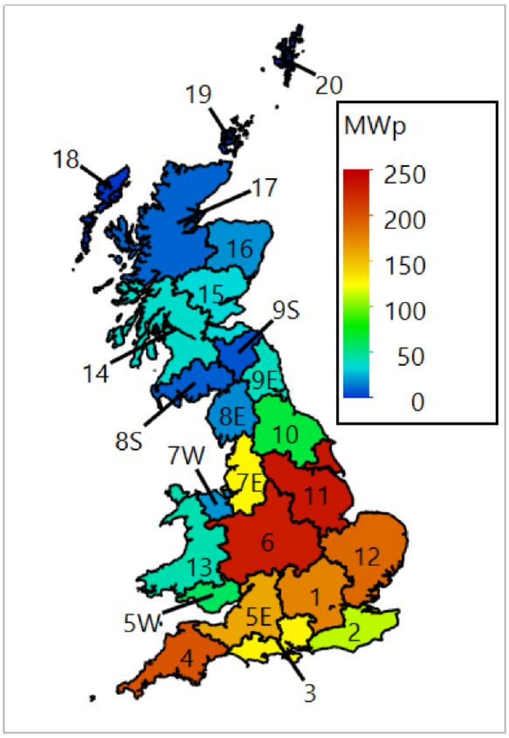

Figure 6; SAP2012 Region Coloured by Installed Capacity of Sub 5 MWp PV as of 1st Jan 2014

Region	Mean Elevation (deg from horiz)	Mean |Azimuth| (deg from South)	Representative Lat (°N)	Representative Long (°)
3	33	20	50.9	-1.8
5E	34	21	51.5	-2.2
4	31	19	50.5	-4
5W	36	23	51.5	-3.4
13	34	17	52.6	-3.6
1	32	17	51.6	-0.8
12	34	18	52.1	0.8
2	33	32	51.1	0.5
6	36	19	52.6	-1.8
9E	30	19	55.2	-2
10	34	14	54.4	-1.4
11	41	26	53.5	-0.5
7E	34	30	53.5	-2.4
14	30	27	55.9	-4.5
15	39	13	56.2	-3.5
9S	39	41	55.2	-2.8

Figure 7; Table of parameters used in the MCS (1) and PVGIS-CMSAF (2) predictions of Figure 3. Representative latitudes for each region are taken from SAP2012 [2] whilst representative longitudes are the approximate longitudes of the centre of each region. The PVGIS prediction is slightly sensitive to whether the azimuth is East or West of South, so we take the mean absolute azimuth (deg from south) and calculate the prediction for both +|Azimuth| and -|Azimuth| and then take the mean of these predictions.

Acknowledgements

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