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Forecasting Equity Trends of India's Renewable Energy Sector Using Artificial Neural Networks

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Abstract

India has emerged as a prominent advocate for climate-related initiatives on a global scale, consistently maintaining a respected presence in international forums and intergovernmental climate events. In conjunction with sustainable practices and the Sustainable Development Goals (SDGs), the pursuit of a cleaner environment not only yields tangible benefits but also serves as a catalyst for advancements in healthcare, urban governance, finance, investment management, and the circular economy. In this context, this study investigates the stock prices of ten Indian companies involved in green renewable energy, utilizing the Artificial Neural Network (ANN) model to forecast these prices for the period 2020-2024.A comprehensive analysis of macroeconomic variables has been conducted, highlighting their impacts and the associated volatility. The study concludes that the COVID-19 pandemic exerted a differential impact on Indian green companies, and the Efficient Market Hypothesis has been evaluated in this context. Furthermore, it is concluded that while the ANN model is effective, it exhibits certain limitations in predicting the volatility of high-range stocks and the unaccounted volatile movements of stocks due to uncontrolled macroeconomic variables.

Keywords: ANN, Forecasting, Green Finance, Renewable Energy Stocks, Sustainable Investing.

1. Introduction

The world is getting connected daily due to energy requirements. Energy is essential as it is the most basic need for all human activities including mobility and communication.(Edenhofer et al., 2011) More than 1.4 Billion people lack basic electricity and 85% are in rural areas and they use biomass for energy needs and this needs to increase by almost 30% by 2030.(Kaygusuz, 2012) Indian Wind Energy has grown at a Compounded Annual Growth Rate (CAGR) of about 15% and out of that Wind Energy has grown 8%.(Kumar et al., 2022) With great awareness and investors' readiness, India still faces some barriers in the implementation of Solar Energy infrastructure due to policies at the government level, land availability, technical issues, technical barriers, etc., in such scenarios awareness, research and development, and Off-grid Solar infrastructure seems to be an apt solution.(Rathore & Panwar, 2022) The investment needed in the Indian renewable energy sector during the period 2022-27 is INR 6.1 Trillion, this provides a great opportunity for investors. (Shrimali, 2021) With increase in consumption of green energy there is less environmental degradation (Alvarado et al., 2019) (Li et al., 2024)along with an increased in economic potential (Dogan et al., 2020) (Zafar et al., 2019) . With the enhancement of green energy there is an increase in the supply of energy and sustainable practices.(Xia et al., 2024) India has been committed to its commitments towards climate change and transitioning to a cleaner fuel source, which is very much evident from the government's focus and policy readiness for green energy along with various schemes and subsidies it has been approving for clean energy generation at individual or commercial levels.

In such given circumstances, the importance of green energy companies cannot be undermined especially after the Global South debate, the vulnerability of developing nations and the finance demanded from the earlier industrialized nations like the USA, UK, Germany, France, etc. But geopolitically speaking, India has been a champion of climate change-related activism and a respectfully heard voice of the Global South. In such circumstances, it is very clear that it has been advanced in clean energy practices in comparison to its peers. A lot has been studied on sustainability and has been debated on each SDG, but one should also not ignore the fact that with such a cordial environment for the green energy sector, there exists a greater opportunity from the investment point of view. In such case this paper studies 10 green renewable energy companies chosen based on various criteria and forecast their prices using Artificial Neural Network (ANN) Machine Learning (ML) algorithm. Green energy companies considered here are renewable energy companies whose operations are based on energy sources that are abundant and naturally replenishable and have no or very little carbon emissions. Most of the green energy companies became public around 2020 and has been performing at par and in most cases better than the traditional energy stock due to their resilience and nature of operations compatible with financial and investment landscape of our country.

2. Review of Literature

India has set a goal of 450 GW of green energy capacity by 2030 for its sustainable development commitments.(Lal S R et al., 2022) Securing energy and managing its impact on climate change are two different but important aspects.(Abbasi & Abbasi, 2011) Dominance of fossil fuel based energy and the ever-growing population increased the demand along with higher CO_2 emissions leading to climate change.(Asumadu-Sarkodie & Owusu, 2016) Renewable energy is replenishable easily and naturally, they cannot be depleted and includes bioenergy, hydropower, tidal, solar, wind etc. (Owusu & Asumadu-Sarkodie, 2016) By 2040 renewable energy is estimated to account for almost 49% of India's energy needs, due to increasing battery demand and climate related commitments towards mitigating climate change. (Singh et al., 2023) COVID-19 affected every sector in some ways. But green energy sector was unique in this case, as energy demand was less during the pandemic, traditional energy sector faced a downtrend. However, in the case of green energy, the industry was sluggish due to a lack of capital investment, supply chain disruptions, etc. (Olabi et al., 2022) In the case of India, the renewable sector was at a bright spot due to mild effect during the pandemic along with the government liquidity injection post-crisis and the increasing of renewable share in the overall energy mix.(Deshwal et al., 2021) The sector is maturing and financing through Private Equity is a sought-after option currently. (Gandhi et al., 2025) Due to the pandemic, huge delays and infrastructural setbacks have been witnessed but the investors are ready to invest and the sector is booming at a rapid scale. The government needs to intervene in a specific sectoral manner. (Shekhar et al., 2021) Indian renewable energy is a booming yet nascent sector and a comprehensive governance and policy level intervention and regulation is expected from the government for trade, operations and overall sectoral growth.(Raihan et al., 2024) As per the new model developed in the study to evaluate the competitiveness among nations in the renewable energy sector, it was found that the US has strong competitiveness and markets of China and India have grown rapidly with few key differences. (Shuai et al., 2022) Renewable Energy sector is less volatile, risky, and more lucrative than the traditional fossil fuel sector.(Shrimali, 2021) The Renewable energy companies of Islamic Stock market Turkey, India, and Malaysia are not much affected by the Russia-Ukraine War.(Ghallabi et al., 2024) NGBoost has outperformed other models in predicting clean energy companies and ESG markets in USA and India have stronger potential for prediction of clean stocks than other countries like Australia.(Ghallabi et al., 2025) Many studies have argued on the relationship of clean energy stocks and financial assets driven by increase in clean energy stock and it acting as an independent investment avenue.(Ferrer et al., 2018) Wind energy has reduced around 14% of emissions in Ireland.(Forbes & Zampelli, 2019) Green energy plays an important role in sustainability and hence it becomes an important focal point for research.(Ma et al., 2025) Climate change poses lots of challenges across the fields including physical vulnerabilities and has a huge potential to disrupt the investment landscape, in such given circumstances, it becomes imperative to have a green-hedged portfolio.(Alekseev et al., n.d.) A Study using copula model has suggested that green investments are an excellent hedge for investments.(Liu & Hamori, 2020) Applying quantitative analysis in investment have become very common and in such scenario, Artificial Neural network (ANN) is effective for general purpose, pattern recognition and clustering time series with high accuracy. (Khashei & Bijari, 2010) Neural network forecasting predicts with great accuracy especially when compared with Fourier transformations and has scope for customization in multiple steps.(Atiya et al., 1999) Based on evaluation matrices, in the case of stock prediction ARIMA has better forecasting when compared to LSTM.(Albeladi et al., n.d.) LSTM models could be used over a wide spectrum including healthcare, finance, weather, energy, environment , etc but hybrid models are able to forecast very well. ReLU activation function is very common in good forecasts.(Ahmed et al., 2022)

3. Research Gap

Extensive research has been conducted on sustainability and the Sustainable Development Goals (SDGs), establishing it as a distinct field of study. However, the implementation of sustainability practices and their components exerts both positive and negative influences on the financial and investment sectors. While some investigations have explored Environmental, Social, and Governance (ESG) factors and their impact on corporate financial performance, or have forecasted sustainability indices such as BSE CARBONEX and NSE GREENEX, green and renewable energy companies are intrinsic drivers of the sustainable landscape. These companies have garnered attention from policymakers and investors for various reasons. Notably, the world is experiencing unprecedented global challenges, including the COVID-19 pandemic and geopolitical tensions, yet there is a paucity of research examining the renewable energy sector within the Indian investment context. This gap is also evident on a global scale. It is noteworthy that many renewable energy companies went public around 2020, further underscoring the need to study green companies from a forecasting perspective.

4. Scope of the Study

This study represents a pioneering effort in forecasting the performance of Indian Green Energy companies utilizing Artificial Neural Network (ANN) Machine Learning Architecture. Specifically, the research examines 10 Green Energy Companies over a period of five years, selected based on criteria such as market share and data availability. The Long-Short Term Memory (LSTM) architecture was employed due to its demonstrated high accuracy in similar studies. In addition to forecasting, the study provides an in-depth analysis of price movements, taking into account macroeconomic factors. The evaluation metrics, including RMSE, MAPE, MSE, and MAE, indicate promising results. This research serves as a foundational study in forecasting stock prices within the Green Energy sector and is anticipated to inform future studies in this domain, both in India and globally, given the paucity of research employing ANN and other time series forecasting models.

5. Limitations of the Study

While this study employs one of the most promising machine learning architectures for forecasting and addresses a significant gap in the field, several notable limitations warrant discussion. These limitations include the following:

- The study examines various aspects of price movement and forecasting; however, specific macroeconomic variables influencing these movements have neither been identified nor analyzed, although their impact on price movement is discussed.
- There is a scarcity of prior research on forecasting related to green energies, resulting in a limited literature review on green companies, particularly those in the Indian green energy sector.
- The application of ANN-based stock price forecasting is still in its early stages, which restricts the selection of an appropriate model and architecture. Consequently, the study is limited to using LSTM for simplicity and ease of handling.

6. Research Methodology

6.1. Data Collection and Preprocessing

6.1.1. Data Sources

Data pertaining to ten companies has been obtained from Investing.com, with each company contributing approximately 1,370 entries. The dataset spans the period from June 6, 2019, to December 12, 2024. Notably, no supplementary data has been employed in the analysis.

6.1.1. Data Cleaning

Missing data was handled using forward filling (fillna(method='ffill')) i.e. used in code for the Prices used for the prediction. Some efforts were also made to address the outliers in the data.

6.1.2. Feature Engineering

Out of various features like High, Low, Open, Volume, Price, the Price feature was used for analysis and prediction. However, no Sentiment analysis feature has been used utilized.

6.1.3. Data Transformation

The Price was normalized using MinMaxScaler to convert the price values to a range between 0 and 1 to prevent features with larger values from dominating the training. Hence, accuracy of prediction is enhanced.

6.2. ANN Model Development

6.2.1. Model Selection

LSTM has been chosen as the ANN Model for time series forecasting due to its accuracy in sequential data and capturing temporal variations.

6.2.2. Network Architecture

The model has two LSTM layers of 50 units each and a Dense output layer. The output layer uses linear activation function suitable for regression-related analysis due to its high accuracy.

6.2.3. Training Process

The code uses Adam optimizer and Mean Square Error (MSE) loss function. The batch size is 32 with 100 epochs.

6.2.4. Software and Libraries

Python software has been used through Jupyter Notebook with IPython kernel. Libraries utilized include TensorFlow, Keras, Pandas, NumPy, and Matplotlib.

6.3. Evaluation Matrices

The study employs Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Mean Square Error (MSE) for evaluating the performance of the model.

From the above we have received the segmented whereabouts about the model and tools that have been utilized let's look at each of them in an integrated and detailed manner. Firstly, the libraries were imported for data manipulation, machine learning and visualization. Pandas were used to handle data in tabular form, in order to use the excel based data easily. NumPy was used to perform the numerical-mathematical operations and array manipulation. MinMaxScaler from scikit-learn was used to normalize the data. TensorFlow and Keras API were used to build and train the LSTM model for time series forecasting. Matplotlib was used to visualize the model and its performance and results.

Then data was loaded from the specific file path in the form of excel workbook in such a format that manipulation of arrays was possible. Out of various columns the price column was loaded for each company data. After loading missing values were filled based upon most recent values. Then the data is normalized using MinMaxScaler into values 0 and 1. Now, the data set is prepared in the format of input and output pair and NumPy x and y arrays. 10 variables are used to predict the output and x values are converted to 3D arrays. Using TensorFlow and Keras, linear tacked sequential model is formed. First layer is of 50 units configured to return the data to next layer, following dropout layer randomly drops few units of data to prevent overfitting. Finally a dense layer with single unit is used to predict output.

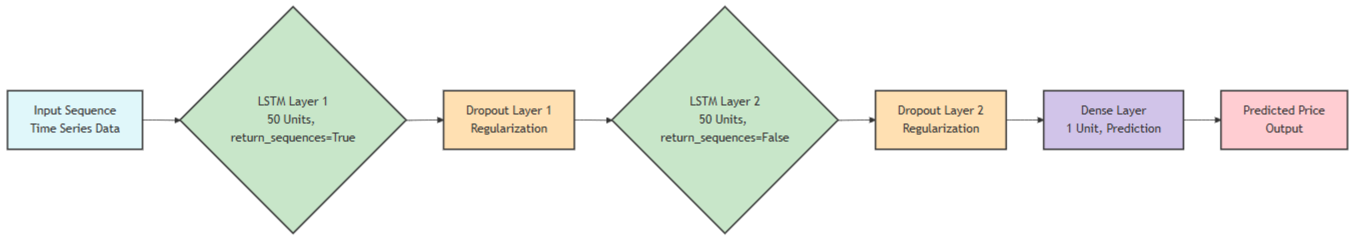

Figure 1. Visual representation of the ANN Model.
Source: Authors' own formulation using AI.

Then the model is compiled using Adam optimizer and Mean Square Error (MSE) loss function. These are done for optimization and management of difference of actual and predicted values. The next step is training the model. The x input features and y target values is trained for 100 epochs meaning, it will go through entire dataset 100 times to understand the underlying patterns. The batch size is of 32, meaning the weights will be adjusted every 32 entries processed in a time.

Now, based on input data x, predictions are made, generating predicted values. So the predicted values are in normalized form, so the inverse transform method of the scaler is applied to convert to the original price scale. This makes direct contrast with original prices easier. After getting the predicted values, actual and predicted values are visualized using Matplotlib, and plot is displayed. Further, to evaluate the effectiveness of the model necessary functions are imported from sklearn.metrics and Mean Square Error (MSE), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) is computed for each prediction. MSE and RMSE measure average square differences while MAE quantifies average absolute error. MAPE expresses error as in percentage terms.

7. Analysis, Results and Discussion

Prior to engaging in the primary analysis, it is imperative to examine and monitor the price movements of the ten selected companies.

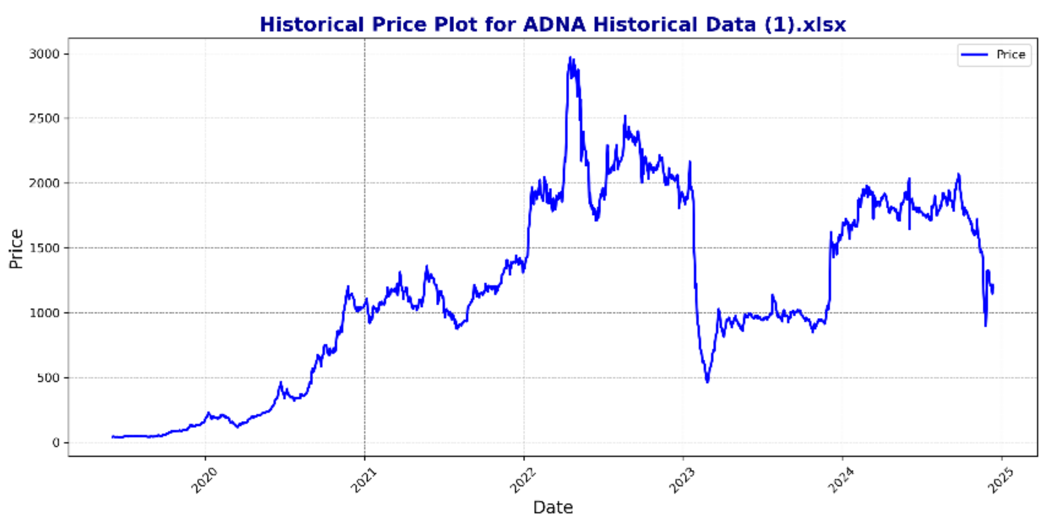

Figure 2. Stock Price movement of Adani Green Energy.
Source: Authors' formulation using Python Software.

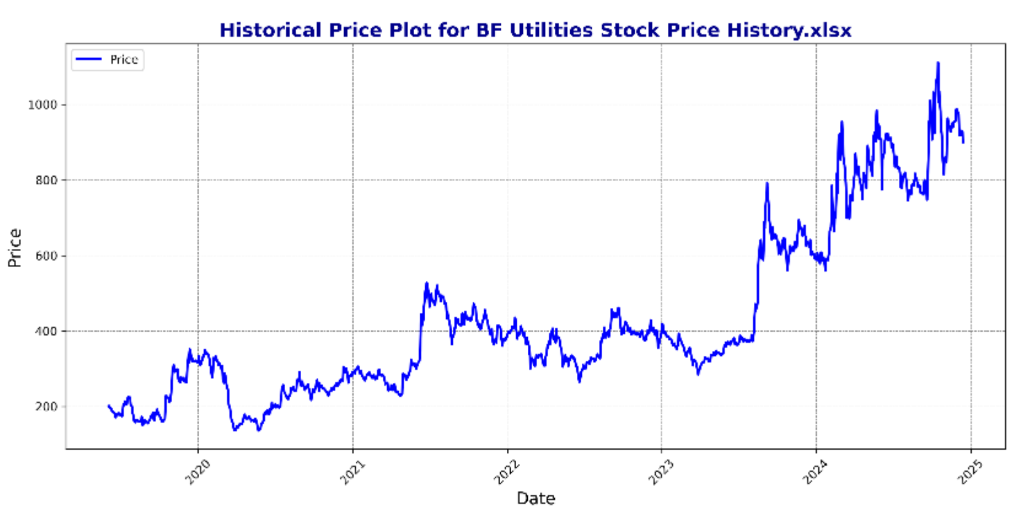

Figure 3. Stock Price movement of BF Utilities Ltd.
Source: Authors' formulation using Python Software.

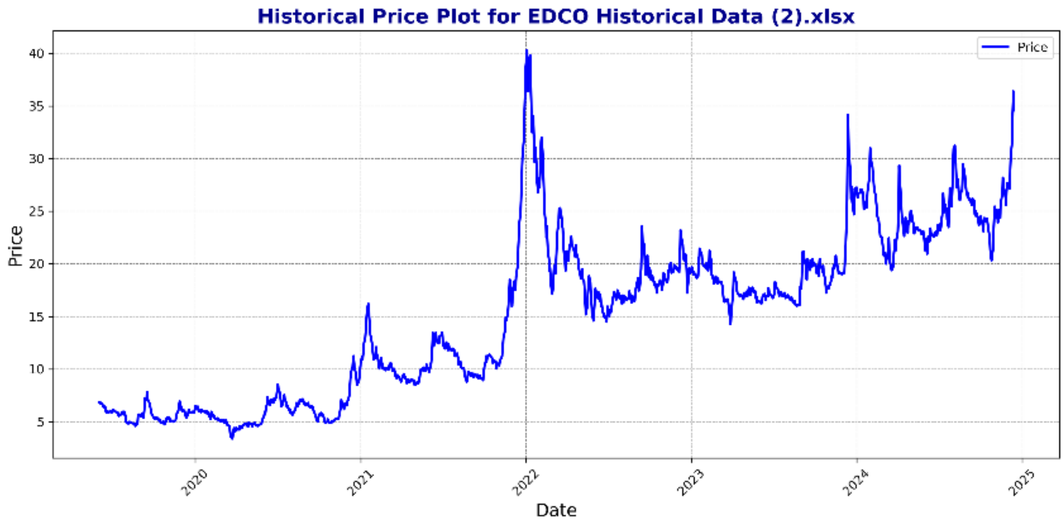

Figure 4. Stock Price movement of Energy Development Company Ltd.
Source: Authors' formulation using Python Software.

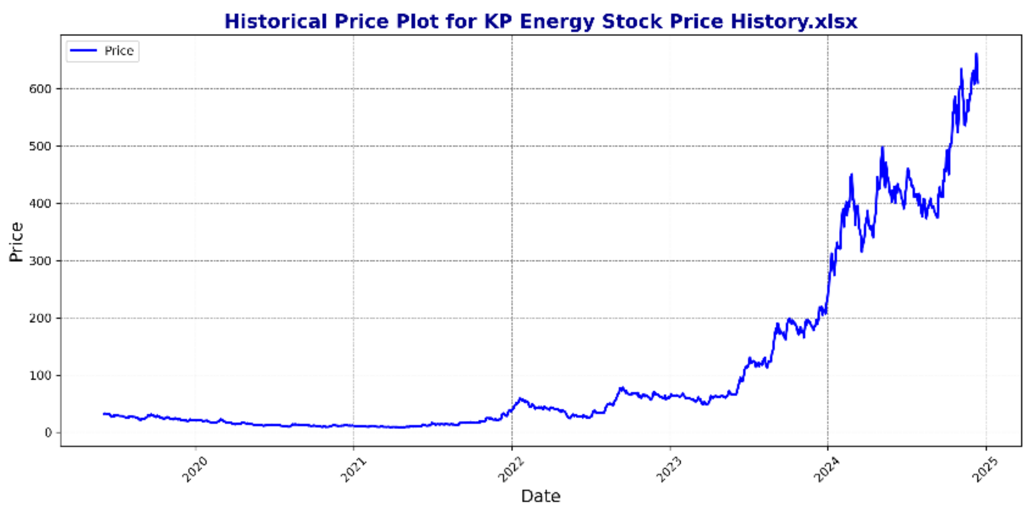

Figure 5. Stock price movement of KP Energy Ltd.
Source: Authors' formulation using Python Software.

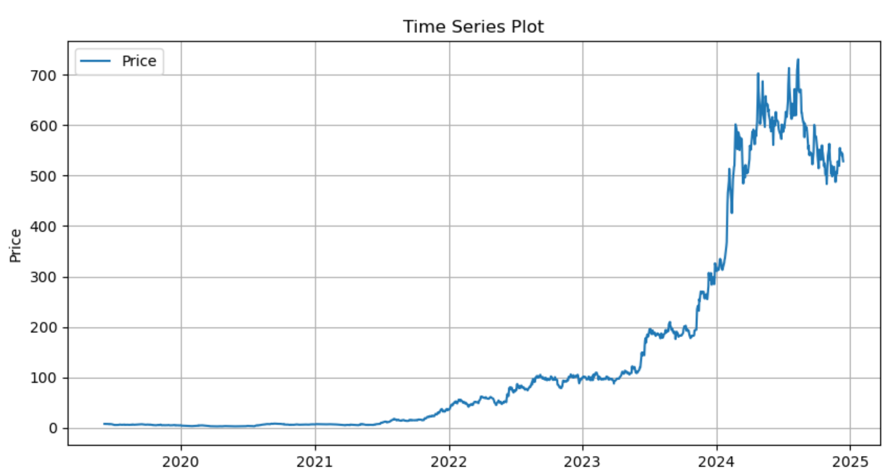

Figure 6. Stock price movement of KPI Green Energy Ltd.
Source: Authors' formulation using Python Software.

Figure 7. Stock price movement of Orient Green Power Company Ltd.
Source: Authors' formulation using Python software.

Figure 8. Stock price movement of SJVN Ltd.
Source: Authors' formulation using Python Software.

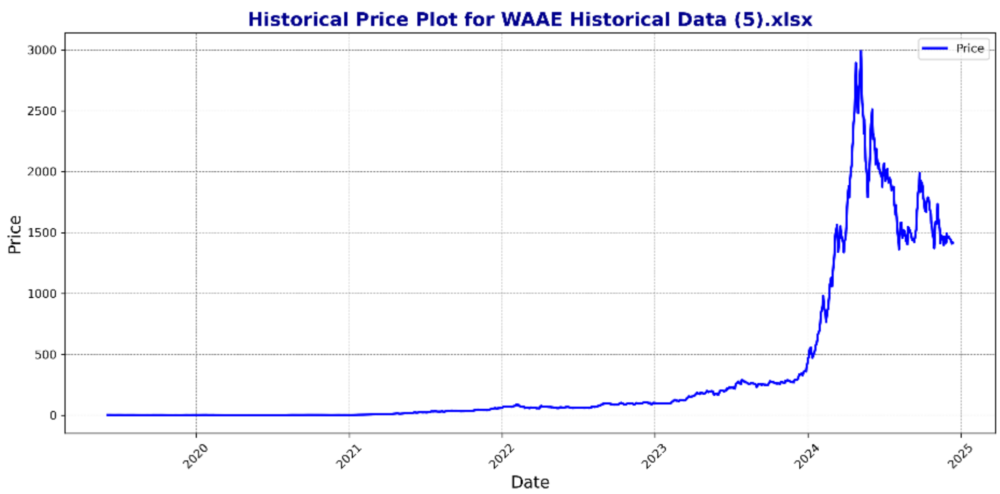

Figure 9. Stock price movement of Waaree Renewable Technologies Ltd.
Source: Authors' formulation using Python Software.

Figure 10. Stock price movement of WAA Solar Ltd.
Source: Authors' formulation using Python Software.

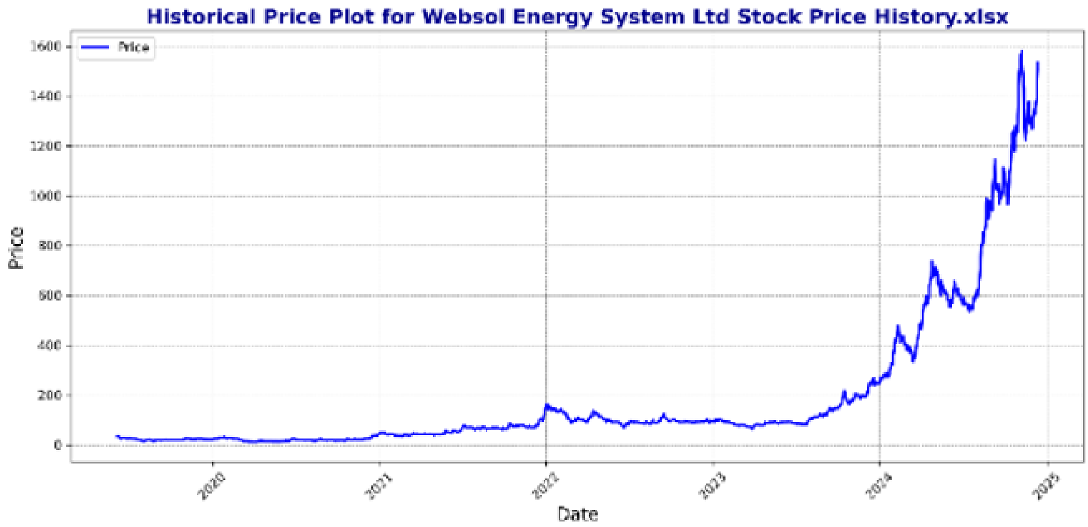

Figure 11. Stock Price movement of Websol Energy System Ltd.
Source: Authors' formulation using Python Software.

From Figures 2 to 11, generalizations can be drawn regarding the price movements of the ten green energy stocks analyzed in this study. This analysis seeks to enhance the understanding of the influence exerted by market dynamics and other macroeconomic variables on individual stocks. Notably, the COVID-19 pandemic appears to have exerted minimal or no adverse impact on stock prices. In contrast, stock prices have either appreciated or remained stable during this period. From a comprehensive perspective, most stocks exhibit some degree of seasonal trends, with exceptions such as KP Energy, KPI Green Energy, SJVN, Waaree, and Websol. These exceptions, however, demonstrate seasonality in the latter part of the plots, following the first quarter of 2024. Overall, the stocks of all companies considered exhibit similar movement patterns. Nevertheless, it is crucial to examine each company individually to discuss its specific nuances in greater detail.

An examination of the stock movement of Adani Green Energy (Figure 2) from 2019 to early 2021 reveals a consistent increase in stock prices. This trend can be attributed to the growing global awareness of green investments and an expansionary monetary and fiscal outlook, which emerged as a response to the economic slowdown during the COVID-19 pandemic, resulting in increased liquidity for investors. The parabolic growth observed around 2022 may be ascribed to a speculative bubble, low interest rates, and the rising trend of ESG (Environmental, Social, and Governance) sensitive investments. In 2023, a specific event related to Adani, triggered by the Hindenburg report, led to a decline in stock prices, likely due to significant sell-offs and market corrections. By the end of 2024, a rapid recovery is evident, potentially due to self-correction in the market, Adani regaining investor confidence, or related macroeconomic dynamics. However, in the last two months of 2024 and early 2025, a decline and unusual volatility are observed, which can be attributed to high interest rates, market corrections, and the cyclical decline in the attractiveness of Adani Green Energy stock.

B.F. Utilities Ltd.'s (Figure 3) price movement graph from 2020 to December 2025 shows a price increase from INR 200 to approximately INR 1000 on average. The movement demonstrates an upward trend accompanied by recurrent volatility, with a notable surge post 2023. In the initial phase from 2020 to 2021, fluctuations were observed around INR 200 to 300, likely due to the impact of the COVID-19 pandemic and associated events that dampened investment. From 2021 onwards, an upward trend became apparent, possibly attributable to market recovery from the pandemic and the increased focus of investors and the government on green companies. A significant rise was observed late in 2022, reaching a value of approximately INR 600, potentially due to heightened green commitments during this period, in addition to the COP 26 agreements. Post 2023, exponential growth was recorded, with the value reaching around INR 1000 by December 2024. Probable reasons for this growth include the rapid expansion of green energy projects, increased investments focused on environmental, social, and governance (ESG) criteria, and a competitive global energy market during this period.

The analysis of price movements of Energy Development Corporation (Figure 4), spans from 2020 to December 2024, with fluctuations observed between INR 5 and 40. During the period from 2020 to 2021, the price ranged from INR 5 to 10, likely influenced by the COVID-19 pandemic and a downturn in capital-intensive sectors, including green energy. Nevertheless, the company's diversified focus on green energy contributed to the stock's resilience and stability during these turbulent times. In 2022, a sudden increase in price to INR 40 was noted, potentially attributable to the outcomes of COP 26, the government's emphasis on clean energy infrastructure, and market sentiment driven by speculative news. Subsequently, the market corrected itself, stabilizing around INR 15 to 25 by 2023 and 2024, albeit with periodic volatility. This improvement can be ascribed to enhanced financial conditions, investor sentiment, and company-specific developments during this period, which influenced the price trajectory and volatility.

In the case of K.P. Energy Limited (Figure 5), it is observed that the stock price initially started at a relatively low level but eventually escalated to INR 600 by the conclusion of 2024. The price trajectory remained relatively stable until 2022, after which exponential growth accompanied by volatility was evident from 2023 onwards. Until late 2022, the price increased only to INR 40, attributable to limited growth factors such as awareness, infrastructure, and investment. This period also coincided with the COVID-19 pandemic. Post-2022, the exponential increase can be attributed to heightened ESG-related investment, infrastructure development, and improved market sentiment, supported by the company's strong fundamentals during that period. The observed volatility can be interpreted as the market's periodic self-correction mechanism.

KPI Green Energy (Figure 6) exhibits a trajectory similar to that of KP Energy Ltd. Initially, the company started with a relatively low valuation, which by the end of 2024, had remarkably increased to INR 700. Up until 2022, the price movement remained subdued, approximately INR 20, likely attributable to the nascent stage of the company, adverse macroeconomic conditions, and negative market sentiment stemming from the COVID-19 pandemic and a delayed market recovery. Post-2022, the company experienced significant growth, driven by an increasing sentiment towards Environmental, Social, and Governance (ESG) investments, robust company fundamentals, and expansionary operations, which collectively fostered positive market sentiment, further bolstered by market corrections. In the subsequent period leading up to December 2024, the price exhibited volatility, fluctuating between INR 500 and 700, influenced by company-specific news, heightened green investments, and favorable market conditions.

Orient Green Energy (Figure 7) experienced limited growth until December 2024 in contrast to KPI Green Energy and KP Energy, reaching a peak value of approximately INR 30. Until 2021, the company's stock prices remained stable at around INR 5, attributed to its efforts to secure its market position and investors' cautiousness regarding the nascent small-scale renewable energy sector. In 2022, the stock prices surged to approximately INR 28, driven by an increased focus on renewable energy, supportive policy measures, market corrections, and significant corporate expansions. However, following 2022, the prices declined to INR 7, influenced by market corrections and negative news speculation. Additionally, profit-taking by investors, prompted by the recent price increases, contributed to this decline. By 2024, the prices stabilized at INR 18-20, supported by improved financial performance, project announcements and executions, and enhanced investor sentiment.

SJVN Limited's (Figure 8) stock price has fluctuated between INR 20 and 160. Until 2022, the price trend exhibited a general upward trajectory with limited volatility. This pattern can be attributed to the overall sluggish market conditions and the relatively low investor interest in the hydropower sector compared to other renewable energy sources. From mid-2022 to late 2023, there was a gradual increase in the stock price, reaching approximately INR 80. This rise is attributed to a renewed focus on hydropower, governmental support, and the expansion and execution of projects. Following 2023, the stock price increased to INR 150, driven by enhanced market sentiment and reactions to positive news events. However, in the latter part of 2024, the prices stabilized and experienced a decline due to market corrections and investors capitalizing on profits from the previous exceptional stock price increases.

Waaree Renewable Technologies Ltd.'s (Figure 9), the stock price reached a peak of INR 3000 in 2023 before undergoing a correction. The stock remained relatively stable until mid-2022, attributable to the company's nascent stage and the concurrent impact of the COVID-19 pandemic, which impeded typical growth patterns due to supply chain disruptions and operational challenges. By late 2022 and early 2023, the stock price surpassed INR 500, eventually reaching INR 3000 in 2023. This increase can be attributed to a heightened focus on renewable energy by all stakeholders, coupled with the undertaking of significant projects. Subsequently, the substantial rise in stock price stabilized by late 2023, settling between INR 1000 and INR 1500, as a result of market efficiency, profit-taking by investors, and news-related shocks.

WAA Solar Limited (Figure 10) experienced a gradual increase in its valuation over a period of five years, rising from INR 10 to INR 250. This progression is characterized by steady growth until the end of 2023, followed by a surge in early 2024, and a subsequent correction by the end of 2024. The initial slow growth of WAA Solar can be attributed to factors similar to those affecting previously discussed companies. The peak in valuation is ascribed to an efficient market and the effective execution of projects. However, the decline in the final phase is uniquely attributed to overvaluation, distinguishing it from other cases previously examined.

Websol Energy System Limited's (Figure 11), price reached a peak of INR 1600. Prices remained stagnant until 2022, after which they experienced a gradual increase from late 2022 to 2024, followed by an exponential rise until late 2024. This trajectory can be succinctly summarized as being influenced by early-stage barriers, the impact of COVID-19, and low market sentiment until 2022. Subsequently, there was improved support from macroeconomic factors and investors until 2024, alongside increased capacity, government incentives, and anticipated growth by the end of the period.

Now after looking at the price graphs, lets look at the forecasted plots for each company along with evaluation matrices.

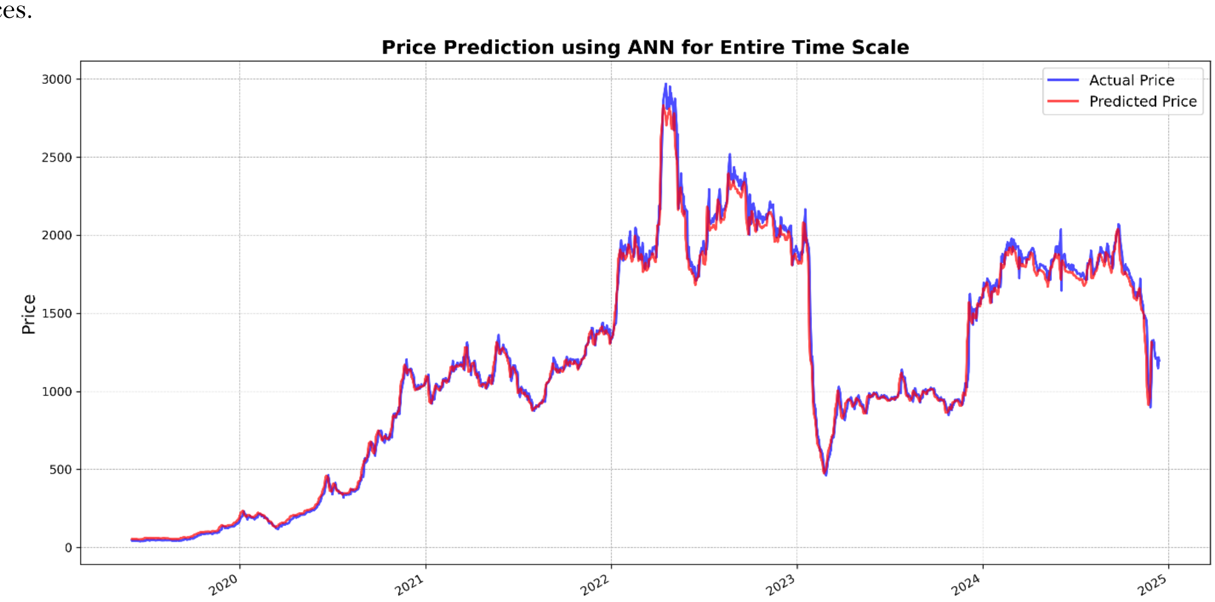

Figure 12. Forecasted Plot of Adani Green Energy.
Source: Authors' own formulation using Python software.

Figure 13. Forecasted Plot of BF Utilities Limited.
Source: Authors' own formulation using Python Software.

Figure 14. Forecasted Plot Energy Development Company Limited.
Source: Authors' own formulation using Python Software.

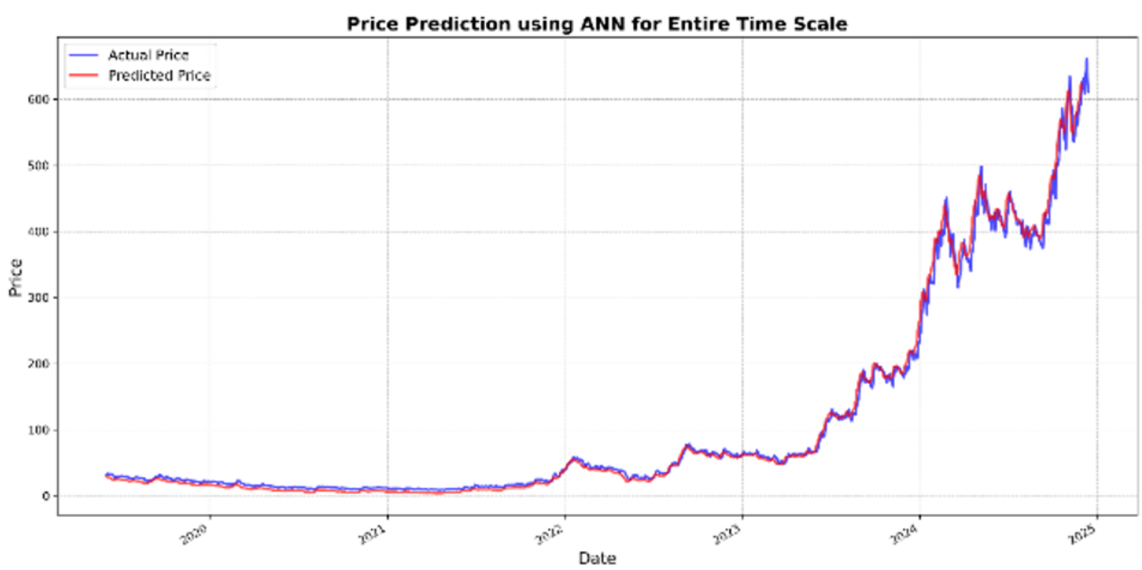

Figure 15. Forecasted Plot of KP Energy Limited.
Source: Authors' own formulation using Python Software.

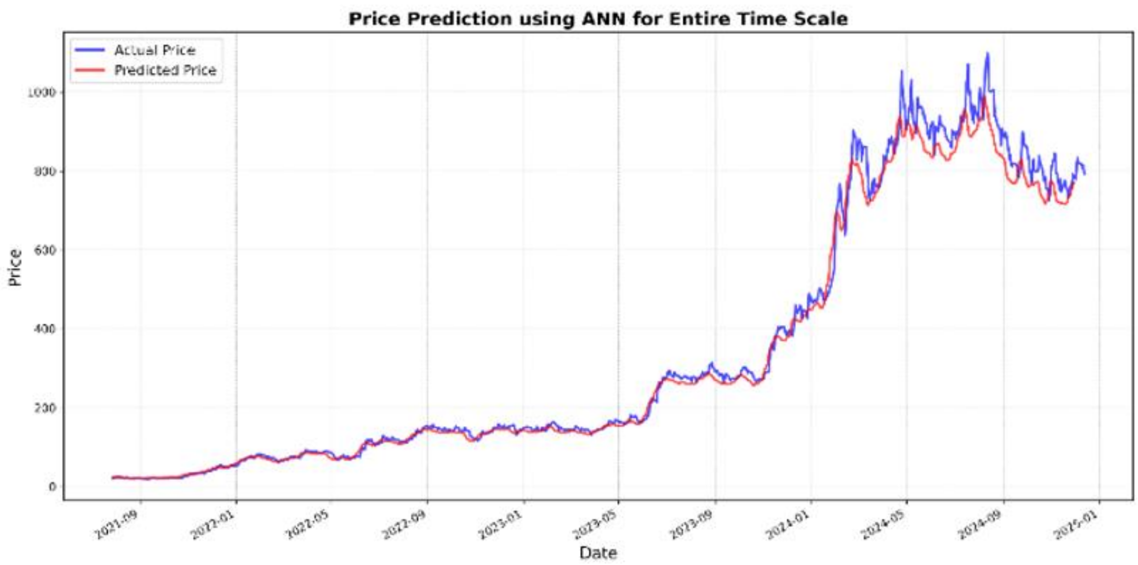

Figure 16. Forecasted Plot of KPI Green Energy.

Source: Authors' own formulation using Python Software.

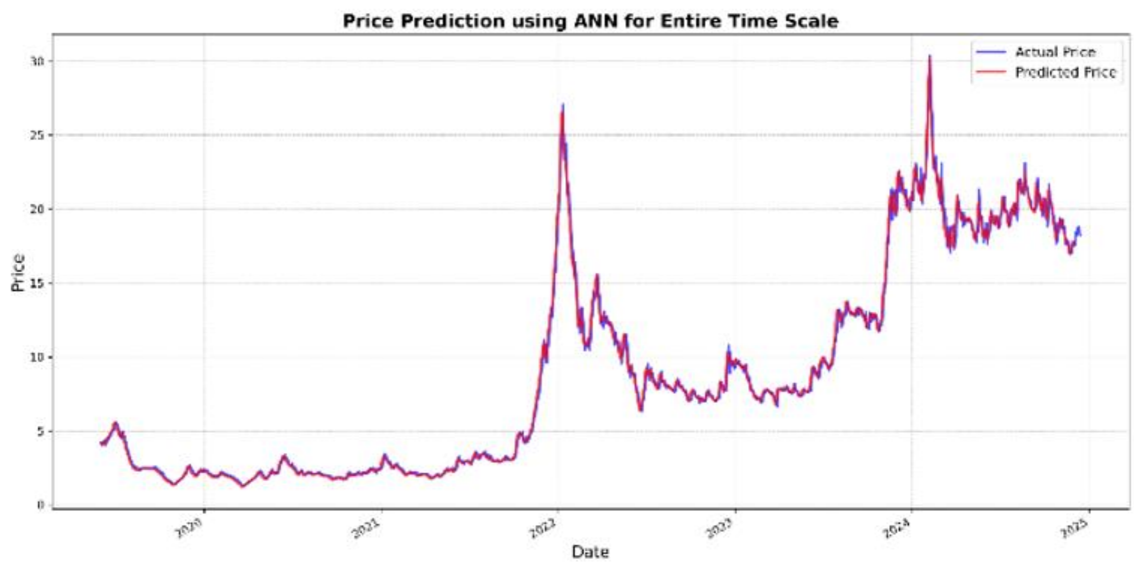

Figure 17. Forecasted Plot of Orient Green Energy.

Source: Authors' own formulation using Python Software.

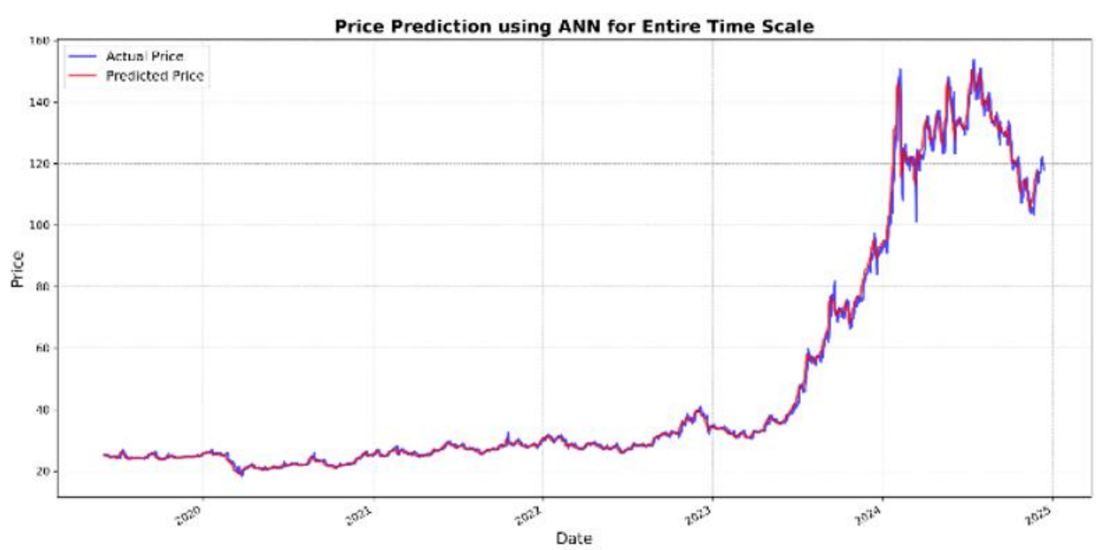

Figure 18. Forecasted Plot of SJVN Limited.

Source: Authors' own formulation using Python Software.

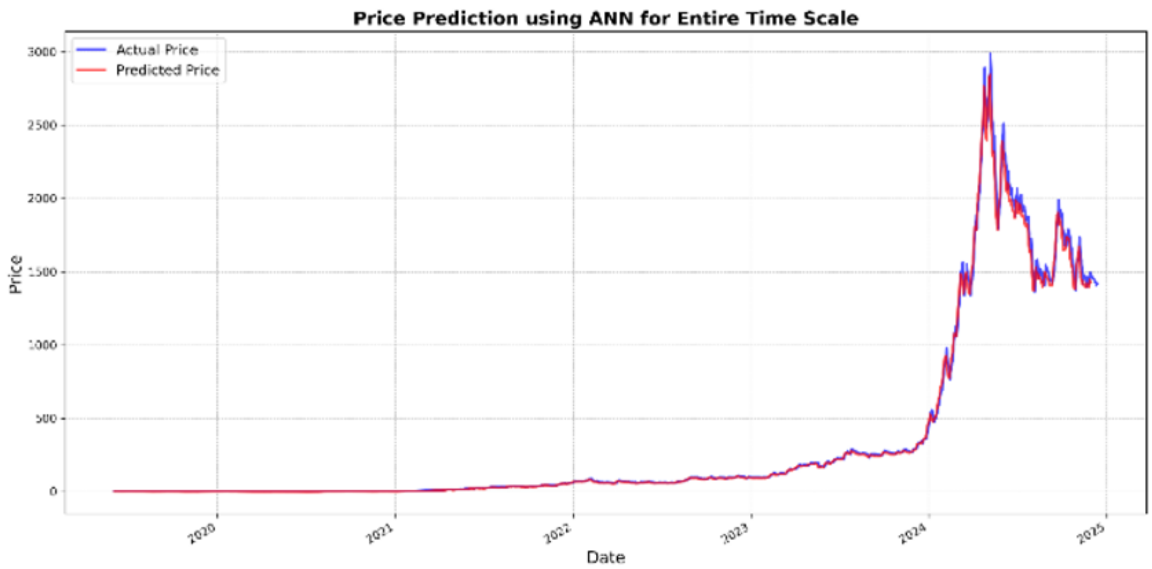

Figure 19. Forecasted Plot of Waaree Renewable Technologies Limited.
Source: Authors' own formulation using Python Software.

Figure 20. Forecasted Plot of WAA Solar Limited.
Source: Authors' own formulation using Python Software.

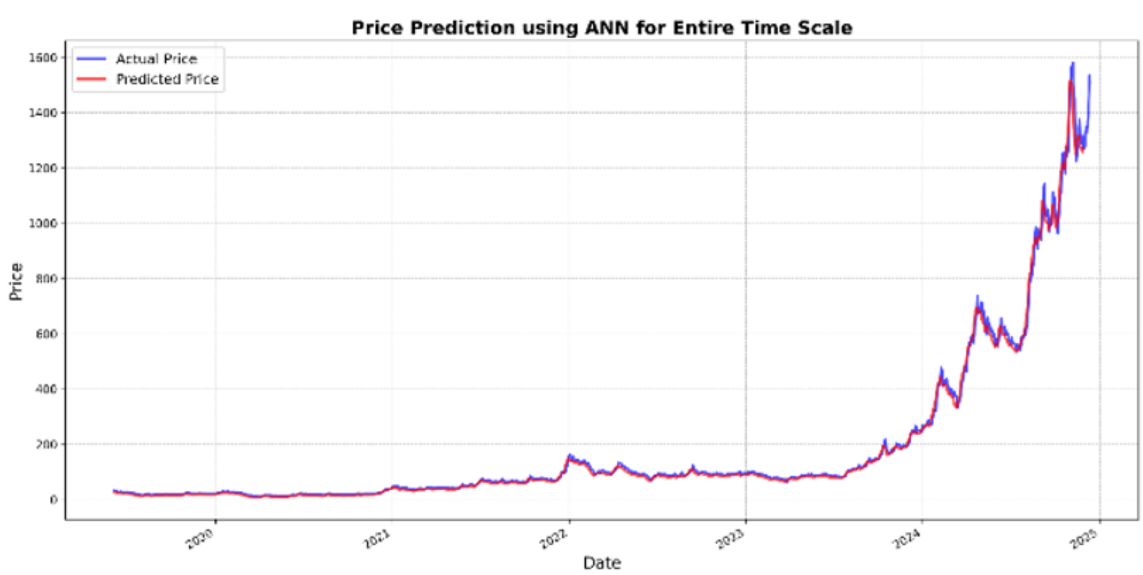

Figure 21. Forecasted Plot of Websol Energy Systems Limited.
Source: Authors' own formulation using Python Software.

Table 1. Evaluation Matrices for the forecasted output.

Company Name	Evaluation Matrices	Values
Adani Green Energy	Mean Squared Error (MSE)	3886.47
	Root Mean Squared Error (RMSE)	62.3416
	Mean Absolute Error (MAE)	40.0106
	Mean Absolute Percentage Error (MAPE)	5.53701
BF Utilities	Mean Squared Error (MSE)	342.466
	Root Mean Squared Error (RMSE)	18.5058
	Mean Absolute Error (MAE)	11.9053
	Mean Absolute Percentage Error (MAPE)	2.89669
Energy Development Company	Mean Squared Error (MSE)	0.57198
	Root Mean Squared Error (RMSE)	0.75629
	Mean Absolute Error (MAE)	0.59929
	Mean Absolute Percentage Error (MAPE)	5.53726
KP Energy	Mean Squared Error (MSE)	109.651
	Root Mean Squared Error (RMSE)	10.4714
	Mean Absolute Error (MAE)	6.95796
	Mean Absolute Percentage Error (MAPE)	17.958
KPI Green Energy	Mean Squared Error (MSE)	1040.4
	Root Mean Squared Error (RMSE)	32.2552
	Mean Absolute Error (MAE)	19.1741
	Mean Absolute Percentage Error (MAPE)	5.60862
Orient Green Energy	Mean Squared Error (MSE)	0.23571
	Root Mean Squared Error (RMSE)	0.4855
	Mean Absolute Error (MAE)	0.31679
	Mean Absolute Percentage Error (MAPE)	4.146
SJVN Limited	Mean Squared Error (MSE)	6.32129
	Root Mean Squared Error (RMSE)	2.51422
	Mean Absolute Error (MAE)	1.24416
	Mean Absolute Percentage Error (MAPE)	2.2204
Waaree Renewable Technologies	Mean Squared Error (MSE)	1611.19
	Root Mean Squared Error (RMSE)	40.1397
	Mean Absolute Error (MAE)	16.7867
	Mean Absolute Percentage Error (MAPE)	25.9594
WAA Solar	Mean Squared Error (MSE)	19.3572
	Root Mean Squared Error (RMSE)	4.39969
	Mean Absolute Error (MAE)	2.72295
	Mean Absolute Percentage Error (MAPE)	5.06561
Websol Energy System	Mean Squared Error (MSE)	316.942
	Root Mean Squared Error (RMSE)	17.8029
	Mean Absolute Error (MAE)	9.90823
	Mean Absolute Percentage Error (MAPE)	10.2558

Before commenting on forecasting, let's briefly understand each evaluation matrix from Table 1 and its important and key consideration for the ease of analysis. Mean Squared Error (MSE) measures the average squared difference between actual and predicted statistics. Academically, it has been argued that MSE is sensitive to large values. Root Mean Squared Error (RMSE) is the squared root of MSE, used to get the absolute deviation of actual and predicted values. Mean Absolute Error (MAE) is the average difference between each forecasted and actual value over subsequent time. This is very useful in identifying outliers in the data. Mean Absolute Percentage Error (MAPE) measures forecasting accuracy as a percentage of actual value, which is useful in comparing pricing over different ranges.

Now, let's discuss each forecasted plot from Figures 12 to 21 simultaneously with their evaluation matrices for each company. We can see in the case of Adani Green Energy, that the MSE value is 3886.47, which is very high along with the RMSE value. However, the MAPE value confirms that prediction is relatively good in percentage terms despite high actual error. This summarizes the fact, that the model was not very accurate in mapping volatility due to high price fluctuations. From the forecasted plot also, we can observe that for almost a year between 2022 and 2023, there is a discrepancy in the actual and forecasted plot. This may be attributed to the Adani Hindenburg controversy and allied events, which the model failed to account for.

BF Utilities Limited has values of MSE, RMSE, MAE, and MAPE as 342.4656937, 18.50582864, 11.90534161, and 2.896686525 respectively. These are excellent statistics and very low MAPE value confirms the precision in the prediction. From the forecasted plot as well the evaluation matrices could be confirmed. The reason for such accurate prediction can be attributed to favorable macroeconomic variables and no unexpected event unlike Adani Green Energy.

Energy Development Company has ideal statistics signaling perfect forecasting. Values of MSE, RMSE, MAE, and MAPE are 0.571976141, 0.756291042, 0.599290007, and 5.537259867 respectively. The forecast has captured prices with very less deviations. Looking at the plot we see, some deviation before 2022. The high precision forecast can be attributed to the low-price range.

In the KP Energy, moderate level accuracy could be found with a 17.958 MAPE value. This signifies the difficulty in capturing percentage-based deviations due to volatility. However, from the plot it is evident that when the price rose extraordinarily in the later phase around 2023 and 2024, there is some minute difference in the forecasting. The same is the time when volatility is more prevalent.

KPI Green Energy has a high MSE and RMSE value of 1040.4 and 32.25 respectively. However, it has a MAPE value of around 5.6, meaning relatively accurate prediction in percentage deviation terms. From the plot, in the later part, we see the difference in the actual and forecasted. The reason is the sudden and extraordinary volatility that the model partially failed to capture.

Orient Green Energy has one of the lowest statistics, MSE: 0.24, RMSE: 0.49, MAE: 0.32, MAPE: 4.15. This may be attributed to the small-cap of Orient Green and less volatility. Even from the plot, the excellent statistics are confirmed. However, the company had its lows and highs in price over the period of study.

SJVN was a relatively stable stock and its matrices are MSE: 6.32, RMSE: 2.51, MAE: 1.24, and MAPE: 2.22, signaling a good forecast with low error across the forecast and could be confirmed by the plot. Around mid-2024, there are some deviations due to uncontrollable macroeconomic variables which the model was not able to account for.

Waaree Renewable Technologies experienced exponential growth and volatility since mid-2024. Since it reached a very high value, errors like MSE and RMSE are at moderate levels but the MAPE value is 25.96, which is high and signs that there was difficulty in predicting exponential growth and associated volatility.

WAA Solar was accurately predicted with less error due to excellent matrices of MSE: 19.36, RMSE: 4.40, MAE: 2.72, MAPE: 5.07. But from the plot, it could be observed that in the later phase of growth and volatility, there is a difference evident in the actual and predicted value but the evaluation statistics are on the healthier side.

In the case of Websol Energy System, matrices are relatively signifying low to moderate level of error and MAPE suggests a relatively good to moderate prediction of deviations in percentage terms. MAPE value is 10.25, which is a moderate level of error. From the plot also we see nearly accurate prediction, unlike previous predictions growth and volatility has also been predicted with less error.

8. Conclusion, Suggestions, and Recommendations

With the increasing green energy focus and the triple burden of climate change, global warming, and unforeseen natural disasters, it becomes imperative to find sustainable energy options for day-to-day use and keep the average mean temperature under 1.5 degrees pre-industrial level. With the continuous flow of new climate agreements and updates of previous each year, green energy companies have been to the center point of both investors and governments. The whole academic domain has been mining and connecting dots around sustainability but none of the research have focused on forecasting the stock prices of Green Energy companies. This is true not only in the case of India but also across economies. In this scenario, despite huge interest and awareness, investors and other stakeholders, feel lost and become suspicious about the investment and this disturbs the circular flow related to the green energy companies.

To address this this study has considered 10 Indian green energy companies. They are chosen based on varied criteria including data availability and it has been made sure that all renewables are represented. The timeline was from 2020 to the end of 2024 and it was well considered that it is coinciding with the COVID-19 pandemic and other larger geopolitical events like news-related volatility, energy crisis due to war, conflict, etc. The companies studied included Adani Green Energy, BF Utilities, Energy Development Company, Orient Green Energy, SJVN Ltd., KP Energy, KPI Green Energy, Waaree Renewable Technologies, WAA Solar, and Websol Energy Systems.

For forecasting, there are several models available both in programmed and non-programmed environment which includes ARIMA, Random Forest, XGBoost, Neural Network forecasting etc. This study has used Artificial Neural Network (ANN) under LSTM environment to predict the companies for a 5-year duration. The LSTM environment was used for its accuracy in predicting time series datasets with long term dependencies.

From the price movement aspects we can say, that almost all the companies started publicly trading around 2020 and have grown irrespective of global uncertainties at least more than 20 times but for some companies, growth is more than 400 times. In this sequence, starting with Adani Green Energy becomes essential. The company had a great start, got its peak around the end of 2022 till 2023, then was stabilized by market correction, macroeconomic factors, etc. It was loosely affected by COVID-19 but mostly affected by the Hindenburg controversy along with market corrections in the later phase. Waaree Renewable Technologies grew exceptionally to a mark of INR 3000 like Adani Green Energy but it was comparatively less volatile. Some companies like WAA Solar, SJVN, Energy Development Company, and Orient didn't cross much mark. KPI and KP Energy have similar trajectories.

Generally, we can say green companies were not affected by the COVID-19 pandemic but their growth slowed down due to the initial phases of public listing, infrastructural, and execution bottlenecks, supply chain disruptions, etc. Soon in the next phase, at the end of 2022, every company recovered and some even reached exceptional heights due to improved policymakers' focus due to climate-related commitments, investors' attention, and a general wave for green investments but the market corrected itself due to its efficient market nature and by the end of 2024, we see sustained prices for each company. The companies have been volatile due to news-related, profit-making investors and macroeconomic factors etc. and the effect was more pronounced in the case of companies with high price range like Adani, Waaree Renewable Technologies and KPI green energy.

From the forecasting point of view, SJVN, Orient Green, Energy Development Company, WAA Solar have good evaluation matrices, this also coincides with the low price range criteria. However, companies with high price ranges have average or less-than-average matrices due to pronounced volatility. One common observation that has been noted is that the ANN-based LSTM model is efficient in predicting sequence-dependent time-series datasets, however in the case of volatility and the unexpected sudden price movements due to uncontrolled variables, the ANN-LSTM environment fails to predict accurately.

Taking the shortcomings in the prediction based on the model used in the paper, improvements in the layers could have been done like using more layers or using Gated Recurring Unit (GRU) layer for improved performance. Another important improvement that could have been done was using the ReLU activation function for the dense layer. The model chose standard 100 epoch and 32 batch size for training purposes but it should have been tuned to the specific nature of the dataset. Some academicians have emphasized on higher accuracy of traditional forecasting models like ARIMA over the Neural Network but one more precise approach would be using a Hybrid model for example, ARIMA-LSTM. Neural network forecasting in financial datasets is in its nascent stage and there is scope for lots of experimentation in the area. Future researchers can customize the model based on dataset and based upon accuracy could decide on the model to be used for the particular datasets. Neural Network based models are more reliable and convenient due to less pre-required limitations like in traditional econometric models.

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