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Preliminary Characterization of Solar Radiation Patterns in the Canary Islands: An Integrated Approach Combining Clustering and Spatial Interpolation Techniques

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Abstract. This study focuses on categorize solar radiation patterns in the Canary Islands using the clearness index (Kt) and clustering techniques This study utilizes data from multiple meteorological stations measurements to create a comprehensive dataset. The K-means algorithm is applied to the clearness index data, identifying distinct radiation zones within the Canary Islands. The analysis reveals four distinct radiation zones, each characterized by varying frequencies of cloudy, partially clear, and very clear days. The study highlights the necessity for tailored calibration to enhance predictive accuracy across different zones. Despite the high prediction errors observed, the clustering approach effectively categorizes the Canary Islands' radiation patterns, suggesting that further refinement of the model could lead to more accurate solar radiation forecasts.

Key words. Canary Islands; solar radiation; diffuse solar radiation; clearness index.

1. Introduction

The calculation of the photovoltaic (PV) energy is one of the most important challenges in the renewable energy deployment. Due to the performance of the PV modules is affected by multiple factors, the calculation of the irradiance is one of the most important defies to assure the adequate energy production [1–5].

An accurate prediction of the PV production requires a thorough understanding of the diffuse and beam irradiance which composes the global irradiance, with a remarkable relevance in regions where real measurements are not accessible. In this sense, the analysis of the surrounding meteorological stations and the satellite measurements are the only available values to estimate the PV production.

In recent years, clustering methods such as K-means have been employed to improve the characterization of solar radiation [6], by applying this algorithm to a Typical Meteorological Year (TMY), created using the Sandia method [7].

In this sense a comprehensive study on solar radiation zoning and the development of daily global radiation models for regions in China, focusing on areas with only surface meteorological measurements have demonstrated the accuracy of the method [8].

K-means has been used to classify solar tilt irradiance and assess the impact of different solar variabilities on monocrystalline and thin-film photovoltaic systems [9], validating their clustering results using the elbow method, Silhouette Coefficient, and Gap Statistic, identifying four types of solar variabilities: overcast, moderate, mixed (clear/mild), and high variability.

The goal of this research is to estimate the PV potential of the Canary Islands. This objective involves analyzing the solar radiation data to determine the optimal conditions for PV energy production.

In this study is presented a characterization and classification of the climatic diversity of the Canary Islands, with a specific focus on solar radiation to calculate the PV production. This characterization aims to discern variations in the behavior of global irradiation among different subclimates within the archipelago. This objective is accomplished through the application of the K-means clustering algorithm to a comprehensive dataset collected from numerous weather stations distributed across the Canary Islands.

Subsequently, the clusters generated are analyzed by comparing an annual distribution of daily radiation with the daily data measured by the weather stations. This distribution is built using the mean irradiation values from each weather station assigned to the respective radiation zones. This analysis allows for a detailed comparison of the annual radiation patterns within each identified cluster.

This work presents an analysis of the values from different stations to obtain the most suitable interpolation methods to obtain irradiation values, using Canary Islands a test case due to its significant variation in the irradiance received on the surface.

2. Methodology

This study proposes an integrated framework to characterize and map solar radiation over the Canary Islands by combining statistical clustering with spatial interpolation techniques. The methodology comprises four main components: data acquisition and preprocessing, clearness index analysis with subsequent clustering, evaluation of spatial interpolation methods, and the integration of these approaches to generate a final radiation map.

A. Canary Islands Description

The Canary Islands is a Spanish outermost region with special treatment according to Article 349 of the Treaty on the Functioning of the European Union, composed by 8 islands, placed in front of the Morocco coast. Due to its volcanic nature and therefore its orography, joint to the proximity of the Trade winds, the weather in Canary Islands is stable along the year with different climate zones. Latitude ranges from 27.73°to 29.22° (mean of 28.35°) and Longitude spans 18.15°to 13.45° (mean of 16.46°). This distribution captures the archipelagos full east west extent, from El Hierro in the southwest to Lanzarote in the northeast.

Altitude extends from just 7 m above sea level to 2,071 m at mountainous stations, with an average of 464 m. The high standard deviation (444.85) confirms significant orographic variability, a hallmark of the Canary Islands. The Slope variable, taking the value 1 for north-facing locations and 0 for south-facing locations, has a mean of 0.315. This suggests that roughly 31.5% of the stations face north and the remaining 68.5% face south. The median of 0 implies that over half of the stations are south oriented.

B. Data obtainment and preprocessing

Global solar radiation data were obtained from three primary sources (in Figure 1 the weather stations are located across the Canary Archipelago):

Daily accumulated horizontal global solar irradiance data recorded for each day from January 2010 to December 2020, obtained from ground-based weather stations provided by Agrocabildo of the Cabildo de Tenerife [10]

Hourly Horizontal global solar irradiance data from ground-based weather stations available in in the Agroclimatic Information System for Irrigation of the Ministry of Agriculture, Fisheries, and Food of the Spanish Government (SIAR) [11], for each hour from January 2010 to December 2020.

Hourly Horizontal global solar irradiance data recorded for each hour from January 2020 to December 2023, obtained from ground-based weather stations available in Grafcan, from Cartográfica de Canarias S.A. [12]

All datasets were subjected to a preprocessing stage to harmonize the temporal resolution and ensure spatial consistency.

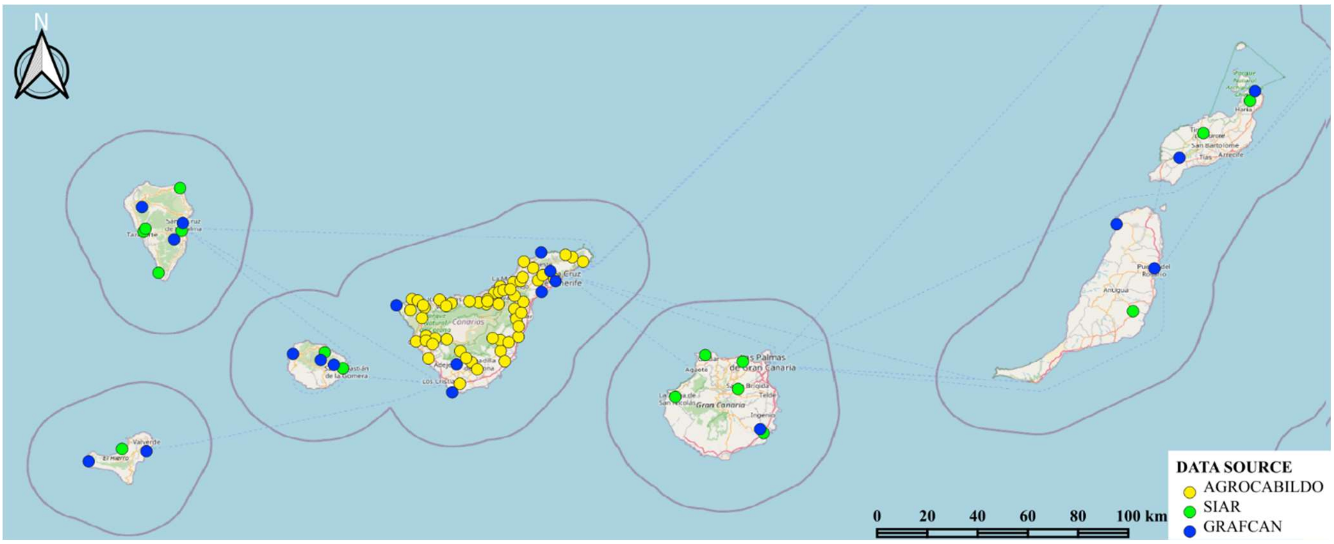

Fig. 1 Ground weather locations. Source: own elaboration.

C. Selection of Independent Variables

The following geospatial variables were selected to explain spatial variability in solar radiation:

Latitude and Longitude: Latitude and longitude specify the exact geographic location of the meteorological stations and delineate the boundaries of each island, serving as key factors for representing spatial gradients of solar radiation. In the context of the Canary Islands, these coordinates help capture critical differences related to the interaction with trade winds, cloud formation, and the incidence of radiation across coastal versus inland regions. Moreover, they enable discrimination of each islands relative position (eastwest and northsouth), facilitating the modeling of specific variations arising from geographic setting and, by extension, solar resource availability. Consequently, geopositioning is incorporated into the model as a primary variable for identifying and quantifying spatial radiation patterns.

Altitude: Altitude affects atmospheric density and, consequently, radiation attenuation. Higher elevations often experience reduced cloud cover and enhanced irradiance, as lower values of other parameter as aerosol optical depth, water vapor and ozone content. In Canary Islands particular case the thermal inversion above 1000 meters in height leads to cloud stagnation, thereby generating stratiform cloudiness at that altitude.

Slope aspect (north/south): The slope aspect influences cloud formation and trade wind patterns. In this study, slope aspect was considered as a categorical variable, distinguishing between north-facing and south-facing slopes. This classification was based on the methodology described in [13], which defines a threshold for differentiating between these two aspects.
Variable selection was initially guided by theoretical insights and previous experience in regional climatology. Their relevance was further assessed through exploratory analyses that revealed correlations and spatial patterns consistent with the initial hypotheses.

D. Clearness index analysis
The clearness index (Kt), defined as the ratio of the measured global solar irradiance (Hg) to the extraterrestrial irradiance (I_0) (equation 1), serves as a key indicator for assessing atmospheric clarity.

$$Kt = H_g / I_0 \quad (1)$$

Where the extraterrestrial global horizontal irradiance (I_0) is defined in equation 2.

$$I_0 = I_{SC} \cdot \left(1 + \left[0.033 \cdot cos\left(\frac{2 \cdot \pi}{365} \cdot n_{day}\right)\right]\right) \cdot cos\theta_Z \quad (2)$$

Where Isc is the solar constant and its value is 1367 W/m^2 [14–17], n_{day} is defined as the sequential day of the year (i.e., n_day = 1 for January 1, n_day = 2 for January 2, and so on, up to 365 or 366 in leap years), representing the Earth's position in its orbit relative to the sun. and the solar zenith angle (θ_Z) is obtained by using the equation 3.

$$\theta_Z(º) = acos[sin\varphi \cdot sin\delta + cos\varphi \cdot cos\delta \cdot cos\omega_S] \quad (3)$$

In eq. 3, φ is the geographic latitude of the location, ω_S is the sunset hour angle and δ is the solar declination, which is calculated using the Meeus algorithm [18].
Based on the thresholds established by Orgill [19], Kt values were categorized to differentiate between cloudy (Kt ≤ 0.35), partially clear (0.35 < Kt ≤ 0.75), and very clear sky conditions (Kt > 0.75).
A representative clearness index ($Kt_{Representative}$) was computed for each station by weighting the frequency of each sky condition category.

E. Radiation zones clustering
To capture the spatial variability of solar irradiance across the Canary Islands, we apply the K-means clustering algorithm to the $Kt_{Representative}$ values. K-means is an iterative partitioning method that aims to divide a set of n observations into k clusters, where each observation belongs to the cluster with the nearest mean. The algorithm minimizes the within-cluster sum-of-squares (WCSS), ensuring that the total variance within each cluster is as low as possible.
Mathematically, the objective function of the K-means algorithm is given by:

$$\boldsymbol{WCSS = \sum_{j=1}^{k} \sum_{i=1}^{n} \left|\left| x_i^{(j)} - c_j \right|\right|^2} \quad (4)$$

where:
WCSS is the Within-Cluster Sum of Square and represents the sum of the squared distances between each point in a cluster and the centroid of that cluster.
k represents the number of clusters.
n indicates the number of cases in the dataset.
x_i represents the case "i".
c_j is the value of the centroid in the cluster "j".

By applying K-means clustering to the $Kt_{Representative}$ values, distinct radiation zones are identified, which reflect differences in atmospheric conditions influenced by factors such as altitude, slope orientation, and geographic location.

F. Spatial Interpolation Techniques
To generate a continuous spatial map of $Kt_{Representative}$, several spatial interpolation methods were evaluated:
Multiple Linear Regression (MLR) and Multiple Quadratic Regression (MQR): These methods model the relationship between $Kt_{Representative}$ and geographic predictors (latitude, longitude, altitude, and slope aspect) using ordinary least squares. While MLR assumes a linear association, MQR incorporates polynomial terms to capture non-linear effects inherent in complex terrain.
Inverse Distance Weighting (IDW): IDW is a deterministic method that estimates $Kt_{Representative}$ at unsampled locations by computing a weighted average of observed values, where the weights decrease with distance. In this study, a power parameter of 2 was used.
Initial validation of the interpolation methods was performed using various training–validation splits (e.g., 90–10%, 80–20%, and 70–30%), which confirmed the robustness of the approaches. For the purpose of this conference paper, however, the final interpolation results are presented using the entire dataset, with the IDW method yielding the best performance based on the error metrics considered.

G. Integration of the Approach
The final step in our methodology involves integrating the clustering and interpolation components. The identified radiation zones from the K-means clustering provide a spatial framework that reflects regional differences in solar irradiance. The representative clearness index is then interpolated over the study area using the selected method (IDW), thereby producing a continuous radiation map for the Canary Islands.
This integrated approach not only accounts for the heterogeneity of local atmospheric conditions but also ensures that the spatial interpolation is grounded in a robust statistical classification. Detailed analyses of model performance, including discussions on multicollinearity in polynomial regressions and cross-validation results, are reserved for future publications.

3. Results and Discussion

In this section, we present the preliminary results obtained from applying our integrated methodology to the Canary Islands dataset. The discussion is divided into three subsections: clustering results, spatial interpolation outcomes, and an overall discussion of the integrated approach.

A. Clustering results

The K-means clustering algorithm was applied to the $Kt_{Representative}$ values computed for each meteorological station. The objective was to partition the stations into distinct radiation zones that reflect variations in atmospheric clarity across the archipelago. The within-cluster sum-of-squares (WCSS) was monitored during the iterative process to ensure convergence.

Figure 2 displays the distribution of the stations across the identified clusters, with each cluster representing a distinct radiation zone. The clusters exhibit clear differences in the $Kt_{Representative}$ values:

Zone 1. This zone is characterized by low $Kt_{Representative}$ values, which correspond to a high frequency of cloudy days. Stations in Zone 1 are generally located in areas where persistent cloud cover is common, likely due to the influence of local topography and prevailing meteorological conditions. These areas may be found on the windward side of the islands or in regions where orographic lifting enhances cloud formation.

Zone 2 exhibits intermediate $Kt_{Representative}$ values, suggesting a mix of cloudy and partly clear days. The stations within this zone experience transitional sky conditions, reflecting a balance between cloudiness and periods of higher irradiance. This zone typically includes regions where the effect of orography and atmospheric dynamics produces moderate variability in solar radiation.

Zone 3 the $Kt_{Representative}$ values are higher, indicating a greater occurrence of clear to mostly clear days. Stations in this zone are often located in regions less affected by persistent cloud cover, which might be due to their position relative to the trade winds or lower humidity levels. These areas tend to have favorable conditions for higher solar irradiance, supporting enhanced photovoltaic potential.

Zone 4 displays the highest Kt_{Representative} values, corresponding to predominantly clear conditions. The stations in this zone are usually found in areas with minimal cloud interference, such as leeward or sun-exposed locations. The resulting high level of solar irradiance makes these zones particularly attractive for photovoltaic energy generation.

The calculated centroids of the clusters serve as representative measures for the corresponding zones. These preliminary results indicate that the K-means algorithm effectively captures the spatial heterogeneity in sky conditions, thereby providing a robust classification that can be further utilized in spatial interpolation.

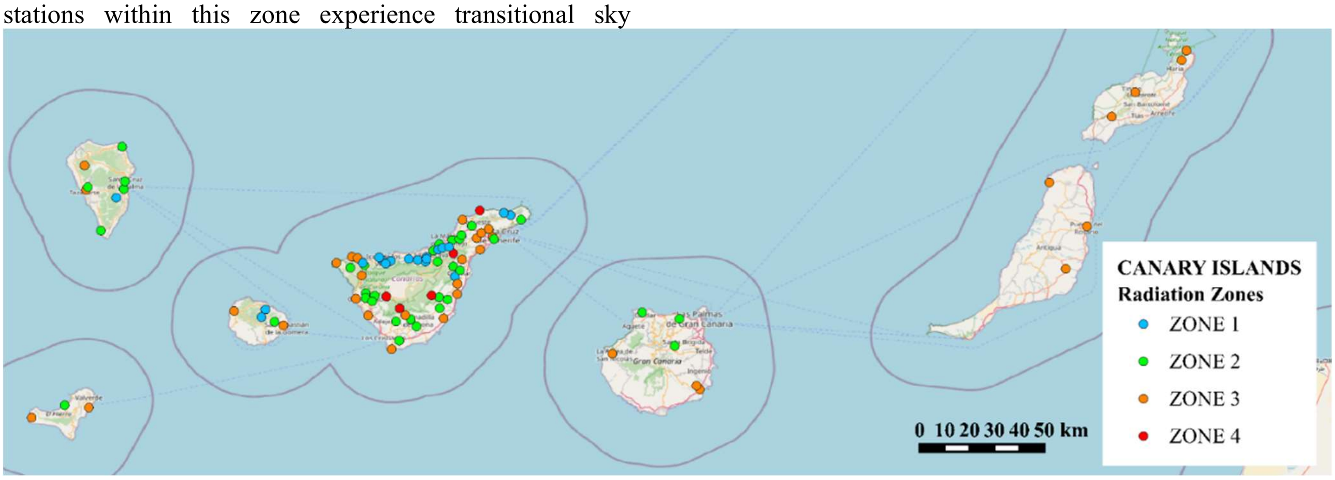

Fig. 2**.** Classification of Canary Islands weather stations.

B. Spatial Interpolation Results

To generate a continuous map of the $Kt_{Representative}$ across the Canary Islands, we evaluated several spatial interpolation techniques, including Multiple Linear Regression (MLR), Multiple Quadratic Regression (MQR), Inverse Distance Weighting (IDW), and Ordinary Kriging (OK). After a series of validation tests (using various training–validation splits), the IDW method (with a power parameter p = 2) yielded the most favorable performance based on error metrics such as RMSE, MAPE, and rRMSE.

Figure 3 presents the final continuous map of $Kt_{Representative}$ derived from the IDW interpolation. The map clearly delineates the different radiation zones identified through clustering, with transitions in the clearness index corresponding to topographical and geographical variations (e.g., the differences between northern and southern slopes).

The interpolation errors, as summarized in Table 1, indicate low RMSE and MAPE values, confirming the robustness of the IDW approach. In particular, the spatial pattern of $Kt_{Representative}$ aligns with known microclimatic features of the Canary Islands, such as the influence of orographic uplift and the persistent stratiform cloudiness on the northern slopes.

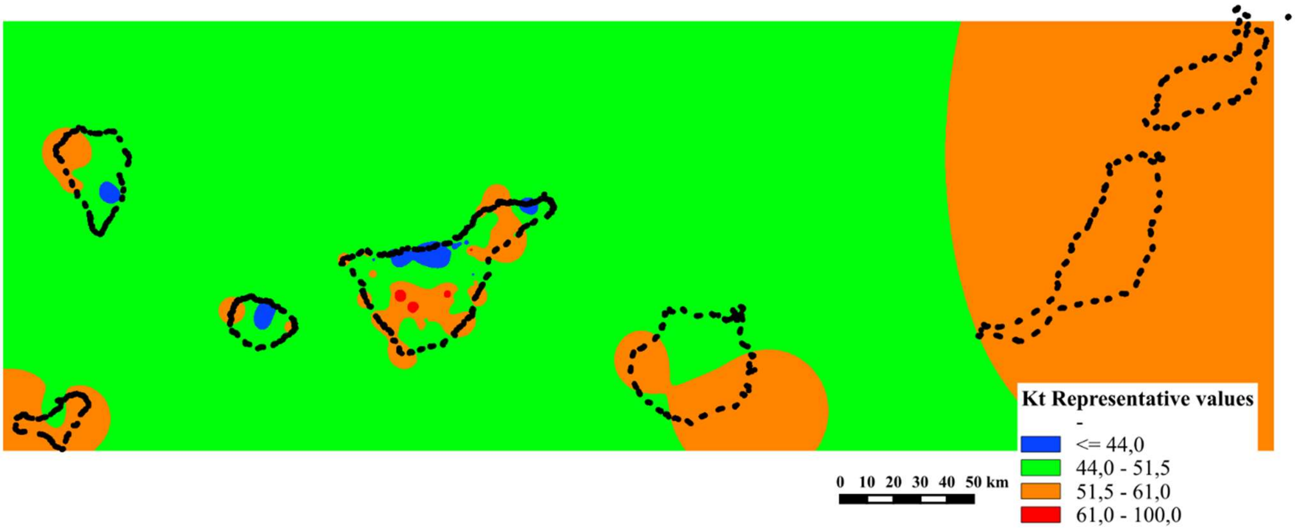

Fig. 3. Canary Island $Kt_{Representative}$ map result of applying IDW interpolation method with p=2.

Table I. Summary of Model Performance Across Training–Validation Splits

Model	MABE (A / B / C)	MAPE (A / B / C)	MBE (A / B / C)	RMSE (A / B / C)	rRMSE (A / B / C)	R^2 (A / B / C)
MLR without constant	7.34 / 6.61 / 5.25	16.18% / 13.87% / 9.41%	–1.81 / –0.38 / 2.60	8.03 / 8.03 / 8.45	16.40% / 16.46% / 16.31%	0.0291 / 0.0887 / 0.0013
MLR with constant	6.78 / 6.11 / 4.98	14.96% / 12.94% / 8.94%	–1.87 / –0.45 / 2.15	7.58 / 7.71 / 8.08	15.48% / 15.60% / 15.59%	0.0004 / 0.2082 / 0.0431
MQR without constant	4.33 / 4.92 / 4.52	9.20% / 10.53% / 8.64%	–0.25 / –1.07 / 0.58	5.44 / 5.91 / 5.35	11.11% / 11.96% / 10.31%	0.5148 / 0.5370 / 0.6503
MQR with constant	4.41 / 4.60 / 4.25	9.51% / 9.55% / 8.15%	–0.96 / 0.36 / 1.30	5.46 / 5.81 / 5.33	11.14% / 11.75% / 10.28%	0.5040 / 0.5353 / 0.6538
IDW with p = 2	4.45 / 3.96 / 5.13	9.40% / 8.42% / 9.25%	0.02 / –2.48 / 1.84	4.89 / 4.61 / 8.12	9.98% / 9.34% / 15.67%	0.6147 / 0.3947 / 0.0624

Notes: Each cell displays the metric for Split A / Split B / Split C, respectively.

C. Discussion

The integrated approach presented in this study successfully combines statistical clustering and spatial interpolation to map solar radiation over the Canary Islands. The K-means clustering provided a clear segmentation of the region into distinct radiation zones based solely on the $Kt_{Representative}$ values. This classification is consistent with the underlying climatic and topographic variability of the region.

Subsequently, the spatial interpolation of the representative clearness index using the IDW method produced a continuous map that accurately reflects the spatial distribution of the radiation zones. The low error metrics and the correspondence between the interpolated values and the observed microclimatic patterns underscore the efficacy of the chosen methods.

It is noteworthy that the validation process, which involved multiple training–validation splits, demonstrated the stability of the interpolation results. Although detailed cross-validation results are beyond the scope of this conference paper, the consistent performance across different splits supports the robustness of the overall methodology.

Overall, these preliminary findings highlight the potential of integrating clustering with spatial interpolation to improve solar radiation mapping in regions with complex orography. The approach provides a solid foundation for enhancing photovoltaic potential assessments and offers a promising avenue for further research. Future work will extend these analyses by incorporating more detailed error diagnostics, exploring additional interpolation techniques, and addressing potential multicollinearity issues observed in polynomial regression models.

4. Conclusions

This study presents a preliminary yet robust framework for characterizing and mapping solar radiation across the

Canary Islands by integrating statistical clustering with spatial interpolation techniques. The key findings and contributions of this work can be summarized as follows:

1. Integrated methodology:
By combining the analysis of the clearness index (Kt) with K-means clustering, the study effectively segmented the region into distinct radiation zones. These zones, ranging from areas with predominantly cloudy conditions (Zone 1) to regions with high solar clarity (Zone 4), reflect the inherent spatial variability driven by local orography and meteorological dynamics.

2. Performance of spatial interpolation:
Several spatial interpolation methods were evaluated, including Multiple Linear Regression (MLR), Multiple Quadratic Regression (MQR), Inverse Distance Weighting (IDW), and Ordinary Kriging (OK). Cross-validation using various training–validation splits confirmed the stability of the methods. Among these, the IDW method (with a power parameter of 2) demonstrated superior performance based on error metrics such as RMSE, MAPE, and rRMSE, thereby providing a continuous map of the representative clearness index that aligns with observed microclimatic patterns.

3. Preliminary validation:
The validation process, performed through different training–validation splits, revealed that the proposed methodology is robust. Although detailed cross-validation results and additional diagnostic analyses are reserved for forthcoming publications, the consistent performance across splits underscores the viability of the integrated approach.

4. Implications for photovoltaic assesment:
The preliminary findings underscore the potential of this integrated framework to improve solar radiation mapping in regions with complex topography. By providing a more nuanced spatial characterization of solar irradiance, the approach lays the groundwork for enhanced photovoltaic potential assessments and more informed energy planning.

While the results presented here are promising, this communication represents an initial step toward a comprehensive understanding of solar radiation variability in the Canary Islands. Future work will address additional aspects such as refined error diagnostics, the exploration of further interpolation methods, and the mitigation of multicollinearity issues in polynomial regression models. These efforts will provide a deeper insight into the spatial dynamics of solar irradiance and further validate the methodology for broader application.
In summary, this study demonstrates that an integrated approach combining clustering and spatial interpolation can effectively capture the complex spatial variability of solar radiation. The promising preliminary results pave the way for more detailed analyses, which will be reported in subsequent publications.

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