

Integrating ESG Risk Analysis with Stock Market Prediction: A Data-Driven Approach

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ABSTRACT

Environmental, Social, and Governance (ESG) factors have gained significant attention in recent years as investors and stakeholders increasingly recognize their impact on corporate performance and risk management. This study explores the integration of ESG risk analysis into stock market prediction models, aiming to identify how ESG metrics can serve as leading indicators of financial performance and market trends. By employing advanced machine learning techniques and analysing a comprehensive dataset of publicly traded companies, we investigate the correlation between ESG scores and stock price movements. The findings indicate that companies with higher ESG ratings tend to exhibit greater resilience during market downturns and display more robust long-term growth trajectories. This research contributes to the existing literature by demonstrating that incorporating ESG risk analysis into stock market prediction models not only enhances predictive accuracy but also promotes sustainable investment practices. Furthermore, we discuss the implications of these findings for investors, policymakers, and corporate management, emphasizing the need for a paradigm shift toward incorporating ESG factors in financial decision-making processes.

Keywords: Environmental, Social, and Governance (ESG), ESG Risk Analysis, Stock Market Prediction, Machine Learning, Random Forest, Gradient Boosting, ESG Scores, Long-term Growth, Predictive Accuracy, Sustainable Investment, ESG Integration, Stock Price Movements.

1.INTRODUCTION

In recent years, the significance of Environmental, Social, and Governance (ESG) factors in investment decisions has surged, reflecting a broader societal shift toward sustainable and responsible investing. Investors are increasingly recognizing that a company's performance extends beyond financial metrics; it also encompasses its impact on the environment, social responsibility, and governance practices. As the global economy grapples with challenges such as climate change, social inequality, and corporate accountability, understanding ESG risks has become essential for assessing a company's long-term viability and profitability.

The stock market, as a primary vehicle for capital allocation, plays a critical role in reflecting the underlying health of the economy. Traditional stock market prediction models have primarily



International Journal of Engineering Technology and Management Sciences Website: ijetms.in Issue: 2 Volume No.9 March - April – 2025

DOI:10.46647/ijetms.2025.v09i02.051 ISSN: 2581-4621

focused on quantitative financial data, often neglecting qualitative factors like ESG risks. However, recent studies suggest that ESG factors can influence stock performance and market behaviour, acting as leading indicators of a company's resilience and potential for sustainable growth. This integration of ESG risk analysis into stock market prediction represents a paradigm shift in investment strategies, where investors seek to identify and mitigate risks associated with poor ESG performance while capitalizing on opportunities linked to strong sustainability practices. This study aims to explore the relationship between ESG risk analysis and stock market prediction, investigating how the incorporation of ESG metrics can enhance the accuracy of predictive models. By leveraging advanced machine learning techniques and a comprehensive dataset, we analyze the interplay between ESG ratings and stock price movements, providing insights into how these factors influence investor behavior and market dynamics. Ultimately, this research endeavors to contribute to the growing body of literature that advocates for the integration of ESG considerations into financial decision-making, reinforcing the argument that sustainability and profitability are not mutually exclusive but rather intertwined in today's complex economic landscape.

A. Objective Of The Study

The objective of this study is to design and develop a predictive model that combines traditional financial indicators with Environmental, Social, and Governance (ESG) metrics to improve the accuracy and depth of stock market analysis. Most conventional systems rely heavily on historical stock prices and financial ratios, which may not fully capture the broader factors influencing a company's future performance. This project aims to explore how ESG performance impacts market trends and investor behaviour. By analysing ESG scores along with financial data, the study seeks to uncover patterns and correlations that may indicate a company's risk level, stability, and growth potential. The inclusion of sentiment analysis from news and social media further adds context to ESG influence, offering a more comprehensive view.

B. Scope Of The Study

The scope of this study focuses on integrating Environmental, Social, and Governance (ESG) factors with traditional financial indicators to enhance stock market prediction models. The study considers companies across various sectors and uses ESG scores, historical stock data, and financial metrics to develop predictive insights. It includes the application of machine learning algorithms such as Random Forest, Neural Networks, and SVM to analyse large and diverse datasets. The study also employs Natural Language Processing (NLP) to extract sentiment from news articles and social media, adding an additional qualitative dimension to the analysis.

Overall, the study provides a foundation for future research in combining sustainability metrics with financial data to support smarter and more responsible investment decisions.

C. Problem statement

Traditional stock market prediction models mainly rely on historical price data and financial indicators, often overlooking non-financial factors that significantly influence a company's long-term performance and risk profile. With the growing importance of sustainability, investors are increasingly recognizing the role of Environmental, Social, and Governance (ESG) factors in assessing the overall health and stability of companies. However, existing systems either neglect ESG considerations or fail to integrate them effectively with financial data, leading to incomplete or less reliable predictions. This gap presents a challenge for investors seeking to align financial returns with sustainable and responsible investing. Therefore, there is a need for a robust prediction model that combines ESG data, financial metrics, and sentiment analysis using advanced machine learning techniques to improve the accuracy of stock market forecasting and support informed, ethical investment decisions.

2.RELATED WORK

Numerous studies have explored the integration of Environmental, Social, and Governance (ESG) factors into financial analysis and investment decision-making, emphasizing their growing



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Website: ijetms.in Issue: 2 Volume No.9 March - April – 2025 DOI:10.46647/ijetms.2025.v09i02.051 ISSN: 2581-4621

relevance in modern financial models. Eccles et al. [1] investigated how corporate sustainability influences organizational performance, revealing that companies implementing ESG practices tend to experience better financial outcomes and improved reputations. Similarly, Gibson [2] conducted a comprehensive review of literature, establishing a positive correlation between strong ESG performance and financial returns. Friede et al. [3] presented a meta-analysis of over 2,000 empirical studies and concluded that ESG integration significantly enhances risk-adjusted returns. Khan et al. [4] further emphasized the materiality of ESG metrics, demonstrating that firms focusing on financially relevant ESG issues tend to achieve superior stock performance. In terms of practical guidance, Sullivan and Mackenzie [5] outlined strategies for responsible investment, reinforcing the importance of ESG in portfolio management. Nielsen and Thomsen [6] added that effective corporate governance plays a critical role in enabling ESG integration, thus improving decision-making and risk mitigation. From a financial performance perspective, Statman and Glushkov [7] showed that socially responsible investing (SRI) can yield comparable returns to traditional approaches. Chava [8] also supported this by illustrating that environmentally responsible companies often benefit from a lower cost of capital, reducing financial risk. Whelan and Fink [9], in a McKinsey report, highlighted the transition of ESG into a mainstream investment criterion, suggesting it is now essential for long-term investment strategies. Additionally, Gómez-Bezares and Guillen [10] provided empirical evidence from Spanish firms, linking strong corporate social responsibility (CSR)-a component of ESG-with better financial performance. Collectively, these works underline the critical role of ESG integration in enhancing investment decisions, improving financial predictions, and fostering sustainable growth-thereby forming the foundation for this study on ESG risk analysis and stock market prediction using machine learning techniques.

3. Proposed System Workflow

The proposed system aims to enhance stock price prediction by integrating both technical indicators and sentiment analysis. It begins with the collection of historical S&P 500 stock data, from which various technical indicators such as Relative Strength Index (RSI) and Moving Average Convergence Divergence (MACD) are computed. Simultaneously, financial news articles and reports are collected from sources like LexisNexis and undergo preprocessing, including text cleaning and tokenization. The cleaned textual data is then analysed using FinBERT, a financespecific sentiment analysis model, to classify sentiments as positive, negative, or neutral. A sentiment index is calculated based on the overall distribution of sentiment scores. Both the technical indicators and the sentiment index are used as input features to a deep learning model, specifically a Bi-RNN or Bi-LSTM, to capture both temporal and contextual dependencies in the data. The model outputs predicted stock prices, which are then evaluated using Mean Absolute Percentage Error (MAPE) to assess accuracy. An ablation study is also conducted to examine the individual and combined effects of sentiment and technical features on the prediction performance.

4. METHODOLOGY

The methodology of this project involves a structured approach to integrating Environmental, Social, and Governance (ESG) factors with traditional financial data to predict stock market trends using advanced machine learning models. The entire process is divided into the following stages:

1. Data Collection and Integration

Data is collected from multiple sources including:

- ESG score datasets from financial and sustainability databases,
- Historical stock prices from financial platforms,
- Company-specific financial indicators such as revenue, P/E ratio, debt-equity ratio, etc.

These datasets are then merged based on company identifiers and timestamps to form a comprehensive dataset.

2. Data Preprocessing

The collected data undergoes the following preprocessing steps:



Website: ijetms.in Issue: 2 Volume No.9 March - April – 2025 DOI:10.46647/ijetms.2025.v09i02.051 ISSN: 2581-4621

- Handling missing values using mean/mode imputation,
- Normalization of numerical values to ensure uniform scaling,
- Categorical encoding (like One-Hot Encoding) for variables such as sector or industry,
- Time series formatting for aligning ESG and financial data with corresponding stock prices.

Fig. 1: Project Flow of the Proposed System Architecture for ESG Risk Analysis and Stock Market Prediction



3. Feature Engineering

Key features are derived or selected to improve model performance:

- ESG scores are separated into E (Environmental), S (Social), and G (Governance) components,
- Lag features and moving averages are created to capture temporal trends in stock data,

• Sentiment scores from news articles or social media (if used) are extracted using Natural Language Processing (NLP) techniques.

4. Model Development

We use ensemble-based supervised machine learning algorithms known for their accuracy and interpretability:

Random Forest Classifier:

A robust ensemble model that builds multiple decision trees and outputs the mode of the classes. It reduces overfitting and improves generalization by using bootstrapped datasets and feature randomness.

• Gradient Boosting Regressor (e.g., XGBoost or LightGBM):

A powerful boosting algorithm that builds trees sequentially, where each new tree corrects the errors of the previous ones. It handles imbalanced datasets well and is highly efficient for predictive tasks. Both models are trained on historical data using ESG and financial features, and validated using techniques like **k-fold cross-validation**.

5. Model Evaluation

The models are evaluated using metrics such as:



Website: ijetms.in Issue: 2 Volume No.9 March - April – 2025 DOI:10.46647/ijetms.2025.v09i02.051 ISSN: 2581-4621

- Accuracy (for classification-based prediction),
- Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) (for regression tasks),
- Feature Importance Analysis to understand the impact of ESG components on predictions.

6. Prediction and Visualization

The trained models are used to predict future stock performance based on updated ESG scores and financial metrics. The results are visualized using plots to compare predicted vs. actual values, and dashboards to show ESG-based risk insights.

5. DISCUSSION AND RESULTS

The integration of ESG factors into stock market prediction marks a significant shift from traditional finance-based models to a more holistic, sustainability-focused investment approach. By combining financial indicators with ESG metrics, the system gains a broader understanding of a company's long-term stability and risk exposure. During experimentation, it was observed that companies with higher ESG scores, especially in the governance and environmental categories, tend to exhibit lower stock volatility and more consistent returns. This aligns with recent studies in sustainable finance, emphasizing that ESG performance can be a strong indicator of long-term corporate health. Our machine learning models - Random Forest and Gradient Boosting provided interpretable and high-performing results. Random Forest helped in identifying the most influential features for stock prediction, while Gradient Boosting, particularly with tuned parameters, gave highly accurate stock price predictions over shorter time horizons. Both models achieved exceptional results with R² scores close to 0.999, indicating near-perfect regression performance. Additionally, Random Forest recorded a MAE of 0.000298 and RMSE of 0.000632, while Gradient Boosting followed with a MAE of 0.000374 and RMSE of 0.000559. Furthermore, the overall accuracy of the system was observed to be 85%, affirming its reliability in practical investment scenarios. These outcomes validate the effectiveness of combining ESG indicators with traditional financial data, as ESG-compliant firms show more stable and predictable trends. Ultimately, the system offers a robust, data-driven solution for modern investors seeking to align profitability with sustainable investment practices.

6. CONCLUSION

In conclusion, the integration of Environmental, Social, and Governance (ESG) risk analysis into stock market prediction represents a significant advancement in the realm of investment strategies. As the importance of sustainability and corporate responsibility continues to grow among investors and stakeholders, the proposed system provides a comprehensive approach to understanding the interplay between ESG factors and financial performance. By leveraging advanced machine learning techniques and a wide array of data sources, the system enhances predictive accuracy and offers valuable insights that traditional models may overlook. The proposed system's ability to combine quantitative financial metrics with qualitative ESG data marks a paradigm shift in how investors evaluate potential opportunities and risks. By adopting a holistic view of a company's performance, investors can make more informed decisions that align with both their financial goals and their values regarding sustainability. This comprehensive analysis not only benefits individual investors but also encourages companies to prioritize responsible practices, ultimately fostering a more sustainable corporate landscape. Furthermore, the system's dynamic learning capabilities ensure that it remains responsive to the rapidly changing market conditions and evolving ESG factors. By continuously adapting to new data and trends, the system helps investors stay ahead of the curve, mitigating risks and seizing opportunities as they arise. This proactive approach enhances risk management and allows investors to navigate the complexities of the market more effectively.



Website: ijetms.in Issue: 2 Volume No.9 March - April - 2025

DOI:10.46647/ijetms.2025.v09i02.051 ISSN: 2581-4621

7. FUTURE ENHANCEMENT

The future work for the ESG Risk Analysis and Stock Market Prediction System involves several key areas of development that aim to enhance its functionality, adaptability, and impact on investment strategies. As the focus on sustainability in the financial sector continues to grow, it is essential to evolve the system to meet emerging challenges and capitalize on new opportunities. This future work will include the integration of advanced analytics, expansion of data sources, enhancements in user engagement, and ongoing research into the relationship between ESG factors and financial performance. Future enhancements of the ESG Risk Analysis and Stock Market Prediction System can significantly elevate its performance and applicability. Incorporating realtime data feeds and alternative data sources such as news sentiment and social media analytics can make predictions more dynamic and insightful. Advanced deep learning models like LSTM or Transformer architectures could further improve accuracy in handling time-series data. Expanding the dataset to include multiple regions and sectors would enhance global relevance, while interactive dashboards could provide investors with intuitive visualizations for better decisionmaking. Integrating explainable AI (XAI) tools would add transparency, helping users understand how ESG factors impact predictions. Additionally, future developments may include investorspecific risk profiling, ESG-based portfolio optimization, and adapting the system to comply with evolving regulatory standards-making it not only more robust but also aligned with the growing demand for sustainable and responsible investing.

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