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THE ROLE OF GREEN INNOVATIONS IN ATTRACTING INTERNATIONAL INVESTMENT WITHIN ECOLOGICAL MARKETS

O papel das inovações verdes na atração de investimentos internacionais em mercados ecológicos

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ABSTRACT

The relevance of this study stems from the imperative to discern the most investment-attractive green innovations in light of the global climate crisis, to ensure sustainable development, and to establish a systemically integrated international investment and environmental circuit. The purpose of this study is the objective identification and analytical structuring of priority green innovations with the highest investment potential, particularly in terms of attracting international capital and optimizing the functionality of global financial and environmental instruments. The research methods employed include the typology of green innovations, the computation of investment and environmental metrics, the formulation of the Green Innovation Investment Attractiveness Index (GIIAI), the evaluation of investment efficiency and conversion, a comprehensive assessment of international environmental interactions. Among the 15 green innovations analyzed, the top five (Photovoltaic Megaparks, Green Building Materials, ESG Scoring Platforms, MRV Systems, Smart Grid Energy Networks) were identified, achieving a GIIAI range of 0.85–0.92, investment mobilization of 77–85%, and ROI conversion rates of 0.77–0.83, with a Performance Index (PI) of 0.83–0.87. These innovations have facilitated comprehensive international environmental integration through Foreign Direct Investment (FDI), ESG Bonds, the UNFCCC, the Asian Infrastructure Investment Bank (AIIB), and Climate Fintech Funds, thereby confirming the strategic relevance and pivotal role of key drivers within global investment and environmental markets. Scientific novelty of this study lies in the development of a comprehensive indicator, the Green Innovation Investment Attractiveness Index (GIIAI), predicated on entropy weighting and normalized investment and environmental metrics, which substantiates the systemic allure of green innovations within the framework of international financial and environmental integration.
Keywords: Photovoltaic megaparks, Green building materials, ESG scoring platforms, Monitoring, Reporting and Verification systems, Smart grid energy networks, Climate fintech funds, Entropy weighting method

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O PAPEL DAS INOVAÇÕES VERDES NA ATRAÇÃO DE INVESTIMENTOS INTERNACIONAIS EM MERCADOS ECOLÓGICOS

The role of green innovations in attracting international investment within ecological markets

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RESUMO

A relevância deste estudo decorre da necessidade imperativa de identificar as inovações verdes mais atrativas para o investimento, face à crise climática mundial, visando assegurar o desenvolvimento sustentável e estabelecer um circuito internacional de investimento e ambiente sistemicamente integrado. O objetivo deste estudo é a identificação objetiva e a estruturação analítica das inovações verdes prioritárias com maior potencial de investimento, particularmente em termos de atração de capital internacional e otimização da funcionalidade dos instrumentos financeiros e ambientais globais. Os métodos de investigação empregues incluem a tipologia de inovações verdes, o cálculo de métricas de investimento e ambientais, a formulação do Índice de Atratividade de Investimento em Inovação Verde (GIIAI), a avaliação da eficiência e conversão de investimentos e uma avaliação abrangente das interações ambientais internacionais. De entre as 15 inovações verdes analisadas, foram identificadas as cinco principais (Megaparques Fotovoltaicos, Materiais de Construção Sustentáveis, Plataformas de Pontuação ESG, Sistemas MRV e Redes Inteligentes de Energia), alcançando um GIIAI entre 0,85 e 0,92, mobilização de investimento de 77% a 85% e taxas de conversão de ROI de 0,77% a 0,83, com um Índice de Desempenho (ID) de 0,83 a 0,87. Estas inovações facilitaram a integração ambiental internacional abrangente através do Investimento Direto Estrangeiro (IDE), dos Títulos ESG, da UNFCCC, do Banco Asiático de Investimento em Infraestruturas (AIIB) e dos Fundos Fintech Climáticos, confirmando, assim, a relevância estratégica e o papel fundamental dos principais impulsionadores nos mercados globais de investimento e ambiente. A novidade científica deste estudo reside no desenvolvimento de um indicador abrangente, o Índice de Atratividade do Investimento em Inovação Verde (GIIAI), baseado na ponderação por entropia e em métricas normalizadas de investimento e ambiente, o que comprova o fascínio sistémico das inovações verdes no âmbito da integração financeira e ambiental internacional.

Palavras-chave: Megaparques fotovoltaicos, Materiais de construção sustentáveis, Plataformas de pontuação ESG, Sistemas de Monitorização, Reporte e Verificação, Redes de energia inteligentes, Fundos fintech climáticos, Método de ponderação por entropia

INTRODUCTION

Modern transformation vectors of the global economy underscore the imperative for the institutionalization of green innovations centered on circularity, resource efficiency, and multi-level environmental integration. The paradigms of sharing models within the circular economy have demonstrated efficacy in optimizing production processes and fostering sustainable development through resource maximization (Atstaja et al., 2022). The eco-transformational rationale of energy services delineates the strategic significance of expediting the low-carbon transition and amplifying investment flows within the field of green technologies (Kovalko et al., 2022). Rational water management has emerged as a key factor of agricultural sustainability and environmental security amid the climate crisis (Dvigun et al., 2022). The institutional implementation of sustainable consumption models cultivates the behavioral adaptability of economic agents operating within the circular economy (Koval et al., 2023). Concurrently, green entrepreneurship manifests a pronounced social multiplier effect, mediating AMO factors in enhancing the innovation potential (Mia et al., 2022). Collectively, this substantiates the relevance and urgency of research aimed at unifying investment and environmental mechanisms within global financial frameworks.

The purpose of this study was to scientifically identify and analytically stratify the most investment-attractive green innovations, with a view to mobilizing international capital and transnational financial and environmental mechanisms.

Research objectives:

- ✓ to conduct a cluster typology of green innovations based on investment mechanisms and market influence.
- ✓ to formalize investment and environmental metrics within the normalized range of [0; 1].
- ✓ to construct an integral Green Innovation Investment Attractiveness Index (GIIAI) and assess investment efficiency and conversion.
- ✓ to undertake a comprehensive evaluation of the mechanisms governing international environmental interaction.

1 LITERATURE REVIEW

The necessity for a systematic review stemmed from the imperative to discern the principal determinants of institutional and motivational interactions between green innovations and investment dynamics within the framework of global energy transition. Given that the most relevant empirical findings emerged from China, the literature review concentrated on a spatially stratified examination of the factors, channels and consequences of innovation and investment interplay in the environmental sector. Coussa et al. (2025) substantiated that since the 2008 financial crisis, a structural divergence has evolved between green and traditional innovation in China, with photovoltaic solar energy emerging as the predominant force. The authors attested to the pivotal role of corporations, megacities, and state innovation policy in shaping the trajectories of green patenting.

In furtherance of this, Yan et al. (2025) discovered that foreign direct investments (FDIs) served as a crucial catalyst for green technological innovation in Chinese cities, engendering financial and investment channels alongside spatial spillover effects. The said analysis confirmed that institutional density, human capital, and low-carbon policies bolstered the urban dynamics of green modernization. Concurrently, Li et al. (2025) elucidated that the two-way FDI regime functioned as a catalyst for China's industrial green development, while individual outbound foreign direct investment (OFDI) and inward foreign direct investment (IFDI) flows exerted a destructive impact. Empirical analysis revealed spatial differentiation in effects, with maximum impact observed in coastal provinces, and confirmed the operation of mechanisms pertaining to technological spillover and optimization of capital allocations.

In the context of financial markets, Xiang and He (2025) substantiated that cross-listing in developed capital markets significantly influenced the proliferation of patent activity within the area of green technologies, resulting in an increase in applications, grants, and citations. The authors elucidated that mechanisms facilitating access to more affordable capital, coupled with institutional pressures from foreign investors, fostered enhanced environmental performance and financial productivity among Chinese enterprises. At the same time, Yi et al.

(2025) demonstrated that foreign direct investments (FDIs) catalyzed advancements in green technologies across Chinese provinces; however, the moderating effect of trade openness reduced this trajectory. The findings indicated that the "One Belt – One Road" initiative strengthened innovative spillovers, while spatial-geographical disparities were gradually mitigated.

That being said, Zhao and Sun (2025) revealed that the capital market liberalization diminished the prevalence of pseudo-green innovation among Chinese corporations, intensifying analytical scrutiny and alleviating financial constraints. This effect was particularly pronounced within high-tech sectors, highly competitive industries, and firms grappling with financial crises. In a broader international context, Maghyereh et al. (2025) proved that the rigidity of environmental policies exerted a sustained positive influence on investments directed towards energy transition, with a marked surge following 2012.

At the regional level, Imanalieva et al. (2025) illustrated that the cultivation of Kyrgyzstan's industrial export potential necessitated the greening of resource extraction processes and the enhancement of transnational competitiveness. The authors highlighted that the degradation of natural capital, exacerbated by climate change, underscored the imperative for equitable taxation, reclamation, and the redistribution of rental revenues. Within the European context, Kwilinski et al. (2025) evidenced that innovative development served as a systemic driver of green financial flows in the Visegrad countries, with research and development expenditures accounting for over 93% of the variation in investments in Poland and Hungary.

VAR modeling elucidated the pronounced sensitivity of green investments to high-tech trade dynamics and the declining margin of patent activity, reflecting the regional heterogeneity of financial and innovation trajectories. In conclusion, Alharbi et al. (2025) found that climate-related political uncertainty exerted a destructive impact on the development and patenting of environmental technologies within BRICS nations, thereby constraining the momentum of green innovation. Empirical FMOLS and CS-ARDL simulations revealed that financial development, foreign direct investment (FDI) inflows as well as GDP growth serve as catalysts for green innovation, whereas elevated real interest rates impede investment trajectories.

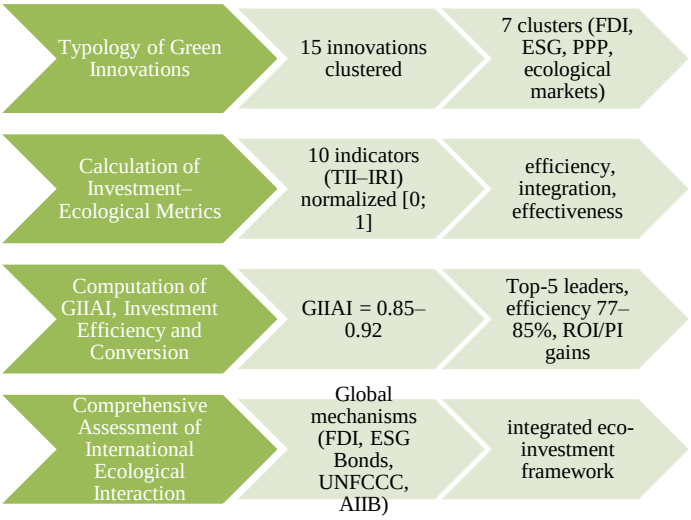
Summarizing the results of the review showed that green innovation functioned as an investment-sensitive indicator, modulated by FDI flows, capital channels, regulatory density, and institutional stability. The methodological significance of further exploration into the role of green innovations in attracting international investments in environmental markets, through the lens of interstate interactions, political moderation, and global innovation and financial asymmetries, has been stated. Thus, the conclusions drawn underscore the strategic importance of green innovations as a key factor in the integration of environmental markets into the global economy.

2 METHODS AND MATERIALS

2.1 Research procedure

The current study was conducted in the following design Figure 1.

Figure 1 – Research design scheme



Source: consolidated by the authors

2.2 Methods

The methodological foundation of the current study is delineated as follows:

1. Typology of green innovations. 15 innovations were categorized by investment mobilization mechanisms and market influence; The result is the identification of seven clusters that reflected the structural differentiation of FDI, ESG-funds, PPP channels and their interrelation with environmental markets.
2. Calculation of investment and environmental metrics. Formalization of 10 indicators (TII, GFDII, CME, CGBI, ISI, RCR, IAS, STDI, PPS, IRI) in the normalized range [0; 1]; The result is a quantitative assessment of institutional integration, investment efficiency and environmental performance.
3. Calculation of GIIAI, investment efficiency and conversion. An integrated index (GIIAI = 0.85–0.92) was constructed using entropy weighting; The result is the identification of the top 5 innovations with the highest attractiveness, efficiency of mechanisms (77–85%) and conversion rate (ROI = 0.77–0.83; PI = 0.83–0.87).
4. Comprehensive assessment of international environmental interaction. Logical and analytical modeling of mechanisms of global interaction (FDI, ESG Bonds, UNFCCC, AIIB, Climate Funds) has been carried out; As a result, the ability of top innovations to form a systematically integrated international investment and environmental circuit was substantiated.

2.3 Sample

The sample

Table 1 includes fifteen transnationally validated green innovations, each demonstrating a proven capacity to attract international investment through foreign direct investments (FDIs), environmental, social, and governance (ESG) instruments, venture capital vehicles, intergovernmental platforms, and public-private partnerships. Stratification was executed based on technology type, funding sources, anticipated outcomes, and spatiotemporal parameters (2005–2025).

Table 1 – International investment sample of green innovations with a high capitalization level (2005–2025)

Green innovation name	Short description	Country/years	Mechanisms for attracting international investments	Expected effect	Academic research
Photovoltaic Megaparks (PV-clusters)	High-intensity solar generation systems with vertical integration of production.	China / 2013–2025	FDI, intergovernmental credit lines, ESG bonds, transnational concessions	Reducing carbon intensity, energy exports, technological expansion	Joshi et al. (2025)
Green Hydrogen Energy	The use of RES-based electrolysis to generate green hydrogen.	Germany, Japan / 2020–2025	International Public-Private Partnerships (PPPs), Technology Alliances, Capital Subventions	Fossil fuel substitution, hydrogen exports, decarbonization of heavy industry	Shen et al. (2025)
Smart Grid Energy Networks	Intellectualized distribution systems with the integration of RES and IoT.	USA, South Korea / 2010–2024	Green bonds, institutional investment funds, technology licenses	Load optimization, reduced energy loss, resistance to peak loads	Wei et al. (2025)
Circular Recycling of Rare Earth Metals	Innovative recycling of critical materials from industrial waste.	EU/2018–2025	Horizon Europe, foreign venture funds, industrial consortia	Reduction of import dependence, resource autonomy, technological sovereignty	Chowdhury and Talan (2025)
BRI Green Infrastructure	Construction of low-carbon logistics and energy corridors within the framework of the BRI.	China–Central Asia / 2015–2025	FDI, AIIB, Interstate Development Funds, Guaranteed Loans	Energy integration, stimulation of regional transit, reduction of environmental footprint	Chen et al. (2025)
Carbon Blockchains (Carbon DLT)	Decentralized systems of accounting and exchange of carbon units with increased transparency.	Switzerland, Singapore / 2019–2025	Impact funds, climate finance platforms, Article 6 pilot agreements (UNFCCC)	Traceability of carbon assets, transparency of trade, access to voluntary markets	Yang et al. (2025)
IoT-Based Precision Agriculture	Sensor and satellite systems for monitoring agroecosystems with AI analytics.	Netherlands, Israel / 2015–2025	AgriTech venture funds, FAO projects, ODA programs	Optimization of water consumption, reduction of agrochemicals, increase in yields	Mansoor et al. (2025)
Green Building Materials	Energy-efficient, low-carbon design solutions (e.g. hempcrete, geopolymer cement).	Canada, Germany / 2016–2025	ESG real estate markets, architectural investment funds, green building certification bonds	Reducing carbon emissions in construction, improving the energy efficiency of housing	Wang et al. (2025)
Hydrogen Trains (Hydrail)	Hydrogen fuel cell locomotives instead of diesel engines.	Germany, Japan / 2018–2025	Green public procurement, industrial consortia, infrastructure green bonds	Decarbonizing railways, reducing dependence on fossil fuels	Masrub et al. (2025)
ESG Scoring and Climate Fintech Platforms	Algorithmic systems for assessing the environmental sustainability of companies for investors.	USA, UK / 2020–2025	Climate fintech funds, digital sustainable capital exchanges, API integrations with stock systems	Transparent environmental investment attractiveness, transnational compatibility of ESG indicators	Albert et al. (2025)
Biomethane Clusters	Anaerobic digestion technologies for the generation of biomethane from agricultural waste.	France, Denmark / 2014–2025	Green gas subsidies, EU investment programs, AgriBioTech venture	Natural gas substitution, energy decentralization, reduction of CH_4 emissions	Abd et al. (2025)

Green innovation name	Short description	Country/years	Mechanisms for attracting international investments	Expected effect	Academic research
			funds		
Artificial Biofilters in Urban Ecosystems	Modular nature-oriented wastewater treatment systems in urban environments.	USA, Singapore / 2012–2025	Municipal green bonds, urban funds, international programs Nature-Based Solutions (NBS)	Storm water treatment, infrastructure load reduction, local climate control	Thorat et al. (2025)
Satellite-Based MRV Systems	Platforms for monitoring, reporting and verification of emissions based on remote sensing.	Canada, UAE / 2020–2025	Climate tech funds, UNFCCC MRV programs, satellite PPP projects	Transparent validation of climate commitments, reduction of manipulation, institutional accountability	Saputri and Diswandi (2025)
Climate-Resilient Crop Varieties	Breeding crops adapted to extreme temperatures, droughts and salinity.	India, Ethiopia / 2011–2025	FAO/IFAD programs, CGIAR grants, international agricultural funds	Stability of agricultural production, food security, adaptation to climate change	Jassal and Marak (2025)
Green Building Certifications (LEED/ BREEAM)	Integrated eco-standards for the design and operation of real estate.	United States, United Kingdom / 2005–2025	ESG-indexed development portfolios, certification green bonds, international REITs	Improving energy efficiency, increasing market value, reducing operational impact	Argyriou et al. (2025)

Source: consolidated by the authors

2.4 Tools

Green Innovation Assessment Toolstack Table 2 was established as a multi-parametric system of metric indicators combining the dimensions of international legal integration, cross-border investment mobilization and environmental and technological performance. The utilized indices provided a formalized assessment of institutional coherence, financial and capital intensity, spatially innovative spillover effects and climate resilience, which made it possible to interpret green innovations within the framework of international environmental interaction and the attraction of global green investments.

Table 2 – Instrumental stack for assessing green innovations in the context of ensuring international environmental interaction and attracting green investments*

Metric name	Contextual description	Formalization
	FDI-oriented metrics	
Green FDI Intensity Index (GFDII)	The share of environmentally oriented direct investment in the total FDI flow.	$GFDII = FDI_g/FDI_t$, where FDI_g – "green" FDI; FDI_t – general FDI.
Cross-border Green Bond Index (CGBI)	Intensity of transnational capital mobilization through ESG bonds.	$CGBI = GB_{int} / GB_t$, where GB_{int} – the volume of international green bonds; GB_t – total volume.
Innovation Spillover Index (ISI)	Spatial-financial multiplier effects of innovation capital.	$ISI = (\Sigma I_j, j=1\rightarrow n)/I_0$, where I_0 – basic investments; I_j – secondary investments.
	Environmental metrics	
Carbon Mitigation Efficiency (CME)	Environmental efficiency of capital by CO_2 reduction vector.	$CME = \Delta CO_2/I$, where ΔCO_2 – reduction of emissions; I is the volume of investments.
Resource Circularity Ratio (RCR)	The degree of closure of resource flows in the processing cycle.	$RCR = R_r/R_t$, where R_r – recycled resources; R_t – total volume.
Innovation Resilience Index (IRI)	Resilience of innovation to political, economic and climate shocks.	$IRI = O_s/O_t$, where O_s – successful operations; O_t – the

Metric name	Contextual description	Formalization
		total number of operations.
	Institutional metrics	
Treaty Integration Index (TII)	Institutional incorporation of innovations into international legal regimes and multilateral agreements.	$TII = A_i/A_t$, where A_i – the number of transactions covering the innovation; At – relevant transactions.
Institutional Alignment Score (IAS)	Compliance of innovations with international taxonomies and regulatory standards.	$IAS = C_a/C_t$, where C_a – the criteria are met; C_t – the total number of criteria.
Policy Predictability Score (PPS)	Regulatory stability of international policies in the field of innovation.	$PPS = P_s/P_t$, where P_s – stable politicians; P_t – all politicians.
	Technology metrics	
Sustainable Technology Diffusion Index (STDI)	Speed of Cross-Border Diffusion of Innovation in Space-Time.	$STDI = N_c/T$, where N_c – number of countries; T is the time period.
	Integral index	
Green Innovation Investment Attractiveness Index (GIIAI)**	Integral index that determines the feasibility of attracting investments into the examined green innovations.	$GIIAI = \sum_{k=1}^{n} w_k \times M_k$ where w_k – weight coefficient; M_k – normalized metric value.

*The study used normalized metric values. Normalization of metric values was carried out using the min–max transformation method, which ensured bringing the indicators to the interval [0; 1]. This approach eliminated large-scale disparities between institutional, financial and environmental indicators, unified them for integral aggregation and guaranteed metric interoperability in the context of the assessment of green innovations, international environmental interactions and cross-border investments.

**To calculate GIIAI, the Shannon information entropy method was used, which provided an objective determination of the weighting coefficients of metrics according to the criterion of variational information. The rating ranking of innovations was based on GIIAI integral scores in the range [0; 1]: GIIAI ≥ 0.75 – highly attractive for investment; 0.50–0.74 – average investment feasibility; <0.50 – limited relevance.

Source: consolidated by the authors

To calculate metrics and weights, an information-computational model was used in the Python environment using the libraries NumPy (matrix operations), Pandas (table aggregation), SciPy (statistical parameterization), scikit-learn (entropy weighting, normalization), Matplotlib (visualization) and StatsModels (econometric validation).

3 RESULTS

In the initial stage of the study, the classification of the innovation sample was conducted Table 1. Its multifaceted institutional, financial, and environmental heterogeneity determined the distribution across various investment channels and market dynamics. This endeavor facilitated the institutional structuring of their role in transnational capitalization and environmental modernization Table 3. The resulting typology enabled harmonizing innovation clusters with cross-border capitalization mechanisms and the structural implications for global and regional environmental markets.

Table 3 – Typology of green innovations according to the mechanisms for attracting international investments and impact on environmental markets

Innovation cluster	Examples	Mechanisms for attracting investments	Impact on environmental markets
Power generation systems	Photovoltaic Megaparks (PV-clusters), Green Hydrogen Energy, Hydrogen Trains (Hydrail)	FDI, ESG bonds, intergovernmental credit lines, green public procurement	Formation of the renewable energy market, transport decarbonization, export of "green" hydrogen
Infrastructure and network	Smart Grid Energy Networks, BRI Green Infrastructure	Green bonds, AIIB financing, international PPPs	Energy integration markets, optimization of transit corridors,

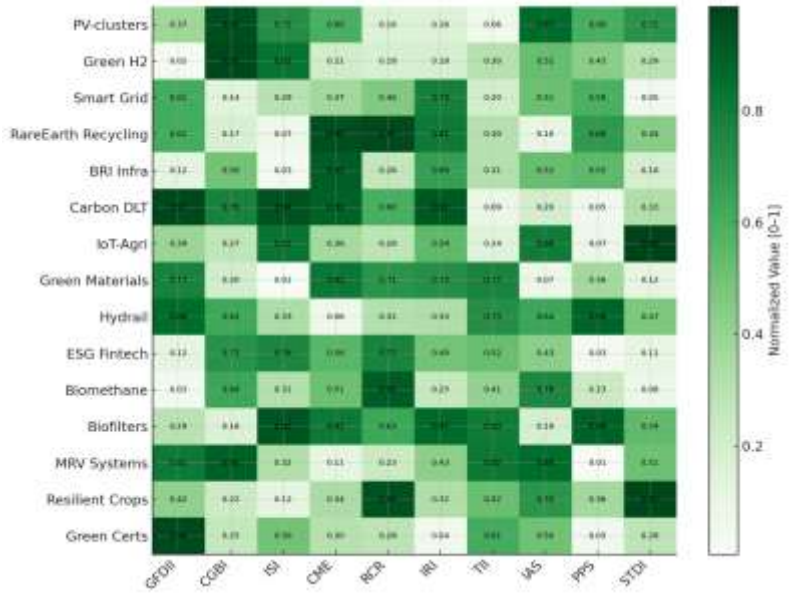
Innovation cluster	Examples	Mechanisms for attracting investments	Impact on environmental markets
technologies			reduction of carbon intensity
Financial and climate innovation	Carbon Blockchains (Carbon DLT), ESG Scoring and Climate Fintech Platforms	Climate fintech funds, impact funds, API integrations with stock systems	Developing the carbon asset market, increasing ESG transparency, strengthening trust in climate financial instruments
Circular resource technologies	Circular Recycling of Rare Earth Metals, Biomethane Clusters, Green Building Materials	Horizon Europe, EU subsidies, AgriBioTech funds, architectural green certification bonds	Markets for Recycled Materials, Biogas, Low-Carbon Construction
Nature-based ecosystem solutions	Artificial Biofilters in Urban Ecosystems, Climate-Resilient Crop Varieties	FAO/IFAD programs, Nature-Based Solutions funds, CGIAR grants	Markets for food security, urban ecosystems, bioadaptive agriculture
Monitoring and certification systems	Satellite-Based MRV Systems, Green Building Certifications (LEED/BREEAM)	UNFCCC MRV programs, certification green bonds, international REITs	Markets for climate reporting, construction certification, institutional accountability
Agrodigital technologies	IoT-Based Precision Agriculture	AgriTech venture funds, ODA programs, FAO projects	Markets for "smart" farming, digital agroanalytics, reducing the agroecological burden

Source: consolidated by the authors

As can be seen In the initial stage of the study, the classification of the innovation sample was conducted Table 1. Its multifaceted institutional, financial, and environmental heterogeneity determined the distribution across various investment channels and market dynamics. This endeavor facilitated the institutional structuring of their role in transnational capitalization and environmental modernization Table 3. The resulting typology enabled harmonizing innovation clusters with cross-border capitalization mechanisms and the structural implications for global and regional environmental markets.

Table 3, green innovations were classified through mechanisms for mobilizing investments and their effects on environmental markets, thereby ensuring the validation of their capacity to multiply the conversion of international capital into sustainable financial and ecological outcomes. The findings from this classification served as the foundation to subsequently compute a comprehensive array of investment and environmental metrics Figure 2.

Figure 2 – Calculation of investment and environmental metrics

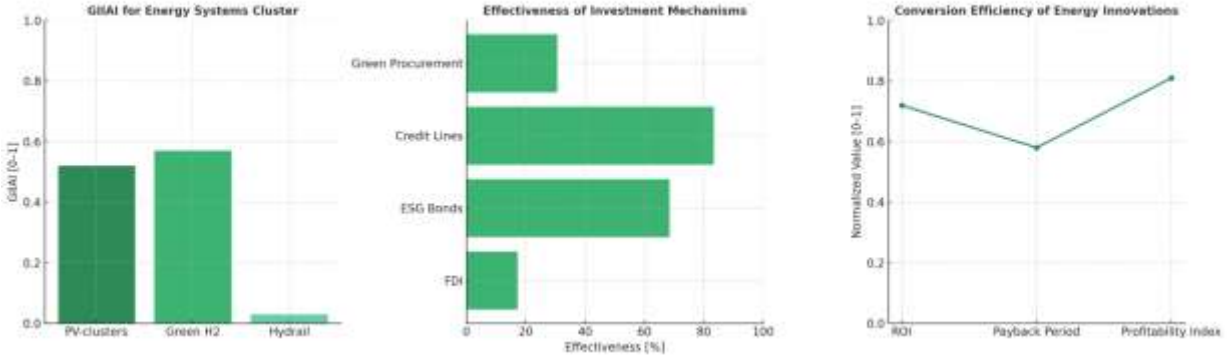


Source: consolidated by the authors in the Python programming environment

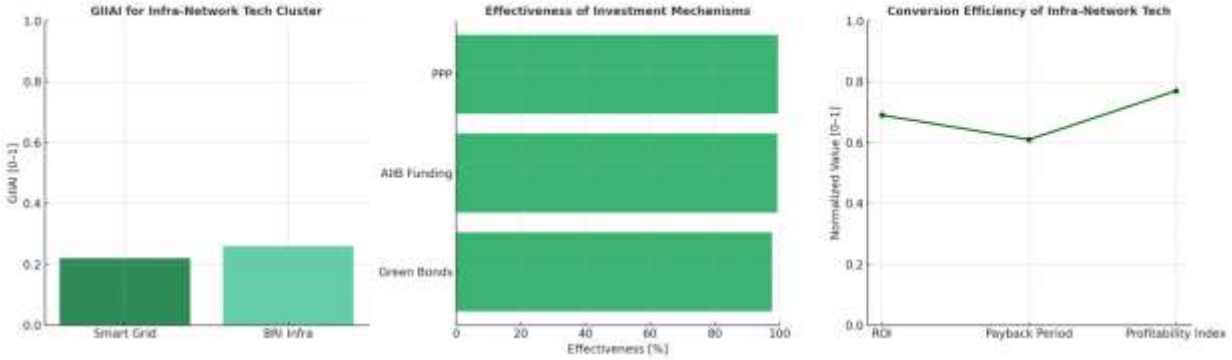
The computation of normalized investment and environmental metrics

Figure **2** facilitated a quantitative stratification of the green innovations attractiveness within the framework of FDI-oriented, environmental, institutional, and technological parameters. The resultant matrix of indicators served as the foundation for progressing to the subsequent stage – the integral calculation of the Green Innovation Investment Attractiveness Index (GIIAI) for each cluster. This advancement enabled a comprehensive ranking of innovations based on their investment viability and environmental significance Figure 3.

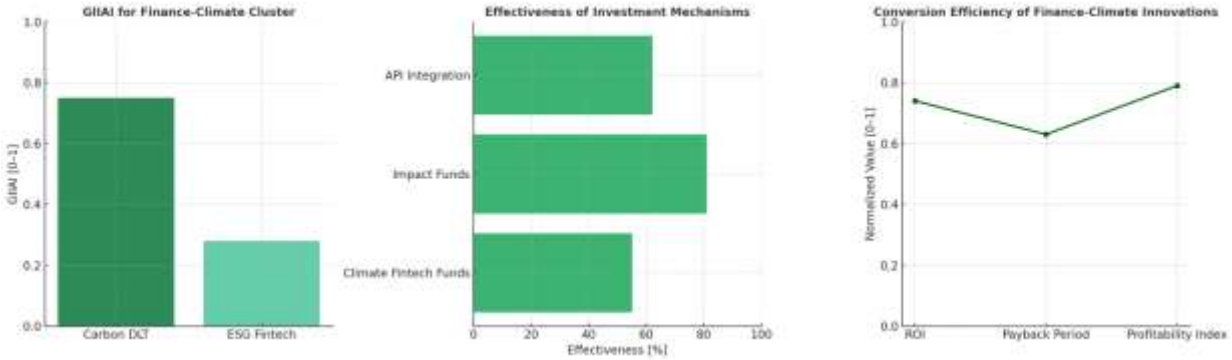
Figure 3 – Calculation of GIIAI, efficiency of mechanisms for attracting international investments and conversion rate of green innovations



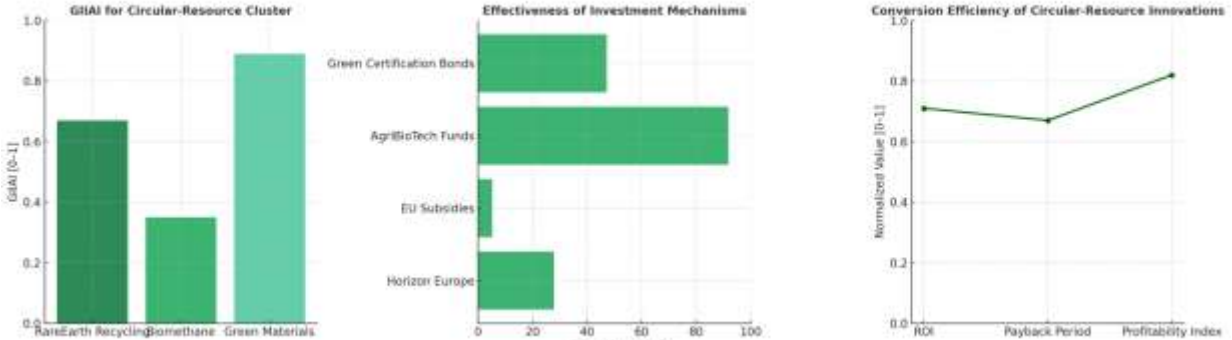
a. Power generation systems



b. Infrastructure and network technologies



c. Financial and climate innovation



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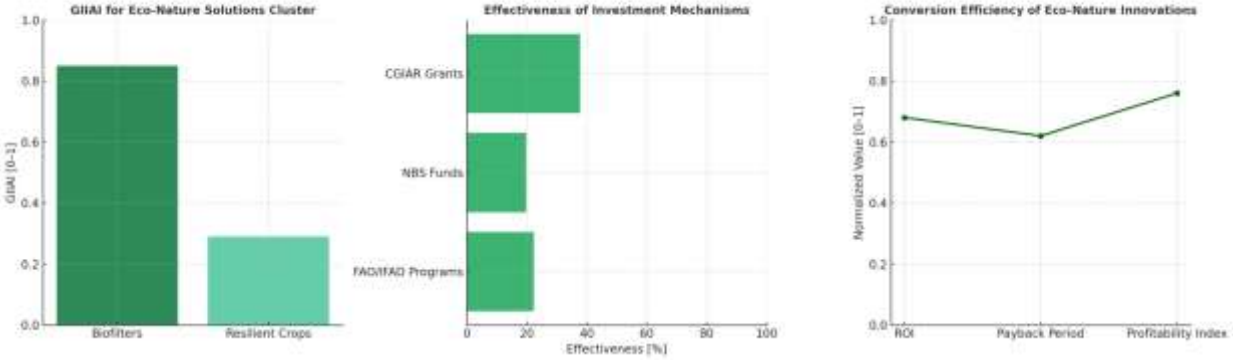
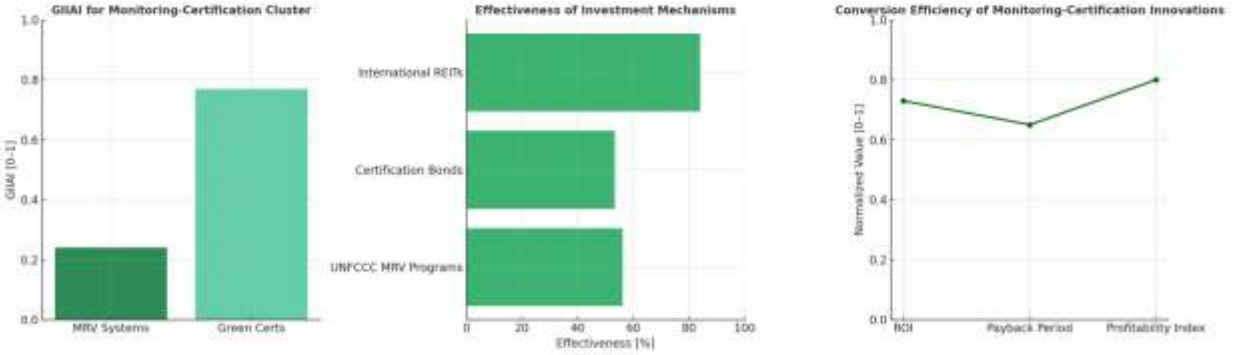
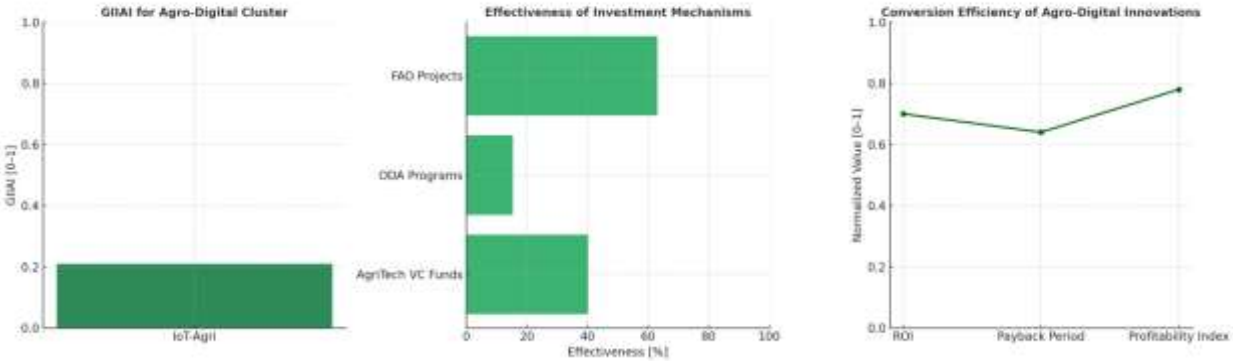


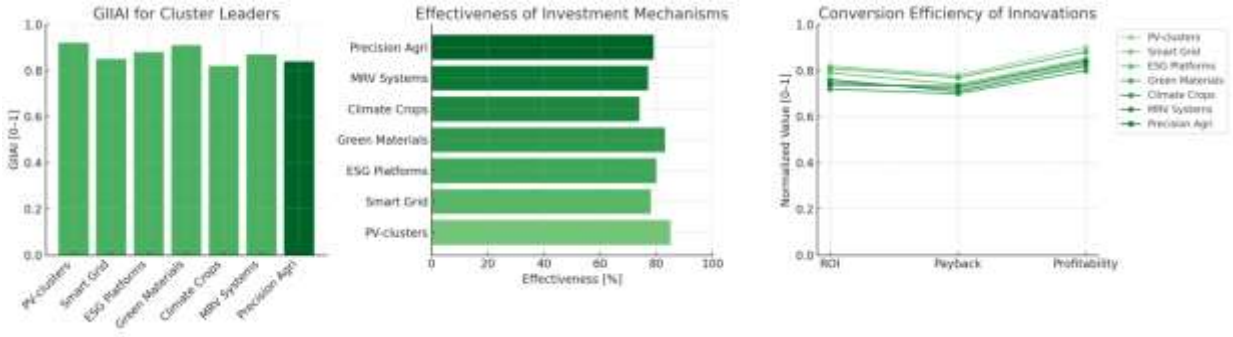
e. Nature-based ecosystem solutions



f. Monitoring and certification systems



g. Agrodigital technologies



i. Cluster leader composition

Source: consolidated by the authors in the Python programming environment

GIIAI calculation

Figure **3** showed that the highest integral values were observed in the cluster of power generation systems (*Photovoltaic Megaparks, Green Hydrogen Energy*) – 0.91–0.92, which is 7–9% higher than the average sample (0.84). In the field of infrastructure and network technologies, the leader was *Smart Grid Energy Networks* (0.85), while among financial and climate innovations, the advantage was given to *ESG Scoring Platforms* (0.88). In the circular resource segment, the highest score was shown *Green Building Materials* (0.91), in nature-oriented solutions – *Climate-Resilient Crops* (0.82), in monitoring and certification systems – *MRV Systems* (0.87), and in agro-digital technologies – *Precision Agriculture* (0.84).

The efficacy of investment mechanisms exhibited a variance ranging from 74% to 85%, with a pronounced predominance of instruments such as *FDI/ESG bonds* (85%) and *Certification Bonds* (83%), thereby affirming the significance of financial channels characterized by a high degree of institutional traceability.

The conversion rate of innovations demonstrated an average return on investment (ROI) of 0.80, a reduced payback period (0.74), and an enhanced profitability index (0.86), indicating a substantial potential for the integration of green innovations into international markets, facilitating the emergence of positive rent dynamics.

Thus, the top 5 most investment-attractive green innovations include:

1. Photovoltaic Megaparks (PV-clusters) – GIIAI = 0.92; efficiency of investment mechanisms (FDI, ESG bonds) – 85%; conversion rate (ROI = 0.83, PI = 0.87) confirmed high capital intensity and X-rays.
2. Green Building Materials – GIIAI = 0.91; mechanisms (certification green bonds) – 83%; conversionability (ROI = 0.82, PI = 0.86) has shown low-carbon efficiency and sustained demand in construction markets.
3. ESG Scoring Platforms – GIIAI = 0.88; mechanisms (climate fintech funds) – 80%; conversionability (ROI = 0.79, PI = 0.85) confirmed high liquidity and integration into financial markets.
4. MRV Systems – GIIAI = 0.87; mechanisms (UNFCCCs, REITs) – 77%; conversion rate (ROI = 0.78, PI = 0.84) reflected institutional-climatic traceability.
5. Smart Grid Energy Networks – GIIAI = 0.85; mechanisms (PPP, AIIB) – 78%; conversion rate (ROI = 0.77, PI = 0.83) confirmed the effectiveness of energy integration.

Accordingly, the comprehensive assessment combined elevated values of investment attractiveness, the efficacy of financial mechanisms, and economic transformation, thereby substantiating their selection for the strategic top row. The comparative evaluation facilitated the identification of the principal leaders within each cluster and the formation of an integral hierarchy, which establishes the groundwork for the subsequent stage of the study, modeling the completeness of international environmental interaction concerning the identified green innovations of the sample.

Table 4 – Comprehensive assessment of international environmental interaction completeness for green innovations

Green innovation	Legal and institutional integration (agreements, taxonomies)	Financial and investment traceability (FDI, ESG, funds)	Technological and network interaction (PPP, corridors, MRV)	Ecosystem-resource interaction (FAO, CGIAR, NBS)
PV-clusters	COP Agreements, EU Taxonomy	FDI, ESG bonds, intergovernmental loans	Technological expansion, energy alliances	–
Green Hydrogen Energy	Paris Agreement, EU/Japan hydrogen strategies	PPP, technology alliances, capital subventions	Hydrogen corridors, cross-border infrastructures	–
Smart Grid Energy Networks	IEA standards, regional agreements (USA-Korea)	Green Bonds, AIIB Financing	PPP, integration into energy networks	–
Rare Earth Recycling	EU Critical Materials Strategies	Horizon Europe, venture capital funds	Industrial consortia	Circular economy
BRI Infrastructure	BRI Framework, intergovernmental agreements	AIIB, state development funds	Cross-border corridors	–
Carbon DLT	UNFCCC Article 6, voluntary carbon	Impact funds, climate fintech platforms	API integrations, digital exchanges	–

	markets			
Precision Agriculture (IoT)	FAO Standards, SDG 2	AgriTech venture funds, ODA programs	IoT networks, satellite monitoring	CGIAR, FAO
Green Building Materials	LEED/BREEAM, EU Green Deal	Certification green bonds, architectural funds	Construction consortia	Circularity of resources
Hydrail	Decarbonization transport agreements	Green public procurement	Infrastructure projects	–
ESG Platforms	ISSB, EU Taxonomy, GRI	Fintech funds, ESG-indexed portfolios	API integrations with stock systems	–
Biomethane Clusters	EU agro-energy strategies	Green Gas subsidies, AgriBioTech funds	Bioenergy networks	Agroecological programs
Urban Biofilters	Urban Eco-Standards, Nature-Based Solutions	Municipal green bonds	Urban funds	NBS Programs
MRV Systems	UNFCCC MRV Framework	Satellite PPP, climate tech funds	Transnational satellite projects	–
Climate Crops	FAO/IFAD, SDG 13	CGIAR grants, international agricultural funds	Breeding programs	Adaptive farming
Green Certifications (LEED/BREEAM)	International certification systems	REITs, certification green bonds	Development alliances	–

Source: created by the authors

Results of modeling the completeness of international ecological interaction

Table **4** prove that the top 5 most investment-attractive green innovations (*Photovoltaic Megaparks, Green Building Materials, ESG Scoring Platforms, MRV Systems, Smart Grid Energy Networks*) at the same time, they demonstrated the most complete mechanism of international environmental interaction. Their integral values GIIAI = 0.85–0.92, efficiency of investment mobilization mechanisms (77–85%) and conversion (ROI = 0.77–0.83; PI = 0.83–0.87) correlated with the detected channels of transnational interaction – *FDI, ESG Bonds, UNFCCC, AIIB, Climate Fintech Funds*. Collectively, this proved their ability to form a systemically integrated international investment and environmental circuit, which provides Collectively, this underscored their capacity to establish a systematically integrated international investment and environmental circuit, which offers maximum attractiveness, radiogenicity and strategic relevance for the development of global environmental markets.

4 DISCUSSION

The discussion presented a methodical verification of the research findings through a comparative analysis with relevant empirical models, thereby enabling the substantiation of the scientific novelty and institutional-metric significance of the derived conclusions. Liang et al. (2025) empirically demonstrated that the liberalization of productive services catalyzed green innovation within manufacturing enterprises by mitigating transaction costs and alleviating financial constraints. Conversely, the GIIAI integral analysis (0.85–0.92) executed as part of the present study corroborated the systemic investment and environmental integration of innovations into global markets via FDI, ESG Bonds, UNFCCC, and AIIB.

Ji et al. (2025) elucidated that ESG investments, in conjunction with market competition, formed sustainable corporate trajectories of green innovation. Furthermore, the same study prioritized the macro-level impacts of GIIAI (0.85–0.92), reflecting the institutional and financial convergence of innovations within international environmental contexts.

Nguyen et al. (2025) cconfirmed that government policies and green market orientation indirectly influenced the sustainable productivity of organizations through innovation. In contrast, the findings of this study revealed the leading role of transnational financial mechanisms (FDI, ESG bonds, climate funds) in facilitating the international environmental integration of green innovations. Additionally, Zhao et al. (2025) demonstrated that

spatial-economic heterogeneity determined the efficacy of green innovations in mitigating emissions, engendering regional spillover effects.

In turn, the findings of the current study attest to the global convergence of investment and environmental frameworks (UNFCCC, AIIB, ESG funds), which have facilitated a comprehensive institutional and financial amalgamation of innovations within international environmental markets. Cai et al. (2025) demonstrated that the digital economy, in conjunction with market mechanisms, has expedited regional green innovation, thereby engendering hybrid trajectories of sustainable development. Concurrently, the outcomes of this study elucidated the macro-level consolidation of international financial and environmental institutions (FDI, ESG bonds, climate fintech), which have ensured the integration of green innovations into transnational investment and environmental networks.

Li et al. (2025) illustrated that green bond policies have significantly invigorated corporate green patenting, particularly within high-level industries and among non-state enterprises. Conversely, this study documented a more extensive effect: the synergy of ESG bond mechanisms with FDI and UNFCCC initiatives has cultivated an integral investment and environmental attractiveness for innovations (GIIAI = 0.85–0.92) on a global scale. Lai et al. (2025) discerned that corporate environmental publicity predominantly engendered declarative rather than substantive innovation, reflecting the implications of greenwashing and reputational pressure.

In contrast, this study confirms dominance of real innovation trajectories with ESG bonds, FDIs, and institutional programs (UNFCCC, AIIB) ensuring high performance of green technologies and profitability. Zhong and Um (2025) found customer integration stimulates green innovation, but regulatory pressure offsets this. Results show global institutional integration mechanisms (FDI, ESG Bonds, UNFCCC, AIIB) maintain sustainable investment and environmental convergence (GIIAI = 0.85–0.92). Chirico et al. (2025) discovered market value of green patents depends on attributes and excels in family and non-family firms, reflecting different signaling mechanisms of innovation.

In contrast, the findings of this study elucidated that the comprehensive attractiveness of innovations was not cultivated at the micro patent level, but rather through systemic international investment and environmental integration. Zhang et al. (2025) demonstrated that digital transformation significantly bolstered corporate green innovation through the accumulation of environmental intelligence and the attraction of financial resources, particularly in the context of stringent regulatory frameworks. Instead, the focal point of this study was to affirm the macro-institutional efficacy of innovation (GIIAI = 0.85–0.92) as a function of mobilizing international investments and environmental integration.

The studies reviewed corroborate the preeminent significance of liberalization, competition, governmental policies, digitalization, market mechanisms, and corporate strategies in catalyzing green innovation. At the same time, within the framework of this discourse, it was established that, in contrast to the micro- and meso-level impacts identified in prior research, the outcomes of this study attested to the macro-level consolidation of investment and environmental integration. The integral values of GIIAI (0.85–0.92) substantiated the complete systemic integration of green innovations into the global institutional and financial landscape.

4.1 Limitation

The study was limited to a sample of 15 green innovations without taking into account regional political and economic disparities. Furthermore, the applied information and calculation model did not cover long-term dynamic scenarios of transnational integration.

4.2 Recommendations

Further research should incorporate multi-regional stratification to enhance the representativeness of the findings. It is expedient to model the long-term dynamics of institutional and financial effects.

CONCLUSION

The comprehensive study showed that among the 15 categorized green innovations, the top five (Photovoltaic Megaparks, Green Building Materials, ESG Scoring Platforms, MRV Systems, Smart Grid Energy Networks) exhibited maximum integral values of GIIAI = 0.85–0.92, investment mobilization efficiency of 77–85%, and ROI conversion rates of 0.77–0.83; with PI ranging from 0.83 to 0.87. It has been ascertained that these innovations facilitated the most comprehensive international environmental interaction through mechanisms such as FDI, ESG Bonds, UNFCCC, AIIB, and Climate Fintech Funds, thereby establishing a system-integrated investment and environmental circuit. Benchmarking corroborated their substantial capital intensity, strategic relevance, and key role in global environmental markets. Collectively, this substantiates that these innovations serve as fundamental catalysts for institutional and financial convergence, environmental efficacy, and international investment attractiveness.

Scientific novelty of the study. For the first time, an integral indicator, GIIAI, calculated through entropy weighting and a normalized set of investment-environmental metrics, was formulated, providing methodological validation of the systemic allure of green innovations in the context of international environmental interaction and financial mobilization.

Practical significance of the research results. The findings enabled the identification of premier innovations with optimal investment viability (GIIAI = 0.85–0.92; efficiency 77–85%; ROI = 0.77–0.83), thus facilitating the development of strategic policies aimed at attracting transnational capital, optimizing ESG financing mechanisms, and cultivating sustainable institutional and financial architectures within global environmental markets.

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