

Article

Mapping of the Literal Regressive and Geospatial–Temporal Distribution of Solar Energy on a Short-Scale Measurement in Mozambique Using Machine Learning Techniques

Fernando Venâncio Mucomole ^{1,2,3,*} , Carlos Augusto Santos Silva ⁴  and Lourenço Lázaro Magaia ⁵

¹ CS-OGET—Center of Excellence of Studies in Oil and Gas Engineering and Technology, Faculty of Engineering, Eduardo Mondlane University, Mozambique Avenue Km 1.5, Maputo 257, Mozambique

² CPE—Centre of Research in Energies, Faculty of Sciences, Eduardo Mondlane University, Main Campus No. 3453, Maputo 257, Mozambique

³ Department of Physics, Faculty of Sciences, Eduardo Mondlane University, Main Campus No. 3453, Maputo 257, Mozambique

⁴ Department of Mechanical Engineering, Instituto Superior Técnico, University of Lisbon, 1600-214 Lisbon, Portugal; carlos.santos.silva@tecnico.ulisboa.pt

⁵ Department of Mathematics and Informatics, Faculty of Science, Eduardo Mondlane University, Main Campus No. 3453, Maputo 257, Mozambique; lourenco.l.magaia@uem.mz

* Correspondence: fernando.mucomole@uem.mz or fernandomucomole1@gmail.com

Abstract

The earth's surface has an uneven solar energy density that is sufficient to stimulate solar photovoltaic (PV) production. This causes variations in a solar plant's output, which are impacted by geometrical elements and atmospheric conditions that prevent it from passing. Motivated by the focus on encouraging increased PV production efficiency, the goal was to use machine learning models (MLM) to map the distribution of solar energy in Mozambique in a regressive literal and geospatial–temporal manner on a short measurement scale. The clear-sky index (K_t^*) theoretical approach was applied in conjunction with MLM that emphasized random forest (RF) and artificial neural networks (ANNs). Solar energy mapping was the result of the methodology, which involved statistically calculating K_t^* for the analysis of solar energy in correlational and causal terms of the space-time distribution. Utilizing data from PVGIS, NOAA, NASA, and Meteonorm, a sample of solar energy was gathered at 11 measurement stations in Mozambique over a period of 1 to 10 min between 2012 and 2014 as part of the FUNAE and INAM measurement programs. The statistical findings show a high degree of solar energy incidence, with increments (ΔK_t^*) in the average order of -0.05 and K_t^* mostly ranging between 0.4 and 0.9 . In 2012 and 2014, K_t^* was 0.8956 and 0.6986 , respectively, because clear days had a higher incident flux and intermediate days have a higher frequency of ΔK_t^* on clear days and a higher occurrence density. There are more cloudy days now 0.5214 as opposed to 0.3569 . Clear days are found to be influenced by atmospheric transmittance because of their high incident flux, whereas intermediate days exhibit significant variations in the region's solar energy.

Keywords: atmospheric; solar energy; photovoltaic; mapping; short term; long term



Academic Editor: Jesús Polo

Received: 25 March 2025

Revised: 29 April 2025

Accepted: 8 May 2025

Published: 24 June 2025

Citation: Mucomole, F.V.; Silva, C.A.S.; Magaia, L.L. Mapping of the Literal Regressive and Geospatial–Temporal Distribution of Solar Energy on a Short-Scale Measurement in Mozambique Using Machine Learning Techniques. *Energies* **2025**, *18*, 3304. <https://doi.org/10.3390/en18133304>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Every year, the sun provides the earth's surface with energy with a flux density of 1.05 kW/m^2 in the range of 0.3 and $2.5 \text{ }\mu\text{m}$, making it the primary and most abundant source of energy on the planet [1–3]. This energy serves as the primary guarantee for

the survival of humans, animals, and plants, among other things. It stimulates processes such as photosynthesis, hydrological cycles, atmospheric balance, and terrestrial mass transport. These processes are typically brought about by the unequal distribution of solar energy that the earth receives, which is occasionally brought on by the earth's sporadic orientation in different seasons and times of the year [4–6]. However, as time goes on, the need for energy to meet human demands continuously rises. The cost of adopting renewable technologies, their accessibility, and the lifespan of the same plants, as well as global disasters and endemic diseases like COVID-19 and malaria, among others, can make it difficult to achieve the Sustainable Development Goals (SDGs) of complete electrification using clean and renewable energy [7–9]. The majority of the energy demand is in rural areas, with statistics showing that 81.52% of areas lack access to electricity. Mozambique, the study area, has a rate of about 22 million people without access to electrification, making it one of the countries in Sub-Saharan Africa with the highest rate of de-electrification. Many of these people live in remote areas (rural and district outskirts), where population density is relatively discrete [10–12]. Like in other rural areas, this area still relies heavily on hydroelectric conversion technology, such as thermal power plants, wind farms, and tidal conversion, to produce energy. However, there is a strong call for the adoption of solar PV formation technologies [13,14] which are a clean, sustainable, efficient, and low-cost source that can be used in any region where there is full sun, using solar cells that directly convert solar energy into electricity [2,6,15]. This is necessary to ensure the conservation of the ecosystem and ecological balance in the surrounding regions, preserving the characteristic species that are endangered by the implementation of the technologies previously described. Furthermore, variations in solar energy cause variations in the PV power output of a solar plant, which in turn causes variations in electrical power [16,17]. Large-area power plants are more likely to generate power more consistently, whereas small-area power plants are more susceptible to solar oscillations because of cloud cover. The uneven distribution of solar energy throughout the earth's surface is the cause of this. But only about 80% of the sun's total solar energy reaches the earth's surface; the rest is absorbed by the atmosphere and its components, with 25% of that energy being reflected back into space by reflection mechanisms. This is due to its trajectory, which reduces solar energy by 5% absorption by aerosols, 7% by uniformly mixed gases, 10% by water vapor, and 10% by the ozone layer [15]. Dispersion processes, Mie dispersion, Rayleigh, absorption, and the reflection of solar energy are all highlighted [6,18,19]. Furthermore, the direction of the Earth in relation to the land that the Mozambican region faces defines this distribution [14,20]. The earth facing the sanctuary of the projection of solar radiation with wide exposure is favored by the varied areas during the hot season, as per Kepler's law of areas [6,21,22]. As a result, it receives more heat from the sun, which increases the likelihood of exciting, spreading, and dispersing atmospheric particles. Additionally, it is the hot and rainy season, which literally means that the rainfall clears the atmosphere of solid particles and permits a higher incidence of solar energy [10,23,24]. The opposite happens during the cold season, when the area receives a smaller amount of solar energy despite being diametrically opposed to the greatest incidence of solar energy. This results in a greater absorption of solar energy and a lower transmittance of this resource because fewer solid particles, which are primarily suspended in the atmosphere, are scattered [15,25,26]. This is the time to focus more on solar system design and sizing so that the systems can support all seasons by operating in accordance with the month with the least amount of solar energy available [27–29]. The fact is that human activity processes, like the release of gases into the atmosphere, can sometimes affect even the minimum energy and cause a significant decrease in solar energy. These processes can be modeled to remove variations in a solar plant's power output [18,19,30]. In order to size solar systems with the actual solar energy available in

all locations and so reduce energy fluctuations, there is a greater emphasis on monitoring solar energy in order to gain a better understanding of solar energy [25,31].

Furthermore, recent research analyzed the elevation and energy, together with economic metrics, and also matched the applicability of single axis tracking systems, according to the study of solar energy resource mapping, site suitability, and technoeconomic feasibility analysis for utility-scale PV power plants [9,23,32]. Research has used a hybrid Pythagorean fuzzy-based decision approach to evaluate renewable energy projects based on sustainability goals and found that solar energy was the most appropriate renewable resource [33–35]. Studies have evaluated the viability of solar PV-based microgrids using both single-criteria and multi-criteria decision analysis, and they come to the conclusion that they are not as economically appealing in the near future [36,37]. In short measurement metrics of 0.1 to 0.001 s, studies have identified the variability of solar energy in the spatial order [22,26,38]. These studies also show a pattern of progressive energy increases, but they also use the cloud fractal model to observe the cloud and note more interesting intermediate-sky characteristics that are prone to variability [26,38]. The radiation was found to exhibit fluctuations and progressive increases in short measurements [29,39]. This suggests a decrease in energy and its increments in the regression and correlational analysis of the coefficients over the whole distance [25,38,40]. Using a machine learning model, this summarized solar energy fluxes at the earth's surface with a build-up of believable extrapolations during summertime [28,29,39]. The resulting arrangement shows the potential of the world's solar resources in tropical areas like Mozambique. Compared to larger plants, which have a compromised incidence and can be entirely obscured by the passage of an occulting atmospheric cloud, other mapping analyses of variability show more variability in small areas [11,12,21,41,42]. However, the output of machine learning models does not fully approximate the experimental energy to the theoretical energy under standardized conditions, that is, the theoretical solar energy as in the statistical theoretical model, even when analysis conditions are met without the use of predictive parameters of solar energy. Using coefficients and/or occasionally the amount of solar energy measured at the location, the description of earlier research shows the energy distribution geospatially. However, a number of factors that primarily hinder solar energy's journey to the Earth's surface and result in the drop in the power curve, depicted in Figure 1, under various energy content conditions upon arrival at the Earth's surface, make this a significant contribution and advancement in understanding the power of solar energy available on the Earth's surface in a geolocalizable region.

There are a number of factors that present different output powers in different portions of solar energy incidence affected by the fluctuations in energy upon arrival at the Earth's surface, as shown in Figure 1a. The power drop is interpreted by the fluctuations in solar energy, which are caused by the opposition to the passage of solar energy by the composition of particles in the atmosphere and its significant constituents (aerosols, dust, gases, and ozone, among others), here identified as the local cloud. As illustrated in Figure 1b, a solar plant's output power also exhibits a wide range for various day types, including clear, cloudy, and intermediate days, with the potential for high energy flow densities and significant complications from the perspective of solar energy use. Only by integrating all atmospheric factors, which are represented by the transmittances and absorptances of all atmospheric constituent parameters, can the actual availability of solar energy supplies be predicted, offering a potential solution to this fluctuation problem. Given this, the problem is ignorance regarding solar energy's true proportion and mapping with regard to the resource that is actually accessible and extracted while accounting for all atmospheric factors, with worldwide validity for all regions and in comparable patterns for even desert regions and uninhabitable seas that can be thought of as an alternative for

the effective implementation of PV utilization, as well as offering a methodology and a consultation tool for various solar energy assessment projects. Solar energy is mapped across the Mozambican region in this study, which also conditions solar energy for different kinds of sky. Though they did not use mapping by K_t^* and its ΔK_t^* , earlier investigations did use a mapping and analysis strategy. The mapping of solar energy behavior that we describe here, however, eliminates all fluctuations caused by the geometry of space by using the K_t^* magnitude. To totally eliminate variations in solar energy, global energy was measured in light of characteristics that decrease its arrival at the earth's surface. This is an additional feature that was incorporated in earlier approaches. In order to estimate the actual energy resource in any region, all atmospheric parameters were calculated based on the amount that they absorb, reflect, or disperse into the void, taking into account their transmittance and absorptance. The K_t^* is determined using machine learning models that minimize the inaccuracy in the energy evaluated from the K_t^* and in the determined power output in order to increase efficiency and minimize error induced into the findings. In addition to employing both short-term and long-term measurements, it made it possible to interpolate solar energy across the nation and determine the predicted energy for applications aimed at regulating and optimizing solar harnessing systems. A sample of solar energy was gathered for this purpose between 2012 and 2014, from April to December, using pyranometers to measure at short-range intervals of 1 to 10 min. This sample's treatment indicates a propensity for rises on days with intermediate-sky conditions, in contrast to fluctuations in other locations that tend to have substantial energy deviations in relation to solar energy. The frequency and tendency to increase increments of clear-sky days were higher in 2012 than in 2013 and 2014, according to regional mapping. The frequency of occurrence density was higher in 2012, but it decreased to 2014, when there was a greater inclination to increase the K_t^* . Both the frequency and tendency to increase ΔK_t^* were higher on cloudy-sky days. According to observations and spectra reported in the literature, intermediate-sky days exhibit a fluctuating form with intermediate incremental characteristics between the high frequencies of clear days and the low frequencies of clouded sky days. By mapping the available resources throughout the region, these findings aid in the categorical elimination of energy oscillations upon arrival to the earth's surface.

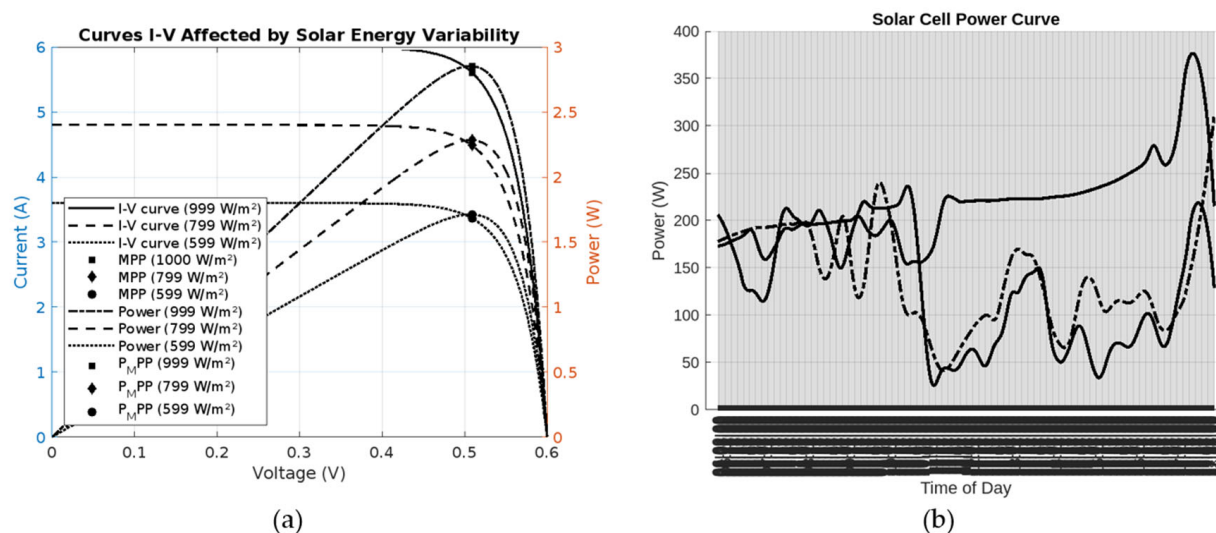


Figure 1. Solar power production from a solar power plant under the following conditions: (a) I-V curve influenced by solar energy variability under different solar energy fluxes displaying different points of maximum power. (b) The daily power output of a solar cell measured over a one-minute period.

2. Materials and Methods

2.1. Data Collection and Processing

Installing pyranometers, which measure global solar energy (GHI) on a short measurement scale of the order of 0.01 s and 1 to 10 min, was the method used for the solar energy sampling. In order to prevent measurement obstructions from natural human activity and other factors, the radiometers were placed 40 and 60 m above the ground on towers that were either installed or participated in, nevertheless, the stations where they were folded were horizontal.

2.2. Study Area

The data were collected in all the provinces of Mozambique, during the solar radiation measurement campaign carried out by the National Energy Fund (FUNAE) [43] in 2012, 2013, and 2014 in the region of Mozambique. This covered the provinces of Maputo, Gaza, Inhambane, Zambezia, Sofala, Manica, Tete, Cabo Delgado, Nampula, and Niassa, specifically in the localities of UEM-Maputo, Massangena, Dindiza, Pomene, Lugela, Vanduzi, Choa, Chiputo, Ocuca, Nanhupo, and Massangulo, resulting in a total of 16 high-resolution radiometers positioned at distances greater than 1000 km. GHI samples were also collected between 2004 and 2024, measured at the meteorological stations of the National Institute of Meteorology of Mozambique (INAM) [44], and another sample was extracted from the PVGIS, NOAA, NASA, and Meteonorm [45] database, in the time period previously considered, a sample of atmospheric parameters was extracted from the Aerosol Robotic Network (AERONET) [46] database, with measurement intervals of 1 to 4 min, at the locations of the stations shown in Table 1.

Table 1. Location of the study stations.

Name	Province	Longitude (X)	Latitude (Y)
MZ01_UEM-Maputo	Maputo	33°6′13.64″ E	25°19′18.02″ S
MZ15_Massangena	Gaza	32°56′26.72″ E	21°34′59.51″ S
MZ17_Dindiza	Gaza	33°25′22.78″ E	23°27′37.09″ S
MZ03_Pomene	Inhambane	35°35′35.52″ E	17°47′32.54″ S
MZ03_Chomba	Cabo Delgado	39°23′36.16″ E	11°32′57.57″ S
MZ06_Maravia	Tete	31°40′33.7″ E	14°58′28.07″ S
MZ11_Nhangau	Sofala	35°2′18.72″ E	19°43′46.64″ S
MZ21_Nhapassa	Manica	33°13′0.79″ E	17°47′32.54″ S
MZ24_Nanhupo	Nampula	39°30′46.77″ E	15°57′57.38″ S
MZ25_Massangulo	Niassa	35°26′12.82″ E	13°54′25.93″ S
MZ32_Lugela	Zambezia	36°42′47.51″ E	16°28′4.45″ S

The stations are strongly correlated, from the southern region, mid to the northern part of the entire territory, depending strongly on the distance from the Indico Ocean to Zumbo, illustrating the positive relationship of dependence with travel through the region. Attached to each measurement station was a system that included an inserted pyrhelimeter that directly determined the DNI component. Together, the GHI and DHI radiation components were sampled by pyranometer radiometer sensors (NRG Systems, Houston, TX, USA) optimized for shielding with the following configurations: location factor 295–2800 nm, spectral range with 1 min response, linearity $\pm 0.5\%$, and cosine $\pm 1\%$. The collected data were directly stored in the NRG system cloud, where the interface stored

the data from three years of short-term and long-term measurements. The interface output displays the daily behavior of solar energy, the variation of the solar energy deviation, and statistical parameters such as the variance, also presenting the preliminary analysis graph as a function of the time of day, as depicted in Figure 2.

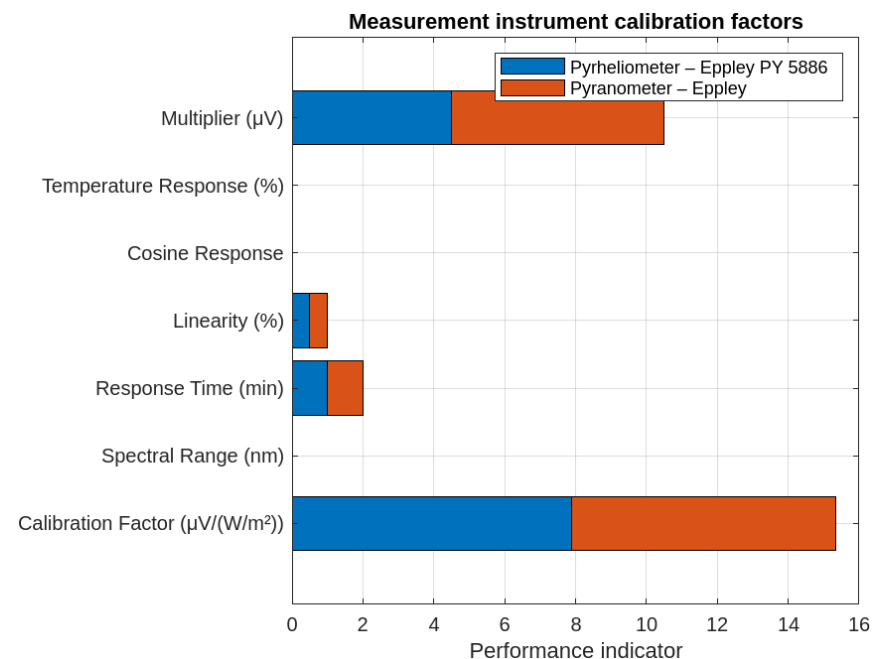


Figure 2. Characteristics and specifications of the Eppley pyranometer used in the sample collection.

2.3. Sample Size

The in-site sample consists of a period of measurements from April 2012 to December 2014, excluding the other percentage from 2012 to 2024, in 11 stations in all provinces, three of which had doubled pyranometers to better measure the power, as previous statistics revealed a high flow of energy variability in the region associated with industrial mining activity in the regions considered in UEM-Maputo, Massangena, Dindiza, Pomene, Marávia, Nhapassa (two stations), Nhangau, Massangulo (two stations), Nanhupo (two stations), and Chomba. The sample totals 1,424,388.00 days, with 512,779,680.00 GHI measurements analyzed during each day. The period from sunrise to sunset, or hours of full sunlight (N_d), was adopted for all days, taking ϕ as the local latitude and δ as the declination found from the relationship [2,15].

$$N_d = \frac{2}{15} \cos^{-1}(-\tan \phi \tan \delta) \quad (1)$$

The influx into the sample is higher between 6:00 a.m. and 6:00 p.m. Along with routine seasonal maintenance for data transfer and related maintenance, where the cleaning and orientation periods were recorded, the chosen sample also underwent quality control and the removal of erroneous values to eliminate failures that would have occurred during measurements, with the exception of data selection, such as periods of interference and turbulence. as addition to discarding atmospheric, spatial, and geographic data, the sample was saved as time series and subsequently arranged in a separator. For the aforementioned conditions, the ideal parameters were selected and evaluated, and the “good behavior” was selected and examined as input for the machine learning model (MLM). It was then determined what the K_t^* was, which is the ratio of the expected value to the theoretical global solar radiation of clear skies. The voltage angle was marked appropriately if a data calibration problem was detected, however this did not happen very often during the week-long campaign.

The study area lies between the meridians 30°12' and 40°51' longitude and the parallels 10°27' and 26°52' South latitude. Figure 3 depicts the region's topography, including the locations of the measuring stations, obtained using the data provided in the Supplementary Material ghi_station_data_collection.csv.

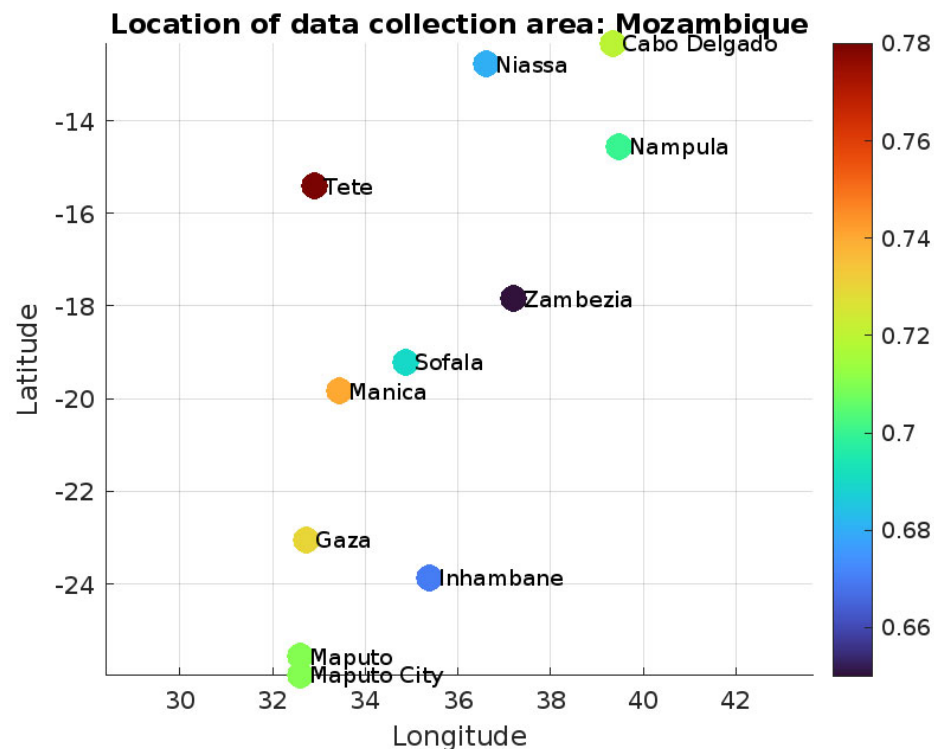


Figure 3. Section of the physical study area: region of Mozambique sample size.

2.4. Methodology

2.4.1. Spectral Characterization of the Sample

The sample population representing the development with the highest values at noon and the lowest values at the end of the day was chosen from the entire sample that was gathered and arranged into geospatial–temporal series. Nonetheless, the data exhibit distinct tendencies every day. The daily trajectory of empirically recorded solar energy and theoretical solar energy, that is, the behavior of solar energy and interruption by any atmospheric magnitude, were compared for each day. The statistical model also allows for the consideration of solar energy. Acceptable days were those when the daily energy course was within the statistical model's bounds and/or near the theoretical spectrum. Due in large part to the lack of significant outliers, as shown in Equation (2), the sample is now reliably reproduced for research and statistical analysis, lowering the margin of error [15,47].

$$\text{outliers} = \{(GHI_i | GHI) < T_1 - 1.5 \times IQR, \text{ for } GHI_i > T_3 - 1.5 \times IQR\} \quad (2)$$

As seen in Figure 4, the daily course of the ideal acceptable day displays a probability density that is both in agreement with the statistical model of the tested distribution and the theoretical optimal radiation spectrum that was generated using the theoretical model.

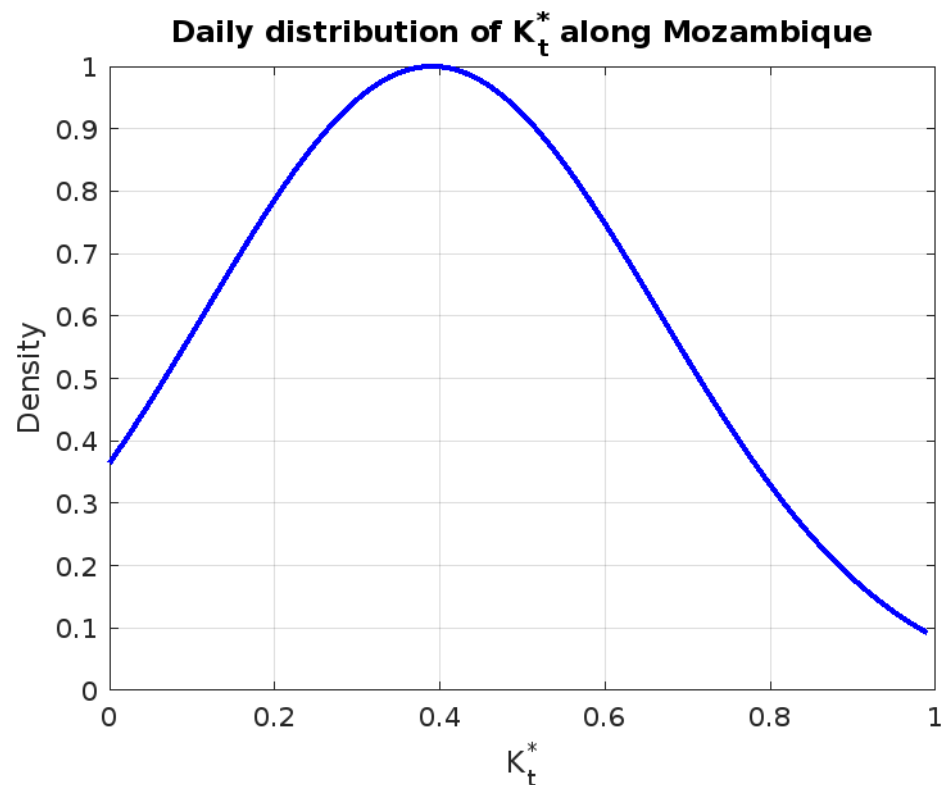


Figure 4. Daily progression of K_t^* value with time along the coast of Mozambique.

However, the sample included days which presented very oscillating values of the theoretical and/or statistical spectrum, also presenting values of sudden highs and lows as well as values above the solar constant, in which they appear in a very fluctuating and abrupt manner in relation to the theoretical and statistical spectrum, and these were considered as unacceptable days; however, their analysis contributed to the adherence to the percentage results, having these as measurements caused by multiple reflections and/or human intervention and/or of natural–animal origin among others, which conditioned other behavior analyzed in part and eliminated the outliers in their entirety from study and classification. Another set of measurements that were excluded were days with up to 50% of missing measurements because of a variety of reasons, including obstructions to the pyranometer’s solar collection interface, power outages at electrical grid-connected stations, sample transportation failures, and device deprogramming while the researcher was away. Following this, the sampling error resulting from the scale, observation, and measuring tool was calculated for every kind of data, corresponding to a 99% dependability or confidence level. According to the statistical analysis, the normal distribution is optimally adopted ($h = 0, p = 0.38534$), with energy rising from dawn until midday and then falling until the end of the day, as is typical of normal statistical distribution algorithms.

2.4.2. Experimental Procedure

The bibliometric approach to reference management, which involved managing the references and keywords related to the gathered references in the VOS viewer, was linked to the gathering of bibliographic data. The ePPI reviewer, a platform accessible at <https://eppi.ioe.ac.uk/eppireviewer-web/home>, accessed on 28 March 2025, was used to undertake the systematic analysis of the data gathered in accordance with PRISMA guidelines for systematic reviews [48]. For the collected sample, with n , the number of observation data to be distributed, the midpoints and the amplitude of oscillations $A_t = L_i - l_i$ were analyzed. The simple absolute frequency (f_i) was determined, which assumes the percentage formula,

$f_{r_i} \% = f_{r_i} \times 100$. Through the amostral mediation, the arithmetic mean of position was found. For grouped data, the classes were found, with the mode or norm (M_0) using the Czuber process with $\Delta_1 = f_{max.} - f_{ant.}$ and $\Delta_2 = f_{ant.} + f_{post.}$ [2,15,29]. The total theoretical radiation was calculated, which is the sum of the diffuse and direct radiation on the horizontal surface that arrive in a specific amount of time. Additionally, as demonstrated in Equations (3), block hybrid approaches were also applied to first-order boundary value problem (BVP) models [1,6,15,49].

$$y' = \psi(GHI, y_r) + \phi(GHI, y_r)y \quad (3a)$$

$$\psi(GHI, y_r) = f(GHI, y_r) - \frac{\partial f}{\partial y}(GHI, y_r)y_r \quad (3b)$$

$$\phi(GHI, y_r) = \frac{\partial f}{\partial y}(GHI, y_r) \quad (3c)$$

The calculation of global radiation took into consideration all predictive factors that decrease solar energy of atmospheric, meteorological, geographic, and spatial-temporal origin. These factors include the amount of water vapor, aerosols, uniformly mixed gases, and the ozone layer, which primarily reduce solar energy reaching the earth's surface by about 28%, with only about 70% of that energy being transmitted to the earth's surface and the remaining 2% being scattered to the void region. By reflecting, absorbing, and dispersing solar energy, cumulative global radiation takes into account the effects of transmittance and absorptance.

Global solar energy is the total of diffuse and direct solar energy received by Earth. Considering the zenithal angle θ_z , the diffuse irradiance by multireflection $G_{dr\lambda}$, by the aerosols $G_{da\lambda}$ and the albedo of aerosols and the ground $\rho_{g\lambda}\rho'_{a\lambda}$, g is combined using the formula in Equation (4) [15,17], as follows:

$$G = \frac{(G_{n\lambda}\cos\theta_z + G_{dr\lambda} + G_{da\lambda})}{(1 - \rho_{g\lambda}\rho'_{a\lambda})} \quad (4)$$

The results of machine learning models, such as simple linear regression (SLR), random forest (RF), regression kriging (RK), support vector machine model (SVM), autoregressive integrated moving average (ARIMA), gradient boosting machines (GBMs), gaussian process regression (GPR), and networks with long short-term memory (LSTM), were subjected to summative analysis. Artificial neural networks were specifically targeted because they demonstrated a lower ANN error margin of order 6.30 W/m^2 . Taking into account an input range of u_1 to u_n for each neuron j , the weights w_{ij} , gathered in neuron j , ANN is indicated by the relationship in Equation (5) [50,51].

$$G_j = \sum_{i=1}^n w_{ij}u_j + w_{0j} \quad (5)$$

The random forest model (RF) with r being a parameter that amplifies the relevance of closer neighbors and reduces the weights of more distant ones, given by Equation (6) as follows [1,6,15,49]:

$$\bar{z}(N_0^k) = \frac{\sum_{i \in N_0^k} \lambda_r GHI_i}{\sum_{i \in N_0^k} \lambda_i} \quad (6)$$

The support vector machine (SVM) model is used to find the maximum martingale of a group of n points, where each point has a multidimensional vector. The model's output is a vector of rank -1 (with the average *Hinge Loss*), given in Equation (7) as follows: [16,19,52]

$$\|w\|^2 + C \cdot \text{Hinge Loss} \quad (7)$$

The ARIMA model is a statistical analysis method that uses time series data to understand and predict future trends, using parameters like L^i , θ_i , L and ε_t to represent normal distribution with zero media ($A(L)$ and $B(L)$ are lag polynomial for X_t) and ε_t , given in Equation (8) as follows: [7,44,49]

$$A(L)X_t = B(L)\varepsilon_t \quad (8)$$

Kriging regression (RK) is a geostatistical model that combines regression by interpolation and spatial interpolation. It predicts the regression rate using a mean $\hat{z}(GHI_0)$, and taking β and coefficients of regression, $\hat{m}$ as trends, $\hat{e}$ as residuals, and $\hat{w}$ as Kriging weights, as follows: [7,16,42]

$$\hat{z}(GHI_0) = \hat{m}(GHI_0) + \hat{e}(GHI_0) \quad (9)$$

Simple linear regression (SLR) shows the relationship between an independent variable x and a dependent variable, with linear function and identic error terms. It differs between observed values and a dependent variable, based on continuous variables and x , given in Equation (10) as follows: [10,49,52]

$$\hat{GHI}_i = \beta_0 + \beta_1 \cdot GHI_i + \varepsilon_i \quad (10)$$

The Persistence model is a simple forecasting method that assumes future value, $\hat{X}_{t-1}$ and forecasted at time $t + h$, while the Horizonte model is used as a benchmark, given by Equation (11) as follows: [7,15,49,50]

$$\hat{GHI}_{t-1} = GHI_t \quad (11)$$

The Gradient boosting machines (GBMs) are a model used for regression classification that combines decision trees to create a prediction/forecasting model, with initial condition $F_0(GHI)$, given by the prediction in Equation (12) as follows: [1,6,18,42]

$$\hat{GHI}_i = F_0(GHI_i) + \sum_{m=1}^M \eta h_m(GHI) \quad (12)$$

The Gaussian process regression (GPR) is a non-parametric Bayesian regression technique that offers a flexible approach for modeling complex data relationships, assuming a Gaussian process, given by Equation (13) as follows: [10,35,51]

$$f(GHI) \sim GP(m(GHI), k(GHI, GHI')) \quad (13)$$

Long short-term memory (LSTM) networks are recurrent neural networks designed to accumulate and predict data sequences. They consist of cell state, input gate, hidden state, and forget gate, which determine the amount of information to store and remember, given by Equation (14) as follows: [24,43,49]

$$f_t = \sigma(W_f[h_{t-1}, GHI_t] + b_f) \quad (14)$$

The days analyzed are within the theoretical distribution range of clear-sky radiation, obeying a normal distribution curve. To link the GHI with clear-sky radiation, the K_t^* was introduced. This index represents the correlation between the GHI and the theoretical clear-sky radiation, which refers to the irradiation of the earth's atmosphere on cloudless days [3,26,52], shown in Equation (15) [7,20,38] as follows:

$$K_t^* = \frac{GHI}{G_{Clear}} \quad (15)$$

G_{Clear} is the total radiation received on a horizontal surface, which includes direct and diffuse radiation over a one-hour period. The mean value was determined using a one-day GHI measurement interval (amplitude) with M measurement intervals to categorize various sky types. The separatrix was determined, whose impeccable progression of the daily path perfectly corresponded to the theoretical frequency density and the frequency of the K_t^* averages derived from Equation (6). This demonstrates an ideal representation of the experimental treatment, sample selection and the K_t^* algorithm used. To assess fluctuations in temporal variability, a metric to calculate the disparity between current and previous values of the K_t^* was employed. The obtained values of the K_t^* were separated into classes, thus determining the number of classes (n).

After analyzing the distribution of the gathered solar radiation, it was found to be symmetrical, bell-shaped, and to have a spectrum of infinite values in both directions, all of which are identical to the normal distribution. However, the probability density distribution was also derived for our research, which focuses on the region of interest during the 6 a.m. to 6 p.m. hours of sunshine.

After estimating and obtaining the solar energy based on K_t^* , it was classified into classes of days with a percentage of 16 classification blocks (statistical quartiles of sample classification and GHI). However, the classification of the days was for each year in all the measured stations in order to better map the energy.

Cloudy-sky days, which are defined by a low variation in comparison to the sample norm for these days, were found to be those that fall inside the first qualifier of the statistical classification, which is less than 25% of the entire range. On the other hand, days with an average clear-sky index of 75% to 25% were categorized as intermediate-sky days. These days showed a high deviation and continuous variations in solar energy, which could influence PV production and result in damage to apartments because of the high output variability in a solar plant.

However, days that exceeded 75% of the sample maximum for each year are categorized as clear-sky days. These days have a high degree of clear-sky index and a low deviation; the percentage is larger during the hot and rainy season, but the deviation is bigger than that of cloudy-sky days. In order to improve the filling of gaps in missing sample data for a number of previously discussed concerns, the random forest model was employed, with a particular emphasis on the inverse distance weighting (IDW) model. Random forest and ordinary kriging were the models that were most suited for this purpose. The ordinary kriging interpolative model is used to estimate the solar energy at other stations from the station, but the IDW model, considering vectors and $\vec{w} = \frac{\vec{d}^{-p}}{d^{-p}}$, with p as the power parameter, it which fully covers the analysis region using the following connection, is also given more attention, as shown in Equation (16) [4,53].

$$\vec{Z}(GHI) = \frac{\sum_{i=1}^n z_i(GHI)w_i}{\sum_{i=1}^n w_i} \quad (16)$$

The energy examined on all days inside the theoretical radiation spectrum based on analyzed K_t^* histograms indicate a very good fit, according to the statistical testing of

the examined model. Based on the t-student sample analysis, however, the hypothesis of high energy flow with solar energy potential was demonstrating a stronger influx in the center with decorrelative displacements, displaying asymmetry Skewness: 1.19, with Kurtosis: 3.0525. It further supports the decision presented here. The distribution of solar energy over the course of a day with a measurement interval of 1 to 10 min has a right-hand tail (positive model), but it also demonstrates that the distribution has heavy tails (positive model).

It was shown that the final analysis presented a greater accuracy of sample visualization and its variance, with intermediate-sky days in all the stations evaluated in all provinces presenting greater variance. This was done by separating the extracted sample into classes of types of solar energy days, assuming hypotheses that they are of the same magnitude.

However, cloudy days compared to clear days show homogeneously greater variance, compared to overcast days ($Prob > F$). Intermediate-sky days are the days most prone to high fluctuations in solar energy, due to the high variations and instability of solar energy reaching the earth's surface. In order to observe the accumulation of days in all classes simultaneously, histograms were created. These histograms plotted the variation of K_t^* against the frequency density for each type of day in each year. Different values of K_t^* were examined for different types of days (clear, intermediate, and cloudy), establishing a link based on the distance of the correlation coefficient or systematic relationship of the clear-sky index $\rho_{ij}^{\Delta K_t^*}$, as shown in Equation (17) [15,26,54].

$$\rho_{ij}^{\Delta K_t^*} = \frac{cov(\Delta K_{t,i}^*(t), \Delta K_{t,j}^*(t))}{\sigma_{\Delta K_{t,i}^*(t)} \sigma_{\Delta K_{t,j}^*(t)}} \quad (17)$$

The increments and corresponding arithmetic means of the time series between two location i e j , denoted as $\Delta K_{t,i}^*$, $\Delta K_{t,j}^*$ and $\overline{\Delta K_{t,i}^*}$, $\overline{\Delta K_{t,j}^*}$, respectively, were analyzed [15,54]. Statistically, the inequality $-1 \leq \rho_{ij}^{\Delta K_t^*} \leq 1$ holds true. Spatially, when considering a subspace station located between two points x' and y' , the randomized values related to $x' + y'$ can be expressed as $\sigma_{x'+y'}$ (it is important to note that $\sigma_{\Delta K_{t,i}^*} \neq 0$ and $\sigma_{\Delta K_{t,j}^*} \neq 0$) [55–58]. Inferring the regression coefficient of K_t^* and its increments $\beta_{ij}^{\Delta K_t^*}$, as shown in Equation (18) [29,32].

$$\Delta K_{t,j}^*(t) = \alpha_l + \beta_{ij}^{\Delta K_t^*} \Delta K_{t,i}^*(t) + \varepsilon_t \quad (18)$$

With α_l as the intercept constant and ε_t as the error term, described the characteristics of the regression inferential analysis of K_t^* and its increments for various classes and types of days in all years, between the previously indicated seasons [29,58–60].

3. Results

3.1. Estimates of the Solar Energy's Temporal Evolution Using Local Predictors

The daily course of a day at all the stations under evaluation shows an average intensity of about 1297 W/m², with maximum and minimum allowable averages of about 94 W/m². Nevertheless, solar energy changes from sunrise to sunset, exhibiting the aforementioned maximum, and then gradually declining until the end of the day. The annual course of solar energy averages in all the stations across the analyzed territory peaks between September and February during the hot and rainy season, and troughs between March and August during the cold and dry season, which is near the equinoxes. The fact that the planet faces this energy flow throughout the summer months helps to explain this; the southern hemisphere receives more solar energy thanks to this orientation, as shown in Figure 5.

The ozone layer contributes to the excitation of gases inside its layer, enabling energy transitions and the development of layers that are more susceptible to solar radiation, shown in Figure 5a. Rainwater drains some aerosols, but it also gives others energy to take part in atmospheric energy shifts, depicted in Figure 5b.

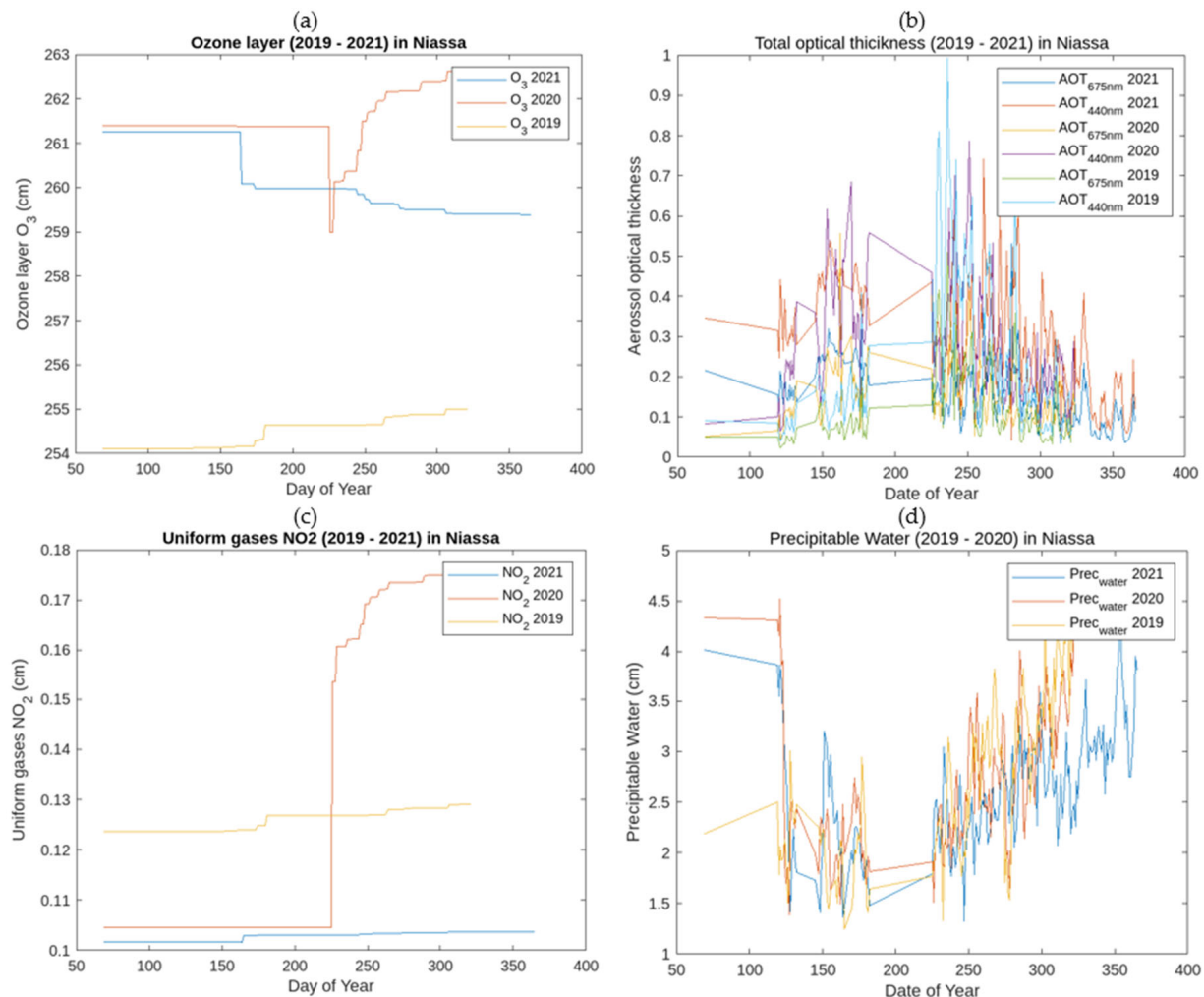


Figure 5. Spatial-temporal atmospheric parameters reduction solar energy on the earth's surface, (a) ozone layer, (b) aerosols (total optical thickness), (c) uniformly mixed gases, and (d) precipitable water.

However, water vapor, for example, is agitated by thermal exchanges and excitation and can precipitate towards the earth even during this season, as shown in in Figure 5c. The entropy of systems is disturbed, which causes some gases and particles to move to more static areas, increasing the precipitable water as shown in in Figure 5d.

This season, however, has a higher average solar energy transmittance of 0.98, which enables the earth to receive a larger share of energy and is always susceptible to clear-sky days. higher moderate and clear days, with an estimated 92% sun energy incidence rate based on the contribution of all solar energy prediction criteria.

The earth's translation during the cold and dry season, however, turns the earth in the Southern Hemisphere with its back to the direction of solar energy reception. This phenomenon of the earth's rotation around its axis contributes to the daily scattering by Rayleigh or Mie scattering, which is the result of receiving less energy traveling through greater space and the intensity of energy being weakened by the distance it travels. Observing the projection of areas varied in equal time intervals, there is no perfectly circular

trajectory and can be elliptical, occasionally presenting the region of study even further away from the sun.

This suggests that a considerable amount of the incident energy is absorbed, with aerosols, water vapor, and mixed gases that have the ability to undergo energy transitions and produce smooth discharges absorbing a larger amount of this energy. The ozone layer also contributes to this growth, increasing solar energy absorption and lowering transmittance during this time by around 0.56, as Figure 6 illustrates.

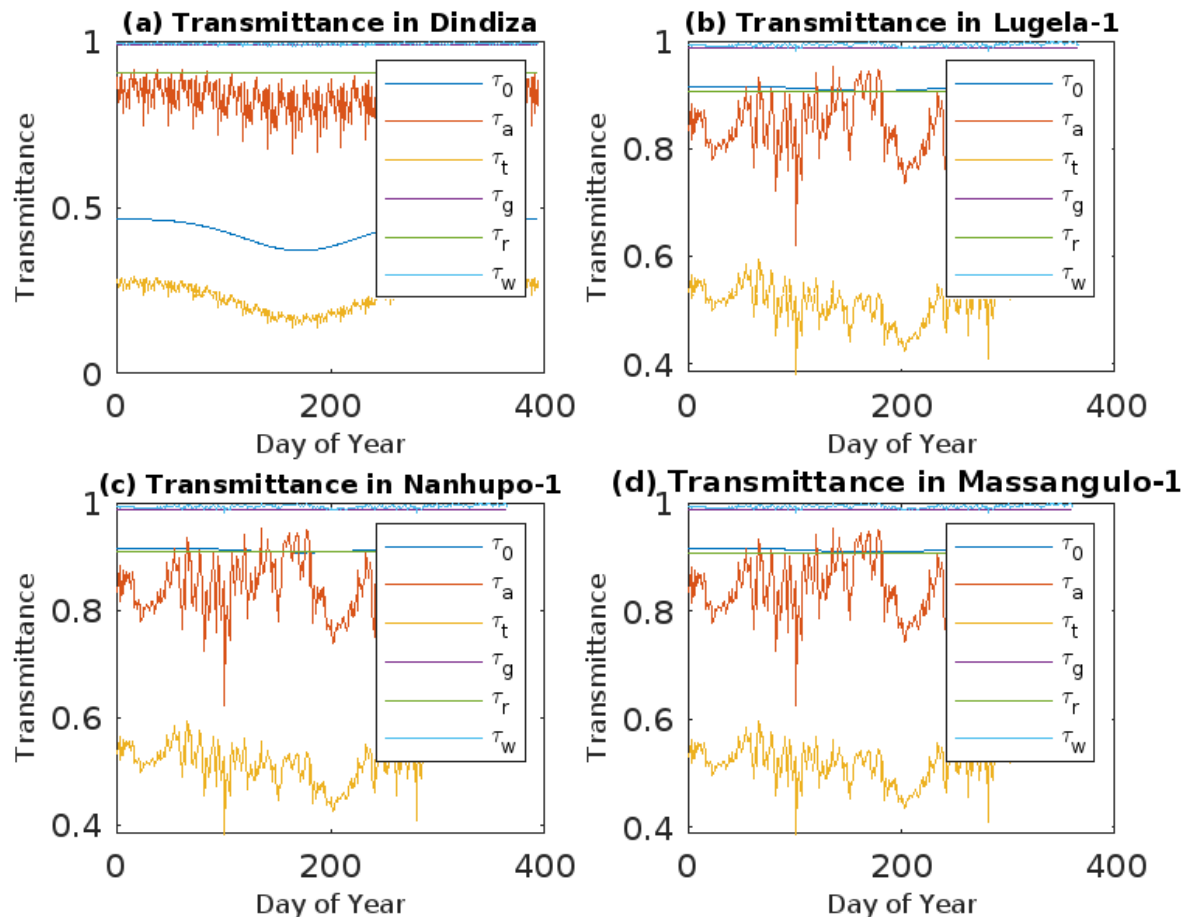


Figure 6. Influence of atmospheric transmittance on the disposition of solar energy on the earth's surface. The energy absorbed and reflected from the fraction transmitted by it as the summative atmospheric cloud blocking sun energy can be estimated since the transmittance displayed is multiplicative between the transmittances due to all atmospheric characteristics. The 2020 and 2021 years are depicted in the above images. Due to the ongoing strengthening of atmospheric parameter deposition by earthly activity, a greater transmittance was observed at the Nipepe station in 2020 compared to 2021 at Massangulo-1 located in the province of Niassa.

Nevertheless, the amount of solar energy entering the system is reduced. Above all, the predictor particle stationarity has a significant role in the formation of the cloud that lowers solar energy and contributes to the rise in solar energy increments of about -0.05 , which lowers the K_t^* . On cloudy days, it stays below 0.3 and falls between 0.3 and 0.8 on days in between. On days with clear skies, however, its intensity might range from 0.8 to 1, indicating a substantial influx of solar energy. The MLMs that focus on the output of the ANN model, whose measured energy fully matches with the correction to the calculated energy, with a margin of error between 5 and 10 W/m^2 , provide an excellent summary of the solar energy estimated based on the predictor parameters. A comparison between the actual and predicted K_t^* values is presented in Figure 7, which also explains

how atmospheric parameters are actually causing the simultaneous energy fluctuation on the horizontal surface and how fleet management of this can fully resolve the issue of output variability in a solar plant.

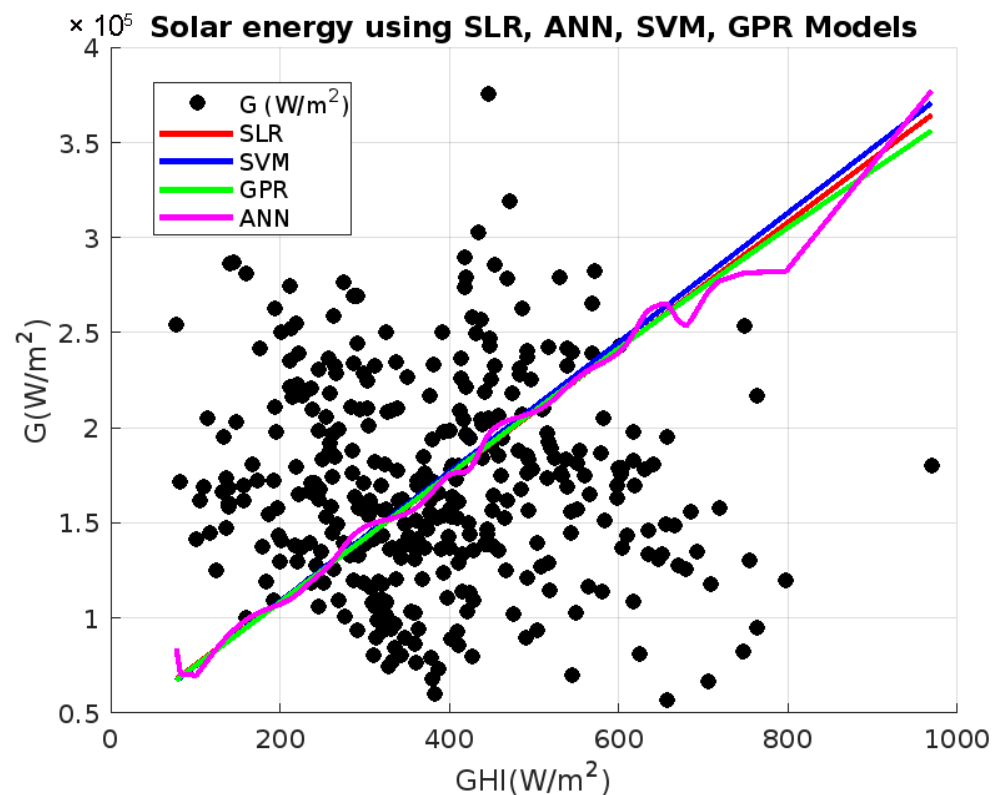


Figure 7. Estimation of global solar energy using SLR, SVM, GPR, RF, and ANN (enabled for GHI behavior) machine learning models.

A better understanding and favorable tests were obtained for the estimated radiation values in the order of error assessment based on MAE (W/m^2), MAPE (%), RMSE (W/m^2), and a coefficient error, R^2 , by using the ANN and RF models and their variables in all the stations under consideration. For instance, additional treatment attention and evaluation was given to the entire sample from 2004 to 2024. In 2021, the Massangulo station at Niassa had ANN errors of 7.45, 4.02, 11.48, and 0.82; RF errors of 10.14, 4.44, 15.74, and 0.91; RK errors of 27.08, 11.74, 35.46, and 0.32; SVM errors of 27.07, 11.65, 35.48, and 0.31; ARIMA errors of 25.15, 11.81, 34.41, and 0.42; GBM errors of 25.11, 11.23, 34.08, and 0.42; GPR errors of 24.14, 11.10, 35.03, and 0.41; LSTM errors of 25.02, 10.15, 33.14, and 0.39; and SLR errors of 30.41, 11.14, 34.05, and 0.92 (compiled from the Supplementary data set quantification_total_days.csv). The decrease in solar energy that reaches the planet is a result of geographic, spatiotemporal, and regressive factors. The output of a solar plant significantly reduces the variations in solar energy when this energy is taken into account for measuring the flux, as the preceding figure demonstrates. This allows for a greater focus on the impacts of variability in small-area solar panel systems.

Larger regions likely have higher inefficiencies and a higher chance of converting radiation collected over a larger area through the PV effect and consistent production, but tiny areas do not experience these outcomes. Nevertheless, Figure 8 illustrates that the theoretical energy displays the energy range in the absence of any factor lowering the intensity of solar energy when solar energy is evaluated using the parameterization. The estimated solar energy is near the theoretical energy when all predictors are taken into account. This allows for the selection and assessment of each predictor based on the

transmission of energy to the earth's surface and the transmittance of that energy. Figure 8 illustrates how the cumulative taxation of diffuse parameters, including Rayleigh scattering and Mie scattering of extremely small diffuse transmittances, leads to a larger diffuse energy relative to other diffuse characteristics, obtained partially from the Supplementary data set quantification_total_days.csv.

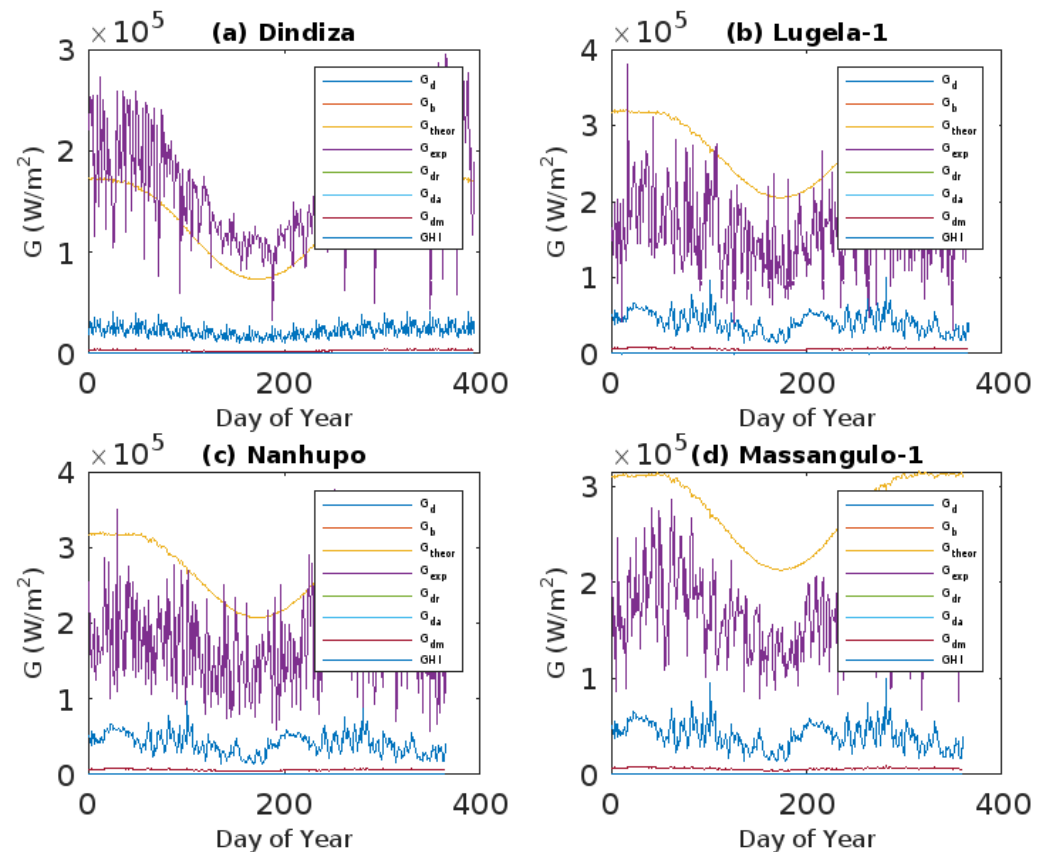


Figure 8. Summative solar energy characteristics of the seasons throughout the territory under analysis, specifically in (a) Dindiza (2014), (b) Lugela-1 (2014), (c) Nanhupo-1 (2014) and (d) Massangulo-1 (2014). In all regions near the theoretical energy, the global energy is displayed. Although the transmittance level is higher in the summer and to the detriment of the cold season, this estimate greatly eliminates swings.

Clear-sky days have K_t^* values near 1, while cloudy days have values between 0.1 and 0.2. Occasionally, intermediate-sky days have intermediate characteristics, showing values between upper intermediate (near cloudy) and superior intermediate (near clear days). The destruction of the void region, atmospheric depletion, and current climate changes, primarily due to climate change gases, are the main causes of the increase in solar energy. As a result, all types of days have a central maximum near zero, but on cloudy days, it gently decreases to values below the frequency density in the order of 0.001; on clear days, it presents flattened edges and decreases to a density in the order of 0.03; and on intermediate-sky days, it presents long and very flattened edges, descending gently to frequency density values in the order of 0.2, additional description of related geospatial–temporal distribution of solar energy is characterized in Section 3.2, partially based in visual analyses from randomized compiled data of K_t^* and ΔK_t^* provided in the Supplementary Material south_mid_north_data.csv.

3.2. Geospatial–Temporal Distribution of Solar Energy in Terms of Clear-Sky Days

The distribution of solar energy in terms of K_t^* over 8 months in 2012 revealed a varying intensity energy density. The southern region of Mozambique has an $\overline{K_t^*}$ of 0.8779, with acceptable days ranging from 0.8489 to 0.9068. This average is consistent across Gaza province, Massangena district, and Inhambane province. The $\overline{K_t^*}$ is also varying between acceptable days (0.8956 for acceptable days and 0.9046 for unacceptable days) and between acceptable days (0.5686 for acceptable days and 0.3638 for unacceptable days), as depicted in Figure 9a.

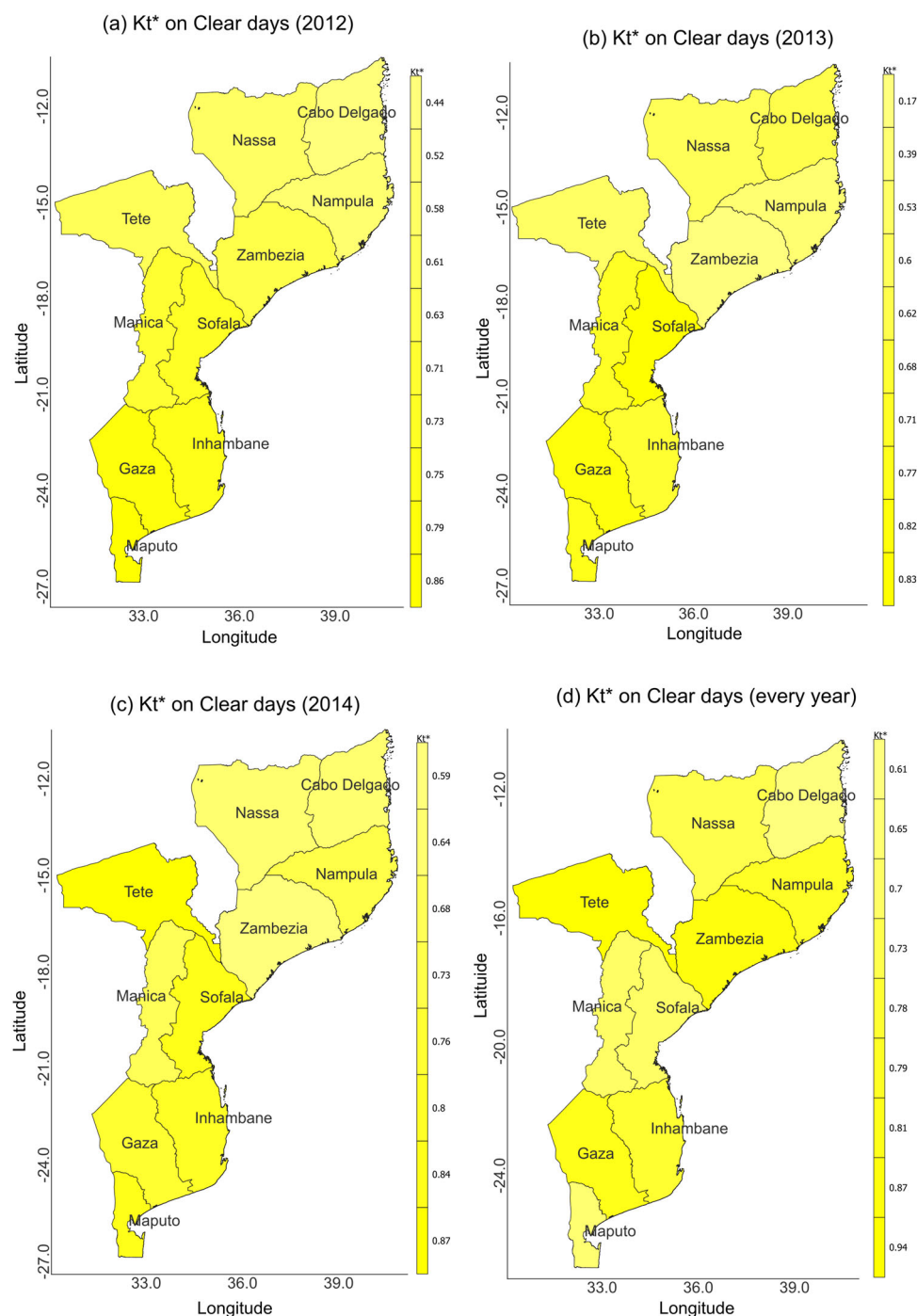


Figure 9. Map of geospatial temporal distribution of solar energy in Mozambique, through modeling of K_t^* during the years 2012, 2013, and 2014, and in all years for clear-sky days, being (a) K_t^* on clear days in 2012, (b) K_t^* on clear days in 2012, (c) K_t^* on clear days in 2014, and (d) K_t^* on clear days in all years.

The analysis of the mid-region of Mozambique reveals that the provinces of Tete, Sofala, Manica, Lugela, and Zambezia have varying average K_t^* values. Tete has an $\overline{K_t^*}$ of 0.6195, with acceptable days ranging from 0.8723 to 0.3668. Sofala has an $\overline{K_t^*}$ of 0.7360, with acceptable days ranging from 0.8197 to 0.6319. Manica has an $\overline{K_t^*}$ of 0.7258, with acceptable days ranging from 0.8197 to 0.6319. Lugela-1 has an average K_t^* of 0.6936, with acceptable days ranging from 0.7812 to 0.6061, and an average of 0.6385 for Lugela-2. The North region of Mozambique has an $\overline{K_t^*}$ of approximately 0.6033 for Niassa (Massangulo-1 station), 0.7071 for acceptable days, and 0.5134 for unacceptable days (Massangulo-2 station), 0.5854 for Nampula (Nanhupo-1 station), 0.5444 for Nampula (Nanhupo-2 station), and 0.4434 for Cabo-Delgado (Chomba station). These averages range from 0.8956 for acceptable days to 0.9068 for unacceptable days. The provinces have varying levels of acceptable and unacceptable days, as depicted in Table 2.

Table 2. Geospatial–temporal distribution of solar energy in terms of clear-sky days in 2012.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.8779	0.3399	0.8489	0.7141	0.9068	−0.0343
	Gaza	Dindiza	0.8425	0.2569	0.8483	0.4483	0.7569	0.0408
		Massangena	0.8545	0.3756	0.8956	0.2489	0.8489	0.0348
	Inhambane	Pomene	0.7589	0.2778	0.8478	0.3483	0.7912	0.0748
Mid-region	Tete	Marávia	0.6195	−0.0256	0.8723	−0.0274	0.3638	−0.0238
	Sofala	Nhangau	0.7360	−0.0597	0.8197	−0.0727	0.6319	−0.0467
	Manica	Nhapassa-1	0.7258	−0.0403	0.8197	−0.0621	0.6319	−0.0185
		Nhapassa-2	0.7245	−0.1303	0.8489	−0.2351	0.6001	−0.0255
	Zambezia	Lugela-1	0.6937	−0.0414	0.7812	−0.0508	0.6061	−0.0319
		Lugela-2	0.6385	−0.0459	0.7437	−0.0631	0.5332	−0.0288
North region	Niassa	Massangulo-1	0.6033	−0.1109	0.7071	−0.1609	0.5528	−0.0609
		Massangulo-2	0.6049	−0.1211	0.7570	−0.1711	0.5134	−0.0702
	Nampula	Nanhupo-1	0.5854	−0.0793	0.6385	−0.0977	0.5323	−0.0609
		Nanhupo-2	0.5444	−0.0544	0.5686	−0.0721	0.5202	−0.0367
	Cabo-Delgado	Chomba	0.4434	−0.0475	0.6019	−0.0825	0.4434	−0.0475

The analysis of solar energy distribution in Mozambique over 2012, spanning 8 months, reveals a differential density of $\Delta\overline{K_t^*}$, as showed in Table 2. The $\Delta\overline{K_t^*}$ in the southern Mozambique region is 0.4219, with acceptable days ranging from 0.8572 to 0.6168, while in Maputo, Gaza, Massangena, and Inhambane, the average is 0.8779, 0.8425, and 0.8545, respectively. The $\Delta\overline{K_t^*}$ is also varying in the provinces of Maputo, Gaza, Massangena, and Pomene, as illustrated in Figure 10a.

The mid-region of Mozambique has an average $\Delta\overline{K_t^*}$ of −0.0256, with acceptable days ranging from −0.0274 to −0.0238, at the province of Tete (Marávia station). Sofala province has an $\Delta\overline{K_t^*}$ of −0.0597, with acceptable days ranging from −0.0727 to −0.0467. Manica province has an $\Delta\overline{K_t^*}$ of −0.0403, with acceptable days ranging from −0.0621 to −0.0185. Zambezia province has an average −0.0414, with acceptable days ranging from −0.0508 to −0.0319, and unacceptable days ranging from −0.0631 to −0.0288 at Lugela-2. The North region shows an $\Delta\overline{K_t^*}$ in the provinces of Niassa, Nampula, and Cabo-Delgado. In Niassa, the average is −0.1109, with acceptable days ranging from −0.1609 to −0.0609, and unacceptable days ranging from −0.1711 to −0.0702. In Nampula, the average is −0.0793,

with acceptable days ranging from -0.0977 to -0.0609 , and unacceptable days ranging from -0.0721 to -0.0367 . The province of Cabo-Delgado (Chomba station) has an average ΔK_t^* of -0.0475 , with -0.0825 for acceptable days and -0.0475 for unacceptable days.

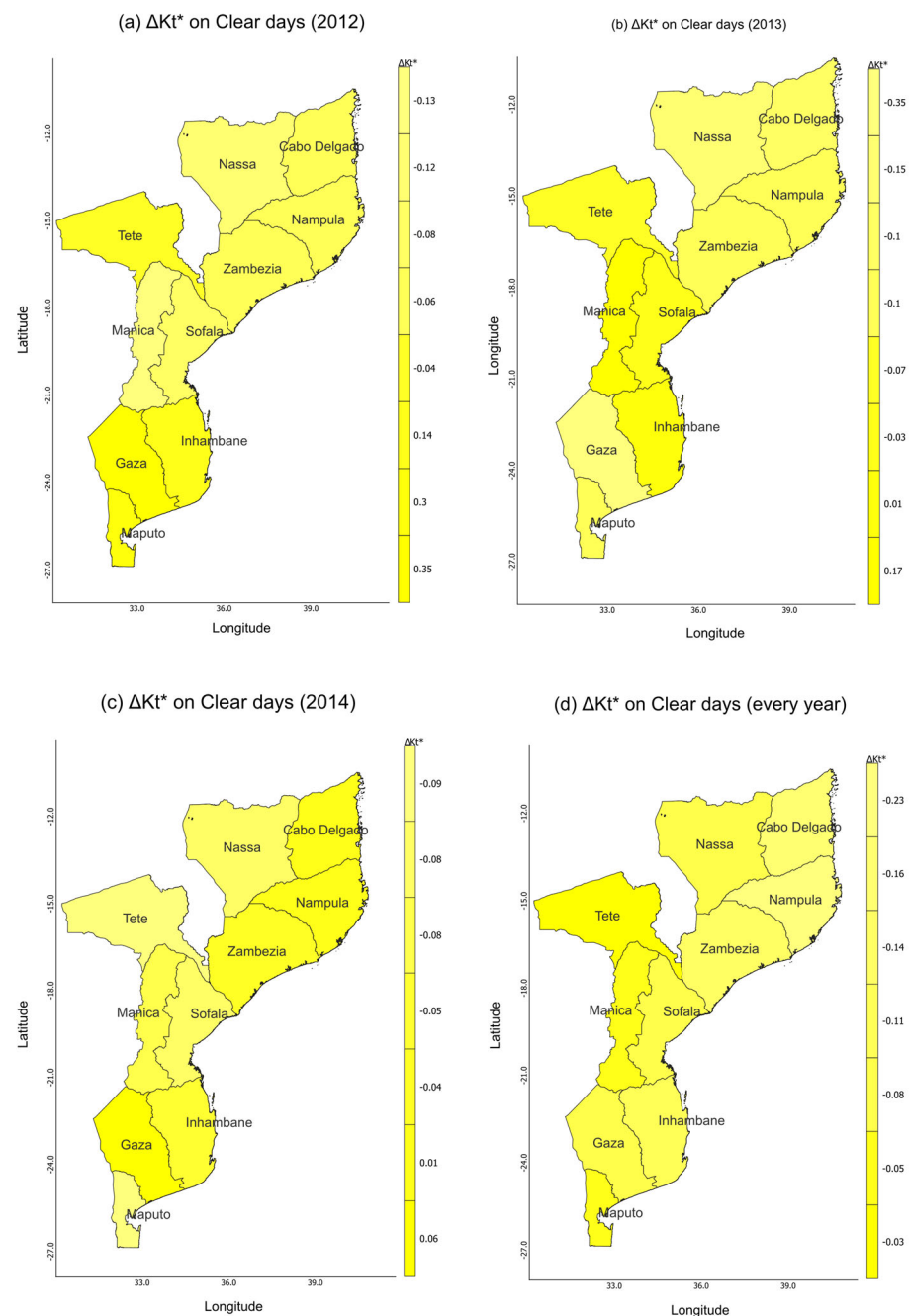


Figure 10. Map of geospatial temporal distribution of solar energy in Mozambique, through modeling of ΔK_t^* during the years 2012, 2013, and 2014, and in all years for clear-sky days, being (a) ΔK_t^* on clear days in 2012, (b) ΔK_t^* on clear days in 2012, (c) ΔK_t^* on clear days in 2014, and (d) ΔK_t^* on clear days in all years.

In 2013, the density of K_t^* was found to be distributed unevenly in terms of solar energy availability. The $\bar{K}_t^*$ in the southern region of Mozambique is 0.7816, with acceptable days ranging from 0.7528 to 0.8539. In Maputo, Gaza, Massangena, and Inhambane provinces, the $\bar{K}_t^*$ is also 0.8219, with acceptable days ranging from 0.8463 to 0.8489, depicted in Figure 9b. These averages are consistent across the country. In 2013, the mid-region of Mozambique had an K_t^* of 0.5774 in Tete, 0.8501 in Sofala, 0.7276 in Manica, 0.7255 in

Napassa-1, and 0.7246 in Napassa-2, respectively. In Zambezia, the $\overline{K_t^*}$ was 0.1585, and 0.1686, with no acceptable days and unacceptable days, respectively. These data highlight the challenges faced by the region in managing its climate and ensuring sustainable development. The North region shows $\overline{K_t^*}$ values in Niassa, Nampula, and Cabo-Delgado provinces. Massangulo-1 station in Niassa has an $\overline{K_t^*}$ of 0.6172, with acceptable days ranging from 0.7215 to 0.5128. Nampula province has an $\overline{K_t^*}$ of 0.4412, with acceptable days ranging from 0.6549 to 0.2275. Cabo-Delgado's $\overline{K_t^*}$ is 0.6286, with no acceptable days and 0.6380 for unacceptable days, as shown in Table 3.

Table 3. Geospatial–temporal distribution of solar energy in terms of clear-sky days in 2013.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.8219	−0.0878	0.8463	−0.3456	0.8489	−0.02458
	Gaza	Dindiza	0.7896	−0.0786	0.6489	−0.0358	0.8756	−0.0358
		Massangena	0.8256	−0.3456	0.7256	0.2489	0.8456	0.1489
	Inhambane	Pomene	0.6892	0.0467	0.7895	−0.0849	0.8458	−0.0848
Mid-region	Tete	Marávia	0.5774	−0.0550	0.6659	−0.0939	0.4891	−0.0162
	Sofala	Nhangau	0.8501	−0.0057	--	--	0.8502	−0.0057
	Manica	Nhapassa-1	0.7255	−0.7801	0.8197	−0.0821	0.6319	−0.0639
		Nhapassa-2	0.7246	0.7296	0.8489	0.8489	0.6001	0.6001
	Zambezia	Lugela-1	0.1588	−0.0853	---	---	0.1588	−0.0853
		Lugela-2	0.1686	−0.0853	---	---	0.1626	−0.0875
North region	Niassa	Massangulo-1	0.6172	−0.1111	0.7215	−0.1525	0.5128	−0.0697
		Massangulo-2	0.6189	−0.1123	0.7219	−0.1545	0.5189	−0.0997
	Nampula	Nanhupo-1	0.4412	−0.0881	0.6549	−0.0919	0.2275	−0.0843
		Nanhupo-2	0.4411	−0.0881	0.6575	−0.0938	0.2248	−0.0849
	Cabo-Delgado	Chomba	0.6286	−0.0997	---	---	0.6380	−0.0853

The analysis of solar energy distribution in Mozambique over 2013 reveals a density of $\Delta\overline{K_t^*}$ in the differentiated, as depicted in Figure 10b. The $\Delta\overline{K_t^*}$ in the southern region of Mozambique is −0.0878 in Maputo, Gaza, Massangena, and Inhambane provinces. The acceptable days range from −0.3456 to −0.0246, with unacceptable days being between −0.0634 and −0.0245. The $\Delta\overline{K_t^*}$ in md-region of Mozambique is −0.0550, with −0.0939 acceptable days and −0.0162 unacceptable days. In Sofala, it is −0.0058 with no acceptable days and −0.0057 unacceptable days. In Manica, it is −0.7801 with −0.0821 acceptable days and −0.0639 unacceptable days. In Zambezia, it is −0.0853, with no acceptable days and −0.0853 unacceptable days. In Lugela-2, it is −0.0853, with no acceptable days and −0.0875 unacceptable days. The northern region of Mozambique has an $\Delta\overline{K_t^*}$ of −0.0619, with acceptable days ranging from −0.0722 to −0.0518. In Niassa, the average is −0.1111, with acceptable days ranging from −0.1525 to −0.0697. In Nampula, the average is −0.0881, with acceptable days ranging from −0.0919 to −0.0843. In Cabo-Delgado, the average is −0.0997, with no acceptable days and −0.0853 for unacceptable days.

The analysis reveals that in 2014, over a 12-month period, the density of K_t^* was observed to be in a diversified order, as shown in Figure 9c. The southern region has an average $\overline{K_t^*}$ of 0.8728, with acceptable days ranging from 0.8489 to 0.8998. In Maputo, Gaza, Massangena, and Inhambane, the $\overline{K_t^*}$ is 0.7722, with acceptable days ranging from 0.7011 to 0.4592. The $\overline{K_t^*}$ in Inhambane is also 0.82256, with acceptable days ranging from 0.7563 to 0.8562. The $\overline{K_t^*}$ in mid-region of Mozambique is 0.9774 in Tete province, 0.8521 in Sofala province, 0.9856 in Manica province, 0.7258 and 0.7244 in Nhapassa-1 and Nhapassa-2 stations, and 0.6612 in Zambezia province. These averages range from 0.8443 for acceptable days to 0.6001 for unacceptable days. The $\overline{K_t^*}$ values vary across different stations, with some stations having no acceptable days and others having unacceptable days. The data are based on Marávia station data. The northern region of Mozambique has an $\overline{K_t^*}$ of 0.5128 in the province of Niassa, with no acceptable days and 0.5133 for unacceptable days. In the province of Nampula, the $\overline{K_t^*}$ is 0.6446, with no acceptable days and unacceptable days. In the province of Cabo-Delgado, the $\overline{K_t^*}$ is 0.6468, with no acceptable days and 0.7282 for unacceptable days. These conditions are observed at Massangulo-1, Nanhupo-1, and Chomba stations, as depicted in Table 4.

Table 4. Geospatial–temporal distribution of solar energy in terms of clear-sky days in 2014.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.8548	−0.0875	0.8489	−0.1245	0.8489	−0.0342
	Gaza	Dindiza	0.7722	0.0876	0.7011	−0.0956	0.8582	−0.0456
		Massangena	0.7569	0.0844	0.6259	−0.1244	0.4592	−0.4578
	Inhambane	Pomene	0.82256	−0.0458	0.7563	−0.0045	0.8562	−0.0025
Mid-region	Tete	Marávia	0.9774	−0.0859	--	--	0.9856	−0.0879
	Sofala	Nhangau	0.8521	−0.0815	0.7892	−0.0897	0.8956	−0.0526
	Manica	Nhapassa-1	0.7258	−0.0456	0.6259	−0.0148	0.8789	−0.2589
		Nhapassa-2	0.7244	−0.0744	0.6001	−0.0085	0.8489	−0.0256
	Zambezia	Lugela-1	0.6612	−0.0618	---	--	0.7666	−0.0115
		Lugela-2	0.5886	−0.0255	---	--	0.5886	−0.0204
North region	Niassa	Massangulo-1	0.5128	−0.0515	--	--	0.5133	−0.0601
		Massangulo-2	0.6523	−0.0788	---	--	0.7525	−0.0658
	Nampula	Nanhupo-1	0.6446	−0.0612	---	--	0.7656	−0.0909
		Nanhupo-2	0.7528	0.0518	---	--	0.7962	−0.0909
	Cabo-Delgado	Chomba	0.6468	0.0545	---	--	0.7282	−0.0456

The analysis of solar energy distribution in Mozambique over 2014, spanning 12 months, reveals a density of $\Delta\overline{K_t^*}$ in the differential, as shown in Figure 10c. This study found that the southern region of Mozambique has an average density of $\Delta\overline{K_t^*}$ of −0.0875 in the province of Maputo, Gaza, Massangena, and Inhambane, with varying values at different stations. The density is consistent across all the years of measurements. The $\Delta\overline{K_t^*}$ in the mid-region of Mozambique is observed in several provinces, including Tete, Sofala, Manica, and Zambezia. The average values are −0.0859, −0.0815, −0.0456,

−0.0744 and −0.0618, respectively, at Marávia station, Nhangau station, Nhapassa-1 and Nhapassa-2 stations, respectively. The northern region of Mozambique has an $\Delta\bar{K}_t^*$ of −0.0515 in the province of Niassa, −0.0612 in Nampula, with an average of 0.0545 in the province of Cabo-Delgado.

Figure 9d shows that the $\bar{K}_t^*$ density varied over 12 months, indicating a consistent pattern throughout the years. The southern region has an $\bar{K}_t^*$ of 0.6645, with acceptable days ranging from 0.5692 to 0.6789. In Maputo, Gaza, Massangena, and Inhambane provinces, the $\bar{K}_t^*$ is 0.7781, with acceptable days ranging from 0.8489 to 0.7489. The $\bar{K}_t^*$ is also varying in Inhambane province. The mid-region of Mozambique has an $\bar{K}_t^*$ of 0.9775, with no acceptable days and 0.0850 for unacceptable days. In the province of Tete, the $\bar{K}_t^*$ is 0.9774, with no acceptable days and 0.9501 for unacceptable days. In Sofala, the $\bar{K}_t^*$ is 0.7211, with acceptable days being 0.8634 and unacceptable days being 0.6088. In Manica, the $\bar{K}_t^*$ is 0.7258, with acceptable days being 0.8197 and unacceptable days being 0.6319 and 0.6001, respectively. In Zambezia province (Lugela-1 station) about $\bar{K}_t^*$ of 0.9553, with no acceptable days and 0.9411 for unacceptable days, and (Lugela-2 station) about $\bar{K}_t^*$ of 0.9252, with no acceptable days and 0.0626 for unacceptable days, depicted in Table 5. The northern region of Mozambique has an $\bar{K}_t^*$ of 0.7139, with no acceptable days and 0.8485 for unacceptable days. In Niassa province, it has an $\bar{K}_t^*$ of 0.7351, with no acceptable days and 0.7264 for unacceptable days. In Nampula province, it has an $\bar{K}_t^*$ of 0.8561, with no acceptable days and 0.8566 for unacceptable days. In Cabo-Delgado province, it has an $\bar{K}_t^*$ of 0.6088.

Table 5. Geospatial–temporal distribution of solar energy in terms of clear-sky days in all years.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\bar{K}_t^*$	$\Delta\bar{K}_t^*$	$\bar{K}_t^*$	$\Delta\bar{K}_t^*$	$\bar{K}_t^*$	$\Delta\bar{K}_t^*$
South region	Maputo	UEM-Maputo	0.6645	−0.0429	0.5692	−0.0339	0.6789	−0.0459
	Gaza	Dindiza	0.7756	−0.0548	0.6957	−0.0489	0.7998	−0.4558
		Massangena	0.8256	−0.0678	0.6895	−0.0456	0.8485	−0.0256
	Inhambane	Pomene	0.7781	−0.0778	0.8489	−0.0256	0.8489	−0.0789
Mid-region	Tete	Marávia	0.9774	−0.0091	--	--	0.9501	−0.0092
	Sofala	Nhangau	0.7211	−0.0654	0.8634	−0.0256	0.6088	−0.0487
	Manica	Nhapassa-1	0.7258	−0.0403	0.8197	−0.1478	0.6319	−0.0725
		Nhapassa-2	0.7244	−0.0403	0.8489	−0.0258	0.6001	−0.0487
	Zambezia	Lugela-1	0.9553	−0.2399	--	--	0.9411	−0.0047
		Lugela-2	0.9252	−0.1435	--	--	0.90626	−0.0078
North region	Niassa	Massangulo-1	0.7351	−0.0482	--	--	0.7264	−0.0478
		Massangulo-2	0.7402	−0.0697	---	--	0.7171	−0.0486
	Nampula	Nanhupo-1	0.8561	−0.2583	---	--	0.8566	−0.0478
		Nanhupo-2	0.7895	−0.2333	----	--	0.7659	−0.0457
	Cabo-Delgado	Chomba	0.6088	−0.1472	----	--	0.6512	−0.0485

The analysis of solar energy distribution in Mozambique over 12 months reveals a density of $\Delta\bar{K}_t^*$ in the differential, as depicted in Figure 10d. This study found that the density in the southern region of Mozambique is highest in Maputo, Gaza, Massangena, and Inhambane

provinces. The average density is -0.0429 at UEM-Maputo station, -0.0548 and -0.0678 at Dindiza and Massangena stations, and -0.0778 at Pomene station. The $\Delta\bar{K}_t^*$ in mid-region Mozambique was observed in various provinces, including Tete, Sofala, Manica, and Zambezia. In Tete, it was -0.0091 , Sofala was -0.0654 , Manica was -0.0403 , and Zambezia was -0.2399 . These observations highlight the varied and fluctuating nature of the $\Delta\bar{K}_t^*$ in Mozambique. The northern region of Mozambique showed averages of -0.0482 and -0.0697 in Niassa province, -0.2583 and -0.2333 in Nampula province, and -0.1472 in Cabo-Delgado province, respectively, with a mean of -0.0485 and -0.0485 , respectively.

3.3. Geospatial–Temporal Distribution of Solar Energy in Terms of Cloudy-Sky Days

The distribution of solar energy in terms of K_t^* indicates a diversified order throughout 2012, evaluated in 8 months. As shown in Figure 11a, this study reveals that the $\bar{K}_t^*$ in the southern region of Mozambique is 0.4219 , with acceptable days ranging from 0.5214 to 0.3168 . The $\bar{K}_t^*$ in Maputo, Gaza, Massangena, and Inhambane provinces is also 0.4776 , with acceptable days ranging from 0.8423 to 0.8451 . The data are consistent across all the stations in the region. The $\bar{K}_t^*$ in mid-region Mozambique is 0.4857 in Tete province, 0.4365 in Sofala province, 0.3236 in Manica province, 0.3364 and 0.3257 in Nhapassa-1 and Nhapassa-2 provinces, and 0.3037 in Zambezia province. These values range from 0.8723 for acceptable days to 0.3668 for unacceptable days. The $\bar{K}_t^*$ in Manica province is 0.3197 for acceptable days and 0.3319 for unacceptable days, while in Zambezia province, it is 0.5212 for acceptable days and 0.0862 for unacceptable days. The northern region of Mozambique has an $\bar{K}_t^*$ of 0.4126 in Niassa province, 0.4542 for acceptable days and 0.3708 for unacceptable days, and 0.4014 in Nampula province. The $\bar{K}_t^*$ in Nampula province is 0.3513 , with acceptable days ranging from 0.4542 to 0.4571 , and 0.4698 to 0.4045 , while in Cabo-Delgado province, the $\bar{K}_t^*$ is 0.4698 , depicted in Table 6.

Table 6. Geospatial–temporal distribution of solar energy in terms of cloudy-sky days in 2012.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\bar{K}_t^*$	$\Delta\bar{K}_t^*$	$\bar{K}_t^*$	$\Delta\bar{K}_t^*$	$\bar{K}_t^*$	$\Delta\bar{K}_t^*$
South region	Maputo	UEM-Maputo	0.4219	-0.0318	0.5214	-0.0122	0.3168	-0.0514
	Gaza	Dindiza	0.3456	-0.0456	0.4643	-0.0863	0.3469	-0.0849
		Massangena	0.4256	-0.0875	0.8463	-0.0843	0.8489	-0.0848
	Inhambane	Pomene	0.4156	-0.0458	0.4483	-0.0848	0.4489	-0.0848
Mid-region	Tete	Marávia	0.4857	-0.0595	0.6047	-0.0958	0.3668	-0.0238
	Sofala	Nhangau	0.4365	-0.0597	0.4634	-0.0767	0.2088	-0.0467
	Manica	Nhapassa-1	0.3364	-0.0403	0.3197	-0.0621	0.3319	-0.0862
		Nhapassa-2	0.3259	-0.02932	0.5489	-0.4965	0.6001	-0.0865
	Zambezia	Lugela-1	0.3037	-0.0659	0.5212	-0.0905	0.0862	-0.0415
		Lugela-2	0.2933	-0.0679	0.4997	-0.0863	0.0867	-0.0496
North region	Niassa	Massangulo-1	0.4126	-0.0754	0.4542	-0.1161	0.3708	-0.0367
		Massangulo-2	0.4585	-0.0119	0.4570	-0.1609	0.2028	-0.5028
	Nampula	Nanhupo-1	0.4014	-0.0637	0.4698	-0.0961	0.3331	-0.0369
		Nanhupo-2	0.3513	-0.0474	0.4045	-0.0659	0.2982	-0.0295
	Cabo-Delgado	Chomba	0.4982	-0.0497	0.4698	-0.088	0.3329	-0.0497

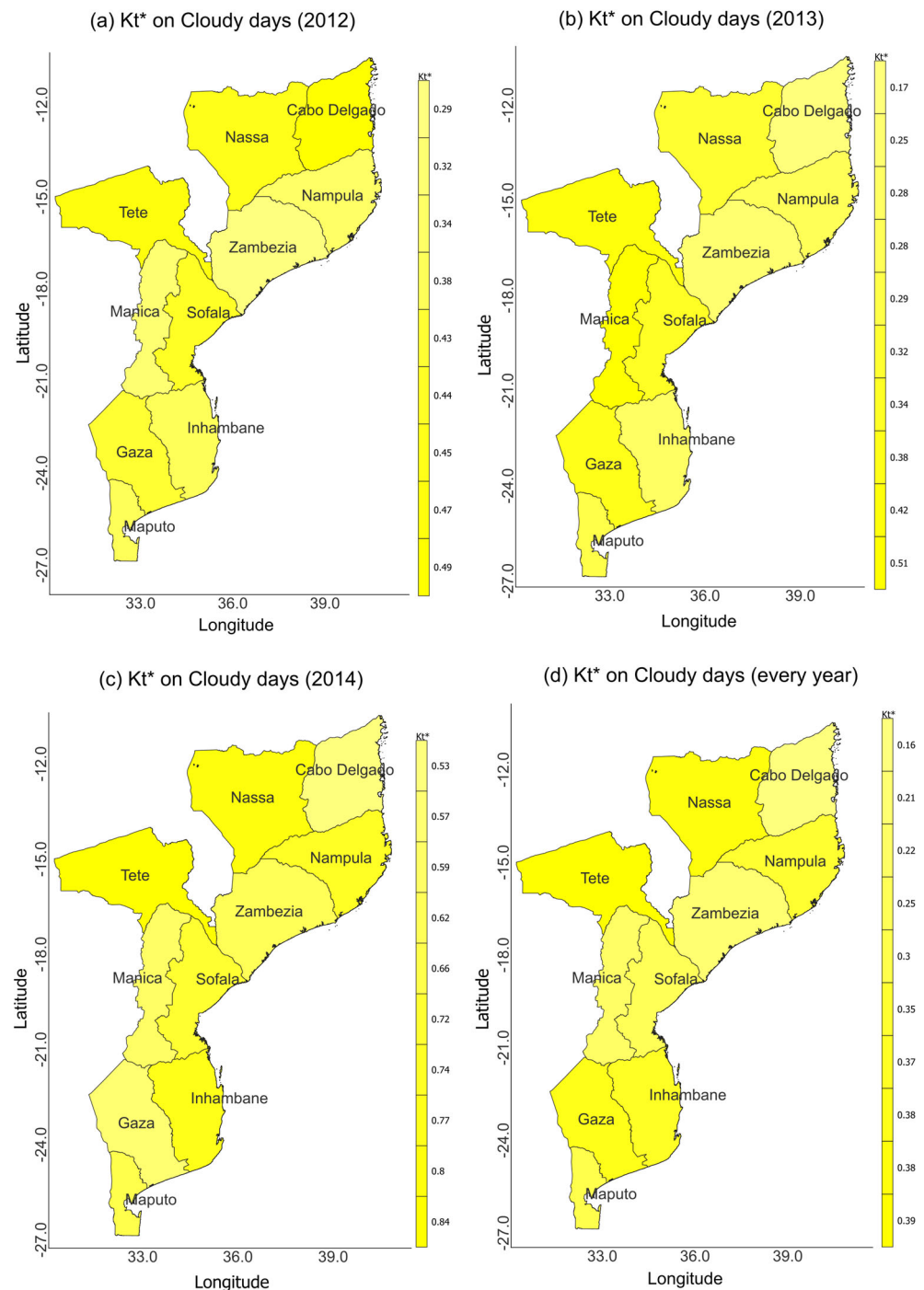


Figure 11. Map of geospatial–temporal distribution of solar energy in Mozambique, through the modeling of K_t^* during the years 2012, 2013, 2014, and in all years for cloudy-sky days, being (a) K_t^* on cloudy days in 2012, (b) K_t^* on cloudy days in 2012, (c) K_t^* on cloudy days in 2014, and (d) K_t^* on cloudy days in all years.

The analysis of solar energy distribution in Mozambique over 2012, spanning 8 months, reveals a density of ΔK_t^* in the differential, as shown in Figure 12a. This study reveals a density of $\Delta \bar{K}_t^*$ in the southern region of Mozambique, with an average of -0.0318 in Maputo province, -0.0456 in Gaza province, -0.0875 in Massangena province, and -0.0458 in Inhambane province.

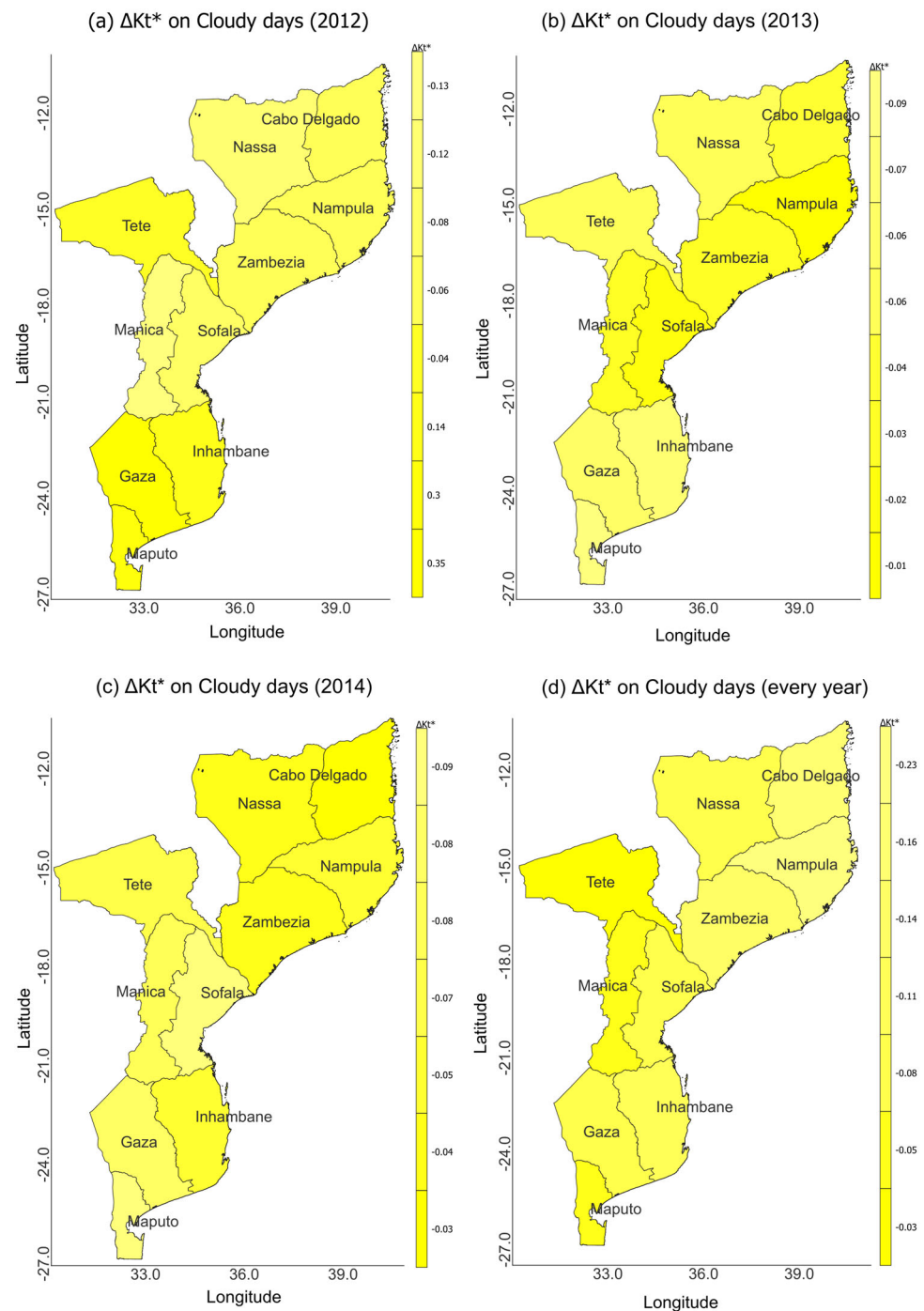


Figure 12. Map of geospatial–temporal distribution of solar energy in Mozambique, through the modeling of ΔK_t^* during the years 2012, 2013, and 2014, and in all years for cloudy-sky days, being (a) ΔK_t^* on cloudy days in 2012, (b) ΔK_t^* on cloudy days in 2012, (c) ΔK_t^* on cloudy days in 2014, and (d) ΔK_t^* on cloudy days in all years.

The averages range from -0.0122 for acceptable days to -0.0514 for unacceptable days. This study highlights the importance of accurate measurements in predicting weather patterns. The mid-region of Mozambique has an $\Delta \bar{K}_t^*$ of -0.0595 in Tete province, -0.0958 for acceptable days and -0.0238 for unacceptable days. In Sofala province, -0.0597 , -0.0767 for acceptable days and -0.0467 for unacceptable days. In Manica province, -0.0403 , -0.0621 for acceptable days and -0.0862 for unacceptable days. In Zambezia province, -0.0659 , -0.0905 for acceptable days and -0.0415 for unacceptable days. In Lugela-2 province, -0.0659 , -0.0863 for acceptable days and -0.0496 for unacceptable

days. The northern region of Mozambique has an $\Delta \bar{K}_t^*$ of -0.0754 in Niassa province, -0.0754 for acceptable days and -0.1161 for unacceptable days. In Nampula province, -0.0637 , -0.0961 for acceptable days and -0.0369 for unacceptable days, and -0.0474 , -0.0659 for acceptable and -0.02895 for unacceptable days, here -0.0498 , with -0.0888 for acceptable days and -0.0497 for unacceptable days, as reported by Chomba station in Cabo-Delgado province.

Throughout the year 2013, evaluated in 12 months, it is possible to observe the density of K_t^* in the order as shown in Figure 11b. Mozambique's southern region has an $\bar{K}_t^*$ of 0.3025 , with acceptable days ranging from $0.0.2489$ to 0.3989 . The provinces of Maputo, Gaza, Massangena, and Inhambane have varying $\bar{K}_t^*$ values, with the latter having an average of 0.2778 , with acceptable days ranging from 0.2489 to 0.4489 . The $\bar{K}_t^*$ in these regions is also varying. Mozambique's mid-region has varying $\bar{K}_t^*$ values across different provinces. Tete has an $\bar{K}_t^*$ of 0.4557 with 0.5801 acceptable days and 0.3314 for unacceptable days. Sofala has an $\bar{K}_t^*$ of 0.3520 , with acceptable days ranging from 0.3634 to 0.2088 . Manica province has an $\bar{K}_t^*$ of 0.7258 , with acceptable days ranging from 0.8197 to 0.6319 . Zambezia province has an $\bar{K}_t^*$ of 0.2698 , with no acceptable days and 0.2685 for unacceptable days. Mozambique's northern region has an $\bar{K}_t^*$ of 0.6172 in the province of Niassa, with acceptable days ranging from 0.4636 to 0.3064 . In Nampula, the $\bar{K}_t^*$ is 0.2369 with acceptable days ranging from 0.4071 to 0.0668 . In Cabo-Delgado, the $\bar{K}_t^*$ is 0.1739 , with no acceptable days and 0.1782 for unacceptable days. These data highlight the region's diverse weather patterns and varying levels of weather conditions.

In 2013, Mozambique's solar energy distribution showed a density of ΔK_t^* in the differentiated, as shown in Figure 12b, indicating a consistent distribution throughout the year. The southern region of Mozambique exhibits a density of $\Delta \bar{K}_t^*$, with an average of -0.0878 in Maputo, Gaza, Massangena, and Inhambane provinces. The average is between -0.0828 for acceptable days and -0.0819 for unacceptable days, with acceptable days being between -0.0889 and -0.0883 , as shown in Table 7.

The density varies between acceptable days and unacceptable days, indicating a diverse distribution of ΔK_t^* in Mozambique. As shown in Figure 12b, In Mozambique, the $\Delta \bar{K}_t^*$ is -0.0491 in Tete province, -0.0897 in Sofala province, -0.8512 in Manica province, -0.7258 and -0.0346 in Nhapassa-1 and Nhapassa-2 provinces, and -0.0372 in Zambezia province. These values indicate that the country experiences a significant number of days with unacceptable days, with some days being unacceptable and others being acceptable. The country's climate is characterized by extreme weather conditions, with some days being considered unacceptable and others being considered acceptable. The North region has an average of -0.0654 , with -0.1063 for acceptable days in Niassa province, -0.0511 for acceptable days, and -0.1525 for unacceptable days in Massangulo-2 station. In Nampula province, -0.0513 for acceptable days, -0.0657 for acceptable days, and -0.0667 for unacceptable days in Nanhupo-1 and Nanhupo-2 stations. In Cabo-Delgado province, an average of -0.0413 in Chomba station, with no acceptable days and -0.0414 for unacceptable days.

In 2014, a diversified K_t^* density was observed throughout the Mozambican territory, as depicted in Figure 11c over a 12-month period. The $\bar{K}_t^*$ in the southern region of Mozambique is 0.4556 , with acceptable days ranging from 0.3489 to $0.0.3456$. In Gaza province, it is 0.2452 , with acceptable days ranging from 0.2489 to 0.2224 . Massangena province has an $\bar{K}_t^*$ of 0.3556 , with acceptable days ranging from 0.2454 to 0.3479 . In Inhambane province, it is 0.2451 . The mid-region of Mozambique has an $\bar{K}_t^*$ of 0.2774 in Tete province, 0.4505 in Sofala province, 0.73218 in Manica province, 0.3244 in Nhapassa-1 and Nhapassa-2 provinces, and 0.1661 in Zambezia province. These averages range from no acceptable days to 0.1661 for unacceptable days. The $\bar{K}_t^*$ values vary across different

stations, with some stations having no acceptable days and others having unacceptable days. The data highlight the need for improved quality control measures in the region. The Northern region of Mozambique has an $\overline{K}_t^*$ of 0.3064 in Niassa province, 0.2640 in Nampula province, and 0.1628 in Cabo-Delgado province. These averages are based on the Massangulo-1 and Massangulo-2 stations, respectively. The $\overline{K}_t^*$ values are based on the number of days with no acceptable days and unacceptable days, with no acceptable days and unacceptable days in each province, as presented in Table 8.

Table 7. Geospatial–temporal distribution of solar energy in terms of cloudy-sky days in 2013.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K}_t^*$	$\Delta\overline{K}_t^*$	$\overline{K}_t^*$	$\Delta\overline{K}_t^*$	$\overline{K}_t^*$	$\Delta\overline{K}_t^*$
South region	Maputo	UEM-Maputo	0.3025	−0.0878	0.2489	−0.0483	0.3489	−0.0889
	Gaza	Dindiza	0.4015	−0.08778	0.3489	−0.0828	0.3489	−0.0819
		Massangena	0.4025	−0.0578	0.4422	0.0478	0.4489	−0.0843
	Inhambane	Pomene	0.2778	−0.0672	0.2489	−0.0889	0.4489	−0.0883
Mid-region	Tete	Marávia	0.4557	−0.0491	0.5801	−0.0897	0.3314	−0.0085
	Sofala	Nhangau	0.3520	−0.0057	0.3634	−0.0057	0.2088	−0.0125
	Manica	Nhapassa-1	0.7258	0.7258	0.8197	0.8197	0.6319	0.6319
		Nhapassa-2	0.7244	−0.0345	0.8489	0.8489	0.6001	0.6001
	Zambezia	Lugela-1	0.2698	−0.0372	---	---	0.2685	−0.0372
		Lugela-2	0.2744	−0.0346	---	---	0.2756	−0.0349
North region	Niassa	Massangulo-1	0.3851	−0.0654	0.4636	−0.1063	0.3064	−0.0245
		Massangulo-2	0.3172	−0.0511	0.7215	−0.1525	0.5128	−0.0397
	Nampula	Nanhupo-1	0.2369	−0.0513	0.4071	−0.0656	0.0668	−0.0371
		Nanhupo-2	0.2856	0.0005	0.4071	−0.0657	0.2275	0.0667
	Cabo-Delgado	Chomba	0.1739	−0.0413	---	---	0.1782	−0.0414

The analysis of solar energy distribution in Mozambique over 2014, spanning 12 months, reveals a density of $\Delta\overline{K}_t^*$ in the differentiated, as depicted in Figure 12c. This study found that the southern region of Mozambique has an average density of $\Delta\overline{K}_t^*$ of −0.0878, with acceptable days ranging from −0.0629 to −0.0848. In Maputo, Gaza, Massangena, and Inhambane provinces, the average density is also −0.0472, with acceptable days ranging from −0.0456 to −0.0452. These findings suggest that the southern region of Mozambique has a density density that varies between acceptable and unacceptable days. The $\Delta\overline{K}_t^*$ in the mid-region of Mozambique is −0.0574 in Tete, −0.0574 in Sofala, −0.0628 in Manica, −0.0628 in Nhapassa-1, and −0.0724 in Nhapassa-2, and −0.0356 in Zambezia. These values indicate that there are no acceptable days and some unacceptable days in different provinces, with the highest values in Tete and Sofala, and the lowest values in Zambezia and Lugela. These data highlight the challenges faced by the region in managing climate change. The northern region of Mozambique has shown an $\Delta\overline{K}_t^*$ of −0.0245, with no acceptable days and −0.0245 for unacceptable days. In Niassa, Massangulo-1 and Massangulo-2 stations have −0.0356 and −0.0397 unacceptable days, respectively. In Nampula, Nanhupo-1 and Nanhupo-2 stations have −0.0472 and −0.0425 unacceptable

days, respectively. In Cabo-Delgado province, Chomba station has an $\Delta\bar{K}_t^*$ of -0.0122 and -0.0113 unacceptable days.

Table 8. Geospatial–temporal distribution of solar energy in terms of cloudy-sky days in 2014.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\bar{K}_t^*$	$\Delta\bar{K}_t^*$	$\bar{K}_t^*$	$\Delta\bar{K}_t^*$	$\bar{K}_t^*$	$\Delta\bar{K}_t^*$
South region	Maputo	UEM-Maputo	0.4556	-0.0878	0.3489	-0.0629	0.3456	-0.0848
	Gaza	Dindiza	0.2452	-0.0472	0.2489	-0.0456	0.2224	-0.0452
		Massangena	0.3556	-0.0782	0.3454	-0.0452	0.3479	-0.0649
	Inhambane	Pomene	0.2451	-0.0546	0.2489	-0.0417	0.2489	-0.0421
Mid-region	Tete	Marávia	0.2774	-0.0574	---	---	0.2550	-0.0550
	Sofala	Nhangau	0.4505	-0.0850	0.3634	-0.0825	0.4018	-0.0618
	Manica	Nhapassa-1	0.3218	-0.0628	0.3112	-0.0317	0.3319	-0.0631
		Nhapassa-2	0.3244	-0.0724	0.2482	-0.0819	0.4021	-0.0892
	Zambezia	Lugela-1	0.1661	-0.0356	---	---	0.1661	-0.0356
		Lugela-2	0.1586	-0.0397	---	---	0.1586	-0.0397
North region	Niassa	Massangulo-1	0.3064	-0.0356	---	---	0.3061	-0.0356
		Massangulo-2	0.3128	-0.0397	---	---	0.3114	-0.0398
	Nampula	Nanhupo-1	0.2640	-0.0476	---	---	0.1639	-0.0472
		Nanhupo-2	0.2128	-0.0476	---	---	0.2128	-0.0425
	Cabo-Delgado	Chomba	0.1628	-0.0122	---	---	0.1599	-0.0113

The evaluation of all the years of measurements reveals a density of K_t^* with a diversified intensity of solar energy incidence, as depicted in Figure 11d. The $\bar{K}_t^*$ in Mozambique's mid-region was observed at 0.3876, while in the southern region, it was 0.3452. The $\bar{K}_t^*$ in Gaza, Massangena, and Inhambane was also 0.3778. The mid-region's $\bar{K}_t^*$ was 0.3989 in Tete, and 0.2856 in Sofala, Manica, and Zambezia provinces. The $\bar{K}_t^*$ in each province was 0.2258, 0.2244, 0.2326, and 0.2195, respectively. The $\bar{K}_t^*$ in Niassa province, Nampula province, and Cabo-Delgado provinces is 0.3349, 0.3885, 0.3506, 0.3496, and 0.1628, respectively, indicating varying levels of rainfall and precipitation in the North region, as shown in Table 9.

The analysis of solar energy distribution in Mozambique, spanning 12 months, reveals a density of $\Delta\bar{K}_t^*$ in the differentiated, as depicted in Figure 12d. This study found that the density of $\Delta\bar{K}_t^*$ in the southern region of Mozambique was -0.0319 in Maputo, -0.0238 in Gaza, -0.0456 in Massangena, and -0.0756 in Inhambane provinces, with an average of -0.0356 in Maputo, -0.02566 in Gaza, and -0.0257 in Massangena. The mid-region of Mozambique shows a trend of observations, with average values of -0.0319 and -0.1422 observed in various provinces. These include Tete province (Marávia station), Sofala province (Nhangau station), Manica province (Nhapassa-1 station), and Zambezia province (Lugela-1 station), and all have a negative $\Delta\bar{K}_t^*$. The northern region of Mozambique experiences $\Delta\bar{K}_t^*$ of -0.1653 and -0.2333 in Niassa province, -0.1675 and -0.0942 in Nampula province, and -0.0657 and -0.0478 in Cabo-Delgado province, respectively.

Table 9. Geospatial–temporal distribution of solar energy in terms of all cloudy-sky days for all years.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.3218	−0.0319	0.4569	−0.0356	0.2695	−0.0558
	Gaza	Dindiza	0.2625	−0.0238	0.2629	−0.0256	0.1892	−0.0569
		Massangena	0.3782	−0.0456	0.3985	−0.0256	0.2865	−0.0445
	Inhambane	Pomene	0.3778	−0.0756	0.3826	−0.0569	0.3406	−0.0459
Mid-region	Tete	Marávia	0.3989	−0.0319	0.2965	−0.0456	0.2562	−0.0143
	Sofala	Nhangau	0.2856	−0.0654	0.2256	−0.0589	0.1962	−0.0489
	Manica	Nhapassa-1	0.2258	−0.0403	0.2985	−0.0458	0.2526	−0.0256
		Nhapassa-2	0.2244	−0.0402	0.3259	−0.0145	0.0895	−0.0486
	Zambezia	Lugela-1	0.2326	−0.1388	0.1892	−0.2045	0.1896	−0.0329
		Lugela-2	0.2195	−0.1422	0.2895	−0.0145	0.1899	−0.0456
North region	Niassa	Massangulo-1	0.3349	−0.1653	0.3859	−0.0458	0.2879	−0.0589
		Massangulo-2	0.3885	−0.2333	0.3259	−0.0059	0.2899	−0.0853
	Nampula	Nanhupo-1	0.3506	−0.1675	0.2862	−0.0456	0.3859	−0.1248
		Nanhupo-2	0.3496	−0.0942	0.3256	−0.0598	0.3562	−0.0458
	Cabo-Delgado	Chomba	0.1628	−0.0657	0.1526	−0.4785	0.1246	−0.0478

3.4. Geospatial–Temporal Distribution of Solar Energy in Terms of Intermediate-Sky Days

In 2012, the territorial area centered on the major provinces displayed a diversified density in the distribution of solar energy in terms of K_t^* for intermediate-sky days. It was discovered that the $\overline{K_t^*}$ in the southern part of Mozambique was 0.6736 in Maputo province, in Gaza province 0.6588 in Dindiza station and 0.6798 in Massangena station, and 0.5458 in Inhambane provinces. These averages varied between acceptable and undesirable days, ranging from 0.6807 to 0.4672. Numerous factors appear to have an impact on the nation's weather patterns, according to the statistics, as shown in Figure 13a.

In Mozambique's mid-region, the $\overline{K_t^*}$ is 0.7539, with acceptable days measured at 0.7245 and unacceptable days at 0.6589. With acceptable days at 0.7895 and unacceptable days at 0.5294, Tete's $\overline{K_t^*}$ is 0.6594. With good days at 0.5634 and unacceptable days at 0.3088, the $\overline{K_t^*}$ in Sofala is 0.5360. With 0.5197 for good days and 0.5319 for bad days, Manica's average K_t^* is 0.5258. In Zambezia, suitable days have a $\overline{K_t^*}$ of 0.6845, whereas unacceptable days have a $\overline{K_t^*}$ of 0.3747 on average. The acceptable days in the northern part of Mozambique range from 0.5813 to 0.78989, with an $\overline{K_t^*}$ of 0.7221. The acceptable days in Niassa range from 0.5885 to 0.4059, with an $\overline{K_t^*}$ of 0.4973. The acceptable days in Nampula range from 0.5486 to 0.4494, with the $\overline{K_t^*}$ being approximately 0.4996. With tolerable days ranging from 0.5433 to 0.17338, the $\overline{K_t^*}$ in Cabo-Delgado is around 0.3583, depicted in Table 10.

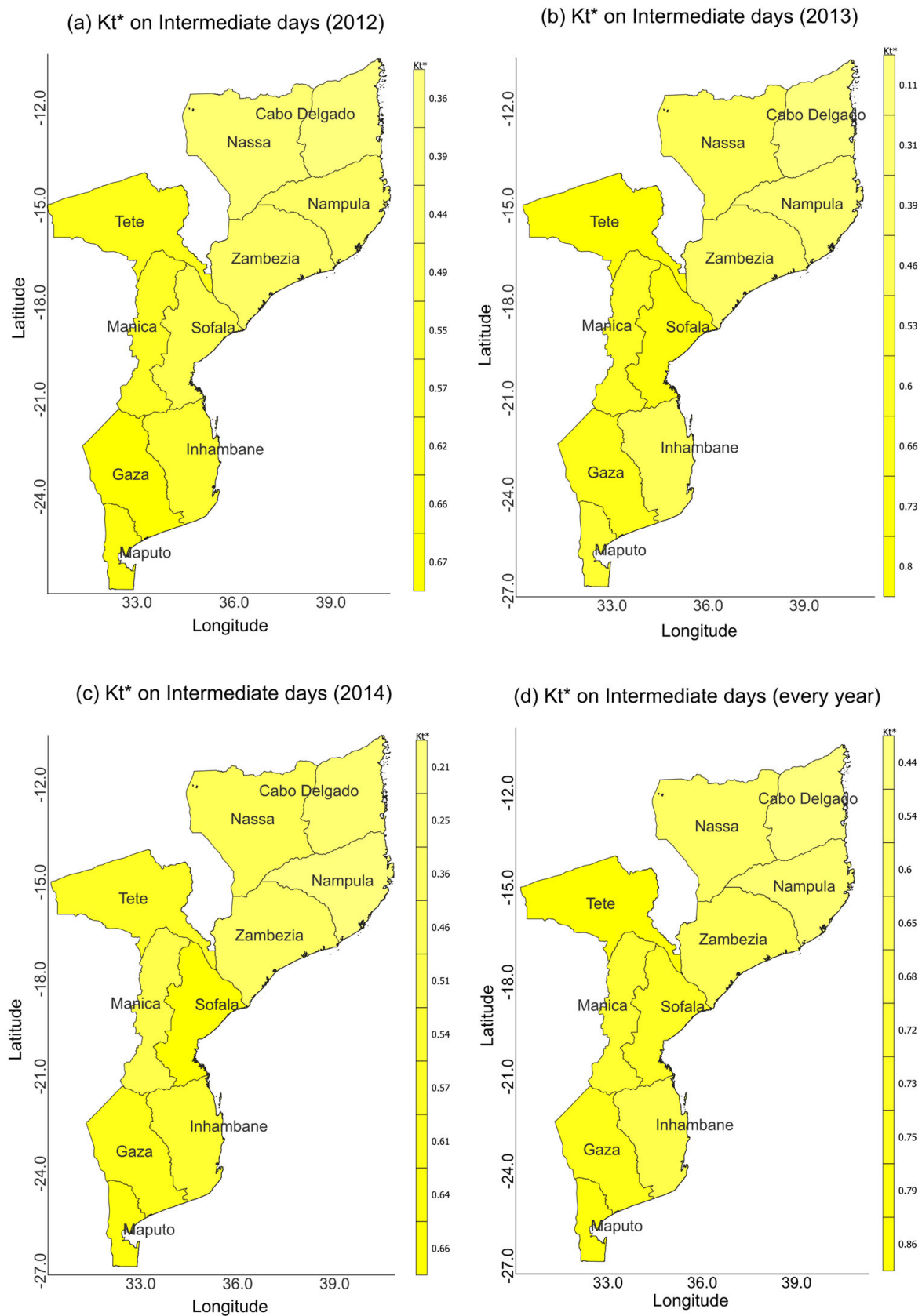


Figure 13. Map of geospatial–temporal distribution of solar energy in Mozambique, through modeling of K_t^* during the years 2012, 2013, 2014, and in all years for intermediate-sky days, being (a) K_t^* on intermediate days in 2012, (b) K_t^* on intermediate days in 2012, (c) K_t^* on intermediate days in 2014, and (d) K_t^* on intermediate days in all years.

Table 10. Geospatial–temporal distribution of solar energy in terms of intermediate-sky days in 2012.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.6739	−0.0567	0.6807	−0.0566	0.4672	−0.0552
	Gaza	Dindiza	0.6588	−0.0780	0.6489	−0.0549	0.4489	−0.0489
		Massangena	0.6798	−0.0778	0.5489	−0.0841	0.6489	−0.0259
	Inhambane	Pomene	0.5458	−0.0782	0.4489	−0.0289	0.5489	−0.0489
Mid-region	Tete	Marávia	0.6594	−0.0622	0.7895	−0.0859	0.5295	−0.0382
	Sofala	Nhangau	0.5360	−0.0597	0.5634	−0.0727	0.3088	−0.0467
	Manica	Nhapassa-1	0.5258	−0.0403	0.5197	−0.0621	0.5319	−0.0862
		Nhapassa-2	0.5844	−0.0293	0.5489	−0.4916	0.4021	−0.0867
	Zambezia	Lugela-1	0.5296	−0.0599	0.6845	−0.0835	0.3747	−0.0363
		Lugela-2	0.4651	−0.1161	0.6803	−0.2039	0.2499	−0.0284
North region	Niassa	Massangulo-1	0.4973	−0.0743	0.5885	−0.1217	0.4059	−0.0262
		Massangulo-2	0.4049	−0.0109	0.5070	−0.1609	0.4028	0.0328
	Nampula	Nanhupo-1	0.4996	−0.0679	0.5486	−0.0839	0.4494	−0.0519
		Nanhupo-2	0.4656	−0.0677	0.5283	−0.1030	0.4029	−0.0324
	Cabo-Delgado	Chomba	0.3583	−0.06792	0.5433	−0.0839	0.1733	−0.0519

According to the report, Mozambique’s solar energy distribution over an 8-month period in 2012 showed a density based on varying intensities. Various stations reported that the southern region of Mozambique had an average of -0.0567 acceptable days in Maputo province, -0.0566 acceptable days, and -0.0552 unacceptable days in Gaza province, -0.0780 acceptable days in Gaza province, -0.0841 acceptable days in Massangena province, and -0.0489 unacceptable days in Inhambane province, as shown in Figure 14a.

Mozambique’s mid-region has an $\Delta\overline{K_t^*}$ of -0.0627 , with suitable days being -0.0859 and unacceptable days being -0.03822 . Tete province’s $\Delta\overline{K_t^*}$ is -0.0622 , with acceptable days being -0.0859 and unacceptable days being -0.0382 . Manica province’s $\Delta\overline{K_t^*}$ is -0.0403 , with acceptable days being -0.0621 and unacceptable days being -0.0862 . In the province of Zambezia, the $\Delta\overline{K_t^*}$ is -0.0599 , with acceptable days being -0.0835 and unacceptable days being -0.0363 . In the northern part of Mozambique, acceptable days average -0.0743 , unacceptable days average -0.1217 , and acceptable days average -0.0262 . Massangulo-1 and Massangulo-2 stations in Niassa have tolerable days with averages of -0.1109 and -0.1609 , respectively. The acceptable days for Nanhupo-1 and Nanhupo-2 stations in Nampula are, respectively, -0.0679 , -0.0839 , -0.0519 , -0.0677 , -0.1030 and -0.0324 . Additionally, an average of -0.0679 is noted at Cabo-Delgado.

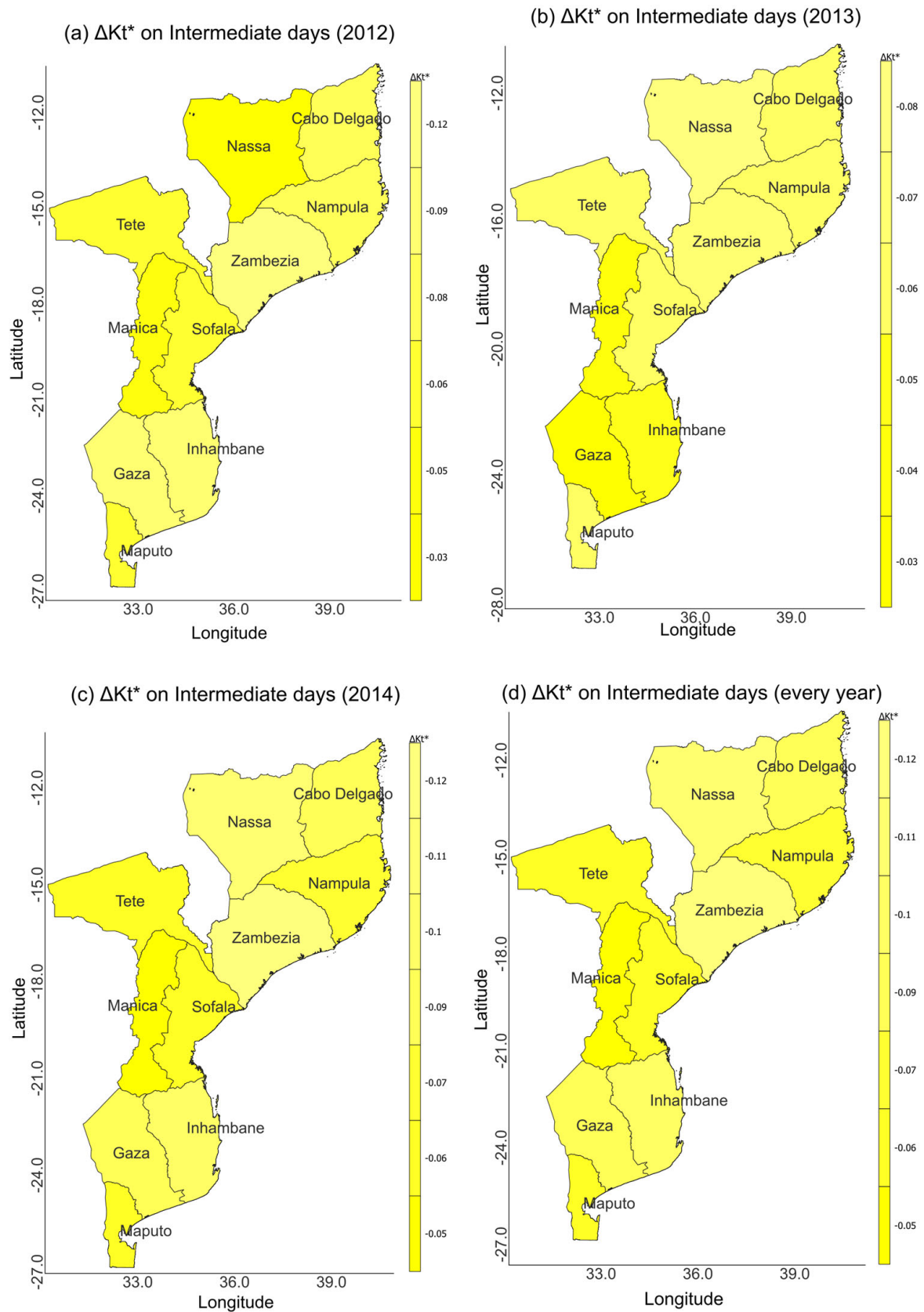


Figure 14. Map of geospatial–temporal distribution of solar energy in Mozambique, through modeling of ΔK_t^* during the years 2012, 2013, 2014, and in all years for intermediate-sky days, being (a) ΔK_t^* on intermediate days in 2012, (b) ΔK_t^* on intermediate days in 2012, (c) ΔK_t^* on intermediate days in 2014, and (d) ΔK_t^* on intermediate days in all years.

The analysis shows that the distribution of solar energy in terms of K_t^* fluctuated in intensity during a 12-month period in 2013, suggesting a diverse distribution of solar energy, as shown in Figure 13b. In the southern part of Mozambique, the $\overline{K_t^*}$ is 0.7886, with acceptable days falling between 0.8483 and 0.8483. With acceptable days falling between 0.5486 and 0.4289, the $\overline{K_t^*}$ in the provinces of Maputo, Gaza, Massangena, and Inhambane is 0.51716. In the province of Inhambane, the $\overline{K_t^*}$ varies as well. The $\overline{K_t^*}$ at Tete, Sofala, Manica, Napassa-1, Nhapassa-2, and Lugela-1 stations in mid-region Mozambique is 0.8397. There are different acceptable and undesirable days at these stations. The $\overline{K_t^*}$ values for Tete, Sofala, Manica, Nhapassa-1, and Lugela-2 are 0.8368, 0.7850, 0.6258, 0.6244, and 0.4155, respectively. In Niassa province in northern Mozambique, the $\overline{K_t^*}$ is 0.5118, with acceptable days falling between 0.6006 and 0.4222. The acceptable days in Nampula province range from 0.5917 to 0.1073, and the $\overline{K_t^*}$ is approximately 0.4392. The $\overline{K_t^*}$ in the province of Cabo-Delgado is around 0.112, with no acceptable or unacceptable days, as depicted in Table 11.

Table 11. Geospatial–temporal distribution of solar energy in terms of intermediate-sky days in 2013.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$	$\overline{K_t^*}$	$\Delta\overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.5268	−0.0567	0.5489	−0.0489	0.4289	−0.0549
	Gaza	Dindiza	0.6001	−0.0481	0.5113	−0.0459	0.6489	−0.0489
		Massangena	0.6853	−0.0248	0.5489	−0.0824	0.5429	−0.0124
	Inhambane	Pomene	0.5171	−0.0456	0.5489	−0.0489	0.3489	−0.0521
Mid-region	Tete	Marávia	0.8368	−0.0592	0.6659	−0.0939	0.9079	−0.0245
	Sofala	Nhangau	0.7850	−0.0597	0.6634	−0.0426	0.8001	−0.0057
	Manica	Nhapassa-1	0.6258	−0.0403	0.6197	−0.5197	0.4319	−0.0639
		Nhapassa-2	0.6244	−0.0292	0.6489	−0.0849	0.5001	0.6001
	Zambezia	Lugela-1	0.4155	−0.0684	---	---	0.1155	−0.0684
		Lugela-2	0.4104	−0.0684	---	---	0.4155	−0.0674
	North region	Niassa	Massangulo-1	0.5118	−0.0855	0.6006	−0.1346	0.4229
Massangulo-2			0.5172	−0.0845	0.5215	−0.1525	0.5128	−0.0697
Nampula		Nanhupo-1	0.4392	−0.0664	0.5917	−0.0617	0.1073	−0.0655
		Nanhupo-2	0.3495	−0.0636	0.5917	−0.0617	0.1073	−0.0652
Cabo-Delgado		Chomba	0.1121	−0.0649	---	---	0.1120	−0.0632

Over the course of a year, the solar energy distribution in 2013 displayed a varied density of ΔK_t^* , with the highest locations experiencing a notable decline, as shown in Figure 14b. According to this study, permissible days in the southern part of Mozambique range from 0.06636 to 0.0782, with an $\Delta \overline{K_t^*}$ of 0.088. With tolerable days falling between −0.0481 and −0.0489, the average in Gaza province is −0.0481. The allowed days range from −0.0824 to −0.0124, with the average for Massangena province being −0.0248. The average in Inhambane province is −0.0456. The mid-region of Mozambique has −0.0939 acceptable days and −0.0245 unacceptable days, with an $\Delta \overline{K_t^*}$ of −0.0592. The $\Delta \overline{K_t^*}$ in Sofala province is −0.00597, meaning that there are no acceptable days and −0.0057 for unacceptable days. The province of Manica has an $\Delta \overline{K_t^*}$ of −0.0403, with acceptable days

being -0.5197 and unacceptable days being -0.0639 . In the province of Zambezia, the $\Delta \overline{K_t^*}$ is -0.0684 , meaning that there are no acceptable days and -0.0684 for unacceptable days. In Mozambique's northern area, the average for acceptable days is -0.1346 , for acceptable days it is -0.0366 , and for unacceptable days it is -0.0855 in the province of Niassa. The average in Nampula province is -0.0664 , acceptable days are -0.0617 , and unacceptable days are -0.0655 . As seen in Figure 9d, the average in Cabo-Delgado province is -0.0649 , with no acceptable days and -0.0632 for unacceptable days.

A density of K_t^* across different orientations of solar energy intensity in 2014, assessed over a 12-month period, is indicated by the distribution of solar energy in terms of $\overline{K_t^*}$ on intermediate-sky days, as shown in Figure 13c. While permissible days range from 0.7569 to 0.8956, the $\overline{K_t^*}$ in southern Mozambique is 0.7882. With acceptable days ranging from 0.5428 to 0.4433, the value in Gaza province is 0.5524. The $\overline{K_t^*}$ in Massangena province is 0.6409, with acceptable days being between 0.6409 and 0.4481. In the province of Inhambane, it is 0.5412. Mozambique's mid-region has an $\overline{K_t^*}$ of 0.5775, meaning that there are no suitable days and 0.0850 unacceptable days. The $\overline{K_t^*}$ in Sofala is 0.6850, with acceptable and unsatisfactory days of 0.5634 and 0.6008, respectively. With acceptable days of 0.4197 and unacceptable days of 0.5319, the $\overline{K_t^*}$ in Manica is 0.5258. The average K_t^* in Zambezia is 0.4979, with unacceptable days and no acceptable days being 0.4975 and 0.4156 respectively. The Massangulo-1 and Massangulo-2 statistics indicate that the $\overline{K_t^*}$ in northern Mozambique is 0.4229 and 0.4122 for days with no acceptable conditions and 0.4225 and 0.5128 for days with unacceptable conditions. The $\overline{K_t^*}$ in Nampula province is 0.2204 for no acceptable days and 0.2201 for unacceptable days, but in Cabo-Delgado province, it is 0.2628 for no acceptable days and 0.0788 for unsuitable days, as depicted in Table 12.

Table 12. Geospatial–temporal distribution of solar energy in terms of intermediate-sky days in 2014.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.6514	−0.0567	0.6489	−0.0489	0.5489	−0.0259
	Gaza	Dindiza	0.5524	−0.0578	0.5428	−0.0258	0.4433	−0.0289
		Massangena	0.6406	−0.0778	0.6409	−0.0489	0.4481	−0.0259
	Inhambane	Pomene	0.5412	−0.0471	0.4261	−0.0458	0.5489	−0.0412
Mid-region	Tete	Marávia	0.5774	−0.0622	---	---	0.5650	−0.0850
	Sofala	Nhangau	0.6850	−0.0597	0.5634	−0.0634	0.6008	−0.6081
	Manica	Nhapassa-1	0.5258	−0.0403	0.4197	−0.0397	0.5319	−0.0619
		Nhapassa-2	0.5244	−0.0232	0.5489	−0.0489	0.4001	−0.0601
	Zambezia	Lugela-1	0.4979	−0.0599	---	---	0.4975	−0.0568
		Lugela-2	0.4122	−0.0161	---	---	0.4156	−0.0127
	North region	Niassa	Massangulo-1	0.4229	−0.0366	---	---	0.4225
Massangulo-2			0.5128	−0.1109	---	---	0.5128	−0.0697
Nampula		Nanhupo-1	0.2204	−0.0366	---	---	0.2201	−0.0366
		Nanhupo-2	0.2102	−0.0462	---	---	0.2014	−0.0426
Cabo-Delgado		Chomba	0.2628	−0.0765	---	---	0.2589	−0.0788

Throughout the course of 2014, the solar energy distribution in terms of ΔK_t^* shows a diverse density. The provinces of Maputo, Gaza, Massangena, and Inhambane in southern Mozambique have an $\overline{\Delta K_t^*}$ of -0.0567 . Days between -0.0489 and -0.0259 are unacceptable, while days between -0.0258 and -0.0289 are in accordance with the distribution, as shown in Figure 14c. In the mid-region of Mozambique, the average is -0.0622 , with -0.0850 for unacceptable days and no acceptable days. It is -0.0597 in Sofala, with acceptable days being -0.0634 and unacceptable days being -0.6081 . It is -0.0397 in Manica, with acceptable days being -0.0619 unacceptable days being -0.0403 . It is -0.0599 in Zambezia, meaning that there are no acceptable days and that there are -0.0568 for unacceptable days. With no acceptable days and -0.0137 for undesirable days, the $\overline{\Delta K_t^*}$ is -0.0367 . The northern region's provinces of Niassa, Nampula, and Cabo-Delgado have experienced unacceptable days, with averages of -0.0366 and -0.0697 of ΔK_t^* . No suitable days were found in Niassa, Nampula, Nampula, and Cabo-Delgado, indicating that the conditions in all three provinces were unacceptable.

A density of K_t^* in the intensity of differentiated solar energy is shown by the distribution of solar energy in terms of K_t^* on intermediate-sky days throughout all the measurement years. In the southern region, different stations state that the $\overline{K_t^*}$ is 0.6739 in Maputo, 0.6778 in Gaza, 0.5778 in Massangena, and 0.7778 in Inhambane, as shown in Figure 13d. In mid-region of Mozambique, the $\overline{K_t^*}$ across stations in Marávia, Nhangau, Nhapassa-1, Nhapassa-2, and Lugela-1 is 0.8725 in Tete, 0.7211 in Sofala, 0.6258 in Manica, 0.6258 and 0.5878 in Nhapassa-1 and Nhapassa-2, and 0.6138 in Zambezia. In the northern Mozambique region, the $\overline{K_t^*}$ is approximately 0.8203 in Niassa, 0.8287 in Nampula, 0.7583 in Nanhupo-1, 0.7496 in Nanhupo-2, and 0.5258 in Cabo-Delgado. The highest values are seen in the Massangulo-1 and Nanhupo-2 installations, as depicted in Table 13.

Table 13. Geospatial–temporal distribution of solar energy in terms of all intermediate-sky days in all years.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\overline{\Delta K_t^*}$	$\overline{K_t^*}$	$\overline{\Delta K_t^*}$	$\overline{K_t^*}$	$\overline{\Delta K_t^*}$
South region	Maputo	UEM-Maputo	0.6739	-0.0567	0.5895	-0.02565	0.5982	-0.07862
	Gaza	Dindiza	0.6778	-0.0978	0.6256	-0.0459	0.6589	-0.0656
		Massangena	0.5778	-0.0778	0.4895	-0.0476	0.5895	-0.0478
	Inhambane	Pomene	0.7778	-0.0878	0.6259	-0.0878	0.6253	-0.0586
Mid-region	Tete	Marávia	0.8725	-0.0622	0.7952	-0.0789	0.7089	-0.0456
	Sofala	Nhangau	0.7211	-0.0597	0.7256	-0.0895	0.7952	-0.0789
	Manica	Nhapassa-1	0.6258	-0.0403	0.6569	-0.0456	0.5985	-0.0456
		Nhapassa-2	0.5878	-0.0232	0.5456	-0.0785	0.5081	-0.0256
	Zambezia	Lugela-1	0.6531	-0.0599	0.6562	-0.0263	0.5592	-0.0456
		Lugela-2	0.6553	-0.1161	0.6952	-0.0456	0.6012	-0.0789
North region	Niassa	Massangulo-1	0.8203	-0.0743	0.7952	-0.0745	0.7001	-0.0456
		Massangulo-2	0.8287	-0.1109	0.7562	-0.0745	0.8004	-0.0789
	Nampula	Nanhupo-1	0.7583	-0.0679	0.7569	-0.0412	0.7895	-0.0456
		Nanhupo-2	0.7496	-0.0677	0.6859	-0.0745	0.7456	-0.0478
	Cabo-Delgado	Chomba	0.5258	-0.0765	0.5023	-0.0456	0.5891	-0.0256

A varied distribution of solar energy over all the measurement years is revealed by the evaluation of ΔK_t^* , as shown in Figure 14d, with the solar energy content as follows. Several stations in the region have reported that the $\Delta \overline{K_t^*}$ in the southern Mozambique region is -0.0567 in Maputo, -0.0978 in Gaza, -0.0778 in Massangena, and -0.0586 in Inhambane. In mid-region of Mozambique, the $\Delta \overline{K_t^*}$ is -0.0622 in Tete, -0.0597 in Sofala, -0.0403 in Manica, -0.0232 in Nhapassa-1 and Nhapassa-2, and -0.0599 in Zambezia. Stations in Tete (Marávia), Sofala (Nhangau), Manica (Nhapassa-1 and -2), and Zambezia (Lugela-1 and -2) record a range of values. The average values in the northern region are -0.0743 , -0.1109 , -0.0679 , and -0.0765 in Niassa province, -0.1951 and -0.19578 in Nampula province, and -0.1158 in Cabo-Delgado province. Massangulo-1 station reports -0.1962 , Nanhupo-1 station reports -0.1991 , and Chomba station reports -0.1153 .

3.5. Geospatial–Temporal Distribution of Solar Energy in Terms of Days of All Years

Upon evaluating the solar energy distribution in terms of K_t^* over the course of eight months in 2012, it was discovered that the entire plane had an intermittent density of $\overline{K_t^*}$ in different orders. The $\overline{K_t^*}$ in the southern part of Mozambique, according to this study, is 0.6278 in Maputo, 0.6772 in Gaza, 0.5256 in Massangena, and 0.6568 in Inhambane provinces. Acceptable days have an average of 0.6858 , whereas unacceptable days have an average of 0.5576 . The information is derived from a number of regional stations, as shown in Figure 15a.

Additional visual representation is available in Supplementary Figure S1, which, through a heat map, reveals that the mid-region of Mozambique has an $\overline{K_t^*}$ of 0.6594 in Tete province, 0.6360 in Sofala province, 0.7258 in Manica (Nhapassa-1) province, 0.7721 in Manica (Nhapassa-2) province, and 0.5316 in Zambezia province. The range of acceptable days is 0.7589 to 0.5463 , while suitable days are 0.5634 and unacceptable days are 0.6088 . Between 0.6167 and 0.6987 , the $\overline{K_t^*}$ in the Nhapassa-1 and Nhapassa-2 stations is 0.6197 for good days and 0.7721 for bad days. The acceptable days in the northern part of Mozambique range from 0.5972 to 0.5042 , with an $\overline{K_t^*}$ of 0.5971 . The $\overline{K_t^*}$ in Niassa is 0.6049 , and suitable days fall between 0.5885 and 0.4059 . The average K_t^* in Nampula is 0.5068 , with acceptable days being between 0.5591 and 0.4546 and unacceptable days falling between 0.4961 and 0.4074 , as depicted in Table 14.

Table 14. Geospatial–temporal distribution of solar energy in terms of days of all skies in 2012.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	ΔK_t^*	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.6278	-0.0416	0.6859	-0.0484	0.5576	-0.0348
	Gaza	Dindiza	0.6772	-0.0485	0.6489	-0.0442	0.5423	-0.0458
		Massangena	0.5256	-0.0456	0.5241	-0.0542	0.5412	-0.0456
	Inhambane	Pomene	0.6568	-0.0658	0.6001	-0.0632	0.5264	-0.0321
Mid-region	Tete	Marávia	0.6594	-0.0532	0.7589	-0.0754	0.5463	-0.0312
	Sofala	Nhangau	0.6360	-0.0597	0.5634	-0.0727	0.6088	-0.0467
	Manica	Nhapassa-1	0.7258	-0.0403	0.6197	-0.0621	0.6987	-0.0462
		Nhapassa-2	0.7721	-0.0232	0.5293	-0.0421	0.7149	-0.0667
	Zambezia	Lugela-1	0.5316	-0.0563	0.6645	-0.0766	0.3988	-0.0357
		Lugela-2	0.4722	-0.0583	0.6294	-0.0846	0.3149	-0.0321

Table 14. Cont.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$
North region	Niassa	Massangulo-1	0.5972	−0.0745	0.5885	−0.1217	0.4059	−0.0262
		Massangulo-2	0.5042	−0.0109	0.5271	−0.0609	0.4928	−0.0328
	Nampula	Nanhupo-1	0.5068	−0.0702	0.5591	−0.08862	0.4546	−0.0518
		Nanhupo-2	0.4517	−0.0484	0.4961	−0.0642	0.4074	−0.0326
	Cabo-Delgado	Chomba	0.3907	−0.0685	0.5259	−0.0853	0.2554	−0.0518

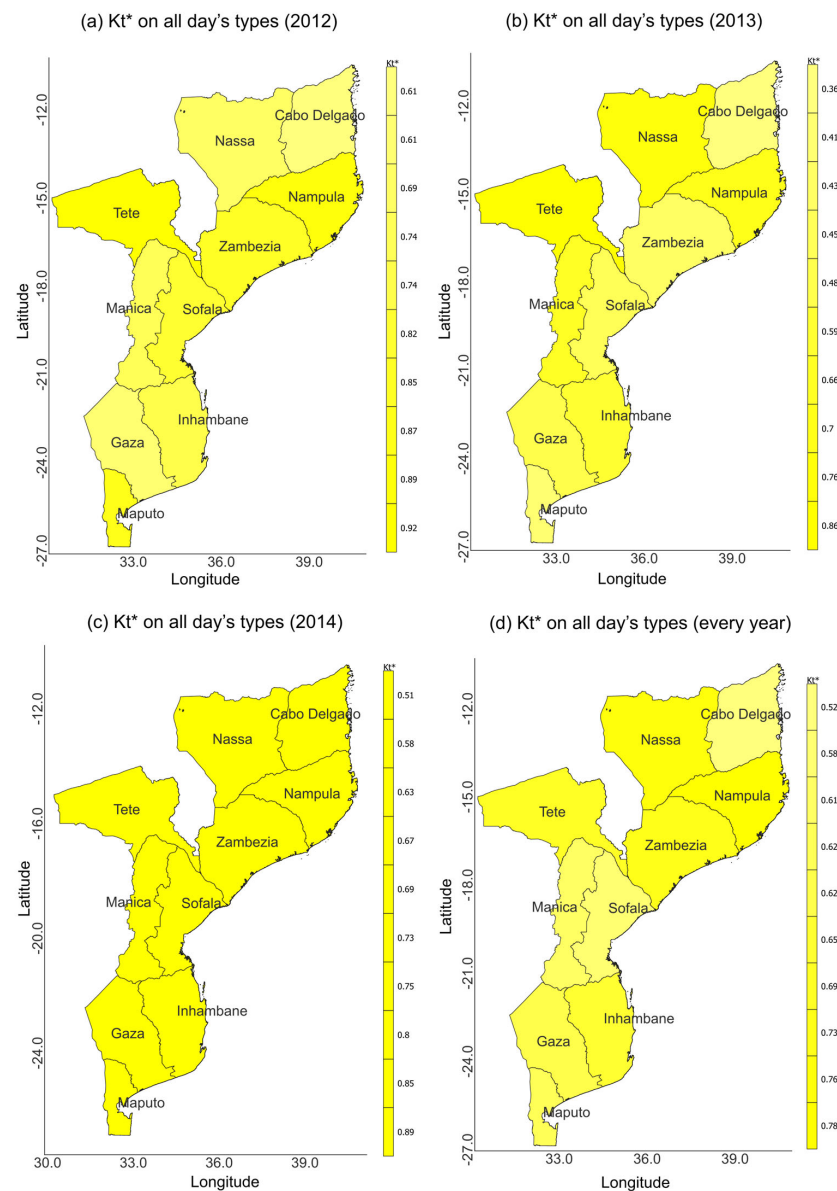


Figure 15. Map of geospatial-temporal distribution of solar energy in Mozambique, through the modeling of K_t^* during the years 2012, 2013, and 2014, and in all years for all days types, being (a) K_t^* on all days types in 2012, (b) K_t^* on all days types in 2013, (c) K_t^* on all days types in 2014, and (d) K_t^* on all days types in all years.

However, the ΔK_t^* density was recorded in Mozambique over eight months in 2012 in a varied sequence, as shown in Figure 16a. The average acceptable days in the southern part of the country are -0.0416 , acceptable days are -0.0484 , and unacceptable days are -0.0348 . There are different acceptable and unacceptable days in Gaza province, with an average of -0.0485 . There are different acceptable and unacceptable days in Massangena province, with an average of -0.0456 . Supplementary Figure S2 provides an additional visual representation, using a heat map to illustrate the spatial variability of mapped solar irradiance across the region.

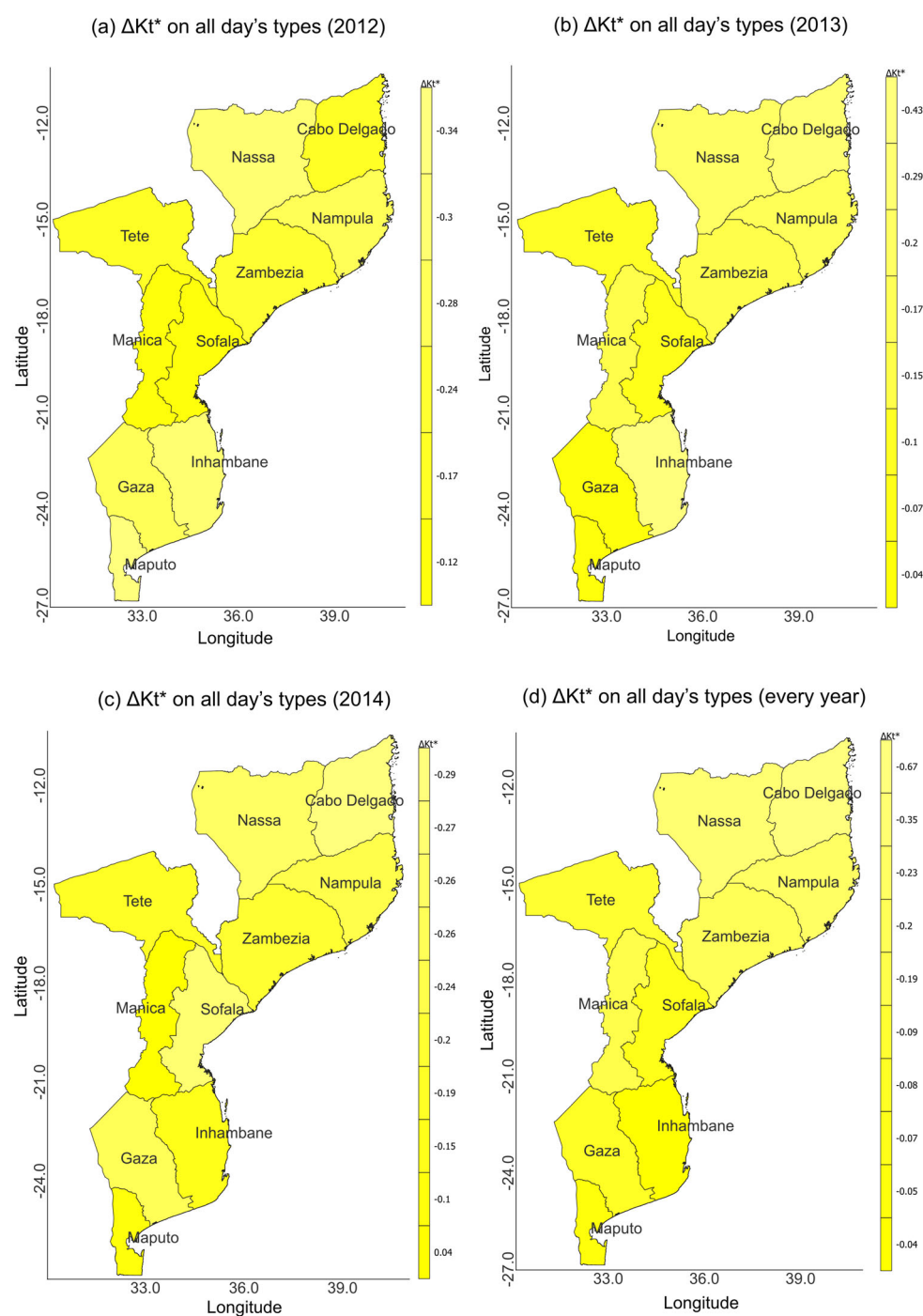


Figure 16. Map of geospatial–temporal distribution of solar energy in Mozambique, through modeling of ΔK_t^* during the years 2012, 2013, and 2014, and in all years for all days types, being (a) ΔK_t^* on all days types in 2012, (b) ΔK_t^* on all days types in 2013, (c) ΔK_t^* on all days types in 2014, and (d) ΔK_t^* on all days types in all years.

Throughout the mid-region of Mozambique, it is shown that, in the province of Tete (Marávia station), the $\Delta\bar{K}_t^*$ is -0.0532 , with -0.0754 for acceptable days and -0.0312 for unacceptable days. In the province of Sofala (Nhangau station), the $\Delta\bar{K}_t^*$ is -0.0597 , with -0.0727 for acceptable days and -0.0467 for unacceptable days. In Manica province (Nhapassa-1 station), the $\Delta\bar{K}_t^*$ is about -0.0403 , with -0.0621 for acceptable days and -0.0462 for unacceptable days, and (Nhapassa-2 station) has about an $\Delta\bar{K}_t^*$ of -0.0232 , with -0.0421 for acceptable days and -0.0667 for unacceptable days. Zambezia province (Lugela-1 station) has an $\Delta\bar{K}_t^*$ of about -0.0563 , with -0.3988 for acceptable days and -0.0357 for unacceptable days, and (Lugela-2 station) has an $\Delta\bar{K}_t^*$ of about -0.0583 , with -0.0846 for acceptable days and -0.0329 for unacceptable days. Mozambique's Northern region averages acceptable days at -0.0745 , unacceptable days at -0.0262 , and acceptable days at -0.1217 . Relatively, -0.1109 and -0.1609 are the averages for Massangulo-1 and Massangulo-2 stations in Niassa province, respectively. Their respective averages are -0.0702 , -0.0886 , -0.0518 , and -0.0484 for Nanhupo-1 and Nanhupo-2 stations in Nampula province. In Cabo-Delgado, the average values for Chomba station are -0.0685 , -0.0853 , and -0.0518 .

The distribution of solar energy in terms of K_t^* was evaluated over 12 months in 2013, with a diversified order, as depicted in Figure 15b. The UEM-Maputo station in the province of Maputo, in southern Mozambique, demonstrates that the $\bar{K}_t^*$ is 0.6456 , with acceptable days being 0.5478 and unacceptable days being 0.5246 . Average K_t^* values in Gaza province (Dindiza station) are 0.6522 , with acceptable days 0.6785 and unacceptable days 0.5445 . Similarly, Massangena station has an $\bar{K}_t^*$ value of 0.5263 , with acceptable days 0.4256 and unacceptable days 0.5421 . $\bar{K}_t^*$ in Inhambane province (Pomene station) is 0.6241 , with acceptable days being 0.6622 and undesirable days being 0.4752 . The mid-region of Mozambique has an $\bar{K}_t^*$ of 0.5949 , with acceptable days falling between 0.7812 and 0.4892 . The acceptable days range from 0.4568 to 0.4488 , with an $\bar{K}_t^*$ of 0.4502 in Sofala. The acceptable days in Manica province range from 0.5007 to 0.4319 , with an $\bar{K}_t^*$ of 0.5298 . With no acceptable days and 0.3131 unacceptable days, the $\bar{K}_t^*$ in the province of Zambezia is 0.3139 . The acceptable days range from 0.5786 to 0.4149 , with the $\bar{K}_t^*$ in Niassa province, Northern Mozambique, being 0.4968 . In Nampula province, acceptable days range from 0.5334 to 0.1309 , with an $\bar{K}_t^*$ of 0.4369 . In the province of Cabo-Delgado, the $\bar{K}_t^*$ is 0.1141 , meaning that there are no acceptable with 0.1141 density of unacceptable days. In the area, these conditions are noted at several sites, depicted in Table 15.

According to this study, as shown in Figure 16b, the distribution of solar energy in Mozambique over the course of the year 2013 manifested a diverse order in terms of ΔK_t^* . Mozambique's southern region has an $\Delta\bar{K}_t^*$ of -0.0778 , with acceptable days falling between -0.0848 and -0.0699 . Its acceptable days range from -0.0454 to -0.0449 , with an average of -0.0874 in Gaza province. With tolerable days falling between -0.0259 and -0.0755 , Massangena province's average is -0.0677 . The average in the province of Inhambane is -0.0758 . The mid-region of Mozambique has an $\Delta\bar{K}_t^*$ of -0.0841 , with -0.1521 acceptable days and -0.0162 unacceptable days. It is -0.0564 for unacceptable days and -0.0657 for unacceptable days in Sofala province. It is -0.0758 in Manica province, with acceptable days being -0.6197 and unacceptable days being -0.0639 . It is -0.0642 in the province of Zambezia, meaning that there are no acceptable days and -0.0646 for unacceptable days. In Niassa province, the average for acceptable days in the Northern region of Mozambique is -0.0824 ; at Massangulo-1 and Massangulo-2 stations, the average is -0.0871 . The Nampula province also records tolerable days at -0.0667 , unacceptable days at -0.0667 , and unacceptably unacceptable days at -0.0637 . The Chomba station in Cabo-Delgado province records -0.0669 for unacceptable days.

Table 15. Geospatial–temporal distribution of solar energy in terms of days of all skies in 2013.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.6456	−0.0778	0.5478	−0.0848	0.5246	−0.0699
	Gaza	Dindiza	0.6522	−0.0874	0.6785	−0.0454	0.5445	−0.0449
		Massangena	0.5263	−0.0677	0.4256	−0.0259	0.5421	−0.0755
	Inhambane	Pomene	0.6241	−0.0758	0.6622	−0.0417	0.4752	−0.0689
Mid-region	Tete	Marávia	0.5949	−0.0841	0.7008	−0.1521	0.4891	−0.0162
	Sofala	Nhangau	0.4502	−0.0658	0.4568	−0.0564	0.4488	−0.0657
	Manica	Nhapassa-1	0.5298	−0.0758	0.5007	−0.6197	0.4319	−0.0639
		Nhapassa-2	0.5454	−0.0349	0.4989	−0.0489	0.4001	−0.0621
	Zambezia	Lugela-1	0.3139	−0.0642	---	---	0.3131	−0.0646
		Lugela-2	0.3185	−0.0615	---	---	0.3118	−0.0615
North region	Niassa	Massangulo-1	0.4968	−0.0824	0.5786	−0.1293	0.4149	−0.0356
		Massangulo-2	0.4462	−0.0871	0.4641	−0.1525	0.3111	−0.0797
	Nampula	Nanhupo-1	0.4369	−0.0667	0.5334	−0.0695	0.1309	−0.0637
		Nanhupo-2	0.4039	−0.0667	0.5334	−0.0695	0.1309	−0.0637
	Cabo-Delgado	Chomba	0.1141	−0.0669	---	---	0.1141	−0.0669

The distribution of solar energy in terms of K_t^* over 2014 was evaluated over 12 months, revealing a diversified order density. The acceptable days in the southern part of Mozambique range from 0.6982 to 0.3646, with an $\overline{K_t^*}$ of 0.6449. The provinces of Maputo, Gaza, Massangena, and Inhambane likewise have varied $\overline{K_t^*}$, with some days being acceptable and others being unacceptable. These results demonstrate the region's need for better communication and transportation systems, as shown in Figure 15c. In mid-region of Mozambique provinces, the $\overline{K_t^*}$ is 0.5774, with 0.7850 for bad days and unacceptable days. With 0.5634 for good days and 0.4088 for bad days, the value in Sofala province is 0.5850. It is 0.5197, with acceptable days being 0.6319 and unacceptable days being 0.5358 in the province of Manica. In the province of Zambezia, it is 0.4102, meaning that there are no acceptable days and that there are unacceptable days. Mozambique's northern area contains a number of provinces with different $\overline{K_t^*}$ values. The $\overline{K_t^*}$ at the Massangulo-1 station in Niassa is 0.5183, with no acceptable days and 0.5207 for bad days. In Nampula, the $\overline{K_t^*}$ for Nanhupo-1 and Nanhupo-2 stations is 0.5998, with 0.5968 for bad days and no acceptable days. With no acceptable days and unsatisfactory days of 0.5952, Cabo-Delgado's average K_t^* is 0.5628, as depicted in Table 16.

The analysis of solar energy distribution in Mozambique reveals a high intermittency to very high potential density of ΔK_t^* over 50% of solar energy present in 2014, as shown in Figure 16c over 12 months. The acceptable days range from −0.0627 to −0.0879, with the $\Delta \overline{K_t^*}$ in the southern part of Mozambique being −0.0759. With acceptable days falling between −0.0756 and −0.0898, the average in the provinces of Maputo, Gaza, Massangena, and Inhambane is −0.0876. UEM-Maputo and Pomene stations also have this average. Mozambique's mid-region has an $\Delta \overline{K_t^*}$ of −0.0575, meaning that there are no

acceptable days and -0.0685 for unacceptable days. With acceptable days of -0.0526 and unsatisfactory days of -0.0851 , the average in the province of Tete is -0.0524 . In Manica province, acceptable days are 0.0997 and -0.6318 , respectively, while the average is -0.0701 . The average in the province of Zambezia is -0.0702 , with undesirable and no acceptable days being -0.0715 and -0.0712 , respectively. In the North region, the average number of unacceptable days is -0.0418 in Niassa province (Massangulo-1 station), -0.0697 in Massangulo-2 station, -0.0674 in Nanhupo-1 station, -0.0675 in Nanhupo-2 station, and -0.1628 in Cabo-Delgado province (Chomba station). These signs point to unfavorable weather patterns and the possibility of severe weather occurrences.

Table 16. Geospatial–temporal distribution of solar energy in terms of days of all skies in 2014.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.6449	-0.0756	0.6982	-0.0489	0.3646	-0.0529
	Gaza	Dindiza	0.5456	-0.0898	0.5012	-0.0489	0.4466	-0.0789
		Massangena	0.5798	-0.0858	0.5489	-0.0289	0.4489	-0.0599
	Inhambane	Pomene	0.5728	-0.0876	0.5489	-0.0487	0.4289	-0.0789
Mid-region	Tete	Marávia	0.7774	-0.0524	---	---	0.6950	-0.0851
	Sofala	Nhangau	0.5850	-0.0850	0.5634	-0.0534	0.4088	-0.6088
	Manica	Nhapassa-1	0.5358	-0.7258	0.5197	-0.0997	0.4319	0.6319
		Nhapassa-2	0.5209	-0.7244	0.5489	-0.0489	0.4001	-0.6001
	Zambezia	Lugela-1	0.4102	-0.0701	---	---	0.4202	-0.0702
		Lugela-2	0.4657	-0.0715	---	---	0.4957	-0.0712
North region	Niassa	Massangulo-1	0.5183	-0.0418	---	---	0.5207	-0.0416
		Massangulo-2	0.5898	-0.0697	---	---	0.5182	-0.0692
	Nampula	Nanhupo-1	0.5998	-0.0674	---	---	0.5108	-0.0674
		Nanhupo-2	0.5968	-0.0675	---	---	0.5952	-0.0674
	Cabo-Delgado	Chomba	0.5628	-0.1628	---	---	0.5658	-0.6585

The distribution of solar energy in terms of K_t^* is demonstrated over all the years of measurements, with density varying in intensity, as depicted in Figure 15d. In the southern part of Mozambique, different stations in the provinces of Maputo, Gaza, and Pomene reported an $\overline{K_t^*}$ of 0.6218 in Maputo, 0.5656 in Gaza, 0.6778 in Massangena, and 0.6545 in Inhambane. Tete, Sofala, Manica, Nhapassa-1, and Nhapassa-2 have $\overline{K_t^*}$ values of 0.9212, 0.8217, 0.7258, and 0.7556 in mid-region of Mozambique, respectively. The many stations in the provinces that these averages are based on show different levels of energy efficiency. In the northern part of Mozambique, the average K_t^* is approximately 0.6432 in Niassa, 0.6163 in Nampula (Nanhupo-1), also 0.6756 in Nampula province (Nanhupo-2), and 0.5566 in Cabo-Delgado. Massangulo-1 station reports a $\overline{K_t^*}$ of 0.6432, Massangulo-2 station reports a $\overline{K_t^*}$ of 0.6245, and Chomba station reports a $\overline{K_t^*}$ of 0.5822 for unacceptable days, as depicted in Table 17.

Table 17. Geospatial–temporal distribution of solar energy in terms of days of all skies, in all years.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$
South region	Maputo	UEM-Maputo	0.6218	−0.0412	0.6277	−0.0245	0.5798	−0.0485
	Gaza	Dindiza	0.5256	−0.0569	0.5589	−0.0455	0.4456	−0.0456
		Massangena	0.6778	−0.0777	0.4252	−0.0456	0.6562	−0.0466
	Inhambane	Pomene	0.6545	−0.0458	0.5562	−0.0478	0.6756	−0.0556
Mid-region	Tete	Marávia	0.9212	−0.0947	0.8952	−0.0456	0.9895	−0.0586
	Sofala	Nhangau	0.8217	−0.0654	0.7562	−0.0125	0.8562	−0.0789
	Manica	Nhapassa-1	0.7258	−0.0403	0.7562	−0.0695	0.7056	−0.0465
		Nhapassa-2	0.7808	−0.0403	0.6956	−0.0785	0.8245	−0.0892
	Zambezia	Lugela-1	0.7556	−0.1985	0.7525	−0.0785	0.7008	−0.0236
		Lugela-2	0.7922	−0.1915	0.6596	−0.0569	0.7956	−0.0452
North region	Niassa	Massangulo-1	0.6432	−0.0162	0.6825	−0.0452	0.5006	−0.0785
		Massangulo-2	0.6245	−0.0333	0.6956	−0.0785	0.6723	−0.0263
	Nampula	Nanhupo-1	0.6163	−0.0242	0.6825	−0.0856	0.4595	−0.0425
		Nanhupo-2	0.6756	−0.0825	0.5895	−0.0256	0.5756	−0.0785
	Cabo-Delgado	Chomba	0.5566	−0.0537	0.4589	−0.0489	0.5822	−0.0256

As shown in Figure 16d, which evaluates all the years of measurements, the examination of the distribution of solar energy in Mozambique shows a varied order of $\Delta \overline{K_t^*}$ density throughout the year. According to different stations, the $\Delta \overline{K_t^*}$ in the southern part of Mozambique is −0.0412 in Maputo, −0.0569 in Gaza, −0.0777 in Massangena, and −0.0458 in Inhambane province. In the mid-region of Mozambique, the $\Delta \overline{K_t^*}$ is −0.0987, −0.0654, −0.1985, and −0.1915, according to this study. Tete province (Marávia station), Sofala province (Nhangau station), Manica province (Nhapassa-1 station), Zambezia province (Lugela-1 station), and Lugela-2 station have the highest values. The northern region shows average values of −0.0162 and −0.0333 in Niassa province, −0.0242 and −0.0825 in Nampula province, and −0.0537 in Cabo-Delgado province, with Massangulo-1 and Nanhupo-1 stations reporting similar values.

3.6. Geospatial–Temporal Distribution of Solar Energy in MOZAMBIQUE

The distribution of solar energy in Mozambique shows a greater and varied intensity of K_t^* density across all the measurements. In different stations, the average K_t^* values for different provinces in Mozambique are displayed. The $\overline{K_t^*}$ in Gaza is 0.7612 for the Dindiza and Massangena stations, but it is 0.8494 in Maputo. The value in Inhambane is 0.6895, as shown in Figure 11. Manica, Zambezia, Sofala, and Tete all have different $\overline{K_t^*}$ values; the average for Tete is 0.9345, the average for Sofala is 0.7361, the average for Manica is 0.7252, and the average for Zambezia is 0.6835 and 0.7123. In the northern Mozambican provinces of Niassa, Nampula, and Cabo-Delgado, the average $\overline{K_t^*}$ at Massangulo-1 and Nanhupo-1 stations is 0.6191, 0.6649, and 0.4286, respectively. Figure 17a indicates that the $\overline{K_t^*}$ in Cabo-Delgado is 0.5256. According to this study, Mozambique’s solar energy distribution (obtained

Table 18. Cont.

Region	Province	Station Name	Total Average		Acceptable Average		Unacceptable Average	
			$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$	$\overline{K_t^*}$	$\Delta \overline{K_t^*}$
North region	Niassa	Massangulo-1	0.6191	−0.0962	0.5862	−0.0478	0.5992	−0.0425
		Massangulo-2	0.6108	−0.0333	0.6935	−0.0289	0.6252	−0.0745
	Nampula	Nanhupo-1	0.6649	−0.0242	0.6783	−0.0456	0.5005	−0.0478
		Nanhupo-2	0.6248	−0.0824	0.5789	−0.0236	0.5925	−0.0465
	Cabo-Delegado	Chomba	0.4286	−0.0537	0.4456	−0.0489	0.5256	−0.0156

3.7. World Geospatial–Temporal Distribution of Solar

The nations of Mozambique, Angola, Botswana, Namibia, Malawi, and Zimbabwe are all parts of Africa Austral. With a comparatively high clearness score (0.60), Mozambique offers immense potential for harnessing solar radiation. With a more shaded and desert climate that contributes to the high clearness index, Namibia (0.75) has the highest clearness index and comparable potential. Despite having a littoral climate, the southern parts of Africa are more mountainous, which may lower the clearness score, as shown in Figure 18.

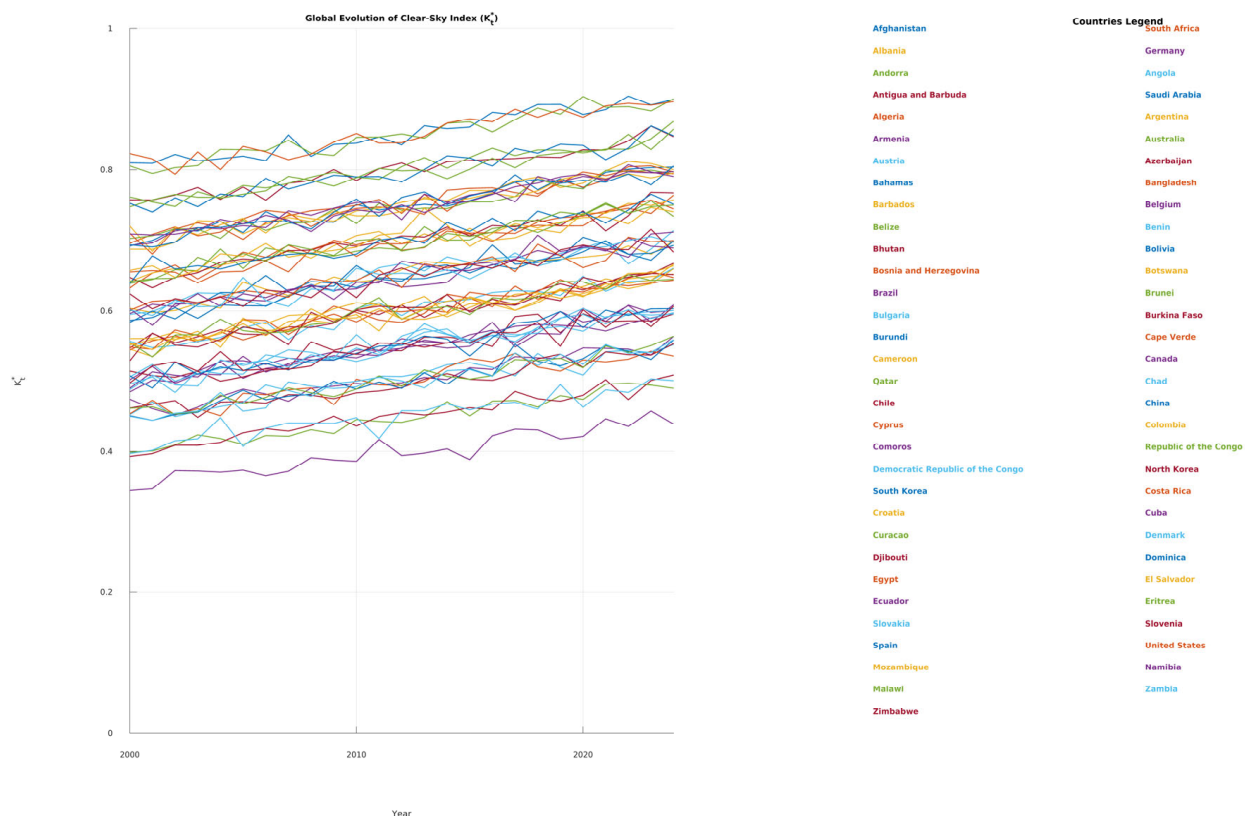


Figure 18. World geospatial–temporal distribution of solar, through modeling of K_t^* and ΔK_t^* .

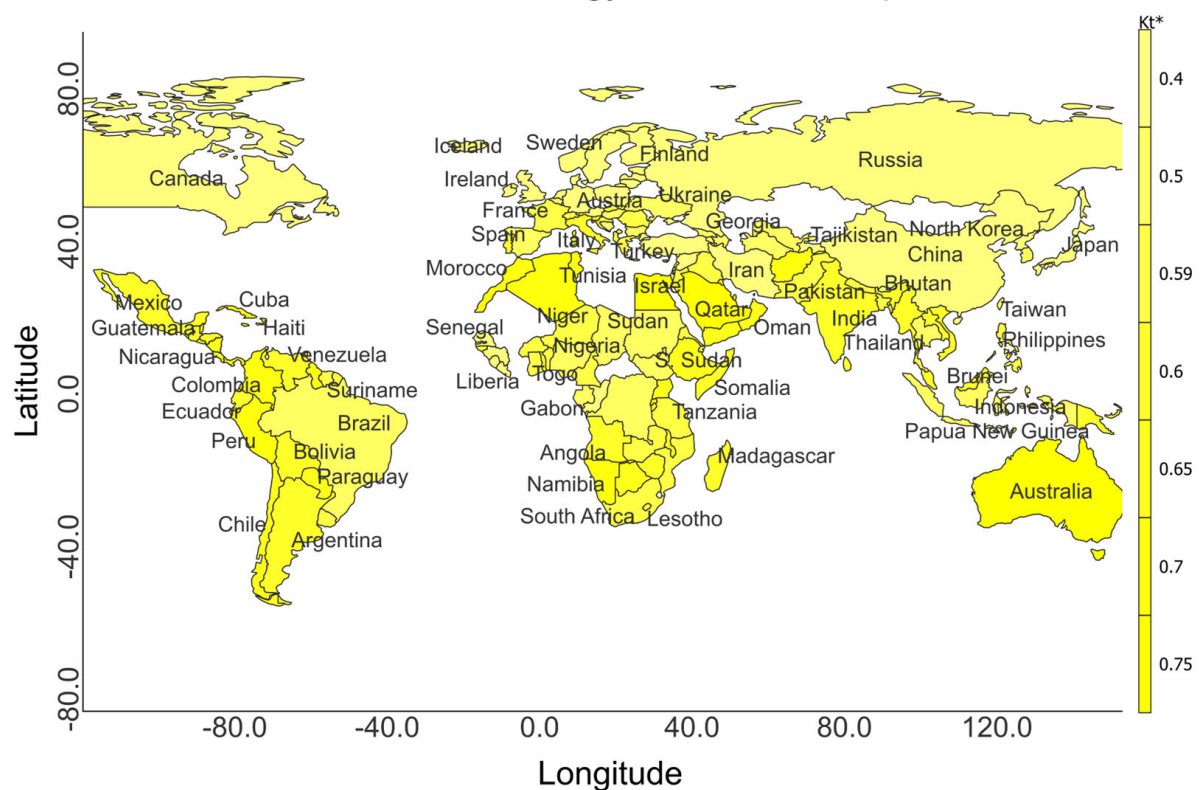
Africa boasts some of the world's clearest skies, with nations like Namibia, Ethiopia, Morocco, and Botswana enjoying exceptionally pure skies. Table 19 shows that, with a low, clear sky, Mozambique is above the average of nations like the Democratic Republic of the Congo, Cameroon, and Nigeria but below the average of northern and southern nations.

Table 19. Geospatial–temporal distribution of solar energy in terms of days of all skies.

Continent	$\overline{K_t^*}$		$\Delta\overline{K_t^*}$		Stage
	<i>min</i>	<i>max</i>	<i>min</i>	<i>max</i>	
Asia	0.5189	0.6912	−0.018	0.028	Above average
Europe	0.3945	0.6245	−0.015	0.025	Below average
Africa	0.6556	0.8571	−0.020	0.030	Upper middle
America	0.5845	0.7342	−0.022	0.032	Upper middle
Oceania	0.7126	0.8435	−0.012	0.020	Upper middle

The United States, Mexico, Peru, Panama, Chile, Brazil, Colombia, and Canada are among the nations in the Americas with high, clear skies. In the middle of the table, Mozambique has a K_t^* than Canada and Brazil, but a lower one than the Andes and tropical–dry tropical nations. As seen in Figure 18, Saudi Arabia, Qatar, Kuwait, India, China, Indonesia, Japan, and Iran are among the Asian nations with the highest clearest skies. Only the Middle East, which dominates global rankings, offers brighter sky than Mozambique. In general, Europe—which includes nations like Germany, France, Portugal, the United Kingdom, Norway, Switzerland, and Finland—has low clear-sky scores. Mozambique’s skies are frequently clear, which is far better than the norm for most European nations. In contrast to the majority of the Pacific nations, which are among of the most solarized in the world, Oceania has fewer clear skies, as depicted in Figure 19.

World Solar Energy Distribution Map

**Figure 19.** World map of geospatial–temporal distribution of solar energy in all provinces of Mozambique, through modeling of K_t^* and ΔK_t^* .

Mozambique has a greater clearness score than nations with more nublated or frisky climates, such as Finland (0.40), Iceland (0.45), and Iran (0.45). It is lower than nations

with hot, desert climates, such as Saudi Arabia (0.85), Qatar (0.85), and Egypt (0.85), which have a very high $\overline{K_t^*}$. Insular nations with a low degree of climate variance, such as the Maldives and Curaçao (which have a clearness index of 0.80), also have high clearness taxes. The arid and desertic climates of Saudi Arabia and Qatar may contribute to their high $\overline{K_t^*}$, whereas tropical nations with more hospitable climates, such as Brazil and Mozambique, have more moderate clearness indices. Due to the desert climate, northern African nations like Ethiopia have extremely dry climates; yet, because of the presence of arid regions, they are somewhat limited in their use of water and other vital resources.

4. Discussion

Clear-sky day counts have a stronger tendency to decline, declining between 2012 and 2014. On the other hand, it is evident in the South: the province of Maputo (UEM-Maputo) has an $\overline{K_t^*}$ of 0.8491 in 2012, 0.756 in 2013, and 0.8963 for the interpolated year 2014, indicating 0.2830 in the assessment of all day types. Its greater prevalence in Gaza's Dindiza and Massangena provinces is 0.7612, 0.7653 in 2012, 0.6589, 0.7428 in 2013, and 0.7412, 0.7426 in 2014, indicating 0.2537, 0.2476 for all sky types. In the province of Inhambane (Pomene station), the numbers were 0.7509 in 2012, 0.7743 in 2013, and 0.7728 in 2014; nevertheless, the overall number of days was 0.5157. There was a higher flow in 2012 of around 0.7845, 0.7038 in 2013, 0.7712 in 2014, and 0.4961 for all kinds of days in the mid-region, in the province of Tete (Marávia). All clear-sky days in Sofala province are classified as 0.3189, while 0.7361 was recorded in 2012 and 0.1101 and 0.1206 in 2013 and 2014. It was recorded in 2012 at 0.7258 and 0.7245, in 2013 at 0.7771 and 0.7741, in 2014 at 0.7771 and 0.7789, and in the classification of all days in the province of Manica (Nhapassa-1 and Nhapassa-2). In the Zambezia province (Lugela-1 and Luugela-2), it was recorded at 0.7275, 0.6385, and 0.1580 in 2012, 0.1582 in 2013, 0.1662, 0.1587 in 2014, and 0.3506, 0.3184 on all days. On all clear-sky days in the northern region, 0.4434, 0.1629, 0.1678, and 0.2021 were recorded in the province of Cabo Delgado (Chomba) in 2012, 2013, and 2014, respectively. The year 2012 saw 0.5854 and 0.5444, 2013 saw 0.4412 and 0.4413, 2014 saw 0.1640 and 0.1652, and for all days, 0.3969 and 0.3832 were recorded in the province of Nampula (Nanhupo-1 and Nanhupo-2). In 2012, scores of 0.6049, 0.6332, 0.6173, 0.6629, 2014, 0.5128, and 0.6528 were recorded, and for all kinds of clear-sky days, 0.5783 and 0.6496 were recorded, in the province of Niassa (Massangulo-1).

There is a greater tendency for the number of cloudy days to increase, rising from 2012 to 2014, as shown in the southern region: In the province of Maputo (UEM-Maputo) 0.5272 was observed in 2012, 0.5244 in 2013, and 0.6523 in 2014, and 0.1757 on all days. In the Gaza Strip (Dindiza and Massangena) in 2012, 0.4671 and 0.4863 were recorded, in 2013 0.4214 and 0.4263, in 2014 0.4263 and 0.1557, and 0.1421 on all days analyzed. In the province of Inhambane (Pomene), in 2012, 0.4263 was observed, 0.4043 in 2013, 0.4453 in 2014, and 0.2832 on all days analyzed with cloudy skies. In the Tete (Marávia) province in the central region, 0.4858, 0.4557, 0.4239, and 0.3138 were recorded on all days in 2012, 2013, 2013, and 2014, respectively. In the mid-region: 0.4605, 0.623, 0.6234, and 0.1950 were recorded on all days in the province of Sofala (Nhangau) in 2012, 2013, and 2014. In the province of Manica (Nhapassa-1 and Nhapassa-2), 0.3885 and 0.3037 were recorded in 2012, 0.511 and 0.5544 in 2013, and 0.5502, 0.4703, and 0.4808 on all days in 2014. Lugela-1 and Lugela-2 in the province of Zambezia maintained 0.3037 and 0.2932 in 2012, 0.0678 and 0.0639 in 2013, and 0.0610 and 0.0626 in 2014, but 0.1441 and 0.1399 for all kinds of days. In the northern region, 0.0798, 0.0740, and 0.0513 were recorded in the province of Cabo-Delgado (Chomba) in 2012, 2013, and every observation day. In the province of Nampula (Nanhupo-1 and Nanhupio-2), 0.0798 and 0.4014 were recorded in 2012, 0.2369 and 0.1851 in 2013, 0.0756 and 0.0756 in 2014, and 0.2380 and 0.2040 for all day types. In the province of Niassa

(Massangulo-1 and Massangulo-2) scores was recorded at 0.4125, 0.3329, 0.3850, and 0.3773 in 2012, 0.3064 and 0.3671 in 2014, and 0.3681 and 0.3591 for all kinds of days.

The observation for intermediate-sky days has a tendency in all years, with lower characteristics close to cloudy and higher characteristics close to clear, between the years 2012, to 2014; however, it is shown that in the South region, in the province of Maputo (UEM-Maputo), in the year 2012, 0.6808 was observed; in 2013, 0.6856 was observed; in 2014, 0.6823 was observed; and 0.6803 was observed for all types of days. In Gaza province (Dindiza and Massangena), in 2012, approximately 0.6828 and 0.6825 were observed; in 2013, 0.5862 and 0.5896 were observed; in 2014, 0.5826 and 0.5814 were observed; and 0.21 and 0.1954 were observed for observations in all years of measurements. In the province of Inhambane (Pomene), in 2013, 0.6481 was observed; in 2014, 0.6334 was observed; and 0.4272 was observed for all types of days. In the mid-region, in the province of Tete (Marávia), in 2012, 0.6595 was observed; in 2013, 0.5781 was observed; and 0.4272 was observed on all types of days. In the province of Sofala (Nhangau), approximately 0.6046 was observed in 2012, approximately 0.0853 in 2013, and approximately 0.0853 in 2014, but 0.2584 for all types of days. In the province of Manica (Nhapassa-1 and Nhapassa-2), in 2012, 0.5611 and 0.5700 were observed; in 2013, 0.6402 and 0.6411 were observed; in 2014, 0.6411 and 0.6423 were observed; and for all types of days, 0.4007 and 0.6174 were observed. In the province of Zambezia (Lugela-1 and Lugela-2), in 2012, 0.5297 and 0.4652 were observed; in 2013, 0.1104 and 0.1123 were observed; in 2014, 0.1123 and 0.1159 were observed; and for all days, 0.2293 and 0.2510 were observed. In the northern region: 0.3584 was recorded in 2012 and 0.1122 in 2013 in the province of Cabo-Delgado (Chomba); nonetheless, 0.1568 was recorded for all kinds of intermediate-sky days. In the province of Nampula (Nanhupo-1 and Nanhupo-2), 0.4991, 0.4656, 0.4393, 0.3495, 0.2201, and 0.1136 were recorded in 2012, 2013, 2013, and 2014, respectively; however, 0.3861 and 96 were recorded for all day types. In Niassa province (Massangulo-1 and Massangulo-2), 0.4973 and 0.5041 were recorded in 2012, 0.5118 and 0.5169 in 2013, and 0.4230 and 0.5031 in 2014. For all types of days, 0.4773 and 0.5281 were recorded.

Since the mapping is done over interprovincial distances of temporal spacing, the results of the measurement and mapping of solar energy are consistent with the spatial-temporal correlation analysis in Hoff and Perez (2010) [20] and Lohmann (2018) [38], which measure the same degree of tuning and behavior of different types of days, observing the energy correlation and bimodality characteristics of solar energy in terms of the K_t^* . This research differs in terms of the metric and measurement intervals applied, and each station's energy content is found in addition to measuring the variability in a station both temporally and spatially.

The frequency of clear-sky days, $\overline{\Delta K_t^*}$ increased more frequently in 2012 than in 2013 and 2014. The southern portion of the province, however, saw -0.0343 in 2012, -0.0306 in 2014, -0.0305 in 2014, and -0.0114 for all days in the province of Maputo (UEM-Maputo). In Gaza Province (Dindiza and Massangena), it was recorded at -0.0943 and -0.0035 in 2012, -0.0843 and -0.0754 in 2013, and -0.0314 and -0.0263 on all days. While -0.0549 was recorded on all days, -0.0036 , -0.0721 , and -0.00927 were recorded in the province of Inhambane (Pomene) in 2012, 2013, and 2014, respectively. In the mid-region, in the province of Tete (Marávia), in 2012, around -0.0260 was observed; in 2013, -0.1256 ; and for all types of days, -0.0505 was observed. In the province of Sofala (Nhangau), in 2012, -0.0597 was observed; in 2013, -0.0110 was observed; in 2014; -0.0156 was observed; and, on all days, -0.0272 was observed. In the provinces of Manica (Nhapassa-1 and Nhapassa-2), in 2012, it was maintained around -0.0597 and -0.0403 ; in 2013, -0.0627 and -0.0627 were observed; in 2014, -0.0627 and -0.0628 were observed; and for all types of days, -0.0552 and -0.0425 were observed. In the province of Zambezia (Lugela-1 and

Lugela-2), in 2012, -0.0414 and -0.0475 were observed; in 2013, -0.0853 and -0.0875 were observed; and in 2014, -0.1132 and -0.0602 were observed; however, the evaluation in all types of days shows -0.0801 and -0.0645 . In the northern region, the province of Nampula (Nanhupo-1 and Nanhupo-2) shows -0.0793 and -0.0544 in 2012, -0.0881 and -0.0882 in 2013, and -0.0909 , -0.0908 , -0.0861 , and -0.0778 in 2014 for the examination of all clear-sky day types. In the province of Niassa (Massangulo-1 and Massangulo-2), it was found to be around -0.1109 and -0.0349 in 2012, -0.1111 and -0.0408 in 2013, and -0.0697 and -0.0504 in 2014. Nevertheless, it was recorded to be -0.0972 and 20 on all types of days.

On cloudy days, there is a greater frequency and tendency for increases and increases in the clear-sky index, with a greater frequency of occurrence and density in 2012, decreasing to 2014, where a greater tendency for the K_t^* was observed, that is, the decline in the index and its increase is diverse. However, it can only be observed that, throughout the southern region, in the province of Maputo (UEM-Maputo), during the year 2012, -0.0515 was observed; in 2013, -0.0514 was observed; in the year 2014, -0.0512 was observed; and for all days, -0.0172 was observed. In the province of Gaza (Dindiza and Massangena), it was possible to observe during the year 2012, -0.0832 and -0.0045 ; in the year 2013, -0.0541 and -0.0544 were observed; and for all types of days, -0.0277 was observed. In the province of Inhambane (Pomene), in 2013, -0.0706 was observed and in 2014, -0.0697 was observed; however, for all types of days, -0.0468 was observed. In the mid-region: in the province of Tete (Marávia), in 2012, -0.0598 was observed; in 2013, -0.0491 was observed; and for all types of days, -0.0363 was observed. In the province of Sofala (Nhangau), in 2012, -0.0329 was observed; in 2013, -0.0001 was observed; in 2014, -0.0125 was observed; and for all types of days, -0.0111 was observed. In the province of Manica (Nhapassa-1 and Nhapassa-2), in 2012, -0.0385 and -0.0455 were observed; in 2013, -0.0905 and -0.0921 were observed; in 2014, -0.0923 and -0.915 were observed; and for all types of days, -0.0435 was observed. In the province of Zambezia (Lugela-1 and Lugela-2), in 2012, -0.0660 and -0.0679 were observed; in 2013, -0.0372 and -0.0346 were observed; in 2014, -0.0356 and -0.0356 were observed; and for all types of days, -0.0463 and 474 were observed. In the northern region, in the province of Cabo Delgado (Chomba), -0.0498 was recorded in 2012, -0.0414 in 2013, and -0.0304 for all days. The following values were recorded in the province of Nampula (Nanhupo-1 and Nanhupo-2): -0.0638 and -0.0474 in 2012; -0.0513 and 0.0005 in 2013; -0.0476 and -0.0476 in 2014; and -0.0542 and -0.0315 for all types of days. It was recorded as -0.0754 and -0.0557 in 2012, -0.0654 and -0.0380 in 2013, -0.0245 and -0.0621 in 2014, and -0.0551 and 9 for all types of days in the province of Niassa (Massangulo-1 and Massangulo-2).

For intermediate-sky days, it has intermediate incremental characteristics between the high frequencies of clear days and the low frequencies of cloudy-sky days, presenting itself in a fluctuating manner. However, the following can be observed throughout the southern region: in the province of Maputo (UEM-Maputo), during the year 2012, -0.0553 was observed; in the year 2013, -0.0554 was observed; in the year 2014, -0.0546 was observed; and for all types of days, -0.0184 was observed. In the province of Gaza (Massangena and Dindiza), in 2012, -0.1220 and -0.126 were observed; in 2013, -0.1167 and -0.1067 were observed; and for all types of days, it was possible to observe -0.0407 and -0.0398 . In the province of Inhambane (Pomene), in 2013, it was possible to observe -0.0802 , in 2014 it was only possible to observe -0.1106 , and for all types of days it was possible to observe -0.0636 . In the mid-region: in the province of Tete (Marávia), in 2012, only -0.0621 could be observed and in 2013, -0.0592 was observed; however, for summary in all types of days, -0.0404 was shown. In the province of Sofala (Nhangau) in 2012, it was possible to observe -0.0502 ; in 2013, -0.0061 was observed, in 2014, -0.0161 was observed; and for all types

of days, -0.0208 was observed. In the province of Manica (Nhapassa-1 and Nhapassa-2), in 2012, it was possible to observe -0.0468 and -0.0626 ; in 2013, it was possible to observe -0.0762 and -0.0762 ; in 2014, -0.0762 and -0.0762 were observed; and for all types of days, -0.0664 and -0.0717 were observed. In the province of Zambezia (Lugela-1 and Lugela-2), in 2012, it was possible to observe around -0.0599 and -0.1161 ; in 2013, -0.0684 and -0.0607 were observed; in 2014, -0.0669 and -0.0728 were observed; and for all types of days, it was observed -0.0651 and -0.08322 . In the North region: in the province of Cabo-Delgado (Chomba), in 2012, only -0.0766 could be observed; in 2013, -0.0662 was observed; and for all types of days, -0.0472 could be observed. In the province of Nampula (Nanhupo-1 and Nanhupo-2), in 2012, it was possible to observe -0.0679 and -0.0677 , in 2013, it was possible to observe -0.0662 and -0.0636 , in 2014, it was possible to observe -0.0654 and -0.0644 , and for all types of days, it was possible to observe -0.0653 . In the province of Niassa (Massangulo-1 and Massangulo-2), in 2012, it was possible to observe -0.0740 and -0.0580 ; in 2013, -0.0856 and -0.0533 ; and in 2014, it was possible to observe -0.0366 and -0.0505 ; however, for days with all types of skies, it was possible to observe -0.0654 and -0.0539 .

However, the above-mentioned increases in the K_t^* are primarily due to the atmosphere's little attenuation, which is primarily caused by uniformly mixed gases. Ozone attenuates a little more than uniformly mixed gases; however, some models do not include a separate absorption term for evenly mixed gases. The amount of ozone in the atmosphere obviously affects this. In a specific investigation of a range of thousands of kilometers between measurement sites, Mucomole et al. (2024) [29] similarly report the observation results of ΔK_t^* , noting an incremental dynamic. However, the mapping done here specifically demonstrates the incremental dynamic primarily on clear-sky days, followed by intermediate-sky days that are amplified as high solar energy fluctuations and deviations, thereby increasing the likelihood of variability in a solar plant's solar power output (additionally see Supplementary Material provided on data set mozambique_ghi_kWh_per_m2_per_day.csv).

The three primary attenuators are additionally found to be water vapor, aerosols, and (dispersion) by air molecules; however, the relative significance of water vapor and aerosols again depends on their atmospheric concentration. Additionally, the absorbance of aerosols is dependent on the albedo of single scattering. In general, the transmittances of molecular absorbers are not affected by the zenith angle. The Rayleigh and aerosol transmittances decrease significantly with zenith angle, these results are similarly analyzed in Duffie and Beckman, (1991) [2], Iqbal (1983) [15], Mucomole et al. (2024) [29], and Mucomole et al. (2025) [6], who observe the same cloud interference; however, here, the cloud is modeled in such a way as to perceive the totative horizontal energy with a focus on its mapping, observing in all results that there is high transmissivity in hot periods with correlated seasons in terms of transmittances in the order of 0.92, intra-mid (central) and northern regions as well as mid-southern and northern regions.

The sky of Africa is among the clearest in the world; countries Morocco, Ethiopia, Namibia, and Botswana are among the nations with the purest skies. With a low, clear sky, Mozambique rates higher than nations like Nigeria, Cameroon, and the Democratic Republic of the Congo, but lower than those in the north and south. The skies in Asia are the cleanest, whereas the skies in the Americas are high and clear. In general, clear-sky scores are low in Europe.

5. Conclusions

The adoption of alternative sources is encouraged by the need to find energy to fulfill the increasing demand. Compared to other renewable energy sources like wind and hydro,

solar technology is a clean, sustainable resource that does not harm the environment when used. The ozone layer, uniformly mixed gases, aerosols, and water vapors that contribute to the attenuation, dispersion, and other forms of reduction of solar energy, such as attenuation, absorption, and reflection, are among the atmospheric parameters that are being modeled and mapped in order to completely eliminate the variability of solar energy on the earth's surface. This is because the emission of gases has been stimulating fluctuations that affect the adherence to this resource and reduce the effectiveness and permanence of the plants.

The atmospheric transmittance contributes approximately 0.98 during the hot and rainy season compared to 0.56 during the cold and dry season. This is to account for the region of study's orientation with respect to the sun, which absorbs more energy and promotes its dispersion to the surface. On the other hand, there are greater circulations of hydrological circle parameters, which promote the fall of particles like dust and Aitkins's aerosols in the atmosphere and a greater incidence of direct solar energy.

In high-altitude regions, the transmittance of uniformly mixed gases is higher than that of the ozone layer. Water vapor and aerosols follow, creating a cumulative transmittance that affects the variable form of solar energy that reaches the earth's surface.

The number of clear-sky days increases as a result of human activity that releases particles into the atmosphere, such as dust, aerosols, uniformly mixed gases, and substances that strengthen the ozone layer. Therefore, the K_t^* , which was 0.8956 in 2012, is in the range of 0.6986 in 2014. Conversely, on cloudy days, the K_t^* intensifies between 0.3569 and 0.5214, indicating an increase in cloudiness, with a concentration on the mid and northern regions along the study region. This is caused by emissions from mining activities as well as the involvement of natural cyclones, which assist in transporting masses of different particles to unfavorable regions, resulting in this situation. Lower characteristics, which resemble the behavior of cloudy-sky days, and higher characteristics, which resemble clear-sky days, are displayed on clear-sky days. Energy fluctuates in various frequency scales, with a focus on high solar energy trends, which affect a solar plant's output. As a result, solar generation must be dimensioned in relation to the total energy presented.

The clear-sky days that have been mapped exhibit a high incidence flow, with values near one in the categorization diagram. Cloudy days, on the other hand, exhibit a low deviation with features in the low order of the categorization diagram. In contrast, the intermediate days have tendencies of large deviation of solar energy values, displaying characteristics that fall somewhere in between those of the two categories of days.

Variability in the amount of solar energy that reaches the earth's surface is caused by the high tendency for high swings in solar energy on days with intermediate features in comparison to other days that also show a high flux and solar energy flux.

On the other hand, days in between show a steady decline in solar energy with long, flattened borders and a central maximum. The clear-sky days degrade gradually and then abruptly to frequencies below 0.0003 with significant variance, while the clear days vary abruptly to frequencies below 0.002.

Mozambique performs upper middle in terms of clarity than hot, desert countries like Saudi Arabia, Qatar, and Egypt, but better than those with nublated or frisky climates. There are significant clearness taxes in insular countries like Curaçao and the Maldives. Tropical countries like Brazil and Mozambique have moderate clearness indices, whereas arid climates increase the K_t^* .

The frequency of growing trends in clear-sky days is larger in 2012 than it is in 2013 and 2014. K_t^* increases are more common and show an increasing trend on cloudy-sky days. In 2012, the frequency of occurrence density was higher, but it decreased until 2014, when

the K_t^* trended higher. Between the high frequencies of clear days and the low frequencies of cloudy-sky days, intermediate-sky days vary in their incremental characteristics.

Supplementary Materials: Additional data related to the mapping solar energy implemented in this research study can be find at https://github.com/Muco-1990/mapping_solar_energy_mozambique.git (accessed on 1 May 2025).

Author Contributions: Conceptualization, methodology, validation, and formal analysis: F.V.M. and C.A.S.S.; investigation, resources, data curation, writing, preparation of the original draft, writing—review and editing, acquisition of funding, visualization, and software: F.V.M., C.A.S.S., and L.L.M.; supervision and project administration: C.A.S.S.; and advanced curation of data, writing, and supervision: F.V.M., C.A.S.S., and L.L.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by CS-OGET, the Faculty of Engineering, Eduardo Mondlane University, underfunding number Nr.5-09/2023/CS-OGET, for doctoral research.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that back up the reported outcomes are accessible on the AERONET [46] website at https://aeronet.gsfc.nasa.gov/new_web/webtool_aod_v3.html (accessed on 10 April 2023), the NOAA [61] web-site at <https://www.noaa.gov/weather> (accessed on 6 January 2023), Meteosat [45] website at <https://osi-saf.eumetsat.int/products/radiative-fluxes-products> (accessed on 12 February 2023) and the NASA POWER [62] website <https://power.larc.nasa.gov/data-access-viewer/> (accessed on 18 May 2023). Additional data that support the conclusions of this research have not been released and can be obtained from INAM [44], FUNAE [43], or UEM [63], or by contacting the corresponding author upon request.

Acknowledgments: We thank the FUNAE entities for their assistance in providing us with sample data from the campaign conducted between 2019 and 2021. We would also like to thank INAM for supplying us with the sample of solar radiation data spanning from 1995 to 2024, and for granting us access to their facilities for training and experimental tests. Additionally, we extend our appreciation to the Department of Physics at Eduardo Mondlane University for generously making their facilities available for real-time testing and for the latest solar energy behavior measurements. Their provision of a laboratory for data processing greatly contributed to the compilation of this research. Lastly, we would like to acknowledge CS-OGET for its support, as it played an integral role in the culmination stage of this doctoral research.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DNI	Direct Normal Irradiance;
DHI	Diffuse Horizontal Irradiance;
eq.	Equation;
PV	Photovoltaic;
FUNAE	National Energy Fund;
G_{on}	Extraterrestrial radiation on a horizontal surface;
G_{cnb}	Normal clear-sky DNI;
G_{cb}	Normal clear-sky DHI;
G_{cd}	Theoretical horizontal radiation;
GHI	Global radiation;
INAM	National Institute of Meteorology;
K_t	Clearness index;

K_t^*	Clear-sky index;
ΔK_i^*	Clear-sky index variation;
KDE	Kernel density estimation;
PDF	Probability density function;
τ_b	Atmospheric transmittance;
τ_d	Transmittance of diffuse radiation from a clear sky on a horizontal surface;
Total	Calculated theoretical total radiation;
UEM	Eduardo Mondlane University;
w_s	Hour angle;
σK_t^*	Standard deviation of K_t^* ;
ITR	Interquartile range;
w_{low}	Whisker;
T_1	First quadrant;
T_2	Second quadrant;
T_3	Third quadrant;
w_{up}	Upper whisker;
w_{low}	Lower whisker;
E	East;
S	South;
N	North;
W	West;
Jan.	January;
Feb.	February;
Mar.	March;
Apr.	April;
May	May;
June	June;
July.	July;
Aug.	August;
Spt.	September;
Oct.	October;
Nov.	November;
Dec.	December;
$\phi(^{\circ})$	Latitude given in degrees.
δ	Declination angle;
β	Inclination angle;
γ	Surface azimuth angle;
ω_s	Hour angle;
θ	Incidence angle;
θ_z	Zenith angle;
γ_s	Solar azimuth angle.
n	Number of days in accumulation, for each month of the year;
O_3	Ozone;
CO_2	Carbon dioxide.

References

1. Abuela, M.; Chowdhury, B. Random forest ensemble of support vector regression models for solar power forecasting. In Proceedings of the 2017 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Washington, DC, USA, 23–26 April 2017; pp. 1–5. [\[CrossRef\]](#)
2. Duffie, J.A.; Beckman, W.A. *Solar Engineering of Thermal Processes*; Wiley: New York, NY, USA, 1980.
3. Mucomole, F.V.; Silva, C.A.S.; Magaia, L.L. Temporal Variability of Solar Energy Availability in the Conditions of the Southern Region of Mozambique. *Am. J. Energy Nat. Resour.* **2023**, *2*, 27–50. [\[CrossRef\]](#)

4. Abedinia, O.; Amjady, N.; Ghadimi, N. Solar energy forecasting based on hybrid neural network and improved metaheuristic algorithm. *Comput. Intell.* **2018**, *34*, 241–260. [\[CrossRef\]](#)
5. Fish, C.S.; Calvert, K. An Analysis of Interactive Solar Energy Web Maps for Urban Energy Sustainability. *Cartogr. Perspect.* **2016**, *85*, 85. [\[CrossRef\]](#)
6. Mucomole, F.V.; Silva, C.A.S.; Magaia, L.L. Modeling Parametric Forecasts of Solar Energy over Time in the Mid-North Area of Mozambique. *Energies* **2025**, *18*, 1469. [\[CrossRef\]](#)
7. Durand, Y.; Brun, E.; Merindol, L.; Guyomarc'h, G.; Lesaffre, B.; Martin, E. A meteorological estimation of relevant parameters for snow models. *Ann. Glaciol.* **1993**, *18*, 65–71. [\[CrossRef\]](#)
8. Levy, R.C.; Remer, L.A.; Dubovik, O. Global aerosol optical properties and application to Moderate Resolution Imaging Spectroradiometer aerosol retrieval over land. *J. Geophys. Res. Atmos.* **2007**, *112*, D13. [\[CrossRef\]](#)
9. Thekaekara, M.P. Solar radiation measurement: Techniques and instrumentation. *Sol. Energy* **1976**, *18*, 309–325. [\[CrossRef\]](#)
10. Brent, A.C.; Hinkley, J.; Burmester, D.; Rayudu, R. Solar Atlas of New Zealand from satellite imagery. *J. R. Soc. N. Z.* **2020**, *50*, 572–583. [\[CrossRef\]](#)
11. Hoyer-Klick, C.; Wald, L.; Ménard, L.; Blanc, P.; Wey, E.; Suri, M.; Cebecauer, T.; Huld, T.; Allal, H.; Bida, A.; et al. Solar Atlas for the Southern and Eastern Mediterranean. Presented at the ISES Solar World Congress 2011, Aug. 2011. p. paper #41947. Available online: <https://minesparis-psl.hal.science/hal-00630739> (accessed on 15 March 2025).
12. Lefevre, M.; Blanc, P.; Espinar, B.; Gschwind, B.; Ménard, L.; Ranchin, T. The HelioClim-1 Database of Daily Solar Radiation at Earth Surface: An Example of the Benefits of GEOSS Data-CORE. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **2014**, *7*, 1745–1753. [\[CrossRef\]](#)
13. Lappalainen, K.; Valkealahti, S. Photovoltaic mismatch losses caused by moving clouds. *Sol. Energy* **2017**, *158*, 455–461. [\[CrossRef\]](#)
14. Wan, C.; Zhao, J.; Song, Y.; Xu, Z.; Lin, J.; Hu, Z. Photovoltaic and solar power forecasting for smart grid energy management. *CSEE J. Power Energy Syst.* **2015**, *1*, 38–46. [\[CrossRef\]](#)
15. Iqbal, M. *An Introduction to Solar Radiation*; Academic Press: Toronto, NY, USA, 1983.
16. Kapica, J.; Canales, F.A.; Jurasz, J. Global atlas of solar and wind resources temporal complementarity. *Energy Convers. Manag.* **2021**, *246*, 114692. [\[CrossRef\]](#)
17. Mucomole, F.V.; Silva, C.A.S.; Magaia, L.L. Experimental Parametric Forecast of Solar Energy over Time: Sample Data Descriptor. *Data* **2025**, *10*, 37. [\[CrossRef\]](#)
18. Boland, J.; David, M.; Lauret, P. Short term solar radiation forecasting: Island versus continental sites. *Energy* **2016**, *113*, 186–192. [\[CrossRef\]](#)
19. Kruitwagen, L.; Story, K.T.; Friedrich, J.; Byers, L.; Skillman, S.; Hepburn, C. A global inventory of photovoltaic solar energy generating units. *Nature* **2021**, *598*, 604–610. [\[CrossRef\]](#)
20. Hoff, T.E.; Perez, R. Quantifying PV power Output Variability. *Sol. Energy* **2010**, *84*, 1782–1793. [\[CrossRef\]](#)
21. Kashyap, Y.; Bansal, A.; Sao, A.K. Solar radiation forecasting with multiple parameters neural networks. *Renew. Sustain. Energy Rev.* **2015**, *49*, 825–835. [\[CrossRef\]](#)
22. Marcos, J.; Marroyo, L.; Lorenzo, E.; Alvira, D.; Izco, E. Power output fluctuations in large scale pv plants: One year observations with one second resolution and a derived analytic model: Power Output Fluctuations in Large Scale PV plants. *Prog. Photovolt. Res. Appl.* **2011**, *19*, 218–227. [\[CrossRef\]](#)
23. Martinez, A.; Iglesias, G. Hybrid wind-solar energy resources mapping in the European Atlantic. *Sci. Total Environ.* **2024**, *928*, 172501. [\[CrossRef\]](#)
24. McIntyre, J.H. Community-scale assessment of rooftop-mounted solar energy potential with meteorological, atlas, and GIS data: A case study of Guelph, Ontario (Canada). *Energy Sustain. Soc.* **2012**, *2*, 23. [\[CrossRef\]](#)
25. Mucomole, F.V.; Silva, C.S.A.; Magaia, L.L. Quantifying the Variability of Solar Energy Fluctuations at High-Frequencies through Short-Scale Measurements in the East-Channel of Mozambique Conditions. *Am. J. Energy Nat. Resour.* **2024**, *3*, 21–40. [\[CrossRef\]](#)
26. Perez, M.J.R.; Fthenakis, V.M. On the spatial decorrelation of stochastic solar resource variability at long timescales. *Sol. Energy* **2015**, *117*, 46–58. [\[CrossRef\]](#)
27. Jawaid, F.; NazirJunejo, K. Predicting daily mean solar power using machine learning regression techniques. In Proceedings of the 2016 Sixth International Conference on Innovative Computing Technology (INTECH), Dublin, Ireland, 24–26 August 2016; pp. 355–360. [\[CrossRef\]](#)
28. Pirayonesi, S.M.; El-Diraby, T.E. Using Machine Learning to Examine Impact of Type of Performance Indicator on Flexible Pavement Deterioration Modeling. *J. Infrastruct. Syst.* **2021**, *27*, 04021005. [\[CrossRef\]](#)
29. Mucomole, F.V.; Silva, C.A.S.; Magaia, L.L. Regressive and Spatio-Temporal Accessibility of Variability in Solar Energy on a Short Scale Measurement in the Southern and Mid Region of Mozambique. *Energies* **2024**, *17*, 2613. [\[CrossRef\]](#)
30. AlYahya, S.; Irfan, M.A. Analysis from the new solar radiation Atlas for Saudi Arabia. *Sol. Energy* **2016**, *130*, 116–127. [\[CrossRef\]](#)
31. Arnds, D.; Böhner, J.; Bechtel, B. Spatio-temporal variance and meteorological drivers of the urban heat island in a European city. *Theor. Appl. Climatol.* **2017**, *128*, 43–61. [\[CrossRef\]](#)

32. Hamad, J.; Ahmad, M.; Zeeshan, M. Solar energy resource mapping, site suitability and techno-economic feasibility analysis for utility scale photovoltaic power plants in Afghanistan. *Energy Convers. Manag.* **2024**, *303*, 118188. [\[CrossRef\]](#)
33. Dehshiri, S.J.H.; Amiri, M.; Mostafaeipour, A.; Le, T. Evaluation of renewable energy projects based on sustainability goals using a hybrid pythagorean fuzzy-based decision approach. *Energy* **2024**, *297*, 131272. [\[CrossRef\]](#)
34. Adib, R. Renewables 2015 Global Status Report, REN21 Secretariat, Paris, France, 2015. Available online: https://www.ren21.net/wp-content/uploads/2019/05/GSR2015_FullReport_en.pdf (accessed on 5 May 2024).
35. Arumugham, D.R.; Rajendran, P. Modelling global solar irradiance for any location on earth through regression analysis using high-resolution data. *Renew. Energy* **2021**, *180*, 1114–1123. [\[CrossRef\]](#)
36. Abo-Zahhad, E.M.; Rashwan, A.; Salameh, T.; Hamid, A.K.; Faragalla, A.; El-Dein, A.Z.; Chen, Y.; Abdelhameed, E.H. Evaluation of solar PV-based microgrids viability utilizing single and multi-criteria decision analysis. *Renew. Energy* **2024**, *221*, 119713. [\[CrossRef\]](#)
37. de Leeuw, G.; Holzer-Popp, T.; Bevan, S.; Davies, W.H.; Desclotres, J.; Grainger, R.G.; Griesfeller, J.; Heckel, A.; Kinne, S.; Klüser, L.; et al. Evaluation of seven European aerosol optical depth retrieval algorithms for climate analysis. *Remote Sens. Environ.* **2015**, *162*, 295–315. [\[CrossRef\]](#)
38. Lohmann, G.M. Irradiance Variability Quantification and Small-Scale Averaging in Space and Time: A Short Review. *Atmosphere* **2018**, *9*, 264. [\[CrossRef\]](#)
39. Pillot, B.; Muselli, M.; Poggi, P.; Haurant, P.; Hared, I. Solar energy potential atlas for planning energy system off-grid electrification in the Republic of Djibouti. *Energy Convers. Manag.* **2013**, *69*, 131–147. [\[CrossRef\]](#)
40. Perez, R.; Lauret, P.; Perez, M.; David, M.; Hoff, T.E.; Kivalov, S. Solar Resource Variability. In *Wind Field and Solar Radiation Characterization and Forecasting: A Numerical Approach for Complex Terrain*; Perez, R., Ed.; in Green Energy and Technology; Springer International Publishing: Cham, Switzerland, 2018; pp. 149–170. [\[CrossRef\]](#)
41. Suri, M.; Huld, T.; Dunlop, E.; Albuissou, M.; Lefèvre, M.; Wald, L. Uncertainties in solar electricity yield prediction from fluctuation of solar radiation. In Proceedings of the 22nd European Photovoltaic Solar Energy Conference 2007, Milan, Italy, 3–7 September 2007.
42. Wald, L. Basics in Solar Radiation at Earth Surface: O.I.E.—Centre Observation: Impacts, Énergie. 2018. Available online: <https://hal.science/hal-01676634/> (accessed on 2 June 2024).
43. FUNAE (National Energy Fund of Mozambique). 2023. Available online: <https://funae.co.mz/> (accessed on 30 April 2023).
44. INAM (National Meteorology Institute of Mozambique). 2024. Available online: <https://www.inam.gov.mz/index.php/pt/> (accessed on 5 May 2023).
45. Meteonorm Version 8—Meteonorm 2025. Available online: <https://meteonorm.com/meteonorm-version-8> (accessed on 4 April 2023).
46. AERONET (Aerosol Robotic Network). 2024. Available online: <https://aeronet.gsfc.nasa.gov/> (accessed on 12 February 2023).
47. Amillo, A.G.; Ntsangwane, L.; Huld, T.; Trentmann, J. Comparison of satellite-retrieved high-resolution solar radiation datasets for South Africa. *J. Energy S. Afr.* **2018**, *29*, 63–76. [\[CrossRef\]](#)
48. Mucomole, F.V.; Silva, C.A.S.; Magaia, L.L. Parametric Forecast of Solar Energy over Time by Applying Machine Learning Techniques: Systematic Review. *Energies* **2025**, *18*, 1460. [\[CrossRef\]](#)
49. Benali, L.; Notton, G.; Fouilloy, A.; Voyant, C.; Dizene, R. Solar radiation forecasting using artificial neural network and random forest methods: Application to normal beam, horizontal diffuse and global components. *Renew. Energy* **2019**, *132*, 871–884. [\[CrossRef\]](#)
50. Amrouche, B.; Le Pivert, X. Artificial neural network based daily local forecasting for global solar radiation. *Appl. Energy* **2014**, *130*, 333–341. [\[CrossRef\]](#)
51. Mellit, A.; Kalogirou, S.A.; Hontoria, L.; Shaari, S. Artificial intelligence techniques for sizing photovoltaic systems: A review. *Renew. Sustain. Energy Rev.* **2009**, *13*, 406–419. [\[CrossRef\]](#)
52. Perez, R.; Kivalov, S.; Schlemmer, J.; Hemker, K.; Hoff, T. Energy, Parameterization of site-specific short-term irradiance variability. *Sol. Energy* **2011**, *85*, 1343–1353. [\[CrossRef\]](#)
53. Ahmad, M.W.; Reynolds, J.; Rezugui, Y. Predictive modelling for solar thermal energy systems: A comparison of support vector regression, random forest, extra trees and regression trees. *J. Clean. Prod.* **2018**, *203*, 810–821. [\[CrossRef\]](#)
54. Lohmann, G.M. Solar Irradiance Variability on Small Spatial and Temporal Scales. Ph.D. Thesis, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany, 2017.
55. Aksoy, B.; Sen, S.E.R.; Akinog, B.G. A simple correlation to estimate global solar irradiation on a horizontal surface using METEOSAT satellite images. *Turk. J. Eng. Environ. Sci.* **2011**, *35*, 125–137.
56. Ayensa-Jiménez, J.; Pérez-Aliacar, M.; Randelovic, T.; Sanz-Herrera, J.A.; Dowlar, M.; Doblaré, M. Analysis of the Parametric Correlation in Mathematical Modeling of In Vitro Glioblastoma Evolution Using Copulas. *Mathematics* **2020**, *9*, 27. [\[CrossRef\]](#)
57. Elfeky, K.E.; Mohammed, A.G.; Ahmed, N.; Wang, Q. Thermal performance of cascaded and combined sensible-latent heat storage tank under fluctuations in sunlight and electric demand. *Appl. Therm. Eng.* **2023**, *229*, 120575. [\[CrossRef\]](#)

58. Wilson, P.; Tanaka, O.K. Statistics, Basic Concepts—Wilson Pereira/Oswaldo K. Tanaka. 2018. Available online: <https://www.estantevirtual.com.br/livros/wilson-pereira-oswaldo-k-tanaka/estatistica-conceitos-basicos/189548989> (accessed on 6 February 2023).
59. Kumar, R.; Aggarwal, R.K.; Sharma, J.D. Comparison of regression and artificial neural network models for estimation of global solar radiations. *Renew. Sustain. Energy Rev.* **2015**, *52*, 1294–1299. [[CrossRef](#)]
60. Lam, J.C.; Li, D.H.W. Regression Analysis of Solar Radiation and Sunshine Duration. *Archit. Sci. Rev.* **1996**, *39*, 15–23. [[CrossRef](#)]
61. NOAA AVHRR Derived Aerosol Optical Depth Over Land—Hauser—2005—Journal of Geophysical Research: Atmospheres—Wiley Online Library. Available online: <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2004JD005439> (accessed on 4 September 2024).
62. Aerosol Optical Depth Retrieval Over the NASA Stennis Space Center: MTI, MODIS, and AERONET | IEEE Journals & Magazine | IEEE Xplore. Available online: <https://ieeexplore.ieee.org/abstract/document/1499013> (accessed on 4 September 2024).
63. UEM-Eduardo Mondlane University. Department of Physics-Solar Energy Data Source. 2023. Available online: <https://uem.mz/index.php/en/home-english/> (accessed on 9 December 2024).

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.