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Output of solar panels pointing to the south depending on the slope and the month

This is a translation into English of my Dutch note: “Opbrengst van zonnepanelen op het zuiden afhankelijk van de dakhoek (slope) en de maand”.

At 11-3-2024 I have written the Dutch note: “Opbrengst van zonnepanelen in december afhankelijk van de dakhoek (slope) en de stand t.o.v. het zuiden (azimuth)”. At 20-3-2024 I have written the Dutch note: “Opbrengst van zonnepanelen in juni afhankelijk van de dakhoek (slope) en de stand t.o.v. het zuiden (azimuth)”. The figures given in both notes can also be read by someone who doesn’t understand Dutch. It seems to be worthwhile to find out how high the output would be for the other months but to make things not too complicated, now only solar panels are taken into account which are pointing exactly to the south and so for which the azimuth is 0°. The calculations are executed by means of the website of PVGIS Europe which has as link:
https://joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis_en

At this website, you first click at the block “Photovoltaic performance”. At the left side of the page which you get after clicking, there is a map. You have to click at your country in this map and I clicked at Netherlands. If you don’t click at the map, nothing is working! You can fill in how much kW peak power is totally installed. You can also fill in the slope and the azimuth. After doing this you can click on the block “Visualize results” which gives you a bar chart with the output for every month. If you put the cursor at the bar, you get the output in kWh.

Assume that we chose the number of solar panels such that the peak power is 10 kW. This requires about 24 panels with a width of 1.1 m, a height of 1.75 m and 430 kW peak. Advantages of the choice of 10 kW peak are that it is easy to derive the values for another peak power and that only a small mistake is made if the values are rounded to one kWh.

The output is given per month but not all months have the same length and this gives a distorted image. Therefore it was determined how many hours there are in every month. For February it is assumed that it has 28 days = 672 hours because in this case, the total number of hours in a month is divisible by 12. Then an average month has 730 hours. If the monthly output in kWh is divided by the number of hours in that month, you get the average power in kW. If this value is multiplied by 1000, you get the average power in W. The output rounded to 1 kWh and the power rounded to 1 W are given in table 1.

		Slope 15°		Slope 30°		Slope 45°		Slope 60°		Slope 75°		Slope 90°	
Month	Hours	kWh	W	kWh	W	kWh	W	kWh	W	kWh	W	kWh	W
January	744	262	352	338	454	391	526	419	563	422	567	401	539
February	672	420	622	501	742	551	816	570	844	558	827	513	760
March	744	808	1086	894	1202	933	1254	922	1239	863	1160	755	1015
April	720	1147	1593	1195	1660	1184	1644	1114	1547	987	1371	804	1117
May	744	1297	1743	1290	1734	1229	1652	1109	1491	933	1254	715	961
June	720	1326	1842	1293	1796	1211	1682	1072	1489	881	1224	656	911
July	744	1282	1723	1260	1694	1187	1595	1060	1425	881	1184	665	894
August	744	1138	1530	1159	1558	1126	1513	1040	1398	902	1212	715	961
September	720	911	1265	985	1368	1009	1401	980	1361	899	1249	768	1067
October	744	591	794	687	923	743	999	758	1019	731	983	663	891
November	720	323	449	408	567	466	647	495	688	496	689	468	650
December	744	210	282	276	371	323	434	350	470	356	478	340	457
total	8760	9715	13281	10286	14069	10353	14163	9889	13534	8909	12198	7463	10223

Table 1 Output per month depending on the slope for 10 kW peak and azimuth = 0°

Table 1 shows that the yearly output is largest for a slope of 45° (10353 kWh) but for a slope of 30° it is only slightly lower (10286 kWh). The yearly output for a slope of 60° is again somewhat lower (9889 kWh). A larger slope than 60° or a smaller slope than 30° isn’t advisable if only the yearly output is important. This is the case if balancing is allowed. But if the price which is received in summer for a supplied kWh is much lower than the price which has to be paid in winter for an obtained kWh, a large slope is just more favourable.

For each slope, it now can be determined what percentage the monthly output is of the total yearly output. However, this gives a distorted image because not all months have the same length. If the powers in W are summarised and if the monthly power in W is compared to this summarised power, the distortion is cancelled. So this gives the percentage if all months have the same length. The result of this procedure is given in table 2.

		Slope 15°		Slope 30°		Slope 45°		Slope 60°		Slope 75°		Slope 90°	
Month	Hours	W	%	W	%	W	%	W	%	W	%	W	%
January	730	352	2.65	454	3.23	526	3.71	563	4.16	567	4.65	539	5.27
February	730	622	4.68	742	5.27	816	5.76	844	6.24	827	6.78	760	7.43
March	730	1086	8.18	1202	8.54	1254	8.85	1239	9.15	1160	9.51	1015	9.93
April	730	1593	11.99	1660	11.80	1644	11.61	1547	11.43	1371	11.24	1117	10.93
May	730	1743	13.12	1734	12.32	1652	11.66	1491	11.02	1254	10.28	961	9.40
June	730	1842	13.87	1796	12.77	1682	11.88	1489	11.00	1224	9.21	911	8.91
July	730	1723	12.97	1694	12.04	1595	11.26	1425	10.53	1184	9.71	894	8.74
August	730	1530	11.52	1558	11.07	1513	10.68	1398	10.33	1212	9.94	961	9.40
September	730	1265	9.52	1368	9.72	1401	9.89	1361	10.06	1249	10.24	1067	10.44
October	730	794	5.98	923	6.56	999	7.05	1019	7.53	983	8.06	891	8.72
November	730	449	3.38	567	4.03	647	4.57	688	5.08	689	5.65	650	6.36
December	730	282	2.12	371	2.64	434	3.06	470	3.47	478	3.92	457	4.47
total	8760	13281	100	14069	100	14163	100	13534	100	12198	100	10223	100

Table 2 Percentage of the yearly output as a function of the slope for months of 730 hours

December is the most difficult month because the output is smallest in that month. The supplied power in December is highest for a slope of 75° (478 W) but also rather high for a slope of 60° (470 W) and for a slope of 90° (457 W|). So for a slope of 75°, it is only 478 – 470 = 8 W higher than for a slope of 75°. At large slopes, the power is highest in April. It is 1371 W for a slope of 75° and 1547 W for a slope of 60°. So a slope of 75° instead of 60° gives a reduction of the power in April of 1547 – 1371 = 176 W. This shows that it isn't necessary to chose for a larger slope than 60°.

In table 2 it can be seen that for a slope of 90°, 4.47 % of the yearly output is supplied in December. For a slope of 75°, 3.92 % of the yearly output is supplied in December. For a slope of 60°, 3.47 % of the yearly output is supplied in December. For a slope of 15°, only 2.12 % of the yearly output is supplied in December.

At a slope of 15°, the maximum power is 1842 W (in June) and the minimum power is 282 W (in December). So in December only a factor 282 / 1842 = 0.153 of the maximum power is supplied which gives a strong grid imbalance.

At a slope of 60°, the maximum power is 1547 W (in April) and the minimum power is 470 W (in December). So in December only a factor 470 / 1547 = 0.304 of the maximum power is supplied and so the grid imbalance is much smaller.

At a slope of 75°, the maximum power is 1371 W (in April) and the minimum power is 478 W (in December). So in December only a factor 478 / 1371 = 0.349 of the maximum power is supplied and so the grid imbalance is even smaller than for a slope of 60°.

At a slope of 90°, the maximum power is 1117 W (in April) and the minimum power is 457 W (in December). So in December only a factor 457 / 1117 = 0.409 of the maximum power is supplied and so the grid imbalance is even smaller than for a slope of 75°.

To be able to show the supplied powers out of table 1 or 2 in a graph, the total number of hours in a year is put on the x-axis. It is assumed that every month has 8760 / 12 = 730 hours. The powers as found in table 1 and 2 are gives half way the month and so for January after 730 / 2 = 365 hours. For February after 365 + 730 = 1095 hours. For March after 1095 + 730 = 1825 hours, and so on. The powers as found in table 1 and 2 are given in figure 1 as a function of the number of hours as passed from 1 January, 0 hour.

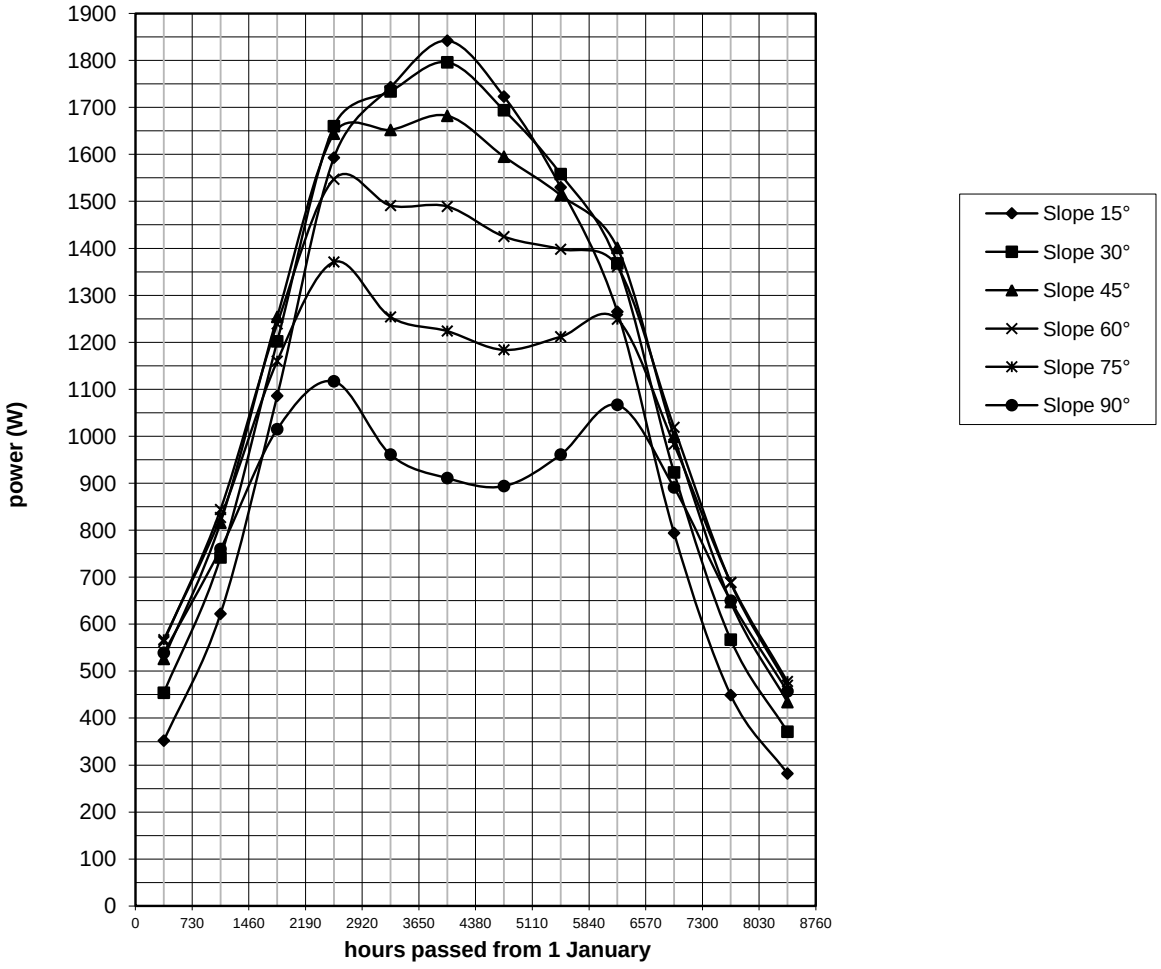

Figure 1 Generated average power at 10 kW peak as a function of the slope and the number of hours passed from 1 January for an equal length of the months and 0° azimuth

For a month of 730 hours, January is from 0 up to 730 hours. February is from 730 up to 1460 hours. March is from 1460 up to 2190 hours, and so on.

In figure 1 it can be seen that for large slopes, there is a dip in the curves. The dip is largest for a slope of 90°. For small slopes, the power is highest during the summer months. The dip at large slopes is because in summer the maximum sun height is very large. The area of the solar panel projected perpendicular to the solar beams is then considerably smaller than the real area.

A slope of 60° give 470 W in December. A slope of 30° gives 371 W in December. So a slope of 60° gives in December a factor 470 / 371 = 1.267 more than a slope of 30°. A slope of 60° gives 1491 W in May. A slope of 30° gives 1724 W in May. So a slope of 60° gives in May a factor 1491 / 1734 = 0.860 less than a slope of 30°. The absolute difference in December is 470 – 371 = 99 W. The absolute difference in May is 1734 – 1491 = 243 W. So the advantage of a small slope in May is larger than the advantage of a large slope in December.

If the yearly outputs as given in table 1 are compared it can be seen that the output for a slope of 60° is 9889 kWh and that the output for a slope of 30° is 10286 kWh. So the difference is 10286 - 9889 = 397 kWh. As long as balancing is allowed, a small slope can be defended. But if balancing is ended, supplied energy in winter has a much higher value than supplied energy in summer. A large slope is then important to get a high efficiency of the investment costs.

Balancing is a special Dutch phenomenon for which the owner of solar panels receives the same amount of money for a kWh supplied during the summer months as what he must pay for an obtained kWh during the winter months. It is unfair because his profit is paid by those who have no solar panels. The balancing arrangement will probably be ended in 2027.