SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2025
ORGANIZATION AND MANAGEMENT SERIES NO. 235

EXPLORATION OF THE MECHANISMS OF RISK MANAGEMENT FOR GREEN TRANSFORMATION IN INNOVATIVE SECTORS

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Purpose: The purpose of this study is to investigate how key components of risk management—risk identification (RI), risk analysis (RA), and risk monitoring (RM)—influence the development of transformational environmental management (TEM) in innovative firms. The study also examines the mediating role of enterprise risk management (ERM) in strengthening these relationships.
Design/methodology/approach: The study is based on quantitative research using structural equation modeling (PLS-SEM). Empirical data were collected through a structured survey conducted among 587 representatives of innovative firms. All variables were measured using a seven-point Likert scale.
Findings: The results reveal that RI exerts a significant direct influence on TEM, while RA and RM influence TEM primarily through ERM. Enterprise risk management demonstrates a strong direct effect on transformational environmental outcomes and functions as a critical mediating mechanism—particularly in converting risk monitoring activities into effective environmental performance (Variance Accounted For, VAF = 69.9%). In contrast, the mediating effect of ERM in the relationship between RI and TEM, although statistically significant, is relatively weak (VAF = 8.6%). These findings emphasize the role of enterprise risk management as a systemic integrator of risk-related processes that facilitates the long-term embedding of environmental strategy within innovation-driven firms.
Research limitations/implications: The study is limited by its cross-sectional design and reliance on self-reported data from representatives of innovative firms, which may affect the generalizability of the findings. Future research could adopt longitudinal approaches and extend the analysis to other types of enterprises.
Practical implications: The findings offer valuable insights for managers of innovative firms, highlighting the importance of embedding comprehensive risk management systems to support long-term environmental strategies and improve organizational resilience.
Social implications: By demonstrating how structured risk management contributes to proactive environmental action, the study supports the wider transition toward corporate sustainability and environmental responsibility.
Originality/value: This research contributes to the understanding of how risk management mechanisms support green transformation in innovative firms. It is one of the few empirical studies that examine the mediating role of enterprise risk management (ERM) in this context, offering a novel perspective on risk as a strategic enabler of environmental change.
Keywords: risk management, environmental strategy, enterprise risk management, innovative firms, green transformation, structural equation modeling.
Category of the paper: Research paper.

1. Introduction

The imperative to address climate change has intensified the global push for green transformation, compelling firms across sectors to adopt environmentally sustainable practices, reduce emissions, and integrate renewable energy sources into their operations. This transition, while necessary, presents numerous risks—financial, regulatory, operational, and technological—which are particularly pronounced in dynamic and innovation-driven environments. As firms navigate this shift, robust risk management systems have become essential tools for enhancing organizational resilience and strategic adaptability (Verreynne et al., 2023). In recent years, the evolving economic landscape and rising environmental pressures have underscored the need to embed sustainability into core business strategies. Empirical evidence suggests that climate-related risks often act as a catalyst for innovation and business model transformation, positioning environmental responsibility as a driver of long-term competitiveness and market trust (Błach et al., 2025). Nonetheless, the path toward green transformation remains complex and uncertain—especially for innovative firms that operate in rapidly changing technological and policy contexts. Fluctuating regulatory frameworks, high R&D costs, and disruptive innovations amplify their exposure to strategic and operational vulnerabilities (Dugbartey, 2025; Zebisch et al., 2021). To mitigate these challenges, firms increasingly turn to structured risk management approaches, including green finance instruments, environmental performance assessments, and technology-based monitoring systems (Gorzeń-Mitka, 2024; Hallikas et al., 2020). These mechanisms not only support compliance and financial stability but also enhance firms' ability to proactively adapt to shifting market and policy conditions (Pertheban et al., 2023; Adomako, 2021). Moreover, digital transformation serves as an enabler of efficient risk control, offering real-time data, scenario modeling, and scalable solutions that accelerate the adoption of green innovations (Shahzad et al., 2022; Thomas et al., 2022; Gorzen-Mitka, Sipa, 2025). Despite the growing interest in the intersection of risk management and sustainability, empirical studies examining how innovative firms manage environmental risks remain limited—particularly in terms of integrated, firm-level approaches. This paper addresses this gap by exploring how key components of risk management—risk identification (RI), risk analysis (RA), and risk monitoring (RM)—contribute to transformational environmental management (TME). The study places particular emphasis on the mediating role of enterprise risk management (ERM) in strengthening the relationship between traditional risk functions and green strategic outcomes. Through the analysis of survey data from 587 representatives of innovative firms, this research offers new insights into the preparedness and risk-responsiveness of these organizations in the context of environmental transformation. The findings are intended to inform both management practice and public policy by highlighting how integrated risk

management can serve as a catalyst for sustainability-oriented innovation and strategic alignment.

Thus, in Section 2, we conduct a literature review that provides the conceptual foundation for the role of enterprise risk management (ERM) as a mediating variable between core risk management activities—risk identification (RI), risk analysis (RA), and risk monitoring (RM)—and the strategic implementation of environmental transformation in innovative firms. This section also presents the theoretical justification for each of the research hypotheses formulated in this study. Section 3 outlines the research methodology, including the data collection process, the sample characteristics, the operationalization of the constructs, and the modeling procedure. The empirical analysis is based on data gathered through a structured survey of 587 representatives of innovative firms, with variables measured on a seven-point Likert scale. The results and discussion are presented in Section 4, where the evaluation of the measurement model and the structural model is reported. The validity and reliability of the constructs are assessed, followed by hypothesis testing. The method applied is structural equation modeling (SEM), using the partial least squares (PLS) technique. PLS-SEM is particularly suited for exploratory research involving complex models and mediating relationships and has been widely adopted across various fields for modeling latent constructs. Finally, Section 5 summarizes the main conclusions drawn from the analysis, highlights managerial and policy implications, and suggests avenues for future research focused on risk governance and sustainability strategies in innovation-oriented enterprises.

2. Theoretical background and Hypotheses Development

Environmental transformation is increasingly seen as a strategic imperative for firms, particularly those operating in innovation-intensive contexts. Responding to growing ecological, regulatory, and societal pressures, companies are rethinking how sustainability can be embedded in their core strategies, operations, and innovation processes (Lozano, 2015; Dobler et al., 2012; Kadir et al., 2020). In this study, we introduce the concept of transformational environmental management (TME), which we define as a firm's strategic and systemic approach to integrating environmental objectives into long-term development, innovation, and value creation. While the term itself is not yet established in the academic literature as a standardized construct, it draws conceptually from established theories such as strategic environmental management (Sharma, Vredenburg, 1998), proactive environmental strategy (Aragón-Correa, Sharma, 2003), and corporate sustainability integration (Engert, Baumgartner, 2016; Gorzen-Mitka, Sipa, 2025). TME, as conceptualized here, captures a firm's capacity to go beyond compliance or incremental environmental improvements, and instead pursue deep, strategic change—driven by top management commitment, resource reallocation,

and sustainability-oriented innovation. This notion aligns with the broader discourse on sustainability transitions, which frames transformation as a shift in core business logic, not just in peripheral environmental practices.

The literature indicates that such transformation is inherently complex and uncertain, particularly in the case of innovative firms, which face amplified exposure to technological, regulatory, and market-related risks (Wieczorek-Kosmala, Henschel, 2022; Aven, 2016). As a result, risk management mechanisms—specifically risk identification (RI), risk analysis (RA), and risk monitoring (RM)—are vital. These processes help firms systematically detect, assess, and prepare for potential disruptions and opportunities linked to environmental change (Arena et al., 2010; Gorzeń-Mitka, 2024; Hallikas et al., 2020). However, a growing number of studies emphasize that the effectiveness of risk management depends not only on individual practices, but also on their integration within a firm-wide governance framework. Enterprise Risk Management (ERM) represents such an integrated approach—offering cross-functional coordination, alignment with strategic objectives, and a dynamic view of risk that includes sustainability dimensions (Aziz et al., 2016; Beasley et al., 2024; Hoyt, Liebenberg, 2025). In the context of environmental transformation, ERM can facilitate a shift from reactive risk treatment to proactive opportunity management—transforming environmental uncertainty into a driver of innovation and strategic renewal (Florio, Leoni, 2017; Kraus et al., 2020; Haywood, 2021).

In this study, we conceptualize ERM as a mediating variable between traditional risk management practices (RI, RA, RM) and transformational environmental outcomes (TEM). This enables a deeper understanding of how innovative firms leverage risk awareness and governance structures to support sustainability-oriented change. It also reflects a broader theoretical integration of risk management and strategic environmental leadership—offering a framework for empirically testing both direct and indirect effects of risk management mechanisms on environmental transformation.

2.1. Enterprise Risk Management and Transformational Environmental Outcomes

Drawing on recent literature, we formulate our first hypothesis regarding the relationship between integrated risk governance and strategic environmental transformation in innovative firms. Enterprise Risk Management (ERM) has emerged as a key framework enabling firms to manage increasingly complex and interconnected risks in a structured, cross-functional, and forward-looking manner (Beasley et al., 2024; Hoyt, Liebenberg, 2025). It goes beyond traditional, siloed risk practices by aligning risk oversight with long-term strategic objectives—making it especially relevant in the context of environmental and innovation-driven change.

Recent studies emphasize that ERM facilitates both risk mitigation and opportunity creation, particularly when firms are navigating sustainability transitions. ERM has been shown to improve organizational agility and long-term resilience, especially in environments characterized by regulatory uncertainty, rapid technological change, and sustainability

pressures (Florio, Leoni, 2017; Adenutsi, Whajah, 2023; Hallikas et al., 2020; Haywood, 2021). In innovation-driven firms, which operate under higher environmental and market volatility, ERM enables strategic decision-making, resource reallocation, and long-term environmental planning (Lozano, 2015; Al-Nimer, 2024).

Empirical evidence supports the role of ERM as a catalyst for green innovation and sustainability performance. Al-Nimer (2024) and Krysiak 2009 demonstrate that ERM can act as a mediating mechanism, strengthening the link between operational risk activities and environmental innovation outcomes. Similarly, studies using structural modeling approaches confirm that ERM fosters the organizational capacity to implement sustainability-oriented strategies, particularly when combined with environmental risk identification, monitoring, and analysis (Kraus et al., 2020; Gorzeń-Mitka, 2024; Aziz et al., 2016; Dobler et al., 2012).

Given these findings, our study focuses on transformational environmental outcomes—defined as the strategic and integrated embedding of environmental goals into long-term innovation and decision-making processes in innovative firms. Although not yet a standardized concept in the literature, we define transformational environmental management (TEM) for the purposes of this study as a proactive and systemic integration of environmental considerations across organizational strategy, consistent with the frameworks of proactive environmental strategy (Sharma, Vredenburg, 1998; Kadir et al., 2020) and strategic environmental management (Aragón-Correa, Sharma, 2003; Dobler et al., 2012).

To empirically test this relationship, we adopt partial least squares structural equation modeling (PLS-SEM), a method particularly suited for complex, predictive models involving latent constructs and smaller sample sizes. This approach is increasingly used in sustainability and risk management research (Adenutsi, Whajah, 2023; Al-Nimer, 2024), and enables the examination of both direct and mediated relationships between constructs.

Based on this theoretical and methodological grounding, we propose the following hypothesis:

Hypothesis 1 (H1). Enterprise Risk Management (ERM) has a positive and significant influence on transformational environmental outcomes (TEM).

2.2. Risk Identification and its Influence on Transformational Environmental Outcomes

Following the previous discussion on the strategic role of ERM, we now focus on one of its foundational components—risk identification (RI)—and its relevance in supporting firms' environmental transformation. Risk identification refers to the process of systematically detecting potential internal and external events or conditions that could affect an organization's ability to achieve its objectives (Arena et al., 2010; Hallikas et al., 2020). Within environmental and sustainability contexts, RI involves anticipating environmental threats, stakeholder pressures, compliance risks, and sustainability-related disruptions (Wieczorek-Kosmala, Henschel, 2022; Aven, 2016; Haywood, 2021).

Recent studies emphasize that effective risk identification is not only essential for risk mitigation but also forms the basis for proactive environmental management (Sharma, Vredenburg, 1998). For innovative firms, which are often early adopters of new technologies and exposed to shifting regulatory environments, the ability to identify environmental risks early enables them to adapt their strategies, improve resource allocation, and align their innovation pathways with long-term sustainability goals (Lozano, 2015; Zenios et al., 2021).

Empirical evidence also suggests that structured RI practices contribute to organizational learning and strategic foresight—two elements closely linked to sustainability-oriented innovation and transformation (Ullah et al., 2021; Kadir et al., 2020). In this context, RI enables firms to anticipate opportunities related to green technologies, new markets, or policy incentives, and to proactively reconfigure their strategies to incorporate environmental considerations. This leads us to propose the following hypothesis:

Hypothesis 2 (H2). Risk Identification (RI) has a positive and significant influence on transformational environmental outcomes (TEM).

However, the effectiveness of RI may depend on how well it is integrated into the firm's broader risk governance system. Recent research shows that isolated risk identification efforts may not be sufficient unless they are embedded within a structured, enterprise-wide approach to risk management (Beasley et al., 2024; Cui et al., 2024). In this regard, Enterprise Risk Management (ERM) provides the platform through which risk information is synthesized, prioritized, and translated into strategic action.

Several studies have confirmed the mediating role of ERM in transforming the input from operational-level risk activities into strategic sustainability outcomes (Adenutsi, Whajah, 2023; Al-Nimer, 2024). For example, in the manufacturing and energy sectors, firms that embedded RI into ERM frameworks were more successful in aligning their sustainability and innovation strategies (Krysiak, 2009; Kraus et al., 2020).

Therefore, we posit that while RI may have a direct influence on transformational environmental outcomes, its impact is likely to be enhanced when mediated by ERM, which supports cross-functional coordination and strategic alignment. This leads to our second mediating hypothesis:

Hypothesis 2M (H2M). The influence of Risk Identification (RI) on transformational environmental outcomes (TEM) is positively mediated by Enterprise Risk Management (ERM).

2.3. Risk Assessment and Its Influence on Transformational Environmental Outcomes

Building upon the central role of risk identification, the next critical phase in comprehensive risk governance is risk assessment (RA)—the process of evaluating the likelihood and potential impact of identified risks, enabling organizations to prioritize actions and allocate resources accordingly (Aven, 2016; Wieczorek-Kosmala, Henschel, 2022). In sustainability-driven contexts, RA involves the evaluation of environmental, regulatory, technological, and reputational risks that may hinder or support a firm's green transformation agenda.

In recent years, researchers have emphasized that robust risk assessment practices are essential for enabling strategic alignment between environmental risk exposure and organizational response (Ullah et al., 2021; Sharma, Vredenburg, 1998). For innovative firms in particular—operating at the edge of regulatory shifts, market disruptions, and evolving stakeholder expectations—RA helps translate uncertain environmental signals into structured decision-making and innovation strategy (Cui et al., 2024; Zenios et al., 2021; Haywood, 2021).

Empirical studies show that firms with mature risk assessment systems are better positioned to develop proactive environmental strategies, manage trade-offs, and identify opportunities related to clean technologies, regulatory incentives, or resource efficiency (Lozano, 2015; Kraus et al., 2020). These capabilities are fundamental to transformational environmental outcomes, understood as the strategic integration of sustainability across planning, innovation, and leadership. Hence, we propose the following hypothesis:

Hypothesis 3 (H3). Risk Assessment (RA) has a positive and significant influence on transformational environmental outcomes (TEM).

However, as with other risk management activities, the effectiveness of RA depends heavily on its institutionalization within a broader governance system. Without such integration, risk evaluations often remain isolated and underutilized in strategic decision-making (Beasley et al., 2024; Florio, Leoni, 2017). Here, Enterprise Risk Management (ERM) plays a crucial role, acting as a coordinating mechanism that embeds risk insights into firm-wide strategies and long-term sustainability plans.

Recent studies confirm the mediating role of ERM in converting operational-level risk assessments into transformational change. For instance, Al-Nimer (2024) and Krysiak (2009) provide evidence from industry settings showing that RA, when channeled through ERM systems, leads to improved environmental performance and sustainability integration. These findings suggest that ERM enhances the strategic relevance of RA by ensuring alignment across departments, leadership, and planning processes. Accordingly, we formulate the following mediating hypothesis:

Hypothesis 3M (H3M). The influence of Risk Assessment (RA) on transformational environmental outcomes (TEM) is positively mediated by Enterprise Risk Management (ERM).

2.4. Risk Monitoring and Its Influence on Transformational Environmental Outcomes

The final core dimension of the risk management process is risk monitoring (RM), which refers to the continuous tracking and reassessment of risks over time to detect changes in their likelihood, impact, or strategic relevance (Aven, 2016; Wieczorek-Kosmala, Henschel, 2022). RM ensures that previously identified and assessed risks remain visible, relevant, and manageable in dynamic business environments—especially where sustainability issues evolve rapidly and unpredictably.

In the context of environmental transformation, risk monitoring serves as an early warning system, enabling firms to adjust their sustainability strategies and operational practices in response to emerging environmental regulations, stakeholder expectations, and technological innovations (Lozano, 2015; Ullah et al., 2021). For innovative firms, whose business models are often agile and future-oriented, RM provides the necessary feedback loops to refine green strategies, correct course when needed, and capitalize on sustainability-related opportunities (Cui et al., 2024).

Recent studies show that organizations with structured RM systems are more likely to embed sustainability goals into ongoing decision-making and performance evaluation (Beasley et al., 2024; Kraus et al., 2020; Dobler et al., 2012). In such cases, RM enhances strategic adaptability and resilience, which are critical capabilities in achieving long-term environmental outcomes. Consequently, we propose the following hypothesis:

Hypothesis 4 (H4). Risk Monitoring (RM) has a positive and significant influence on transformational environmental outcomes (TEM).

Nonetheless, the success of risk monitoring in promoting sustainability transformation depends on its integration within broader governance and decision-making systems. Without a strategic framework such as Enterprise Risk Management (ERM), monitoring efforts may remain fragmented, resulting in lost signals or delayed responses to sustainability risks and opportunities (Florio, Leoni, 2017; Al-Nimer, 2024).

Empirical research supports the view that ERM plays a key mediating role, ensuring that monitoring insights are not only recorded but actively translated into cross-functional learning, corrective action, and strategic alignment (Adenutsi, Whajah, 2023; Krysiak 2009). For example, in the energy and technology sectors, firms with integrated ERM systems have been shown to respond more effectively to evolving environmental risk profiles—achieving higher levels of innovation and environmental performance. In light of these insights, we formulate the following mediating hypothesis:

Hypothesis 4M (H4M). The influence of Risk Monitoring (RM) on transformational environmental outcomes (TEM) is positively mediated by Enterprise Risk Management (ERM).

3. Material and Methods

The data used in this study were obtained from a structured survey administered to representatives of innovative firms operating in various sectors of the economy. The survey was conducted between July and Semtember of 2024 and resulted in 587 valid responses. Firms were selected using purposive sampling, targeting organizations involved in environmental innovation, R&D activities, or the integration of sustainability into strategic planning—thus aligning with commonly accepted definitions of innovative firms. Table 1 presents the characteristics of the sample, including firm size, sector of activity, years of

operation, and level of engagement in environmental innovation. This information provides context for the analysis by describing the profile of the innovative firms surveyed and ensuring the relevance of the sample to the study's objectives.

Table 1.
Characteristics of the Sample N = 587

Category	Subcategory	N	%
Firm Size	Small	**234**	**39,9**
	Medium	**219**	**37,3**
	Large	134	22,8
Firm Maturity (years)	1-5	72	12,3
	6-10	106	18,1
	11-15	82	14,0
	>15	**327**	**55,7**
Main Business Activity	Trade	77	13,1
	Manufacturing	164	27,9
	Services	**346**	**58,9**
Gender	Female	**269**	**45,8**
	Male	**318**	**54,2**
Job Position	Specialist/Analyst	**270**	**46,0**
	Middle Management	164	27,9
	Senior Management	82	14,0
	Accounting	66	11,2
	Owner	5	0,9

Source: own elaboration.

The survey instrument was developed based on validated scales used in previous studies on risk management and sustainability (e.g., Beasley et al., 2024; Kraus et al., 2020). It consisted of multiple items measuring five latent constructs: risk identification (RI), risk analysis (RA), risk monitoring (RM), enterprise risk management (ERM), and transformational environmental outcomes (TEM) (Table 2). All items were measured on a seven-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree), allowing for the assessment of respondents' perceptions regarding risk practices and sustainability integration.

Table 2.
Reflective constructs and survey items

Construct	Description / Item labels	Cronbach's α
Risk Identification (RI)	p1_1 Risk identification is carried out …	0.819
	p1_3 We prepare reports on the identified …	
	p1_4 We periodically update the list/catalog ..	
Risk Assessment (RA)	p1_6 We carry out customer satisfaction ….	0.750
	p1_7 We operate strictly in accordance …	
	p1_8 We have implemented a risk assessment …	
Risk Monitoring (RM)	p1_9 In our company, we have defined ….	0.832
	p1_10 To prevent errors	
	p1_11 We always review the results …	
	p1_12 We have developed action plans …	
Enterprise Risk Management (ERM)	p1_13 When identifying risks, we focus on all …	0.857
	p1_14 We always assess the impact of the risk …	
	p1_15 We determine who within the company …	
	p1_16 In our company, we have defined …	

Cont. table 2.

Transformational Environmental Management (TEM)	p2_25 We recognize that climate change …	0.893
	p2_26 We are concerned about the future …	
	p2_27 We are ready to invest in modern …	
	p2_28 We invest in environmental …	
	p2_29 Environmental issues have influenced …	
	p2_30 Environmental protection goals …	

Source: own elaboration.

The results presented in Table 1 confirm the accuracy of the construct, as evidenced by Cronbach's alpha coefficient values above 0.7 (Cronbach 1951). Therefore, TEM can be measured through subjective responses regarding the degree of assessment of four constructs in the area of risk management. Before conducting the main analysis, the data were screened for completeness. Cases with missing values on key variables were excluded. No severe violations of assumptions regarding collinearity or extreme outliers were identified.

To evaluate the proposed relationships between constructs, we employed Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS 4.0. PLS-SEM was selected due to its suitability for theory development, complex predictive models, and its ability to handle latent constructs with non-normal data distributions, which are typical in management and sustainability research (Hair et al., 2021).

The analysis followed a two-step approach. First, we assessed the reflective measurement model, examining:

- Indicator reliability through outer loadings (threshold >0.708),
- Internal consistency reliability using Cronbach's alpha, Composite Reliability (CR) (acceptable range: 0.70-0.95),
- Convergent validity via Average Variance Extracted (AVE) (threshold >0.50),
- Discriminant validity using the Fornell-Larcker criterion and Heterotrait-Monotrait ratio (HTMT) (<0.85).

In the second stage, we evaluated the structural model by analyzing the path coefficients, coefficient of determination (R^2), and effect sizes (f^2). To test the significance of direct and mediating effects, we used a bootstrapping procedure with 5000 resamples, following the approach recommended by Zhao, Lynch, and Chen (2010). Mediation was interpreted as significant if both the indirect effect and the confidence intervals did not include zero.

This methodological approach ensures robustness in testing the proposed model and hypotheses, especially in the context of examining unobservable constructs such as strategic environmental orientation and integrated risk management capabilities. The conceptual model is presented in Figure 1. To thoroughly test the proposed hypotheses, a reflective conceptual model was developed (Hair et al. 2022). This study introduces two innovative contributions to the scientific analysis of transformational environmental management (TEM): (1) various aspects related to the elements of the risk management process are assessed subjectively, and (2) the indirect influence of enterprise risk management (ERM) on the relationship between

these aspects and TEM is taken into consideration. All constructs are measured, and the hypotheses are subsequently tested.

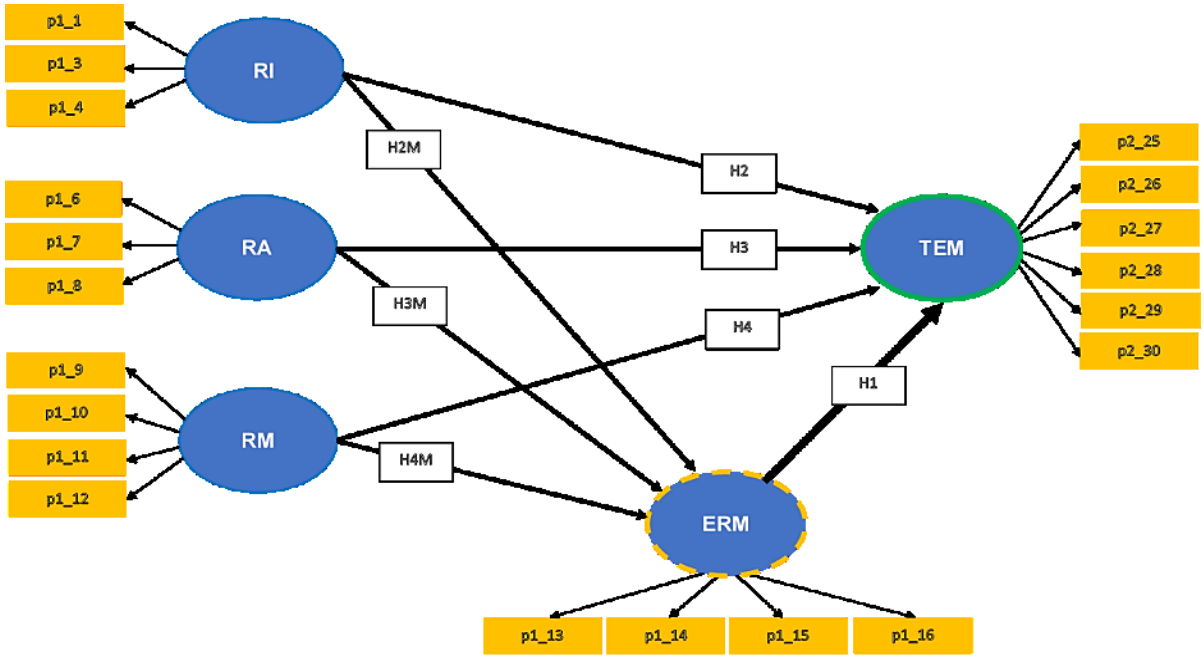

Figure 1. Conceptual model.

Source: own elaboration.

4. Results and Discussion

Initially, the measurement model is assessed using PLS, followed by the testing of the proposed hypotheses.

4.1. Measurement Model Performance

In assessing reflective measurement models, the focus is on examining both the reliability of the indicators—specifically, indicator reliability and internal consistency—and the validity of the constructs, including convergent and discriminant validity. To evaluate indicator reliability, the individual correlations between indicators and their respective constructs were analyzed, with items retained if their loadings were equal to or above 0.708 (Hair et al., 2019). Although one observed variable (p1_11; Figure 2) have standardized loadings slightly below the recommended threshold 0,704, but Chin (1998) notes that the 0.708 rule allows for some flexibility, particularly when the indicators enhance content validity. Then, to assess the internal consistency reliability of the reflective construct, composite reliability (CR) was calculated. This should be between 0.7 and 0.95 (Hair et al., 2019).

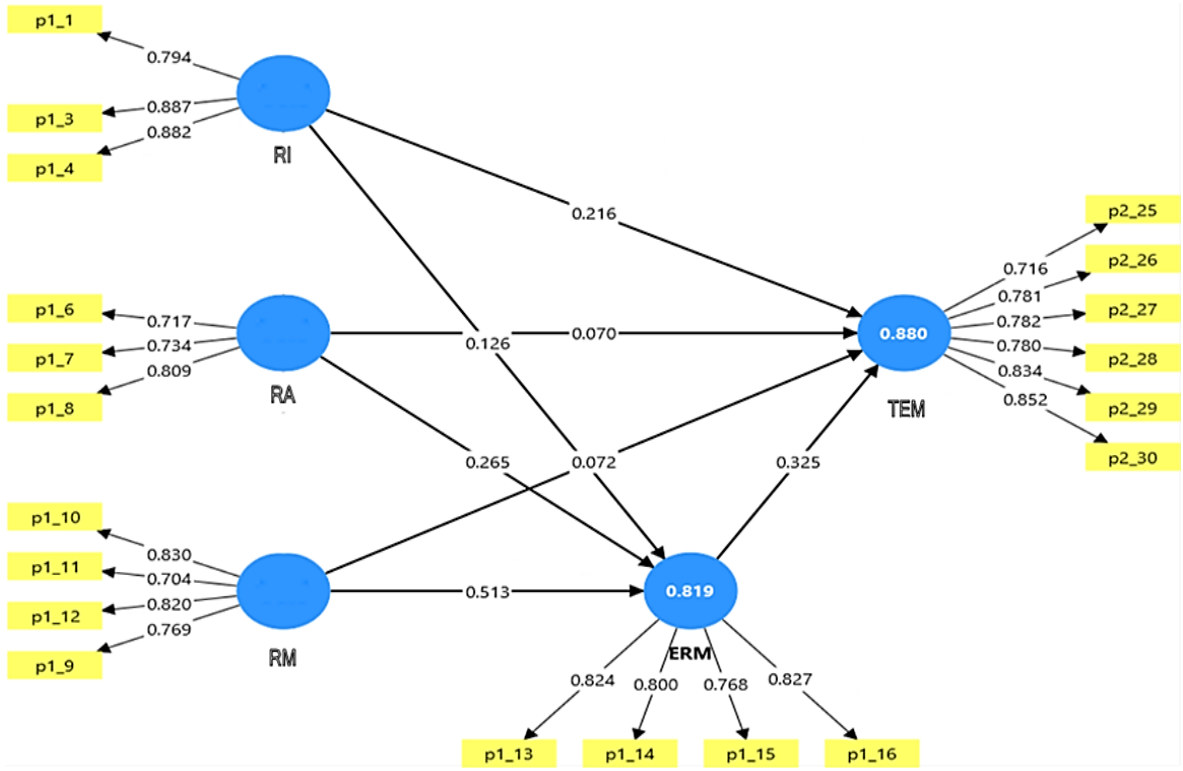

Figure 2. Estimated model.

Source: own elaboration.

The model demonstrates adequate reliability, as both Cronbach's Alpha and composite reliability values exceed the threshold of 0.7 for all constructs. This suggests that the indicators reliably reflect their respective constructs. In terms of measurement model validation, the acceptable levels of Average Variance Extracted (AVE) across all constructs further confirm their reliability (Table 3).

Table 3.

Assessment of Measurement Model: Reliability and Validity Indicators

Construct	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Reference values (Hair et al., 2019)	*>=0,708*	*>=0,7*	*>= 0,50*
Risk Identification (RI)	0.819	0,891	0,731
Risk Assessment (RA)	0,750	0,798	0,569
Risk Monitoring (RM)	0,832	0,863	0,612
Enterprise Risk Management (ERM)	0,857	0,880	0,648
Transformational Environmental Management (TEM)	0,893	0,910	0,627

Source: own elaboration.

Discriminant validity was evaluated using the Fornell–Larcker criterion, correlation matrix, and the Heterotrait–Monotrait ratio (HTMT), as presented in Table 4. The diagonal elements (in bold) represent the square root of the AVE for each construct and are greater than the corresponding correlations with other constructs, confirming discriminant validity per Fornell–Larcker. Correlations between constructs (values below the diagonal) are all below the conservative threshold of 0.85, indicating no multicollinearity concerns. Additionally,

all HTMT values (above the diagonal, in italics) are below the recommended threshold of 0.90, further supporting discriminant validity (Hair et al., 2019). These results suggest that the constructs in the model are conceptually distinct and appropriately measured.

Table 4.
Discriminant Validity of Constructs

	ERM	RA	RI	RM	TEM
ERM	**0,805**	*0,797*	*0,764*	*0,675*	*0,665*
RA	0,729	**0,754**	*0,682*	*0,742*	*0,661*
RI	0,630	0,657	**0,855**	*0,789*	*0,602*
RM	0,709	0,742	0,643	**0,782**	0,618
TEM	0,569	0,502	0,513	0,520	**0,792**

Note: The values on the diagonal (bold) represent the square root of the AVE. The values below the diagonal indicate the correlations between constructs, while the values above the diagonal (italics) show the HTMT ratios.

Source: own elaboration.

4.2. Structural model performance

After confirming the validity of the model, we apply the nonparametric PLS bootstrapping method (Hair et al., 2022) to assess the significance of the path coefficients (β), clarify the relationships between the constructs, and evaluate the proposed hypotheses (Hair et al., 2022). The results of this structural model analysis are presented in Table 5.

Table 5.
Assessment of Structural Model: Estimation and Hypothesis Verification

Hypothesis	Structural Relationship	Path (β) Standardised	* t Value Bootstrap	p-value	Contrast
H1	ERM➔TEM	0,325	4,492	0,000	Supported
H2	RI➔TEM	0,216	3,701	0,000	Supported
H3	RA➔TEM	0,070	1,105	0,269	Rejected
H4	RM➔TEM	0,072	1,021	0,307	Rejected

Source: own elaboration.

Based on the findings presented in Table 4, we accept Hypothesis 1 (H1), which indicates that Enterprise Risk Management (ERM) has a positive and statistically significant effect on Transformational Environmental Management (TEM). This supports the strategic importance of comprehensive enterprise-level risk frameworks in facilitating organisational transformation towards environmental sustainability. This link is corroborated by recent studies: for instance, Hanif et al. (2023) found that firms with robust ERM practices have a greater capacity to implement environmental change, and Monazzam and Crawford (2024) emphasised the role of ERM in enhancing adaptive governance and green innovation.

Furthermore, hypothesis 2 (H2) is also supported, demonstrating that risk identification positively influences TEM, albeit to a lesser extent. This finding is consistent with the research of Hock-Doepgen et al. (2021), who argue that the early detection of environmental hazards enables organisations to adapt their strategies and allocate their resources effectively in

advance. Thus, RI meaningfully contributes to the readiness required for transformative environmental action.

In contrast, hypotheses 3 and 4 (RA → TEM and RM → TEM) are rejected, as risk assessment (RA) and risk monitoring (RM) show no direct significant effects on TEM. These results align with those of Settembre-Blundo et al. (2021) and Shah et al. (2025), who observed that the impact of isolated risk quantification or surveillance processes is diminished when they are not embedded in a broader ERM context. The findings suggest that RA and RM likely exert indirect influence through ERM or become effective only when aligned with strategic leadership and organisational culture.

Our results show that ERM is the most influential predictor of transformational environmental performance, followed by risk identification. The limited direct roles of RA and RM suggest that they are best utilised within a comprehensive ERM system, rather than as standalone processes. This finding is consistent with recent integrative frameworks (e.g. Monazzam, Crawford 2024), which emphasise the importance of coordinated risk functions and system-wide governance in achieving environmental transformation.

While the direct paths provide insight into the immediate relationships between risk-related factors and transformational environmental outcomes, they do not reveal the underlying processes through which these effects occur. Therefore, a mediation analysis was conducted to determine whether ERM functions as an intermediary variable in these relationships, offering a deeper understanding of the structural dynamics within the model.

Table 6.
Mediating Effects of ERM on the Relationship Between Risk Constructs and Transformational Environmental Management (TEM)

Hypothesis	Indirect Path	Indirect Effect (β)	t-value	p-value	Confidence Interval	VAF (%)	Mediation Type	Significance
H2M	RI → ERM → TEM	0.041	2.095	0.036	[0.005; 0.082]	8.6%	Weak mediation	Significant
H3M	RA → ERM → TEM	0.086	3.847	0.000	[0.045; 0.124]	25.7%	Partial complementary mediation	Significant
H4M	RM → ERM → TEM	0.167	3.827	0.000	[0.092; 0.240]	69.9%	Partial complementary mediation	Significant

Source: own elaboration.

The mediation analysis was conducted to assess the role of Enterprise Risk Management (ERM) as a mediator in the relationship between three key dimensions of risk management—Risk Identification (RI), Risk Assessment (RA), and Risk Monitoring (RM)—and Transformational Environmental Management (TEM). The results, including indirect effects, t-values, confidence intervals, and the Variance Accounted For (VAF), are summarized in Table 6. The results for the RI → ERM → TEM path (H2M) reveal a statistically significant

indirect effect (β = 0.041, p = 0.036), with a 95% bias-corrected confidence interval that does not include zero [0.005; 0.082]. However, the VAF is only 8.6%, suggesting that ERM accounts for a very small proportion of the total effect of RI on TEM (β = 0.476). This implies that, although the mediating effect is statistically significant, it is practically weak or negligible. In this context, it appears that RI directly contributes to environmental transformation, with ERM playing a limited mediating role. In contrast, the RA → ERM → TEM mediation path (H3M) shows both a statistically significant and meaningful indirect effect (β = 0.086, p < 0.001; 95% CI: [0.045; 0.124]). The VAF of 25.7% suggests that approximately one-quarter of the total effect of RA on TEM is explained by ERM. Moreover, given that the direct effect of RA on TEM is not statistically significant (p = 0.269), this relationship can be interpreted as a case of full mediation. ERM here plays a critical transitional role, serving as the main mechanism through which risk assessment processes are translated into effective environmental management strategies. The strongest mediating effect is observed in the RM → ERM → TEM path (H4M). The indirect effect is high and statistically robust (β = 0.167, p < 0.001; 95% CI: [0.092; 0.240]), with a VAF of 69.9%. This indicates that a large portion of RM's impact on TEM is transmitted through ERM. Since both the direct and indirect effects are significant and share the same direction (positive), this case reflects a partial complementary mediation. This suggests that ERM plays a central, integrative role in converting ongoing risk-monitoring activities into organizational capacity for transformational environmental performance. Collectively, these findings confirm that ERM functions as a significant mediating variable, particularly in relation to structured and continuous risk practices such as assessment and monitoring. Conversely, its mediating influence is less pronounced in the case of early-stage processes like risk identification. The results underscore ERM's importance not only as a governance mechanism but also as a strategic enabler of environmental transformation, helping organizations bridge the gap between operational risk management and sustainability-focused outcomes.

5. Conclusions

This study offers a novel contribution to the literature on environmental sustainability, innovation management, and enterprise risk governance by developing and empirically testing a structural model linking risk management practices with Transformational Environmental Management (TEM) in innovative firms. Central to this research is the conceptualization of Enterprise Risk Management (ERM) as both a direct predictor and a mediating mechanism that enables the transformation of traditional risk processes—namely Risk Identification (RI), Risk Assessment (RA), and Risk Monitoring (RM)—into strategic and systemic environmental change.

The findings confirm that ERM has a significant and positive direct effect on TEM, supporting prior research that highlights the importance of integrated risk governance in fostering organizational agility, innovation, and long-term resilience in the face of environmental uncertainty (Florio, Leoni, 2017; Al-Nimer, 2024). This underscores ERM's dual function—not only as a compliance or risk control system but also as a strategic enabler of sustainability transformation.

From the operational perspective, the direct effects of RI on TEM were found to be statistically significant, suggesting that early-stage risk awareness is indeed influential in shaping a firm's environmental trajectory. However, the mediating effect of ERM on RI → TEM was statistically significant but weak in magnitude (VAF = 8.6%), indicating that while ERM plays a supporting role in this relationship, RI's influence on TEM is primarily direct and independent of ERM structures.

By contrast, the RA → TEM and RM → TEM direct relationships were not statistically significant, but both displayed strong and significant indirect effects via ERM. Specifically, the mediation analysis revealed that RA's influence on TEM is fully mediated by ERM (VAF = 25.7%), suggesting that risk assessments only become strategically impactful when embedded within a broader, enterprise-wide risk framework. Similarly, RM's impact on TEM is largely transmitted through ERM (VAF = 69.9%), supporting the interpretation of a partial complementary mediation. This means that ongoing and institutionalized monitoring practices provide critical input for ERM systems, which in turn facilitate strategic alignment with sustainability objectives.

These findings collectively suggest that ERM acts as a dynamic integrator—translating fragmented, operational-level risk activities into coherent, forward-looking strategies for environmental transformation. It not only bridges the gap between risk mitigation and opportunity creation but also strengthens the internal infrastructure through which environmental innovation and planning can occur. The differences observed in mediation strength across RI, RA, and RM also point to important distinctions in how various risk processes contribute to sustainability outcomes: while risk identification provides initial awareness, it is risk assessment and monitoring—when processed through ERM—that drive systemic change.

The study further validates the use of Partial Least Squares Structural Equation Modeling (PLS-SEM) as a robust analytical tool for examining complex, theory-driven models involving latent constructs, particularly in sustainability and innovation contexts. The methodological rigor, including the application of bootstrapping, multi-stage validation of measurement models, and mediation testing, reinforces the reliability of the conclusions drawn.

In summary, the findings highlight several key theoretical and practical implications:

- theoretical: the study advances our understanding of how and when ERM enhances the impact of risk management on sustainability, contributing to emerging frameworks that integrate risk governance with strategic environmental management;

- managerial: Firms aiming to achieve transformational environmental outcomes should focus not only on implementing risk identification or assessment tools but also on embedding these tools within integrated ERM systems. Doing so enhances coordination, strategic foresight, and environmental responsiveness;
- policy-oriented: for regulators and policy-makers, the results imply that encouraging enterprise-wide risk integration practices—especially in innovation-intensive sectors—may accelerate firms' transitions toward sustainability.

Ultimately, this research reinforces the strategic importance of ERM in enabling firms to not merely comply with environmental standards but to lead proactive and transformational sustainability initiatives.

Despite its theoretical and empirical contributions, this study has limitations that provide opportunities for future research. Firstly, the study focuses on a purposive sample of innovative firms within a single national context, which may restrict the generalisability of the findings. Comparative studies across different countries, sectors or regulatory environments could validate and extend the model's applicability. Secondly, the conceptual model focuses on a limited set of constructs. Future research should explore additional factors, such as leadership style, organisational culture or regulatory pressure, as potential moderators or mediators of the identified relationships. Thirdly, as Transformational Environmental Management (TEM) is a relatively novel construct, its operationalisation would benefit from further refinement and validation in diverse empirical contexts. Taking these directions would enhance the depth, reliability and external validity of research on risk governance and strategic environmental transformation.

Acknowledgements

Research carried out as part of the research project: „ECOnimics4Climate II: Managing risks of green transition in innovative sectors" Funding: GZM Metropolis / Metropolitan Science Support Fund and University of Economics in Katowice.

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