International Journal of Innovative Research and Scientific Studies, 8(5) 2025, pages: 1188-1201

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

Sustainable banking in Indonesia: Leveraging risk management practice and artificial intelligence integration to enhance sustainable performance

Boy Tjahyono[1*], Mts Arief[2], Willy Gunadi[3], Diena Dwidienawati[4]

[1,2,3,4]*Bina Nusantara University, Jakarta, Indonesia.*

Corresponding author: Boy Tjahyono (*Email: Boy.tjahyono@binus.ac.id*)

Abstract

The Indonesian banking industry faces ongoing challenges in maintaining resilience while achieving sustainable performance, particularly in enhancing governance, risk management, and compliance. This study aims to develop a strategic model to improve sustainable bank performance by strengthening risk management practices through the integration of artificial intelligence (AI). Additionally, it investigates the moderating effect of environmental volatility on the relationship between risk management practices and sustainable performance. The research focuses on commercial banks in Indonesia categorized under KBMI II, III, and IV, with data collected from managerial-level respondents, including C-level executives, Senior Vice Presidents, Vice Presidents, Assistant Vice Presidents, and managers. Using convenience sampling, a total of 117 valid responses were gathered through a 36-item online questionnaire and analyzed using partial least squares structural equation modeling (PLS-SEM). The findings reveal that AI integration significantly enhances risk management practices, which in turn positively affect sustainable bank performance. However, environmental volatility exerts a minimal moderating effect on this relationship. These insights suggest that Indonesian banks should adopt a comprehensive and technology-driven approach to enhance long-term sustainability.

Keywords: AI Integration, Bank, Environmental volatility, Risk management practice, Sustainable bank performance.

DOI: 10.53894/ijirss.v8i5.9081
Funding: This study received no specific financial support.
History: Received: 5 June 2025 / **Revised:** 10 July 2025 / **Accepted:** 15 July 2025 / **Published:** 5 August 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Publisher: Innovative Research Publishing

1. Introduction

A country's economic framework is significantly influenced by its financial sector. Banks act as financial intermediaries and are essential for stimulating the real sector and the economy. The banking sector functions as a conduit for the efficient transfer of cash, which is vital for economic development initiatives [1]. Banks stimulate economic growth

by providing company capital, increasing consumer spending and economic activity, advancing money markets through market penetration, producing financial products, and strengthening the financial sector [2, 3].

The Indonesian banking sector faces challenges similar to those of international banks, where profit generation is difficult. Escalating economic pressures, which reduce public purchasing power and are exacerbated by increased competition among banks, result in significant non-performing loan management issues and constrained liquidity as third-party fund growth slows [4, 5].

The current momentum of stable performance in the banking sector can be leveraged to explore methods by which banks in the country may annually improve their business performance and, importantly, how they can focus their efforts on sustaining their operations. Banks are motivated to participate in sustainability initiatives through the sustainable finance scheme, which involves applying sustainable finance principles to fund environmentally friendly sectors such as renewable energy, energy efficiency, waste management, sustainable agriculture and fisheries, green buildings, and sustainable tourism. The promulgation of OJK Regulation No. 51/POJK.03/2017 on Sustainable Finance requires commercial banks to support projects and investments that further sustainable development goals, such as carbon emission reduction, renewable energy promotion, and social initiative facilitation.

The global bank risk survey conducted by EY & Institute of International Finance [6] reveals that Chief Risk Officers see five critical adjustments necessary for managing risks associated with digital asset strategies: 1) modifications in risk management, 2) the imperative for workers to possess pertinent skills and knowledge, 3) technological advancements, 4) enhanced staff training, and 5) banks' thorough comprehension and ability to manage circumstances and regulatory changes. Banks require leadership experience and proficiency in managing a variety of disruptions or potential business interruptions, as indicated in point 5 [6].

Moreover, alterations in risk management strategies are essential for improving bank performance and maintaining sustainability for both the present and future. Organizations should not solely engage in risk management to meet banking standards or compliance mandates; they are encouraged to proactively anticipate exceptional risks by increasingly leveraging historical data [7].

Effective risk management in the banking sector is crucial, since insufficient procedures can adversely affect both the institution and the global economy [8]. As a result, the field of risk management has become increasingly important, especially in the financial sector. Effective risk management has proven its ability to allow banks to withstand global crises. A robust risk culture and unified organizational processes have proven their capacity to improve value-added performance and yield significant economic benefits. Frameworks and guidelines for risk management in the banking sector primarily focus on the concepts and execution of bank risk management as outlined by OJK Regulation No. 18/POJK.03/2016 concerning the application of risk management in commercial banks. The results of risk management implementation may vary according to the bank's size, operational complexity, and resource availability. Nevertheless, the Indonesian banking sector continually strives to improve its risk maturity to guarantee resilience in a dynamic and competitive economic environment [9].

Firms are compelled to adopt sustainable leadership to enhance their sustainability performance, as one of the escalating challenges posed by climate change is currently identified as a primary risk [10, 11]. Studies by Avery and Bergsteiner [12] and Iqbal et al. [11] indicate that sustainable leadership significantly enhances organizational learning, thereby bolstering sustainable performance. This study emphasizes the importance of developing sustainable leadership skills, such as cultivating a collective vision and employee appreciation, to improve the quality of life for long-term stakeholders and organizational performance.

Mossavar-Rahmani and Zohuri [13] contend that the financial sector is undergoing a substantial transformation, primarily propelled by the ongoing incorporation of Artificial Intelligence (AI) into the core functions of financial institutions. It is clear that AI is not merely a trend but a transformative force that is redefining the core of traditional financial institutions, particularly banking, as we navigate the intricate landscape of technological advancement. The banking industry is utilizing AI to redefine the essence of its services, resolve intricate challenges, and uncover extraordinary opportunities in an era where data is a valuable asset and agility is essential.

However, a survey conducted by Deloitte [14] indicates that the application of AI in many banking functions, including risk management, is still constrained. Furthermore, the utilization of AI is more prevalent among market-leading institutions that have already embraced digital adoption due to their financial strength. In Indonesia, banks categorized as KBMI III (core capital above IDR 14 trillion to IDR 70 trillion) and KBMI IV (core capital beyond IDR 70 trillion) are included [15].

The incorporation of AI in banking is a multifaceted endeavor that utilizes several technologies to enhance both front- and back-office functions. It is imperative for banks aiming to sustain competitiveness in the digital age. A comprehensive strategy is essential to modernize core technology, implement new operational models, and provide robust data security and governance [16].

Banks recognize that the oscillations inherent in their operations are closely tied to a volatile environment, drawing ideas from their experiences during the 1997 Asian financial crisis and the 2019 COVID-19 pandemic. In the financial sector, the term signifies rapidly changing market conditions that are challenging to predict. This incorporates a variety of factors within the banking sector, such as legislative modifications, the emergence of new technology, competition from non-banking entities, customer behavior, prevailing conditions, external dangers, and the effects of globalization. Indonesian banks must rapidly adapt, make astute strategic judgments, and persist in innovation to maintain their competitiveness and business viability in this volatile market.

2. Literature Review and Hypothesis Development

2.1. AI Integration

Artificial intelligence marks a significant advancement in digitizing traditional banking by enhancing efficiency and driving potential revenue growth, although its implementation has been somewhat limited. AI has been tested in applications such as real-time fraud detection, cost reduction through know-your-customer (KYC) procedures, and improving labor productivity by automating repetitive tasks. Achary [17]. Boustani [18] found that bank clients and employees in several developing Asian countries are satisfied with current technologies, demonstrating readiness to adopt AI for improved business transactions. Sunmola and Lawrence [19] emphasize that successful AI integration depends on aligning business models, technology, employee readiness, and regulatory factors. To minimize disruption, integration should utilize mature, compatible systems and be timed for when the organization is prepared. Training is essential to upskill employees for advanced technologies, while legal and financial considerations must align with expected benefits, especially given the current regulatory uncertainties and high investment costs.

2.2. Risk Management Practice

Risk management is essential for maintaining organizational resilience in a dynamic and uncertain environment, as highlighted by Hudáková and Lahuta [20], who emphasize its role in crisis prevention and enhancing business awareness. Teece et al. [21] add that modern risk management emphasizes addressing significant uncertainties, including unknown unknowns. The banking sector, in particular, has faced increased challenges due to the pandemic, leading to reduced profitability, slower loan growth, and weakened economic development, which necessitate proactive hazard control strategies Alabdullah et al. [22]. Puspitasari et al. [23] identify four major threats to bank stability: credit, market, operational, and liquidity risks and emphasize the importance of managing these to safeguard performance. Teece et al. [21] reinforce the need for robust risk management frameworks, especially in developing countries, to ensure long-term sustainability and financial stability amid growing financial uncertainties.

Effective risk management enables financial institutions to require less capital while accelerating growth by identifying, managing, and minimizing potential losses efficiently. Aligned with the fourth pillar of the Indonesian Banking Architecture (API), risk management is essential for building a robust and integrated banking system [5], requiring commercial banks to assess ten types of risks, including credit, market, operational, and reputational risks. Bessis [24] views risk management as a strategic process to mitigate organizational threats, while Enterprise Risk Management (ERM) is linked to competitive advantage. Chance and Brooks [25] and Keown et al. [26] define risk as the uncertainty in future profitability and income variability. According to International Organization for Standardization [27] and Purdy [28], risk management aims to reconcile inconsistencies in methods and terminology, offering a unified framework for addressing organizational risk exposure.

Abdullah et al. [29] emphasize that risk management involves the board of directors, organizations, and management in identifying events that could impact the firm, with disclosures deemed "destructive" if they reveal potentially harmful risks. Unlike traditional approaches, Enterprise Risk Management (ERM) offers a holistic framework for managing risks across all organizational levels. Defined by COSO, ERM is a structured process involving the board and staff to identify opportunities and manage risks aligned with the entity's risk appetite, ensuring the achievement of objectives [30]. The implementation of ERM is guided by International Organization for Standardization [27] which provides a standardized framework using the "Plan, Do, Check, Act" cycle. Florio and Leoni [31] argue that ERM enhances organizational performance and mitigates diverse risks, while Bromiley et al. [32] view it as an integrated system combining risk management with corporate governance and strategy.

Khalid and Amjad [33] delineate five steps for the implementation of risk management (RM). The stages must be systematically arranged and implemented based on necessity, yielding more effective outcomes [34]. The protocol is as outlined:

a. Understanding risk and risk management demonstrates the systematic implementation of sophisticated risk management strategies, including continuous evaluation and analysis of potential risks [33, 35]. Entities, including senior management, managers, and employees in the banking sector, must understand the concept of risk in banking operations and the threats to their investments and activities. A thorough comprehension of risk and risk management techniques can demonstrate the effectiveness of banks in long-term risk management and positively influence other risk management strategies [36]. Understanding risk and risk management can improve banking performance, as demonstrated above.

b. Risk identification entails taking initiative, raising awareness, expressing broad viewpoints, gaining commitment, and outlining expectations. Risk identification is a critical first step in implementing effective risk management, particularly in the banking sector. It involves establishing criteria to detect specific hazards by analyzing risk factors [37]. This process includes recognizing sources of risk and the activities they may affect, as emphasized by Jabnoun and Al-Khalifa [38] and Power [36], who highlight its role in regulating and supervising the overall risk management process. Laycock [39] outlines two key techniques: (a) risk mapping, which requires banks to understand various risk categories, classify them based on frequency and severity, and focus mitigation efforts on the most common and impactful threats; and (b) risk analysis, which ranks risks by importance to help management allocate resources efficiently and strengthen strategic responses.

c. Risk analysis and assessment involve analyzing the likelihood of risk occurrence using quantitative and qualitative methodologies, evaluating the costs and benefits of risk management, and prioritizing risks to identify those requiring active management [33]. Additional elements to consider in risk analysis and evaluation include economic issues, legal considerations, environmental aspects, and social dimensions. The active risk analysis and assessment process aids

decision-makers in commercial institutions in the formulation of plans, thereby allowing them to effectively mitigate, prioritize, and quantify risks [40]. Risk assessment allows top management to estimate the extent of risk. Thus, organizations with these competencies may demonstrate enhanced business performance.

d. Risk monitoring involves evaluating the effectiveness of internal controls and risk management methods to address threats faced by banks, ensuring proper reporting and communication systems are in place for effective decision-making [33]. It also ensures consistent application of risk strategies and helps detect errors [41] with attention to system effectiveness despite limited oversight capacity [40, 42]. Credit risk, as the most significant threat to banking stability, requires thorough assessments of borrowers' creditworthiness, including integrity, capacity, collateral, and economic conditions, before loan approval [33]. As 60% of risk in banking is attributed to credit issues [24] credit risk analysis aims to enhance risk-adjusted returns by minimizing defaults and credit downgrades.

Risk management practice is delineated as a systematic process for discovering, evaluating, and addressing risks to prevent potential adverse effects on an organization. It includes a series of processes: risk identification, risk analysis, risk evaluation, risk management, monitoring, and review. This strategy aims to manage and monitor risks in alignment with business goals and risk appetite, thereby reducing the probability of negative outcomes while maximizing opportunities.

2.3. Environmental Volatility

Environmental volatility refers to the frequency and intensity of rapid changes in an organization's external environment, including fluctuations in market demand, consumer preferences, and technology, which create uncertainty and risk [43, 44]. These dynamic conditions hinder accurate forecasting and demand continuous adaptation [45-47]. While large firms face heightened risks due to their complex operational environments, small firms may experience fewer external pressures, leading to potentially slower but steadier growth [48]. In such environments, organizations must strategically balance economic, social, and environmental factors to achieve a sustainable competitive advantage [49]. Empirical studies by Soto-Acosta et al. [50] and Sanchez et al. [51] affirm a positive relationship between environmental dynamism and firm performance, highlighting the importance of monitoring external changes. Overall, environmental volatility underscores the necessity for adaptive strategies and robust environmental assessments [47, 52].

2.4. Sustainable Bank Performance

Historically, organizational performance was assessed through financial assets, market position, and liabilities [11], but there has been a shift towards sustainable performance that aligns financial outcomes with social and environmental impacts [46]. This shift reflects the interdependence of organizations, the environment, and society in promoting mutually beneficial outcomes. Integrating ecological, environmental, and social considerations offers a competitive advantage [53, 54] as organizations adopt sustainable practices to mitigate negative impacts [55] and meet stakeholder expectations [11, 56]. Sustainable performance is evaluated by considering economic, environmental, and social indicators across all stakeholders without clear boundaries [57] with emphasis on resource efficiency, environmental initiatives, and stakeholder value creation [58]. Sustainable leadership also involves long-term vision, systemic thinking, and managerial development [12]. In the banking context, sustainable performance means maintaining financial success while adhering to sustainability principles [59]. This study explores how AI integration and risk management practices influence sustainable performance in banking, aiming to provide practical strategies for enhancing sector resilience and sustainability.

2.5. Theoretical Framework, Hypotheses Development, and Research Model

2.5.1. Theoretical Framework

This study examines the Indonesian banking industry's response to ongoing uncertainty and turbulence, where maintaining sustainable growth and performance requires effective risk management and adaptation strategies. It focuses on how banks navigate environmental volatility through AI integration, risk management practices, and adherence to industry regulations to ensure long-term viability. Grounded in Dynamic Capability Theory, the research frames banks as entities capable of generating and transforming knowledge to address environmental shifts. Dynamic capabilities, rooted in the resource-based view [60] are defined as a firm's capacity to integrate, build, and reconfigure internal and external competencies [61] involving deliberate and repeatable organizational processes [62, 63]. These capabilities consist of three core activities: sensing opportunities and threats, seizing them, and reconfiguring resources accordingly [64]. As Nonaka et al. [65] highlight, firms must constantly explore technologies and markets across geographic contexts, though translating perceived opportunities into practical action remains a significant challenge in volatile business environments..

2.5.2. Hypotheses Development and Research Model

2.5.2.1. AI Integration and Risk Management Practice

Digital technologies such as artificial intelligence, machine learning, and advanced data analytics have existed in various forms for the last few decades. A good example of a bank risk management area that can benefit significantly from the utilization of AI technology is fraud detection [66]. AI has also assisted banks in risk assessment processes. Similarly, Mhlanga [67] has researched the role of AI and machine learning in credit risk assessment. Farayola [68] examined the role of AI technology in cybersecurity risk management. Choo et al. [69] studied the role of integrating AI and the Internet of Things into risk management. In risk management, Rodríguez-Espíndola et al. [70] empirically investigated the impact of organizational and external factors in applying AI, blockchain, cryptocurrency, and big data for risk management based on the RBT lens and institutional theory. Based on the findings conducted by Sunmola and Lawrence [19], Mossavar-

Rahmani and Zohuri [13], Bráset al. [71], Mohamed [72], Meena et al. [73], Galaz et al. [74], Kalogiannidis et al. [75] and Mhlanga [67], the first hypothesis is formulated as follows:

H_1: AI Integration (AI) positively affects Risk Management Practice (RM)

2.5.2.2. Risk Management Practice and Sustainable Bank Performance

Risk management is valuable and relevant for enhancing institutional value [35]. Risk management is also essential for protecting assets and owner equity. Furthermore, banks implementing risk management efficiently can leverage international regulations, attract customers, and generate profits, supporting bank performance [76]. The study by Sleimi [35] examined the role of risk management in the efficacy of commercial banks in Jordan, filling a knowledge gap in the Arab context. The findings indicate that strong risk management practices, including understanding and analyzing risk, regular assessment, identification, monitoring, and credit risk analysis, are significantly associated with improved bank performance. This study shows that these practices contribute 77.1% of the variation in bank performance, highlighting the significant contribution of strong risk management to the success of financial institutions. A similar study by Abdullah et al. [29] reinforced the importance of risk management in enhancing financial resilience and bank performance, providing valuable insights for the banking sector in Oman.

Based on previous research findings by Sleimi [35], Soltanizadeh et al. [76], Faupel and Michels [77] and Alabdullah et al. [22] the seventh hypothesis is formulated as follows:

H_2: Risk Management Practice (RM) positively affects Sustainable Bank Performance (SP)

2.5.2.3. AI Integration and Sustainable Bank Performance

The study by Chen et al. [78] highlights the transformative potential of AI in e-commerce, exploring its ability to drive firm performance. Using the Resource-Based Theory (RBT), the research examines how AI capabilities can be leveraged for competitive advantage. The findings suggest that AI indirectly enhances firm performance by boosting corporate creativity and AI-driven decision-making.

From previous research by Olan et al. [79] AI can identify redundancies in business processes and offer optimal resource utilization for performance enhancement. However, the lack of integration between existing and new knowledge makes it problematic to ensure the nature of knowledge required for AI capabilities to enhance organizational performance optimally. Consequently, organizations continue to face recurring challenges in their business processes, competition, technological advancements, and finding new solutions in a rapidly changing society. To bridge this knowledge gap, the study conducted by Sunmola and Lawrence [19] views on AI integration from several aspects, including business processes, supporting technology, organizational and employee support as users, and finally, the capital and costs required to ensure AI implementation can continue to be developed.

Based on the findings from Sunmola and Lawrence [19], Wamba-Taguimdje et al. [80], Chen et al. [78] and Mossavar-Rahmani and Zohuri [13] the fourth hypothesis is formulated as follows:

H_3: AI Integration (AI) positively affects Sustainable Bank Performance (SP)

2.5.2.4. Risk Management Practice, AI Integration and Sustainable Bank Performance

Current studies have highlighted the growing importance of artificial intelligence (AI) in enhancing risk management and ensuring business continuity, though further exploration is needed to understand the specific AI components most effective in various corporate contexts [73, 74]. While AI technologies such as machine learning, natural language processing (NLP), data analytics, and predictive maintenance show promise, their distinct impact on mitigating different risk types remains underexamined. Biolecheva and Valchev [81] and Božić [82]. Wong et al. [52] emphasized AI's transformative role in improving supply chain agility for SMEs, particularly in managing risks and reengineering supply chains during market disruptions. Similarly, Kalogiannidis et al. [75] identified strategic AI applications such as NLP for risk assessment and AI-based predictive models as crucial for financial stability and operational resilience, based on insights from 360 industry experts in Greece. The convergence of findings from multiple studies underscores the urgent need for businesses to invest in AI-driven solutions to remain competitive and adaptable in the face of cybersecurity threats and economic uncertainty. The eighth hypothesis is formulated as follows:

H_4: Risk Management Practice (RM) mediates AI Integration (AI) to Sustainable Bank Performance (SP)

2.5.2.5. Environmental Volatility, Risk Management Practice and Sustainable Bank Performance

Based on the findings of Achi et al. [83], Aftab et al. [84] and Li et al. [85], environmental volatility significantly influences organizational strategies and performance outcomes. Achi et al. [83] revealed that higher perceived environmental volatility weakens the positive indirect relationship between Corporate Social Responsibility (CSR) and financial performance, indicating that uncertainty undermines the strategic benefits of CSR. Aftab et al. [84] Similarly, it was noted that environmental volatility hampers firms' ability to implement green practices and achieve financial goals, especially in developing countries with weak institutional support. Li et al. [85] emphasized that environmental volatility, such as political and regulatory instability, drives Emerging Market Multinational Enterprises (EMNEs) to adopt joint ventures as a risk mitigation strategy, although favorable host country conditions may support wholly owned subsidiaries. These studies collectively underscore that while environmental volatility presents strategic challenges, it also necessitates adaptive and risk-conscious business approaches to maintain sustainable performance. The eleventh hypothesis is formulated as follows:

$H_{5:}$ Environmental Volatility (EV) moderates Risk Management Practice (RM) and Sustainable Bank Performance (SP).

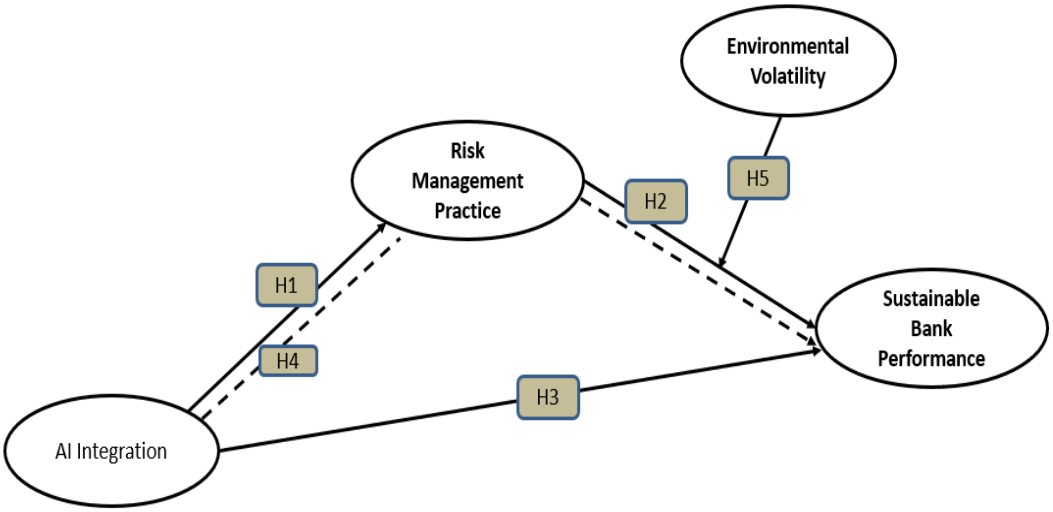

Figure 1.
Research Model.

3. Research Methodology

The study employs a quantitative methodology to examine how risk management practices, AI integration, and sustainable bank performance relate to one another in Indonesia's banking industry. To gather data at a specific point in time and provide a snapshot of industry trends influenced by environmental volatility, a cross-sectional research design was selected. This design is suitable for evaluating risk management practices and technological influences in a rapidly changing industry.

The study was conducted from December 2024 to April 2025, utilizing an online survey with questions based on variable operationalization (Table 1) a Likert scale with six response options, 1 indicating strongly disagree and 6 indicating strongly agree was used to gather data. To efficiently collect information and understand the phenomenon, the convenience sampling technique was employed. The questionnaire was subsequently distributed to obtain prompt responses and insights. Through the National Bank Risk Association and the author's network, the questionnaire was administered to respondents who were senior management-level employees from each bank, specifically C-level executives, senior vice presidents, vice presidents, assistant vice presidents, senior managers, and managers. All participants provided written informed consent to participate in this study via the questionnaire.

Structural equation modeling (SEM) was used for data analysis to ascertain the causal relationship between the dependent and latent variables. Using SmartPLS4 v4.1.0.0 software, partial least squares (PLS) SEM was employed in this study to investigate patterns as specified in the research model.

4. Results and Discussions

4.1. Respondent Profile

The respondents in Table 1 comprise banking respondents predominantly aged between 28–43 years old. A significant portion holds advanced degrees, with 57% having completed a master's degree and 38% possessing a bachelor's degree. This highly educated and experienced group provides valuable insights into strategic risk and leadership challenges related to sustainable performance. Additionally, banking respondents were represented by 49% from banks with core capital between IDR 14 trillion and IDR 70 trillion (Kelompok Bank dengan Modal Inti / KBMI III), 27% from banks with core capital exceeding IDR 14 trillion (KBMI IV), and 23% from banks with core capital below IDR 14 trillion (KBMI II). By bank category, this offers a robust foundation for analyzing how organizational scale and structure impact sustainable performance.

The key variables AI Integration, Risk Management Practice, Environmental Volatility, and Sustainable Bank Performance were operationalized as reflective constructs, each measured using multiple items to comprehensively capture the nuances of each construct.

Table 1.
Respondent Profile.

Variable	Category	Frequency	Percentage
Gender	Male	93	79.5%
	Female	24	20.5%
Age	between 44 - 59 years old	44	37.6%
	between 28 - 43 years old	67	57.3%
	between 12 - 27 years old	6	5.1%
Education level	Doctor (S3)	4	3.4%
	Master (S2)	67	57.3%
	Bachelor (S1)	45	38.5%
	Diploma (D3)	1	0.9%
Work experience in the banking industry	less than 5 years	12	10.3%
	6 - 10 years	15	12.8%
	more than 10 years	90	76.9%
Work experience in the current bank	less than 5 years	46	39.3%
	6 - 10 years	23	19.7%
	more than 10 years	48	41.0%
Job Position	Manager	12	10.3%
	Senior Manager	9	7.7%
	Assistant Vice President	20	17.1%
	Vice President	33	28.2%
	Senior Vice President	26	22.2%
	Senior Executive Vice President	4	3.4%
	Board of Directors	4	3.4%
	Others	9	7.7%
Bank Category	KBMI 4 (core capital > IDR 70 trillion)	32	27.4%
	KBMI 3 (core capital IDR 14 trillion – IDR 70 trillion	58	49.6%
	KBMI 2 (core capital < IDR 14 trillion)	27	23.1%
Majority Shareholder	SOE bank	38	32.5%
	Regional Development Bank	5	4.3%
	Private bank	19	16.2%
	Foreign bank	55	47.0%

The surveys used a six-point Likert scale, with 1 denoting "strongly disagree" and 6 denoting "strongly agree." A six-point Likert scale is recommended for the following reasons: to prevent neutral replies, to increase variety, and to strike a balance between overwhelm and differentiation [86, 87].

a. AI Integration denotes the incorporation of AI technologies into various aspects of company operations, services, and everyday products. AI integration evaluates the bank that combines technology, organizational and employee benefits, business processes, capital, and regulations.
b. Risk management practices quantify the methodical process of understanding, recognizing, evaluating, and responding to risks in order to reduce the adverse effects they could have on an organization.
c. Environmental volatility quantifies the degree of unpredictability and rapid fluctuations in scenarios where external forces and market conditions impact a business swiftly and unpredictably.
d. Key performance indicators, such as economic, environmental, and social performance, were used to assess sustainable bank performance in order to determine overall organizational success.

With SmartPLS software (version 4.0), data analysis was conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM). PLS-SEM was chosen because of its ability to effectively manage complex models involving small sample sizes and non-normal data distributions, making it suitable for exploratory studies involving latent constructs [88]. This method facilitates the concurrent evaluation of the measurement model (outer model) and the structural model (inner model), providing insights into the interrelations among AI integration, risk management practices, environmental volatility, and sustainable bank performance.

5. Results

The research assessed the internal consistency and validity of each construct through Average Variance Extracted (AVE), Composite Reliability (CR), and Cronbach's alpha, as presented in Table 2. According to Fornell and Larcker [89] convergent validity for all constructs was established when the Average Variance Extracted (AVE) surpassed 0.50, indicating that the constructs explained over 50% of the variance in their measured indicators. Risk Management Practice exhibited the highest indicator representation (AVE=0.776), whereas AI Integration (0.675), Sustainable Bank Performance (0.606), and Environmental Volatility (0.564) also satisfied the validity threshold.

Composite Reliability (CR) values, indicating the internal consistency of a set of indicators, surpassed the minimum threshold of 0.70 for all constructs [88]. The Risk Management Practice attained the highest Composite Reliability (CR) of

0.965, indicating exceptional reliability. Other constructs exhibited the following CR values: AI Integration (AI) = 0.936, Sustainable Bank Performance (SP) = 0.938, and Environmental Volatility (EV) = 0.853. The results indicate strong reliability throughout the model. Elevated CR values indicate that the indicators reliably reflect their underlying constructs, thereby confirming the robustness of the measurement model [89].

The factor loadings of each indicator were analyzed to enhance internal consistency reliability. All items met a threshold of 0.70, indicating that individual indicators exhibit strong correlations with their respective constructs [90]. This practice adheres to established methodologies in structural equation modeling (SEM), effectively integrating composite reliability (CR) and loading factors to validate measurement models. The findings support the validity of the constructs, aligning with methodologies employed in comparable research [91].

Cronbach's Alpha values for all constructs exceeded 0.70, thereby confirming construct reliability. AI integration demonstrated the highest Cronbach's Alpha at 0.965, signifying strong consistency in measuring this construct. These metrics collectively indicate that the construct in the model demonstrates convergent validity and high internal reliability, thereby affirming the robustness of the measurement model in this study.

Table 2.
Convergent validity and reliability.

	Average Variance Extracted (AVE)	Composite Reliability (rho_c)	Cronbach's Alpha
AI Integration	0.675	0.936	0.965
Risk Management Practice	0.776	0.965	0.958
Environmental Volatility	0.564	0.853	0.802
Sustainable Bank Performance	0.606	0.938	0.926

The Fornell-Larcker criterion, which is satisfied when each construct's square root of the Average Variance Extracted (AVE) exceeds its correlations with other constructs, was used to evaluate discriminant validity. This criterion guarantees the distinctiveness of each construct within the model. AI Integration's uniqueness is confirmed by its square root of AVE of 0.917 in this study, which is higher than its correlations with other constructs. Environmental Volatility (EV) exhibits a strong diagonal value of 0.894, affirming its unique function within the model. The discriminant validity of Risk Management Practice (RM) is supported by its diagonal value of 0.881, which is better than its correlations with other constructs. Sustainable Bank Performance (SP) is quantified at 0.778, demonstrating a clear distinction from other constructs. The results presented in Table 3 confirm that each construct is unique and distinct, thereby supporting the overall reliability and robustness of the model. Additionally, Table 4 indicates that all Heterotrait-Monotrait (HTMT) ratios were below 0.85, demonstrating that the constructs are distinct and non-overlapping.

Table 3.
Fornell-Larcker criterion.

	AI	EV	RM	SP
AI Integration (AI)	0.917			
Environmental Volatility (EV)	0.224	0.894		
Risk Management Practice (RM)	0.234	0.283	0.881	
Sustainable Bank Performance (SP)	0.322	0.274	0.745	0.778

Table 4.
Heterotrait-Monotrait (HTMT) ratio.

	AI	EV	RM	SP
AI Integration (AI)	-	0.266	0.315	0.441
Environmental Volatility (EV)	0.266	-	0.324	0.348
Risk Management Practice (RM)	0.315	0.324	-	0.778
Sustainable Bank Performance (SP)	0.441	0.348	0.778	-

Table 5 presents clear insights into how risk management practices and AI integration influence sustainable bank performance within the banking sector. The integration of AI significantly and favorably influences risk management practice (RM), as indicated by a p-value of 0.000, thus corroborating hypothesis 1 (H1). The results of this study align with the research undertaken by Brás et al. [71], Galaz et al. [74], Meena et al. [73] and Kalogiannidis et al. [75], which shows that the integration of AI significantly enhances risk management procedures within organizations.

Likewise, the results affirm that risk management practices impact sustainable bank performance, evidenced by a p-value of 0.023, thus substantiating Hypothesis 2 (H2). This result indicates that banks emphasizing risk management practices encompassing risk comprehension, risk identification, risk analysis, and risk monitoring are better equipped to protect their performance successfully. This research corresponds with Sleimi [35] study in the banking sector, which demonstrated that robust risk management practices encompassing risk comprehension, analysis, assessment, identification, and monitoring, especially in credit risk analysis, substantially enhance bank performance. The study by Alabdullah et al. [22] corroborates these findings, highlighting the importance of strengthening risk management

techniques to enhance financial resilience and overall bank performance, thereby providing valuable insights for the banking sector.

Upon assessing Hypothesis 3 (H3), which asserts that AI integration (AI) favorably influences sustainable bank performance (SP), the findings indicate support for this hypothesis, evidenced by p-values of 0.001. This discovery aligns with prior studies by Chen et al. [78], which suggests that AI capabilities can confer a competitive advantage, thereby indirectly improving company performance through the enhancement of corporate innovation and AI-driven decision-making. This study corresponds with the research of Wamba-Taguimdje et al. [80], which examined the impact of AI on corporate performance, demonstrating that AI integration has augmented organizational capabilities in processes such as chatbots and machine learning, significantly improving operational efficiency and offering benefits in finance, marketing, and administration. This research aligns with the findings of Olan et al. [79], indicating that AI deployment can detect redundancies in corporate processes and provide optimal resource utilization for performance improvement.

The fourth purpose of this research project is to investigate the mediating role of risk management practices in the relationship between AI integration and sustainable bank performance. The SEM results from the hypothesis analysis indicate a T statistic of 1.710, exceeding 1.64, and a p-value of 0.044, which is below 0.05; therefore, H4 (Risk management practice moderates the beneficial impact of AI integration on sustainable company performance) is accepted. This study's findings demonstrate that risk management practices mitigate the impact of AI integration on sustainable bank performance within the banking sector. This aligns with prior research by Galaz et al. [74], which demonstrated that risk management can mediate the connection between AI integration and sustainable bank performance. These findings are consistent with previous research indicating that robust AI integration can directly impact sustainable bank performance [13, 19, 78].

Conversely, the results do not support Hypothesis 5 (H5), which asserts that Environmental Volatility (EV) moderates the relationship between Risk Management Practice (RM) and Sustainable Bank Performance (SP). The findings suggest that this hypothesis lacks validity. The path coefficient of 0.027, along with T-statistics of 0.345 and a p-value of 0.365, indicates that this moderating relationship is statistically insignificant. Instead, its effect on performance may be influenced by other variables. This suggests that Risk Management Practices directly promote an environment favorable to bank performance; however, their impact is not moderated by Environmental Volatility in terms of immediate performance improvements.

Table 5.
Path coefficients and hypothesis testing.

Relationship	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Explanation
H1: AI → RM	0.188	0.190	0.051	3.655	0.000	Accepted
H2: RM → SP	0.611	0.618	0.305	2.003	0.023	Accepted
H3: AI → SP	0.135	0.133	0.042	3.193	0.001	Accepted
H4: AI>RM>SP	0.115	0.117	0.067	1.710	0.044	Accepted
H5: EV x AI → SP	0.027	0.025	0.079	0.345	0.365	Rejected

The results demonstrate that the AI Integration and Risk Management Practice establishes a solid foundation for sustainable bank performance. While risk management acts as a business enabler and AI contributes to tangible performance improvements. The following section, illustrated in Figure 2, further visualizes how these constructs interact within the model, emphasizing the role of Risk Management Practice in linking strategic enablers to measurable outcomes.

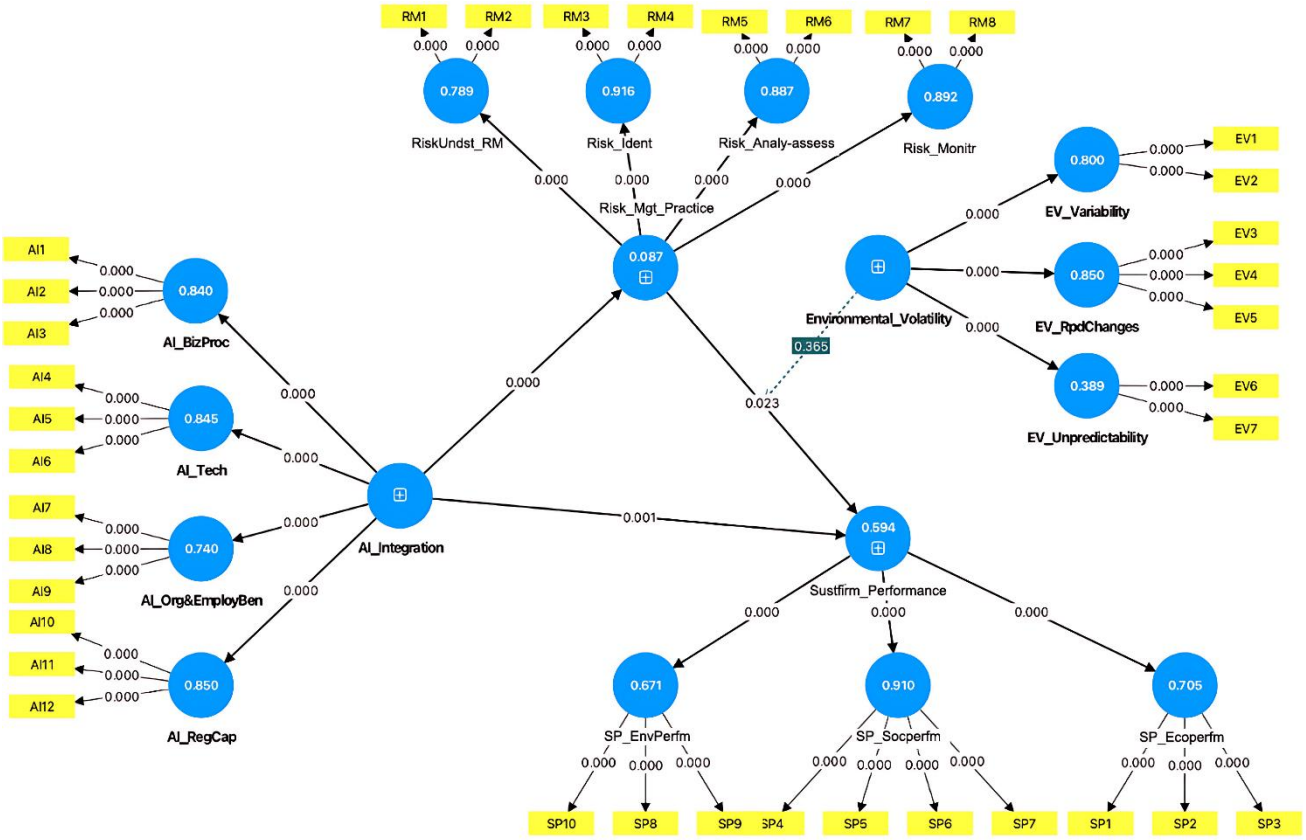

Figure 2.
Measurement Model Result.

Figure 2 depicts the dynamics within the measurement model, emphasizing the relationships among AI Integration, Risk Management Practices, Environmental Volatility, and Sustainable Bank Performance. The chart indicates that while AI Integration positively affects Risk Management Practices, its direct influence on Sustainable Bank Performance is also statistically significant. Furthermore, Figure 2 highlights the significant positive impact of risk management practices on sustainable bank performance, emphasizing its role as a crucial mediator.

The R^2 values in Table 6 indicate the model's explanatory capacity regarding each principal variable. Risk Management Practice (RM) accounts for a significant percentage of the variance in Sustainable Bank Performance (SP) (R2 = 0.594), highlighting the critical importance of risk management in enhancing sustainable performance in the sector. AI integration accounts for a minimal amount of variance in risk management (R2 = 0.087), underscoring its limited significance in enhancing risk management initiatives.

The F2 findings clarify the significance of each predictor within the model. RM exhibits a minor effect (F2 = 0.054) on SP, validating its significance in risk assessment for predicting bank performance. AI exhibits minor impacts with F2 = 0.095 on RM and F2 = 0.085 on SP. This outcome signifies their minimal impact on promoting risk management practices and performance.

Table 6.
R2 and F2 values for explanatory power and predictor effect sizes.

Path	R^2	Adjusted R^2	F^2	Effect Size of Interpretation
RM → SP	0.594	0.580	0.054	Small Effect
AI → RM	0.087	0.079	0.095	Small Effect
AI → SP	-	-	0.085	Small Effect

The mediation model emphasizes that, although AI integration is a less significant predictor of Risk Management Practice, it is the Risk Management Practice itself that significantly mediates the relationship between AI integration and sustainable bank performance.

Table 7.
Mediation effects.

Path	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Explanation
AI → RM → SP	0.115	0.117	0.067	1.710	0.044	Significant

The significant indirect effects, demonstrated by the AI à RM à SP, further emphasize that risk management efforts facilitated by AI integration are the key drivers of improved sustainable bank performance outcomes in the banking sector, as shown in Table 7. Although R2 and F2 values confirm the robustness of the model, emphasizing that AI integration indirectly bolsters sustainable bank performance through its influence on risk management practices as a mediating factor.

6. Discussions

6.1. Theoretical Contribution

These results indicate that AI integration has a significant positive effect on risk management practices. This result strengthens previous research on these relationships, with the addition of this empirical evidence for the banking industry. Risk management practices involve robust process steps starting from risk understanding, risk identification, risk analysis, risk monitoring, and reporting. AI integration can support one or more of these processes, for example, in the areas of predicted risk assessment or fraud risk detection [75]. This study confirms that AI integration provides a value proposition to risk management practice.

The path coefficient result of the direct relationship between risk management practice and sustainable bank performance (0.611) is the highest among other direct relationships, such as AI integration and risk management practice (0.188) or AI integration and sustainable bank performance (0.135), which shows that risk management practice is the key ingredient for sustainable bank performance. This aligns with previous research, which validates that risk management practice has a positive effect on a firm's performance [22, 35, 76, 77].

Interestingly, from the perspective of sustainable bank performance, the weight relationship between AI integration and sustainable bank performance (0.135) is slightly higher than the weight of the relationship between AI integration and sustainable bank performance through the mediating variable: risk management practice (0.115). This indicates that AI integration has a slightly more significant effect on sustainable bank performance compared to its influence through risk management practice as a mediating variable. Using the Resource-Based Theory (RBT), the research examines how AI integration can be leveraged for competitive advantage. The findings suggest that AI directly enhances bank performance by boosting scalability and efficiency.

Lastly, regarding the moderating effects, environmental volatility does not moderate risk management practices and sustainable bank performance. This finding indicates that environmental volatility is not a critical factor in moderating risk management practices and sustainable bank performance; it may be influenced more by other factors. Risk management practices, which are primarily regulated by the Indonesian Financial Services Authority and Bank Indonesia, ensure that banks comply with mandatory risk regulations. Besides regulatory aspects, Indonesia's banking industry has learned from several financial crises, facing unstable situations and unpredictable circumstances, which have increased banks' awareness and led them to periodically conduct risk simulations or stress tests concerning environmental volatility.

6.2. Practical Implications

The results of this study provide implications for banks that, to achieve sustainable bank performance, it is essential to have effective risk management practices. This research can serve as a guide for banks to continuously develop their risk management practices by first considering internal factors, particularly AI integration. Through these advanced digital capabilities within the banking institution's environment, banks will strengthen their risk management practices as a business enabler to support the achievement of sustainable bank performance.

Another managerial implication of this study highlights the role of AI integration, which has a direct impact on sustainable bank performance. The banking industry is undergoing a significant digital transformation. AI is one of the key pillars of this transformation, helping banks enhance operational efficiency, reduce costs, and improve customer experience, ultimately leading to improved sustainable bank performance.

This should be a consideration for banks, especially those that have reached technological maturity, to begin and continue developing AI technology that is increasingly integrated into business processes and digital operation activities. Although the implementation of AI is still relatively new in Indonesia, some large banks have already been implementing it. Certainly, investments in AI can enhance scalability, resulting in improved digital services for bank customers. By utilizing AI, banks can better manage the social and environmental impacts of their operations. AI can assist in analyzing environmental and social risks, as well as support more sustainable investment decisions.

7. Conclusion

The study aims to understand the role of AI integration, risk management practices, and environmental volatility, which affect sustainable bank performance. To achieve this objective, a structural equation modeling (SEM) model was constructed to examine the correlations between variables. The dynamic capabilities theory is used to provide perspective, analysis, and insights. First, it validates that risk management practices have a positive effect on sustainable bank performance. AI integration also has a positive effect on sustainable bank performance and risk management practices but with a lesser effect. The results indicate that risk management practices are a key factor for sustainable bank performance. Second, this study confirms that AI integration positively affects sustainable bank performance. AI integration positively affects risk management practices with a lesser effect. Third, AI integration influences sustainable bank performance through risk management practices, but with a lesser effect than AI integration's direct effect on sustainable bank performance. Fourth, environmental volatility has no impact on increasing or reducing the quality of risk management practices to enhance bank performance. These findings enrich the dynamic capabilities theory in the banking industry by highlighting that risk management practices are the key enabler for sustainable bank performance. A practical implication

is that the banking industry needs to focus on providing robust risk management practices, as this is a source of enhancing bank performance, which together safeguards the bank from potential financial losses or other risks.

References

[1] K. Matthews, "Trends in domestic and international banking," 2020. www.worldscientific.com

[2] A. Dunn, K. Hood, and A. Driessen, *Measuring the effects of the COVID-19 pandemic on consumer spending using card transaction data*. Washington, DC: US Department of Commerce, Bureau of Economic Analysis, 2020.

[3] A. A.-A. Idun, A. Q. Q. Aboagye, and G. A. Bokpin, "The effect of bank market power on economic growth in Africa: The role of institutions," *Cogent Economics & Finance*, vol. 8, no. 1, p. 1799481, 2020. https://doi.org/10.1080/23322039.2020.1799481

[4] A. D. Alhadeff, *Monopoly and competition in banking*. Berkeley, CA: University of California Press, 2022.

[5] OJK, "OJK," 2023. https://www.ojk.go.id/iru/dataandstatistics/detaildataandstatistics/10114/nbfi-industry-assessment-march-2023

[6] EY & Institute of International Finance, *Global bank risk management survey 2023: Resilient banking in uncertain times*. Washington, DC: Institute of International Finance, 2023.

[7] D. W. Hubbard, *The failure of risk management: Why it's broken and how to fix it*, 2nd ed. Hoboken, NJ: John Wiley & Sons, 2020.

[8] J. Fraser and B. J. Simkins, *Enterprise risk management: Today's leading research and best practices for tomorrow's executives*. Hoboken, NJ: Wiley, 2010.

[9] OJK, "OJK. Indonesia," 2016. https://ojk.go.id/id/regulasi/Pages/POJK-tentang-Penerapan-Manajemen-Resiko-bagi-Bank-Umum.aspx

[10] World Economic Forum Report, "Global risk report," 2024. www.weforum.org/publications/global-risks-report-2024

[11] Q. Iqbal, N. H. Ahmad, and H. A. Halim, "How does sustainable leadership influence sustainable performance? Empirical evidence from selected ASEAN countries," *SAGE Open*, vol. 10, no. 4, p. 2158244020969394, 2020. https://doi.org/10.1177/2158244020969394

[12] G. C. Avery and H. Bergsteiner, "Sustainable leadership practices for enhancing business resilience and performance," *Strategy & Leadership*, vol. 39, no. 3, pp. 5-15, 2011. https://doi.org/10.1108/10878571111128766

[13] M. F. Mossavar-Rahmani and B. Zohuri, "AI's global impact on economy and policy," *Science Set Journal of Economic Research*, vol. 2, no. 3, pp. 1-6, 2023.

[14] Deloitte, "Deloitte," 2021. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-ai-transforming-future-of-banking.pdf

[15] S. Biswas, B. Carson, V. Chung, S. Singh, and R. Thomas, "AI-bank of the future: Can banks meet the AI challenge?," 2020. https://www.mckinsey.com/move

[16] McKinsey, *Global banking annual review 2024: Attaining escape velocity*. New York: McKinsey & Company, 2024.

[17] R. Achary, "Fraud detection in banking transactions using machine learning," in *Proceedings of the 2023 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE)*, 2023.

[18] N. M. Boustani, "Artificial intelligence impact on banks clients and employees in an Asian developing country," *Journal of Asia Business Studies*, vol. 16, no. 2, pp. 267–278, 2021.

[19] F. Sunmola and G. L. Lawrence, "Key success factors for integration of blockchain and ERP systems: A systematic literature review," *Procedia Computer Science*, vol. 232, pp. 775-782, 2024. https://doi.org/10.1016/j.procs.2024.01.077

[20] M. Hudáková and A. Lahuta, "Risk management as a tool for increasing the competitiveness of small and medium enterprises in Slovakia," *Sustainability*, vol. 12, no. 3, p. 1005, 2020.

[21] D. Teece, M. Peteraf, and S. Leih, "Dynamic capabilities and organizational agility: Risk, uncertainty, and strategy in the innovation economy," *California Management Review*, vol. 58, no. 4, pp. 13-35, 2016. https://doi.org/10.1525/cmr.2016.58.4.13

[22] T. Y. T. Alabdullah, S. A. L. Mamari, Hamdan, A. A. L. S. Ghassani, and E. R. Ahmed, "Risk management practices and financial performance: The case of banks in Sultanate of Oman," *Journal of Accounting Science*, vol. 6, no. 1, pp. 69–84, 2022.

[23] I. Puspitasari, R. L. Nugraheni, and F. Purnamasari, "Risk management practices in the Indonesian banking sector," *Journal of Risk and Financial Management*, vol. 14, no. 2, p. 89, 2021.

[24] J. Bessis, *Risk management in banking*, 3rd ed. Chichester, UK: Wiley, 2011.

[25] D. M. Chance and R. Brooks, *Introduction to derivatives and risk management*, 9th ed. Boston, MA: Cengage Learning, 2015.

[26] A. J. Keown, J. D. Martin, J. W. Petty, and D. F. Scott, *Financial management: Principles and applications*, 9th ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2004.

[27] International Organization for Standardization, *ISO 31000:2009 – Risk management – Principles and guidelines*. Geneva, Switzerland: ISO, 2009.

[28] G. Purdy, "ISO 31000:2009—Setting a new standard for risk management," *Risk Analysis*, vol. 30, no. 6, pp. 881–886, 2010.

[29] M. Abdullah, K. N. I. K. Ismail, and M. M. Jalil, "The impact of risk disclosure on firm value: A Malaysian evidence," *Procedia Economics and Finance*, vol. 31, pp. 72–80, 2015.

[30] Y. Yang, P. Sharma, and R. Davidson, "Enterprise risk management and firm performance: The moderating effect of organizational culture," *Journal of Risk Research*, vol. 21, no. 6, pp. 671-693, 2018.

[31] C. Florio and G. Leoni, "Enterprise risk management and firm performance: The Italian case," *The British Accounting Review*, vol. 49, no. 1, pp. 56–74, 2017.

[32] P. Bromiley, M. McShane, A. Nair, and E. Rustambekov, "Enterprise risk management: Review, critique, and research directions," *Long Range Planning*, vol. 48, no. 4, pp. 265–276, 2015.

[33] S. Khalid and S. Amjad, "Risk management practices in Islamic banks of Pakistan," *The Journal of Risk Finance*, vol. 13, no. 2, pp. 148-159, 2012. https://doi.org/10.1108/15265941211203198

[34] J. Fang, C.-K. M. Lau, Z. Lu, Y. Tan, and H. Zhang, "Bank performance in China: A Perspective from Bank efficiency, risk-taking and market competition," *Pacific-Basin Finance Journal*, vol. 56, pp. 290-309, 2019. https://doi.org/10.1016/j.pacfin.2019.06.011

[35] M. Sleimi, "Effects of risk management practices on banks' performance: An empirical study of the Jordanian banks," *Management Science Letters*, vol. 10, no. 2, pp. 489-496, 2020.
[36] M. Power, "The risk management of nothing," *Accounting, Organizations and Society*, vol. 34, no. 6-7, pp. 849-855, 2009.
[37] M. Ayam and G. Ahinful, "Risk identification and assessment in the banking sector," *International Journal of Economics, Commerce and Management*, vol. 3, no. 7, pp. 1–13, 2015.
[38] N. Jabnoun and K. N. Al-Khalifa, "Risk management in banks: A review of techniques," *International Journal of Bank Marketing*, vol. 21, no. 1, pp. 37–50, 2003.
[39] J. Laycock, "Risk management techniques for banking," *Journal of Risk Management in Financial Institutions*, vol. 7, no. 3, pp. 291–302, 2014.
[40] R. Rosman, "Risk management practices and risk management processes of Islamic banks: A proposed framework," *International Review of Business Research Papers*, vol. 5, no. 1, pp. 242-254, 2009.
[41] Airmic, *A risk management standard*. London, UK: The Association of Insurance and Risk Managers (AIRMIC), ALARM, and IRM, 2002.
[42] R. Pausenberger and A. Nassauer, "Risk monitoring and control in financial institutions," *Journal of Banking Regulation*, vol. 2, no. 1, pp. 28–34, 2000.
[43] M. J. Matanda and S. Freeman, "Environmental uncertainty, environmental change and internationalization strategy," *Journal of International Marketing*, vol. 17, no. 3, pp. 32–49, 2009.
[44] S. Wilhelm, M. Preis, and M. V. Solms, "Environmental uncertainty and firm performance: The moderating role of managerial flexibility," *Strategic Management Journal*, vol. 36, no. 4, pp. 519–535, 2015.
[45] R. S. Achrol and L. W. Stern, "Environmental determinants of decision-making uncertainty in marketing channels," *Journal of Marketing Research*, vol. 25, no. 1, pp. 36–50, 1988.
[46] Q. Zheng, Y. Wang, and X. Chen, "Navigating environmental turbulence through innovation: Firm growth under dynamic market conditions," *Technovation*, vol. 92-93, p. 102072, 2020.
[47] E. Taskan, E. Bozdag, and A. Turkyilmaz, "Adaptive strategies in volatile environments: The role of environmental assessment in firm performance," *Management Decision*, vol. 60, no. 5, pp. 1105-1124, 2022.
[48] A. F. Alkhafaji, *Strategic risk management*. Boca Raton, FL: St. Lucie Press, 2003.
[49] A. Sulich and L. Soloducho-Pelc, "Sustainable competitive advantage: Balancing economic, social, and environmental factors," *Sustainability Accounting, Management and Policy Journal*, vol. 12, no. 21, p. Article 8832, 2024.
[50] P. Soto-Acosta, S. Popa, and D. Palacios-Marqués, "The role of environmental dynamism and technological turbulence in the development of dynamic capabilities," *European Journal of Innovation Management*, vol. 21, no. 2, pp. 276-297, 2018.
[51] M. Sanchez, L. Sanchez, and C. Alvarez, "The effects of environmental dynamism and heterogeneity on firm performance: Evidence from the Spanish banking sector," *Journal of Business Research*, vol. 70, pp. 344-352, 2017.
[52] P. K. Wong, Y. P. Ho, and E. Autio, "Entrepreneurship, innovation and economic growth: Evidence from GEM data," *Small Business Economics*, vol. 37, no. 2, pp. 255–270, 2011.
[53] U. Atz, I. Gölgeci, and R. Greenwood, "Sustainable competitive advantage through stakeholder engagement and sustainable practices," *Journal of Business Ethics*, vol. 172, no. 4, pp. 785–807, 2021.
[54] A. Paulraj, "Understanding the relationships between internal resources and external stakeholder pressures: Implications for supply chain sustainability," *Journal of Supply Chain Management*, vol. 47, no. 3, pp. 1–20, 2011.
[55] J. Markard, "Transitions to sustainable energy systems: An editorial introduction," *Energy Policy*, vol. 105, pp. 1–3, 2017.
[56] B. R. Chabowski, N. C. Smith, and Y. Grégoire, "Transforming marketing strategy into brand performance: Brand orientation as a resilience mechanism under environmental dynamism," *Journal of Marketing*, vol. 87, no. 2, pp. 100–117, 2023.
[57] M. Charter and U. Tischner, *Sustainable quality: A bibliography of sustainable management principles*. Stoke-on-Trent, UK: Staffordshire University Press, 2017.
[58] P. Burawat, "Corporate sustainability and organizational efficiency: Evidence from emerging Asian firms," *Management of Environmental Quality*, vol. 30, no. 5, pp. 1034–1049, 2019.
[59] S. Galletta, S. Mazzù, and V. Naciti, "ESG controversies and bank risk-taking: Empirical evidence from international banking institutions," *Business Strategy and the Environment*, vol. 32, no. 1, pp. 16–30, 2022.
[60] J. Barney, "Firm resources and sustained competitive advantage," *Journal of Management*, vol. 17, no. 1, pp. 99–120, 1991.
[61] D. J. Teece, G. Pisano, and A. Shuen, "Dynamic capabilities and strategic management," *Strategic Management Journal*, vol. 18, no. 7, pp. 509–533, 1997.
[62] S. A. Zahra, O. Petricevic, and Y. Luo, "Toward an action-based view of dynamic capabilities for international business," *Journal of International Business Studies*, vol. 53, no. 4, pp. 583–600, 2022.
[63] V. Ambrosini, C. Bowman, and N. Collier, "Dynamic capabilities: A review and research agenda," *International Journal of Management Reviews*, vol. 24, no. 3, pp. 391–414, 2022.
[64] D. J. Teece, "Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance," *Strategic Management Journal*, vol. 28, no. 13, pp. 1319–1350, 2007.
[65] I. Nonaka, R. Toyama, and N. Konno, "SECI, Ba and leadership: A unified model of dynamic knowledge creation," *Long Range Planning*, vol. 33, no. 1, pp. 5–34, 2000.
[66] Economist, "AI and machine learning analysis and insights," 2025. https://www.eiu.com/n/global-themes/artificial-intelligence-insights
[67] D. Mhlanga, "Financial inclusion in emerging economies: The application of machine learning and artificial intelligence in credit risk assessment," *International Journal of Financial Studies*, vol. 9, no. 3, p. 39, 2021. https://doi.org/10.3390/ijfs9030039
[68] O. A. Farayola, "Revolutionizing banking security: Integrating artificial intelligence, blockchain and business intelligence for enhanced cybersecurity," *Finance & Accounting Research Journal*, vol. 6, no. 4, pp. 501–514, 2024. https://doi.org/10.51594/farj.v6i4.990
[69] K.-K. R. Choo, K. Gai, L. Chiaraviglio, and Q. Yang, "A multidisciplinary approach to Internet of Things (IoT) cybersecurity and risk management," *Elsevier*, vol. 102, p. 102136, 2021.

[70] O. Rodríguez-Espíndola, S. Chowdhury, P. K. Dey, P. Albores, and A. Emrouznejad, "Analysis of the adoption of emergent technologies for risk management in the era of digital manufacturing," *Technological Forecasting and Social Change*, vol. 178, p. 121562, 2022.

[71] J. Brás, R. Pereira, and S. Moro, "Intelligent process automation and business continuity: Areas for future research," *Information*, vol. 14, no. 2, p. 122, 2023. https://doi.org/10.3390/info14020122

[72] N. Mohamed, "Current trends in AI and ML for cybersecurity: A state-of-the-art survey," *Cogent Engineering*, vol. 10, no. 2, p. 2272358, 2023. https://doi.org/10.1080/23311916.2023.2272358

[73] R. Meena, A. K. Mishra, and R. K. Raut, "Strategic insights: mapping the terrain of artificial intelligence (AI) in banking through mixed method approach," *VINE Journal of Information and Knowledge Management Systems*, vol. 21, p. 4255, 2024.

[74] V. Galaz *et al.*, "Artificial intelligence, systemic risks, and sustainability," *Technology in Society*, vol. 67, p. 101741, 2021.

[75] S. Kalogiannidis, D. Kalfas, O. Papaevangelou, G. Giannarakis, and F. Chatzitheodoridis, "The role of artificial intelligence technology in predictive risk assessment for business continuity: A case study of Greece," *Risks*, vol. 12, no. 2, p. 19, 2024. https://doi.org/10.3390/risks12020019

[76] S. Soltanizadeh, S. Z. Abdul Rasid, N. Mottaghi Golshan, and W. K. Wan Ismail, "Business strategy, enterprise risk management and organizational performance," *Management Research Review*, vol. 39, no. 9, pp. 1016-1033, 2016. https://doi.org/10.1108/mrr-05-2015-0107

[77] C. Faupel and R. Michels, *Value-based risk management: costs and benefits. In Advances in Management Accounting*. Leeds, UK: Emerald Group Publishing Limited, 2014.

[78] D. Chen, J. P. Esperança, and S. Wang, "The impact of artificial intelligence on firm performance: An application of the resource-based view to e-commerce firms," (in English), *Frontiers in Psychology*, vol. 13, p. Article 884830, 2022. https://doi.org/10.3389/fpsyg.2022.884830

[79] F. Olan, E. Ogiemwonyi Arakpogun, J. Suklan, F. Nakpodia, N. Damij, and U. Jayawickrama, "Artificial intelligence and knowledge sharing: Contributing factors to organizational performance," *Journal of Business Research*, vol. 145, pp. 605-615, 2022. https://doi.org/10.1016/j.jbusres.2022.03.008

[80] S.-L. Wamba-Taguimdje, S. Fosso Wamba, J. R. Kala Kamdjoug, and C. E. Tchatchouang Wanko, "Influence of artificial intelligence (AI) on firm performance: The business value of AI-based transformation projects," *Business process management journal*, vol. 26, no. 7, pp. 1893-1924, 2020.

[81] P. Biolecheva and E. Valchev, "Roadmap for risk management integration using AI," *Journal of Risk & Control*, vol. 9, no. 1, pp. 13–28, 2022.

[82] V. Božić, "Integrated risk management and artificial intelligence in hospital," *Journal of AI*, vol. 7, no. 1, pp. 63–80, 2023.

[83] L. Achi, J. Smith, and A. Ahmed, "Environmental volatility and CSR effectiveness: Evidence from developing economies," *Journal of Business Ethics*, vol. 170, no. 3, pp. 587–603, 2021.

[84] J. Aftab, N. Abid, A. Amin, H. Sarwar, M. Abedini, and M. Veneziani, "Does corporate social responsibility drive financial performance? Exploring the significance of green innovation, green dynamic capabilities, and perceived environmental volatility," *Corporate Social Responsibility and Environmental Management*, vol. 31, no. 3, pp. 1634–1653, 2023.

[85] F. Li, C. Yang, Z. Li, and P. Failler, "Does geopolitics have an impact on energy trade? Empirical research on emerging economies," *Energy Trade Studies*, vol. 20, no. 10, pp. 1–20, 2021.

[86] J. Dawes, "Do data characteristics change according to the number of scale points used?," *International Journal of Market Research*, vol. 50, no. 1, pp. 61–77, 2008.

[87] C. C. Preston and A. M. Colman, "Optimal number of response categories in rating scales: reliability, validity, discriminating power, and respondent preferences," *Acta Psychologica*, vol. 104, no. 1, pp. 1–15, 2000.

[88] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, "Partial least squares structural equation modeling (PLS-SEM) techniques using SmartPLS: Basic concepts, applications, and programming," *Journal of Marketing Theory and Practice*, vol. 29, no. 2, pp. 220–232, 2021.

[89] C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservable variables and measurement error," *Journal of Marketing Research*, vol. 18, no. 1, pp. 39–50, 1981.

[90] J. Henseler, C. M. Ringle, and M. Sarstedt, "A new criterion for assessing discriminant validity in variance-based structural equation modeling," *Journal of the Academy of Marketing Science*, vol. 43, no. 1, pp. 115–135, 2015.

[91] N. Schmitt and M. Horner, "Measurement validity and reliability in research: Guidelines and recommendations," *Journal of Business Research*, vol. 135, no. 365–376, 2021.