



The Use of Artificial Intelligence for Managing Emerging Risks in Green Finance: A Literature Review on Financial Institutions

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Abstract

This study aims to analyze the role of Artificial Intelligence (AI) in managing emerging risks within the green finance sector through a systematic literature review approach. The growing importance of green finance in supporting sustainable development has been accompanied by the emergence of new and complex risks, including greenwashing, regulatory uncertainty, renewable energy project volatility, and reputational risk faced by financial institutions. These risks are often difficult to predict and manage using traditional risk management frameworks due to their dynamic nature and limited historical data. To address this issue, this study adopts the PRISMA 2020 framework, complemented by the SPAR-4-SLR and TCCM models, to systematically review and synthesize recent academic literature published between 2020 and 2025. The findings indicate that AI plays a significant role in enhancing the effectiveness of risk management in green finance by enabling large-scale data analysis, identifying complex and non-linear risk patterns, and improving the accuracy and timeliness of risk prediction. AI applications, such as machine learning and predictive analytics, are particularly effective in detecting greenwashing practices, supporting regulatory compliance, and strengthening sustainable investment decision-making. However, the implementation of AI in managing emerging risks in green finance still faces several challenges. Key obstacles include limited data availability and quality, potential algorithmic bias, and the absence of clear regulatory frameworks governing the use of AI in sustainable finance. Despite these challenges, the study concludes that AI represents a strategic and promising solution for strengthening sustainable risk governance. This research contributes to the existing literature by providing a comprehensive overview of current trends, challenges, and opportunities related to AI-driven risk management in green finance, particularly in the context of developing economies.

Keywords: *Artificial Intelligence, Emerging Risk, Green Finance, Risk Management*

INTRODUCTION

Climate change and sustainability demands have increasingly compelled the financial sector to transform its conventional practices. Rising global temperatures, extreme weather events, and environmental degradation have not only generated ecological concerns but also introduced significant economic and financial implications. As a response to these challenges, the concept of green finance has emerged as a strategic instrument aimed at mobilizing capital toward environmentally friendly and sustainable projects, such as renewable energy, energy efficiency, sustainable infrastructure, and low-carbon technologies. Green finance is widely recognized as a crucial mechanism for supporting the transition toward a low-carbon economy and for achieving long-term environmental sustainability.

However, despite its promising objectives, the implementation of green finance is not free from risk. Unlike traditional financial activities, green finance operates within a complex environment characterized by regulatory evolution, technological uncertainty, and heterogeneous sustainability standards. Many of these risks are relatively new, difficult to quantify, and lack sufficient historical data, thereby classifying them as emerging risks. Key emerging risks associated with green finance include greenwashing risk, regulatory uncertainty, volatility in renewable



energy projects, and reputational risks faced by financial institutions. If these risks are not properly identified and managed, they may undermine investor confidence, distort capital allocation, and ultimately threaten the stability of the financial system.

In addition, the growing development of sustainable finance taxonomies, such as green classification frameworks used to define environmentally sustainable economic activities, has become increasingly relevant to risk governance in green finance. These taxonomies help reduce ambiguity regarding what qualifies as “green,” support regulatory consistency, and can provide structured inputs for AI-based monitoring and compliance systems.

Previous studies emphasize the strategic importance of green finance in achieving broader sustainability goals. [Zhang et al. \(2022\)](#) argue that green finance plays a vital role in supporting the Sustainable Development Goals (SDGs), particularly in promoting sustainable urban development and environmental innovation. Nevertheless, the increasing complexity of green finance activities has introduced multidimensional risks that cannot be adequately addressed using conventional risk management approaches. Similarly, the Organisation for Economic Co-operation and Development ([OECD, 2021](#)) highlights that the rapid expansion of green financial instruments has been accompanied by rising concerns related to greenwashing practices, inconsistent regulatory frameworks, renewable energy market volatility, and reputational exposure of financial institutions.

Traditional risk management frameworks, which largely rely on historical data and static risk models, are often insufficient in addressing these emerging risks. According to [Alijoyo \(2025\)](#), emerging risks tend to be dynamic, interconnected, and forward-looking, making them difficult to predict using traditional quantitative techniques. As a result, financial institutions face increasing pressure to adopt more adaptive, data-driven, and predictive approaches to risk management that can respond effectively to rapidly changing sustainability-related risks.

From a theoretical perspective, this study is also informed by the Risk Governance Framework, particularly the International Risk Governance Council (IRGC) perspective, which emphasizes risk identification, assessment, communication, and adaptive response under conditions of uncertainty. This framework is relevant because emerging risks in green finance often involve interconnected financial, environmental, and institutional dimensions that require governance-oriented rather than purely technical responses. Within this framework, artificial intelligence can be positioned not only as a predictive tool but also as an adaptive governance mechanism that supports monitoring, compliance, and risk-informed decision-making.

In this context, artificial intelligence (AI) has gained growing attention as a potential solution for enhancing risk identification, assessment, and mitigation in the financial sector. AI technologies, including machine learning, natural language processing, and predictive analytics, enable the analysis of large volumes of structured and unstructured data, thereby improving the accuracy and timeliness of risk predictions. Several empirical studies demonstrate that AI-based models outperform traditional methods in financial risk management. [Saeedi and Ashraf \(2024\)](#), for instance, emphasize that digital technologies, particularly AI, play a significant role in strengthening risk assessment in green finance and improving transparency in sustainability and ESG reporting. Meanwhile, [Fahrezi \(2024\)](#) finds that AI and machine learning applications in areas such as fraud detection, credit risk assessment, and market volatility prediction provide more accurate and efficient results compared to conventional approaches.

Within the context of green finance, AI holds particular potential in addressing emerging risks. AI-driven tools can be utilized to detect greenwashing practices by analyzing inconsistencies between sustainability disclosures and actual environmental performance. Moreover, AI can support the optimization of capital allocation by identifying projects that genuinely meet sustainability criteria, thereby enhancing the credibility and effectiveness of green finance

initiatives ([Moodaley & Telukdarie, 2023](#)). These capabilities position AI as a strategic enabler for strengthening sustainable investment decision-making and risk governance.

Despite its potential benefits, the application of AI in managing emerging risks in green finance is not without challenges. The lack of consistent and high-quality sustainability data, particularly in developing countries, poses a significant barrier to effective AI implementation. Additionally, algorithmic bias, data transparency issues, and ethical concerns may lead to inaccurate risk assessments and undermine stakeholder trust. Furthermore, the absence of clear regulatory standards governing the use of AI in green finance increases the risk of misuse and limits its broader adoption ([United Nations Environment Programme Finance Initiative \[UNEP FI\], 2022](#)). Given these opportunities and challenges, a systematic literature review on the role of artificial intelligence in managing emerging risks in green finance is essential. Such a review is necessary to synthesize existing academic insights, identify prevailing trends and research gaps, and evaluate the effectiveness of AI-based approaches in sustainable risk management. By providing a comprehensive overview of current knowledge, this study aims to contribute to the development of more robust, adaptive, and sustainability-oriented risk management strategies within the green finance ecosystem.

Despite the growing body of literature on artificial intelligence in financial risk management, there is still limited systematic synthesis that explicitly examines how AI contributes to the governance of emerging risks within the green finance context. Existing studies tend to focus on technical applications such as credit risk prediction and fraud detection, with relatively little attention given to sustainability-specific risks, including greenwashing detection, regulatory compliance, and ESG accountability.

Furthermore, prior research has largely been conducted within developed economies, with limited exploration of the challenges faced by developing countries, where data limitations, regulatory fragmentation, and institutional capacity may significantly influence the effectiveness of AI implementation. Therefore, this study aims to address both a theoretical gap, by integrating AI, emerging risk, and green finance into a unified framework, and an applied gap, by providing insights into how AI can improve risk governance practices in sustainability-oriented financial systems. This study primarily adopts an applied research perspective, aiming to provide practical insights into how AI can be utilized to strengthen risk governance and improve decision-making processes in green finance.

To guide the analysis, this study addresses the following research questions:

1. What are the key emerging risks in the green finance sector identified in recent literature?
2. How can artificial intelligence contribute to managing these emerging risks?
3. What are the main challenges and opportunities in implementing AI for risk management in green finance?

This study contributes to the existing literature in both theoretical and practical dimensions. From a theoretical perspective, this research integrates the concepts of artificial intelligence, emerging risk typology, and sustainable risk governance within the context of green finance. By synthesizing these domains, the study provides a more comprehensive framework for understanding how AI can be utilized to address complex and evolving risks in sustainability-oriented financial systems.

From a practical perspective, this study offers important implications for policymakers, regulators, and financial institutions. The findings highlight how AI can be leveraged to improve risk identification, enhance regulatory compliance, and strengthen transparency in ESG reporting. In addition, this study provides insights into the challenges and considerations that must be addressed to ensure effective and responsible implementation of AI in green finance, particularly in developing countries where regulatory and data constraints are more pronounced.

Taken together, these issues indicate that the relevance of AI in green finance extends beyond predictive efficiency toward its broader role in strengthening governance, accountability, and systemic resilience in sustainability-oriented financial systems.

LITERATURE REVIEW

Theoretical Framework

The analysis of emerging risks in green finance requires a strong theoretical foundation to understand how risks are identified, managed, and governed within complex and dynamic systems. In this context, several theoretical frameworks are relevant, including Enterprise Risk Management (ERM), risk governance frameworks, and sustainability-oriented governance approaches.

Enterprise Risk Management (ERM) provides a structured approach to identifying, assessing, and managing risks across an organization. ERM emphasizes a holistic and integrated view of risk, where financial and non-financial risks are considered simultaneously. This framework is particularly relevant in the context of green finance, where risks are not only financial but also environmental, social, and reputational in nature.

In addition, this study is informed by the Risk Governance Framework proposed by the International Risk Governance Council (IRGC), which emphasizes four interrelated dimensions: risk identification, risk assessment, risk communication, and adaptive risk management. This framework is particularly relevant for emerging risks in green finance because such risks are characterized by uncertainty, interconnectivity, and potential systemic impacts. Within this perspective, managing risk is not solely a technical exercise but also a governance process involving institutions, regulation, and stakeholder coordination.

Furthermore, sustainability-oriented governance and ESG frameworks emphasize the integration of environmental, social, and governance factors into decision-making processes. These approaches recognize that long-term financial stability is closely linked to sustainable practices and responsible governance.

Within these theoretical perspectives, artificial intelligence (AI) can be positioned as an enabling tool that enhances risk governance and management capabilities. AI supports the implementation of ERM by improving risk identification and prediction, strengthens governance frameworks through increased transparency and data-driven insights, and facilitates ESG integration by analyzing large volumes of sustainability-related data. Therefore, AI not only serves as a technical solution but also plays a strategic role in advancing adaptive and sustainability-oriented risk management systems.

This theoretical grounding provides a basis for analyzing how AI can address the limitations of traditional risk management approaches in the context of emerging risks in green finance.

Emerging Risk in the Financial Context

Emerging risks refer to newly evolving risks that arise from significant changes in economic, regulatory, technological, environmental, and social environments. Unlike traditional financial risks, emerging risks are characterized by high uncertainty, limited historical data, and rapidly changing risk drivers. These characteristics make emerging risks particularly difficult to identify, measure, and manage using conventional risk management frameworks that rely heavily on historical trends and static assumptions.

According to the [OECD \(2021\)](#), emerging risks often originate from structural transformations such as climate change, digitalization, geopolitical shifts, and regulatory reforms. In the financial context, these risks can have systemic implications, as they may simultaneously affect multiple institutions, markets, and stakeholders. The lack of historical data further

complicates risk assessment, as traditional quantitative models may fail to capture non-linear relationships and long-term impacts associated with emerging risks.

Furthermore, emerging risks tend to be interconnected, meaning that a single risk event can trigger cascading effects across the financial system. For example, environmental risks related to climate change may translate into credit risk, market risk, and reputational risk for financial institutions. As a result, managing emerging risks requires a forward-looking and adaptive approach that integrates qualitative judgment, scenario analysis, and advanced data analytics. This complexity highlights the limitations of traditional risk management practices and underscores the need for innovative tools capable of addressing uncertainty and dynamic risk environments.

Green Finance and Risk Challenges

Green finance has developed as a key financial mechanism to support environmentally sustainable economic activities. It encompasses various financial instruments, including green bonds, green loans, sustainability-linked financing, and climate-focused investment funds. These instruments aim to channel capital toward projects that contribute to environmental protection, climate change mitigation, and sustainable development.

Despite its rapid growth, green finance faces several unique risk challenges that distinguish it from conventional finance. One of the most prominent risks is greenwashing, which refers to misleading or exaggerated claims about the environmental benefits of financial products or projects. Greenwashing undermines the credibility of green finance initiatives and poses significant reputational risks to financial institutions. When investors perceive that sustainability claims are unreliable, their trust in green financial markets may deteriorate, potentially leading to reduced investment flows.

In addition to greenwashing, regulatory uncertainty represents a major challenge in the green finance landscape. Regulatory frameworks for green finance vary significantly across countries and regions, and in many cases, sustainability standards continue to evolve. This regulatory fragmentation increases compliance costs and creates uncertainty for financial institutions attempting to align their portfolios with sustainability objectives. An additional stream of literature emphasizes the role of sustainable finance taxonomies, such as classification frameworks used to define environmentally sustainable activities, in reducing ambiguity and mitigating greenwashing risks. These taxonomies provide clearer criteria for project eligibility, strengthen regulatory consistency, and support more reliable sustainability disclosures. From a governance perspective, such taxonomies can also provide structured inputs for AI-based compliance monitoring and risk assessment systems. Market risks also remain prevalent, particularly in sectors such as renewable energy, where project performance may be affected by technological change, policy shifts, and price volatility.

The existing literature reveals both converging and diverging perspectives regarding risk challenges in green finance. Several studies consistently identify greenwashing as a major concern that undermines investor trust and weakens the credibility of sustainability initiatives ([Moodaley & Telukdarie, 2023](#)). Similarly, [Liu and Huang \(2022\)](#) highlight reputational and regulatory risks as critical issues affecting financial institutions.

However, differences emerge when comparing findings across contexts. While studies conducted in developed economies tend to emphasize transparency and ESG standardization as key solutions, research in developing countries highlights regulatory inconsistency and limited institutional capacity as more dominant challenges. This suggests that the nature and intensity of green finance risks are highly context-dependent, requiring adaptive and localized risk management approaches.

Artificial Intelligence in Risk Management

Artificial intelligence (AI) has been increasingly adopted in the financial sector as a tool to enhance risk management capabilities. AI technologies, such as machine learning, neural networks, and predictive analytics, enable financial institutions to process large volumes of data, identify complex patterns, and generate more accurate risk assessments. Compared to traditional statistical methods, AI-based models are better suited to handle non-linear relationships and rapidly changing risk factors.

Empirical evidence supports the effectiveness of AI in financial risk management. [Alijoyo et al. \(2021\)](#), in their study of fintech firms in Indonesia, find that risk management practices often remain fragmented and ad hoc, particularly in emerging markets. They argue that the integration of AI can help strengthen risk management systems by enabling continuous monitoring and real-time risk detection. AI-based systems can also improve decision-making by providing early warning signals and predictive insights.

Similarly, [Giudici and Wu \(2025\)](#) demonstrate that incorporating environmental, social, and governance (ESG) factors into machine learning models enhances the reliability of credit risk assessment. Their study highlights that AI not only improves predictive accuracy but also supports sustainable investment decisions by integrating financial and non-financial risk factors. These findings indicate that AI has the potential to transform traditional risk management from a reactive process into a proactive and strategic function.

AI and Sustainability in Green Finance

The intersection between artificial intelligence and green finance has attracted growing attention in recent academic literature. AI-driven models are increasingly used to evaluate the sustainability performance of investment projects by analyzing diverse data sources, including ESG disclosures, carbon emission metrics, and sustainability reports. [Elhady and Shohieb \(2025\)](#) find that machine learning-based models outperform traditional rule-based systems in assessing sustainable investment performance, particularly in complex and data-intensive environments.

Beyond the financial sector, AI has also been applied to enhance sustainability across related domains, such as supply chains. [Albert and Alijoyo \(2024\)](#) show that AI contributes to strengthening supply chain capabilities in developing countries while simultaneously promoting sustainability outcomes. Although their study does not focus exclusively on green finance, the findings are highly relevant, as sustainable supply chains are an integral component of the broader green finance ecosystem.

In the Indonesian context, [Judijanto and Fawait \(2025\)](#) examine the application of AI in risk analysis for green bond projects. Their study reveals that AI can be used to simulate risk scenarios, monitor environmental compliance, and identify potential regulatory risks. However, they also highlight persistent challenges, including limited data availability, weak technological infrastructure, and the absence of clear regulatory standards governing AI usage. These challenges suggest that while AI offers significant potential for strengthening green finance, its effectiveness depends on supportive institutional and regulatory environments.

The literature also reveals a tension between optimism regarding AI's technical efficiency and concerns regarding governance limitations. While many studies emphasize AI's predictive advantages in risk detection and sustainability assessment, others highlight limitations related to explainability, data bias, and weak regulatory oversight. This divergence suggests that the effectiveness of AI in green finance does not depend solely on technical performance but also on the governance structures that shape its accountability, transparency, and institutional legitimacy. While green finance is a global phenomenon, its implementation challenges are often more pronounced in developing countries, where regulatory frameworks are still evolving and data

availability remains limited. These conditions create additional complexities in managing emerging risks and highlight the need for more adaptive and technology-driven approaches.

Research Gap

Based on the reviewed literature, it is evident that although numerous studies have examined the application of artificial intelligence in financial risk management, research that explicitly connects AI with the management of emerging risks in green finance remains limited. Existing studies predominantly focus on technical applications, such as credit risk prediction, fraud detection, or market volatility analysis, without adequately addressing sustainability-specific risks. Moreover, the role of AI in detecting greenwashing, supporting regulatory compliance, and enhancing accountability in green finance has received relatively little scholarly attention. This gap is particularly pronounced in the context of developing countries, where data limitations and regulatory uncertainty pose additional challenges. Therefore, there is a clear need for a comprehensive synthesis of existing research to understand how AI can be leveraged to manage emerging risks in green finance more effectively.

Accordingly, this study aims to fill this gap by conducting a systematic literature review that examines the role of artificial intelligence in managing emerging risks within the green finance framework. By integrating insights from prior studies, this research seeks to contribute to the development of more adaptive, transparent, and sustainability-oriented risk management strategies.

This gap also indicates the need to examine AI not only as a predictive technology but as part of an adaptive risk governance mechanism within sustainable finance systems.

RESEARCH METHOD

Research Design

This study adopts a Systematic Literature Review (SLR) approach to examine the role of Artificial Intelligence (AI) in managing emerging risks within the green finance sector. The SLR method is particularly suitable for this research because it allows for a structured, transparent, and replicable synthesis of existing academic studies. Given that the intersection of AI, emerging risks, and green finance is a relatively new and rapidly evolving research area, a systematic review is essential to consolidate fragmented findings and provide a comprehensive understanding of current knowledge.

The SLR in this study is primarily guided by the PRISMA 2020 framework ([Page et al., 2021](#)), which provides clear guidelines for identifying, screening, and selecting relevant literature, thereby enhancing transparency and methodological rigor.

Review Framework

In addition to PRISMA, this study adapts the SPAR-4-SLR framework proposed by Paul et al. (2021), which consists of four interrelated stages: Setup, Process, Analysis, and Reporting. The integration of PRISMA and SPAR-4-SLR enables a more comprehensive and structured review, combining procedural transparency with analytical depth.

Setup Stage

The setup stage involved defining the research objectives, identifying the scope of the review, and determining the expected academic contribution. At this stage, the focus was placed on understanding how AI has been applied to manage emerging risks in green finance, including risks related to greenwashing, regulatory uncertainty, reputational exposure, and sustainability performance. The research questions were formulated to guide the literature selection and analysis

process.

Process Stage

The process stage focused on systematically identifying relevant academic literature. A comprehensive search was conducted using multiple academic databases, including Google Scholar, ResearchGate, DOAJ, MDPI, SpringerLink, and Frontiers. These databases were selected to ensure broad coverage of peer-reviewed journals in the fields of finance, sustainability, risk management, and artificial intelligence.

The keyword combinations used in the search included “artificial intelligence AND risk management”, “emerging risk AND green finance”, “AI AND sustainable finance”, and “AI AND green bonds”. The search was limited to studies published between 2020 and 2025 to ensure that the reviewed literature reflects the most recent developments in AI and sustainable finance. This time frame is particularly relevant given the rapid evolution of AI technologies and the increasing global focus on sustainability and ESG issues.

The study adopts a purposive database sampling strategy combined with a keyword-based search approach. This method allows the selection of relevant academic articles that specifically address the intersection of Artificial Intelligence, emerging risks, and green finance. The purposive approach ensures that only studies aligned with the research objectives are included, rather than relying on random selection.

The literature selection process followed the PRISMA 2020 framework to ensure transparency and replicability. A total of 145 articles were initially identified through database searches. After removing 25 duplicate records, 120 articles remained for screening. During the title and abstract screening stage, 70 articles were excluded due to lack of relevance to the research topic. The remaining 50 articles were then assessed for full-text eligibility. Of these, 30 articles were excluded for the following reasons: lack of focus on AI or green finance, non-peer-reviewed sources, or insufficient methodological rigor.

Finally, a total of 20 articles were included in the systematic literature review and analyzed in depth. The inclusion of 20 studies was considered adequate because thematic saturation was reached, as additional articles did not generate substantially new themes beyond the identified categories of emerging risks, AI applications, and governance challenges.

Table 1. Summary of Selected Articles

Author	Focus	Method	Key Findings
Alijoyo et al. (2021)	AI in risk management	Empirical	AI improves risk detection
Liu & Huang (2022)	Green finance risk	Case study	Regulatory uncertainty significant
Moodaley & Telukdarie (2023)	Greenwashing	Review	Reputational risks increase
Giudici & Wu (2025)	ESG + AI	ML model	Improves credit risk assessment

Inclusion and Exclusion Criteria

To ensure the relevance and quality of the selected studies, clear inclusion and exclusion criteria were applied during the literature screening process. Articles were included in the review if they met the following criteria:

1. The study focuses on artificial intelligence, risk management, green finance, sustainability, ESG, or emerging risks.
2. The publication is an empirical study or a literature review published in a peer-reviewed

academic journal.

3. The full text of the article is accessible.
4. The study provides theoretical, methodological, or practical insights relevant to sustainable risk management.

Conversely, articles were excluded if they were non-academic publications, opinion pieces, editorials, conference abstracts without full papers, or sources that were not indexed in recognized academic databases. This screening process helped ensure that the reviewed literature maintains a high level of academic credibility.

Data Analysis

The data analysis in this study was conducted using a thematic analysis approach to systematically identify, analyze, and synthesize patterns across the selected literature. The analysis adopts a hybrid approach, combining inductive and deductive strategies. Inductively, themes were derived from recurring patterns observed in the literature, while deductively, the analysis was guided by the TCCM (Theory, Context, Characteristics, Methodology) framework.

The analytical process involved several stages. First, open coding was conducted by reviewing each article and identifying key concepts, findings, and recurring topics related to artificial intelligence, emerging risks, and green finance. Second, these initial codes were grouped into broader categories through a process of categorization, such as AI in risk management, emerging risks in green finance, ESG and sustainability analysis, and implementation challenges.

Finally, a synthesis stage was carried out to integrate the categorized findings into coherent themes, allowing for comparison across studies and identification of converging and diverging perspectives. This structured analytical procedure enables a comprehensive understanding of how AI contributes to managing emerging risks in green finance.

Validity and Reliability

To ensure the validity and reliability of the literature review process, several measures were implemented throughout the study. First, the article screening and selection process was conducted systematically based on predefined inclusion and exclusion criteria. To enhance reliability, the screening process can be replicated and verified using the same criteria and keyword combinations.

To further strengthen reliability, the screening and coding process involved independent review by two reviewers, followed by cross-checking of inclusion decisions. Any discrepancies in study selection or thematic coding were resolved through discussion until agreement was reached. This process helped improve coding consistency and reduce subjective bias in the synthesis.

In addition, the selection and classification of articles were carried out with careful cross-checking to minimize bias. Where necessary, inclusion decisions were re-evaluated to ensure consistency with the research objectives. Any discrepancies in interpretation or classification were resolved through iterative review and critical assessment of the articles.

Furthermore, thematic analysis was applied to synthesize the findings, and coding consistency was maintained by grouping studies into clearly defined categories, such as AI in risk management, emerging risks in green finance, and implementation challenges. This structured coding process ensures that the analysis remains consistent, transparent, and aligned with the research framework.

These steps contribute to enhancing the robustness, transparency, and reproducibility of the study, thereby strengthening the overall credibility of the research findings.

Reporting and Synthesis

The final stage of the review involved systematically reporting the findings in accordance with the PRISMA 2020 guidelines ([Page et al., 2021](#)). This includes a transparent description of the literature selection process and a structured presentation of the review results. The synthesis of findings emphasizes how AI contributes to managing emerging risks in green finance, as well as the limitations and challenges associated with its implementation.

This study adheres to the PRISMA 2020 checklist to ensure transparency, completeness, and methodological rigor in reporting the systematic literature review process.

Complementary Framework: TCCM Analysis

As a complementary analytical tool, this study applies the TCCM (Theory, Context, Characteristics, Methodology) framework to further examine the reviewed literature. The TCCM framework facilitates a deeper understanding of the theoretical foundations employed in prior studies, the contexts in which AI is applied within green finance, the characteristics of the emerging risks addressed, and the methodological approaches adopted by researchers.

By applying the TCCM framework, this study is able to systematically identify research gaps and propose future research directions, particularly in relation to developing countries and sustainability-oriented risk governance.

Methodology Contribution

By integrating PRISMA, SPAR-4-SLR, and TCCM, this study ensures methodological rigor, transparency, and analytical depth. This integrated approach allows the research to produce a comprehensive and systematic literature review that aligns with academic publication standards in the fields of risk management, artificial intelligence, and sustainable finance.

FINDINGS AND DISCUSSION

The findings presented in this section are based on the studies selected through the PRISMA 2020 process, as illustrated in the PRISMA flow diagram in the methodology section.

Identification of Emerging Risks in Green Finance

The findings of this systematic literature review indicate that the concept of emerging risk has become increasingly central in discussions of sustainable and green finance. Unlike conventional financial risks, emerging risks are characterized by high levels of uncertainty, limited historical data, and the potential to generate systemic impacts across financial markets. The [OECD \(2021\)](#) emphasizes that these risks are often driven by structural changes, such as climate transition, regulatory transformation, and technological disruption, which evolve faster than traditional risk management frameworks can accommodate.

In the context of green finance, emerging risks are particularly complex because they involve both financial and non-financial dimensions. Environmental performance, regulatory compliance, and stakeholder perception are closely intertwined, making risk identification and assessment more challenging. The literature consistently highlights several key emerging risks that dominate the green finance landscape.

Greenwashing Risk

Greenwashing risk is one of the most frequently discussed emerging risks in green finance literature. It refers to situations in which companies or financial institutions make misleading or exaggerated claims regarding the environmental benefits of their products, projects, or investments. [Moodaley and Telukdarie \(2023\)](#) argue that greenwashing undermines the credibility

of sustainability reporting and erodes investor trust, which is essential for the long-term development of green financial markets.

From a risk management perspective, greenwashing poses significant reputational and legal risks. Financial institutions associated with greenwashing practices may face regulatory sanctions, litigation, and loss of investor confidence. Moreover, the difficulty in verifying sustainability claims due to inconsistent reporting standards further amplifies this risk. These findings suggest that traditional compliance-based risk controls are insufficient to address greenwashing, reinforcing the need for more advanced, data-driven monitoring tools.

Regulatory Uncertainty

Regulatory uncertainty represents another major emerging risk in green finance, particularly in developing and emerging economies. Green finance regulations are often fragmented, evolving, and inconsistent across jurisdictions. [Liu and Huang \(2022\)](#) illustrate how overlapping and rapidly changing regulations in China have increased compliance costs and operational risks for banks involved in green lending activities.

The literature indicates that regulatory uncertainty can negatively affect investment decisions by increasing ambiguity regarding eligibility criteria, reporting obligations, and long-term policy support. As a result, financial institutions may become reluctant to expand their green finance portfolios despite strong sustainability commitments. This highlights the importance of adaptive risk management systems capable of tracking regulatory developments in real time and assessing their potential impact on financial performance.

Volatility of Renewable Energy Projects

Another emerging risk identified in the literature relates to the volatility of renewable energy projects. Renewable energy investments are exposed to market risks arising from fluctuations in energy prices, technological advancements, and changes in government subsidies. Unlike traditional energy projects, renewable energy initiatives often rely on policy incentives and emerging technologies, making their cash flows more uncertain.

This volatility poses challenges for financial institutions in terms of credit risk assessment and long-term project valuation. The findings suggest that conventional financial models may underestimate these risks due to their reliance on historical performance data, which may not accurately reflect future market dynamics in the renewable energy sector.

Reputational Risk

Reputational risk in green finance arises when financial institutions fail to meet the sustainability commitments communicated to stakeholders. This risk is closely linked to greenwashing and regulatory compliance, as discrepancies between stated sustainability goals and actual performance can lead to public criticism and loss of credibility. The literature emphasizes that reputational damage can have long-lasting financial consequences, including reduced investor confidence and higher funding costs.

Table 2. Emerging Risks Identified Across Reviewed Studies

Risk Type	Description	Impact	Key References
Greenwashing	Misleading sustainability claims	Loss of investor trust, reputational damage	Moodaley & Telukdarie (2023)

Risk Type	Description	Impact	Key References
Regulatory Uncertainty	Inconsistent and evolving regulations	Increased compliance costs, investment hesitation	Liu & Huang (2022)
Renewable Energy Volatility	Fluctuations in energy markets and technology	Uncertain project returns, higher financial risk	OECD (2021)
Reputational Risk	Failure to meet ESG commitments	Reduced credibility and funding access	Multiple studies

The Role of AI in Risk Management

The limitations of conventional risk management methods have driven the increasing adoption of Artificial Intelligence (AI) in the financial sector. Traditional risk management approaches often rely on backward-looking data and static models, which are inadequate for addressing emerging risks characterized by uncertainty and rapid change. [Alijoyo et al. \(2021\)](#) highlight that many fintech firms in Indonesia exhibit low levels of risk management maturity, with risk practices that remain reactive and fragmented.

AI-based risk management systems offer a more dynamic and forward-looking alternative. [Fahrezi \(2024\)](#), through a systematic literature review, demonstrates that AI and machine learning techniques have been widely applied in areas such as credit risk prediction, fraud detection, and market volatility analysis. These techniques enable financial institutions to process large datasets, identify complex patterns, and generate early warning signals.

[Giudici and Wu \(2025\)](#) further emphasize that incorporating ESG factors into machine learning models enhances the reliability of credit risk assessments. Their findings suggest that AI enables a more holistic evaluation of risk by integrating financial and sustainability-related information. Overall, the literature identifies several key contributions of AI to risk management :

1. Enhanced prediction accuracy, as AI models can capture non-linear relationships among diverse risk factors.
2. Reduced analysis time, enabling faster identification and response to emerging risks.
3. Increased adaptability, as AI systems can be continuously updated with new data and evolving risk indicators.

These contributions indicate that AI has the potential to transform risk management from a reactive function into a proactive and strategic capability.

Table 3. AI Applications and Governance Implications

AI Application	Function	Benefit	Governance Implication
Machine Learning	Risk prediction	Higher accuracy	Requires data transparency
NLP (Text Analysis)	ESG report analysis	Detect greenwashing	Improves accountability
Predictive Analytics	Market forecasting	Faster decision-making	Supports regulatory compliance
AI Simulation	Risk scenario modeling	Anticipates uncertainties	Enhances risk governance

Integration of AI in Green Finance

Beyond its technical capabilities, the role of artificial intelligence in managing emerging risks can be better understood by linking its functions to the inherent characteristics of these risks.

Emerging risks are typically defined by high uncertainty, strong interconnectivity, and the potential for systemic impact. Traditional risk management approaches, which rely on historical data and linear models, often struggle to capture these complex dynamics.

AI addresses uncertainty by utilizing predictive analytics and machine learning algorithms that can identify hidden patterns within large and diverse datasets. This enables financial institutions to generate forward-looking insights even in the absence of complete historical data. In terms of interconnectivity, AI systems are capable of integrating multiple data sources, such as financial indicators, ESG metrics, and regulatory information, allowing for a more holistic understanding of how risks interact across sectors and systems.

Furthermore, AI contributes to managing systemic risk by detecting early warning signals and simulating potential risk scenarios. This capability is particularly important in green finance, where risks can propagate across financial markets, environmental systems, and regulatory frameworks. Therefore, AI does not merely improve efficiency in risk management but fundamentally enhances the ability of institutions to respond to complex, dynamic, and interconnected risk environments.

The findings also reveal that the integration of AI in green finance is expanding globally and is increasingly viewed as a strategic tool for sustainable investment decision-making. [Elhady and Shohieb \(2025\)](#) find that machine learning models outperform traditional rule-based approaches in assessing sustainable investment performance. This is particularly relevant in green finance, where decision-making often involves unstructured data such as ESG reports, carbon emission metrics, and media coverage.

[Albert and Alijoyo \(2024\)](#) provide additional insights by demonstrating that AI applications in supply chain management can strengthen operational efficiency while promoting sustainability outcomes in developing countries. Although their study does not directly focus on green finance, the findings are relevant because sustainable supply chains are an integral component of the green finance ecosystem and influence the overall risk profile of green investments.

In the Indonesian context, [Judijanto and Fawait \(2025\)](#) examine the application of AI in green bond risk analysis. Their study shows that AI can be used to simulate risk scenarios, monitor environmental compliance, and anticipate regulatory challenges throughout the project lifecycle. However, they also identify critical barriers, including limited data availability, inadequate technological infrastructure, and underdeveloped regulatory frameworks. These findings underscore the contextual challenges faced by developing countries in adopting AI-driven risk management solutions.

This alignment between AI capabilities and emerging risk characteristics highlights its strategic role within adaptive and sustainability-oriented risk governance frameworks.

Challenges and Opportunities in AI Implementation

Despite the significant benefits identified, the literature also highlights several challenges associated with the implementation of AI in managing emerging risks in green finance. [UNEP FI \(2022\)](#) reports that many financial institutions struggle to identify and adopt climate risk assessment tools that align with their specific operational and regulatory environments. Data-related challenges remain particularly prominent, as sustainability and environmental data are often incomplete, inconsistent, or non-standardized.

Algorithmic bias represents another critical concern, as biased training data can lead to inaccurate risk assessments and ethical issues. In addition, the absence of clear regulatory frameworks governing the use of AI in sustainable finance increases the risk of misuse and limits institutional confidence in adopting AI-based solutions.

However, alongside these challenges, the findings reveal substantial opportunities. AI has strong potential to enhance transparency in ESG reporting, detect greenwashing practices at an early stage, and optimize capital allocation toward projects that genuinely meet sustainability standards. These opportunities suggest that, when supported by robust governance frameworks and regulatory clarity, AI can play a pivotal role in strengthening sustainable risk management in green finance.

Table 4. Thematic Synthesis Matrix of Reviewed Studies

Theme	Key Insights	Converging Findings	Diverging Findings
Emerging Risks	Complex & uncertain risks dominate green finance	All studies highlight greenwashing & regulation	Differences across developed vs. developing countries
AI in Risk Management	AI improves prediction & efficiency	Agreement on technical benefits	Differences in governance readiness
AI in Green Finance	AI supports ESG & sustainability decisions	Strong support for AI adoption	Barriers in data & regulation
Implementation Challenges	Data & regulation are key constraints	Consistent across studies	Severity higher in developing countries

The thematic synthesis suggests that the value of artificial intelligence in green finance extends beyond improving technical risk prediction. A consistent pattern across the reviewed studies indicates that AI contributes most effectively when its predictive capabilities are supported by governance structures capable of addressing uncertainty, interconnectivity, and systemic impacts. This finding reinforces the view that AI functions not only as a technological innovation but also as an adaptive governance mechanism within sustainable risk management systems.

Critical Discussion: Emerging Tensions in AI-Driven Risk Management

One key tension lies between predictive efficiency and explainability. AI models, particularly those based on machine learning, are capable of generating highly accurate predictions by identifying complex patterns in large datasets. However, many of these models operate as “black boxes,” making it difficult for stakeholders to understand how decisions are derived. This lack of transparency may create challenges in regulatory compliance and reduce trust among investors and policymakers.

In addition, some studies present contradictory findings regarding the effectiveness of AI in sustainability-related risk management. While several studies report improvements in predictive performance, others question whether these improvements necessarily translate into better governance outcomes, particularly where institutional oversight remains weak. This suggests that technological capability alone does not guarantee improved risk governance outcomes.

Another important tension emerges between technological innovation and regulatory development. While AI technologies are advancing rapidly, regulatory frameworks governing their use in green finance often lag behind. This creates uncertainty for financial institutions, as the absence of clear guidelines may increase the risk of misuse or inconsistent application. As a result, institutions may face a dilemma between adopting innovative solutions and ensuring compliance with evolving regulatory expectations.

Furthermore, differences between developed and developing countries introduce additional complexity. In developed economies, the availability of high-quality data, advanced technological infrastructure, and mature regulatory systems facilitates the adoption of AI in risk management. In contrast, developing countries often face constraints related to limited data availability, weaker institutional capacity, and fragmented regulations. These disparities suggest that the effectiveness of AI in managing emerging risks is highly context-dependent and may require localized adaptation strategies.

These tensions indicate that, while AI offers powerful tools for managing emerging risks, its implementation must be accompanied by strong governance frameworks, regulatory clarity, and ethical considerations. Addressing these trade-offs is essential to ensure that AI contributes not only to technical efficiency but also to sustainable and responsible risk management practices. Overall, the findings indicate that the contribution of AI in managing emerging risks in green finance should be understood not merely in terms of predictive efficiency but in relation to its broader role in enabling adaptive governance, strengthening accountability, and supporting systemic financial resilience. This conceptual synthesis connects the technical, institutional, and sustainability dimensions identified across the reviewed studies.

CONCLUSIONS

This study was guided by several key research questions, namely: (1) what types of emerging risks are present in green finance, (2) how artificial intelligence (AI) can be utilized to manage these risks, and (3) what challenges and limitations are associated with the implementation of AI in this context.

The findings of this study provide clear answers to these questions. First, the analysis identifies major emerging risks in green finance, including greenwashing, regulatory uncertainty, renewable energy project volatility, and reputational risk. Second, the study demonstrates that AI plays a significant role in enhancing risk management through improved prediction accuracy, faster data processing, and the integration of ESG-related information. Third, the findings reveal that despite its potential, AI implementation faces several challenges, particularly related to data quality, algorithmic bias, and regulatory uncertainty.

This study examines the role of artificial intelligence (AI) in managing emerging risks within the green finance framework through a systematic literature review. Based on the synthesis of existing academic studies, the findings indicate that AI has a significant and growing contribution to strengthening risk management practices in green finance. AI technologies enable large-scale data processing, the identification of complex and non-linear risk patterns, and faster as well as more accurate decision-making processes. These capabilities are particularly relevant in the context of emerging risks, which are characterized by high uncertainty, limited historical data, and dynamic risk drivers.

The review highlights that emerging risks in green finance, such as greenwashing, regulatory uncertainty, renewable energy project volatility, and reputational risk, cannot be effectively addressed using traditional risk management approaches alone. Conventional methods tend to be backward-looking and static, making them less responsive to rapidly evolving sustainability-related risks. In contrast, AI-based risk management systems offer a more adaptive and forward-looking approach by integrating financial and non-financial data, including ESG indicators, environmental metrics, and regulatory information. As a result, AI enhances the ability of financial institutions to anticipate risks, improve transparency, and strengthen sustainable investment decision-making.

From a practical perspective, the findings emphasize the importance of encouraging financial institutions to integrate AI into their risk management frameworks. AI adoption can

support early detection of greenwashing practices, enhance the credibility of sustainability reporting, and optimize capital allocation toward projects that genuinely contribute to environmental sustainability. For financial institutions operating in the green finance sector, AI is not merely a technological tool but a strategic enabler for achieving long-term sustainability objectives while maintaining financial stability.

However, the effective implementation of AI in managing emerging risks also depends on the availability of supportive institutional and regulatory environments. The literature consistently highlights challenges related to data quality, algorithmic bias, and the absence of clear regulatory standards governing the use of AI in sustainable finance. Therefore, regulatory authorities play a critical role in establishing clear guidelines, data standards, and governance frameworks to ensure that AI adoption aligns with principles of transparency, accountability, and ethical responsibility.

From an academic standpoint, this study contributes to the existing literature by providing a structured synthesis of research at the intersection of AI, emerging risks, and green finance. By integrating PRISMA, SPAR-4-SLR, and TCCM frameworks, this review offers a comprehensive overview of current research trends, identifies key research gaps, and highlights areas requiring further investigation. Despite the growing body of literature on AI in financial risk management, studies that explicitly focus on emerging risks in green finance, particularly in developing countries, remain limited.

Theoretically, this study extends existing frameworks in risk management and sustainable finance by positioning artificial intelligence not merely as a predictive analytical tool but as an adaptive governance mechanism. In the context of Risk Governance Theory, AI enhances the ability of institutions to monitor, anticipate, and respond to complex and interconnected risks in a dynamic environment. This aligns with the need for adaptive and forward-looking governance structures in managing emerging risks.

Furthermore, the findings contribute to the development of Enterprise Risk Management (ERM) by emphasizing the integration of environmental, social, and governance (ESG) dimensions into risk assessment processes. AI facilitates this integration by enabling the analysis of both financial and non-financial data, thereby expanding the scope of traditional ERM frameworks.

In addition, this study contributes to sustainable finance governance by highlighting the role of AI in improving transparency, accountability, and compliance in green finance practices. These insights suggest that AI can serve as a key enabler in strengthening governance mechanisms and supporting the long-term resilience of the financial system.

Accordingly, future research is encouraged to explore the application of AI in green finance within diverse institutional and regulatory contexts, especially in emerging economies such as Indonesia. Further studies could also examine the development of explainable AI models to enhance transparency and trust, as well as the role of AI governance in supporting sustainable risk management. Addressing these issues will be essential for maximizing the potential of AI as a tool for strengthening resilience and sustainability in the global financial system.

From a practical perspective, this study offers several actionable recommendations for key stakeholders. For regulators, it is essential to develop clear governance frameworks for the use of AI in sustainable finance, including standardized ESG data reporting and guidelines for ethical and transparent AI implementation. Establishing such standards can reduce regulatory uncertainty and enhance market confidence.

For financial institutions, the findings suggest the importance of adopting explainable AI models to improve transparency and accountability in risk assessment processes. Institutions should also strengthen the integration of AI within their compliance and risk management systems to ensure alignment with evolving sustainability regulations.

For policymakers, there is a need to harmonize sustainable finance taxonomies and regulatory standards across jurisdictions. This can facilitate cross-border investments, reduce fragmentation, and support the scalability of green finance initiatives.

Overall, these recommendations highlight that AI should not only be viewed as a technological innovation but as a governance-enabling mechanism that supports compliance monitoring, enhances accountability, and strengthens systemic financial resilience in the context of sustainable finance.

LIMITATIONS AND FURTHER RESEARCH

This study has several limitations. First, as a systematic literature review, the findings depend on the scope and quality of the selected articles, which may limit generalizability. Second, the study focuses primarily on literature published between 2020 and 2025, which may exclude earlier foundational studies relevant to risk governance and sustainable finance. Third, the analysis is constrained by the availability of studies specifically linking artificial intelligence, emerging risks, and green finance, particularly in developing country contexts. These limitations suggest that the findings should be interpreted as a structured synthesis of current knowledge rather than universal conclusions.

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