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Original Research

Using artificial intelligence for enhancement of solar cell efficiency in the south of Iraq

Ibtihal R. N. ALRubeei[1], Safa N. Idi[2] , Ihab L. Hussein Alsammak[3], Haider Th. AlRikabi[4], Hussain A. Mutar[5], Abdul Hadi M. Alaidi[6]

[1,2,4] Electrical Engineering Department, College of Engineering, Wasit University, Wasit, ALkut, Iraq
[3]Ahl al bayt University, Karbala, Iraq
[5,6]College of Computer Science and Information Technology, Wasit University, Wasit, ALkut, Iraq

*Corresponding author E-mail: Ibtihal.Razaq@uowasit.edu.iq

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Abstract

The southern region of Iraq contains substantial solar energy development opportunities because it receives high solar irradiance levels in extensive desert territories. The specific location factors affecting solar energy cell efficiency consist of solar irradiance levels together with temperature conditions dust concentrations and site shading conditions. Traditional site selection approaches neglect how these multiple factors interact with each other so they result in less than ideal solutions. The research seeks to boost solar energy cell performance by establishing an AI-based site selection strategy for south Iraq locations. A Random Forest machine learning method conducts an analysis of environmental elements geographical characteristics and infrastructure factors to calculate site suitability potential. The model proposal incorporates solar irradiance climatic condition data topographic features and land usage along with infrastructure proximity to build composite suitability measures for every potential location. The research identifies locations best-suited for solar energy projects to boost operational effectiveness and decrease both costs and energy generation costs. Through this research, a framework emerges for solar energy project deployment strategy which contributes to sustainable development and helps Iraq advance its renewable energy framework. Research findings confirm that AI-based site selection procedures can boost solar energy cell performance throughout south Iraq. The model uses Random Forest machine learning to integrate diverse data types which enables site suitability prediction together with optimized outcomes in energy production and economic affordability. Research confirms that the proposed method detects top solar installation sites simultaneously with its capability to boost Iraq's sustainable energy projects through maximizing performance with lower prices and reduced environmental impact.

Keywords: Solar energy, Site selection, Artificial intelligence, South Iraq, Renewable energy efficiency

1. Introduction

Solar energy has surged in worldwide demand since climate change occurred and traditional fuel stores started running out. Solar energy has proven itself to be both sustainable and available as an alternative energy source. The southern area of Iraq benefits from enriched solar resources which makes it suitable for developing solar energy projects. The performance of solar energy cells depends heavily on several site-dependent elements that include solar irradiance, temperature, dust conditions, and shading obstacles [1, 2]. The selection of sites based on conventional techniques depends on restricted information resources and fails to address the complete network of variables that impact solar cell operational effectiveness. Artificial Intelligence (AI) utilizes its exceptional analytical functions to analyze large volumes of data which leads to enhanced site selection optimization [3-5]. This research develops an AI-driven method for solar energy site selection which will increase efficiency in south Iraqi facilities [6-8]. According to Forbes, the worldwide shift towards solar power grows because this renewable energy source reduces climate change impacts and supports the findings in their discussion of solar benefits [6]. The benefits of sustainability alongside reduced costs mentioned in [1] exist while solar energy continues facing issues with expensive setup expenses and weather dependence. Technological advancements serve to solve current sustainability barriers in solar energy systems while boosting their operational efficiency.

Recent studies focus on optimizing photovoltaic technology through material innovations as well as smart technologies. Soomar et al., reviewed optimization techniques as well as challenges insolar photovoltaic energy, emphasizing improvements inefficiency as well as system integration [9]. Advancements insolar cell technologies, including multi-junction cells as well as third-generation cells like perovskite as well as dye-sensitized solar cells, offer higher efficiencies as well as lower production costs, as discussed by [10, 11]. Material innovations, such as polycrystalline silicon thin-film solar cells, contribute to cost reductions as well as application flexibility [12].

Iraq's climatic conditions present significant potential for solar energy deployment but also pose challenges. The authors of [13, 14], highlighted theimpacts ofclimate change on Iraq's environment, noting that increasing temperatures as well as high solar irradiance could enhance solar energy potential. However, infrastructural inadequacies as well as frequent power outages hinder reliable energy supply, as examined by [15, 16]. The authors of [17, 18], emphasized exploiting Iraq's vast desert areas for large-scale solar farms, underscoring theimportance of strategic site selection to maximize efficiency.

Environmental factors affecting photovoltaic systems necessitate strategies for performance optimization. Mustafa et al., analyzed how temperature, dust, as well as humidity impact solar PV systems, while Badran and Dhimish investigated degradation mechanisms as well as detection techniques to mitigate efficiency losses [19, 20]. Thermal management as well as the use of advanced materials, are essential for maintaining solar cell efficiency at harsh climatic conditions as investigated by [21, 22].

In conclusion, the literature highlights significant potential for optimizing solar energy in Iraq through technological advancements as well as strategic deployment. Addressing environmental challenges as well as integrating innovative solar technologies are crucial for enhancing efficiency. Policy support along with infrastructural development has been imperative for Iraq to effectively harness its solar energy potential, contributing to energy security along with economic growth.

2. Proposed work

The south of Iraq has a large potential for solar energy production because the solar irradiance reaches high values, and there is abundant appropriate land in the area. Solar energy installation optimization needs suitable site identification, considering environmental conditions combined with the availability of infrastructure and limitations of technology for maximum efficiency and economic viability. Artificial Intelligence (AI) outfits optimization algorithms for improving solar energy cell efficiency in selected installation sites across Iraq. A unified system will bring together machine learning frameworks with spatial examination methods for locating perfect places for the deployment of solar power equipment. This research takes into account some of the most defining factors that influence solar potential, such as environmental factors, topographic characteristics, land use patterns, and socioeconomic factors, in developing appropriate prediction models for the assessment of solar power potential. The project will reach its three main outputs through the identification of optimal solar energy project sites, coupled with the enhancement of performances of solar energy cells and sustainable energy development in Iraq. The main purpose of this study is to integrate AI-driven site selection activities with solar technology while providing recommendations and facilitating investment opportunities to develop sustainable renewable energy adoption in Iraq. This research contributes to the global goal of climate change mitigation and improves energy security and fossil fuel alternatives while lowering consumption. This envisaged work develops an end-to-end approach that harnesses the power of the Random Forest artificial intelligence in predicting suitable sites and determining the optimal areas for the deployment of solar cells within the region.

3. Methodology

We suggest a complete solution to locate suitable solar cell installation sites in southern Iraq that integrates extensive data collection together with AI model development alongside site selection criteria considerations. A machine learning system operates to assess environmental elements together with infrastructure features that enhance solar energy project feasibility and operational efficiency in the region. The methodology presented in Figure 1 includes the following steps:

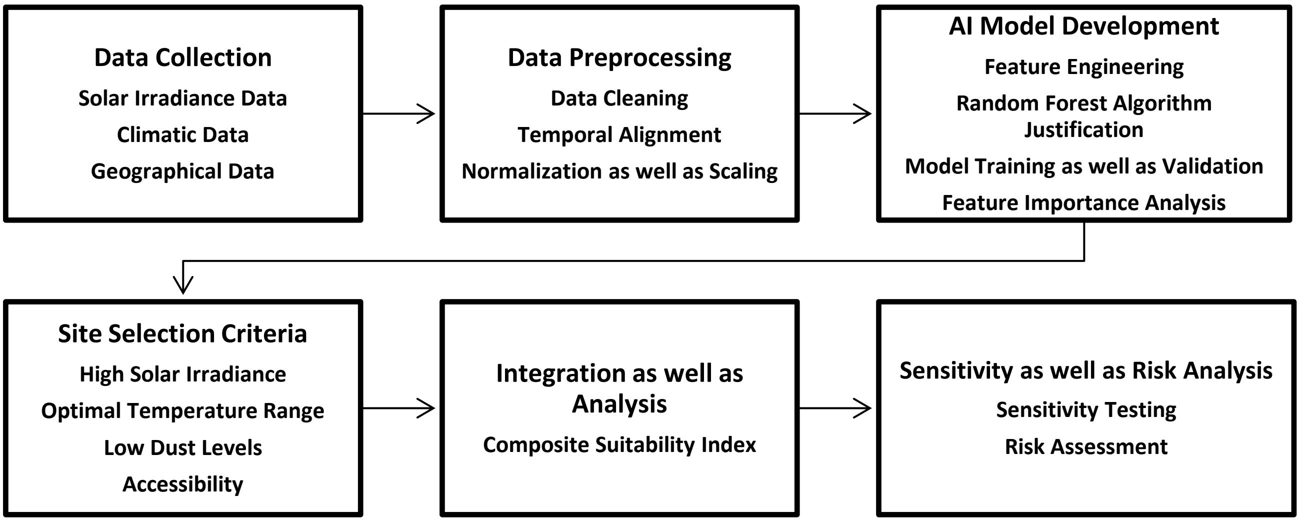


Figure 1. Proposed methodology flowchart

The establishment of proper solar energy project sites depends on getting precise information from dependable data sources. The essential component of location selection is access to solar irradiance data that exists inside the Surface Meteorology and Solar Energy (SSE) database maintained by NASA and within the NASA Prediction for Worldwide Energy Resources (POWER) project. The collection of data ought to include Global Horizontal Irradiance (GHI) to measure total solar radiation along with Direct Normal Irradiance (DNI) to evaluate direct solar radiation and Diffuse Horizontal Irradiance (DHI) to determine radiation that comes from the sky without direct sunlight. Users of NASA's online portals can obtain solar and climatic data by defining their geographic areas of interest which provides data download options through CSV files. Solar irradiance data requires completion through climatic data from the Iraqi Meteorological Organization and Seismology (IMOS). The important parameters in this category consist of daily temperature peak and bottom readings as well as average temperatures and relative humidity measurements and both dust storm activity and particulate matter content together with wind speed and direction data that determine dust behavior and solar panel temperature reduction. These data points present an all-encompassing base for making successful site choices in solar energy projects.

Data acquisition takes place when local meteorological stations enter into partnerships to obtain present climatic data. Data acquisition from geography depends on information from the Iraqi Ministry for Planning joined with GPS data and Landsat and Sentinel satellite imagery. The data acquisition utilizes elevation data slope gradients and aspect orientation properties as well as different soil types needed for construction feasibility assessments. A group of processing methods needs to be carried out with the data before putting them into the AI model for evaluation.

The initial step of data cleaning processes data entries to fix errors and unit-standardize input along with identifying and filling missing values. Through temporal alignment, all measurement points related to time-dependent variables achieve absolute precision when matched. Through normalization and scaling the model preserves its functions by stopping a specific variable from controlling results through its scale values. The site suitability predictions rely on an AI model that implements a Random Forest algorithm to examine obtained data. Feature engineering chooses suitable input variables including solar irradiance (GHI, DNI), temperature averages and extremes, humidity levels, and dust accumulation data as environmental variables. The assessment requires inspection of slope angle measurements besides elevation angles and soil distribution patterns and the power network and urban zone connection details. The model takes into account the assessment of regulatory conditions such as land use restrictions and protection for special areas. Two derived outputs, one being the Solar Potential Index and the other being the dust accumulation risk, can be produced using the meteorological observation database. The former is derived by combining GHI and DNI measurements as a first step, and the latter is derived through dust frequency observation and wind pattern analysis as a second step.

The project uses the Random Forest as its algorithm; it delivers a strong capability of handling complex datasets with non-linear relationships between variables and cross-variable interactions. A Random Forest ensemble model absorbs overfitting resistance in its learning way to ensure consistent performance results on data that it sees for the first time. Random Forest deals with categorical and continuous variables effectively, so it proves to be appropriate in dealing with our complex dataset. The development of models for this project depends upon the implementation tools provided by the Python library sci-kit-learn.

A data partitioning process creates training and testing sets that make up 70 to 80%and 20 to 30%, respectively, for the purpose of model validation. The use of the K-fold cross-validation method in model generalization leads to improved performance estimates. Model optimization on critical parameters like the number of trees along with the maximum depth is done using grid search processes coupled with randomized search techniques. The proposed model is tested in terms of performance by measuring the R^2 score along with MSE and MAE to decide both accuracy and reliability.

Feature importance analysis gives very critical results that point out the variables that strongly influence site suitability during the process. Identification of critical factors during model development channels efforts to focus on those elements that will yield the highest possible results. Solar irradiance is the number one factor for consideration by the AI model since it controls the rate at which energy is generated. The model sets acceptable minimum levels through regional average data derived from both GHI and DNI thresholds. The selected photovoltaic technology requires sites with suitable temperature ranges that would enhance its performance efficiency thus the model rates locations with appropriate temperature derating criteria. The selection phase ends at sites having low dust levels to avoid power efficiency loss and later cleaning costs.

The location of solar installations heavily depends on accessibility because projects near infrastructure enjoy Construction and maintenance operations present lower expenses to the building project. Accessibility site assessments require the measurement of distances that exist between the installation area and road systems and power lines. The designated distance criteria of queries produce accessibility measures numerically to assess site reachability and serviceability.

The development of the composite suitability index during integration and analysis originates from weighing each criterion according to its importance rates. The analysis places solar irradiance at the top of the priority list since it is a determinant factor in energy generation performance. The suitability ranking procedure is completed as the sites have their weighted criteria calculation to determine their final overall score. Sensitivity testing coupled with risk assessment makes the measurement of site suitability effective during the evaluation process.

The sensitivity assessment method evaluates model parameters and confirms which evaluation site variables have the strongest influence on final rankings through testing adjustable input elements and weights. The risk assessment in general evaluates environmental threats from earthquakes and flooding to determine suitable energy generation sites without encountering environmental risks.

The data-intensive approach, with its AI solution capabilities, leads to effective site exploration for solar power facilities in the southern sector of Iraq. Using Random Forest modeling, the results are successful in nonlinear variable detections necessary for accurate site-matching predictions. The location selection process of this method has ensured better solar power performance at a lower installation expense and fostered sustainable development in the region. This leads to a machine learning model in the Random Forest, where a suitable location assessment for solar cells in the southern regions of Iraq is done according to the developed prediction system. A logical deployment system for modeling makes the prediction accurate and efficient as all data gathered are analyzed from the setup to deployment.

The main purpose of this project is to develop a prediction model that determines solar energy installation suitability scores for different areas by analyzing environmental and infrastructure data. The achievement of this goal requires collecting data from multiple sources. The National Aeronautics and Space Administration (NASA) provides solar irradiance data that consists of global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI). The climatic data concerning temperature and humidity levels and dust concentrations originates from the Iraqi Meteorological Organization together with geographical data about elevation and slope and land use from the Iraqi Ministry for Planning. The organization obtains infrastructure information about how close facilities are positioned relative to power networks combined with roadways and urban developments from official government databases.

The collected data continues the integration process as different datasets link based on geographical coordinates to yield spatial alignment. Data cleaning procedures next begin by handling data gaps using imputation or removal techniques and following this process identifies outliers to preserve the data's integrity. Data transformation begins by processing features through normalization and standardization for uniform scale improvement followed by variable conversion from categories into numbers when necessary.

The purpose of feature engineering is to choose appropriate site suitability-determining variables. The modeling process considers essential solar radiation elements (GHI, DNI, DHI) and temperature variations and humidity levels together with dust storm frequency and severity. The formal methodology builds solar energy installation assessment accuracy by establishing a data framework of high-quality information.

This paper analyzes solar energy installation suitability across different geographical terrains and infrastructure conditions. Elevation and slope gradient and land use classification as well as aspects determine how solar energy potential is affected in a location. Infrastructure features contain the measurement of power grid distance along with the ease of road access and urban center proximity since both determine how feasible it is to develop solar projects. The predictive model receives enhancement through the creation of derived features that incorporate two solar metrics: solar potential index (SPI) and global horizontal irradiance (GHI) and direct normal irradiance (DNI). Apart from solar irradiance components, the model includes the Dust Risk Factor which determines solar panel efficiency impacts due to dust accumulation and the temperature derating factor adjusts performance according to temperature variations from optimal levels. Takeup of the Random Forest algorithm in the model development phase results from its capability to function with complex multidimensional data and its resistance against overfitting due to decision tree ensemble averaging. Through ensemble learning the system generates diverse decision trees during training which subsequently produce either class mode outcomes for classifications or regression mean prediction outputs. The site suitability score functions as the target variable either as an input for classification to categorize sites 'Highly Suitable' or 'Moderately Suitable' or 'Unsuitable' or as a continuous variable for predicting numerical suitability scores. The model starts with an input section that includes the derived features extracted from the dataset. Important parameters of the Random Forest model consist of the tree count (nestimators) that shapes forest size while maximum depth (maxdepth) governs tree depth and minimum splitting requirement (minsamplesleaf) preserves model simplicity as well as interpretability. Training data is split into two sections for model building in the first stage: a training set containing 70-80% of data trains the model before the testing set with 20-30% measures performance. The k-fold cross-validation approach strengthens model reliability through the process of dividing the training set into various distinct subsets. A validation set is used per training run in a 'k'-time procedure that enables measuring model generalization by evaluating average performance over all folds. Letting both Grid Search and Random Search perform parameter value exploration and random sampling forms a critical part of this stage. The tuning process focuses on adjusting three parameters for trees in the forest and the maximum depth and minimum samples needed for splitting or reaching leaf nodes along with the maximum number of features at each split.

Model evaluation occurs after training to determine quantitative measures for assessing effectiveness. In regression tasks, the prediction accuracy is evaluated through mean squared error (MSE), root mean squared error (RMSE), and R² Score. The predictive performance of a model across different classes during classification is measured through accuracy precision and recall and the F1-score and confusion matrices. The Random Forest feature importance analysis can be used to evaluate significant predictive factors by utilizing scores computed from forest models. Figure 2 shows the flowchart for a logical framework.

The final steps involve model interpretation along with decision-making. That is to say, producing suitability scores or classes for each potential site by applying the trained model to the whole dataset. If classification is applied, then thresholds for the classes of suitability are defined—for instance, a suitability score above 0.8 can be classified as 'Highly Suitable.' The structured approach ensures not only that the model performs well but also that it correspondingly provides interpretable and actionable insights for solar energy site suitability assessments. Model deployment is one of the critical steps in the entire process and covers several important parts to make sure the developed model is applied effectively.

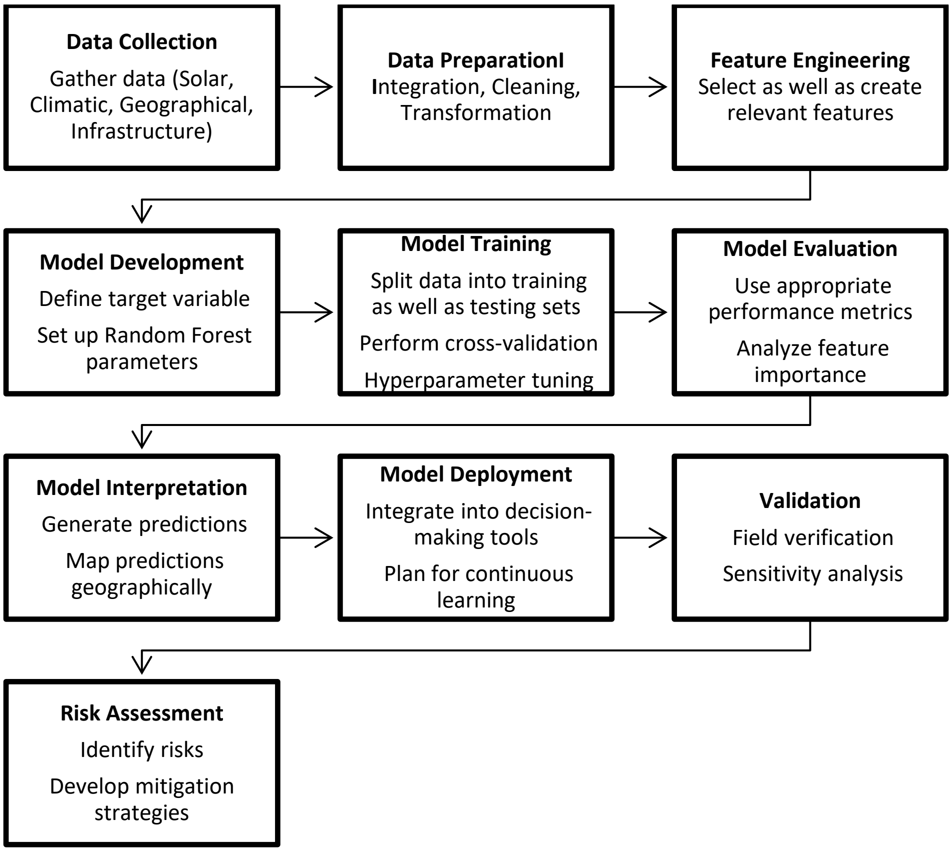


Figure 2. Flowchart for a logical framework

First, integration into decision support systems includes developing interfaces or dashboards with which stakeholders will interact easily in extracting information and insights from model outputs. It also requires continuous learning to keep the model updated and accurate over time. This accessibility lets the users derive insights and make the best decisions based on the predictions made by the model. This may involve updating the model with new information, such as new real-time observations, and also monitoring the performance of the model regularly to assess its accuracy and recalibrate it as needed. Another aspect of ensuring the model is reliable involves validation and testing. This involves field verification: sample sites are selected that the model predicts would be highly suitable for solar energy development and visited to verify actual conditions. This will be further enriched by collecting feedback from local experts, stakeholders in the validation process, and also valuable insights. Sensitivity analysis will test the robustness of this model by varying some input variables and testing their impact on the prediction. Scenario testing allows for assessing how changes in environmental factors might impact site suitability, making sure that all possible outcomes are well-known. Last but not least, risk assessment and mitigation strategies have been important in dealing with uncertainties associated with the model. The first step in this is identifying possible risks, including inaccuracy in data, overfitting of the model, and changes in environmental conditions. This can be mitigated through the use of conservative estimates, including safety margins, in the plan, along with adaptive management planning to ensure a proper response to unforeseen challenges. Together, these components create a holistic approach for deploying, validating, and managing a model in real-world contexts. This logical framework institutes a methodical foundation for developing a Random Forest model for evaluating site suitability for solar energy projects in southern Iraq. It ensures meticulous data collection along with systematic progression to deployment, addressing all crucial elements at each phase. This thorough approach culminates in a dependable tool that greatly improves the selection process for optimal solar energy installation sites.

4. Results and discussion

The expected outcome of the AI-based methodology in selecting optimal sites for solar energy installations in southern Iraq, with specific datasets carried along with the parameters discussed in the proposed work section, will be executed on a laptop that has 3.4 GH, 16 GB for RAM, and 1.5 TB for NVEM SSD and 3050 RTX GPU. A full analysis including data collection, preprocessing, development of AI models, and site assessment yields the following results. A machine learning model was trained by using the collected specific datasets of solar irradiance, climatic conditions, geographical features, and infrastructure data in a Random Forest. The trained model is then used for predicting site suitability over various potential locations in southern Iraq. The analysis identified Al Kut City as the best location for installing solar cells, considering its high solar irradiance levels, optimal temperature range, low dust accumulation, as well as proximity to existing power infrastructure. The coordinates for the optimal site at Al Kut City are latitude 32.49° N as well as longitude 45.78° E, within the time zone for UT+3. When installing solar cells on a specified roof for a house, the quantity of radiation falling on top of the cell is taken into account, as well as expected shade is avoided as shown in Figure 3.

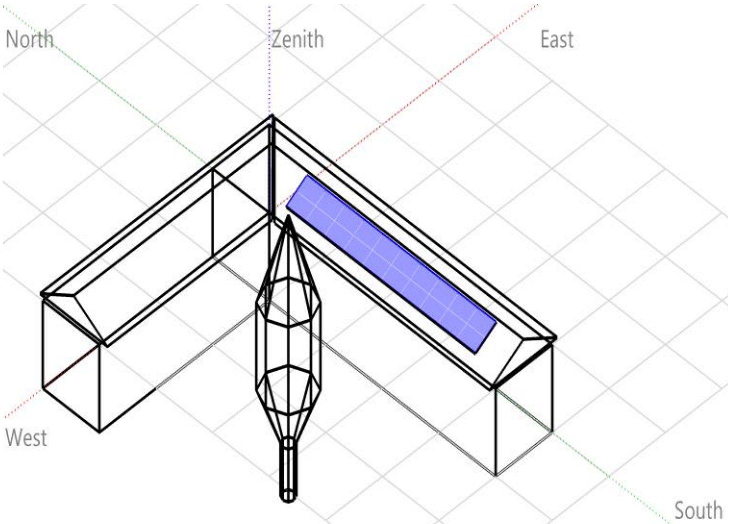


Figure 3. Near shadings parameter

The selected site at Al Kut was further evaluated using a simulated solar-powered house model to determine potential energy production as well as efficiency for solar cells installed at this location. Simulation results indicated that the quantity of radiation falling on solar cells was maximized by avoiding significant shading, as shown in the iso-shadings diagram. This optimal placement led to high solar energy yield as well as performance ratios, demonstrating suitability for a site for solar energy installations as shown in Figure 4.

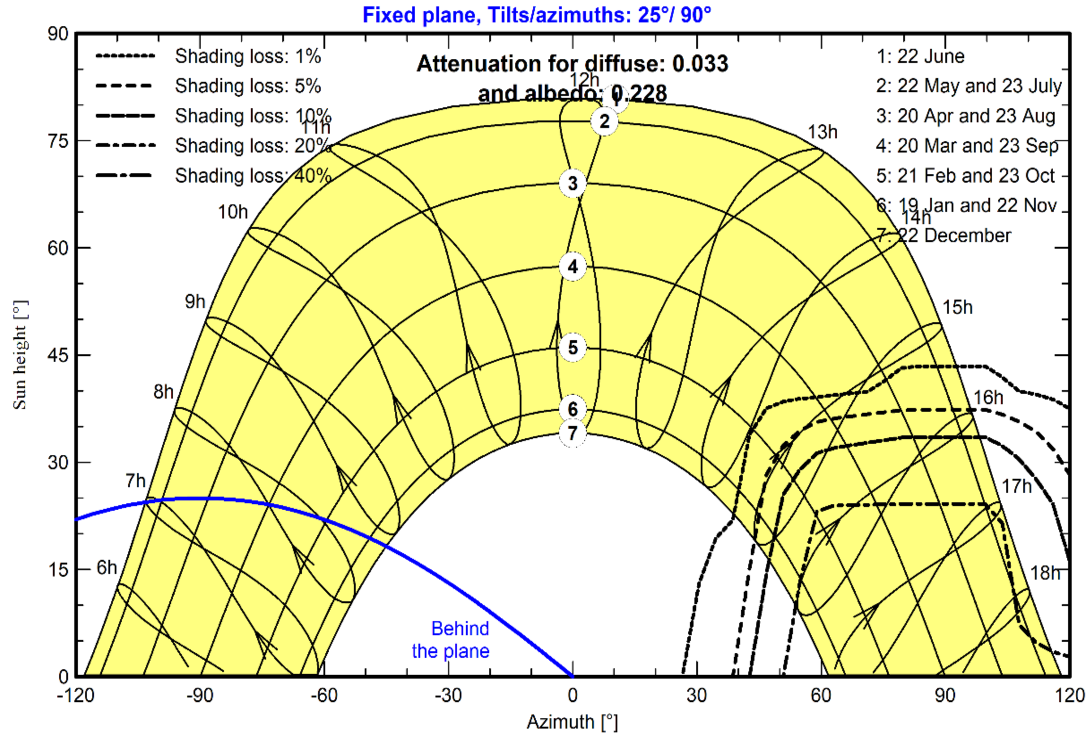


Figure 4. Iso-shadings diagram

The energy production as well as performance ratios for solar energy systems installed at selected sites were calculated based on the AI model's predictions as well as real-time simulations. The system produced a total of 7425.06 kWh/year with a specific production of 1350 kWh/kWp/year as well as a performance ratio (PR) of 76.89%. These metrics confirm high efficiency for solar energy systems at the chosen site, validating the effectiveness of AI, as shown in Figures 5 and 6.

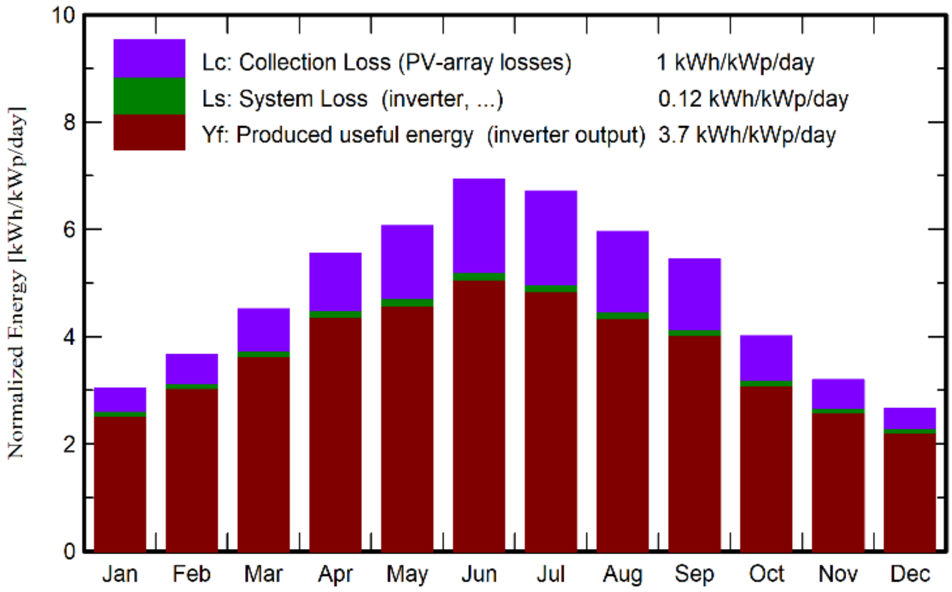


Figure 5. Solar cell's performance ratio

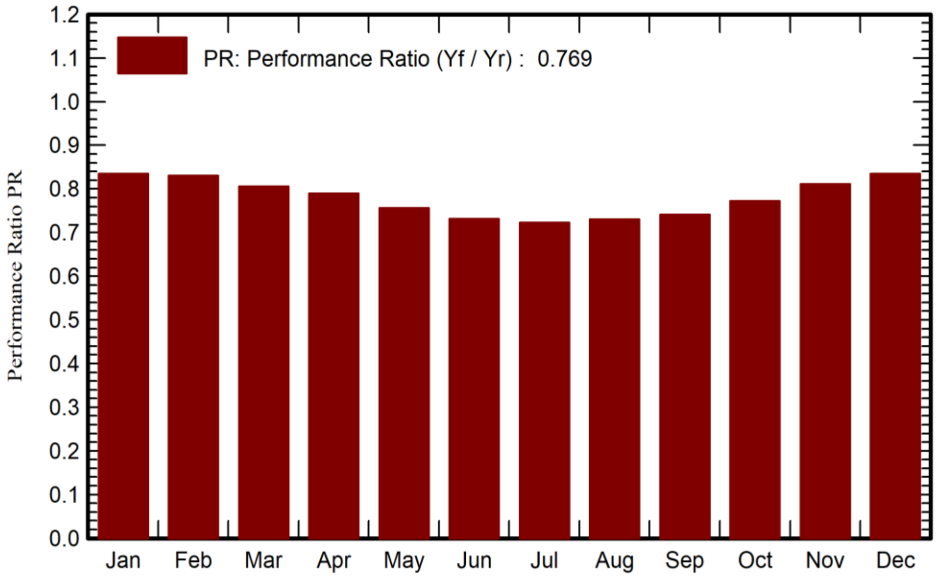
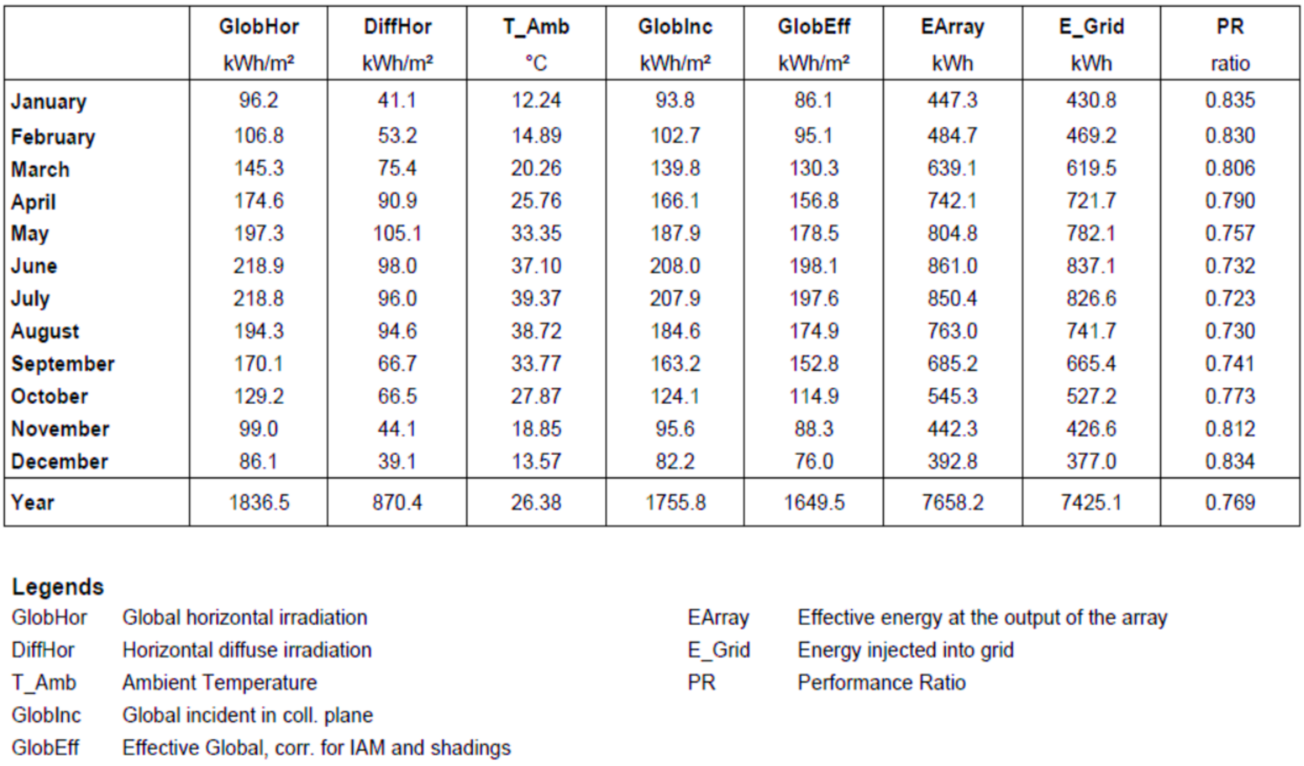


Figure 6. Solar cells vs user load chart

A sensitivity analysis was conducted to evaluate the robustness of the AI model's predictions. The analysis involved altering input variables, such as solar irradiance, temperature, as well as dust levels, to assess their impact on site rankings. Results showed that solar irradiance as well as temperature were the most significant factors influencing site suitability. Sites with consistently high irradiance levels as well as moderate temperatures were consistently ranked higher, demonstrating the model's sensitivity to these key environmental variables. Table 2 summarizes the system's energy production as well as performance ratios over the year. Key metrics such as produced energy (7425.06 kWh/year), specific production (1350 kWh/kWp/year), as well as performance ratio (PR = 76.89%), are presented. These metrics are essential for evaluating efficiency for different sites. The AI-based approach can utilize these results to predict performance for PV systems at various locations, thereby helping to select sites that maximize energy production as well as maintain high-performance ratios.

Table 1. User load as well as solar energy throughout the year



	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	96.2	41.1	12.24	93.8	86.1	447.3	430.8	0.835
February	106.8	53.2	14.89	102.7	95.1	484.7	469.2	0.830
March	145.3	75.4	20.26	139.8	130.3	639.1	619.5	0.806
April	174.6	90.9	25.76	166.1	156.8	742.1	721.7	0.790
May	197.3	105.1	33.35	187.9	178.5	804.8	782.1	0.757
June	218.9	98.0	37.10	208.0	198.1	861.0	837.1	0.732
July	218.8	96.0	39.37	207.9	197.6	850.4	826.6	0.723
August	194.3	94.6	38.72	184.6	174.9	763.0	741.7	0.730
September	170.1	66.7	33.77	163.2	152.8	685.2	665.4	0.741
October	129.2	66.5	27.87	124.1	114.9	545.3	527.2	0.773
November	99.0	44.1	18.85	95.6	88.3	442.3	426.6	0.812
December	86.1	39.1	13.57	82.2	76.0	392.8	377.0	0.834
Year	1836.5	870.4	26.38	1755.8	1649.5	7658.2	7425.1	0.769

Legends

GlobHor	Global horizontal irradiation
DiffHor	Horizontal diffuse irradiation
T_Amb	Ambient Temperature
GlobInc	Global incident in coll. plane
GlobEff	Effective Global, corr. for IAM and shadings
EArray	Effective energy at the output of the array
E_Grid	Energy injected into grid
PR	Performance Ratio

The daily input/output diagram as shown in Figures 7 and 8, presents daily power output distribution for solar PV system. This graph is essential for understanding daily energy generation patterns as well as can help in identifying consistency as well as reliability for power output at different times of the year. Integrating such temporal data into an AI model can enhance prediction for site suitability based on daily as well as seasonal variations in solar power production.

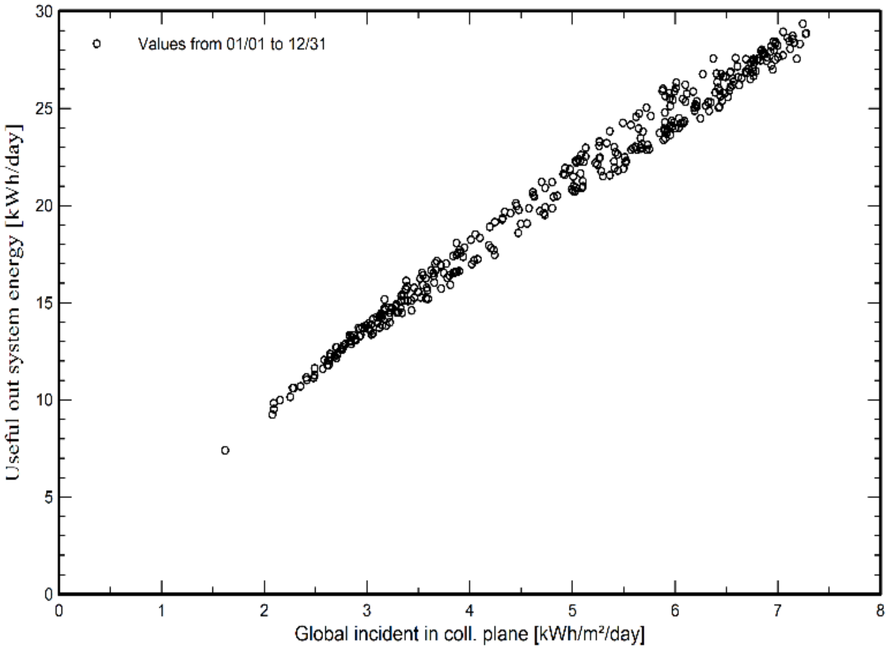


Figure 7. Daily input/output diagram

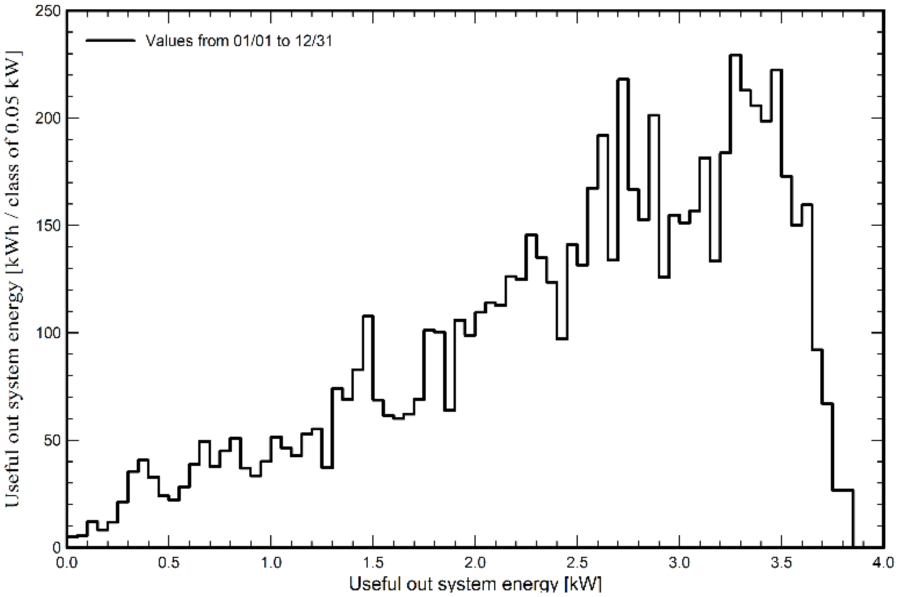
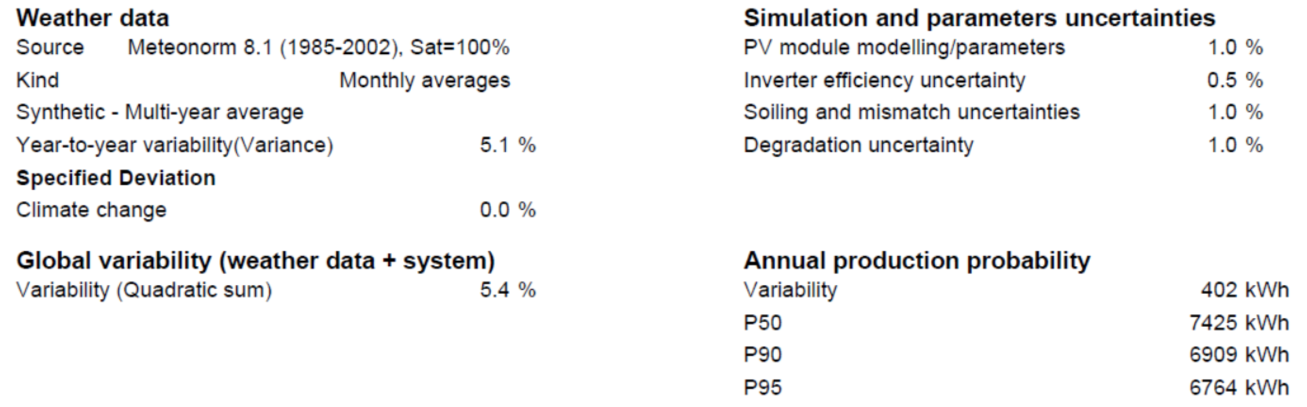


Figure 8. System output power distribution

The probability distribution analysis, including P50, P90, as well as P95 values, was performed to account for variability in weather conditions as well as system uncertainties. P50 value indicated that there is a 50% probability of achieving the expected annual production of 7425 kWh/year, while P90 as well as P95 values suggested more conservative production estimates for 6909 kWh/year as well as 6764 kWh/year, respectively. This probabilistic evaluation helps in understanding potential risks as well as uncertainties associated with solar energy production at selected sites, enabling more informed decision-making for stakeholders as shown in Table 3, as well as Figure 9.

Table 2. Probable energy production values (P50, 90, 95)



Weather data		**Simulation and parameters uncertainties**	
Source	Meteonorm 8.1 (1985-2002), Sat=100%	PV module modelling/parameters	1.0 %
Kind	Monthly averages	Inverter efficiency uncertainty	0.5 %
Synthetic - Multi-year average		Soiling and mismatch uncertainties	1.0 %
Year-to-year variability(Variance)	5.1 %	Degradation uncertainty	1.0 %
Specified Deviation			
Climate change	0.0 %		
Global variability (weather data + system)		**Annual production probability**	
Variability (Quadratic sum)	5.4 %	Variability	402 kWh
		P50	7425 kWh
		P90	6909 kWh
		P95	6764 kWh

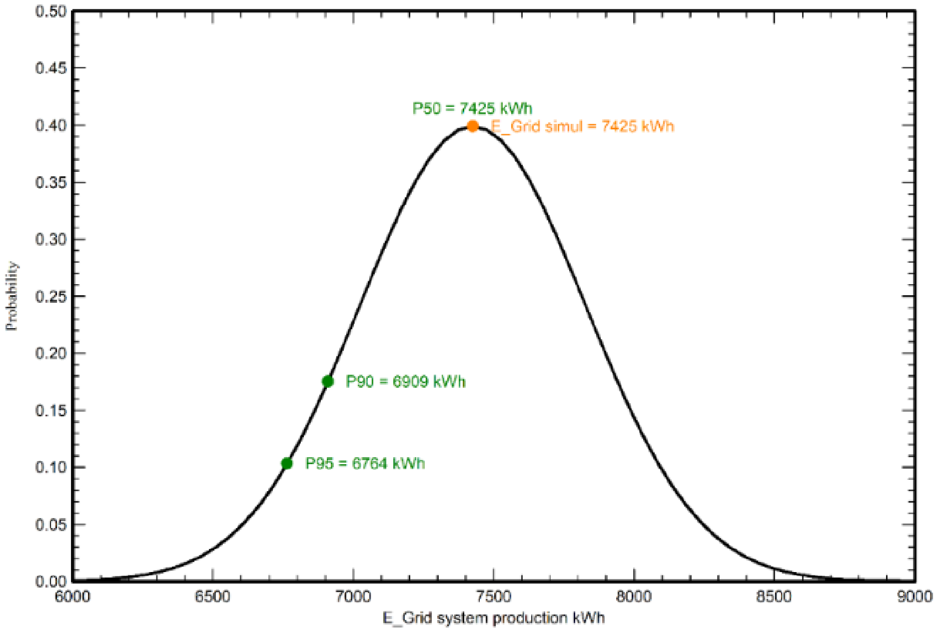


Figure 9. Probability distribution

The economic viability of theselected site was assessed by calculating the Leveled Cost for Energy (LCOE) based on total installation as well as operating costs for thesolar energy system. Results indicated that optimized site selection significantly reduces installation as well as maintenance costs, thus lowering LCOE. This finding emphasizes thefinancial benefits of using an AI-based approach for site selection, providing a higher return on investment for solar energy projects. The selected site at Al Kut also demonstrated substantial potential for CO_2 emission reduction using modern techniques [23-26]. Analysis estimated total replacement for 193.6 t CO_2 over the system's lifetime, compared to conventional grid electricity sources [27-31]. This environmental benefit supports Iraq's efforts to transition to renewable energy as well as contributes to global sustainability goals. This study can be developed, as future works, with the adopted techniques in [32-36].

5. Conclusion

This study demonstrates thepotential for using AI-based methodology to enhance efficiency for solar energy installations in south Iraq via optimizing site selection. Leveraging the Random Forest machine learning model, we integrated various data types—including solar irradiance, climatic conditions, geographical features, as well as infrastructure data—to accurately predict suitability for potential sites for solar cell installations. Results identified Al Kut City as anoptimal location, considering its favorable environmental conditions, high solar irradiance, as well as proximity to existing infrastructure. The AI-driven approach not only increased accuracy for site selection via accounting for complex, non-linear interactions between multiple factors but also significantly improved efficiency for solar energy systems. The selected site achieved high energy production metrics, including total annual production of 7425.06 kWh/year as well as a performance ratio (PR) of 76.89%, demonstrating practical benefits for this method. Additionally, the model's ability to incorporate sensitivity as well as risk analysis through probabilistic evaluations, such as P50, P90, as well as P95, provided valuable insights into reliability as well as financial viability for solar energy projects under varying conditions.

An economic analysis showed that optimal site selection could decrease installation and maintenance costs, therefore reducing the levelized cost for energy (LCOE) and increasing return on investment. Besides, the selected site had great potential to decrease CO_2 emissions, therefore supporting Iraq's transition toward renewable energy and contributing to global sustainability goals.

This research represents a strong framework for strategic solar energy deployment in Iraq, enabling a data-driven approach toward site selection for maximum energy yield while reducing costs and reducing environmental impact. Integration of AI-based site selection techniques with solar energy technologies fosters sustainable energy development alongside international efforts to fight climate change and dependence on fossil fuels. Future research can build from this by including real-time data updates and investigating the potential of other AI models to further refine and enhance site selection processes.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

Ibtihal R. N. ALRubeei: Conceptualization of the study, methodology design, and overall supervision of the research paper. Safa N. Idi, Ihab L. Hussein Alsammak: They contributed to the writing and editing of the manuscript. Haider Th. AlRikabi: He discussed the first draft of this paper and checked all the journal requirements. Hussain A. Mutar and Abdul Hadi M. Alaidi Implemented the AI of the proposed work.

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