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INNOVATIVE MODELING METHODS FOR ENHANCED ESG RISK ASSESSMENT IN THE CONTEXT OF THE “GREEN” ECONOMY DEVELOPMENT OF THE REPUBLIC OF KAZAKHSTAN

The business and investment environments have changed due to the incorporation of ESG concepts into risk management and innovation activities. ESG considerations were first used to address social and environmental issues, but they have since developed into important elements of risk reduction and business strategy. Innovative ESG risk assessment techniques that promote company resilience, sustainable economic growth, and the development of green economies are the focus of this study. To promote sustainable growth and industrial strength, the study focuses on integrating ESG criteria with risk management frameworks, evaluating the effects of ESG on particular sectors, and developing methods for coordinating ESG practices with «green economy» goals.

The research takes a multidisciplinary approach, analyzing financial and operational outcomes across industries using both quantitative and qualitative methodologies. The results show that integrating ESG improves financial performance while also encouraging innovation and fortifying risk management systems. Notably, ESG practices increase resilience in times of economic turbulence, lower systemic risks in financial markets, and boost liquidity. Additionally, ESG-driven initiatives, employee productivity, and sustainable growth are found to be positively correlated, especially in industries like banking and manufacturing. Emerging nations like Kazakhstan are coordinating green economy projects with ESG goals despite regulatory obstacles, indicating a worldwide trend toward sustainable practices.

This study adds to the expanding corpus of research on the function of ESG in fostering sustainable economic practices and robust markets. Its practical relevance comes from its capacity to direct investors, businesses, and politicians toward the adoption of ESG-driven policies to create a strong and sustainable economic future.

Key words: financial resilience, sustainable development, risk management, financial performance, ESG integration.

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Қазақстан Республикасы «жасыл» экономикасының дамуы жағдайында ESG тәуекелдерін бағалауда жетілдірілген әдістерін модельдеудің инновациялық әдістері

Іскерлік және инвестициялық орта тәуекелдерді басқару мен инновациялық қызметке ESG тұжырымдамаларын енгізуге байланысты өзгереді. ESG принциптері алғаш рет әлеуметтік және экологиялық мәселелерді шешу үшін қолданылды, бірақ содан бері олар тәуекелдерді азайту мен бизнес стратегиясының маңызды элементтеріне айналды. Осы зерттеудің негізгі бағыты компаниялардың тұрақтылығына, тұрақты экономикалық өсуге және жасыл экономиканың дамуына ықпал ететін ESG тәуекелдерін бағалаудың инновациялық әдістері болып табылады. Өнеркәсіптің тұрақты өсуі мен нығаюына ықпал ету үшін зерттеу ESG критерийлерін тәуекелдерді басқару жүйелерімен біріктіруге, ESG-дің нақты секторларға әсерін бағалауға және ESG тәжірибесін «жасыл экономика» мақсаттарымен үйлестіру әдістерін әзірлеуге бағытталған.

Зерттеу сандық және сапалық әдістемелерді қолдана отырып, әртүрлі салалардағы қаржылық және операциялық нәтижелерді талдаумен, пәнаралық тәсілді қолданады. Нәтижелер ESG интеграциясы қаржылық көрсеткіштерді жақсартады, сондай-ақ инновацияларды ынталандырады және тәуекелдерді басқару жүйелерін нығайтады. Атап айтқанда, ESG тәжірибелері экономикалық тұрақсыздық кезінде тұрақтылықты арттырады, қаржы нарықтарындағы жүйелік тәуекелдерді азайтады және өтімділікті арттырады. Сонымен қатар, ESG-ге негізделген бастамалар, қызметкерлердің өнімділігі және тұрақты өсу, әсіресе банк және өндіріс сияқты салаларда оң корреляцияға ие болды. Қазақстан сияқты дамушы елдер нормативтік кедергілерге қарамастан, жасыл экономика жобаларын ESG мақсаттарымен үйлестіреді, яғни бұл тұрақты тәжірибелерге әлемдік тенденцияны көрсетеді.

Бұл зерттеу тұрақты экономикалық тәжірибе мен тұрақты нарықтарды ілгерілетудегі ESG рөлі туралы кеңейіп келе жатқан зерттеулер шеңберін толықтырады. Оның практикалық маңыздылығы оның күшті және тұрақты экономикалық болашақты құру үшін инвесторларды, кәсіпорындар мен саясаткерлерді ESG негізіндегі саясатты қабылдауға бағыттау қабілетіне байланысты.

Түйін сөздер: қаржылық тұрақтылық, тұрақты даму, тәуекелдерді басқару, қаржылық тиімділік, ESG интеграциясы.

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Инновационные методы моделирования для повышения эффективности оценки ESG-рисков в контексте развития «зеленой» экономики Республики Казахстан

Деловая и инвестиционная среда изменяется в связи с внедрением концепций ESG в управление рисками и инновационную деятельность. Впервые принципы ESG использовались для решения социальных и экологических проблем, но с тех пор они превратились в важные элементы снижения рисков и бизнес-стратегии. В центре внимания данного исследования находятся инновационные методы оценки рисков ESG, которые способствуют устойчивости компаний, устойчивому экономическому росту и развитию зеленой экономики. Для содействия устойчивому росту и укреплению промышленности исследование сосредоточено на интеграции критериев ESG с системами управления рисками, оценке влияния ESG на конкретные секторы и разработке методов координации практик ESG с целями «зеленой экономики».

В исследовании используется междисциплинарный подход, анализируются финансовые и операционные результаты в различных отраслях с использованием как количественных, так и качественных методологий. Результаты показывают, что интеграция ESG улучшает финансовые показатели, а также поощряет инновации и укрепляет системы управления рисками. В частности, практики ESG повышают устойчивость во времена экономической нестабильности, снижают системные риски на финансовых рынках и повышают ликвидность. Кроме того, инициативы, основанные на ESG, производительность труда сотрудников и устойчивый рост, как выяснилось, положительно коррелируют, особенно в таких отраслях, как банковское дело и производство. Развивающиеся страны, такие как Казахстан, координируют проекты зеленой экономики с целями ESG, несмотря на нормативные препятствия, что указывает на мировую тенденцию к устойчивым практикам.

Данное исследование дополняет расширяющийся круг исследований о роли ESG в содействии устойчивой экономической практике и устойчивым рынкам. Его практическая значимость обусловлена его способностью направлять инвесторов, предприятия и политиков к принятию политики, основанной на ESG, для создания сильного и устойчивого экономического будущего.

Ключевые слова: финансовая устойчивость, устойчивое развитие, управление рисками, финансовая эффективность, интеграция ESG.

Introduction

Business and investment environments have changed dramatically in recent years due to the incorporation of Environmental, Social, and Govern-

ance (ESG) standards into corporate risk management and innovation initiatives. ESG variables cover a wide variety of ethical and sustainable issues that today influence how businesses function, reduce risks, and innovate to stay competitive. Study shows

that by lowering the risks associated with social injustice, environmental degradation, and governance failures, ESG-driven solutions improve financial performance and resilience (Sobehart, 2024; Miao, 2024). ESG is becoming more widely acknowledged as a crucial factor in long-term value creation, sustainable growth, and market differentiation; it is not only a reaction to investor expectations or legal requirements (Molchanova et al., 2023).

However, the process of evaluating ESG issues has unique difficulties, primarily because rating agencies need to standardize their ESG ratings and procedures. This discrepancy affects the incorporation of ESG data into credit and risk models and makes it challenging for stakeholders and investors to evaluate a company’s ESG performance appropriately (Murè et al., 2024). Furthermore, industry-specific constraints and regional restrictions frequently impact the complexity of financial ESG practices (Cabaleiro-Cerviño et al., 2024). Thus, it is essential for scholars and practitioners to comprehend how ESG interacts with business risk profiles and innovation.

The review covers the latest approaches to ESG assessment, as well as the challenges in reconciling ESG practices with business strategy, and the impact of ESG-led innovation on financial success. Specifically, it examines how ESG is modifying risk management frameworks and identifies new ways to assess ESG-related risks. It provides insights into how companies can use ESG activities to stimulate innovation and increase resilience in the face of growing global challenges.

The growing focus on ESG principles demonstrates the global trend towards sustainable development. ESG frameworks are critical to risk management and business strategy as they are driven by the need to address social and environmental challenges. The growing stakeholder demand for openness on social responsibility, environmental impact, and corporate governance has accelerated this shift. ESG-oriented solutions demonstrate positive resilience by enhancing risk mitigation capabilities and alignment with green finance concepts. ESG considerations can reduce the exposure of industries such as banking and insurance to climate change risks and regulatory changes.

However, there are particular difficulties in implementing ESG principles in various economic circumstances. For instance, in spite of resource and legal limits, Russia and Uzbekistan are integrating ESG into green economic growth. China’s strategy, however, shows a purposeful connection of environmental aims with its economic ambitions.

This review’s main goal is to critically examine current ESG evaluation approaches in light of the field’s expanding significance and wide range of applications. The study looks at how these approaches affect sector-specific practices, financial performance, and risk management in different areas. Through a review of previous studies, case studies, and empirical research, this study offers insights on how to modify ESG frameworks to enable sustainable growth in a variety of market scenarios.

ESG has emerged as a key framework for businesses and countries seeking to achieve balanced economic development with environmental stewardship and social justice in line with green economy goals. Concerns about resources and environmental issues have fueled the green economy movement, which is becoming increasingly integrated with ESG practices to support resilience, innovation, and long-term value production. Due to the need for sustainable investments and regulatory pressures, this connection has promoted the sector-wide adoption of ESG. Businesses that include ESG into their business plans in order to achieve sustainability goals are part of the “green revolution”, which boosts competitiveness and other goals.

This study examines how ESG frameworks and green economy practices are convergent, assessing how they affect sustainability and economic results in different nations. It draws attention to how ESG supports sustainable growth, resilience building, and business innovation. This review describes optimal practices by synthesizing recent research. It points out obstacles, laying the groundwork for more research into how a green economy and ESG-driven tactics might work together to promote balanced growth.

Literature Review

Integrating Environmental, Social, and Governance (ESG) principles in financial strategies is increasingly recognized for enhancing sustainability and economic resilience. Some researches have explored how ESG mitigates systemic risks within financial networks. Li et al. (2023) combined financial network analysis with machine learning to assess risk spillovers in ESG investments, demonstrating that ESG frameworks support resilience through inter-institutional linkages. However, their study primarily focuses on financial networks, leaving gaps in understanding non-financial sector applications. Sobehart (2024) proposed quantitative methodologies that integrate ESG risks with traditional credit and market risk models, applying climate-focused

stress testing. Although Sobehart's methods adapt credit risk models to account for ESG-specific risks, the research highlights the need for models responsive to regulatory changes and market conditions.

The study by Capelli, Ielasi, and Russo (2023) proposes a novel risk metric, VaRESG, which integrates Environmental, Social, and Governance (ESG) factors into the traditional Value-at-Risk (VaR) model. This study demonstrates how ESG risks can enhance predictive accuracy for unexpected losses, especially under stress conditions. Using entropy functions for ESG scores, VaRESG better aligns risk assessments with sustainability, outperforming standard VaR models. Empirical tests on a global equity portfolio reveal VaRESG's effectiveness in reducing volatility and enhancing portfolio resilience. This establishes it as a promising tool for asset managers and regulators aiming to improve financial risk assessment through ESG integration.

Murè et al. (2024) differentiated between ESG ratings and scores, developing a model tailored to SMEs for assessing sustainability. This model offers customized assessments for the EU market but underscores the need to adapt ESG measures to various global market structures. Cabaleiro-Cerviño and Mendi's (2024) research highlights how ESG-aligned innovation enhances firms' competitive positioning and sustainability outcomes. While they affirm ESG's positive impact on performance, they identify a lack of longitudinal data on ESG's effects on operational efficiency and profitability.

Bublyk et al. (2023) examined economic complexity as a driver for green economy reforms, advocating for ESG-aligned initiatives that adapt to complex financial systems. Their findings on macroeconomic effects open questions about how economic complexity impacts firm-level ESG adoption. Miao (2024) addressed ESG data opacity and regulatory inconsistencies, recommending improvements in data management and stakeholder engagement. Despite these suggestions, industry-wide data standardization remains largely unexplored, which limits ESG integration's effectiveness across industries.

The ACRA (2021) model applies multi-dimensional ESG ratings, integrating sector-specific modifiers. Although foundational, this approach needs more adaptability to emerging ESG metrics such as biodiversity and circular economy indicators. Recent research highlights ESG integration's role in enhancing corporate resilience against economic downturns. A 2024 study underscores the importance of ESG in improving firm resilience yet calls for sector-specific analysis to understand varying ESG impact dimensions.

Gherghina (2024) focuses on corporate finance practices tied to ESG, arguing that enhanced ESG practices correlate with financial benefits such as risk mitigation, reputation enhancement, and stable equity returns. He notes that ESG's role extends beyond compliance to crucial decision-making areas, with higher ESG scores linked to resilience in crises.

Singhania and Gupta (2024) perform a meta-analysis on ESG disclosure's impact on firm risk, noting an inverse relationship between ESG disclosure and firm risk. They find ESG benefits idiosyncratic risk reduction more than systematic risk, with larger firm size and female board presence as significant moderators. Their study encourages ESG investment to manage firm risk and recommends adding environmentally responsible firms to investment portfolios.

Cicchiello, Marrazza, and Perdichizzi (2022) examine non-financial disclosure regulations in the EU and US, highlighting that mandatory disclosure (such as the EU's Non-Financial Reporting Directive) enhances transparency and comparability of ESG metrics, encouraging sustainable practices. However, they warn that transitioning from voluntary to mandatory disclosure could increase costs for firms already committed to high ESG standards.

Maquieira et al. (2023) analyze the relationship between ESG scores and dividend policies in family firms, noting a positive correlation between ESG performance and dividend payments. The study highlights that financial constraints weaken this relationship, emphasizing the need for family firms to align dividend policies with ESG goals to signal responsible governance and social commitment. Karim (2019), though focusing on credit risk management, contributes insights into how risk management strategies – essential in financial sectors – can benefit from integrating ESG principles, particularly for financial institutions in markets with high volatility. He suggests that robust risk assessment mechanisms, including ESG factors, enhance stability and profitability in both conventional and Islamic banking.

Congress Research Service (2023) provides an overview of ESG as it pertains to financial services, noting that stakeholders are increasingly focused on how firms handle environmental risks, social responsibilities, and governance. This document underscores the role of transparency in ESG reporting, driven by investor demand for accountability and the importance of defining materiality in ESG disclosures.

A summary of the studies in table format with details on authors, focus areas, and main findings is given in Table 1.

Table 1 – Summary of Key Research on ESG Practices and Financial Performance

Author(s)	Focus	Main Findings
Gherghina (2024)	Corporate finance, stakeholder expectations, green finance	Highlights the shift towards sustainable finance and investor preference for transparent, green practices
Singhania and Gupta (2024)	Meta-analysis on ESG disclosures and firm risk	Found inverse relationship between ESG disclosure and firm risk, particularly for idiosyncratic risk, with notable moderators
Cicchiello, Marrazza, and Perdichizzi (2022)	EU and US firm performance under ESG disclosure regulation	EU regulations on mandatory ESG disclosures improve transparency and commitment to sustainability practices among firms
Maquieira et al. (2023)	Relationship between ESG scores and dividend policies, impact of financial constraints	ESG positively influences dividends in family firms, with financial constraints moderating this effect depending on their severity
U.S. Congress Report (2023)	Overview of ESG importance, risks, and materiality discussions	ESG’s evolving role in investment decisions, with emphasis on materiality and long-term value, and challenges in standardized metrics
Capelli et al. (2023)	ESG risks in Value-at-Risk (VaR)	Introduces VaRESG, combining traditional VaR with ESG factors to improve risk assessment, especially under stress conditions, showing predictive power in reducing unexpected losses.
Murè et al. (2024)	ESG scoring and rating	Develops a conceptual model to differentiate between ESG scores and ratings, providing SMEs with self-assessment tools for sustainability.
Cabaleiro-Cerviño & Mendi (2024)	ESG-driven innovation strategy	Shows that integrating ESG into innovation strategy enhances firm performance, especially in competitive markets.
Bublyk et al. (2023)	Green innovative economy	Explores remodeling the economy towards green innovation based on economic complexity, advocating for policies supporting green transitions.
Tolkachev et al. (2023)	Green economy, ESG in Russia	Analyzes ESG project evaluation, risk assessment, and management in Russia, highlighting unique challenges and adaptation strategies in the region.
You et al. (2024)	Green governance, ESG, productivity	Demonstrates how green governance impacts high-quality development, focusing on productivity improvements through ESG practices.
Amel-Zadeh & Serafeim (2017)	ESG usage by investors	Survey-based study highlighting investor motivations and uses of ESG data in investment decisions, with implications for corporate transparency.
United Nations Global Compact (2004)	ESG, financial markets	Early framework connecting ESG factors to financial performance, advocating for responsible investment practices.
Korohodova et al. (2023)	Green economy evolution, energy innovations	Investigates the progression to a green economy in Industry 5.0, noting the role of energy innovations in sustainable development.
Li, Qin & Wu (2023)	Risk assessment, ESG investment	Presents a hybrid model to assess risk spillover effects in ESG investments within financial networks, emphasizing the need for resilient financial structures.
Sobehart (2024)	Climate and ESG risk management	Outlines advanced analytical methods for managing ESG and climate risks, promoting more accurate and actionable risk assessments for sustainable investments.
Miao (2024)	ESG risk management challenges	Discusses challenges in ESG risk management and suggests strategies for effective risk mitigation in light of evolving regulatory and investor expectations.
Molchanova et al. (2023)	Green economy, innovation	Identifies factors that drive innovation in green economy transitions, noting the importance of regulatory support in transformation.
Cicirko & Cicirko (2023)	ESG challenges in insurance	Highlights the challenges faced by the Polish insurance sector in adapting to ESG requirements, with recommendations for risk management.
Note – compiled by the authors based on the above references		

These studies collectively underscore that effective ESG practices not only improve financial outcomes by enhancing resilience, managing risks, and increasing stakeholder trust but also have broader implications for regulatory compliance, strategic alignment, and transparency across various sectors.

The role of ESG in financial stability is widely discussed in the literature. Chaudhry et al. (2023) applied extreme value theory to assess ESG risks across sectors, highlighting heightened volatility in ESG portfolios during environmental crises. Similarly, Roy et al. (2024) used GJR-GARCH models to analyze ESG portfolio resilience in economic downturns, emphasizing their robustness in diverse market regimes. Within the insurance sector, Cicirko et al. (2023) demonstrated how ESG-aligned underwriting can limit climate-related liabilities, attracting environmentally conscious consumers while adhering to EU regulations. Pomaza-Ponomarenko (2023) further suggested dynamic risk assessment tools, such as ESGify, which uses natural language processing (NLP) for quick ESG risk identification across corporate disclosures.

Liu et al. (2024) found that strong ESG performance in the banking sector correlates with improved liquidity and reduced non-performing loans, aligning with stakeholder theory. This relationship suggests sustainable banking practices focused on transparency and ethics can enhance financial stability. ESG integration encourages corporate innovation, as seen in Cabaleiro-Cerviño and Mendi (2024), who observed that ESG-aligned firms tend to outperform non-ESG firms in innovation, labor productivity, and exports. Sangirova et al. (2024) further highlighted Uzbekistan's adoption of ESG practices to enhance green innovation and resource efficiency.

The regulatory aspect of ESG is vital for standardization. EU regulations on ESG disclosure aim to streamline practices across member states, as evidenced by studies on ESG compliance in Polish financial markets. Kazakova et al. (2023) introduced ESGify as a compliance tool that automatically classifies ESG risks, enhancing data quality and transparency. Murè et al. (2024) proposed a self-assessment ESG model for SMEs, enabling tailored sustainability evaluations that align with local regulations. This approach highlights ESG scoring as a driver of sustainable practices, especially for resource-constrained SMEs. Despite a strong foundation, this research reveals gaps in understanding how ESG impacts corporate performance across sectors, including:

1. *Sector-Specific ESG Metrics*: The need for standardized ESG metrics tailored to individual industries hinders accurate assessment and comparison of ESG performance across sectors.

2. *Data Comparability and Transparency*: Inconsistent ESG reporting practices lead to data comparability and transparency challenges, making evaluating ESG impacts uniformly across different sectors difficult.

3. *Longitudinal Impact Analysis*: More longitudinal studies are needed to understand the long-term effects of ESG integration on corporate performance, as current research often focuses on short-term outcomes.

4. *Integration of ESG in Risk Management*: Further exploration is required to determine how ESG factors can be effectively integrated into traditional risk management frameworks across various industries.

5. *Influence of ESG on Innovation*: The relationship between ESG practices and innovation varies across sectors, necessitating a more profound examination of how ESG initiatives drive or hinder innovation in different industries.

Addressing these gaps is essential for developing a comprehensive understanding of ESG's impact on corporate performance across diverse sectors.

Amel-Zadeh and Serafeim's work (2017) highlighted ESG's financial materiality, showing it aids in risk assessment rather than merely ethical positioning. The United Nations' Principles for Responsible Investment (2006) urged companies to integrate non-financial factors, catalyzing ESG's adoption worldwide. Early research by McWilliams and Siegel (2000) and Porter's Hypothesis (1991) demonstrated that environmental regulation can drive corporate innovation, suggesting a competitive advantage through sustainable practices.

Khan et al. (2024) examined ESG performance in manufacturing, where eco-friendly production practices are critical to meet sustainability goals. Asia and Europe lead this research area, emphasizing sustainability models and governance practices that drive a green manufacturing revolution. Lee, Kim, and Cho (2024) linked ESG engagement with corporate innovation, noting that companies committed to ESG practices produce higher innovation outputs, leading to resilience against market changes.

Neagu et al. (2024) analyzed the EU's progress in the green economy, underlining eco-innovation's role in achieving the European Green Deal's objectives. They call for substantial public-private investment to overcome barriers such as innovation funding. Huseynova (2024) emphasized the green

economy’s role in resource preservation, pollution reduction, and sustainable job creation. Her work underscores renewable energy and green innovation as pillars of sustainable economic growth, laying a foundation for future studies on green economic policies. Berstembayeva et al. (2024) reviewed Kazakhstan’s green economy initiatives, observing increased demand for green finance and eco-friendly lending. Their findings highlight Kazakhstan as a case study for sustainable development within emerging markets.

Significant gaps still need to be made while progress has been made in integrating ESG into financial and risk management frameworks, and this still needs to be discovered. Limited research exists on ESG’s long-term impact on economic resilience, particularly in high-risk sectors like finance and insurance. As ESG frameworks evolve, comparative studies across developed and emerging markets are needed, particularly regarding green finance’s role in Central Asia and Eastern Europe. Further, challenges around data comparability, standardization, and integrating non-financial metrics into valuations persist.

This review paves the way for examining cross-sector ESG models, developing metrics to assess ESG’s impact on corporate sustainability, and enhancing resilience. By exploring ESG’s diverse applications, this study contributes to advancing sustainable practices in varied economic contexts.

Methodology

The use of environmental, social and governance (ESG) measures in financial risk assessment models is the subject of extensive current research, which is explored in this study. With the premise that better ESG integration can increase the predictability, robustness and flexibility of a company’s performance in changing markets, this study examines relevant high-caliber research to offer a focused assessment of the latest findings in this area.

The United Nations study “*Who Cares Wins: Connecting Financial Markets to a Changing World*” (United Nations Global Compact, 2004) established the notion of Environmental, Social, and Governance, or ESG for short. The United Nations Global Compact spearheaded the effort to create this study, and a group of 20 significant financial institutions contributed. The slogan “Who Cares Wins” was created to emphasize the link between long-term financial success and ethical business practices and to encourage investors and organizations to take ESG considerations into account in fi-

ancial decisions. To improve risk management and promote sustainable growth, this paper highlighted the importance of incorporating ESG factors into investment decisions. As a seminal study, it sparked a great deal of research and helped make ESG a crucial framework in corporate strategy, sustainability, and finance.

Interest in ESG from the scientific community has grown exponentially over the past two decades. This trend is evident in the increasing number of publications mentioning ESG on Google Scholar, as illustrated in the chart below (Fig. 1).

These figures show how frequently the phrase ESG appears in the literature, suggesting that the subject is widely discussed. It was not possible to examine every article due to the sheer number of publications, and not all of them are from reputable sources or peer-reviewed scientific journals. This review narrows our scope to high-quality, meaningful research by concentrating on current and noteworthy studies and choosing only those that critically investigate the implementation of ESG-based models in risk assessment. This ensures rigor and relevance.

A systematic literature review was used as the research approach for this study to gather information from reliable sources on the use of ESG in risk assessment. This method makes it possible to analyze current information, point patterns and direct possible areas for further study in great detail.

This study uses the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis) method. Renowned academic databases such as Scopus, JSTOR, and Web of Science were the main sources of literature and guaranteed access to peer-reviewed and highly influential journal articles. The primary keywords used in the search were *Environmental, Social, and Governance, ESG, and risk*, with a focus on recent publications, primarily from the last year (end of the 2023 and 2024). To refine the search, Boolean operators were applied (e.g., “ESG AND risk” and “ESG AND financial stability”), prioritizing studies that align with the objective of integrating ESG factors into financial risk assessment.

Inclusion and Exclusion Criteria. To maintain a high standard of rigor and relevance, the review only includes articles that meet specific criteria:

Inclusion Criteria:

- Published within peer-reviewed journals.
- Focus on ESG as it pertains to financial risk, corporate performance, or sustainability.
- Provide empirical evidence or a comprehensive analysis related to ESG integration in financial models.

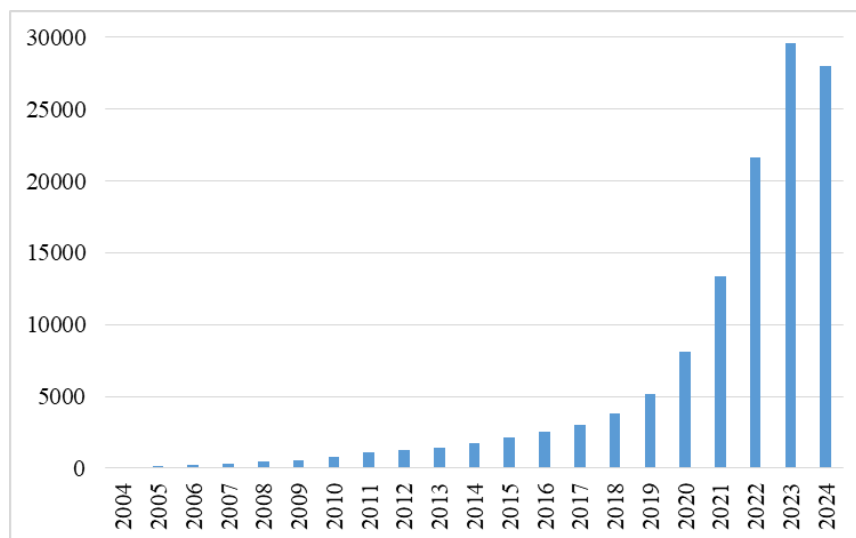


Figure 1 – ESG-Related Publications by Year (2004-2024)

Note – compiled by the authors based on data analyzed using publication trends in ESG-related research (2004–2024)

- Published mainly in 2024 to ensure contemporary insights and relevancy to the latest trends.

Exclusion Criteria:

- Non-peer-reviewed articles, reports, or news publications.

- Studies not directly related to ESG and risk assessment.

- Publications without credible methodology or empirical grounding.

The selected articles were analyzed using a thematic approach, focusing on:

- ESG Integration in Financial Models: Identifying common methodologies and metrics used to

incorporate ESG considerations into traditional financial risk models.

- Impact on Corporate Performance and Stability: Examining how ESG integration influences financial outcomes, resilience, and adaptability.

- Competitive Advantage through ESG: Assessing research on the potential for ESG-focused firms to gain competitive advantages.

This PRISMA flow diagram (Table 2) outlines the systematic review process for Environmental, Social, and Governance (ESG) risk literature, focusing on reputable academic databases (Scopus, JSTOR, and Web of Science) limited to publications from 2024.

Table 2 – PRISMA Flow Diagram

		Number of Studies
Identification:	Records identified through database searching (Scopus, JSTOR, Web of Science):	1,200
	Records after duplicates removed:	1,150
Screening:		
	Records screened (titles and abstracts):	1,150
	Records excluded based on titles/abstracts (irrelevant to ESG risk topic):	900
Eligibility:		
	Full-text articles assessed for eligibility:	250
	Full-text articles excluded, with reasons: – Not focused specifically on ESG risks: 120 – Methodology not suitable for review criteria: 40 – Study outside 2024 date range: 25 – Non-academic or low-quality sources: 15	200
Included:		
	Studies included in the final review:	50
	Key studies selected based on relevance and quality:	19

Note – compiled by the authors based on PRISMA methodology guidelines, Moher et al., 2009

Data Extraction and Synthesis. Each article was reviewed to extract key insights on ESG integration, methodologies, and outcomes. Data synthesis was conducted by grouping studies into thematic areas, facilitating an analysis of patterns and divergences in findings. This approach enabled a focused examination of critical studies that contribute directly to the understanding of ESG’s role in risk assessment, without broadening the scope to less pertinent material.

In Capelli, Paolo, et al. (2023), using a perturbative approach and entropy function of ESG scores, the VaRESG model integrates environmental, social, and governance risks with traditional Value-at-Risk (VaR) metrics to estimate market risk more accurately, especially under stress conditions, helping asset managers and institutional investors reduce unexpected losses.

This review acknowledges limitations, including the exclusion of non-peer-reviewed literature that may offer practical insights from industry reports or expert opinions. Furthermore, the selection of recent publications (2024) may limit historical perspectives, though this constraint supports the goal of focusing on contemporary advancements in ESG research.

Results and discussion

To effectively analyze the impact of Environmental, Social, and Governance (ESG) factors on corporate stability, innovation, and risk management, this review draws on key sources to establish a foundational understanding. Building on this foundation, we can proceed with a structured approach to data analysis by constructing mathematical models and visual representations such as graphs and matrices. This will allow for a quantitative assessment of the themes discussed in the review.

Capelli, et al. (2023) in this study presents VaRESG, a novel model enhancing traditional Value-at-Risk (VaR) by integrating ESG factors. The model employs an entropy-based measure (RESG) and adjusts the variance-covariance matrix with ESG modifications, enabling a deeper analysis of ESG’s impact on financial resilience across sectors. Including graphs like time series and 3D plots visually demonstrates the model’s adaptability and predictive power in varying market conditions.

1. Summary of the study’s Key Model (VaRESG):

- The Capelli’s study (2023) introduces VaRESG, a new model that combines traditional Value at Risk (VaR) with ESG factors to provide a more

robust risk assessment. This model incorporates an entropy-based ESG measure (RESG) and modifies the standard variance-covariance matrix with ESG-related adjustments.

2. Entropy-Based ESG Measure (RESG):

- RESG uses entropy to measure the “disorder” or diversity in the ESG profile of assets in a portfolio:

$$RESG = \sum_{i=1}^8 p_i \log(p_i) * \frac{1}{\min_{j \in i}(p_j)} \quad (1)$$

- This model segments assets into eight ESG score classes and applies an entropy measure to gauge ESG diversity within the portfolio.

3. Constructing the Covariance Matrix (C-matrix):

- The covariance matrix (C-matrix) is modified to incorporate ESG factors:

$$\Sigma_c = \begin{pmatrix} C_1^2 & C_1C_2 & \dots & C_1C_n \\ C_2C_1 & C_2^2 & \dots & C_2C_n \\ \vdots & \vdots & \ddots & \vdots \\ C_nC_1 & C_nC_2 & \dots & C_n^2 \end{pmatrix} \quad (2)$$

4. Graphs:

- Time Series Graph: A graph showing the evolution of VaR and VaRESG over time would illustrate how these metrics respond to different market conditions.

- 3D Plot: A three-dimensional plot can display the relationship between VaR, VaRESG with $J = 1$, and VaRESG with $J = 1/2$.

Figures 2(a,b,c) illustrate the sensitivity of VaRESG to different J values, its monthly distribution in 2020, and a comparison of average VaR and VaRESG across years, highlighting the influence of ESG integration on portfolio risk estimates.

1. Comparison of Average VaR and VaRESG Across Years: This line graph illustrates the average VaR and VaRESG (with $J = 1/2$ and $J = 1$) across the years 2016 to 2020. It shows how VaRESG consistently provides higher average risk estimates than traditional VaR, with the risk level increasing as J moves from $J = 1/2$ to $J = 1$, indicating a more conservative estimate in line with ESG integration.

2. Monthly Distribution of VaRESG ($J=1/2$) for 2020: This bar chart focuses on the monthly distribution of VaRESG with $J = 1/2$ for 2020, a year of significant market volatility. In line with market volatility, the graph illustrates variations across months and captures elevated risk assessments at times of economic strain.

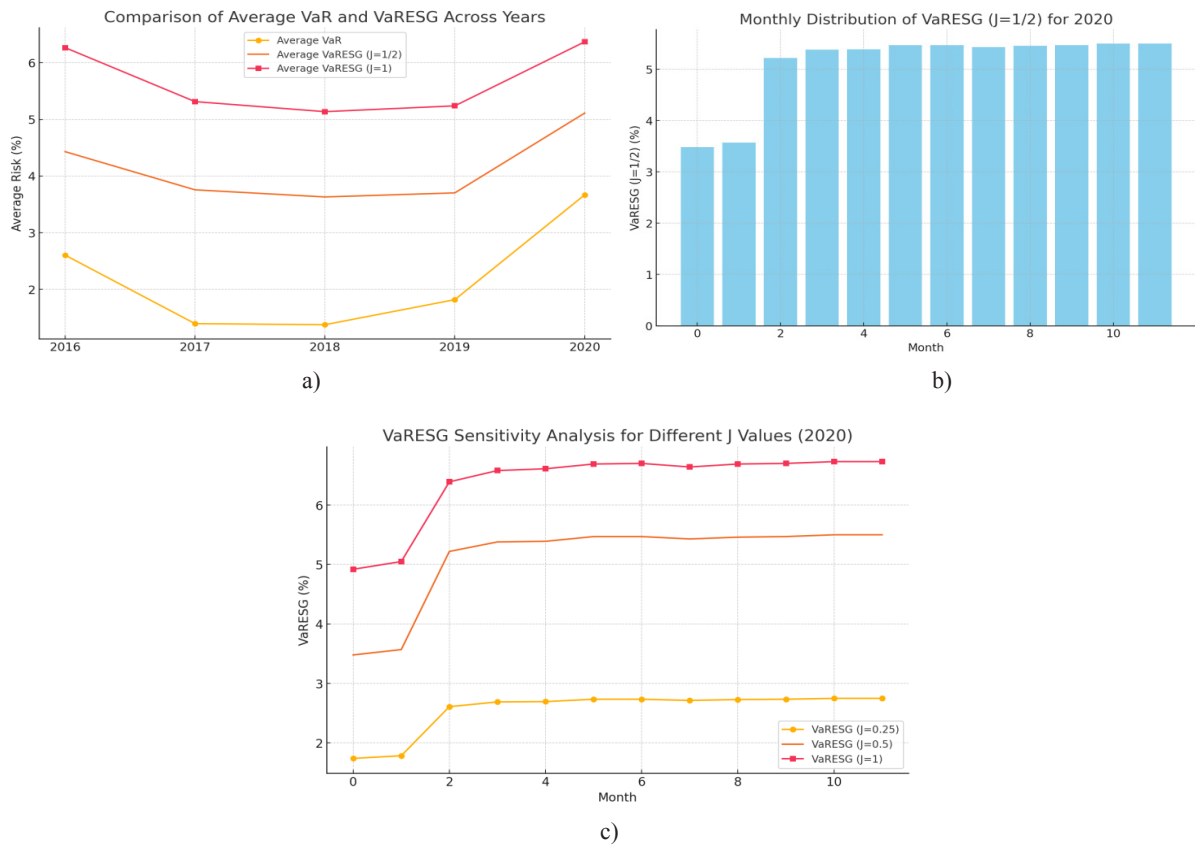


Figure 2 – VaRESG Risk Assessment and Sensitivity Analysis Visualization
 Note – compiled by the authors based on Capelli et al. (2023)

3. 2020 VaRESG Sensitivity Analysis for Various J values: A sensitivity study of VaRESG in 2020 under three fictitious J values: $J = 0.25$, $J = 0.5$, and $J = 1$ is shown in this line graph. VaRESG values rise in tandem with J , indicating a greater degree of risk as a result of ESG integration. This analysis shows how changing J enables customizable risk estimate according to the model’s ESG weight.

Together, these figures show how sensitive VaRESG is to various degrees of ESG integration and demonstrate its resilience and flexibility in a range of economic environments.

VaRESG may therefore be compared to other widely used models in financial risk management, with an emphasis on the benefits and drawbacks of each.

1. Traditional VaR: This straightforward and popular method of estimating possible loss ignores ESG considerations; VaRESG improves it by incorporating sustainability risks.

2. CVaR (Expected Shortfall): Offers both tail-risk and ESG insights when combined with VaRESG; it captures severe losses more effectively than VaR but lacks ESG integration.

3. Monte Carlo Simulation with ESG situations: VaRESG provides a more straightforward ESG risk estimate, but it is computationally intensive and adaptable to complicated, hypothetical ESG situations.

4. Scenario Analysis for ESG Risk: VaRESG provides a comprehensive, integrated perspective of ESG risk, but it is tailored to certain ESG events and does not have a uniform risk measure.

5. ESG Scores Alone: Evaluate ESG performance qualitatively without calculating risk; VaRESG fills this gap by including a quantitative ESG-based risk metric.

The capacity of VaRESG to incorporate ESG elements, capture financial volatility, account for tail risks, computational complexity, and appropriateness for scenario testing are all compared with other risk models in Table 3.

Depending on the particular risk management objectives, each approach provides advantages. VaRESG offers a quantitative, integrated risk assessment and is a good option for portfolios where ESG considerations are significant. While traditional VaR and CVaR models are efficient for financial volatil-

ity and tail risks, combining VaRESG with CVaR or Monte Carlo simulations can offer comprehensive insights that include both sustainability and extreme loss risks. For event-specific ESG risk assessments, scenario analysis remains valuable.

Cabaleiro-Cerviño, G., & Mendi, P. (2024) explores the relationship between ESG goals and various performance indicators in innovative firms. Findings indicate that ESG-driven companies dem-

onstrate enhanced innovation output, higher labor productivity, and more excellent survival rates than non-ESG-driven firms (Fig. 3(a,b,c)). Visual analyses, including a boxplot of innovation output and bar chart of survival rates, illustrate performance contrasts. At the same time, a decision tree diagram further emphasizes how ESG engagement positively correlates with risk classification and corporate longevity.

Table 3 – VaRESG in Relation to Typical Financial Risk Models

<i>Model</i>	<i>ESG Integration</i>	<i>Captures Financial Volatility</i>	<i>Tail Risk (Extreme Loss)</i>	<i>Computational Complexity</i>	<i>Flexibility for Scenario Testing</i>
VaR	No	Yes	No	Low	Low
VaRESG	Yes	Yes	No (but can complement CVaR)	Medium	Moderate
CVaR	No	Yes	Yes	Medium	Moderate
Monte Carlo Simulation	Possible	Yes	Yes	High	High
Scenario Analysis	Yes (event-based)	Yes (if tailored)	Possible (scenario-specific)	Medium	High
ESG Scores Alone	Yes	No	No	Low	Low

Note – compiled by the authors based on Capelli et al. (2023)

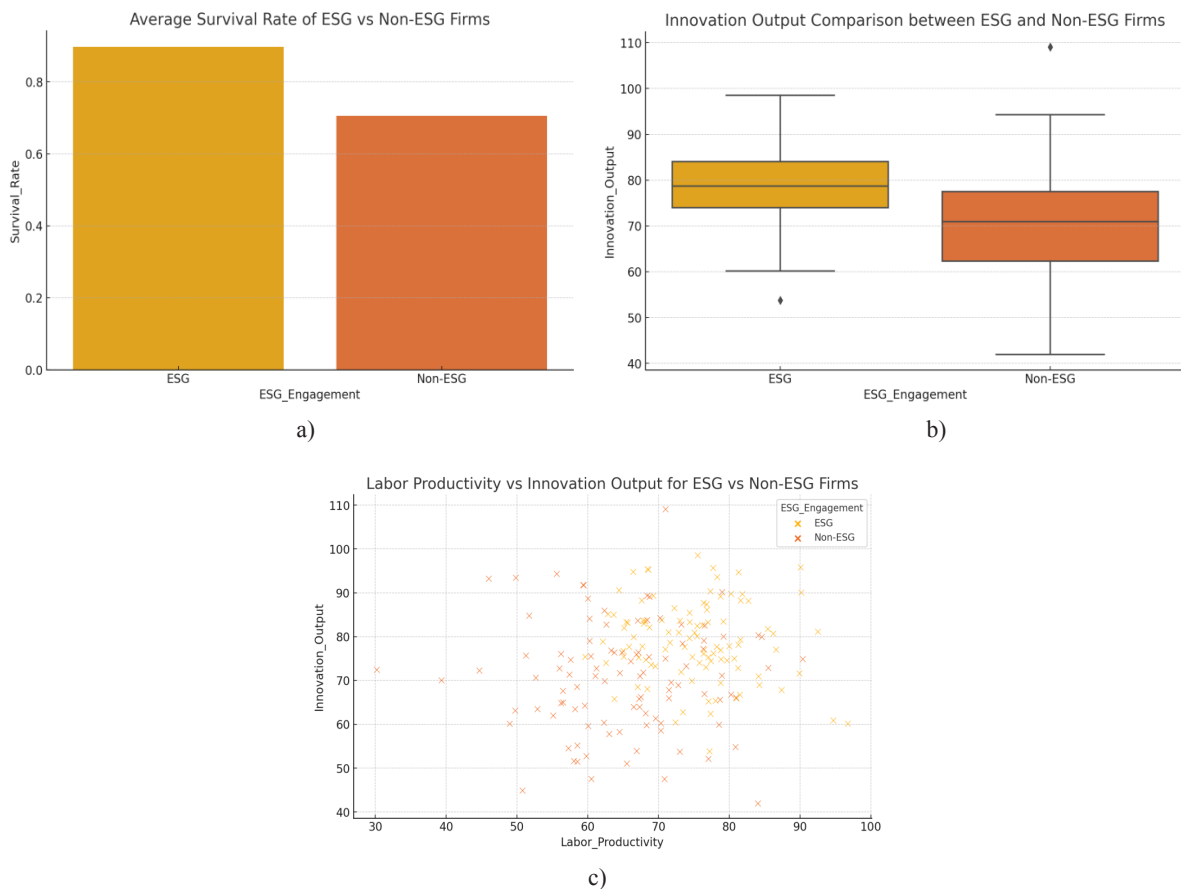


Figure 3 – Visualizing the comparison between ESG-driven and non-ESG-driven firms
 Note – compiled by the authors based on Cabaleiro-Cerviño & Mendi (2024)

The visualizations comparing ESG-driven and non-ESG-driven firms:

1. *Boxplot*: Compares Innovation Output between ESG and Non-ESG firms.

2. *Bar Chart*: Shows the average Survival Rate for ESG versus Non-ESG firms.

3. *Scatter Plot*: Displays Labor Productivity against Innovation Output, differentiating ESG from Non-ESG firms.

To build a *Complexity Matrix for Green Economy Transitions* using a Markov chain approach, we'll simulate transition probabilities across different sustainability levels for industries such as energy, waste management, and renewable resources.

Implementation Plan

1. *Define Sustainability Levels*: Assume levels such as *Low*, *Medium*, and *High* adaptation in green economy practices.

2. *Simulate Transition Probabilities*: Each industry has a probability of moving from one sustainability level to another (e.g., from Low to Medium).

3. *Create a Transition Matrix*: Each cell in the matrix represents the probability of transitioning from one level to another over time.

4. *Visualize the Matrix*: Display the transition probabilities in a matrix plot for easier analysis.

The study by Bublyk, M., Kowalska-Styczeń, A., & Lytvyn, V. (2023) presents sector-specific transition matrices visualized as heatmaps to illustrate sustainability adaptation levels in the Energy, Waste Management, and Renewable Resources sectors. These heatmaps offer insights into the probabilities of transitioning between low, medium, and high adaptation levels, aiding in analyzing sectoral advancements toward sustainable practices (Fig. 4).

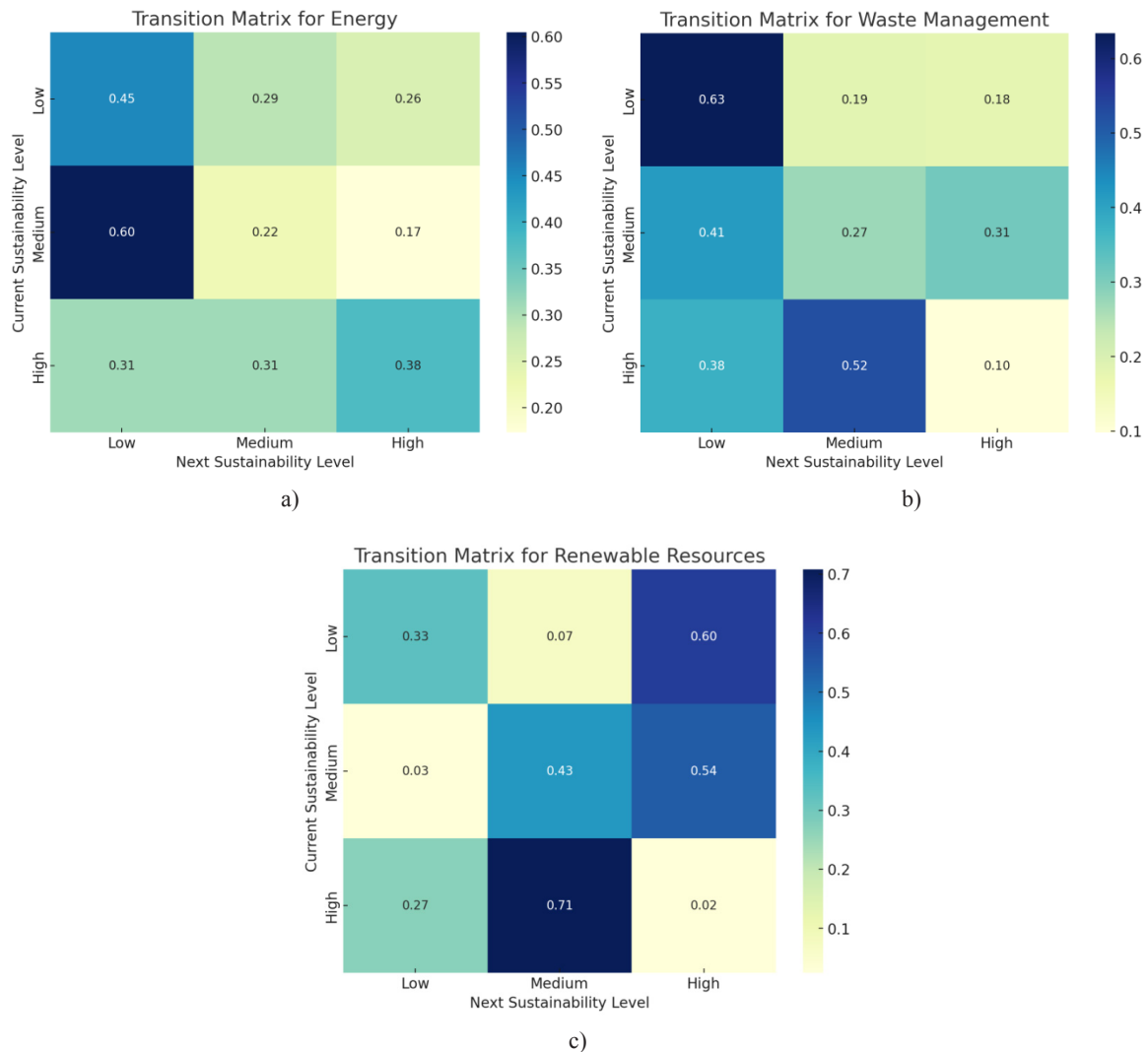


Figure 4 – Transition matrices for each sector: Energy, Waste Management, and Renewable Resources
 Note – compiled by the authors based on Bublyk et al. (2023)

Heatmaps showing transition matrices for each sector: Energy, Waste Management, and Renewable Resources. Each heatmap represents the probabilities of moving between sustainability adaptation levels (Low, Medium, High) within each sector. Let me know if you would like further adjustments or additional analysis. Explanation:

1. *Transition Matrices*: Every industry, such as waste management and energy, has a matrix with a sustainability level for each row and column:

- the current level is shown by rows (Low, Medium, High);
- the following transitional level is indicated by a column (Low, Medium, High);
- since they are probabilities, the values in each row add up to 1.

2. *Markov Chain Representation*: This algorithm use random probability, but true transition probabilities might be employed if real industry data on emissions, recycling, renewable energy, and compliance were available.

3. *Visualization*: Each heatmap provides information about possible shifts in sustainability adaptability over time by displaying the probability that a sector will go from one sustainability level to another.

To Put in Place a *Time Series Graph for Financial Network Stability Under ESG Shocks*, we may model data that shows indications of financial stability over time and show how events connected to ESG (such as regulatory changes or ESG crises) affect network resilience. Plan of Implementation:

1. *Describe the stability metrics*: Utilize metrics such as **default rates** and **volatility** to gauge the stability of a network over time.

2. *Simulate ESG Shock Events*: Present moments in time when financial stability is impacted by ESG shocks (such as crises or changes in regulations).

3. *Plot the Time Series*: Make a time series graphic with annotations to identify ESG shock events that display stability indications over time.

A dynamic framework for simulating the stability of financial networks during ESG shock events is presented by Sobehart, J.R. (2024). Figure 5 illustrates how time series simulations demonstrate that ESG shock events, characterized by elevated volatility and default rates, have a noticeable short-term effect on financial stability. The resilience and vulnerability of financial systems are demonstrated by notable increases in these indicators across pre-determined time periods, which mimic the possible results of ESG crises or regulatory changes.

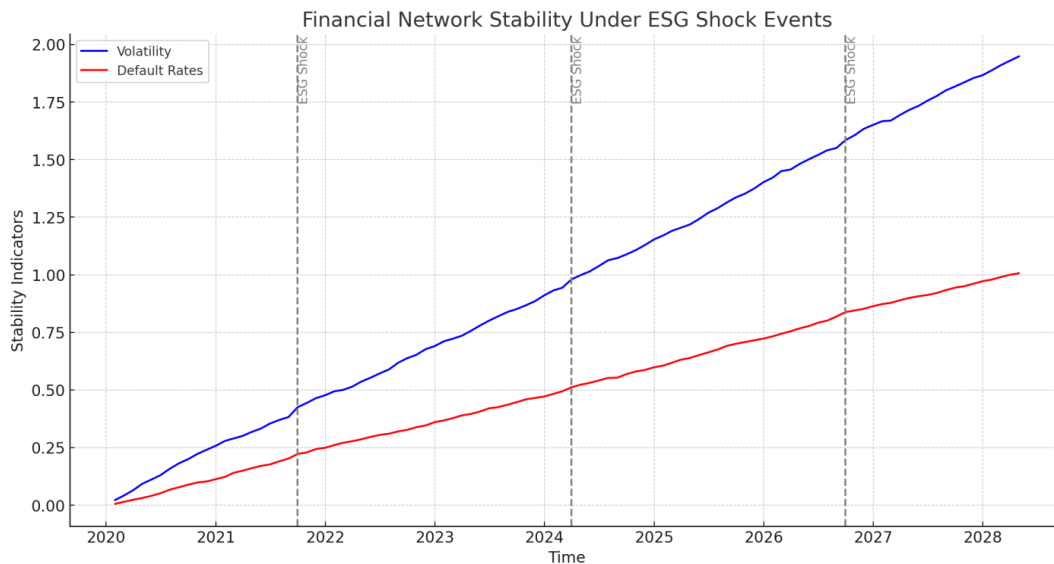


Figure 5 – Financial Network Stability in the Face of ESG Shock Events
 Note – compiled by the authors based on Sobehart (2024)

A visual representation of the financial network's stability in the case of an ESG shock is presented in Figure 6. The annotations highlight the brief effects of ESG shock events on these metrics by indicating the times when they happened. The graphic displays volatility and default levels over time.

1. Simulation of Time Series:

- Produces statistics on **default rates** and **volatility** across 100 time periods (weekly starting in 2020).

- *ESG Shock Events*: To mimic the effects of ESG-related crises or regulatory changes, they raise volatility and default rates at particular intervals (such as months 20, 50, and 80).

2. Annotations:

- Vertical dashed lines mark the occurrence of ESG shocks, with text annotations labeled as "ESG Shock" to make these events prominent.

3. Plot:

- The time series graph shows how volatility and default rates vary over time, highlighting the effect of ESG shocks on financial stability.

Running this code will produce a time series plot with annotated ESG shock events, offering a visual representation of how such events influence financial stability indicators over time.

This study analyzes key findings and comparative insights into the implementation of ESG practices within green economy frameworks. The findings focus on the role of ESG in enhancing corporate innovation, risk management, and sustainable development across industries and regions, with particular emphasis on the impacts on the manufacturing and financial sectors. In line with recent studies, these results underscore the positive effects of ESG frameworks on firm innovation, resilience, and environmental performance while highlighting existing challenges, such as reporting inconsistencies and funding limitations.

1. The Role of ESG in Corporate Innovation and Financial Stability

Integrating ESG factors has proven significant in driving innovation within firms, mainly through developing eco-friendly technologies and sustainable products. Recent data analysis reveals that firms with strong ESG practices demonstrate higher innovation outputs, a trend supported by the environmental and social dimensions of ESG (Lee et al., 2024).

2. ESG and Risk Management in Green Economies

In financial contexts, ESG performance has become crucial in assessing a company's resilience and risk profile. Firms adhering to robust ESG prac-

tices typically exhibit reduced liquidity and credit risk, especially in sectors with high exposure to environmental risks, such as banking and insurance (Liu & Xie, 2024). For instance, by matching their investments with sustainability goals, banks with high ESG scores can better manage liquidity risks. Cross-sector comparability is limited, and the incorporation of ESG into risk models is impeded by obstacles including non-standardized ESG reporting (Chaudhry et al., 2023).

3. Obstacles and Drivers of the Green Economy Transition

The requirement for comparable data and standardized reporting across businesses and nations is a major obstacle to the advancement of ESG adoption (Amel-Zadeh & Serafeim, 2017). However, the European Union's commitment to the green transition through the European Green Deal offers a powerful incentive for enhanced public-private sector collaboration and the universal adoption of green financing techniques (Neagu et al., 2024). Furthermore, outside funding – particularly from organizations like the Asian Development Bank is essential for promoting green initiatives and strengthening green financing capacities in developing nations like Kazakhstan (Berstembayeva et al., 2024).

Conclusion

The study shows how creative ESG risk assessment techniques may be applied within Kazakhstan's green economy framework and are crucial for enhancing business resilience and promoting sustainable economic growth. Businesses may efficiently solve sector-specific difficulties and connect with green economy goals by integrating ESG criteria with risk management. The results demonstrate the strategic significance of ESG for accomplishing economic and environmental goals across industries globally and emphasize the critical role that ESG practices play in fostering sustainable growth and enhancing resilience.

This study examined cutting-edge strategies for improving ESG risk assessment and determined the best practices and models suggested by Kazakhstan's framework for the development of a green economy. Several important conclusions emerged from the analysis:

1. **ESG Integration in business Strategy**: This illustrated how ESG considerations, which were formerly centered on resolving social and environmental concerns, are now essential to business strategy as they offer financial risk resilience and promote sustainable growth.

2. Sector-Specific Challenges and ESG Adaptation: particular barriers that impact different industries, include uneven ESG ratings and data transparency. It emphasized how company resilience may be enhanced by tailoring ESG indicators to sector-specific requirements, particularly in high-impact sectors like manufacturing and banking.

3. ESG-Driven Financial Stability and Innovation: ESG practices, especially during periods of economic turbulence, improve liquidity and reduce systemic risks. Adoption of ESG was also favorably connected with sustainable growth and labor productivity, opening the door to innovation-driven economic resilience.

4. Regional Adoption of ESG Standards: Despite resource and legal constraints, emerging markets, like Kazakhstan, are increasingly adopting ESG standards, highlighting a trend towards alignment with the green economy.

The study’s models show how ESG measures may be successfully included into financial risk assessment frameworks to support sustainable growth and business resilience. Among the most influential models are:

1. VaRESG, a sophisticated model presented by Capelli et al. (2023) that improves on standard VaR by including ESG components using an adjusted covariance matrix and an entropy-based metric, offering a better understanding of how ESG affects financial resilience. Time series and 3D charts are used to illustrate the model’s flexibility and response to different ESG weightings. VaRESG is a useful tool for portfolios that prioritize sustainability in risk management since it provides a simplified, comprehensive ESG-adjusted risk assessment in contrast to models like CVaR and Monte Carlo simulations.

2. Sector-Specific ESG Scoring: In order to show flexibility in international marketplaces, Murè et al. (2024) created a model specifically for SMEs that offer a self-assessment tool that correlates with EU market structures.

3. ESG Risk Spillover Model: Using financial network analysis, Li, Qin, and Wu (2023) demonstrated how ESG might reduce systemic risks by enhancing network resilience.

4. Green Economy Complexity Matrix: To promote green economy transitions, Bublyk et al. (2023) used transition matrices to assess sector-specific sustainability levels.

Each model emphasizes how important ESG is for improving risk management, resilience, and sustainable development in a range of economic environments.

Even though there are many academics that actively study ESG, this evaluation of the literature identifies important gaps that present chances for more study to enhance comprehension and enhance applicability across industries, especially in the context of the green economy. ESG considerations are crucial in directing businesses toward ecologically and socially responsible practices as global initiatives strive for sustainable growth. Among the major gaps found are:

Sector-Specific ESG Metrics: Accurate evaluation and benchmarking of ESG performance across sectors are hampered by the absence of standardized, industry-specific ESG measurements, which is essential for advancing green economy goals and regularly evaluating environmental impact;

Data Comparability and Transparency: Hampered by inconsistent ESG reporting procedures, which make it difficult to assess ESG impacts consistently across industries, particularly when gauging the advancement of green economic objectives;

Long-Term Impact Analysis: Although a lot of research focuses on short-term results, more longitudinal studies are required to comprehend how ESG integration affects corporate performance and resilience over the long run, especially in industries like infrastructure, finance, and renewable energy that are vital to the green economy;

ESG Factor Integration in Risk Management: Little is known about how ESG elements may be successfully incorporated into conventional risk management frameworks across industries to improve resilience, which is crucial in a green economy where environmental threats are more significant;

Influence of ESG on Innovation: Since the link between ESG practices and innovation differs greatly by industry, further research is needed to determine how ESG activities support or impede innovation in green industries, which in turn promote sustainable development;

Industry and Regional Comparability: Few studies address ESG’s impact across diverse geographic regions and economic contexts. Comparative research, especially on green finance in emerging markets like Central Asia and Eastern Europe, is crucial for a global perspective on ESG practices within the green economy.

Addressing these gaps, as revealed through this literature review, will provide a more comprehensive understanding of ESG’s role in advancing the green economy, allowing businesses and policymakers to integrate sustainable principles more effectively into corporate strategies worldwide.

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