

## Applications of RNN, LSTM, and GRU in Solar Irradiance Prediction for Photovoltaic Systems

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### INTRODUCTION & AIM

The importance of solar radiation in the renewable energy landscape demands rigorous data analysis protocols, making Natal, in northeastern Brazil, a strategic location due to its high annual insolation and tropical climate. This study proposes the use of Deep Learning architectures, such as RNN, LSTM, and GRU, which are recognized for their effectiveness in modeling temporal dependencies in multivariate time series. By conducting a detailed comparative analysis under these conditions, this research contributes to the literature and establishes a methodological framework to optimize energy resource forecasting through complex nonlinear models.

### METHOD

The methodology was structured based on data preprocessing, which involved handling missing values through spline interpolation and normalization via z-score standardization. For neural network training, the time series was segmented into 10-sample windows and partitioned into training (90%) and test (10%) sets, strictly maintaining chronological order to preserve data integrity. As detailed in the flowchart in Fig. 1, the predictive modeling employed deep recurrent neural networks implemented in Python, utilizing the TensorFlow and Keras frameworks, along with support from the NumPy, Pandas, and Scikit-learn libraries.

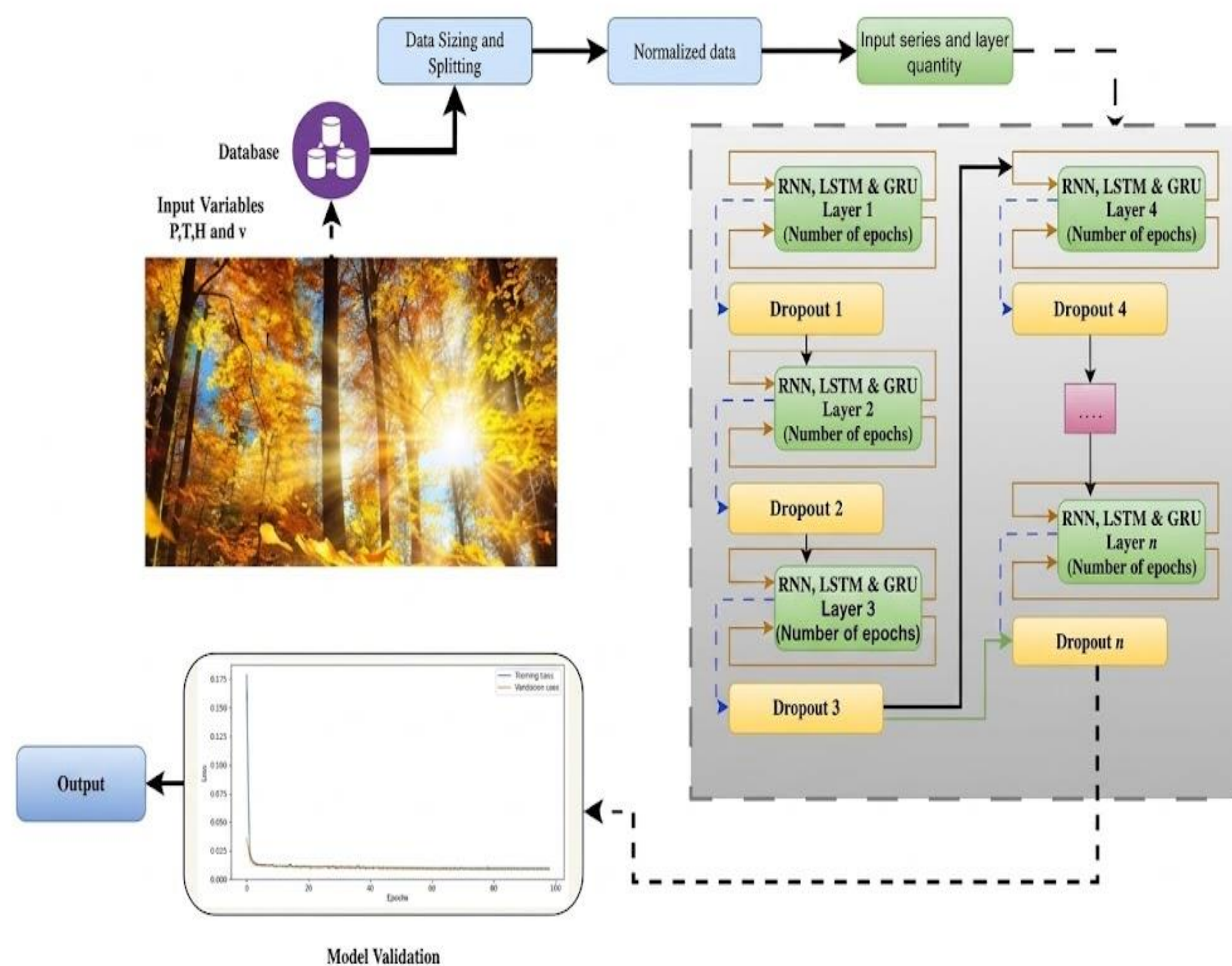


Fig. 1. Predictive Time Series Modeling Methodology using Deep Recurrent Neural Networks and Validation.

### RESULTS & DISCUSSION

Model validation was performed by testing the architectures on a meteorological dataset distinct from the one used for training to verify their generalization capability on unseen data, as shown in Fig 2. This process is fundamental to evaluating the model's adaptability to unknown information. Details regarding experimental parameters include variations in batch size (16, 32, 64) and the number of epochs (50, 100). Furthermore, the four-layer architecture consisted of 256, 128, 64, and 1 neuron in the output layer, utilizing ReLU and linear activation functions, respectively

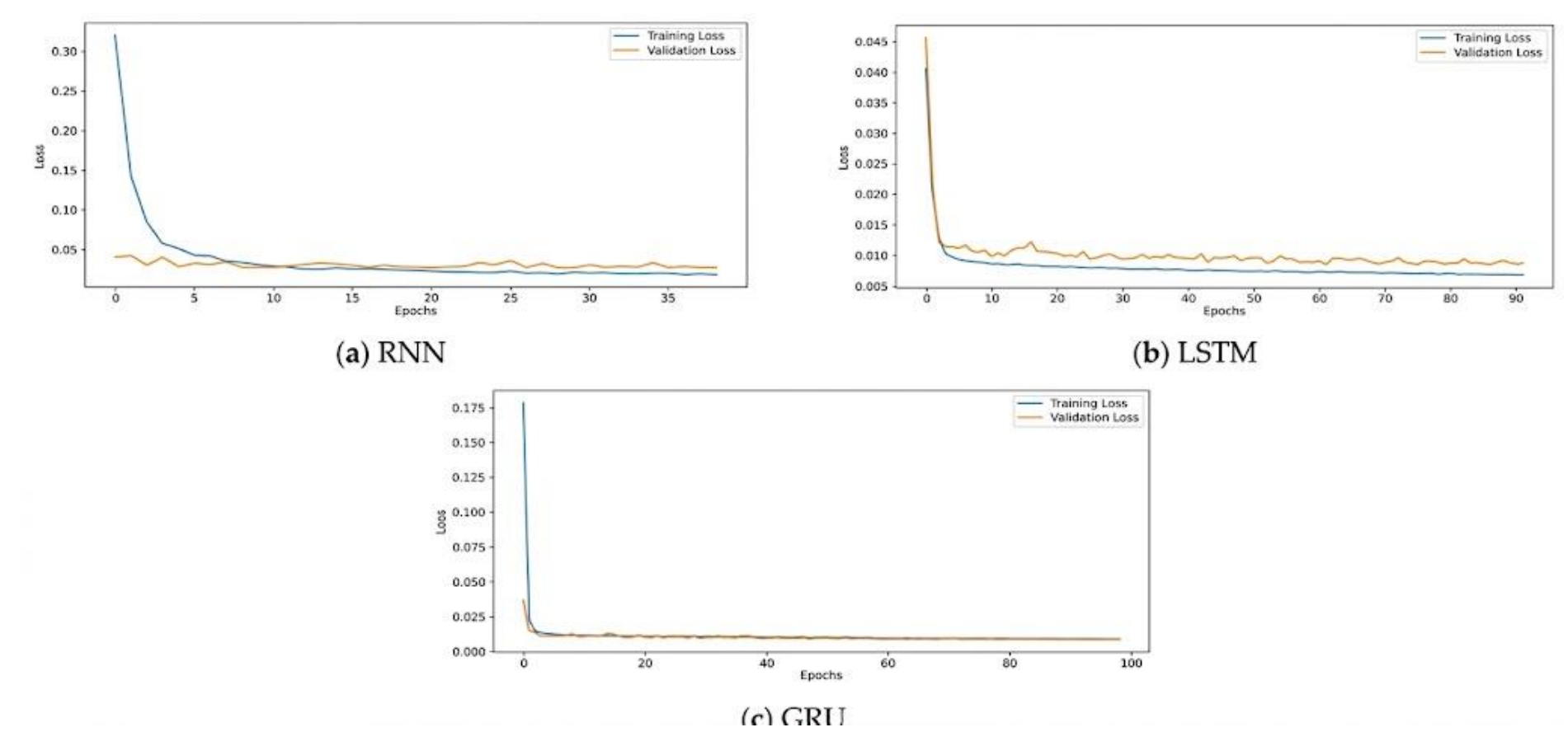


Figure 2: Comparison of the results obtained during the model training with the three techniques: a) RNN, b) LSTM, and c) GRU.

The performance evaluation for solar radiation forecasting, utilizing RNN, LSTM, and GRU architectures, demonstrated the effectiveness of all models in capturing the variability of this parameter, as shown in Table 1. Models such as RNN 3, LSTM 3, GRU 2, and GRU 3 consistently achieved an  $R^2$  of 0.94, highlighting the importance of hyperparameter tuning evidenced by the 4.44%  $R^2$  gain of the LSTM 3 model compared to LSTM 2.

Table 1. Performance of Dierent Models.

Method	Batch_size	Epochs	RMSE	MAE	Train Loss	Train MAE	Validation Loss	Validation MAE	$R^2$
RNN_1	16	50	296.19	216.26	0.0095	0.0706	0.0052	0.0503	0.89
RNN_2	32	50	294.88	212.29	0.0098	0.0713	0.0053	0.0518	0.92
RNN_3	64	100	291.92	208.47	0.0098	0.0719	0.0052	0.0504	0.94
LSTM_1	16	50	333.83	252.59	0.0100	0.0711	0.0051	0.0502	0.92
LSTM_2	32	50	332.49	257.07	0.0096	0.0697	0.0053	0.0491	0.90
LSTM_3	64	100	296.14	213.44	0.0101	0.0711	0.0100	0.0521	0.94
GRU_1	16	50	296.42	214.93	0.0134	0.0847	0.0160	0.0920	0.93
GRU_2	32	50	297.24	216.71	0.0099	0.0706	0.0053	0.0495	0.94
GRU_3	64	100	295.69	211.90	0.0101	0.0711	0.0053	0.0498	0.94

### CONCLUSION

The LSTM model outperformed the RNN in terms of robustness and stability when handling noise and complex climatic relationships in solar forecasting. The GRU architecture exhibited limitations in capturing abrupt peaks, while the RNN failed to integrate exogenous variables, yielding excessively smoothed predictions.

### FUTURE WORK / REFERENCES

Integrate Transformer or attention mechanisms into the LSTM network to enable the model to focus on periods of high variability.