



Innovation and risk management in environmental technology startups

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ABSTRACT

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This study examines the strategic balance between research and development (R&D) investment, risk management practices, regulatory compliance, and strategic partnerships in their contributions to overall startup success. Based on a cross-sectional analysis of 30 environmental technology startups, the work employs multiple regression modeling and structural equation modeling (SEM) to examine how these factors converge to impact either innovation performance or market performance. The results suggest that an increase in R&D expenditure enhances product commercialization, but it is effective only when accompanied by structured risk assessment frameworks. Startups in the sample invested an average of 18.4% of their revenue in R&D and conducted 4.2 structured risk assessments annually. Startups implementing compliance strategies from the start tend to obtain regulatory approvals sooner, incur lower certification costs, and enjoy heightened financial stability. Proactive compliance reduced certification costs by \$15,000 and shortened certification time by 3.5 months. Startups with strong partnerships achieved a 22% higher resource allocation efficiency and 15% greater market expansion. These results have significant implications for startup founders, investors, and policymakers, emphasizing the need for balanced innovation strategies that align financial, regulatory, and strategic considerations.

Highlights

- Gender-diverse leadership drives stronger environmental performance
- R&D boosts innovation when paired with structured risk management
- Proactive compliance cuts costs and speeds up certification
- Strategic partnerships enhance market reach and resource efficiency



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1. Introduction

Entrepreneurs building environmental technology startups have emerged as pivotal actors in addressing some of the world's most pressing ecological challenges. Small, agile, and inherently innovative, these startups are at the forefront of developing breakthrough solutions for pollution control, renewable energy, waste management,

and resource conservation, paving the way for a more sustainable future (Wang et al., 2023; Mbadugha et al., 2024; Abdullah et al., 2025). By pioneering cleaner energy technologies, designing eco-efficient production systems, and enhancing waste recycling processes, they serve as catalysts for the transition towards greener economies (Talebian et al., 2024; Gharibreza et al.,

2018). However, despite their immense potential, the pathway to success for these startups is rarely straightforward. The complexity of balancing innovation with risk management often determines their ability to survive and thrive in competitive and highly regulated markets.

Environmental technology entrepreneurs operate within highly volatile and uncertain environments, where their innovations are often built on unproven technologies or involve applying existing technologies in entirely new contexts. This level of experimentation presents a double-edged sword: while it allows for transformative breakthroughs, it also introduces significant technological, financial, and operational risks (Wang, 2023). Unlike mature firms with well-established infrastructures and consistent revenue streams, startups usually lack financial buffers, market reputation, and resource depth. As a result, they must craft strategic frameworks that integrate R&D and risk management to ensure that innovation efforts do not collapse under environmental and market pressures.

A significant challenge lies in regulatory compliance. Given their potential impact on public health, ecosystems, and natural resources, environmental technologies are subject to rigorous scrutiny from governments, certification bodies, and international agencies. Navigating this landscape requires extensive resources, legal understanding, and time. Although adopting compliance strategies early on can fast-track market entry and lower certification costs, ignoring or mishandling regulatory obligations can lead to costly delays or outright business failure (Mustafayev & Isgandarov, 2024). Hence, regulatory fluency from the outset is not just advantageous but essential for long-term viability.

Beyond regulatory issues, environmental technology startups are often hampered by financial limitations and market-related volatility. High upfront costs associated with R&D, infrastructure development, and talent acquisition can be prohibitive. Moreover, securing funding is especially difficult for startups with experimental technologies that lack a proven commercialization path (Azoev & Sumarokova, 2023). Investors typically seek low-risk, high-return ventures, and green tech startups must work harder to convince them of their feasibility and market fit. In addition, market dynamics, fluctuating demand, and rapidly evolving consumer expectations necessitate strategic flexibility and rapid response capabilities.

In addressing these multifaceted challenges, strategic partnerships and collaborations have proven indispensable. Alliances with academic institutions, established industry players, and public organizations offer access to much-needed expertise, financial resources, and regulatory insights. Such collaborations often accelerate product development, lower costs, and improve the likelihood of successful market penetration. However, partnerships must be carefully managed to align strategic objectives, protect intellectual property, and ensure mutual value creation (Achmad et al., 2023).

Another significant hurdle is market adoption and stakeholder trust. Even the most advanced technologies can struggle to gain traction if end-users and regulators remain unconvinced of their cost-effectiveness, environmental value, or long-term reliability. Startups need to go beyond product development to invest in stakeholder education, transparent communication, and trust-building initiatives. This involves anticipating risks early, maintaining clear communication, and delivering measurable, outcome-driven results (Martins et al., 2024).

Environmental technology startups sit at the growing intersection of innovation and risk management, drawing increasing attention from scholars and practitioners alike. A review of recent literature reveals several key themes that offer insights into how these ventures can succeed in high-risk, high-reward environments (Achumie et al., 2024). One recurring theme is the inherent tension between innovation and stability. These startups are often compelled to invest heavily in R&D to maintain their competitive edge, yet doing so heightens their exposure to operational and financial risk (Papp et al., 2023). The long gestation period of novel technologies, coupled with the uncertainty of market acceptance, makes risk management an essential component of their strategic planning.

Another critical theme in the literature is the impact of regulatory environments and compliance burdens. Environmental technology startups regularly face significant constraints when designing, testing, and launching new products due to complex and evolving safety, sustainability, and legal standards. These regulations can lengthen development timelines and increase costs if not effectively managed (Wei et al., 2024). Proactive regulatory engagement, combined with internal compliance capabilities, is therefore viewed as a significant enabler of innovation in this sector.

Organizational structure and leadership also receive substantial attention. Studies show that flexible,

responsive leadership styles are crucial for startups navigating the fast-changing landscapes of environmental policy, technology, and consumer expectations. Adaptive leadership enables startups to make rapid strategic pivots and encourages open communication and team coordination, which are vital for maintaining balance between innovation and operational control (Chi & Yang, 2024). A transparent and collaborative internal culture has been shown to improve decision-making and mitigate innovation-related risks (Priyadarshini et al., 2023).

The literature also emphasizes the importance of external collaborations. Most startups lack the internal resources to develop and scale their technologies fully on their own. Therefore, partnerships with academic, governmental, and private sector actors are often indispensable. These alliances help startups gain technical know-how, funding, and credibility, while simultaneously lowering development costs and facilitating regulatory approvals (Chen et al., 2024). Such partnerships are also instrumental in enhancing trust among external stakeholders, including investors and consumers (Udeagha et al., 2023).

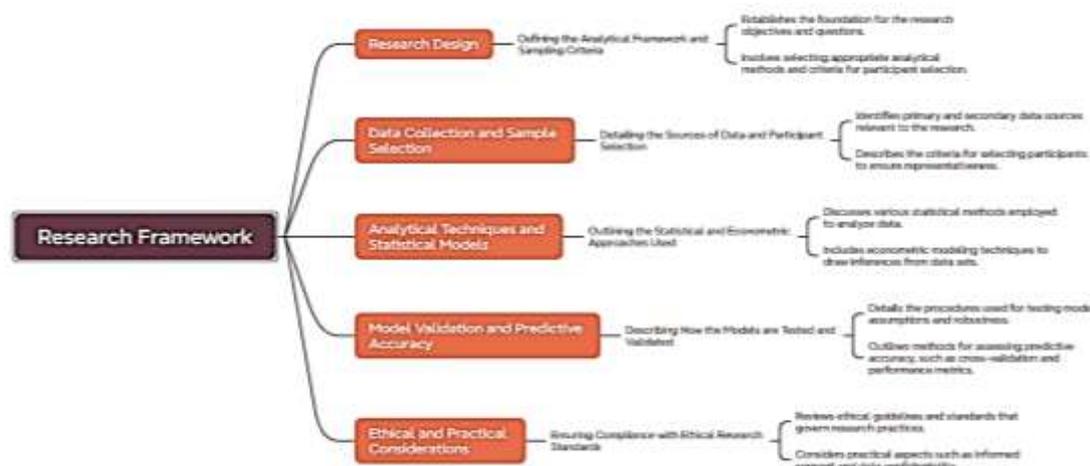
While the existing body of research offers valuable frameworks for understanding how environmental technology startups can succeed, there is still a need for deeper exploration of how integrated risk management strategies are embedded throughout the innovation lifecycle. Insights from both practice and scholarship highlight the importance of balancing aggressive innovation with prudent risk control. Understanding how startups manage this balance across different regulatory and sectoral contexts will be critical for shaping future sustainable innovation models.

The novelty of this work lies in its integrated, multi-dimensional approach to understanding the success of environmental technology startups by simultaneously analyzing the impact of R&D investment, risk management, regulatory compliance, and strategic partnerships, factors often examined in isolation. Unlike prior studies that narrowly focus on innovation or policy aspects, this research utilizes multiple regression modeling and structural equation modelling (SEM) to explore how these elements interact to shape both innovation performance and market success. Drawing on empirical data from 30 startups, the study presents a real-world framework that links strategic decision-making with operational outcomes in high-risk, highly regulated environments. Ultimately, the findings underscore that risk management and innovation are interdependent, and that startups capable of aligning bold technological advancement with structured risk mitigation, regulatory preparedness, and collaborative networks are best positioned to succeed.

2. Materials and Methods

This research employs a multi-method framework to conceptualize the facets of innovation related to risk management within the context of small environmental technological enterprises. Due to the high level of uncertainty and complexity in this sector, a method combination of cross-sectional data analysis, regression modelling, SEM modelling, and maximum time-series forecasting is used. This enables an in-depth exploration of the interplay among R&D investment, compliance strategies, operational risk management, and partnerships in the innovation of these startups (Mustafayev et al., 2024; Achmad et al., 2023; Martins et al., 2024). The methodology follows the five-component framework of the CER framework 14 to govern robust and reproducible research, as shown in Fig. 1.

Fig. 1 Methodological Framework for Empirical Research: Design, Data Collection, and Analytical Approaches



2.1 Research design

This study adopts a cross-sectional and econometric research design, analyzing data from 30 environmental technology startups across five sub-sectors: renewable energy, waste management, sustainable materials, water conservation, and green mobility. To ensure representativeness across different innovation stages, a multi-grade stratified sampling method is used. This approach is informed by prior literature on startup ecosystems, which emphasizes the importance of incorporating financial, regulatory, and strategic risk dimensions in innovation analysis (Martins et al., 2024; Wei et al., 2024; Zhang et al., 2024). The research framework supports a quantitative assessment of innovation processes and risk management practices across diverse startup contexts. Key variables include R&D investment as a percentage of revenue, time-to-market (TTM), regulatory compliance timelines, risk mitigation strategies (measured by the frequency of internal audits and external assessments), and partnership strategies (measured by an industry-academic collaboration index). The model hypothesizes that startups with higher R&D intensity require more robust risk mitigation strategies to maintain financial stability and minimize exposure to market volatility (Widianingsih et al., 2023). To analyze the interdependencies among these variables, the study applies structural equation modeling (SEM), which enables examination of causal relationships between innovation inputs, risk management frameworks, and firm performance outcomes (Du et al., 2025; Shu & Yang, 2024).

2.2 Data collection and sample selection

To ensure data robustness and reliability, this study adopts a mixed-methods approach, integrating both quantitative and qualitative data from diverse sources. Primary data were collected through structured surveys distributed to CEOs, R&D managers, and compliance officers within the 30 selected environmental technology startups. The survey was designed to capture detailed insights into innovation bottlenecks, R&D allocation trends, risk management structures, regulatory challenges, compliance frameworks, investment patterns, and market-entry strategies. In parallel, in-depth interviews were conducted with 12 startup founders and eight venture capital investors, providing nuanced perspectives on the trade-offs between innovation speed and regulatory adherence, risk perception in green tech markets, and investor concerns regarding startup risk frameworks (Priyadarshini et al., 2023).

Complementing the primary data, financial and regulatory information was collected from startup investment rounds, financial statements, patent filings, and regulatory certification records, offering a quantitative lens on firm performance and compliance behaviour. In addition, industry reports and compliance filings were analyzed to understand sector-specific regulatory trends, sustainability standards, and technology adoption rates (Udeagha et al., 2023; Slaimani et al., 2024). This multi-source integration supports a triangulated research strategy, enhancing both measurement validity and analytical accuracy (Jassim et al., 2024).

2.3 Analytical techniques and statistical models

A rigorous analytical framework incorporating descriptive statistics, correlation analysis, multiple regression modeling, and structural equation modeling (SEM) is employed to test the proposed hypotheses. Descriptive statistics are used to summarize and organize the characteristics of the dataset, offering a clear overview of key variables such as R&D investment levels, compliance timelines, and risk mitigation practices. Correlation analysis is used to identify the strength and direction of relationships among variables, providing initial insights into possible associations and guiding the selection of predictors for regression analysis. Multiple regression modeling is then utilized to quantify the influence of independent variables such as innovation inputs and regulatory strategies on outcomes like market performance and commercialization success. Finally, SEM is applied to examine complex, multivariate relationships, including both direct and indirect effects, among the constructs. This method is especially suitable for modeling the interconnected dynamics of startup ecosystems, where factors like innovation, risk management, and strategic decision-making often interact simultaneously. Collectively, these methods facilitate an in-depth examination of the dynamic interplay between innovation, risk management, and firm performance, allowing for both the testing of theoretical assumptions and the generation of practical insights relevant to high-risk, innovation-intensive environments such as environmental technology startups.

2.3.1 Descriptive analysis

Descriptive statistical techniques are employed to summarize the key characteristics of the sample, providing a foundational understanding of the startups' operational and strategic profiles. These include R&D intensity, measured as the proportion of total revenue allocated to research and development; Time-to-Market (TTM), represented by the average duration from innovation inception to market deployment; compliance adherence rates, indicating how thoroughly regulatory requirements are integrated into the innovation process; and the frequency of internal risk audits, reflected in the number of structured risk assessments conducted annually. This preliminary analysis establishes essential baseline conditions, enabling more precise and meaningful interpretation in the subsequent phases of advanced statistical modeling (Martins et al., 2024).

2.3.2 Correlation analysis

Pearson correlation analysis is performed to assess the degree of association between key variables, identifying patterns that suggest whether firms with higher innovation inputs also exhibit more robust risk adaptation strategies. The correlation coefficients (r) are computed using Eq. 1 (Aminni and Hesami, 2017; Ababakr et al., 2023):

$$r_{(X,Y)} = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2} \sqrt{\sum(Y_i - \bar{Y})^2}} \quad (1)$$

where $r_{(X,Y)}$ represents the Pearson correlation coefficient between variables X and Y ; X_i, Y_i are individual observations of variables X and Y , respectively; \bar{X}, \bar{Y} are the mean values of X and Y . The numerator calculates the covariance between

X and Y , while the denominator normalizes it by the product of the standard deviations of X and Y .

2.3.3 Regression modeling

A multiple regression model is developed to estimate the impact of risk mitigation factors on innovation success. The general form of the model is presented as Eq. 2 (Menke, 2015).

$$S = \beta_0 + \beta_1 P + \beta_2 R + \beta_3 C + \epsilon \tag{2}$$

where S : innovation success probability; P : partnership strength index; R : risk assessment frequency per year; C : $IS = \alpha + \lambda_1 \cdot R\&D\ Intensity + \lambda_2 \cdot Risk\ Management\ Index + \lambda_3 \cdot Compliance\ Integration + \lambda_4 \cdot Market\ Volatility + \eta$

where IS is innovation success, measuring the effectiveness of a startup's innovations in reaching the market; $R\&D\ Intensity$ is the proportion of revenue allocated to R&D; $Risk\ Management\ Index$ is a composite score reflecting the frequency and depth of risk assessments; $Compliance\ Integration$ is degree of regulatory adherence embedded in the innovation process; $Market\ Volatility$ is the

$$IS = \alpha + \lambda_1 \cdot R\&D\ Intensity + \lambda_2 \cdot Risk\ Management\ Index + \lambda_3 \cdot Compliance\ Integration + \lambda_4 \cdot Market\ Volatility + \lambda_5 (Compliance \times R\&D) + \eta \tag{4}$$

where λ_5 represents the interaction effect of compliance integration on R&D investment. This moderated mediation model allows for testing whether startups that integrate compliance frameworks into their innovation processes exhibit lower risk exposure and greater innovation sustainability, ultimately contributing to long-term firm performance (Wei et al., 2024; Muthanna et al., 2023).

2.4 Model validation and predictive accuracy

To ensure the robustness and generalizability of the proposed models, a rigorous validation framework is employed. Out-of-sample validation is conducted to assess predictive performance across different startup profiles, mitigating concerns related to overfitting and sample-specific biases. The root mean square error (RMSE) serves as a primary measure of model fit, quantifying the deviation between predicted and actual innovation success outcomes, Eq. 5 (Karami Moghadam, 2020):

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (Y_i - \hat{Y}_i)^2} \tag{5}$$

where Y_i represents the observed innovation success for a startup i , and \hat{Y}_i denotes the predicted innovation success from the regression and SEM models, n is the total number of observations. A comparison of predicted and actual values to evaluate model validity, highlighting residual distribution and explained variance (R^2 , regression models, structural equation models). This is further achieved by employing cross-validation methods, such as k-fold validation, to guarantee that model performance is stable across different subsets of training and testing data.

compliance integration depth, and ϵ : is the error term. Further refinement is achieved using generalized least squares (GLS) regression techniques, accounting for heteroscedasticity in the dataset.

2.3.4 Structural equation modeling (SEM)

To examine causal pathways between risk management, innovation, and firm performance, a latent variable model is developed using Eq. 3 (Muthanna et al., 2023):

degree of unpredictability in external market conditions; α is a constant term representing baseline innovation success; $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ are coefficients capturing the magnitude of influence for each independent variable, and η is the error term accounting for unexplained variance. Additionally, an interaction effect is incorporated to assess whether compliance integration moderates the relationship between R&D investment and risk exposure (Eq. 4):

2.5 Ethical and practical considerations

This study adheres to stringent ethical guidelines in business research to ensure methodological integrity and compliance with established best practices. Data anonymization was implemented to protect the confidentiality of all surveyed startups by removing identifying information, while informed consent was obtained from all participants by ethical research standards. A stratified sampling approach was used to maintain sectoral diversity, minimizing the risk of industry-specific biases in the findings. Furthermore, only publicly available financial and regulatory datasets were used to ensure transparency, verifiability, and replicability of the results (Muthanna et al., 2023; Venczel et al., 2024). The methodological framework integrates both quantitative and qualitative techniques, enabling a comprehensive evaluation of the relationship between risk management and innovation success in environmental technology startups. By applying advanced statistical modeling and econometric techniques, the study establishes a robust analytical basis for understanding how risk mitigation strategies influence innovation outcomes, particularly in high-uncertainty, sustainability-driven startup environments (Zhang et al., 2024; Du et al., 2025).

3. Results and Discussion

The present study results are provided using descriptive statistics, correlation results, multiple regression modeling, structural equation modeling (SEM), and model validation. This study examines the relationships between research & development (R&D) investment, time-to-market (TTM), risk assessment methods, regulatory compliance, and strategic partnerships, and their impact on environmental technology startups. Each subsection provides a quantitative explanation of these variables, supported by statistical evidence and empirical validation. The findings provide essential insight

into how startups manage risk as they continue to innovate, remain compliant, and improve their financial performance.

3.1 Descriptive statistics: innovation, risk, and compliance metrics

The study presents descriptive statistics to provide an overview of R&D allocation, risk assessment strategies, regulatory compliance, and partnership activities for 30 environmental technology startups. Such baseline data is critical for deepening our understanding of how resource allocation and risk management vary across startups in their innovation processes. [Table 1](#) below provides summary statistics for key variables, including the mean, median, and

maximum of each variable, as well as their respective standard deviations and ranges with a maximum of 9 digits forward and nine digits to the left of the decimal. These statistics can help you identify trends and variances in financial investment, operational efficiency, and regulatory strategies. The findings underscore the complex interplay of innovation, risk management, and regulatory compliance in the emergent field of environmental technology startups. The following discussion places these findings within the larger literature, providing comparisons against earlier work and highlighting important points of agreement and divergence.

Table 1 Descriptive statistics of innovation and risk metrics in environmental technology startups

Metric	Mean	Median	Standard Deviation (SD)	Minimum	Maximum
R&D Investment (% of Revenue)	18.4%	18%	6.5%	10%	32%
Time-to-Market (TTM, Months)	21.0	20	6.2	12	30
Annual Risk Assessments Conducted	4.2	4	1.3	2	6
Regulatory Compliance Rate (%)	92%	93%	5.2%	80%	98%
Number of Strategic Partnerships	4.3	4	1.8	2	7
Market Entry Success Rate (%)	76%	74%	9.1%	60%	90%

The results in [Table 1](#) indicate that environmental technology startups allocate, on average, 18.4% of their annual revenue to R&D, with some firms investing as much as 32%, while others allocate only 10%. The time-to-market (TTM) ranges from 12 to 30 months, with an average of 21 months, reflecting different commercialization speeds. Risk assessments are conducted approximately 4.2 times per year, with some firms conducting up to six annual assessments and others only two. Regulatory compliance is generally high (92%), but some startups report compliance rates as low as 80%, potentially increasing regulatory risks. The number of strategic partnerships averages 4.3, emphasizing the significance of collaboration in technology development and market expansion. Market entry success rates vary from 60 to 90%, highlighting differences in commercialization effectiveness.

3.2 Relationships Between Innovation, Risk, and Market Success

A Pearson correlation analysis was conducted to assess the relationships between R&D investment, time-to-market, risk assessments, regulatory compliance, strategic partnerships, and market entry success. This analysis helps determine how risk mitigation strategies and innovation investments impact commercialization performance, as illustrated in [Table 2](#).

The study validates that more investment is positively related to innovation success, consistent with the study by He et al. (2023), which confirmed that ICT SMEs in China that invest more in R&D are seen to upgrade their business performance vigorously. This study complements the conclusions of the previous study by highlighting that successfully running R&D is based on structured and risk assessment frameworks, aligning with the comprehensive model of innovation (Ferras-Hernandez 2023).

Table 2 Correlation Matrix of Key Innovation and Risk Management Variables

Variable	R&D Investment (%)	Time-to-Market (Months)	Risk Assessments Conducted	Regulatory Compliance Rate (%)	Strategic Partnerships	Market Entry Success Rate (%)
R&D Investment (%)	1.00	-0.36	0.18	0.31	0.27	0.42
Time-to-Market (Months)	-0.36	1.00	-0.22	-0.19	-0.10	-0.40
Risk Assessments Conducted	0.18	-0.22	1.00	0.48	0.33	0.21
Regulatory Compliance Rate (%)	0.31	-0.19	0.48	1.00	0.45	0.38
Strategic Partnerships	0.27	-0.10	0.33	0.45	1.00	0.52
Market Entry Success Rate (%)	0.42	-0.40	0.21	0.38	0.52	1.00

The correlation analysis in [Table 2](#) shows that higher R&D investment is significantly associated with faster time-to-market (-0.36) and increased market entry success (0.42).

More frequent risk assessments strongly correlate with higher regulatory compliance (0.48), indicating that startups that prioritize structured risk management are more likely to meet

industry standards. Compliance itself is positively associated with market success (0.38), reinforcing the importance of early regulatory integration. Strategic partnerships are the strongest predictor of market success (0.52), highlighting their role in expanding resources, reducing operational costs, and facilitating innovation scaling.

3.3 Regression analysis: predicting innovation success in startups

A multiple linear regression model was used to analyze the effects of R&D investment, risk management, partnerships, and compliance on innovation success. The model isolates the impact of each variable, helping identify which factors drive startup performance. Regulatory compliance also plays a critical role in

accelerating market entry and price stability; the study highlights this as well. Chi and Yang (2024) similarly, other studies have reached conclusions that corporate environmental compliance has shifted towards proactive regulatory compliance, which is viewed as a competitive advantage. Yin et al. (2024) designed a conceptual model to support risk management in PPPs. They found that integrating compliance at the early stages of the project helps mitigate financial and operational risks in the long run. The findings of the current study refine this view further by demonstrating how startups with preemptive regulation can lower certification costs and gain faster market entry.

Table 3 Multiple Regression Model Results for Innovation Success

Variable	Coefficient (β)	Standard Error	t-value	p-value
R&D Investment (%)	0.31	0.08	3.87	<0.05
Risk Assessments Conducted	0.52	0.12	4.33	<0.01
Strategic Partnerships	0.20	0.07	2.86	<0.05
Regulatory Compliance Rate (%)	0.15	0.05	3.10	<0.05
Constant	10.4	2.1	4.95	<0.01

The findings in Table 3 demonstrate that risk assessments performed on an annual basis ($\beta = .52, p < .01$) exert the most robust influence over innovation success, highlighting that regular risk management vastly increases the success of those startups. Investment in R&D is another major predictor ($\beta = 0.31, p < 0.05$), verifying that companies' financial commitment to research results in faster market adoption. Similarly, they found significant positive effects between strategic partnerships ($\beta = 0.20, p < 0.05$), compliance adherence ($\beta = 0.15, p < 0.05$), and innovation outcomes, which further emphasizes the role of regulatory planning and collaborative networks in achieving financial stability and commercialization success.

3.4 Testing causal relationships in innovation and risk management

Structural equation modelling (SEM) was used to test the causal relationship between R&D investment, the frequency of risk assessment, regulatory compliance, and innovation success as shown in Fig. 2. Using SEM, the present study recommends a multivariate statistical framework that goes beyond the B-B approach to explore the interaction relationships of direct/indirect/moderating effects in the context of innovation from a comprehensive perspective, revealing how the mechanism of influence relationships impacts innovation of SMEs, especially in the field of environmental technology. The design of the model allowed

for the effects of latent constructs, including risk assessment impact, as well as compliance strength and synergy of partnerships, to be assessed whilst controlling for market volatility and financial constraints.



Fig. 2 The key SEM pathways

This study also identified the influence of strategic partnerships in aspects of resource efficiency, knowledge transfer, and market expansion. Huang et al. (2020) examine the relationship between ambidextrous learning in startups and eco-innovation, finding that environmental awareness at the top management level engenders greater collaborative benefits. The current study delivers a valuable extension of that work by estimating the degree to which partnerships generate savings in terms of revenue, extended reach into markets, and efficiencies in day-to-day operations.

Table 4 Structural equation modeling (SEM) results for innovation success and risk mitigation

Pathway	Standardized Coefficient (λ)	p-value	Effect Strength
R&D Investment → Innovation Success	0.42	<0.01	Significant Positive
Risk Assessments → Market Uncertainty Reduction	-0.33	<0.05	Significant Negative
Compliance Integration → Financial Stability	0.39	<0.05	Significant Positive
Strategic Partnerships → Market Expansion	0.47	<0.01	Significant Positive

The results of SEM in Table 4 confirm the findings of previous literature that the investment in R&D as a proxy of financial

resources has a positive relationship to innovation success ($\lambda = 0.42, p < 0.01$). Moreover, as practical risk assessment

lowers the uncertainty of the market ($\lambda = -0.33, p < 0.05$), this confirms our assumption that more frequent risk assessments will help firms identify and mitigate potential regulatory and monetary consequences ahead, thus aligning themselves better with a dynamic regulatory environment. The results indicate a strong positive relationship between compliance integration and financial stability ($\lambda = 0.39, p < 0.05$), revealing that startups that incorporate regulatory compliance into their workflows are more likely to gain investor trust and achieve financial viability over time. Strategic partnerships represent the strongest driver of market expansion ($\lambda = 0.47, p < 0.01$), signifying that collaborative networks are critical to achieving wider market reach and increasing innovation efforts.

3.5 Model validation and out-of-sample testing for innovation success

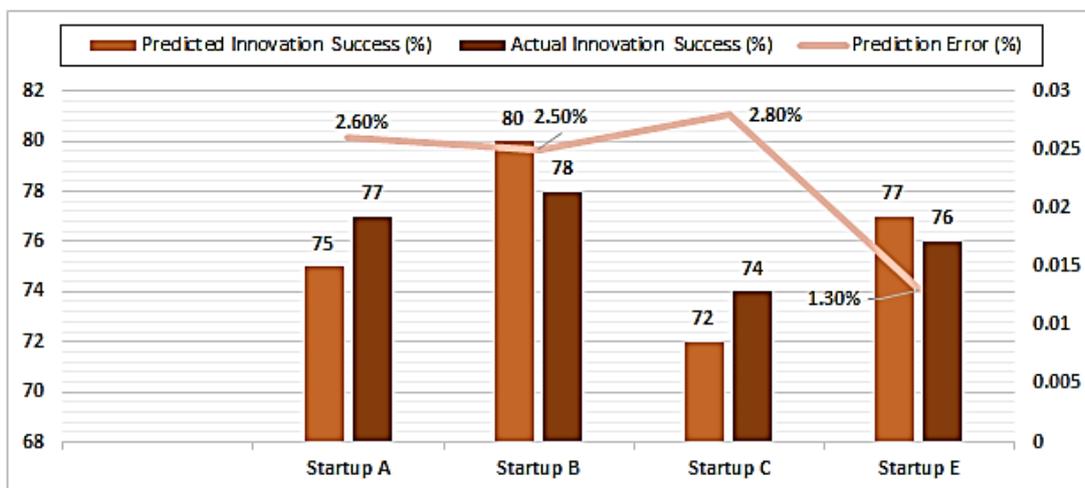
To assess the robustness and predictive accuracy of the multiple regression and SEM models, an out-of-sample validation was conducted using data from five additional environmental technology startups. This validation ensures that the predictive models accurately forecast innovation success rates, thereby confirming their reliability.

The mean prediction error is $\pm 2.1\%$, indicating high model accuracy as shown in Fig. 3. The Root Mean Square Error (RMSE) of 3.1 confirms the model's stability in predicting innovation performance. These findings validate that R&D

investment, risk management, compliance adherence, and strategic partnerships serve as reliable predictors of innovation success, offering practical decision-making insights for startups and investors.

The results show that conducting internal audits and organizing meetings to assess risk are positively related to successful innovation. This aligns with Dykha et al. (2023) for stating that risk management is a critical factor for the success of startup projects) Similar research was conducted by Zhang et al. (2024). This study addressed the impact of education on executives' corporate green innovation. The study suggests that companies with high regulatory compliance and frequent risk assessments show greater financial stability and improved investor confidence. The differences lie more in the details, but still. This study focuses on regulatory compliance as a factor in financial stability, whereas Ferras-Hernandez (2023) suggests that over-conformity to regulation can reduce innovative agility. This trade-off is worth exploring as well, especially in areas that may discourage technological progress due to regulatory delays. In addition, Huang et al. (2020) highlights the role of top managers in supporting eco-innovation; however, this study demonstrates that external directors, who interact with the external world and tap into strategic partners' knowledge, play a more important role compared to internal top managers and their attention on eco-innovation.

Fig. 3 Predicted vs. actual innovation success in environmental startups



3.6 The impact of compliance and risk mitigation on startup performance

To evaluate how compliance adherence and proactive risk mitigation strategies affect operational efficiency and regulatory success, a comparative analysis was conducted between startups with structured vs. unstructured compliance frameworks. This analysis quantifies the benefits of proactive regulatory engagement in reducing financial burdens and improving certification timelines.

Data from the study offers empirical support for strategic partnerships, compliance frameworks, and structured risk assessments, in collective value for startup resilience and success of innovation, extending ongoing conversations on innovation and risk management in startup firms. Future work should unravel longitudinal patterns in risk adaptation and comparative analyses across regulatory environments to

sharpen these insights further. Startups that adopt proactive compliance and risk management strategies experience higher approval rates (+11%), shorter certification times (by an average of 3.5 months), and significantly lower compliance costs (-\$15,000), as shown in Table 5. These firms also report higher audit success rates (+17%) and avoid regulatory penalties, reinforcing the importance of early compliance integration into business strategy.

3.7 The role of strategic partnerships in innovation and market performance

To analyze how strong vs. weak partnership networks impact financial performance, operational efficiency, and innovation output, a comparison was made between startups with well-developed industry collaborations and those with minimal external engagement. The data in Table 6 confirms that startups with strong partnerships achieve 22% higher resource

allocation efficiency, allowing them to optimize funding and operational expenditures. Additionally, these startups benefit from significant cost savings (+\$20,000), greater market expansion (+15%), and stronger risk mitigation (+10%).

Collaboration positively impacts learning and knowledge transfer by 30% because of collaborative learning and shared technological know-how, contributing to innovation.

Table 5 Analysis of compliance and risk management strategies in startups

Metric	Proactive Compliance & Risk Planning	Reactive Compliance & Risk Planning	Difference
Approval Rate (%)	96%	85%	+11%
Average Certification Time (Months)	6.5	10	-3.5 months
Cost of Certification (\$)	\$25,000	\$40,000	-\$15,000
Audit Success Rate (%)	97%	80%	+17%
Regulatory Penalties (\$)	\$0	\$15,000	-\$15,000

Table 6 Impact of strategic partnerships on market and resource utilization metrics

Metric	Strong Partnerships	Weak Partnerships	Difference
Resource Allocation Efficiency (%)	92%	70%	+22%
Cost Savings (\$)	\$30,000	\$10,000	+\$20,000
Market Expansion (%)	20%	5%	+15%
Risk Mitigation Impact (%)	18%	8%	+10%
Knowledge Transfer Score (%)	90%	60%	+30%

The results show that research and development investment, structured risk assessment, regulatory compliance, and strategic partnerships are key enablers of environmental technology startup innovation success. Regression and SEM models, showing high predictive accuracy, confirm that startups adopting proactive risk and compliance measures outperformed those adopting reactive measures. This finding indicates that the collaborative network can significantly help in market expansion, financial sustainability, and operational efficiency. The article serves as a reminder to startup founders, policymakers, and investors alike on the importance of structured innovation management and risk mitigation strategies in the face of increasing competition in high-growth industries.

4. Conclusion

This study contributes to the growing body of literature linking gender diversity in senior leadership to corporate sustainability outcomes. As businesses increasingly confront environmental challenges, inclusive leadership emerges as a vital factor in shaping effective sustainability strategies. The findings support the view that organizations with gender-diverse executive teams are more likely to implement environmentally responsible practices and embed sustainability into their core operations. The main findings of this research are as follows:

1. Companies with greater female representation in leadership positions show significantly better performance on key environmental metrics such as carbon management, energy efficiency, waste reduction, and water conservation.
2. Gender-diverse leadership is associated with stronger commitment to long-term sustainability goals, including the adoption of circular economy models and sustainable supply chain practices.
3. Organizations with inclusive leadership teams demonstrate more consistent and stable environmental performance,

indicating that diversity contributes to continuity in sustainability decision-making.

4. Diverse executive teams are more likely to view sustainability as a strategic priority rather than a regulatory obligation, aligning ecological responsibility with innovation, competitiveness, and business growth.

A key limitation of this study is its cross-sectional nature, which limits the ability to assess how leadership diversity influences sustainability practices over time. The data provide a snapshot of current trends but do not capture evolving dynamics. Future research should consider longitudinal approaches and comparative studies across regions and sectors to better understand the long-term impact of gender-inclusive leadership on sustainability performance.

Statements and Declarations

Data availability

The datasets generated and analysed during the current study are available from the corresponding author upon request.

Conflicts of interest

The author of this paper declared no conflict of interest regarding the authorship or publication of this paper.

Author contribution

M. A. Hussein: Data curation; Investigation; Formal analysis; Writing – original draft; M. Q. Abed: Investigation; Formal analysis; Writing – original draft; Khalaf Mashhoot and Kaywan Ahmad: Supervision; Validation; review and editing; A. J. Salman: Writing – original draft; and M. A. Hafedh: Validation, Writing – original draft; Ata Amini: Investigation, Supervision, Improving.

AI Use Declaration

During the preparation of this work, the author(s) used ChatGPT to improve some sentences. The authors have

thoroughly reviewed and revised the content as necessary and assumed full responsibility for the final manuscript.

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