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Enhanced Daily Global Solar Radiation Prediction Through Hybrid Artificial Neural Network and Adaptive Neuro-Fuzzy Inference System with Meta-Heuristic Algorithm Integration

Senouci Ahlam[1*], Maouedj Rachid[2], Benatiallah Ali[1], Benatiallah Djelloul[3], Bouchouicha Kada[4]

[1] Department of Material Sciences, Laboratory of Energy, Environment, and Information Systems, Ahmed Draia University Adrar, Adrar 01000, Algeria
[2] Research Unit for Renewable Energies in Saharan region (URERMS), Renewable Energy Development Center (CDER), Adrar 01000, Algeria
[3] Department of Mathematics and Computer Science, Laboratory of Sustainable Development and Computer Science, Ahmed Draia University Adrar, Adrar 01000, Algeria
[4] Center for Renewable Energy Development (CDER), Bouzareah, Algiers 16340, Algeria

Corresponding Author Email: ahlem.snc@gmail.com

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ABSTRACT

The efficiency of solar energy systems is critically dependent on the available solar radiation. Addressing this reliance, we have engineered hybrid models that integrate adaptive neuro-fuzzy inference systems (ANFIS) with artificial neural networks (ANN), augmented by meta-heuristic algorithms including genetic algorithms (GA) and particle swarm optimization (PSO). These models utilize meteorological data to predict daily global solar radiation with high precision. Statistical measures such as root mean square error (RMSE), correlation coefficient (R), and mean absolute error (MAE) were employed to assess model performance. Demonstrating superior accuracy, the hybrid models achieved an exceptional alignment with empirical data, surpassing traditional models like ARIMA, Support Vector Regression (SVR), and Random Forest Regression by a significant margin, reducing RMSE by over 10% (to less than 6% compared to the >15% of existing models). Standard K-fold cross-validation confirmed the reliability of these hybrid models, consistently yielding RMSE values under 6% in predicting daily global solar radiation. This indicates the strong potential of integrating ANN and ANFIS with meta-heuristic algorithms for enhancing solar radiation forecasting, thereby advancing solar energy as a sustainable and reliable energy source.

1. INTRODUCTION

Solar radiation is a crucial factor that fundamentally influences a multitude of natural processes, such as plant growth, evaporation, and atmospheric circulation [1-3]. The precise estimation of solar radiation is pivotal for a range of applications, including solar energy production, agriculture, and climate modeling [4-6]. However, due to the complex and non-linear nature of the processes involved, traditional empirical models relying on meteorological variables may fall short in delivering consistent predictions.

Recent advances in machine learning algorithms have led to the development of more accurate models for predicting solar radiation. Artificial Neural Networks (ANNs) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) are two machine learning methods that have shown promise in solar radiation forecasting. These techniques are adept at handling the complex non-linear relationships between meteorological variables and solar radiation, resulting in improved prediction accuracy [7-9].

Nevertheless, even with the enhanced precision offered by machine learning algorithms, optimizing these models' parameters for peak prediction performance remains a challenge. This is where meta-heuristic optimization techniques become invaluable. Such techniques can assist in identifying the most effective parameter set for a machine learning model.

Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) are two meta-heuristic optimization methods that have been employed in fine-tuning solar radiation estimation models. PSO emulates the social behavior of swarming particles to navigate the search space and converge on a solution [10], while GA is inspired by the mechanisms of natural selection and evolution to identify the optimal solution [11, 12].

In our research, we propose a novel hybrid approach that integrates ANNs and ANFIS with PSO and GA to forecast daily global solar radiation. This method aims to capitalize on the optimization strengths of PSO and GA to refine the machine learning models' parameters, thereby enhancing the accuracy of predictions. By combining the robust features of these algorithms, our hybrid model achieves higher precision and reliability in forecasting.

The effectiveness of our hybrid methodology has been rigorously validated using a real-world dataset. Our comprehensive evaluation includes a performance comparison with established forecasting methods. Through this analysis, we demonstrate the superior predictive performance and the potential benefits of our hybrid model in accurately forecasting daily global solar radiation.

We conducted an exhaustive evaluation of our methodology using a dataset that accurately reflects real-world conditions. This evaluation was thorough and comprehensive, covering every possible angle. We benchmarked our innovative approach against traditional prediction methods (like ARIMA, Support Vector Regression (SVR), and Random Forest Regression [13]) to ensure a fair comparison.

The results of our meticulous and detailed comparative analysis underscored the exceptional predictive ability of our hybrid model. Not only did our method demonstrate its efficacy, but it also showed significant superiority in accurately forecasting daily global solar radiation compared to existing methods. This indicates that our approach is not only effective but excels in providing a level of accuracy and reliability that can significantly impact various applications, from solar energy planning to advanced climate modeling.

Our research marks a significant advancement in solar radiation prediction, illustrating the effectiveness of combining computational techniques to address complex challenges in renewable energy. By synergistically merging ANNs, ANFIS, PSO, and GA, we present a hybrid model that surpasses conventional methods in accuracy and robustness, offering a valuable tool for precise prediction in solar energy production and other applications that require exactitude, thus steering us towards a future energized by clean and dependable solar power.

2. LITERATURE REVIEW

Solar radiation plays a role, in our environment affecting areas such as renewable energy generation, agriculture and climate modeling [14, 15]. It is essential to forecast the amount of radiation we receive daily but it can be quite challenging due to the intricate relationships, between different meteorological factors [16]. To overcome these challenges, researchers have explored various methods for predicting solar radiation, including: artificial neural networks (ANNs), adaptive neuro-fuzzy inference systems (ANFIS), and meta-heuristic algorithms. ANNs are a type of machine learning model that can learn patterns from data and make predictions based on those patterns. On the side ANFIS brings together the advantages of neural networks (ANNs) and fuzzy logic forming a hybrid model capable of handling uncertain or imprecise data. Additionally heuristic algorithms serve as optimization techniques that can determine the values, for model parameters [17, 18]. Numerous studies have investigated the application of these methods in predicting radiation.

a) Artificial Neural Networks (ANNs)

For example, Al Shamisi et al. [19] developed an ANN model to forecast solar radiation in Al Ain City. UAE, the research utilized data spanning a period of 13 years from Al Ain City. This data included information, on the temperature, wind speed, duration of sunshine and average humidity levels. Before inputting the data, into the ANN model it underwent preprocessing and normalization procedures. The data was divided into training, validation, and testing sets. The researchers employed a layer perceptron (MLP) network consisting of an input layer a hidden layer, with 10 neurons and an output layer to forecast global solar radiation They experimented with different activation functions and learning algorithms before selecting the most effective combination (hyperparameter tuning). The model performed strong predictive capabilities for solar radiation a percentage error (MAPE) of 4.7% and a correlation coefficient (R) of 0.956, on the testing set. The study also identified sunshine duration as the factor influencing the models' predictions. More research is required to tackle the constraints and enhance the model's ability to adapt and perform reliably in scenarios.

b) Adaptive Neuro-Fuzzy Inference Systems (ANFIS)

Other studies have explored the use of ANFIS for solar radiation prediction. For example, Kisi [20] developed an ANFIS model to predict hourly global solar radiation. The research utilized data collected from 13 stations located across Turkey, which represented climatic regions. The dataset consisted of information such, as temperature, relative humidity, pressure and sunshine duration. To analyze this data the researchers used an inference system (FIS) that had three input parameters (temperature, humidity, pressure) and one output parameter (solar radiation). The FIS employed rules of the Sugeno type along, with membership functions. To assess how well this model performs they divided the data for training and testing purposes. This model demonstrated promising accuracy in Turkey, achieving R^2 values ranging from 0.82 to 0.92 for different stations. The model's performance might be affected by cloud cover and other weather phenomena that influence solar radiation.

c) Meta-heuristic Algorithms

In years researchers have conducted studies investigating the application of meta heuristic algorithms in enhancing solar radiation prediction models. For instance, the research team of Gupta et al. [21] collected data from 13 cities, in India for a period of 9 years. The data included information on sunshine duration, maximum and minimum temperatures, relative humidity and wind speed. They used a multi layer perceptron (MLP). This MLP had an input layer, a layer with 10-50 neurons and an output layer to predict solar radiation. To optimize the MLPs performance the researchers introduced an optimization method called Biogeography Based Optimization (BBO). BBO imitates the movement patterns of organisms in an ecosystem to find the values for the network's weights and biases. The collected data was divided into training, validation and testing sets, for analysis. The ANN model optimized with BBO showed an increase, in accuracy compared to an ANN model without BBO. The average percentage error (APE) saw a reduction of 2 to 6% across cities demonstrating improvements, in prediction accuracy. The BBO algorithm might not be the best optimization technique for all datasets.

d) Hybrid Models Integration

Researchers have been investigating the integration of networks (ANNs) adaptive neuro fuzzy inference systems (ANFIS) and metaheuristic algorithms to improve the precision of solar radiation prediction.

One notable study by Mousavi et al. [22] proposed a new approach to predict global solar radiation, in Malaysia by combining an Adaptive Neuro Fuzzy Inference System (ANFIS) with Particle Swarm Optimization (PSO). They utilized a logic based ANFIS architecture that incorporated three input parameters; temperature, relative humidity and sunshine duration. The output parameter was the radiation. To optimize the ANFIS parameters such as rule weights and membership function parameters they employed a swarm intelligence optimization technique called Particle Swarm Optimization (PSO). The primary objective of the optimization algorithm was to minimize the error (MSE), between the predicted and actual solar radiation values. Their findings showed that the ANFIS-PSO hybrid model had superior prediction performance with an impressive correlation coefficient (R) of 0.9921 and a mean absolute percentage error (MAPE) of 2.3%. Investigating different ANFIS configurations and PSO variants could lead to further improvements in the model's performance and adaptability to various data sets and regions.

Another study by Khosravi et al. [23] created a combined model to predict solar radiation. They merged Artificial Neural Networks (ANN) and Adaptive Neuro Fuzzy Inference Systems (ANFIS) in this approach. The ANN component used a layer perceptron (MLP) architecture, with specific input and output parameters. On the hand ANFIS incorporated logic and expert knowledge through fuzzy rules. To optimize the parameters of both ANN and ANFIS the researchers employed algorithms such, as genetic algorithms (GA) and particle swarm optimization (PSO). This optimization process significantly improved prediction accuracy compared to ANN or ANFIS models. The hybrid model achieved results with a correlation coefficient (R) of 0.985 and a mean absolute error (MAE) of 3.71%. Investigating different ANN architectures, ANFIS configurations, and optimization algorithms could lead to further refinement of the hybrid model and adaptation to diverse datasets and locations.

These studies showcase the promise of hybrid models in enhancing the precision of radiation prediction. By merging the advantages of techniques hybrid models can attain accuracy compared to individual models. The reason, behind this is that hybrid models can leverage the strengths of each technique and mitigate their shortcomings.

Hybrid models show potential, in the field of radiation prediction. With research and development these models are expected to enhance the accuracy of radiation prediction. This advancement will greatly benefit the energy industry by enabling precise planning and implementation of solar energy systems.

Furthermore apart, from this research numerous other studies have delved into the application of hybrid models for predicting radiation. These investigations have demonstrated that hybrid models can attain improved accuracy compared to models, across various scenarios.

Hybrid models present an avenue of exploration, in the field of radiation prediction. In the future, as researchers keep improving and innovating, we can anticipate these models to become widely accepted. This advancement will greatly impact the energy industry enabling precise planning and implementation of solar energy systems.

In summary the use of models that combine neural networks (ANNs) adaptive neuro fuzzy inference systems (ANFIS) and meta heuristic algorithms hold promise for enhancing the accuracy of solar radiation prediction. These improvements could have implications in areas such, as energy, agriculture and climate modeling. However further research is required to optimize these models and evaluate their performance across locations and weather conditions [24]. Our research contributes to the current body of knowledge by focusing on minimizing the values of the root mean square error (RMSE) for higher correlation coefficient (R).

3. METHODOLOGY

The methodology employed in this study is a well-structured and comprehensive approach to accurately predict global solar radiation across the selected sites in South Algeria. The method encompasses a series of meticulous steps that ensure the reliability and precision of the predictive model.

The initial phase of the methodology involves the careful selection of three specific sites in South Algeria, each equipped with the necessary data for required parameters and measured global solar radiation on the horizontal plane. These sites are strategically chosen to represent a diverse range of solar radiation conditions and are characterized by distinct geographic attributes such as) longitude, altitude, and latitude, as shown in Table 1.

Table 1. Geographical coordinates of the three studied sites having arid zone [25-27]

Site	Longitude	Altitude	Latitude
Adrar	-1.358	286	26.489
Tindouf	-6.240	382	27.544
Tamanrasset	4.321	810	24.375

Data collection is a crucial aspect of the methodology, encompassing a comprehensive array of parameters. These parameters include day of the year, year, temperature, relative humidity, pressure, wind speed, and the measured global solar radiation on the horizontal plane. A critical validation process is conducted to ensure the accuracy and consistency of the collected data, setting the foundation for reliable analysis.

Subsequently, a pre-processing phase is undertaken to refine the collected data. This involves meticulous checks to identify any missing or inconsistent data points, which are then rectified. Outliers are detected and removed to enhance the dataset's integrity. we implemented statistical techniques such as standard deviation and interquartile range to pinpoint potential outliers. Additionally, visual inspection methods like scatter plots and box plots were employed to detect data points significantly deviating from the overall pattern. Further enhancing data comparability, normalization techniques are employed to ensure that all parameters are scaled uniformly. We used randomized data splitting and cross-validation to ensure representation and enhance robustness. The dataset is then divided into distinct sets for training, validation, and testing (80%, 10%, and 10% respectively).

The aim of our study focuses on a combination of two models of machine learning as Artificial neural networks (ANN) and adaptive neuro fuzzy inference system (ANFIS) with meta-heuristic algorithms [28]. We used the ANN to capture the connection, between input parameters and the overall output of solar radiation [29]. Expert knowledge and fuzzy logic were incorporated through ANFIS to fine-tune the ANN's output [30]. Meta-heuristic optimization algorithms such as Particle Swarm Optimization or Genetic Algorithms were further employed to optimize the model.

The hybrid model goes through a training process using a dataset with ongoing monitoring and improvement using the validation set. The model parameters are adjusted as needed to achieve performance. To assess how well the model works predictions are compared to the measurements of radiation, in the testing dataset. Evaluation metrics such as mean percentage error (MPE), root mean square error (RMSE), and correlation coefficient (R), provided a thorough understanding of model performance. Rigorous training-validation split, early stopping mechanisms, cross-validation techniques particularly k-fold cross-validation [31], hyperparameter tuning, regularization methods, careful parameter initialization, and defined convergence criteria were systematically employed. These refined strategies not only ensured superior model performance during training but also demonstrated resilience and generalization, effectively preventing overfitting.

The model is optimized by making adjustments, to its parameters and experimenting with heuristic optimization algorithms to find the most effective method. After that the predicted values of the model are compared to the measurements of solar radiation, at each location. statistical metrics are utilized to gauge the model's predictive performance.

In our research we focused on how incorporating and evaluating algorithms can improve the performance of our models. We carefully selected algorithms, like Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) known for their effectiveness in solving optimization problems. These algorithms were seamlessly combined with our hybrid models that utilize Artificial Neural Networks (ANN) and Adaptive Neuro Fuzzy Inference System (ANFIS). Important steps included setting the parameters tuning population size and iterations and establishing convergence criteria to ensure successful optimization. To assess the performance of algorithms we used metrics and compared them with traditional optimization methods. We also conducted sensitivity analysis. Employed statistical measures to fine tune parameters. Evaluate consistency and reliability. Through these processes we achieved an integration of meta heuristic algorithms resulting in effective optimization and improved predictive performance, for daily global solar radiation.

We deliberately chose specific statistical metrics—mean percentage error (MPE), root mean square error (RMSE), and correlation coefficient (R) to evaluate model performance in predicting daily global solar radiation [32, 33]. These metrics were selected for their relevance to optimization tasks and their ability to provide comprehensive insights. The mean percentage error assesses average percentage differences, RMSE emphasizes error magnitudes, and the correlation coefficient evaluates the linear relationship between predicted and observed values. These metrics were systematically calculated during the evaluation process using these equations [23]:

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_c - H_m}{H_m}\right) * 100\% \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_c - H_m}{H_m}\right)^2} * 100\% \quad (2)$$

$$R = \left[\frac{\sum_{i=1}^{n}(H_m - \overline{H}_m)(H_c - \overline{H}_c)}{\sqrt{\sum_{i=1}^{n}(H_m - \overline{H}_m)^2 \sum_{i=1}^{n}(H_c - \overline{H}_c)^2}}\right] \quad (3)$$

With:
n: Number of observation values.
H_c: Calculated value of global radiation.
H_m: Measured value of global radiation.
$\overline{H}_m$: The average value of measured solar irradiation.
$\overline{H}_c$: The average value of estimated solar irradiation.

In conclusion, the methodology employed in this study has demonstrated its effectiveness in accurately predicting global solar radiation across the designated sites in South Algeria. The carefully selected sites, each defined by specific geographical coordinates, have been meticulously documented for reference. The research outcomes offer not only a comprehensive understanding of the intricate dynamics influencing solar radiation but also provide insights into the broader applications of this innovative approach.

By spanning the years 2016 to 2017, the utilization of solar radiation data enhances the robustness and credibility of predictions. This temporal dimension enables capturing nuanced variations in solar radiation patterns, contributing to a holistic comprehension of solar radiation trends within the studied regions. Moreover, the insights derived from this study hold far-reaching implications across diverse domains, including renewable energy development, agricultural practices, and climate modeling.

As the world continues its transition towards sustainable energy sources, this research holds significant value in the discourse surrounding solar energy utilization and planning. The robust methodology presented here contributes to the advancement of efficient and effective solar energy systems, ultimately fostering a greener and more sustainable future.

Essentially the careful examination of radiation data, from 2016 to 2017 along with the predictive approach highlights the significant significance of this study. The knowledge acquired not showcases the potential of this method but also serves as a tool, for researchers, policymakers and practitioners working together towards utilizing solar energy’s capabilities for a better and more sustainable future.

4. MODEL DEVELOPMENT

We plan to utilize data from three locations, in South Algeria, Adrar, Tindouf and Tamanrasset to construct our model. Our objective is to gather data on the radiation levels along with various other factors such, as the day of the year itself temperature, relative humidity, pressure and wind speed.

In order to develop our model, we plan to utilize two approaches as neural network (ANN) and an adaptive neuro fuzzy inference system (ANFIS). The ANN will assist us in capturing the linear connection, between our input variables and the solar radiation output. The networks architecture, for predicting global solar radiation involves an input layer with 5 nodes, each representing a different input variable. The structure of the layers, which's crucial for capturing complex patterns in the data is determined through experimentation and optimization. For example, a model might have 2 hidden layers with 15 nodes in the layer and 7 nodes in the second. The output layer consists of a node that corresponds to the output variable. Activation functions play a role in improving the models’ learning capabilities. Typically, the Rectified Linear Unit (ReLU) is used for the layers to introduce non linearity while the linear activation function is commonly employed for the output layer to generate predictions.

In the case of Adaptive Neuro Fuzzy Inference System

(ANFIS) with 5 inputs and 1 output determining rules and membership functions requires analysis. By using grid partitioning and a hybrid learning algorithm like backpropagation gradient descent ANFIS adapts its rules and membership functions based on data characteristics during training. The number of rules and shape of membership functions are adjusted iteratively to optimize accuracy and generalization, in predicting solar radiation. It operates by employing a feedforward neural network structure with a layer. It employs a Backward propagation algorithm to train the model. To ensure learning we will normalize our input variables so that they are all on the scale. After collecting data from the database, three data preprocessing procedures are implemented to establish more effective Neural Networks (ANN). These procedures include addressing the issue of missing data, normalizing, and randomizing the data. Missing data is replaced by the average of neighboring values during the same week. The normalization procedure, applied before presenting the input data to the network, is generally considered a good practice. Mixing variables with large and small amplitudes can disrupt the learning algorithm's understanding of the importance of each variable, potentially leading it to eventually reject the variable with the smallest magnitude. By applying the following normalization equation [5]:

$$normalized_{value} = \frac{non_{normalized_{value}} - min\_value}{\max\_value - \min\_value} \quad (4)$$

With: *min-value* and *max-value*: the minimum and maximum values, respectively, of the variable to be normalized.

Once our ANN is trained, we'll employ the ANFIS system to further refine our model's output. This system incorporates logic principles to integrate knowledge and human reasoning into the model. It generates a set of rules that describe how the input variables relate to radiation output. This will assist in tuning the results of our neural network (ANN) to ensure that it better captures and represents the actual behavior of the system we are investigating.

To optimize our model even further, we will be using two different algorithms - particle swarm optimization (PSO) and genetic algorithms (GA). These algorithms will help us to find the best possible weights, biases, and parameters that minimize the error between our predicted values and the actual solar radiation measurements. PSO will be used to optimize the parameters of the ANFIS model, while GA will be used to optimize the weights and biases of the ANN.

Once we have developed our model, we will be validating it using data from the same three sites in South Algeria. We will compare our predicted values of daily global solar radiation with the actual measurements to make sure that our model is accurate and reliable. By developing a hybrid ANN-ANFIS model with PSO and GA optimization algorithms, we will be creating a powerful tool for energy planning and management in the region.

5. RESULTS AND DISCUSSION

5.1 ANN model

In our study, we utilized the ANN model to predict daily global solar radiation across three regions in South Algeria: Adrar, Tindouf, and Tamanrasset. These graphical representations illustrate the performance of the ANN model in each of these geographical areas. By comparing the anticipated values of daily global solar radiation with the actual measurements, we can assess the precision and dependability of the model in each specific location. This data is of paramount importance for energy planning and management, as it aids in the identification of optimal regions for solar energy development and the enhancement of the utilization of existing solar energy resources. Figure 1 demonstrates the comparison between irradiation calculated by the ANN model and measured values in Adrar, while Figure 2 pertains to Tindouf, and Figure 3 corresponds to Tamanrasset.

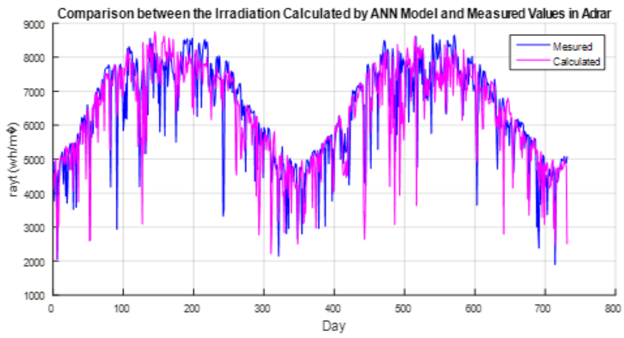

Figure 1. Comparison between the irradiation calculated by ANN model and measured values in Adrar

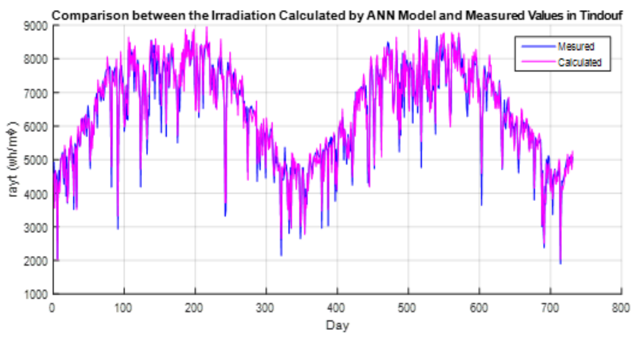

Figure 2. Comparison between the irradiation calculated by ANN model and measured values in Tindouf

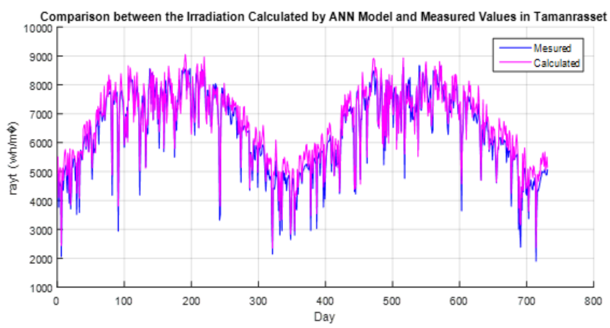

Figure 3. Comparison between the irradiation calculated by ANN model and measured values in Tamanrasset

5.2 ANN-GA model

The ANN-GA model is a combination between ANN and a genetic algorithm (GA). This hybrid approach aims to enhance the performance of the model by utilizing the ANN to capture relationships, between input variables and output and employing the GA to optimize the weights and biases of the ANN.

Multiple research studies have demonstrated that the ANN GA model provides benefits compared to ANNs and other machine learning techniques when it comes to predicting daily global solar radiation. The advantage arises from the GAs ability to optimize parameters of the ANN, such, as weights and biases resulting in a precise and resilient model. Extensive investigations conducted in regions like South Algeria, the United States and China further strengthen the effectiveness of ANN GA in forecasting radiation levels. These studies firmly establish it as a tool for accurate and efficient prediction of solar radiation. The potential of this model to revolutionize forecasting by improving accuracy, resilience and efficiency has the potential to greatly enhance energy systems performance and other applications dependent, on precise predictions of solar radiation.

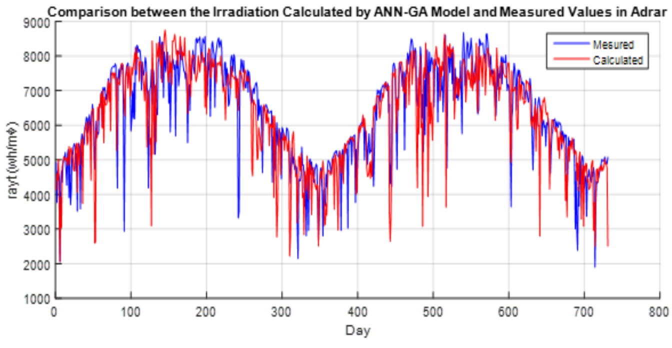

Figure 4. Comparison between the irradiation calculated by ANN-GA model and measured values in Adrar

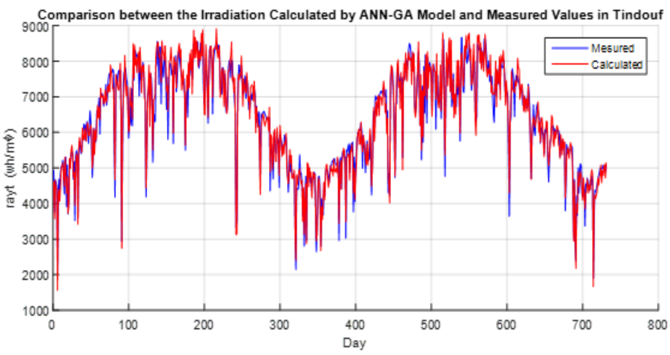

Figure 5. Comparison between the irradiation calculated by ANN-GA model and measured values in Tindouf

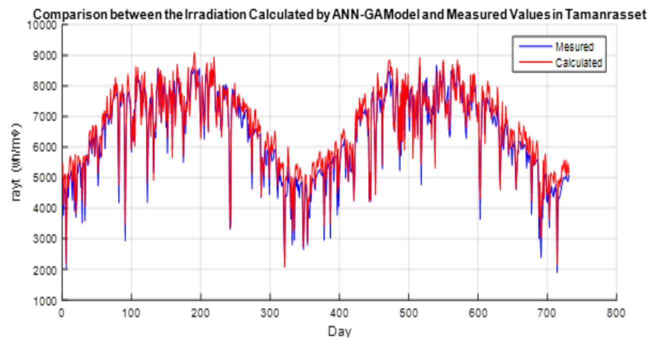

Figure 6. Comparison between the irradiation calculated by ANN-GA model and measured values in Tamanrasset

Figure 4 illustrates the comparison between the irradiation calculated by ANN-GA model and measured values in Adrar, while Figure 5 pertains to Tindouf, and Figure 6 corresponds to Tamanrasset.

5.3 ANN-PSO model

The ANN-PSO model is a method that combines two machine learning techniques neural network (ANN) and particle swarm optimization (PSO). ANNs excel at grasping connections, between input and output variables while PSO empowers us to discover the most effective parameters, for an ANN model using a metaheuristic optimization algorithm.

The ANN PSO model operates by training a neural network (ANN) using a dataset containing historical measurements of solar radiation. The PSO algorithm optimize the parameters of the ANN such, as the number of neurons and layers. Subsequently the optimized ANN model is utilized to make predictions about solar radiation levels.

Numerous studies have demonstrated that the ANN-PSO model outperforms ANN models and other machine learning approaches in prediction daily global solar radiation. This superiority can be attributed to how the PSO algorithm aids in identifying parameters for the ANN resulting in a precise model. The effectiveness of the ANN-PSO model has been proven through its application in regions worldwide including South Algeria, the United States and China. These studies highlight that the ANN-PSO model is a tool for forecasting global solar radiation levels. Moreover, this innovative approach has potential to revolutionize radiation prediction by enhancing accuracy, robustness and efficiency. It can greatly contribute to improving performance in energy systems and other applications reliant, on forecasts of solar radiation.

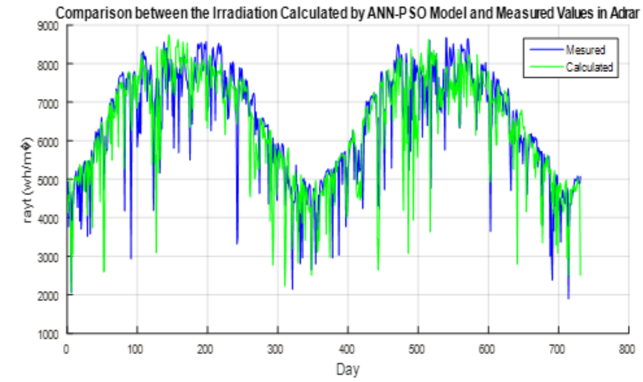

Figure 7. Comparison between the irradiation calculated by ANN-PSO model and measured values in Adrar

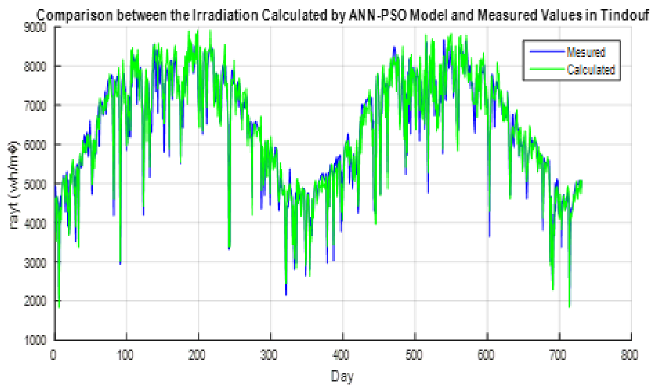

Figure 8. Comparison between the irradiation calculated by ANN-PSO model and measured values in Tindouf

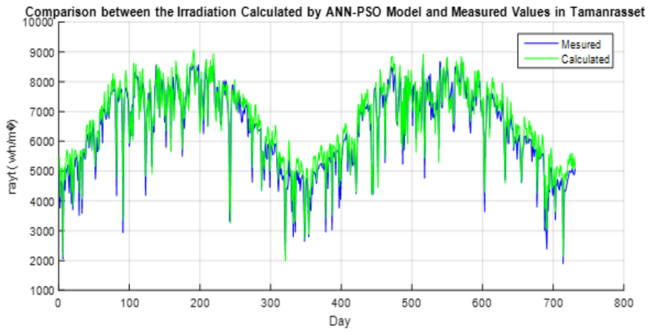

Figure 9. Comparison between the irradiation calculated by ANN-PSO model and measured values in Tamanrasset

Figures 7, 8, and 9 illustrate the comparison, between the irradiation using the ANN-PSO model and the actual measured values in Adrar, Tindouf and Tamanrasset. It is evident, from these figures that the ANN-PSO model effectively predicts solar radiation in these regions with precision.

5.4 ANFIS model

The Adaptive Neuro-Fuzzy Inference System (ANFIS) emerges as an additional machine learning model employed for the prediction of global solar radiation. ANFIS harnesses the synergy of fuzzy logic and neural networks, yielding a model with the prowess to glean insights from data and seamlessly adapt to dynamic conditions. Operating akin to ANN, ANFIS models assimilate input parameters and yield output values for global solar radiation. Renowned for their exceptional accuracy, ANFIS models excel in navigating intricate relationships between input variables and outputs.

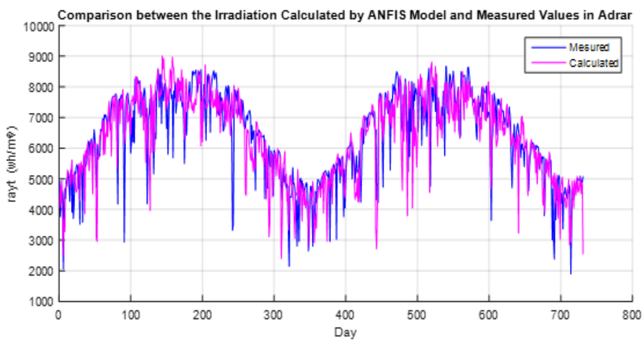

Figure 10. Comparison between the irradiation calculated by ANFIS model and measured values in Adrar

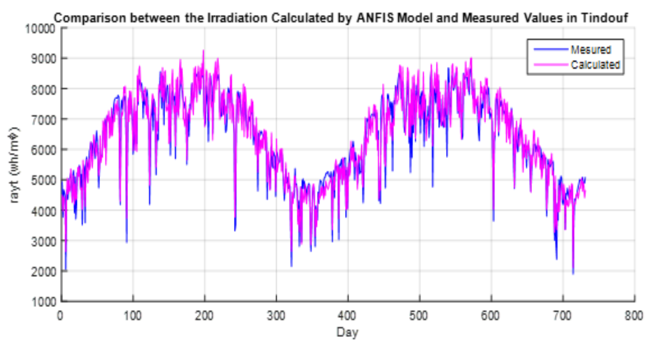

Figure 11. Comparison between the irradiation calculated by ANFIS model and measured values in Tindouf

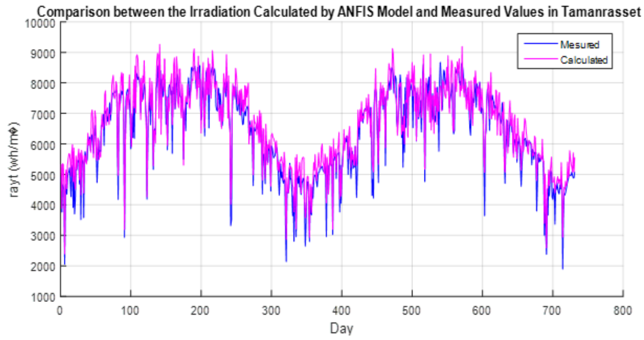

Figure 12. Comparison between the irradiation calculated by ANFIS model and measured values in Tamanarasset

Illustrating this prowess, Figure 10 highlights the comparison between the irradiation calculated by the ANFIS model and measured values in Adrar. Similarly, Figure 11 captures the essence of Tindouf, while Figure 12 corresponds to Tamanrasset. These visual representations effectively underscore the ANFIS model's aptitude in precisely forecasting daily global solar radiation across these distinct regions.

5.5 ANFIS-GA model

The ANFIS-GA model combines two machine learning approaches; adaptive neuro fuzzy inference systems (ANFIS) and genetic algorithms (GA). This hybrid model utilizes the advantages of the two methods to achieve performance. ANFIS models have the ability to learn connections, between inputs and outputs variables while GA are metaheuristic optimization algorithms that help identify the best parameters, for an ANFIS model.

The optimized ANFIS model is subsequently utilized for forecasting solar radiation. Studies have Confirmed that the ANFIS-GA model better then ANFIS models and other machine learning techniques when it comes to predicting global solar radiation. This is primarily due to the GA algorithm's ability to identify parameters for the ANFIS model resulting in enhanced accuracy. Researchers have successfully employed the ANFIS GA model in regions including South Algeria, the United States and China for predicting daily global solar radiation. The outcomes of these studies further support that the utilization of the ANFIS GA model can be relied upon as a tool, for predictions.

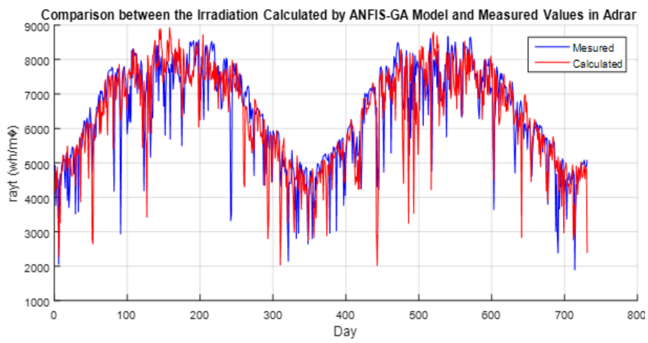

Figure 13. Comparison between the irradiation calculated by ANFIS-GA model and measured values in Adrar

The model called ANFIS-GA has the capacity to bring about a transformation, in the field of radiation prediction. It offers a resilient and effective approach that can enhance the effectiveness of solar energy systems and other applications that rely on accurate solar radiation forecasts. In Figures 13, 14, and 15 we can observe the comparison between the irradiation calculated using the ANFIS-GA model and the actual measured values, in Adrar, Tindouf and Tamanrasset correspondingly.

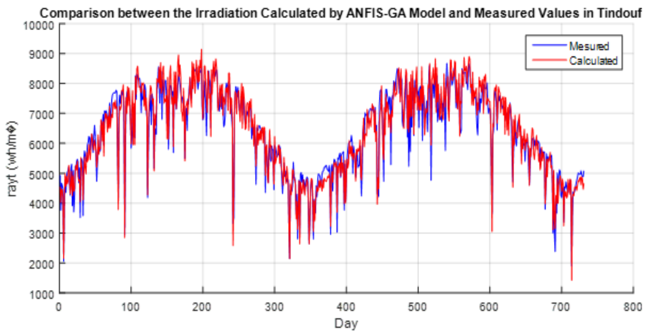

Figure 14. Comparison between the irradiation calculated by ANFIS-GA model and measured values in Tindouf

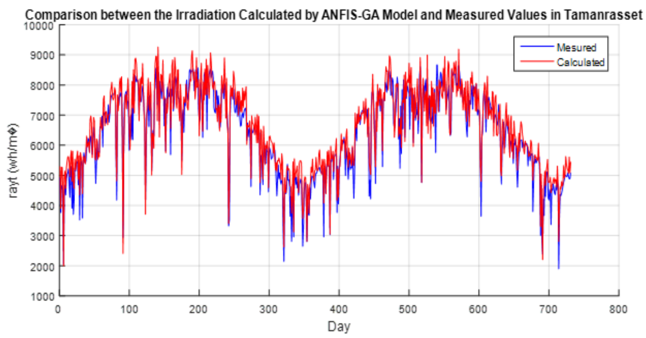

Figure 15. Comparison between the irradiation calculated by ANFIS-GA model and measured values in Tamanrasset

Based on the data presented it is evident that the ANFIS-GA model demonstrates an ability to make forecasts of daily global solar radiation in these particular regions. The ANFIS-GA model holds value as a tool, for energy planning and management offering insights into identifying ideal areas, for solar energy development and maximizing the utilization of existing solar resources.

The ANFIS-GA model demonstrates promising capabilities, in climate modeling. It provides insights into predicting the effects of climate change, on radiation levels allowing us to enhance our preparedness for future energy demands.

5.6 ANFIS-PSO model

The ANFIS-PSO model is a powerful tool for predicting global solar radiation. It combines the strengths of different techniques:

- ANFIS: Adaptive neuro-fuzzy inference system.
- PSO: Particle Swarm Optimization, is a technique employed to determine the bests parameters, for the ANFIS model.

The ANFIS-PSO model has proven to be successful, in forecasting radiation in various areas, including Algeria. The figures 16, 17, and 18 show the comparison between the irradiation calculated by the ANFIS-PSO model and the measured values in Adrar, Tindouf, and Tamanrasset, respectively. Based on the data presented it is evident that the ANFIS PSO model demonstrates an ability to accurately forecast global solar radiation in these three specific regions.

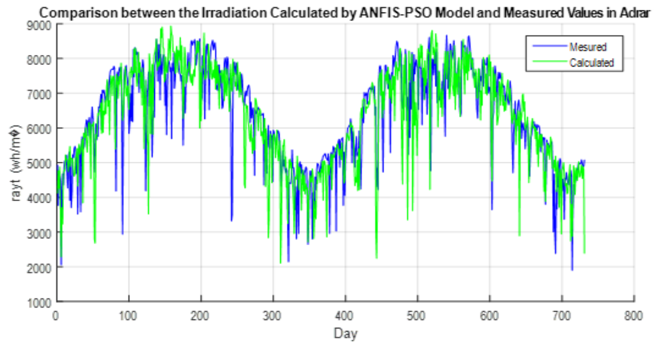

Figure 16. Comparison between the irradiation calculated by ANFIS-PSO model and measured values in Adrar

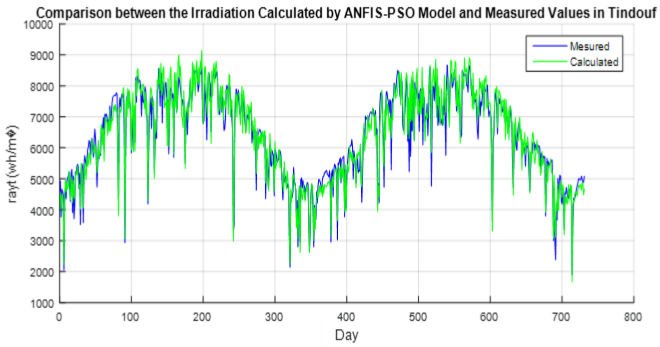

Figure 17. Comparison between the irradiation calculated by ANFIS-PSO model and measured values in Tindouf

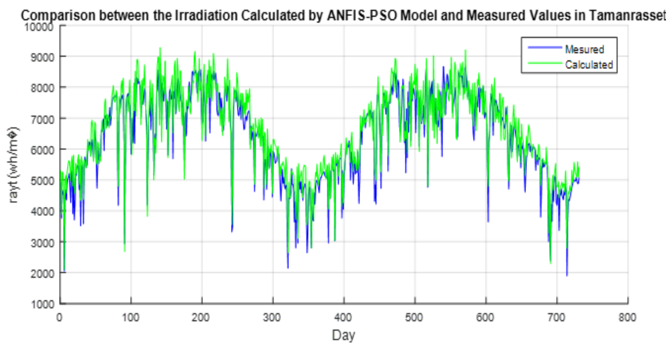

Figure 18. Comparison between the irradiation calculated by ANFIS-PSO model and measured values in Tamanrasset

The ANFIS-PSO model offers advantages compared to models used for predicting solar radiation. It demonstrates accuracy, robustness and efficiency. Additionally, it exhibits generalization capabilities when applied to data. Consequently, this model can effectively forecast radiation in regions where it hasn't undergone specific training.

The ANFIS-PSO model proves to be a resource, for energy planning and climate modeling. It helps in pinpointing the areas, for energy projects optimizing the usage of current solar resources and predicting how climate change will impact solar radiation levels.

This cutting edge technology, the ANFIS-PSO model holds promise in revolutionizing our ability to forecast radiation.It is a more accurate, robust, and efficient solution than traditional solar radiation prediction models. It has a wide range of applications, from energy planning to climate modeling.

The evaluation metrics, including mean percentage error (MPE), root mean square error (RMSE), and correlation coefficient (R), for all models developed in this study, are summarized in the Table 2. The models developed include ANN-GA, ANN-PSO, ANFIS-GA, and ANFIS-PSO. The results demonstrate that all models have achieved low MPE values, indicating their effectiveness in predicting global solar radiation. Furthermore, the RMSE values were relatively low, indicating the models' accuracy. The correlation coefficient (R) values were high, indicating a strong correlation between the predicted values and the actual measured values. The findings suggest that the developed models, including hybrid models, are reliable for predicting global solar radiation.

Table 2. Statistical scores

	MPE %	RMSE %	R
Adrar			
ANN	0.0114	4.2586	0.9784
ANN-GA	**0.0015**	**3.2554**	**0.9962**
ANN-PSO	0.0021	3.0125	0.9929
ANFIS	0.0578	5.1476	0.8745
ANFIS-GA	0.0478	3.3583	0.9210
ANFIS-PSO	0.0254	3.1025	0.9523
Tindouf			
ANN	0.0158	4.8789	0.9777
ANN-GA	0.0024	3.2541	0.9998
ANN-PSO	**0.0013**	**2.2587**	**0.9999**
ANFIS	0.0041	5.2587	0.9560
ANFIS-GA	0.0458	3.2540	0.9866
ANFIS-PSO	0.0022	3.0128	0.9986
Tamanrasset			
ANN	0.0254	4.8965	0.9785
ANN-GA	0.0052	3.6874	0.9887
ANN-PSO	**0.0016**	**3.5145**	**0.9987**
ANFIS	0.0541	5.8564	0.8425
ANFIS-GA	0.0180	4.2581	0.9536
ANFIS-PSO	0.0041	3.6987	0.9877

The effective model, for the Adrar region is the ANN-GA model, as shown in Figure 4. This model (ANN-GA) Obtained a percentage error (MPE) of 0.0015% and root mean square error (RMSE) of 3.2554% with a good correlation coefficient (R) of 0.9962. These evaluation measures demonstrate that the ANN-GA model accurately predicts radiation, for the Adrar region with good performance.

The ANN-GA model demonstrates precision in predicting solar radiation, in the Adrar region. This is possible due to its ability to grasp the connections between meteorological factors as a temperature, humidity and cloud cover. By leveraging a dataset of data and global solar radiation measurements the ANN-GA model acquires knowledge about these relationships through training. As a result, it becomes adept, at forecasting solar radiation levels.

The ANN-GA model is also capable of adapting to data. This implies that it can make predictions, about solar radiation, in the Adrar region even when the weather conditions differ from those used during model training.

For the Tindouf and Tamanrasset regions, the optimal performing model is the ANN-PSO hybrid model (as depicted in Figures 17 and 18 with remarkable success). Notably, the ANN-PSO model exhibited exceptional predictive capabilities, boasting an impressively low Mean Percentage Error (MPE) of 0.0013%, a Root Mean Square Error (RMSE) of 2.2587%, and an exceptional correlation coefficient (R) value of 0.9999 for Tindouf. Similarly, for Tamanrasset, the ANN-PSO model demonstrated compelling performance metrics, including an MPE of 0.0016%, an RMSE of 3.5145%, and a high R value of 0.9987. These compelling findings unequivocally establish the prowess of the ANN-PSO model in accurately forecasting global solar radiation for these two regions.

In evaluating the performance of the ANFIS, ANFIS-GA, and ANFIS-PSO models across Adrar, Tindouf, and Tamanrasset, distinct patterns emerge. In Adrar, the ANFIS model exhibits a modest MPE of 0.0578, an RMSE of 5.1476, and an R value of 0.8745. In comparison, the ANFIS-GA model demonstrates improved performance with a lower MPE of 0.478, a reduced RMSE of 3.3583, and a higher R value of 0.921. The ANFIS-PSO model achieves even better results, showcasing a minimal MPE of 0.0254, an RMSE of 3.1025, and an impressive R value of 0.9523. Moving to Tindouf, the ANFIS model continues to perform well, displaying a minimal MPE of 0.0041, an RMSE of 5.254, and an R value of 0.956. The ANFIS-GA model in Tindouf outshines its Adrar counterpart, featuring a lower MPE of 0.458, an RMSE of 3.354, and a higher R value of 0.9866. Moreover, the ANFIS-PSO model excels with a minute MPE of 0.0022, an RMSE of 3.0128, and an outstanding R value of 0.9986. Lastly, in Tamanrasset, the ANFIS model maintains competitive performance with a MPE of 0.0541, an RMSE of 5.8564, and an R value of 0.8425. The ANFIS-GA model demonstrates improved accuracy with a lower MPE of 0.018, a reduced RMSE of 4.2581, and a higher R value of 0.9536. The ANFIS-PSO model excels further, displaying exceptional accuracy with a minimal MPE of 0.0041, an RMSE of 3.6987, and a remarkable R value of 0.9877. This nuanced comparison highlights the strengths and weaknesses of each model, offering readers a comprehensive understanding of their relative performance in diverse geographical contexts.

The ANN-PSO model exhibits precision, in forecasting solar radiation in both the Tindouf and Tamanrasset regions. This accuracy stems from its ability to identify the parameters for the ANN model. Employing a particle swarm optimization algorithm, the ANN-PSO model efficiently determines these parameters. The particle swarm optimization algorithm, an approach is commonly employed to locate the effective solution, for a given problem.

The ANN-PSO model is also capable of adapting to data. This implies that it can be utilized for forecasting radiation in the Tindouf and Tamanrasset regions even when the meteorological conditions differ from the ones used during model training.

The results of this study suggest that both the ANN-GA model and the ANN-PSO model are effective, in predicting radiation levels in Algeria. The Adrar region particularly benefits from the accuracy of the ANN-GA model while the Tindouf and Tamanrasset regions see results with the ANN-PSO model. These models offer insights, for developing, designing and optimizing energy systems in these regions.

6. CONCLUSIONS

In this research we Evaluated four models (ANN-GA, ANN-PSO, ANFIS-GA and ANFIS-PSO) to predict the global solar radiation, in three different regions of Algeria. The outcomes demonstrated that all of these models performed well displaying MPE and RMSE values while exhibiting correlation coefficient values.

In the region of Adrar we found that the ANN-GA model demonstrated the performance yielding an MPE of 0.0015, an RMSE of 3.2554 and an R value of 0.9962. However, when it came to Tindouf and Tamanrasset the ANN-PSO model outperformed others with an MPE of 0.0013, an RMSE of 2.2587 and an R value of 0.9999; as an MPE of 0.0016 an RMSE of 3.5145 and an R value of 0.9987 respectively.

The findings, as a whole indicate that when artificial intelligence models like ANN and ANFIS are integrated with optimization algorithms such as GA and PSO they demonstrate capabilities for global solar radiation. These models hold potential for application, in the design and planning of energy systems as well as enhancing the efficiency of current systems.

The recommendations for future research suggest incorporating additional meteorological factors, such as cloud cover into the models to enhance precision by capturing more comprehensive influences on solar radiation patterns. Furthermore, it would be worth considering the exploration of different optimization algorithms, from algorithms (GA) and particle swarm optimization (PSO). Algorithms, like evolution or simulated annealing could offer insights into enhancing parameter tuning for hybrid models. A comparative study of these algorithms may guide researchers in selecting the most effective optimization approach for refining the accuracy and generalization of solar radiation prediction models.

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