

Sustainable Finance in the AI Era: The Role of ESG Analytics and Machine Learning Trend

Amit Kumar, Assistant Professor, School of Leadership and Management, Manav Rachna International Institute of Research and Studies, Faridabad amitkumar.slm@mriu.edu.in.

Priyanka Bhayana, Assistant Professor, Department of MBA, IIMT College of Engineering, Greater Noida priyanka4324_gn@iimtindia.net

Abstract

The adoption of Environmental, Social and Governance (ESG) principles in finance has become more important than ever as organizations work to align with sustainable practices from both stakeholder expectations and regulatory perspectives. Simultaneously, the emergence of artificial intelligence (AI) and machine learning (ML) has opened innovative opportunities for analysing and refining ESG factors in the financial decision-making process. Through an analysis of how machine learning technologies are redefining sustainable finance, this article engages with the interplay between ESG and AI. The paper reviews recent developments and identifies the evolution of AI-based ESG scoring systems, prediction analytics for sustainability performance, and natural language processing techniques for ESG disclosures. It also highlights blockchain as a key technology in increasingly transparent and compliant ESG reporting. AI can provide significant new capabilities for increasing the speed of ESG adoption, but comes with challenges — such as data reliability, algorithmic bias and ethical concerns. This paper assesses these challenges and provides several recommendations to promote responsible AI practices in financial systems. By exploring the specific use cases where financial institutions employ AI to adopt sustainable practices, this study emphasizes the revolutionary influence of machine learning on the integration of ESG factors. The paper concludes with an outlook on the future trends, providing a roadmap for financial institutions looking to leverage the potential of AI to untangle the ESG knot.

Keywords: Sustainable Finance, ESG Analytics, Machine Learning, Artificial Intelligence, Responsible Investing
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Introduction

In recent years, the financial sector has witnessed a significant shift towards integrating Environmental, Social, and Governance (ESG) principles into investment strategies and corporate practices. This transition reflects a growing recognition that sustainable and ethical considerations are pivotal to long-term financial performance and risk management. Concurrently, advancements in Artificial Intelligence (AI) and Machine Learning (ML) have revolutionized financial services, offering sophisticated tools for data analysis, decision-making, and operational efficiency.

Overview of ESG in Finance

The integration of ESG factors into finance has transformed from a pature issue into an issue every company must deal with. There has been increasing demand from investors and regulators for transparency and accountability on companies' sustainability practices. In 2024, the European Union announced plans to revamp sustainable finance funds rules, with the goal of increasing transparency and tackling greenwashing, including new categories like "Sustainable," "Transition," and "ESG Collection," aimed at providing investors with clearer information(Agbakwuru, 2024).

The United Nations-supported Principles for Responsible Investment (PRI) network soared with over 5,000 signatories and approximately US\$128 trillion in assets under management as of December 2024. This increase illustrates the ever-growing dedication to responsible investment practices on a wider scale. But the ESG space has its fair share of challenges. The phrase "ESG" has been politicized, causing some heavyweights in the industry to seek out substitutes, such as "sustainability," to avoid controversy(Kim and Yoon, 2023).

Additionally, there are growing fears of greenwashing (making misleading claims about the greenness of a product or service) which has led to regulatory authorities introducing more stringent disclosure requirements to safeguard the legitimacy of the ESG investment.

Role of AI and Machine Learning in Modern Finance

In the financial world, AI and ML technologies have been used to enhance capabilities across several domains. In 2024, banking on Wall Street made further strides in their AI initiatives. JPMorgan, for example, built some A.I. tools for private bankers that are meant to increase efficiency and client service.

Likewise, Goldman Sachs and Morgan Stanley have tapped AI to increase productivity and remain competitive. It covers several topics in the finance industry such as algorithmic trading, credit scoring, fraud detection, and personalized banking services. This technology allows for the processing of huge datasets to find patterns, insights, and patterns that can be used to make strategic decisions. But the fast-track adoption of AI also poses challenges, including risk for increased market volatility and ethical dilemma over decisions-making processes. In some cases, these efforts are driven by safety concerns about the use of AI in the financial markets(LABS, 2024).

This fusion of intent and efficiency is set to not only impact individual companies but entire industries. As ESG integration drives responsible investment, AI and ML have the potential to be his tools to improve efficiency and decision-making. As we learn more about this rapidly changing landscape(Zhang and Yu, 2024), we find ourselves facing both exciting possibilities and complex challenges that demand attention.

Literature Review

1. ESG Frameworks and Sustainability Metrics

Investment today relies upon ESG — Environmental, Social and Governance factors which ensure corporate transparency & accountability. Its not about being the nice guy, rather ESG integration in financial decision-making points to a paradigm shift from purely profit-oriented business models into sustainability-driven methods contenders(Hajdu, Lukács and Ducsa, 2023). The GRI (Global Reporting Initiative), SASB (Sustainability Accounting Standards Board) or the EU Taxonomy for Sustainable Activities are some examples of ESG frameworks helping

companies evaluate their ESG performance. Still, quantifying and comparing ESG data between industries remain problematic due to reporting inconsistencies(Jiang, Gu and Dai, 2023).

Recent studies emphasise the important role of technological developments in meeting these challenges. The KPMG 2023 CEO Outlook presents a good example of this with the increasing use of AI for gathering ESG data(KPMG, 2023), making sustainability assessments more sophisticated and managing greenwashing issues(Gbako *et al.*, 2024). Data-driven ESG analytics can also better allow investors to factor in how the products or services offered by a company are affecting their portfolio so that both environmental impact, social responsibility and governance practices become influential elements of an investment(Belak and Nedelko, 2024).

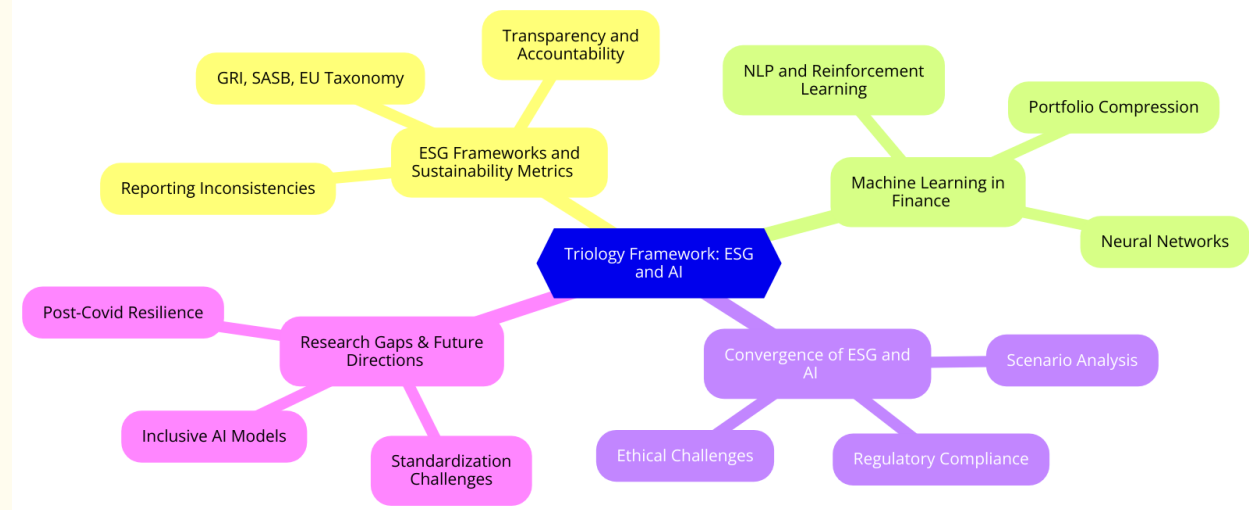


Figure 1. Triology Framework: ESG and AI

2. Machine Learning Applications in Financial Analytics

It has taken this to newer heights is that Machine learning (ML) which enables smart financial analytics by providing machines the ability to process and analyse extensive data, find patterns and predict trends with high levels of accuracy(Sokolov *et al.*, 2021). In ESG investing ML has improved our capability to measure sustainability metrics, allowing investors to steer their portfolios in the direction of longer period environmental and social objectives. For example, neural networks have been applied to portfolio compression — that is a vast decrease in risk exposure at no expense of financial performance(Macpherson, Gasperini and Bosco, 2021).

ESG data are thus analyzed using AI and ML techniques such as NLP (Natural Language Processing) or reinforcement learning. By analyzing text and textual data derived from company disclosures, social media or news sources NLP tools extract sentiment changes & risks for underlying thematic factors linked to ESG(Rane, Choudhary and Rane, 2024). At the same time, reinforcement learning models incorporate asset allocation optimization adjusting to market dynamics and sustainability trends over each period(Briere *et al.*, 2022).

3. Convergence of ESG and AI

The use of AI for ESG practices represents a significant and groundbreaking moment in sustainable finance. Generating the use of AI and ML algorithms, financial institutions can implement scenario analysis to run multiple models which simulate how ESGs outcomes affect portfolio performance(Oyewole *et al.*, 2024). For instance, AI-driven solutions like Finance Denominator Maximizer (FDM) powered by Financial Maximally Filtered Graphs (FMFG), leverages the most advanced machine-learning tools to mine vast and complex datasets on ESG parameters forecasting ATH ('Animal To Human') emissions as well as valuating climate risks(Hemanand *et al.*, 2022).

This also aligns with how AI enriches transparency and accountability in ESG reporting. This allows automated systems to monitor consistency and compliance with regulatory standards such as the EU's Corporate Sustainability Reporting Directive (CSRD). However, numerous ethical challenges like bias in AI models and data privacy exist which necessitates the presence of strong governance frameworks(Chen, 2024).

4. Research Gaps and Future Directions

But there are still holes in AI application to ESG. The absence of standardized social and governance ESG metrics muddies the waters even further for cross-sector comparisons. Additionally, research of AI in ESG decision-making is scarce(Lim, 2024). We need further research aimed to overcome these challenges through the development of inclusive and fair AI models that ensure sustainable solutions required for a post-covid era.

Based on everything above, it is apparent that the confluence of ESG and AI has a high potential to re-imagine financial systems for sustainable growth & resilience. With the help of AI to bring ESG analytics capabilities, stakeholders can tackle intricate issues effectively by promoting transparency and accountability in our financial landscape(Zhao, 2024). Both of these coming together not just in line with the global sustainability goals, but also opening new avenues for transformational innovations around investment strategies.

Emerging Trends in ESG Analytics

1. AI-Driven ESG Scoring Models

Artificial Intelligence (AI) has revolutionized the way ESG factors are evaluated by introducing robust, data-driven scoring models. These models aggregate vast datasets from diverse sources—financial reports, sustainability disclosures, social media, and satellite imagery—to generate objective ESG scores. Unlike traditional methods, AI models employ machine learning algorithms to identify patterns, detect anomalies, and predict future ESG performance with higher accuracy. For example, neural networks and decision trees are widely used to analyze climate data, assess carbon footprints, and evaluate governance risks(Feng, 2024).

One key advantage of AI-driven ESG scoring is scalability. Traditional approaches struggle with the volume and complexity of ESG data, while AI systems excel in processing millions of data points in real time. However, challenges remain, such as algorithmic bias and the transparency of AI models. Regulators and stakeholders are increasingly advocating for explainable AI to ensure fairness in ESG scoring.

2. Use of Natural Language Processing in ESG Report Analysis

NLP tools are changing the way ESG disclosures and Unstructured Textual Data is being analyzed. Although it is no part of one to manually analyze the corporate reports, news articles and Stakeholder Communications as they are enriched with qualitative ESG information. NLP processes these narratives on the information available to understand its context, sentiment etc so that insights can be derived automatically.

NLP models examine sustainability reports to detect net-zero pledges, diversity initiatives or social development programs. There are also sentiment analysis tools that can go hand in glove with the above, analyzing public and investor responses to ESG news. The use of more sophisticated NLP techniques like entity recognition and topic modeling is helping to identify key ESG themes, making it easier for stakeholders consume actionable intelligence.

One of the major applications for NLP is in detection greenwashing. NLP models can verify sustainability claims, making the combat of malicious environmental standards a bit easier. Proof that lies in such data!

3. Blockchain for ESG Compliance Tracking

This revolutionary blockchain technology has positioned itself to become the ultimate tracking tool for ESG compliance, due in no small part to its unrivaled transparency and immutability. Blockchain records an audit trail of ESG metrics and certifications, making data tamper-proof and transparent across multiple parties. This transparency is especially important in the case of supply chain management, where visibility into environmental and labor standards can be difficult to come by.

Block chain-based platforms contain smart contracts that execute compliance tasks intelligently so as to eliminate fraud risk and manual oversights. Organizations can use the blockchain to securely track anything from renewable energy certificates and carbon credits (ensuring their authenticity) to preventing double counting. Further, blockchain allows investors and regulators to monitor ESG performance metrics in real time, thereby generating trust.

However, there are obstacles for blockchain adaptation in terms of ESG compliance which is high energy consumption and Interoperability. However, progress in green blockchain technologies as well as standardization efforts are tackling these issues.

Table 1. Comparison of Technologies in ESG Analytics

Technology	Applications	Advantages	Challenges
AI-Driven	Predicting ESG	High scalability, data-	Algorithmic bias,

Scoring Models	performance, anomaly detection	driven insights	transparency concerns
NLP	Sentiment analysis, ESG disclosure evaluation	Automated, qualitative data processing	Complexity of contextual interpretation
Blockchain	Supply chain tracking, carbon credit verification	Transparency, tamper-proof records	Energy usage, interoperability issues

Applications of Machine Learning in ESG Analytics

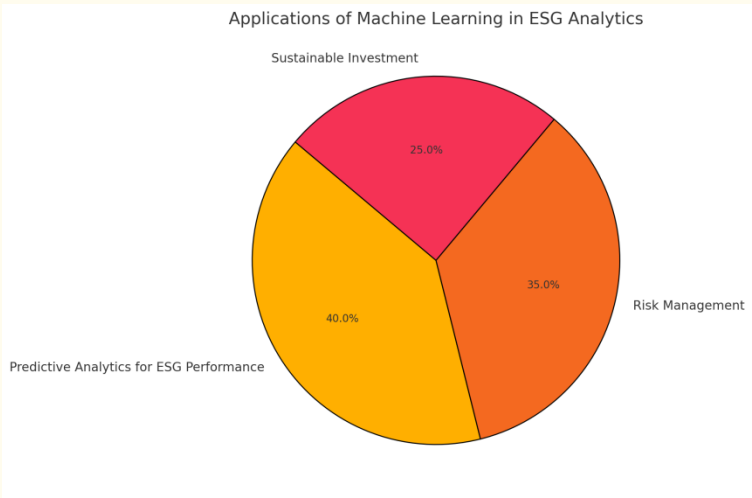


Figure 2. Allocation of Machine Learning in ESG Analytics

1. Predictive Analytics for ESG Performance

Introduction Machine learning (ML) has shown great potential for improving the prediction of ESG (Environmental, Social, and Governance) performance. Predictive analytics, which uses historical and real-time data to predict future trends in ESG metrics will allow organizations and investors for the first time to be aware of risks before they happen (and repeat) or when new opportunities arise.

For instance, we can create an ML model to predict the trajectory of a company's carbon emissions over time based on historical performance as well as industry benchmarks. The same is true for social factors, such as the corporate reputation and investor confidence repercussions that can be modeled now to estimate how they would evolve over time if companies developed diverse workplaces or more thoughtful governance practices. Predictive analytics can also help to detect potential ESG violations, such as environmental compliance breaches or labor disputes long before they become breaking-news.

Providing these insights allows investors and regulators the ability to proactively move investments towards sustainability goals. Challenges still exist on types of data, quality of the data and biases when training an algorithm with connected sources, etc

2. AI Algorithms for Risk Management and Sustainable Investment

Understanding of the most important AI algorithms for assessing and managing risks in ESG investments. AI solutions discern patterns in structured and unstructured data, delivering up-to-the-minute financial-, environmental- and operational-risk analytics. For example, news articles and corporate reports can be combed via natural language processing (NLP) to get early signs of new risks like upcoming regulation changes or environmental dangers.

For sustainable investments, when placed for decision making AI can compare ESG factors to financial metrics. Reinforcement learning algorithms that keep updating investment strategies with time while being aware of market trends, and investor choices so as to optimize the portfolio allocation. For instance, AI can help recognize undercovered high-performing assets that are less harmful to the environment allowing investors earn more on returns with specific sustainability standards.

Scenario analysis, a technique used by risk management tools to simulate different paths of market movements and estimate capacity for ESG-resilience in portfolios. This helps investors understand where they might be exposed and how to adjust their strategies accordingly. There is a lot of work to be done on AI transparency, ethical algorithmic design and privacy rights that touch the UI at various points.

Challenges and Ethical Considerations in ESG Analytics Using AI

AI ESG (Artificial Intelligence Environmental, Social and Governance) analytics are changing the way companies approach sustainability and ethical obligations by typing of Artificial Intelligence on an environmental social and governance matters. As any new technological development, however, such a shift comes with multiple challenges and ethical dilemmas that need to be dealt with.

1. Data Quality and Availability for ESG Metrics

One of the primary issues faced by ESG analytics today is poor quality non-standardised data. The data that drives ESG analytics is inherently unreliable, unstandardized and non-comparable among organizations or between industries. By contrast to financial reporting, which is regulated and uniform across industries ESG disclosures are voluntary in most jurisdictions creating gaps on the content of these publications.

To provide accurate and actionable insights, AI systems need exposure to a wide range of data in the world. Having said that, poor data quality (or limited availability) can and will lead to flawed analyses, potentially misrepresenting an organization's sustainability performance. For instance, if data on carbon emissions or social governance factors is omitted, AI predictions can be affected which in turn impacts investment decisions and the stakeholder trust.

In the face of these issues, organizations should follow consistent ESG reporting frameworks like Global Reporting Initiative (GRI) or Sustainability Accounting Standards Board(SASB). Besides, the cooperation of stakeholders is crucial to enhance data transparency and accessibility.

2. Bias in AI Algorithms

AI algorithms are only as unbiased as the data they are trained on. In ESG analytics, biases in datasets can lead to discriminatory outcomes. For instance, an algorithm trained on historical data may inadvertently favor organizations from regions or industries with higher ESG reporting standards, penalizing others that lack resources for detailed disclosures.

Algorithmic bias can also manifest in social and governance metrics, where subjective judgments about cultural norms and societal expectations influence data interpretation. This bias undermines the credibility of ESG scores and reduces trust among stakeholders.

To mitigate bias, organizations must ensure diversity in training data and employ fairness-testing tools to identify and address algorithmic discrimination. Additionally, explainable AI (XAI) techniques can enhance transparency, allowing stakeholders to understand how AI systems reach their conclusions.

3. Governance Issues in Adopting AI for Finance

ESG analytics with AI may create substantial governance challenges, most notably in finance. Critics raise questions regarding regulatory frameworks of AI applications. In the absence of clear rules, it is possible that organizations would abuse AI tools leading to ethical breaches or undesired consequences.

A third governance problem is accountability. It can be very difficult to know where the responsibility lies when an AI model makes a bad prediction, or worse yet, is biased. This is especially important in finance because mistakes can lead to financial losses or reputational risk.

Companies are advised to have strong governance over their AI initiatives, ensuring the technology is always ethical-by-design and compliant with all existing legacy regulatory requirements. Auditing AI systems on a regular basis, alongside stakeholder engagement can help prevent the values and societal expectations of organizations from being misaligned with their AI tools.

Case Studies and Examples

1. Analysis of Financial Institutions Leveraging AI for ESG

Around the world, financial institutions are adopting AI in their ESG plans to improve decision-making processes and transparency of finance along with sustainability. **JPMorgan Chase**, for instance, uses AI-based analytics tools to assess the various ESG factors associated with companies in its investment offerings. The bank uses machine learning algorithms to assess large datasets on financial reports, media coverage and social media sentiment. The process uses analytics to identify sustainability benefits and trading signals in an economy, which can affect the investment decisions of businesses..

Consider, as an other example at the global scale in this piece from **BlackRock**. BlackRock utilizes the AI-based ESG analytical tools across all its products for providing specific judgments on ESG criteria and their impacts, both risks as well as return related to clients. Its Aladdin platform uses natural language processing (NLP) to analyze unstructured data from sustainability disclosures and map investments against the United Nations Sustainable Development Goals (SDGs). By pioneering this approach, BlackRock is setting the industry standard for sustainable investment.

China-based **Ping An Insurance** has rolled out AI tool that can monitor as well as report ESG compliance (source – Asia) It uses AI to score companies for their environmental, social and governance performance which replaces a manual audit process; saving time and money by an order of magnitude. Automating the ESG assessments helped Ping An to increase transparency and build more trust from stakeholders.

2. Comparison of Traditional vs. AI-Based ESG Evaluations

Current ESG rating-scoring leaves most weight on specialist judgments, human-driven efforts or inferential assessment from organization individuals. Although essential, these ways are very time-consuming as human beings have to go through a large amount of content in order to filter it plus they also come with the feeling that everyone has like sitting ducks and they almost always lack consistency. For instance, legacy assessments may miss critical ESG factors or

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interpret sustainability metrics based on data set availability and the subjective nature of those depictions.

By contrast, AI-powered ESG assessments harness cutting-edge technologies ranging from machine learning to NLP for information collecting and standardization of analysis in order to enhance precision. At the core of why AI models have become invaluable for ESG practitioners is their ability to process wide-ranging datasets (from satellite imagery, to IoT sensors, and even online publications), which paint a comprehensive portrait of an organization's ESG performance.

One of the critical benefits of AI-driven approaches is scalability. Moreover, the AI tools can easily analyze large datasets within seconds and even in a few milliseconds from which traditional evaluation method too long lasting process to be finalized as well. Moreover, AI systems can uncover hidden patterns and forecast future ESG performance, which traditional approaches are deprived of.

Nonetheless, there is also more work to be done with AI-based evaluations due the phenomenon of algorithmic bias and data quality issues. Nevertheless, the improved accuracy and the greater speed that AI-based ESG judgments characterize are a kick-off in both identifying economic backwardness early as years of where it is expected other benchmarks climb off to modern financial institutions, predictive capabilities.

This comparison emphasizes the capability of AI to change ESG analytics, pointing towards a more data-driven automated sustainable evaluation frameworks which can scale across all assets classes.

Conclusion and Future Directions

Artificial Intelligence (AI) in Environmental, Social and Governance analytics is transforming sustainable finance. It provides an example of how AI-driven tools are improving ESG scoring models, predictive analytics and even compliance tracking capabilities to help financial institutions align investments with sustainability targets. We see the influence of AI taking over and industry giants such as JPMorgan Chase, who recently illustrated just how transformative a

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system that can automate data collection and analytics is in improving decision-making with regards to future ESG performance. AI can also address the scalability limits of traditional ESG evaluations by analyzing very large datasets in real time, vs more manual processes.

But barriers, such as inconsistent data quality, algorithmic bias and governance challenges remain prevalent. A much more significant point is to mold the ethical AI design standards in a reliable manner while simultaneously strongly regulating practices.

Opportunities for Further Research and Innovation

There are numerous studies that remain to be undertaken and open questions left unaddressed in light of the changing face of sustainable finance:

1. **Enhanced Data Integration:** Innovations in the advanced methods of structured data and unstructured ESG data integration could empower AI models to be even more accurate and dependable.
2. **Explainable AI (XAI):** Creating greater trust among stakeholders and mitigating concerns of bias can also be addressed with the logical direction XAI development, ensuring that whatever decisions a responsible AI makes will derive from transparent logic which is easy to follow.
3. **Blockchain Integration:** The adoption of blockchain can improve recognition and traceability associated with ESG compliance.
4. **Sector-Specific AI Models:** Creating ESG-suited, industry-tailored models for applications in energy, healthcare or manufacturing may enhance relevance and utility.
5. **Ethical AI Frameworks:** Additional quality of research that explores frameworks which can balance innovation with ensuring ethical practices in sustainable finance activity and the use of AI.

Addressing these areas will enable researchers and practitioners to realize the full potential of AI in promoting sustainability, innovation, as well as resilience within financial systems. This way

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forward is not only an improvement in ESG, it builds a long term, global economy which is fair to all people involved.

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