Assement Solar Database Regarding Production Values in Fuerteventura Photovoltaic Installations

Francisco Javier Diaz Perez1*, D. Chinarro1, A. Guardiola Mouhaffel2, R. Diaz Martin3 and Mª R. Pino Otin1

1Universidad San Jorge, Zaragoza, Spain; fjdiazp@usj.es, dchinarro@usj.es, rpino@usj.es
2Universidad Camilo Jose Cela, Madrid, Spain; guardiolaadib@gmail.com
3Distance university of Madrid (UDIMA), Madrid, Spain; ricardo.diaz.m@udima.es

Abstract

Objectives: To investigate the differences between the 8 main databases irradiation, from the values of equivalent irradiation of 11 generating facilities in operation for the Canaries. Methods/Statistical Analysis: Itobtains the data of the 8 bases of irradiation (DBs) for 0º and pass for 10º of inclination. It compared the average real of all 11 facilities and compared to those of the study DBs, then calculates the equivalent irradiation on flat surfaces at 0º and compared the values of DBs respect to the calculated for the investigated facilities. Calculate the polynomial function for the irradiation curve from the real valour's of the installations Findings: We verified with the data obtained and calculated that the differences between predicted values of the different DBs and the real ones obtained from the facilities can reach monthly differences of more than 30% and annual differences of 10%, the months with the greatest difference being those of winter and autumn. The calculation of equivalent irradiation for inclined surfaces is performed by the simplified system by calculations of the monthly incidence angle, which gives us equivalent global irradiance values with approximate values of +-2% between inclinations of 1 to 55º of the photovoltaic generator. Recommending the use of the data from the UNE 94003: 2007 standard and AEMET data with a difference of less than 1% per year for horizontal surfaces. The PVGIS database is too optimistic in its calculations and its values tend to be with 10% higher yields. The values obtained from differences between databases are comparable with others obtained in their comparisons with data obtained by satellites or in areas such as Poland. Application/Improvements: The article concludes that with the data and the function obtained, realistic forecast can be made quickly and easily for further study.

Keywords: PV, Energy in Canary Islands, nZEB, Irradiation, Photovoltaic, Renewable Energy, Solar Energy

1. Introduction

Photovoltaic solar energy is an energy considered as clean and renewable, recognizing its primary fuel as inexhaustible, which are the energy of the photons emitted by our star the Sun. Among its most important and main features of this energy, it can highlight its Free disposition, gratuitousness and its foreseeable duration of millions of years. In addition, photovoltaic solar installations have the possibility of being modular and increasing the power of the generating plants in a simple way, through an increase of generation surfaces, as well as the possibility of architectural integration in current buildings, which makes it highly recommended for installation (ZEB) or near zero (nZEB)4, there being many examples of its application as integration of photovoltaic solar panels in buildings, Building Integrated Photovoltaics (BIPV)44 and in other types of facilities such as airports5, the main and most important disadvantage is that its production is linked to sunlight, so it can occur during the day, depending on the weather conditions and the incidence of the solar rays of the site where they are installed. It is also verified that the surplus is very small compared to the solar energy received on the surface of the solar plaques, which is increasing annually, passing from its beginnings in 1883 with a yield of 1%6, up to the current values of the plates Of modern silicon with yields of 25%7, being the values of generic panels in the market today, between 12% and 16%.
Taking into account Spain’s photovoltaic potential, due to its geographical location, its annual irradiation and the incentives developed by the different Spanish governments to stimulate the installation of photovoltaic plants, together with the rest of renewable energies (RREE)\textsuperscript{8,10}, achieved that installation of grid-connected generating plants, increased potentially between 2006 and 2011\textsuperscript{11}. This continued increase in facilities and the impossibility of sustainability of the incentive system, the different governments were cutting these subsidies to production, beginning in 2010\textsuperscript{12} and ending with the definitive suspension of these subsidies and incentives to production in the year 2012\textsuperscript{14}. This meant a standstill of the new facilities as of that year, as can be check in Figure1 on the evolution of the photovoltaic power plant at the national level, where it can be observed that as of 2012 the installed power remains constant without increasing it. Due to this suspension of the remunerations to renewable, at present the installations with connection to network no longer have a profitability comparable to the years prior to 2012, although, due to its expected duration of the installations of 25 years, it has not stopped being a bad investment, but with a very low profitability, provided that legal certainty is maintained in its regulation\textsuperscript{14}.

The self-consumption and BIPV applications have become an interesting model for their installation\textsuperscript{15} and integration in existing buildings, which together with other RERs can be made mixed generation models\textsuperscript{16-18} to cover the different demands of energy of the buildings, in order to obtain buildings ZEB or nZEB. On the part of the International Energy Agency (IEA), a study on self-consumption through solar photovoltaic energy has been carried out, comparing and informing on the policies of the different countries\textsuperscript{19} regarding viability and legislation on self-consumption. Spain is the fourth country of the European Economic Community (EEC), with the highest average annual irradiation\textsuperscript{20}, which places it in a leading position in order to achieve high yields in photovoltaic solar installations, with any self-consumption facility being much more efficient In Spain than in most countries of the EEC. This generation potential is also applicable to the archipelago of the Canary Islands, an ultra peripheral region of Europe, located between the co-ordinates 27\textdegree 37’ and 29\textdegree 25’ north latitude and 13\textdegree 20’ and 18\textdegree 10’ west longitude, at about 940 Km to the south of the European continent, but whose average annual irradiation is comparable to the south of mainland Spain, as can be seen by its consideration as zone V, according to the zoning made by the technical code of the building (CTE)\textsuperscript{21} in force in Spain.

Canary Islands, the need for generation through RREE, being an area of special importance, both ecologically and in the capacity to implement development models compatible with its conservation, is very important, proof of this is that 63\%\textsuperscript{22} of the archipelago’s surface is declared a Biosphere Reserve by United Nations Educational, Scientific and Cultural Organisation (UNESCO). The canary current energy model has as one of its main needs to be able to achieve an environmentally sustainable system, the amplification of the systems of generation byRREE, being in values of generation by renewable well below peninsular Spain, where this type of generation has gone from a 19.4\% in 2006 to 40.5\% in 2016, while in the Canaries its value has remained almost unchanged, from 6.2\% in 2006 to 8\% in 2016\textsuperscript{11}, as can be observed In Figure 2, of the structure of electric power generation between 2006 and 2016.

This use of the RREE, has managed to reduce the emission coefficient due to electricity production in mainland Spain 40\%, between the period 2006 to2016, being the
reduction for the Canary Islands of only 7%. This causes that the emission factors of the electrical generation are 262% higher in the Canary Islands than in the Peninsula, as can be seen in Figure 3.

![Figure 3](image-url) Evolution emission factors Spain peninsular and Canary Islands 2006-2016. Source: REE

Taking into account the importance of continuing with the reduction of CO2 emissions, due to the influence on the climate change that they produce, and the possibility of realizing systems of self-generation by photovoltaic solar panels in areas with high irradiation, such as the Canary Islands. It is necessary to verify that the estimated production data calculated by means of the different existing irradiation DBs corresponds to the actual generation of the planned and running plants, since for the estimation of the production of electric energy by means of PV, the main data needed is the irradiation of the installation area, being in this case an area of the archipelago of the Canaries, which together with the characteristics of the generator itself, will give us the estimated production values for each generating plant. The irradiation data is obtained from the different DBs that are publicly accessible, in most cases, and by means of which an approximate production can be estimated. The different values of the DBs can generate very high estimation differences, as can be verified in the study of irradiation data calculated by satellites or in the web-based comparison for Poland overestimation of the winters and the summers are underestimated.

The comparisons of data will be made for 8DB of free access through the corresponding websites of each of them or through access to public regulations. The DBs are: PVGIS-Helioclim, ADRASE-Ciemat, NASA, AEMET, Soda-pro, ITC-Canarias, IDAE-Censolar and UNE standard 94003:2007, comparing the irradiance data of flat surfaces with the calculated values of irradiation for 11 installations of peak power or maximum installed between 88kW and 552kW, all of them with angle of inclination of the plates of 10°.

2. Experimental

Earth Planet, due to its movement of translation around the sun and the decline of the axis of rotation, produces a difference in the incidence of solar radiation between +23.45° to -23.45°, with respect to the reference latitude. This difference makes it necessary to calculate the decline of the earth each day, in order to estimate the optical angle of the photovoltaic solar panels, in order to achieve the highest irradiation. For the calculations of the angle of decline of the earth relative to the Sun, it use the well-known Cooper equation, which gives the value of the approximate decline of the reference point at solar noon of the day considered

\[ \delta(n) = 23.45 \times \sin \left[ 360 \times \frac{284 + n}{365} \right] \]

Where "n" is chosen day counting from January 1 to the day in question. In this study we will use the average decline for each day 15 of each month (14 in February), to later calculate the optimum slope of the collectors on that date, where it would receive the solar rays in a perpendicular way and be able to take advantage of 100% of the energy. The angle of each day will be given by the formula:

\[ \beta(n) = \theta - \delta(n) \]

Where "\theta" is the latitude of the place, "\delta (n)" is the declination of the earth on the chosen calculation day. It should be noted that the slope or angle of the collectors calculated will be South in the Northern Hemisphere and North in the Southern Hemisphere.

The other adjustable angle of the solar panels is the azimuth, which is the orientation angle of the panels with respect to the north south axis thereof. In our case the facilities are always oriented to the south to 0°, per local will not be taken into account. Since the azimuth is a not very important reduction factor, with annual values that, according to the CTE, the value of approximate losses can be calculated for slope values of panels larger than 15°, by means of the function:

\[ L_{\text{az}} = 1 - (3.5 \times 10^3 \cdot (-5) \cdot \mu^2) \]

Where "\mu" is the azimuth angle to the South.

To take into account that the global irradiation data of the different DBs that are obtained are for flat surfaces, so
it is necessary to calculate the same for inclined surfaces. In order to obtain this new value as accurate as possible, the values of the three components of direct, diffuse and albedo radiation must be found, with several methods for obtaining and estimating them\textsuperscript{29-31}. For our model of approximation, we will use the global irradiance values of the DB for the flat surface and calculate the global irradiance value for the angle of inclination of the panels, according to the latitude of the place, for the 15th day of each month (14 In February), with the calculation function where the multiplying factor of the irradiance value is obtained for flat surfaces, and will give us the approximate result for the inclined surfaces, by means of the following function:

\[
K(n) = \frac{\cos(\theta - \alpha - \delta(n))}{\cos(\theta - \delta(n))}
\]

\[G(\beta) = K(n) \cdot G(0^\circ)\]

Where “\(\theta\)” is the latitude of the place, “\(n\)” is the chosen day counting from January 1 to the day in question, “\(\delta(n)\)” is the declination and of the earth on the chosen calculation day, \(\alpha\) “is the fixed inclination angle of the solar panels e” \(G(0^\circ)\)” “is the irradiance value for flat surfaces at 0°.

The approximation values of this method are sufficient for this study, since as can be verified in Figure 4, the differences between the values calculated by this method described above or by the decomposition of global irradiation in direct, diffuse and albedo that the base performs of European PVGIS-Helioclim data, we obtain a maximum difference for the average annual value of 5% at inclinations of 70°. In our research, with 10° tilt angles, the difference is 1.31% over the annual average, so it will use this approximation method.

**2.1. Calculus Production**

In order to carry out generation calculations using PVs, it is necessary to take into account the incident radiation at each moment, the maximum or peak power of the generator and the total losses, which are included in a total efficiency index known as “Performance ratio” (PR)\textsuperscript{32}. With the following function we calculate the generated energy injected in the network, at each moment:

\[
E_{red} = PR \cdot G(\beta, \mu) \cdot P_{pp}
\]

Where “PR” is the global loss index that encompasses all losses of the system, “\(G(\beta, \mu)\)” is the mean irradiance according to a declination and a given azimuth and “\(P_{pp}\)” is the maximum power of photovoltaic generators

The calculation of the PR is made taking into account all the losses of the generating system, which are given by the function:

\[
PR = (1 - (L_T + L_D + L_R + L_p)) \cdot L_E \cdot L_{in} \cdot L_v
\]

The meaning and calculation of the different terms of the equation are as follows:

Temperature loss of the “LT” module. Due to the operation at a temperature different from the one calculated in standard conditions, it generates losses that we calculate them by the method of Osterward\textsuperscript{32}, that according to the \(T^o\) of the cells we will have losses, that comes given by the function

\[
L_T = 1 - (\gamma \cdot (T_C - 25))
\]


\[T_C = T_a + \left(\frac{G_{in} \cdot (NOCT - 25)}{800}\right)
\]

Where “\(Gin\)” is the instantaneous or average daily radiation in W/m\(^2\), “\(\gamma\)” is the coefficient of variation of the maximum power point with temperature, “\(T_C\)” is the plate temperature, “\(T_a\)” is the ambient temperature And “NOCT”\textsuperscript{34} is the nominal operating temperature of the module for radiation values of 800W/m\(^2\), 20°C ambient temperature, with AM 1.5G spectral distribution and 1 m/s air velocity.

Lost by dispersion of parameters “LD”. The PVs are not exactly the same and have a power difference between them, so these differences create losses in generation.

Dirt of “LP” plates. Losses due to dust on the modules. In Canary Islands due to the episodes of “calima”\textsuperscript{35}, this parameter becomes very important and its value can become very high if the modules are not cleaned regularly.

Lost by angular and spectral reflectance “LR”. Due to the angles of incidence of the solar rays and the selective spectrum of the photocells, whose current generated is different for each wavelength of the solar spectrum of the incident radiation.

Losses due to the efficiency of the “LIn” inverter. The European efficiency value of the inverter\textsuperscript{36} given by the manufacturer, which is calculated by the function

\[
\eta_E = \sum a_{eu} \cdot \eta_{MPP}
\]

Where “\(a_{eu}\)” is the European weighting factor, “\(\eta_{MPP}\)” corresponds to the inverter / follower performance / efficiency value for the maximum power point, “\(\eta_5\)” represents the performance at 5% of the power of the follower, “\(\eta_{10}\)” to 10% and so on, with the different yields expressed for the powers represented by the subscript.
Lost in “LE” electrical wiring. Total losses due to voltage drop from the DC and AC part.

Other “LV” losses. There are several other losses not previously considered.

In order to make a comparison of the efficiency of the systems using a common unit or index, the value of YF, which represents equivalent or peak solar hours (HSP), is a unit that measures solar irradiation and is defined as the time in hours of a hypothetical constant solar irradiance of 1000 W/m² calculated in standard conditions (STC), that in case of knowing the generated energy is given by the expression:

\[ YF = HSP = \frac{E_{red}}{P_{pp}} \]

Where “Ered” is the generated energy injected into the grid, and “Ppp” is the maximum power of photovoltaic generators.

Figure 4. Differences between the value obtained by PVGIS and the approximate used, for the annual average of irradiation.

2.2. Methods

The method used to compare the actual data with those of the study DBs was the following:

1. Initially the data of the irradiation values of the different DBs of their web pages or recognized documents and those of production of the study plants supplied by the managers of the facilities were obtained.

2. We pass the irradiance value from flat surface to inclined surface of all DBs, obtaining the monthly irradiation values at 10° of inclination, as well as their average, maximum and minimum values.

3. We calculate the average “PR” for all the research facilities, for which we took the average radiation values of all the data of the monthly DB, obtaining the value of the PR for each month. As the plates are with similar characteristics we use the standard values for all of them.

4. With the data of monthly irradiation and “PR” we calculate the equivalent HSP of each of the DB. The HSPs of the different facilities are also calculated by monthly production of the same and their maximum power or peak installed, obtaining the monthly data per installation as the averages of the generation of the years per installation.

5. We compare the average real HSP data of all the facilities, compared to those of the study DBs at the 10° angle of the plates. Compare the actual generation data with the different DBs: total annual values and monthly values.

6. We pass the actual HSP generation data to equivalent flat surface values at 0°, using the conversion factor K and compare the values. With this data we calculate the equivalent irradiation on flat surfaces at 0°.

7. We compared the values of annual and monthly irradiance on a flat surface at 0° of DBs with respect to the calculated real equivalent for the investigated facilities.

8. Calculate the polynomial function for the equivalent irradiation curve in Fuerte Ventura using the calculated irradiance data from the real installations.

Figure 5 shows the flow diagram of the research carried out to obtain the actual irradiation data of the installations and their comparison with the data of the different general use DBs.

3. Analysis Data

The data of solar irradiation are fundamentally able to realize any calculation of photovoltaic installations, being able to obtain the same ones of several local or global DBs. In this study eight international comparisons are being made, widely used by designers around the world. Have been chosen for the realization of the investigation are the following:

3.1 PVGIS - Helioclim

- The EEC photovoltaic information system, which through the network of meteorological stations, satellites and by means of data interpolation, performs its irradiation calculations with a GIS positioning system and the model “r.sun” [M]. Widely used by all types of institutions and
designers, with data from Europe, Africa and Asia for any inclination.

3.2 ADRASE - CIEMAT

- Access to solar radiation data from Spain (ADRASE) of the Spanish government’s energy, environmental and technological research centre (CIEMAT), which supplies solar radiation data from Spain with a resolution of 5x5 km, with averages of values from the last 20 years of satellite measurements and 50 ground stations. Calculations are obtained for percentile 25 and 75, as well as maximum and minimum of the different zones. Data are taken from the 75th percentile for the study.

3.3 NASA-SSE

- Meteorological and solar data sponsored by the US National Aeronautics and Space Administration (NASA) in the Surface Meteorology and Solar Energy (SSE) program, which provides data for the whole world, with solar radiation values on a horizontal plane. Covers a resolution of 100x100 km. Average of temporary data of 22 years. It compares the data of the satellites with those of its world stations on land. Widely used globally for comparative irradiation studies.

3.4 AEMET

- Data provided by Spain’s state meteorological agency (AEMET), whose data have been condensed into Spain’s solar radiation atlas, with data averages from 1983 to 2005, using satellite data and of the national radiometric network. Average values data are used. The resolution of data is of 3x3 km and the values of provincial capitals are given. In this case, data from Las Palmas de Gran Canarias are used.

3.5 Soda-pro

- A service created from the Information Society Technologies (IST) program of the European Commission for the year 2000. This service offers time series of monthly, weekly and daily values of global solar irradiation in a horizontal plane, as well as the monthly irradiation received by a plane normal to the solar rays. The geographical coverage corresponds to the field of vision of the Meteosat satellite, ie, it covers Europe, Africa, the Atlantic Ocean and the Middle East. The spatial resolution is approximately 20x20 km. The temporal coverage of the data is from 1985 to 2005.

3.6 ITC-Canarias

- Data from the Canaries of the Canary Islands Technological Institute (ITC) which have been

Figure 5. Research Flow Diagram.
obtained from 51 radiometric stations between 1998 and 2009. A geographic information system with approximate resolution of 250x250m per pixel. The data are for horizontal global irradiation and global horizontal irradiation to sky. The data we use are horizontal global irradiation.

3.7 IDAE - Censolar
- The Institute for Diversification and Energy Saving (IDAE) also makes available the solar radiation tables of the company Censolar, for use in the calculation of solar thermal plates, checking its utility for photovoltaics in this study. Average data on the irradiation of provincial capital of various models of calculation of external radiation and by measuring stations, with adjustments of approximately -10% of the actual values that are not useful for useful generation. It refers to provincial capitals, in this case, the data of Las Palmas de Gran Canarias are used.

3.8 UNE 94003: 2007
- Spanish national standard that provides the reference values of global daily irradiance, daily and monthly temperature on horizontal surface, for calculations of low temperature solar thermal plants, but we will check in this study its usefulness for calculations of photovoltaic generation. It refers to provincial capitals, in this case, the data of Las Palmas de Gran Canarias are used.

In the following Table 1, all the data of average irradiation for horizontal surfaces of the different DBs for the study area, that is the capital of the island of Fuerteventura, Puerto del Rosario, located in the coordinates 28.50º north and 13.86º west. This is the easternmost and closest island to Africa, the archipelago of the Canary Islands (Spain). The data will be compared to verify the maximum, minimum and average values of the different DBs, where it can be seen that the differences between irradiation values are very high, reaching values of about 28% difference. In the annual averages, we find differences of 20%, values which to make estimations are already considerable, for calculations of viability of solar installations and must be taken into account for adjustments of possible projects. The shaded DBs give values of the provincial capital, Las Palmas de Gran Canarias and not Puerto del Rosario, being those that have to be used for the whole province, for which, these values are used for comparison.

The data of temperature and daily in isolation will be used those supplied by AEMET for the station located in the municipality of Puerto del Rosario through several programs of public use of AEMET and obtaining the values that appear in Table 2. It can be observed as the average temperatures of 1980-2010 and 2010-2015 have increased an average of 3% in recent years, due to which we will use the average data of the most updated years

Table 1. Solar irradiation data in kWh/m² month of study DB for horizontal surfaces 0º

| MONTH | PVGIS Helioclim | ADRASE Ciemmat | NASA | AEMET | Soda Pro | ITC Canarias | IDAE Censolar | UNE 94003 | Max | Average | min | % Diff. | Max | min |
|-------|----------------|----------------|------|-------|----------|--------------|--------------|------------|-----|---------|-----|---------|-----|-----|
| JAN.  | 3.980          | 3.500          | 3.700| 3.760 | 3.140    | 3.475        | 3.111        | 3.720      | 3980 | 3548    | 3111| 27.9%   | 3910| 3494|
| FEB.  | 4.810          | 4.700          | 4.630| 4.450 | 4.910    | 4.439        | 3.944        | 4.435      | 4910 | 4540    | 3944| 24.5%   | 4910| 3944|
| MAR.  | 5.910          | 5.900          | 5.860| 5.380 | 6.130    | 5.864        | 4.944        | 5.342      | 6130 | 5666    | 4944| 24.0%   | 6130| 4944|
| APR.  | 6.850          | 6.700          | 6.810| 6.240 | 6.410    | 6.428        | 5.444        | 6.132      | 6850 | 6377    | 5444| 25.8%   | 6850| 5444|
| MAY   | 7.390          | 7.400          | 7.320| 6.670 | 6.960    | 7.202        | 6.027        | 6.618      | 7400 | 6948    | 6027| 22.8%   | 7400| 6027|
| JUN.  | 7.540          | 7.700          | 7.320| 6.570 | 6.620    | 7.407        | 6.250        | 6.742      | 7700 | 7019    | 6250| 23.2%   | 7700| 6250|
| JUL.  | 7.530          | 7.600          | 6.990| 6.570 | 7.530    | 7.357        | 6.750        | 6.747      | 7600 | 7134    | 6570| 15.7%   | 7600| 6570|
| AUG.  | 7.220          | 7.000          | 6.880| 6.380 | 6.980    | 6.899        | 6.083        | 6.354      | 7220 | 6724    | 6083| 18.7%   | 7220| 6083|
| SEP.  | 6.280          | 6.000          | 6.110| 5.730 | 5.850    | 6.024        | 5.500        | 5.680      | 6280 | 5897    | 5500| 14.2%   | 6280| 5500|
| OCT.  | 5.220          | 4.700          | 4.990| 5.220 | 4.870    | 4.716        | 4.194        | 4.766      | 5220 | 4834    | 4194| 24.5%   | 5220| 4194|
| NOV.  | 4.200          | 3.700          | 3.930| 3.840 | 4.440    | 3.637        | 3.416        | 3.914      | 4200 | 3850    | 3416| 23.0%   | 4200| 3416|
| DIC.  | 3.660          | 3.200          | 3.400| 3.470 | 3.260    | 3.182        | 2.972        | 3.462      | 3660 | 3326    | 2972| 23.1%   | 3660| 2972|
| Average| 5.890          | 5.675          | 5.660| 5.357 | 5.580    | 5.553        | 4.889        | 5.326      | 5890 | 5491    | 4889| 20.5%   | 5890| 4889|
for the calculation of temperature losses calculations solar panels. The average monthly sunshine data will also be used by AEMET as they are based on the observation data of the Puerto del Rosario weather station with average historical data from 1980 to 2010. The solar hours of the month of February are referred to 28 days.

Table 2. Temperature and insolation data of Puerto del Rosario, Fuerteventura. Source: AEMET

| Month | Insolation hours/month | Insolation hours/day | Tº Average 1980-2010 | Tº Average 2010-2015 | % Differ Averages |
|-------|------------------------|----------------------|----------------------|----------------------|--------------------|
| JAN.  | 190.00                 | 6.13                 | 17.6                 | 18.4                 | 4.82%              |
| FEB.  | 189.90                 | 6.78                 | 17.9                 | 18.2                 | 1.40%              |
| MAR.  | 233.00                 | 7.52                 | 18.9                 | 19.0                 | 0.33%              |
| APR.  | 242.30                 | 8.08                 | 19.5                 | 20.1                 | 3.18%              |
| MAY.  | 280.20                 | 9.04                 | 20.6                 | 21.1                 | 3.71%              |
| JUN.  | 284.80                 | 9.49                 | 22.5                 | 23.2                 | 3.20%              |
| JUL.  | 293.90                 | 9.48                 | 24.0                 | 24.5                 | 2.07%              |
| AUG.  | 288.80                 | 9.32                 | 24.6                 | 25.5                 | 3.66%              |
| SEP.  | 246.20                 | 8.21                 | 24.4                 | 24.8                 | 1.53%              |
| OCT.  | 227.10                 | 7.33                 | 22.9                 | 24.1                 | 5.15%              |
| NOV.  | 202.60                 | 6.75                 | 20.9                 | 21.5                 | 3.05%              |
| DIC.  | 185.90                 | 6.00                 | 18.9                 | 19.6                 | 3.68%              |
| Average | 2835.50                | 7.77                 | 21.1                 | 21.7                 | 3.08%              |

The characteristics of the island of Fuerteventura, where the installations are located, is extremely arid, with 86.6% of the area classified as arid and the remaining 13.4% is semi-arid. Suspension is usually quite high because of the sand and dry land of Fuerteventura geography. To the dust in its own suspension, we must add that of the Saharan air masses that regularly affect the Canary Islands and the island of Fuerteventura mainly due to its proximity to the Sahara, as well as the insignificant annual rainfall, With a mean of 98 mm annually, less than 0.3 L/m² per year, causes that the losses of the plates by dirt due to the dust, are very high in these installations, if it is not made a correct maintenance and control of cleaning them.

Table 3 shows the main data of the 11 study facilities, where there are installations connected to low voltage and medium voltage, with maximum or peak power values ranging from 88 kW to 552 kW, with nominal power greater than 100 kW connected to power transformers medium voltage. All equipment is located on roofs and flat or sloping roofs of industrial buildings. The models of panels are of silicon polycrystalline with values of variation of the coefficient of temperature of between -0.43% °C to -0.48% °C, with an average value of -0.45% °C, as well as a nominal operating temperature between 45°C and 47°C, with an average of all facilities of 47°C. The efficiency of the panels is between minimum values of 13% and above 14%, with an average efficiency of 13.62%. With all these data can be considered that the different panels are of similar characteristics to each other, so the calculations of losses and PR value, we will perform with the average values of the study facilities. Another very characteristic feature of these facilities is the angle of inclination of the panels of 10°, which is with all these data can be considered that the different panels are of similar characteristics to each other, so the calculations of losses and PR value.
we will perform with the average values of the study facilities due to the need of space saving to be able to install more solar modules in the existing surface, that is to say increase the installed power by unit of surface, but without producing shades that diminish the generation in winter. If we take into account that the minimum distance between rows of panels must ensure that the generated shadow produces 4 hours of sunshine around noon of the winter solstice, we can calculate the minimum distance between contiguous panels by the following function:

\[
h = \frac{L \cdot \sin \alpha}{\tan(61 - \theta)}
\]

Where "L" is the height of the panel, "\( \theta \)" is the latitude of the location and "\( \alpha \)" is the fixed inclination angle of the solar panels.

Taking into account this way of calculating it, will verify that the differences between placing the solar plates at the optimal angle of 28° at this chosen angle of 10° reduces the distance between panels by 65%, which means that the distance is 1.7 times lower with this chosen angle, and instead the energy production of using the optimal angle of inclination 28° would only increase by 4% if we used the chosen inclination of 10°. This motivates that the cases of reduced surfaces in roofs of existing buildings, it is advisable to use small angles of inclination in order to be able to install as many photovoltaic modules in the smallest possible space, which in this case, is the own one of the roof of the ship where the generators are installed, and in this way, increase the installed power per unit area.

Table 4. Loss or efficiency values for calculations.
Source: IDAE and own.

| Name      | Description                              | Value   |
|-----------|------------------------------------------|---------|
| L_\text{T} | Temperature losses                        | Calculate |
| L_\text{D} | Lost by dispersion                       | 2.0%    |
| L_\text{P} | Lost dust and dirt                       | 3.0%    |
| L_\text{R} | Lost reflectance                         | 3.0%    |
| L_\text{E} | European Investor Efficiency              | 95%     |
| L_\text{C} | AC and DC circuit efficiency              | 97%     |
| L_\text{v} | Efficiency due to other losses           | 96%     |

4. Calculus

In order to calculate the losses by estimating the PR, the irradiation is taken from all the irradiation values of the DBs, once adjusted for the 10° inclination angle of the study facilities, and with the daily in isolation data, The radiation values are obtained, with which the temperature loss data can be calculated. The rest of the values of losses and average efficiency used will be those of the following Table 4, where they appear the generic coefficients of calculation. Figure 6 shows the graph of the PR value for the different months, checking the validity of the calculation model, since the differences between the maximum and minimum radiation values only influence + - 1% of the PR average value. We take these average values to perform the calculations.

![Figure 6. Differences in PR values according to average, maximum and minimum irradiance data of the different study DBs.](image)

In the following Figure 7 the values in columns of the actual generation of the different installations per year in MWh appear. The values of the graphs, being of installations with different maximum peak power, are not comparable to each other, for which we have to pass the data to the same indicator that does not take into account the generated total energy but the HSP equivalents of production, And in this way we can compare all the facilities to referring an equal index and with the same unit.

In order to carry out the calculations of the facilities to obtain their equivalent HSPs, we take the average generation values per month and per year of each installation, with respect to all the annual and monthly data we have obtained from the different installations. The calculation performed is for the daily averages of HSP, which is calculated by dividing the actual produced energy value between the installed peak power and this value is divided between the days of the month to have a daily HSP value, which will be the comparable data for all generating plants. Once this value is calculated, the plants...
can already be compared to each other, by a same ratio, independent of the total installed power. Figure 8 shows all the average production curves in HSP calculated for the average of each month, with the data of all the years of study of all the generating stations, as well as the average values, maximum and minimum values.

![Figure 7. Production values in kWh of the different installations per year.](image)

![Figure 8. Average real HSP values of the years of the different installations with panels with 10° angle.](image)

The last comparison between the real values of the plants is the YF, which corresponds to the annual production HSP. This value is calculated by dividing the actual output with respect to the installed peak power. This Figure is very important for producers, since this annual value is tabulated by law according to the climatic zone and the type of installation and there are a maximum allowable production values for the payment of production premiums. For study facilities that are untraceable and in climatic zone V, it has maximum values of HSP of 1753, not exceeding this value of the plants, as can be observed in Figure 9 where the different values of HSP of all the facilities and all the years of investigation, being verified that the maximum values are above the 1600 hours, as the FEM with 1635 hours, INS3 with 1607 hours, INS4 with 1636 hours and the highest equivalent production, which is the newest

| Month | Max  | Average | min | Diff. % Max-min | Standard deviation |
|-------|------|---------|-----|-----------------|--------------------|
| JAN.  | 3.29 | 3.09    | 2.86 | 13.2%           | 0.22               |
| FEB.  | 4.22 | 3.70    | 3.06 | 27.6%           | 0.58               |
| MAR.  | 4.93 | 4.53    | 3.89 | 21.2%           | 0.53               |
| APR.  | 5.50 | 4.95    | 4.44 | 19.3%           | 0.53               |
| MAY   | 5.59 | 5.24    | 4.71 | 15.8%           | 0.44               |
| JUN.  | 6.06 | 5.53    | 5.05 | 16.8%           | 0.51               |
| JUL.  | 5.86 | 5.34    | 4.72 | 19.4%           | 0.57               |
| AUG.  | 5.27 | 4.96    | 4.61 | 12.5%           | 0.33               |
| SEP.  | 4.82 | 4.37    | 3.60 | 25.3%           | 0.62               |
| OCT.  | 3.90 | 3.64    | 3.17 | 18.8%           | 0.37               |
| NOV.  | 3.13 | 2.83    | 2.51 | 19.9%           | 0.31               |
| DIC.  | 2.93 | 2.71    | 2.48 | 15.3%           | 0.22               |
| TT    | 4.58 | 4.24    | 3.89 | 14.9%           | 0.34               |
installation INS6 with 1655 hours, but none exceeding the threshold of 1700 equivalent hours.

4.1 Comparison of Actual and Projected Values

Once verified and calculated the actual data of the different facilities, for HSP values, then compare these values with those estimated in the different study DBs, for which it pass the irradiation values shown in Table 1. To new values of global irradiance of plates inclined to 10° with the value of the calculated coefficient K, multiply it by irradiation to 0° and give us the value for 10°. With this global irradiation value on the plates at 10°, we perform the total HSP calculations, for which we divide the value between 1000 kWh/m², and finally perform the calculation of the useful HSP by multiplying by the previously calculated monthly PR value. With the data obtained, Table 6 is generated, showing the actual calculated values for the study facilities and the theoretical values of the DBs, where the differences between the HSP values of each DB and the real can already be verified. With these values we perform the calculations of comparison of all the generation data of the different research plants that are converted from kWh to HSP. Figure 10 shows the annual average differential values of the calculated values of the DBs, where it can be seen that the DBs of the UNE 94003 and AEMET are the ones whose projection is closer to reality in all cases, With average differences that do not exceed 5%, the value calculated by PVGIS which gives higher values with an average difference of 12.9%.

It can also be seen how there are generating installations whose calculated value predicted with respect to the real becomes 22.6% higher, in the installation of INS2 with PVGIS data. The differences between the maximum and minimum values are between the different DBs with respect to the annual data between 1% and 10.2%, proving that the differences between the DBs are very linear and follow a very similar irradiation function. Figure 11

| Month | PV real value | PVGIS | Helioclim | ADRASE | Ciemat | NASA | AEMET | Soda-pro | ITC | Canarias | IDAE | Censolar | UNE 94003 | Max | Average | Min |
|-------|---------------|-------|-----------|--------|--------|------|-------|----------|-----|----------|------|----------|-------------|-----|---------|-----|
| JAN.  | 3.09          | 3.58  | 3.19      | 3.35   | 3.40   | 2.89 | 3.17  | 2.86     |     | 3.37     | 3.58 | 3.23     | 2.86         | 3.37| 3.58    | 2.86|
| FEB.  | 3.70          | 4.13  | 4.05      | 4.00   | 3.86   | 4.21 | 3.85  | 3.46     |     | 3.85     | 4.21 | 3.92     | 3.46         | 3.85| 4.21    | 3.46|
| MAR.  | 4.53          | 4.80  | 4.79      | 4.76   | 4.41   | 4.95 | 4.76  | 4.09     |     | 4.39     | 4.95 | 4.62     | 4.09         | 4.39| 4.95    | 4.09|
| APR.  | 4.95          | 5.27  | 5.17      | 5.24   | 4.86   | 4.97 | 4.99  | 4.30     |     | 4.78     | 5.27 | 4.95     | 4.30         | 4.78| 5.27    | 4.30|
| MAY   | 5.24          | 5.51  | 5.51      | 5.46   | 5.03   | 5.22 | 5.38  | 4.59     |     | 5.00     | 5.51 | 5.21     | 4.59         | 5.00| 5.51    | 4.59|
| JUN.  | 5.53          | 5.54  | 5.64      | 5.39   | 4.90   | 4.93 | 5.45  | 4.68     |     | 5.01     | 5.64 | 5.19     | 4.68         | 5.01| 5.64    | 4.68|
| JUL.  | 5.34          | 5.52  | 5.56      | 5.17   | 4.89   | 5.52 | 5.41  | 5.01     |     | 5.01     | 5.56 | 5.26     | 4.89         | 5.01| 5.56    | 4.89|
| AUG.  | 4.96          | 5.39  | 5.24      | 5.17   | 4.83   | 5.23 | 5.18  | 4.63     |     | 4.81     | 5.39 | 5.06     | 4.63         | 4.81| 5.39    | 4.63|
| SEP.  | 4.37          | 4.87  | 4.68      | 4.76   | 4.50   | 4.58 | 4.70  | 4.33     |     | 4.46     | 4.87 | 4.61     | 4.33         | 4.46| 4.87    | 4.33|
| OCT.  | 3.64          | 4.27  | 3.89      | 4.11   | 4.27   | 4.02 | 3.90  | 3.51     |     | 3.94     | 4.27 | 3.99     | 3.51         | 3.94| 4.27    | 3.51|
| NOV.  | 2.83          | 3.69  | 3.29      | 3.48   | 3.41   | 3.66 | 3.24  | 3.06     |     | 3.46     | 3.69 | 3.41     | 3.06         | 3.46| 3.69    | 3.06|
| DIC.  | 2.71          | 3.33  | 2.95      | 3.12   | 3.18   | 3.00 | 2.94  | 2.76     |     | 3.17     | 3.33 | 3.06     | 2.76         | 3.17| 3.33    | 2.76|
| TT    | 4.24          | 4.77  | 4.64      | 4.62   | 4.39   | 4.56 | 4.55  | 4.05     |     | 4.37     | 4.77 | 4.49     | 4.05         | 4.37| 4.77    | 4.05|
shows the representative graphs of the existing differences between the actual values as compared to those of the monthly level. This is observed more clearly as the winter and autumn months are the ones that generate greater differences, which become up to 31% higher than the values observed in the real installations, and are the main cause of the annual differences that forecast much higher values of generation than the real ones. While in the summer months, the values are quite close to reality, being even lower in some cases. Again, the values obtained by the PVGIS database are those that give higher values, while the values of IDAE-Censolar have lower values than the real ones, and the values of the standard UNE 94003 and of the AEMET Which are more similar to reality, even so, all of them being overly optimistic in HSP values for the months of November mainly.

Figure 10. Differences between total annual values HSP calculated from irradiationDB, with respect to the real value with the plates at 10°.

Once verified and demonstrated the differences of values between the DBs respect of the real production data of the studied facilities, we have to calculate what the actual irradiation incident on flat surfaces of the plants of Fuerteventura, to verify the differences of real values of irradiation With the DBs. Having the average HSP value of the installations with the solar plates inclined 10°, we perform the theoretical calculation of HSP equivalents for a flat surface 0°, calculating the divisor factor K for each month, which is the same one that we use for the Adjustment of the irradiation of the DBs to 10°. Calculating the value of HSP with losses due to the PR factor, we have to calculate the real incident value without losses, dividing this value between the efficiency coefficient of the system or PR previously obtained, finally obtaining the actual value of HSP for horizontal PVs of 0° angle. With the actual value of HSP which allows to have radiation incident, multiplying that value by 1000 kWh/m². Table 7 shows the data corresponding to HSP with losses and real, at 10° and 0°, as well as the values of PR and K, obtaining the final value of the irradiation without losses and for flat surfaces at 0°.

Table 7. Average values of HSP, coefficients PR and K, and irradiance value equivalent to 0°.

| Month | K   | HSP PR 10° | HSP PR 0° | PR     | HSP 0° | Irradiation kWh/m² |
|-------|-----|------------|-----------|--------|--------|-------------------|
| JAN.  | 1.19| 3.09       | 2.59      | 76.45% | 3.39   | 3.394             |
| FEB.  | 1.14| 3.70       | 3.24      | 75.75% | 4.28   | 4.282             |
| MAR.  | 1.09| 4.53       | 4.15      | 74.79% | 5.55   | 5.554             |
| APR.  | 1.04| 4.95       | 4.74      | 74.30% | 6.38   | 6.380             |
| MAY   | 1.01| 5.24       | 5.17      | 74.00% | 6.98   | 6.983             |
| JUN.  | 1.00| 5.53       | 5.53      | 74.00% | 7.47   | 7.467             |
| JUL.  | 1.01| 5.34       | 5.31      | 73.30% | 7.25   | 7.245             |
| AUG.  | 1.03| 4.96       | 4.81      | 73.05% | 6.59   | 6.587             |
| SEP.  | 1.07| 4.37       | 4.09      | 73.06% | 5.59   | 5.593             |
| OCT.  | 1.12| 3.64       | 3.25      | 73.66% | 4.41   | 4.410             |
| NOV.  | 1.18| 2.83       | 2.41      | 75.43% | 3.19   | 3.191             |
| DIC.  | 1.21| 2.71       | 2.24      | 76.22% | 2.94   | 2.944             |
| TT    |     | 4.24       | 3.96      | 74.50% | 5.34   | 5.336             |
Comparing the annual average annual irradiance values for flat horizontal surfaces of the DBs with respect to the calculated real value, we obtained Figure 12, where we can graphically check how the values of AEMET DB and UNE 94003:2007 only differ from + -0.3% in relation to the real value. The biggest differences are PVGIS with a value higher than + 10.2% and with the data from IDAE-Censolar that values are much lower than -8.5%. It is very important to keep in mind that these data refer to irradiation on flat surfaces, ie at 0º of inclination. The calculated values of irradiation show that for annual values the differences are not very excessive, considering that the values of + -5% per year are acceptable, among which we can consider AEMET, Solar-pro, ITC-Canarias and UNE 94003 DBs acceptable.

Figure 12. Percent annual differences between the real value and the DB for horizontal surface irradiation.

It also compare the monthly irradiation data of all the DBs with respect to the calculated real, showing in Figure 13 the graphs of the different irradiations, where it can be observed how the real irradiation is found, in most of the months, between the Values of the different DBs, being in the months of November and December when its value is inferior to all DBs. The data of IDAE-Censolar always are well below the rest of values of irradiation, as well as those of PVGIS also usually have the superior value of the rest in most of the months, reason why it gives calculated values of tan generation Generous in most of the months. In order to perform rapid calculations of irradiation of Fuerteventura, we have calculated the characteristic polynomial function, which is also shown along with the previous graphs, performing the regression of the real irradiation data, giving us the value of the characteristic function, which can be used to make the necessary monthly approximations for calculations of photovoltaic production.

Figure 13. Curves of real irradiation and of the DB for Fuerteventura.

\[ y = -141.51x^2 + 1741.3x + 1682.5 \]

Table 8 summarizes the percentage differences between the actual irradiance value calculated for the installations and the data that the different DBs offer us, where the contrasts between real values and those obtained by the DBs are appreciated.

Having real values of irradiation is very important for its use in monthly and not only annual electricity generation forecasts, since at the moment the current facilities that are made of self-consumption is necessary to have real monthly values, in order to calculate the effective savings according to the electric rate of each billing period, which changes according to the hours and months of the year according to 2, 3 or 6 tariff periods and thus make the amortizations in the shortest possible time. Along with the monetary savings achieved, savings in CO₂ emissions must be taken into account in order to achieve low emission buildings as well as a real alternative to near-zero energy (nZEB) projects.

5. Discussions and Conclusions

Through this research study of irradiation comparison of general DBs with respect to real data, it has been verified that all DBs have different data, not agreeing their values
in any case and with very large differences according to the calculation months. It is verified that the actual data differ from those projected in absolute and monthly annual values, with very large variations depending on the DB used. It has been possible to verify and conclude that:

- The calculation of irradiation for inclined surfaces can be made by the simplified method to values close to 55º of inclination, with differences of + -2% that can be assumed in most projects.
- When installing PV in areas where the surface of use is very important and high values of installed power per unit area are required, smaller angles of inclination should be chosen, lower than the optimum value, in order to reduce the distance between Modules and thus increase the installed power per unit area.
- The different DBs do not agree in their values or in their production estimates, so their use must be careful and whenever annual and non-monthly estimates can be made, whose values are more closely adjusted to actual productions.
- When it is necessary to make monthly production estimates, you must perform calculations with several DBs and take the average values to obtain more realistic adjustments.
- The DBs that have more real values, to be able to make correct estimates, are those that have been calculated by observation and crossing of data of stations, being for the zones of calculation, those generated by national estates, recommending the use of the data from the UNE 94003:2007 standard and AEMET data with a difference of less than 1% per year for horizontal surfaces. The PVGIS database is too optimistic in its calculations and its values tend to be with 10% higher yields.
- In order to carry out more accurate calculations and forecasts, account must be taken of meteorological and land-type data, since in this case it is verified that being an arid zone the losses are probably higher due to dirt on the plates and losses by Dust in suspension in the months of winter and autumn, due mainly to the calima, for which a future investigation on the influence of this phenomenon in the production would have to be made.
- The most up-to-date and modern facilities have a higher efficiency with equivalent HSPs per plant which can be up to 7% higher than the average.

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