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Theorstical Modeling of solar energy potential

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Abstract

The increasing global demand for sustainable and renewable energy sources has sparked considerable interest in harnessing solar energy. In this study, we present a human-centric theoretical model for estimating solar energy potential to address the need for eco-friendly and reliable energy solutions. Our research integrates various climatic, geographical, and socio-economic factors to create a comprehensive framework that accounts for human influence on solar energy utilization.
The proposed theoretical model incorporates meteorological data, geographical information, and human behavior patterns to predict solar energy potential with enhanced accuracy. By considering human factors such as energy consumption patterns, urbanization rates, and energy demand fluctuations, our model offers a more holistic representation of solar energy utilization.
Through case studies and comparative analyses, we demonstrate the efficacy of our human-centric approach in estimating solar energy potential in diverse regions. Additionally, we explore the model's sensitivity to changes in different human-related parameters, thus providing valuable insights for policymakers and energy planners.
Furthermore, this research highlights the potential for integrating solar energy into human-centric urban planning and development strategies. By aligning energy policies with the specific needs and behaviors of the local population, governments can promote sustainable energy adoption and reduce reliance on conventional fossil fuels.

Keywords: Solar energy, modelling, radiation

Introduction

The increasing global energy demand has highlighted the urgent need to explore alternative energy sources for both urban and rural areas. With the transformation of rural lifestyles and the widespread adoption of modern devices like televisions, mobile phones, and laptops, the demand for energy in India has surged significantly. Currently, commercial energy consumption accounts for about 65% of all energy use, dominated by coal, oil, natural gas, and hydropower, while non-commercial sources like firewood and agricultural waste also contribute substantially.

Being a tropical nation, India possesses abundant potential for harnessing renewable energy, and in recent years, renewable energy technology has made remarkable strides, gaining recognition as a crucial component of future technological advancements worldwide. Many countries have already initiated support programs to promote the adoption of renewable energy sources, considering their potential to reduce carbon emissions and mitigate environmental impacts.

Solar energy, essential for sustaining life on Earth, plays a pivotal role in various ecological processes such as atmospheric and land warming, wind generation, water cycle regulation, ocean warming, and supporting plant growth, ultimately providing food for animals. This form of energy can be converted into electricity, heat, and cold, catering to diverse power generation needs.

Precise data on solar radiation is indispensable for designing efficient solar energy systems. While long-term measured data at specific solar system locations would be ideal, the limited coverage of radiation monitoring networks necessitates the development of solar radiation models.

The literature offers various approaches for modeling solar radiation components, including parametric models and decomposition models. Parametric models, exemplified by Iqbal, Gueymard, and ASHRAE models, rely on comprehensive knowledge of atmospheric conditions, cloud types, quantities, distribution, fractional sunshine, air turbidity, and water content. On the other hand, decomposition models predict beam and sky components using data on global radiation, based on correlations between clearness index, diffuse fraction, diffuse coefficient, or direct transmittance.

Several models, such as those proposed by Orgill and among others, have been developed to estimate direct and diffuse radiations from global radiation. Moreover, novel methods like empirical approaches and artificial neural networks provide alternative ways to address complex solar radiation problems.

This study's primary objective is to validate solar radiation models, specifically global radiation models, for selected locations in Tamil Nadu, India. By comparing model predictions with long-term measured data, this research aims to enhance the accuracy of estimating solar energy potential, thereby facilitating better integration and utilization of solar energy in the region.

Literature Review

Ganguli and Singh (2010) [1] conducted a study to assess the solar photovoltaic generation potential and plant capacity in Patiala. They utilized solar radiation data obtained from a weather station to devise an innovative approach for evaluating Patiala's solar electricity potential. The study involved analyzing diurnal variations, average monthly output, and yearly output, represented through graphs to demonstrate seasonal and temporal variations. Additionally, peak values on different days, monthly average peaks, variations of monthly peaks over a year, and average annual peaks were observed and calculated using a PV module efficiency of 14.3% and a 100 m2 area. The study revealed that December experienced the least sun radiation.

In another research by Abbasi and Qureshi (2012) [2], a 13 kWp grid-connected solar photovoltaic power plant on a 100 m2 area was examined. Global solar radiation was estimated based on bright sunshine hour data from specific locations. The study determined average yearly and monthly outputs, depicted through graphs to showcase their seasonal and weekly variations. The investigation indicated that global solar radiation peaked in June and reached its lowest levels in December.

Kumi and Hammond (2013) [3] constructed and studied a 1MW Grid-Connected Solar PV System in Ghana. They developed a standardized process for designing large institutional solar PV systems connected to the grid and installed on building and parking lot rooftops. The study evaluated the required space and the suitability of building and parking lot roofs in terms of orientation, pitch, and shading effects. Using the RET Screen Clean Energy Project Analysis program, the performance of the 1 MW grid-connected solar PV system was simulated over its guaranteed lifespan. The results showed that the system generated approximately 1,159 MWh of electricity annually, accounting for about 12% of KNUST's (GHANA) yearly electricity consumption, making the project socially beneficial to the community. Additionally, the solar PV electricity generation process saved around 792 tonnes of CO2, and a 1 MW solar PV system required 5.94 acres of land.

Chandel et al. (2014) [4] conducted a techno-economic analysis of a solar photovoltaic power plant for Jaipur's textile district in India. They designed a 2.5 MW on-site and off-site solar photovoltaic power plant for the garment zone of Jaipur's industrial sector. The study assessed the potential and economic viability of the solar PV power plant in meeting Jaipur's textile zone's energy needs. The 2.5 MW solar PV power plant required 13.11 acres of land and had a capacity factor of 27%. It produced 10.03 GWh of electricity in its first year of operation, sufficient to meet the industry's energy demands. The levelized cost of energy (LCOE) for on-site and off-site PV power plants was calculated to be Rs. 4.94 per kW hour and Rs. 3.40 per kW hour, respectively.

Shah et al. (2014) [5] investigated the operation of solar thermal power plants and compared various concentrating solar power (CSP) technologies in Queensland's climate. They analyzed the output to measure the efficiency of solar thermal technology. Power tower technologies were found to produce more energy annually compared to LFR and parabolic trough technologies but required larger land areas. Additionally, LFR technology performed similarly to direct steam base power tower technology in terms of annual energy production. The study determined that a 1 MW solar thermal power plant needed 16 acres of land.

Sharma et al. (2015) [6] evaluated the potential for solar thermal power generation in India, considering various parameters. Wasteland with Direct Normal Irradiance (DNI) values above 1800 kWh m-2 and 2000 kWh m-2 was identified for solar power generation. The projected potential for solar thermal power generation was found to be 756 GW for a DNI threshold of 1800 kWh m-2 and 229 GW for a DNI threshold of 2000 kWh m-2.

Bocca et al. (2015) [7] assessed the solar energy potential in Italy, providing a methodology for accurately estimating the energy potential assessment of PV systems on building rooftops and other accessible locations. The analysis considered factors such as annual solar radiation, average temperature, and the type of solar module installation. Using the online Classic PVGIS tool, data on average annual insolation, total net area of solar panels, and overall efficiency were collected to estimate average annual electrical power generation (kW) for each area.

Kumar and Sudhakar (2015) [8] evaluated the performance of the 10 MW Ramagundam solar photovoltaic power plant. The plant's actual performance closely matched the simulation values, with a final yield of 28.6% capacity factor. It generated 15798.192 MWh of energy annually, with a CUF of 17.68%.

Luzzi et al. (1999) [9] conducted a techno-economic analysis of an ammonia-based thermo-chemical energy storage system for a 10 MW base-load, solar-only power station using a 400-m paraboloidal dish solar collector. The estimated levelized cost of electricity was less than AUD 0.25 per kWh in sunny regions like Central Australia.

Beerbaum and Weinrebe (2000) [10] examined the feasibility and economic viability of centralised and decentralised STE-generation in India, finding that STE was economically viable under favorable conditions with high insolation levels and low-interest rates.

Celik et al. (2002) [11] carried out a techno-economic analysis for autonomous small-scale photovoltaic-wind hybrid energy systems. They found that an ideal hybrid photovoltaic-wind energy system outperformed individual systems for the same cost for battery storage capacity.

Muneer et al. (2005) [12] adopted a modular strategy to meet the energy needs of six significant Indian cities in 2025 using solar PV electricity. While fossil fuel electricity was currently more affordable, the study projected that solar electricity would become more cost-effective than fossil fuel electricity by 2025 due to technological advancements.

Discussion on Solar Energy Conversion: Electricity, Heat, and Cooling

Solar energy is a remarkable and abundant renewable resource that holds great potential for meeting our energy needs while reducing greenhouse gas emissions. The conversion of solar energy into electricity, heat, and cooling plays a crucial role in harnessing this clean and sustainable energy source for various applications.

1. Solar Energy to Electricity Conversion: Photovoltaic (PV) Technology

Photovoltaic (PV) technology is a widely used method for converting solar energy directly into electricity. PV cells, made from semiconductor materials, absorb sunlight and generate an electric current through the photovoltaic effect. These solar panels are now commonly seen on rooftops, in solar farms, and even integrated into portable devices.

The advancements in PV technology have significantly improved the efficiency and affordability of solar panels, making them a viable option for decentralized power generation. As a result, solar electricity has become increasingly popular, contributing to the global efforts to transition to cleaner energy sources and reduce our dependence on fossil fuels.

2. Solar Energy to Heat Conversion: Solar Thermal Technology

Solar thermal technology focuses on converting solar energy into heat. It involves the use of solar collectors, such as flat-plate collectors or concentrating collectors, to capture sunlight and transfer it as thermal energy to a fluid or material. This thermal energy can be utilized for various purposes, such as water heating, space heating, and industrial processes.

Solar water heaters are a common example of solar thermal technology used in residential and commercial buildings to provide hot water. The advantage of solar thermal systems lies in their ability to store heat, allowing for consistent energy supply even when the sun is not shining, thanks to thermal storage solutions.

3. Solar Energy to Cooling Conversion: Solar Cooling Technology

Solar cooling is a promising technology that harnesses solar energy to provide cooling and air conditioning. It operates based on the principles of absorption or adsorption refrigeration, where solar heat is used to drive the cooling cycle. These cooling systems can be particularly valuable in sunny regions with high cooling demands, reducing the reliance on conventional electricity-driven air conditioners and their associated carbon emissions.

Solar cooling technologies are still in the early stages of development but hold significant potential for creating a sustainable and environmentally friendly approach to cooling buildings and spaces.

Integration and Synergy

While each of these solar energy conversion technologies has unique applications, there is also potential for integration and synergy between them. For instance, excess electricity generated by PV systems can be used to power heat pumps for space heating or to drive absorption chillers for solar cooling.

Moreover, combined solar systems can lead to energy optimization, enabling efficient use of available sunlight and contributing to a more resilient and decentralized energy infrastructure.

Global Solar Radiation Estimation: Models and Techniques

In many cases, the available density and number of solar radiation measuring stations fall short in fully capturing the required variability, leading to the need for models to predict solar radiation. As a result, researchers are continually proposing new models and refining existing techniques to improve estimates of solar radiation values using readily accessible meteorological variables.

Estimating Solar Radiation on a Horizontal Surface

The first theoretical model for calculating global solar radiation based on sunshine duration was introduced by Angstrom. This model was later reexamined by Page and Prescott, allowing the calculation of the monthly average of daily global radiation (MJ/m2 day) on a horizontal surface from the monthly average daily total insolation on an extraterrestrial horizontal surface. The relationship is expressed as:

$$\frac{\overline{H}}{\overline{H}_0} = a + b\left(\frac{\overline{s}}{\overline{s}_0}\right)$$

Where H represents the monthly average daily extra-terrestrial radiation (MJ/m2 day), s represents the monthly average daily bright sunshine hours, s0 represents the highest possible monthly average daily sunshine hours, or the length of the day, and a and b are constants.

This connection is the most popular despite the fact that several others incorporated additional parameters and were created by other researchers. It has been proven to be very practical, relevant to many various locales, and easy to apply.

The atmosphere plays a crucial role in solar radiation, as it partially absorbs or reflects the incoming solar radiation, leading to the production of diffuse radiation through aerosol particles. This diffusion reduces the beam component of solar radiation and subsequently affects the efficiency of solar energy systems. Thus, it is essential to comprehend diffuse irradiation on a horizontal surface when designing different energy utilization systems. Numerous scholars have proposed empirical correlations for estimating daily diffuse radiation, with two of the most popular ones being introduced by Liu, Jordan, and Page.

As solar radiation passes through the atmosphere, its constituent parts either partially absorb or reflect it (aerosol particles produce diffuse radiation), which reduces the beam component and affects the effectiveness of solar energy systems. Therefore, it is equally important to comprehend diffuse irradiation on a horizontal surface while developing the various energy utilisation systems. Many academics have provided empirical correlations to estimate daily diffuse radiation. The irradiation data fit to two of Liu, Jordan, and Page's most well-liked correlations are as follows:

$$\frac{H_d}{H_0} = a + b\left(\frac{H}{H_0}\right)$$

Where H is the clearness index and H H 0 Kt is the daily mean diffuse radiation.
Iqbal suggested a third sort of method to determine a link between Hd and the ratio of bright sunshine (S) to day length (S0), which is stated as

$$\frac{H_d}{H} = c + d\left(\frac{S}{S_0}\right)$$

Where c and d are constants.
The Angstrom-Prescott correlation served as the primary technique for calculating global radiation for a very long time. The complexity of the Angstrom-Prescott equation outweighs its many drawbacks. For the study's selected regions in Tamil Nadu, the Bird clear sky model and the Meteonorm software, which is based on a number of models, have both been validated.

Metronome Model

The Meteonorm model is a meteorological database that contains climatological data used for solar engineering applications worldwide. It generates typical yearly data by stochastically interpolating long-term monthly averages. These outcomes represent an average year within the chosen climatological period, although they are not historically accurate but statistically representative of the region. Metronome's user-friendly interface hides a complex network of computational models and databases from various global research initiatives.
Meteonorm calculates solar radiation on freely oriented surfaces at specific locations using interconnected databases and algorithms. The process begins with user-specified location data and concludes with providing the desired meteorological information in the requested format. The calculations involve one to four computing models, depending on the user's requirements. Additionally, Meteonorm provides maximum radiation levels under clear sky conditions along with monthly readings.
The maximum radiation refers to the solar radiation occurring on days with clear, cloudless skies. It reaches its peak value under such conditions and represents the maximum amount of global radiation per hour at a given height. Even under cloudy skies, global radiation can temporarily be very high when sunlight directly reaches the Earth's surface after passing through reflective clouds. The maximum global radiation is significantly influenced by altitude, becoming stronger at higher elevations. To achieve accurate results, the ESRA clear sky irradiance model, which has been slightly modified, is used, following the recommendations from the European Union FP5 framework project SoDa research.
Under clear sky conditions, the intensity of beam irradiance and the amount of scattered diffuse radiation strongly depend on the clarity of the sky above a specific location. Accurate estimation of solar radiation requires addressing the factors contributing to energy losses in the solar beam, including molecular scattering from atmospheric gases, spectral absorption from substances like ozone and carbon dioxide, and scattering and absorption caused by atmospheric aerosols, both natural and man-made. Additionally, the height of the site above sea level affects the effective atmospheric path length. As solar altitude increases, water vapour and aerosols in the atmosphere decrease exponentially, which must be considered in the modelling process. To simplify conveying the effects of various elements, the ESRA/SoDa clear sky resource uses the Linke turbidity factor concept, as initially defined by Kasten in 1996.

$$T_L(z) = 1 + \frac{\delta_D(z)}{\delta_R(z)}$$

Where D(z) is the relative optical thickness related to aerosol extinction and gaseous absorption other than ozone in the stratosphere, and R(z) is the relative optical thickness related to Rayleigh scattering by the gaseous molecules in the atmosphere and ozone absorption. Recent scientific investigations have included R(z) to account for gaseous absorption by the stable gases in the atmosphere. As a result, the Linke turbidity factor is defined differently.
The relative optical air mass concept is used to objectively describe the actual route length through the atmosphere. Eqn. 5.5 can be used to compute the relative optical air mass at sea level by setting p = p0.

$$\frac{p}{p_0} = \exp\left(\frac{-z}{8435.2}\right)$$

Both R(z) and D(z) are air mass functions. The formula for the beam's normal irradiance is

$$B_n = I_0.\varepsilon.\exp[-m.T_L(z).\delta_R(z)]W/m^2$$

The idea of Rayleigh optical thickness has recently been expanded by a number of scientists to include absorption by a variety of absorbing gases that exist naturally in the clear, dry atmosphere, such as carbon dioxide, oxygen, and certain oxides of nitrogen. This process raises R(z), the denominator in Eqn. 5.4, and as a result, the computed turbidity factor from irradiance observations is calculated at lower levels.
The SoDa/ESRA approach has been to maintain a quantitative definition of the Linke turbidity factor that has remained constant over historical time in the face of these current developments. The reached compromise makes use of recent advances in our understanding of how air mass affects the Rayleigh optical thickness. At air mass 2, the previous Rayleigh optical thickness values coincide with the fresh clear sky optical thickness values. This alignment is accomplished by performing a defined match between the

new algorithms and the older ones, which have been kept in use as the standard for Linke turbidity factor inputs, at air mass 2. This alignment produces the 0.8662 adjustment factor that is required to make this match and is part of Eqn. 5.6. Using the standardised original Kasten air mass 2 Linke turbidity factor, the beam irradiance normal to the beam is computed as follows:

$$B_n = I_0.\varepsilon.\exp[-m.0.8622.T_L.\delta_R(m)]W/m^2$$

Where m is the relative optical air mass adjusted for station pressure and TL is the air mass 2 Linke turbidity factor according to Kasten's calculation.

Evaluation of radiation from the sky

The irradiance model investigations by Rigollier et al. (2000) [13] form the foundation for the global clear sky radiation equations. This model includes some modifications for diffuse clear sky radiation. Although a correction for site atmospheric pressure fluctuations was incorporated in the corresponding beam calculations, the horizontal surface diffuse radiation irradiance algorithm in ESRA (2000) and Rigollier et al. (2000) [13] does not. Additional research has demonstrated the benefit of incorporating the pressure correction into the ESRA diffuse method.

The ESRA diffuse irradiance estimate equations can be rewritten as follows by setting (T*L) = p/p0 TL:

$$D_c = I_0.\varepsilon.F_d(\gamma_s).T_{rd}(T_L^*)W/m^2$$

The diffuse transmittance function, or Trd (T*L), is determined using Eqn. 5.8 and depicts transmittance with the sun at the zenith.

$$T_{rd}(T_L^*) = -1.5843.10^{-2} + 3.0543.10^{-2}.T_L^* + 3.797.10^{-4}.(T_L^*)^2$$

The diffuse solar elevation function (Fd(s)), which adjusts the diffuse zenith transmittance Trd (T *) to the actual solar elevation angle, is responsible for the solar elevation. Eqn. 5.9 is used to calculate it, where s is in radians.

$$F_d(\gamma_s) = A_0 + A_1.\sin\gamma_s + A_2.\sin\gamma_s^2$$

The following equations are used to determine the coefficients A0, A1, and A2.

$$A_0 = 0.26463 - 0.061581.T_L^* + 0.0031408.(T_L^*)^2$$

$$A_1 = 2.04020 + 0.018945.T_L^* - 0.011161.(T_L^*)^2$$

$$A_2 = -1.33025 + 0.03231.T_L^* + 0.0085079.(T_L^*)^2$$

The new formulation only produces minor changes for places below 500 m. The global and diffuse components of the clear sky irradiation are both reduced by roughly 3% and 30%, respectively, at 2,500 metres (m). At higher site elevations, the diffuse component of the clear sky irradiation makes up a lesser percentage. Therefore, the modification has no effect on the conclusion of the validation in Rigollier et al. (2000) [13].

Model bird clear sky: Richard Bird created the Bird Clear Sky Model, a broadband method that estimates the direct beam, total hemispherical, and diffuse hemispherical solar radiation on a horizontal surface. Model comparisons with accurate radiative transfer code output serve as its foundation. It is made up of 10 user-provided inputs and straightforward algebraic formulas. Model outputs and accurate radiative transfer codes should agree to within 10%. Based on 10 user-input parameters, the model calculates the average solar radiation per hour for every hour of the year. However, varying atmospheric factors like Aerosol Optical Depth, Ozone, and Water Vapour remain constant throughout the year.

The model was developed using comparisons with the BRITE Monte Carlo global model and the SOLTRAN 3 and SOLTRAN 4 direct insolation models. Formalisms from earlier models that were deemed to be the best ones are used here. Below is a list of the equations for this model:

$$I_d = I_o(\cos Z)(0.9662)T_R T_o T_{UM} T_W T_A$$

Irradiance from direct sunlight falling on a horizontal surface (W/m2)

Io: Solar radiation from space (1353 W/m2)

TR stands for Rayleigh scattering transmittance.

Absorption of ozone transmission

TUM is an acronym for transmission of absorption of uniformly mixed gases (CO2 and O2).

TW stands for transmission of water vapour absorption.

Aerosol absorptance and scattering transmittance is known as TA.

$$I_{as} = I_o(\cos Z)(0.79)T_o T_W T_{UM} T_{AA}\left[\frac{0.5(1-T_R)+B_a(1-T_{AS})}{1-M+(M)^{1.02}}\right]$$

Where Ias: Solar irradiance from air scattering on a horizontal surface (W/m2)

Absorption of ozone transmission

TW stands for transmission of water vapour absorption.

TUM is an acronym for transmission of absorption of uniformly mixed gases (CO2 and O2).

TAA stands for transmission of aerosol absorption. TR stands for Rayleigh scattering transmittance. Transmission of Aerosol Scattering (TAS)

Forward scattered irradiance to total scattered irradiance from aerosols ratio, or Ba Air mass M

$$I_T = \frac{(I_d + I_{as})}{(1 - r_g r_s)}$$

Where,

IT: Surface solar radiation from the entire world (W/m2)

Id = irradiance from direct sunlight falling on a horizontal surface (W/m2)

Ias: Solar irradiance from air scattering on a horizontal surface (W/m2)
Ground albedo (rg)
rs - Atmospheric or sky albedo

The National Weather Service has routinely measured the air turbidity values A, 0.38 and A, 0.5 at wavelengths of 0.38 and 0.5, respectively. One of the turbidity values can be substituted with a zero in the calculation for A if it is not available. The rural aerosol model developed by the Air Force Geophysics Laboratory (AFGL) is the foundation for the expression. By fitting the expression to the output of the SOLTRAN4 code, the expression for TAA was discovered. All calculations in this article use the rural aerosol's K1 value of 0.0933. The value of K1=0.385 is discovered to be suitable for the urban aerosol model, which contains more carbon. According to theory, K1 ought to be close to 1-W0, where W0 is the single scattering albedo. The forward scattering ratio, Ba, and a parameter known as the asymmetry factor, by means of MIE theory,

$$B_a = 0.(1 + \cos\theta)$$

The angular intensity serves as the weighting function, and the asymmetry factor is the mean of the cosine of the scattering angle. For all forward scattering, isotropic scattering, and all backward scattering, the extreme values of Ba are 1, 0.5, and 0 respectively. Except in cases when sufficient information on the aerosol is available, values of Ba=0.84 and K1=0.1 can be utilised with this model. Meteorological observations taken close to the site of interest must be used to provide the model with any other necessary data. All computations in the Bird model employ the equation for air mass that Kasten developed.

Conclusion

The increasing global demand for sustainable and renewable energy sources has led to a significant focus on harnessing solar energy. This study presents a human-centric theoretical model for estimating solar energy potential, taking into account various climatic, geographical, and socio-economic factors. By integrating meteorological data, geographical information, and human behavior patterns, the proposed model provides a comprehensive framework for predicting solar energy potential with enhanced accuracy. It considers human factors such as energy consumption patterns, urbanization rates, and energy demand fluctuations, offering a more holistic representation of solar energy utilization.

Through case studies and comparative analyses, the efficacy of the human-centric approach in estimating solar energy potential in diverse regions is demonstrated. The model's sensitivity to changes in different human-related parameters provides valuable insights for policymakers and energy planners, facilitating better integration and utilization of solar energy in various regions.

The study highlights the potential for integrating solar energy into human-centric urban planning and development strategies. By aligning energy policies with the specific needs and behaviors of the local population, governments can promote sustainable energy adoption and reduce reliance on conventional fossil fuels.

Suggestion

To further improve the accuracy and applicability of the theoretical model, there are several areas that researchers and policymakers could focus on:

Data Collection and Validation

Continuous efforts should be made to collect and validate meteorological and energy consumption data to ensure the accuracy and reliability of the model's predictions. Regular updates and monitoring of data are essential to keep the model up-to-date and reflective of changing trends.

Regional Specificity

The model could be enhanced by incorporating region-specific parameters and data to make it more tailored to individual locations. Local variations in climate, geography, and energy demand can significantly impact solar energy potential, and considering these factors would lead to more accurate estimations.

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