iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** XI **Month of publication:** November 2017

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XI November 2017- Available at www.ijraset.com

Optimal PV Technology Selection Depending On Climatic Conditions

Alejandro Braña López[1], Cristina Cabo Landeira[2], Ángeles López-Agüera[3], Raquel Pernas Leiro[4]
[1, 2, 3, 4] Sustainable Energetic Applications Group, Faculty of Physics, Santiago de Compostable University

Abstract: The performance of a PV system suffers with the working conditions, especially with high radiation levels and temperature. This effect worsens in extreme weather conditions. The selection of the most appropriate PV technology improves the system performance, increases the useful lifetime and has a positive effect of the lifecycle. In this paper, an instrument to select the PV technology with the best performance for a considered location in which a detailed climate analysis is available is performed. The work is based on data collected under real sun conditions on two experimental setups (laboratory and commercial grid connected PV array). The study includes mainly climatic conditions dependences. A rude tendency of the effects associate to the ageing and the lack of maintenance is taken in consideration. The work is extended to the most common PV commercial technologies. As an example of application, the tendency decision table is used to perform a map of the most powerful PV technologies worldwide.
***Keywords**: PV performance, PV technology selection, extreme climatic conditions, radiation, temperature*

I. INTRODUCTION

The use of PV technology as a renewable energy based solution presents an enormous potential worldwide, especially for regions with extreme climatic conditions. The high adaptability legated to its modularity favours the implementation on grid-connected and isolate installations. Its robustness and low maintenance needs to ensure a high performance even in complicated locations. Moreover, the actual decrease on the earlier sharp prices and the improvements on their lifecycle, make the PV technology competitive with the conventional energy sources. In the frame of the actual Sustainable Development Goals (SDGs) [1] implementation, it will help the fulfilment of goal two, devote to offer clean and affordable energy for everyone.

Solar energy is available worldwide. While some regions are characterized for having high radiation levels and limited alternative renewable energy sources (like wind or water), other regions show lower solar energy potential but, unlike other renewable energies, this resource is always present. In these conditions, the solar energy constitutes the most suitable renewable energy source worldwide.

Nevertheless, several PV experiences developed on extreme climatic conditions complain about the low performance of the PV systems, the decrease on their efficiency level, its fast degradation and even unexpected failures. The possible causes of their inefficiency are leaded by the installed PV technology and climatic conditions as radiation level (G) or ambient temperature (T). Manufacturing characteristics and a poor maintenance level will also influence. To ensure a good performance of a PV system, an optimal technology selection is mandatory. An adequate PV technology selection leads to a longer system lifetime, decreasing the number and the importance of failures. As associated advantages, also the raw material reduction, an environmental impact diminution and the improvement on their overall lifecycle are considered as most important issues. As main results, the energetic and economic pay-back will drastically decrease.

Many specific studies have been carried out regarding PV technologies performance under warm and tropical conditions [2][3][4][5]. Unfortunately, most of them were developed under so specific conditions that can only offer local conclusions about PV technologies performance [6][7]. The present paper, is focus in experimentally determine the optimal PV technology performance according to the system's location climatic characteristic [8] for a wide range of radiation levels. The analysis has been performed using data collected in two different experimental setups. On the LACEM [9], a dedicated test was performed on a set of new PV modules under controlled conditions. Radiation and temperature effects were separately studied. An array of commercial grid-connected PV systems performs the second setup, in which the PV modules were several years old. In this case, global performance dependence, including temperature, ageing degradation and the absence of maintenance are evaluated. A set of five different technologies has been tested. All the data samples have been collected in real sun conditions. From the comparison of the obtained results in term of performance, a simple decision table about the most suitable PV technology in terms of climatic conditions is extracted.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XI November 2017- Available at www.ijraset.com

II. EXPERIMENTAL SETUP

Aiming to determine the solar PV panels' performance, two experimental setups have been studied. From the test carried on the laboratory, the behaviour under controlled conditions was extracted. This analysis has been complemented with an exhaustive data acquisition on a commercial grid-connected PV array. All the dataset was collected under real sun conditions. To avoid efficiency losses associated to the diffuse radiation component, only full sunny days are included in the analysis.

Table 1. Photovoltaic panels characteristics of both experimental setups

Setup	PV tilt	PV Panel technology	Brand and model
Laboratory test	Fixed Angle	CIS	Wurth Solar (WSK0001)
		m-Si	Isofoton(I-53)
		p-Si	Suntech(STP-280)
		UMG	Ferrosolar(SFS-270)
Grid-connected array	Double Tracker	a-Si	Mitsubishi MA100 (a-Si MI)
		m-Si	Trina (TSM-170) (m-Si TR1)
		p-Si	Suntech (STP270) (p-Si SU2, p-Si SU3)
	Fixed Angle	p-Si	Suntech (STP270) (p-Si SU1)

The most common implemented PV technologies have been compared: Amorphous Silicon (a-Si), Monocrystalline Silicon (m-Si), Polycrystalline Silicon (p-Si), Upgraded Metallurgical Grade Silicon (UMG) [10] and CIS heterojunction. The main characteristics of the tested solar photovoltaic panels are shown in Table 1.

A. Laboratory setup

Figure 1 shows the experimental setup located at the USC-LACEM [9] laboratory (Santiago de Compostela, Spain, coordinates 42.5249; -8.5457)). The data sample has been collected on real sun under strict controlled conditions.

Figure 1. Laboratory setup - Location of the solar PV panels

To avoid effects associated to the diffuse radiation components, only sunny weather days have been considered. Two independent data samples have been collected for each technology, fixing either the irradiance or the temperature. For the measurements, a high-resolution HT IV-400 curve tracer (accuracy better than 1%) has been used.

B. Grid-connected setup

Figure 2 shows a commercial grid-connected experimental setup [11] (Villa, Spain, coordinates 43.3146; -7.6650). The installed power is 100 kWp distributed in 10 independent arrays from different technologies. Eight arrays are instrumented with a double solar tracking, while two are fixed tilted (horizontal tilt). The power for each independent array as well as the global irradiance (80 μA per 1000 W/m2 sensitivity) is measured with a 10-minute frequency. Unfortunately working module temperature is not measured, neither the degradation effects associated to ageing and the lack of maintenance are considered. An 8-year historical data sample has been collected under real sun non-controlled conditions.

Figure1. Experimental setup – Location of the solar PV panels

III.METHODOLOGY

To evaluate the performance of a PV system, the most common used variable is the yield factor, Y_f. The yield factor, as defined in Equation (1) measures the PV system energetic production, E_{DC} (in kWh) normalized to the installed power, $P_{installed}$ (in kW) [12].

$$Y_f(G,T,\beta) = \frac{E_{DC}(G,T,\beta)}{P_{installed}}\left[\frac{kWh}{kWp}\right] \qquad (1)$$

E_{DC}depends on PV module working conditions, in particular, temperature T, radiation level G, and solar panel tilt, β. Equation 2 shows the mathematical dependence forms. The working current I_{DC}, leads the dependence on radiation and angle tilt, while V_{DC} the temperature dependence. STC index corresponds to standard conditions (1000W/m^2, 25^{o}C). In both cases, the observed behaviour are linear and the corresponding slope values (α and β) are characteristic of technology and manufacturer [13].

$$E_{DC}(G,T,\beta) = I_{DC}(G,\beta)V_{DC}(T)$$
$$\text{where}\begin{cases} I_{DC}(G,\beta) = I_{STC}(\beta) - \alpha\,(G - G_{STC}) \\ V_{DC}(T) = V_{STC} - \beta(T - T_{STC}) \end{cases} \qquad (2)$$

The dependence on tilt angle can be corrected by using the reference yield, Yr, (Equation 3) defined as the ratio between H_t, the total irradiation measured in-plane of array (in kWh/m^2), and the radiation at standard conditions, G_{STC} value.

$$Y_r(\beta) = \frac{H_t(\beta)}{G_{STC}}\left[\frac{kWh/m^2}{kW/m^2}\right] \qquad (3)$$

Following the International Electro Technical Commissions Standard IEC 61724 [12], the Performance Ratio, PR, constitutes a global indicator for photovoltaic installations evaluation allowing to assess the reliability and efficiency of a PV array over a specific period [14][15]. The performance ratio is defined as the ratio of the specific yield factor, $Y_{f,}$ and the reference yield, $Y_{r,}$ as show in Equation 4.

$$PR(G,T) = \frac{Y_f\,(G,T,\beta)}{Y_r(\beta)} \qquad (4)$$

In the present study, PR will be used as unbiased indicator, to evaluate the modules technology behaviour with the radiation and temperature. The yield factor will be used for some strategical comparison.

IV.RESULTS

Aiming to compare the photovoltaic technologies performance under different global radiation and temperature conditions, both controlled (hereafter, laboratory setup) and non-controlled (hereafter, grid-connected setup) conditions data will be analysed. From, the laboratory setup, radiation and the temperature effect will be separately evaluated. From the grid-connected setup data, the behaviour under real conditions will be evaluated. In this case, radiation, temperature and time degradation dependence cannot be independently assessed. Finally, from the comparison of obtained results, the optimal PV technology according to the climate conditions can be prioritized across a simple decision table.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XI November 2017- Available at www.ijraset.com

To decrease statistical uncertainties, radiation and temperature range have been divided in four intervals (low, medium, high and very high levels). Moreover, the different technologies will be correspondently noted by a sub-index “lab” or “grid”.

A. Laboratory setup results

Two independent data samples have been collected scanning the characteristic I-V curves of each considered technology. A scanning on radiation (±10 W/m^2 accuracy) with fixed temperature and another scanning on temperature (±2^{o}C accuracy) with fixed radiation level.

Figure 2 shows the I-V curves for the considered CIS (a), m-Si (b), p-Si (c) and UMG (d) photovoltaic panels for a fixed global radiation value. Power production and maximum voltage increase as temperature decreases.

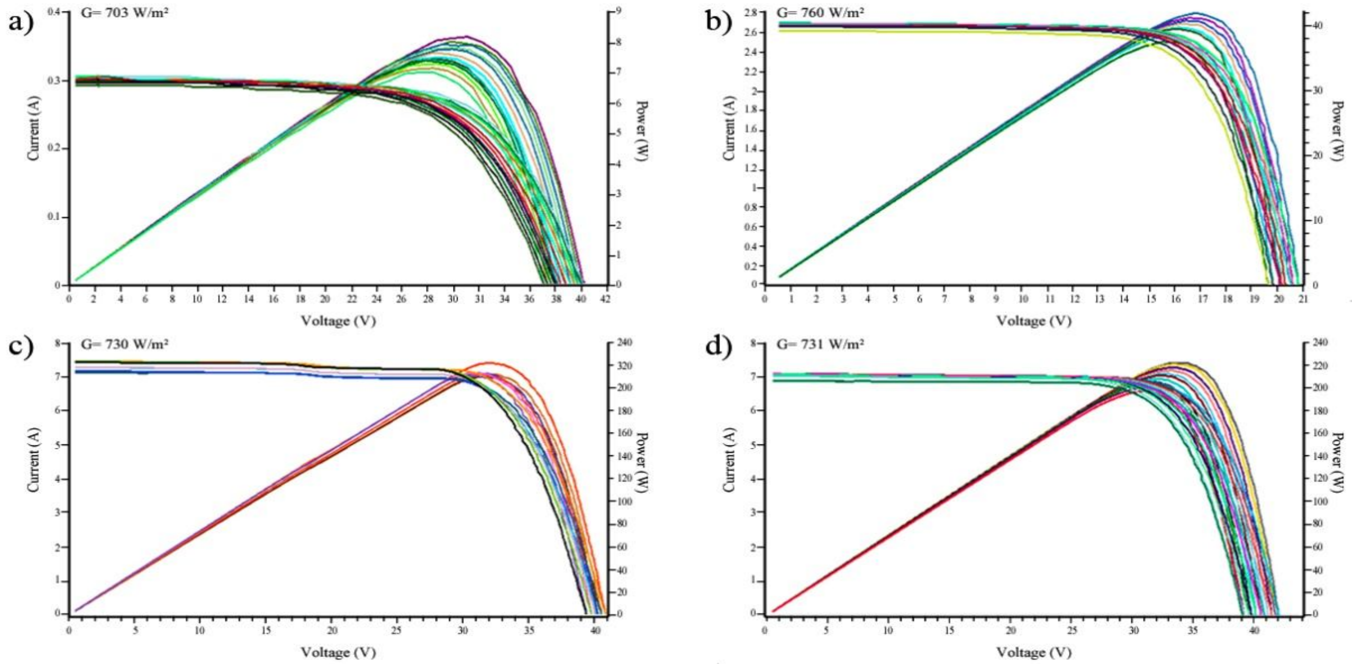

Figure 2.I-V curves for the for fixed global radiation and different panel temperatures for (a) CIS, (b) m-Si, (c) p-Si and (d) UMG PV panels

1) *Radiation dependence:* Figure 4 shows the yield factor fr each panel technology at fixed temperature. As expected (see equation 1), the dependence is mostly linear. Both polycrystalline (p-Si, UMG) technologies show the higher slope while a slightly lower yield factor appears for m-Si and CIS panels. Moreover, CIS technology exhibits a loss of linearity at very low radiation levels.

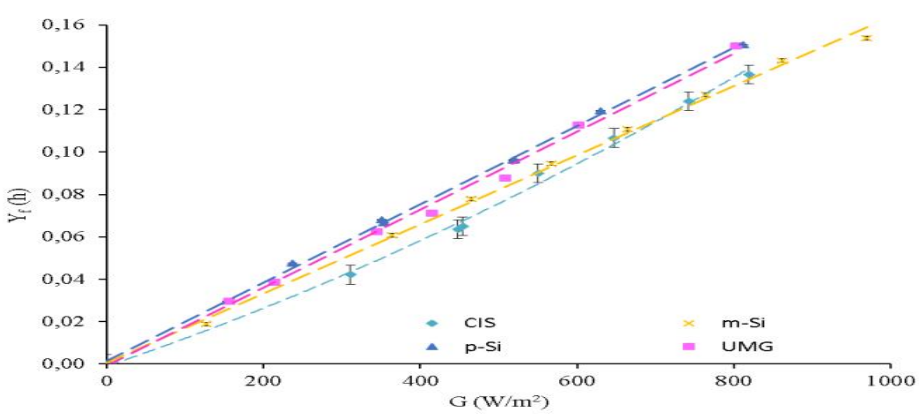

Figure3. Yield factor versus global radiation for different laboratory-tested PV technologies (fixed temperature)

The Performance Ratio, as unbiased estimator, is shown in Figure4, where the <PR> is calculated using a simple fitting procedure for each radiation interval [13]. UMG and m-Si technologies showed the most stable performance along the full radiation range. P-Si shows the best response at low radiation level.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XI November 2017- Available at www.ijraset.com

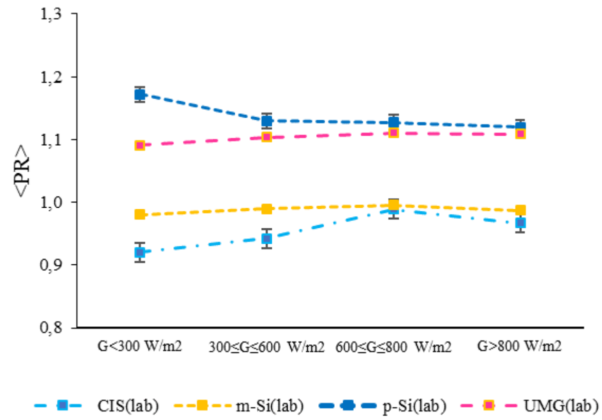

Figure4. Average performance ratio for different radiation intervals under controlled conditions

2) *Temperature dependence:* Figure 5 shows the performance ratio dependence with the working temperature for a fixed radiation value. From a simple linear fitting, the β factor (see Equation 2) is 0.43%/^{o}C for UMG technology and similar for m-Si.

The most stable technology is the p-Si with a β factor of 0.3 %/^{o}C. In these conditions, at climatic zones with high and very high temperatures, the polycrystalline technology looks them most efficient technology.

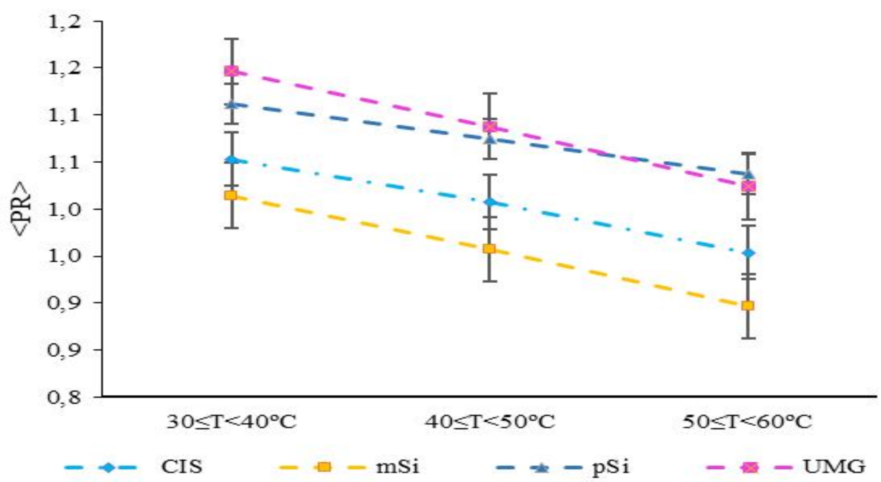

Figure 5.Average performance ratio for different temperature intervals for different laboratory-tested PV technologies (fixed global radiation).

B. *Grid-connected results*

Aiming to assess the previously stated photovoltaic technologies under real outdoor non-controlled conditions, a grid-connected installation is tested as experimental setup. In our case, the experimental setup is mostly a solar tracker system, that is, the PV system optimize it orientation in both azimuth and zenith, collecting the maximum amount of direct radiation component.

The efficiency associated to a tracker hardly depends on the fraction of diffuse component. To avoid systematic effects associated to the diffuse radiation component, only full sunny days has been considered. To simplify the comparison of the obtained results at both laboratory and grid-connected results a simple correction procedure has been performed [15].

As explained below, two arrays present a fixed position (horizontal zenith) for control. Figure 6(a) shows the yield dependence with radiation for both configurations equipped with the same p-Si technology and from the same manufacturer.

Figure 6(b) shows gain associated to the tracker system defined as the ratio between yield factors, Y_f. The estimated uncertainty is lower than 1%. The obtained gain factor will be used as correction factor for the entire grid connected dataset. A more dedicated study for a wide range for diffuse components variations can be found elsewhere [16].

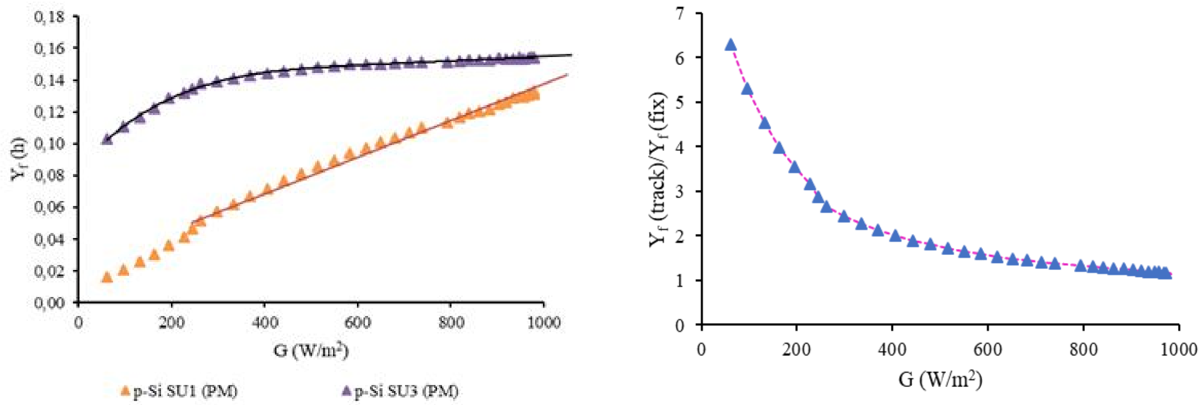

Figure 6.Grid connected yield factor (a) for same-technology, same manufacturer solar PV panels with (p-Si SU3) and without (p-Si SU1) tracking

(b) Ratio between tracking and no tracking yield factors

1) *Radiation dependence:* Figure7 shows the corrected average performance ratio for each technology under study. It can be seen the better performance of p-Si for any considered global radiation interval. The a-Si goes from a 36% less PR than p-Si for low radiations to a 14% less for high global radiations. Meanwhile, m-Si goes from a 14% for low radiation levels to a 8% less PR for high radiation than p-Si.

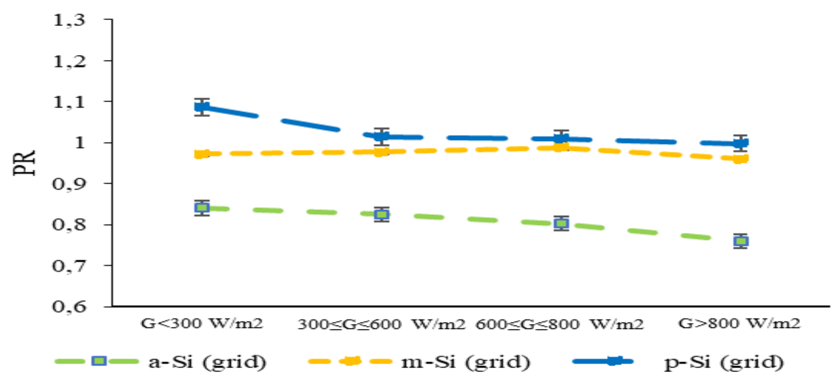

Figure7.Corrected PR mean values for different technologies (a-Si, m-Si and p-Si)

2) *Temperature dependence:* As mentioned above, at the grid-connected setup there is not direct measurement of temperature. However, a rude evaluation of how the a-Si panel suffers the temperature effect can be extract by comparison with m-Si and p-Si, exist in both setup.

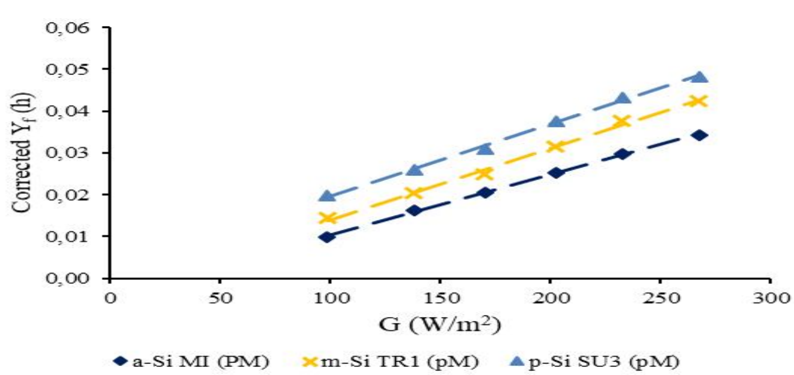

Figure8**.** Yield factor versus global radiations under 300 W/m^2 for the considered PV technologies during the sunset

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XI November 2017- Available at www.ijraset.com

Figure8 shows the yield factor increase with global radiation values under 300 W/m^2 during sunset period. The low radiation range selected avoids possible saturation effects. As sunset ensures high working panels temperature, thermal effects can be neglected. After this plot, it can be seen the quite similar behaviour of m-Si and p-Si when considering this low radiation interval, with slightly better results for m-Si. The a-Si shows lower yield than the other considered technologies. As in the analysis carried on controlled conditions at the laboratory, p-Si shows the best behaviour. Moreover, a-Si and m-Si shows a similar performance.

C. Laboratory and grid-connected results comparison

The final aim of the present work is evaluated the most common commercial PV technologies from both experimental setups. To avoid systematic effects correlated to the different setups, an unbiased variation of the PR, is calculated in the Equation 5.

$$\sigma(\mathrm{PR(i)}) = \frac{\mathrm{PR(i)} - < PR >}{< PR >} .100\ (\%) \qquad (5)$$

where PR(i) is the performance ratio in the radiation interval *i* for a given technology and <PR> the mean value of the PR along the full radiation range for a given technology.

Figure 9 shows the PR deviation at the different radiation intervals for m-Si and p-Si, technologies tested on both experimental setups. The main remark is how the behaviour is compatible in both experimental setups and for each selected radiation interval. The p-Si increases its performance at low radiation regime being rather stable along the complete radiation spectrum. The m-Si is more efficient for medium and high radiation levels.

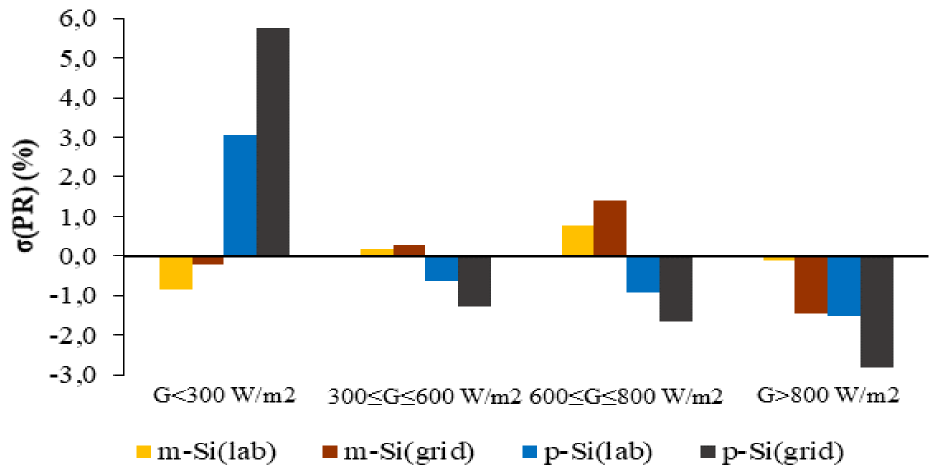

Figure 9. PR deviation (in %) from average PR value for m-Si and p-Si technology

The comparison of the results obtained in both setups, allows to extract the effect associated to ageing degradation and poor maintenance. In both cases, increases of the instability is observed, increasing the performance at high radiation levels.

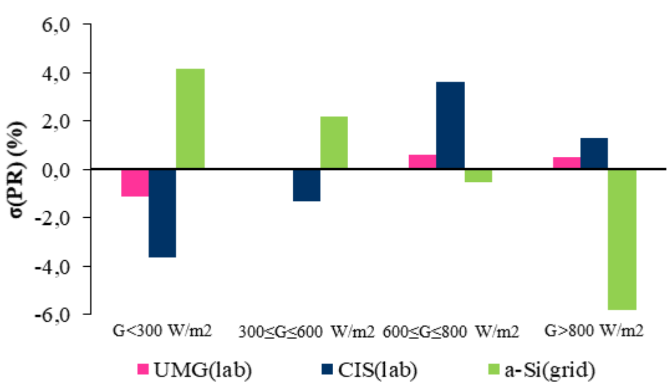

Figure 10.PR deviation (in %) from average PR value for UMG, CIS and a-Si technologies

Figure 10 shows the deviation from the mean PR value of the technologies tested in a single experimental setup. The thin-film technologies (a-Si and CIS respectively) present the more instable behaviour, being the a-Si the most affected technology at very high radiation range. The CIS, shows better performance for high radiation, being less efficient at low radiation levels. Finally, the UMG appears as the most stable candidate, with rather good performance at the full radiation range.

D. Optimal technology selection

The results obtained show how the leading performance comparison parameter between the different PV technologies is the radiation level. In terms of temperature, the behaviour is similar for most of the technologies under study, being the p-Si the most stable along the entire temperature studied range. Other parameters as the budget or technology availability in the location's region, are not taken into consideration in this study.

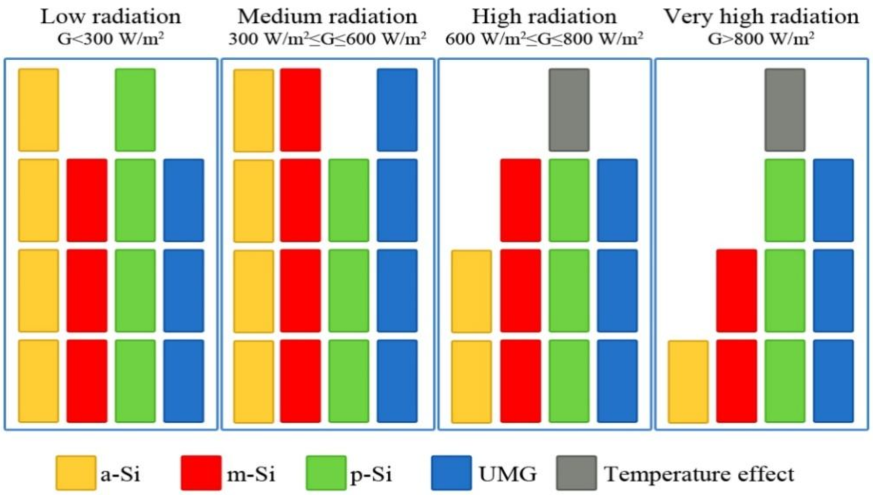

Figure11.Photovoltaic Silicon-based technology selection according to global radiation and temperature

Considering only the information obtained, will be rather ambitious to perform an exhaustive guide of the most efficient photovoltaic panels technology selection for any locations worldwide. Even so, some general indications, concerning the most adequate PV technology can be extracted. Figure11 shows a tendency decision table proposed after the radiation intervals studied in this work. The level of appropriateness is defined from 1 to 4 (from less to high). Because of the good performance of the p-Si technology with the temperature, a suitability point is added to this technology at high and very high intervals.

This tendency decision table constitutes a good instrument to select the PV technology with the best performance for a considered location in which a detailed climate analysis is available. As example, Figure 12 shows a general PV selection based on the Köppen climatic classification [17]. A more accurate analysis including local microclimate could provide a powerful tool for PV system implementation.

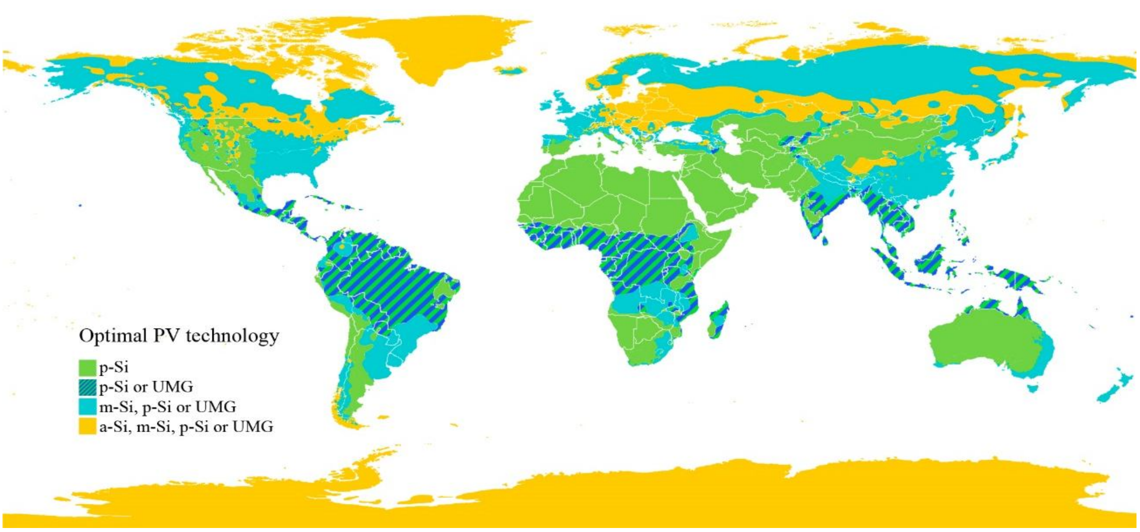

Figure 12.Optimal photovoltaic technology worldwide attending to the Köppen climatic classification

V. CONCLUSIONS

In this paper, commercially available photovoltaic technologies performance for different intervals of global radiation and temperature is assessed.

For this purpose, two real sun outdoor setups were considered: a controlled conditions setup (where global radiation and temperature were separately assessed) and a grid-connected setup (where global radiation and temperature dependence cannot be separately analyzed). The considered PV technologies were CIS, m-Si, p-Si and UMG for the controlled setup and a-Si, m-Si and p-Si for the grid-connected setup.

Results from both setups are compatible, showing an equal to better performance for the polycrystalline photovoltaic technology under all the considered global radiation and temperature values. When considering the high radiation and medium to high temperatures, polycrystalline and upgraded metallurgical grade polycrystalline photovoltaic panels show similar performance. These results in terms of most suitable photovoltaic technologies were used to create a PV world technology map.

VI. ACKNOWLEDGMENT

The authors would like to thank Nor Vento S.A. Company for their support and data sharing. Also, the authors would like to thank to Ferro solar S.L. Company for the material support.

REFERENCES

[1] "Sustainable Development Goals - 17 goals to transform our world." United Nations, 2015.
[2] J. Y. Ye, T. Reindl, A. G. Aberle, and T. M. Walsh, "Performance degradation of various PV module technologies in tropical Singapore," IEEE J. Photovoltaics, vol. 4, no. 5, pp. 1288–1294, 2014.
[3] V. Sharma, A. Kumar, O. S. Sastry, and S. S. Chandel, "Performance assessment of different solar photovoltaic technologies under similar outdoor conditions," Energy, vol. 58, pp. 511–518, 2013.
[4] M. E. Başoılu, A. Kazdaloılu, T. Erfidan, M. Z. Bilgin, and B. Cąkir, "Performance analyzes of different photovoltaic module technologies under ̄zmit, Kocaeli climatic conditions," Renewable and Sustainable Energy Reviews, vol. 52. pp. 357–365, 2015.
[5] E. Elibol, Ö. T. Özmen, N. Tutkun, and O. Köysal, "Outdoor performance analysis of different PV panel types," Renew. Sustain. Energy Rev., vol. 67, pp. 651–661, 2017.
[6] S. R. Williams, T. R. Betts, P. Vorasayan, R. Gottschalg, and D. G. Infield, "Actual PV module performance including spectral losses in the UK," Photovolt. Spec. Conf., pp. 4–7, 2005.
[7] G. Makrides, B. Zinsser, M. Norton, G. E. Georghiou, M. Schubert, and J. H. Werner, "Potential of photovoltaic systems in countries with high solar irradiation," Renew. Sustain. Energy Rev., vol. 14, no. 2, pp. 754–762, 2010.
[8] M. Kottek, J. Grieser, C. Beck, B. Rudolf, and F. Rubel, "World map of the Köppen-Geiger climate classification updated," Meteorol. Zeitschrift, vol. 15, no. 3, pp. 259–263, 2006.
[9] "USC - LACEM Laboratorio de Caracterización Energética y Meteorológica." [Online]. Available: http://www.usc.es/es/servizos/scalmeteo/index.html. [Accessed: 01-Oct-2016].
[10] D. Sarti and R. Einhaus, "Silicon feedstock for the multi-crystalline photovoltaic industry," Sol. Energy Mater. Sol. Cells, vol. 72, no. 1–4, pp. 27–40, 2002.
[11] "Norvento NED Factory - Google Maps." [Online]. Available: https://www.google.es/maps/place/NORVENTO+nED+FACTORY/@43.3138257,-7.664484,617m/data=!3m1!1e3!4m5!3m4!1s0x0:0xabf60b1d78967799!8m2!3d43.3151251!4d-7.6652384?hl=es. [Accessed: 01-Mar-2017].
[12] A. M. Khalid, I. Mitra, W. Warmuth, and V. Schacht, "Performance ratio - Crucial parameter for grid connected PV plants," Renew. Sustain. Energy Rev., vol. 65, pp. 1139–1158, 2016.
[13] A. Braña Lopez, "Placa solar térmica," Trab. Fin Grado. Fac. Física. Univ. Santiago Compost., p. 25, 2015.
[14] SMA Solar Technology AG, "Performance ratio," pp. 1–9, 2015.
[15] D. L. King, J. a. Kratochvil, and W. E. Boyson, "Temperature coefficients for PV modules and arrays: measurement methods, difficulties, and results," Conf. Rec. Twenty Sixth IEEE Photovolt. Spec. Conf. - 1997, no. September, pp. 1183–1186, 1997.
[16] C. Cabo Landeira, A. Lopez Aguera, and A. Braña Lopez, "Performance gain associated to a tracker PV system array dependence with the percentage of diffuse component," 2017.