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# Comparison of solar radiation in Marsaxlokk, Malta and Valladolid, Spain

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ABSTRACT

This paper aims at providing scientific evidence of the existence of a high potential of solar energy, not only for the application of flat photovoltaic installations, but also for tracking systems that use concentration, which promise to contribute towards lowering the cost of photovoltaics to the €1/Wp value. It reports results of solar radiation data gathered in Malta (latitude 36°), which represents a central Mediterranean location and compare it to the Region of Valladolid (latitude 42°), within continental Spain to the west of the Mediterranean region. The availability of direct normal radiation is quite good for both sites and could support the building of concentrated systems in the region. A 5-year cumulative annual global solar radiation on a horizontal surface was found to be 1693 and 1841 kWh/m$^2$/day for Valladolid (Spain) and Marsaxlokk (Malta), respectively. Studies showed that Marsaxlokk had a greater normal direct solar potential than Valladolid, but with lower annual variance. Daily analyses showed that Marsaxlokk had more sunny days, similar frequency of partly cloudy days and much lower overcast days than Valladolid. Seasonal analysis showed that Valladolid had less sunshine in autumn and winter but similar availability as Marsaxlokk in spring and summer. A number of correlations between the Clearness Index and the Diffuse Fraction were also made. Such correlations are very useful in estimating past missing data and forecasting future solar availability.



## 1. Introduction

Villalba de los Alcores is a small village located in the region of Valladolid (Spain), which forms a plateau in central Spain (coordinates of 41.8° N, 4.9° W). Marsaxlokk is a port located in the south-east tip of Malta, which is an island in the middle of the Mediterranean Sea (coordinates 35.8° N, 14.5° E). The monitoring station at Villalba de los Alcores forms part of the Lower Atmospheric Research Centre (Centro de Investigación de la Baja Atmósfera, C.I.B.A.), which was created by a joint effort of the National Meteorological Institute (Instituto Nacional de Meteorología, I.N.M.) and the University of Valladolid. The instruments are placed on a metallic platform in the middle of a field that has no obstacles around. The data measuring instruments at the Institute for Sustainable Energy of the University of Malta in Marsaxlokk are situated on the Institute's roof and enjoy a full view of the Sun's path up to as low as 5° above the horizontal.

## 2. Methodology and data analysis

### 2.1. Data collection

For Valladolid, the instruments used were Kipp & Zonen CM11 pyranometers and an Eppley SBS (shadow band stand), while in Marsaxlokk, the instruments were Kipp & Zonen CM21 and CM121 shadow ring. Essentially, both thermopile sensors CM11 and CM21 have the same characteristics, although the CM21 is slightly better with respect to response time to changes in solar radiation and has lower non-linearity per year. The data collected from the pyranometers was stored by means of micro-loggers. In Valladolid, a Campbell Scientific CR23X is used, while in Marsaxlokk, a 21X logger of the same make was used. It was noted that the clock time of the Valladolid data-logger was GMT, while in Malta it was set for GMT+1 h, throughout the year. This was taken into consideration to enable correct comparison of the data collected in the two sites.

First, the global solar radiation data was checked for any errors or anomalies. A number of data gaps were found in some years and these were omitted from the analyses. The complete data sets were verified for the years 1999, 2001, 2004, 2005 and 2006 years. This was followed by a check for diffuse radiation and it was noted that there were gaps in the Valladolid data in 2004 and 2005. Hence, no

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analyses for diffuse radiation were made for those two years. The third parameter that would be of interest was the calculation of the normal direct component of solar radiation for both sites.

### 2.2. Annual average solar radiation

Table 1 shows the mean annual cumulative radiation for both sites, including the global horizontal and diffuse horizontal values, as well as the calculated normal direct radiation.

The accumulated average global radiation difference between Marsaxlokk and Valladolid was found to be 148 kWh/m$^2$/year but the accumulated direct radiation difference is much higher in Malta, standing at 250 kWh/m$^2$/year. This implies that Marsaxlokk not only enjoys more sunshine but also has a greater potential for use of tracking and concentrated solar systems, which require direct radiation. This implies that the percentage of diffuse radiation has to be more in Valladolid than in Marsaxlokk, because it is the complementary part of the direct radiation. This was calculated and found to be 34.3 percent for Valladolid and 29.7 percent for Marsaxlokk.

Some comparisons between the two regions would explain the differences attained. The geographical locations previously detailed and the rainfall patterns [1] are also important to notice, in order to analyze the variations of solar radiation. In Valladolid, there is between 30 and 50 mm of rainfall for each month between September and June. The month with most rainfall is November. Moreover, winter is characterized by frequent days of fog. On the other hand, unlike Valladolid, Malta has more rainfall concentrated in fewer months and averages about 90 mm/month. Rain is rather scarce in spring and is almost zero in summer. This shows that Malta has overall higher number of clear days throughout the year and with higher solar intensity.

Further information based on data gathered at the two airports of Valladolid and Malta (Table 2), showed that for Malta more rain had fallen and more storms were experienced. This would imply that rain showers are experienced within short time intervals and this explained the fact that more sunny days would be available. Clearly there were more foggy days in Valladolid, which is a characteristic of the place in winter. There are some snowy days in Valladolid but Malta has virtually no snow. Fog and snowing affected solar radiation as they contributed towards the reduction of direct radiation and the increase of the diffuse radiation component.

With the annual accumulated global radiation values, it is clear that Valladolid had higher variations from one year to another, while Marsaxlokk had much lower variations. It is also clear that the Valladolid data had an increasing tendency over the past years. The difference between 1999 and 2006 was 110 kWh/m$^2$/year and it was even higher between 1999 and 2005, 159 kWh/m$^2$/year. This increasing tendency did not happen in Marsaxlokk, which had three out of five years, very close to the average and the largest difference in 2001 amounted only to 41 kWh/m$^2$/year. The difference between the minimum and maximum years amounted to 72 kWh/m$^2$/year, which is half of that in Valladolid.

This implied that in designing solar systems, one would have to cater for the greater variations of solar radiation in Valladolid than in Marsaxlokk, which could require that solar systems would need to be oversized in Valladolid to cater for these variations, otherwise they would be expected to produce a markedly different output from one year to another, when compared to Marsaxlokk. Such variations could be important when it comes to providing guarantees of minimum energy output from solar systems by installers to their customers.

The accumulated direct radiation showed a similar trend to that of global radiation. Since there were 2 missing years for Valladolid, it would be difficult to come to any conclusions, but it seems to have an increasing tendency. For Marsaxlokk, it was clear that there was a cycle around the average.

In the accumulated diffuse radiation, the variations were the same for both sites, although the missing data for Valladolid did not allow us to have concrete conclusions. For Valladolid the difference between the higher and the lower values was 32 kWh/m$^2$/year and for Marsaxlokk it was 33 kWh/m$^2$/year. Although the absolute values seemed to be equal but when compared as a percentage of the global radiation, it was seen that Valladolid had a higher percentage of diffuse radiation than Marsaxlokk (34.3% as compared to 29.7%).

### 2.3. Global data analysis on a monthly basis

Monthly analysis of the data showed that global radiation was more in Marsaxlokk than in Valladolid (for all the months except June). It can be noticed from Fig. 1 that for winter and late autumn, the global radiation was considerably higher in Marsaxlokk. The direct normal radiation analysis showed that Marsaxlokk had more radiation than Valladolid, except for a few months. In April the difference is not very large but May showed a marked difference. Here, one could attribute this to the increase of pollen in the air in Valladolid, which results in more scattering (higher diffuse radiation) of the solar flux. In October there was a big difference in comparison to Marsaxlokk and this trend continued in November and December. This big difference was due to the fact that rain registered in that month was high, as shown in Table 2 [2].

The diffuse radiation seemed to be similar for the two locations, except for spring. This could again be attributed to pollen, since there is more vegetation in Valladolid than in Malta. One has to note that although the values were the same for the remaining months, the percentage of the diffuse to global radiation for the two

**Table 1**
Accumulated solar radiation (global, diffuse and normal direct) for Valladolid (Vll) and Malta (Mt), to the nearest whole number.

| Year | Accumulated radiation (kWh/m$^2$/year) | | | | | |
|---|---|---|---|---|---|---|
| | Global | | Diffuse | | Direct | |
| | Vll | Mt | Vll | Mt | Vll | Mt |
| 1999 | 1622 | 1829 | 597 | 570 | 1690 | 1967 |
| 2001 | 1616 | 1882 | 565 | 537 | 1709 | 2109 |
| 2004 | 1715 | 1837 | – | 539 | – | 2028 |
| 2005 | 1781 | 1810 | – | 550 | – | 1976 |
| 2006 | 1732 | 1846 | 579 | 538 | 1926 | 2047 |
| Avg. | 1693 | 1841 | 580 | 547 | 1775 | 2025 |

**Table 2**
Number of days with rain (R), snow (S), storm (St) or fog (F) For Valladolid and Malta [2].

| Year | R | S | St | F |
|---|---|---|---|---|
| Valladolid, Villanubla | | | | |
| 1999 | 75 | 7 | 13 | 47 |
| 2001 | 83 | 8 | 11 | 39 |
| 2004 | 74 | 9 | 12 | 56 |
| 2005 | 63 | 9 | 12 | 35 |
| 2006 | 93 | 7 | 20 | 40 |
| Year | R | S | St | F |
| Malta, Luqa | | | | |
| 1999 | 102 | 0 | 29 | 7 |
| 2001 | 96 | 0 | 22 | 9 |
| 2004 | 118 | 0 | 32 | 8 |
| 2005 | 113 | 2 | 24 | 11 |
| 2006 | 124 | 1 | 32 | 9 |