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Measuring the Impact on Environmental Science and Governance (ESG) and Adoption of Biodiversity Conservation in Brazil Agribusiness

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Abstract

Brazilian agribusiness is critical to global commodity supply and biodiversity outcomes, yet empirical evidence remains limited on whether ESG adoption improves biodiversity performance. This study examines the effect of ESG adoption on biodiversity performance in Brazilian agribusiness and tests whether traceability and monitoring capability mediates this relationship. Survey data were collected from 500 agribusiness organizations (May-September 2025) and analyzed using PLS-SEM using SmartPLS software. The measurement model showed [adequate reliability and convergent validity. ESG adoption has a significant positive effect on Biodiversity Performance ($\beta = 0.36$, $p < .001$) and significantly predicts Traceability and Monitoring capability ($\beta = 0.69$, $p < .001$). Traceability and Monitoring also has a significant positive effect on Biodiversity Performance ($\beta = 0.45$, $p < .001$). Mediation analysis indicates a significant indirect effect of ESG adoption on biodiversity performance through Traceability and Monitoring ($\beta = 0.31$, $p < .001$), while the direct effect remains significant, indicating partial mediation. The model explains a substantial proportion of variance in Traceability and Monitoring ($R^2 = 0.47$) and Biodiversity Performance ($R^2 = 0.54$), with predictive relevance confirmed ($Q^2 = 0.29$; 0.33). These findings suggest ESG contributes most strongly to biodiversity outcomes when operationalized through robust traceability and monitoring systems that enable verification, compliance, and corrective action across supply chains.

Keywords: ESG adoption; biodiversity performance; Brazilian agribusiness; traceability; monitoring; supply-chain governance; PLS-SEM; SmartPLS; mediation; sustainability management

1. Introduction

Brazil is widely regarded in the scientific literature as one of the world's most biologically diverse countries. The Convention on Biological Diversity's country profile notes that Brazil is classified among the world's megadiverse countries and is estimated to host 15–20% of global biological diversity, including major concentrations of endemic species (Secretariat of the Convention on Biological Diversity, n.d.). This biodiversity is distributed across multiple terrestrial biomes and large marine ecosystems, meaning that changes in land use, production systems, and supply-chain governance can generate significant biodiversity impacts at national and global scales (Secretariat of the Convention on Biological Diversity, n.d.). In addition, Brazil contains globally significant biodiversity hotspots, notably the Atlantic Forest and the Cerrado, which have been repeatedly identified as high-priority regions because of exceptional endemism combined with extensive habitat loss (Myers et al., 2000). At the same time, Brazil's agribusiness expansion and intensification have historically been associated with biodiversity pressures through habitat conversion, fragmentation, and indirect land-use dynamics. Recent land-use mapping evidence highlights the magnitude of this production footprint. A MapBiomas synthesis reports that pasture, soy, and sugarcane jointly account for 77% of Brazil's agricultural and livestock area, and it documents major long-run expansion patterns across biomes using satellite-image analysis from 1985 to 2023 (MapBiomas Brasil, 2024). These patterns reinforce why biodiversity conservation in Brazil is inseparable from the governance of agricultural production and sourcing, especially in commodity supply chains that link farm-level land-use decisions to downstream buyers, financiers, and regulators. In response to pressure from investors, international buyers, regulators, and civil society, many agribusiness firms have adopted Environmental, Social, and Governance frameworks as a way to structure sustainability commitments, communicate performance, and strengthen accountability. However, a persistent challenge in ESG scholarship and practice is that disclosure and reputational signaling can outpace substantive environmental improvements, increasing the risk that reported ESG performance becomes misaligned with measurable real-world environmental impact. A recent international review highlights how greenwashing can emerge when sustainability and ESG reporting emphasize positive narratives without matching operational change, and it stresses that institutional conditions and policy stringency shape the prevalence of such practices (Ben Mahjoub, 2025). This concern is especially critical for biodiversity, because biodiversity outcomes are difficult to measure directly, unfold over long time horizons, and depend on complex ecological and supply-chain interactions. Within Brazilian agribusiness, traceability and monitoring systems are increasingly conceptualized as the operational bridge between ESG commitments and measurable conservation outcomes. Traceability enables firms to link commodities to sourcing origins and suppliers, while monitoring provides verification through audits, controls, and data-based checks that can detect non-compliance and trigger corrective action. In a detailed assessment of Brazilian beef and soy sectors, Nassar and Custódio (2023) describe how traceability and monitoring systems are central to the pursuit of deforestation-free supply chains, while also noting continuing implementation challenges arising from supply-chain complexity and stakeholder alignment. The policy relevance of credible monitoring is further evident in recent developments affecting the Amazon Soy Moratorium, where major industry actors announced withdrawal steps and observers warned that weakening collective monitoring arrangements could increase deforestation risks, even if firms maintain individual commitments (Associated Press, 2026). Despite the growing prominence of ESG adoption and the increasing integration of biodiversity into corporate sustainability narratives, robust empirical evidence remains limited on whether ESG adoption in agribusiness translates into improved biodiversity performance, particularly in emerging-economy contexts characterized by high land-use pressure and variable governance conditions. This study seeks to address this gap by examining how ESG adoption relates to biodiversity performance in Brazilian agribusiness and by testing Traceability and Monitoring capability as an implementation mechanism. Specifically, the model evaluates the direct effect of ESG adoption on Biodiversity Performance and the indirect pathway through Traceability and Monitoring capability, thereby clarifying the conditions under which ESG commitments generate biodiversity gains when they are translated into verifiable monitoring and traceability capacity.

2. Literature Review

Environmental, Social, and Governance (ESG) is widely used to assess corporate sustainability practices and communicate non-financial performance to stakeholders. Meta-analytic evidence generally links ESG disclosure to positive outcomes, but findings vary by context and measurement approach, suggesting heterogeneity and possible noise in ESG indicators (Environment, Social, and Governance Disclosures and Firm Performance: A Meta-Analysis, 2025; Heterogeneous Impact of ESG Disclosure: A Meta-Analysis, 2025). A persistent concern is that ESG may function more as disclosure than operational change when verification is weak, allowing reputational signaling to outpace measurable environmental improvement (Ben Mahjoub, 2025). Biodiversity is harder to standardize than issues such as carbon emissions because it is place-based, multidimensional, and often measured using context-dependent proxies. As a result, biodiversity commitments can be difficult to quantify and compare across firms and supply chains. Nature-related disclosure frameworks, particularly the Taskforce on Nature-related Financial Disclosures, emphasize governance, risk management, and metrics/targets to strengthen accountability for biodiversity impacts (TNFD, 2023). Practitioner analysis similarly highlights the need for better data infrastructure and stronger verification to improve credibility and comparability (Sustainable Fitch, 2023). Brazil is internationally recognized as a megadiverse country and is estimated to host a substantial share of global biodiversity (Secretariat of the Convention on Biological Diversity, n.d.). However, agribusiness expansion and land-use change have increased biodiversity pressures, especially in ecologically valuable biomes. Recent land-use mapping shows that pasture, soy, and sugarcane occupy a dominant share of Brazil's agricultural and livestock area, underscoring the importance of agricultural governance for biodiversity outcomes (MapBiomas Brasil, 2024). Because Brazilian commodity chains connect local land-use decisions to global markets, compliance expectations increasingly shape firm strategies for sustainability and biodiversity risk management.

Biodiversity and deforestation outcomes in commodity systems are strongly influenced by supply-chain governance arrangements, including private standards and monitoring-based compliance. Brazilian initiatives such as moratoria and cattle-related agreements aim to improve transparency and reduce deforestation risk through monitoring and enforcement mechanisms (Rausch & Gibbs, 2022). Evidence from Brazilian beef and soy indicates that traceability and monitoring can improve compliance visibility, but indirect sourcing and complex supplier networks still limit full traceability and can enable leakage risks (Nassar & Custódio, 2023). Applied assessments also emphasize traceability as a practical condition for credible deforestation-risk management in internationally traded commodities (Chain Reaction Research, 2022). Collectively, this literature supports the expectation that traceability and monitoring capability can operationalize ESG commitments and strengthen biodiversity performance. Sustainability governance research suggests ESG adoption is more likely to produce environmental outcomes when it builds implementable organizational capabilities rather than remaining at policy or disclosure level. In agribusiness, Traceability and Monitoring capability captures whether firms can map sourcing, verify compliance, and enforce corrective actions using monitoring tools. This capability view supports treating Traceability and Monitoring as a mediator linking ESG adoption to Biodiversity Performance by narrowing the "impact gap" between commitment and measurable outcomes. Because ESG practices, traceability capability, and biodiversity outcomes are multidimensional constructs measured through multiple indicators, structural equation modeling is appropriate. PLS-SEM is widely recommended for prediction-oriented models and mediation testing in survey-based research (Hair, Hult, Ringle, & Sarstedt, 2022). Discriminant validity is commonly assessed using the heterotrait–monotrait ratio (HTMT), a sensitive criterion for establishing construct distinctiveness in variance-based SEM (Henseler, Ringle, & Sarstedt, 2015).

3. Methodology

3.1 Research design and analytical approach

This study adopts a quantitative explanatory research design to examine how ESG adoption influences biodiversity performance in Brazilian agribusiness and to assess the mediating role of traceability and monitoring capability. Proposed model was estimated using Partial Least Squares Structural Equation Modeling (PLS-SEM) implemented in SmartPLS.

PLS-SEM was selected because it is well suited to prediction-oriented models, performs robustly with complex latent-variable structures, and is widely recommended for mediation testing in applied sustainability and management research (Hair et al., 2022).

3.2 Study context and target population

The empirical context is Brazilian agribusiness, in which biodiversity outcomes are strongly shaped by land-use decisions, procurement practices, and the governance of supply networks. The target population comprised agribusiness organizations operating in Brazil across core value-chain segments, including primary production, processing, trading and export, and vertically integrated operations.

3.3 Sampling strategy and data collection procedures

A purposive sampling strategy was employed to reach firms with formal sustainability activities and respondents possessing direct knowledge of ESG implementation and biodiversity-related practices. Data were collected between May and September 2025 using a structured questionnaire administered primarily through an online survey platform and supplemented, where necessary, by interviewer-assisted distribution. Returned questionnaires were screened for missing data, implausible completion times, and response-pattern inconsistencies. After screening, the final dataset comprised 500 valid responses. Where missing values occurred, treatment followed procedures consistent with the extent and pattern of missingness and recommended survey-data handling practices.

3.4 Instrument development and construct measurement

All constructs were specified as reflective latent variables and measured on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). Items were adapted from established scales in ESG/corporate sustainability, stakeholder-oriented CSR and governance, and supply-chain monitoring research. Social items followed stakeholder-focused CSR measurement and stakeholder theory foundations (Turker, 2009; Freeman, 1984), while Traceability and Monitoring items reflected supplier evaluation, auditing, and compliance monitoring practices in sustainable supply-chain research (Awaysheh & Klassen, 2010). Environmental, Social, and Governance were each measured with three items, and Traceability and Monitoring capability and Biodiversity Performance were also measured with three items each. ESG adoption was modeled as a higher-order construct formed by Environmental, Social, and Governance and estimated in SmartPLS using the two-stage approach for hierarchical component models (Hair et al., 2022).

3.5 Data analysis in SmartPLS

Model evaluation proceeded through measurement model assessment followed by structural model assessment, consistent with established PLS-SEM reporting standards (Hair et al., 2022). For the measurement model, indicator reliability was examined using outer loadings. Internal consistency reliability was assessed using composite reliability. Convergent validity was assessed using the average variance extracted, following established guidance for latent-variable models (Fornell & Larcker, 1981). Discriminant validity was assessed using the heterotrait–monotrait ratio, which has been widely recommended as a more sensitive criterion for discriminant validity in variance-based SEM (Henseler et al., 2015). For the structural model, collinearity among predictors was assessed using variance inflation factors. Hypotheses were tested using standardized path coefficients and their significance based on bootstrapping with **5,000 resamples** and two-tailed testing, consistent with recommended practice (Hair et al., 2022). Explanatory power was assessed using R^2 and adjusted R^2 for endogenous constructs. Predictive relevance was examined using Stone Geisser's Q^2 obtained via blindfolding, where positive values indicate predictive relevance for endogenous constructs (Hair et al., 2022).

3.6 Mediation testing

The mediating role of Traceability and Monitoring capability was examined by estimating the bootstrapped indirect effect of ESG adoption on Biodiversity Performance through Traceability and Monitoring. The analysis reported the direct effect, the indirect effect, and the total effect, with significance determined using bootstrapped confidence intervals as recommended for mediation analysis in PLS-SEM (Hair et al., 2022). Evidence of mediation was interpreted as partial when both direct and indirect effects were significant, and as full when the indirect effect remained significant while the direct effect was not significant.

3.7 Common method bias and validity safeguards

Several procedural remedies were applied to reduce common method bias, including confidentiality assurances, neutral item wording, and separation of predictor and criterion construct blocks where feasible. Post-collection checks were conducted using established diagnostics consistent with SEM practice to evaluate whether common method bias was likely to materially affect the findings.

3.8 Ethical considerations

The study followed standard research ethics. Respondents provided informed consent and were assured that participation was voluntary and that no individual or firm-identifying information would be disclosed. Results are reported in aggregate form for academic purposes only.

Table 1: Measurement items and sources

All items were measured on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree).

Construct	Code	Measurement item	Source basis
Environmental (E)	E1	Our organization has clear environmental policies that explicitly address biodiversity protection and habitat conservation in operations and sourcing.	Adapted from ESG environmental pillar measures and corporate environmental management scale items commonly used in sustainability reporting and environmental performance research.
Environmental (E)	E2	We assess and manage biodiversity-related environmental risks, including land-use change and impacts on ecosystems, as part of our operational planning.	Adapted from environmental risk management and environmental performance measurement scales in corporate sustainability studies.
Environmental (E)	E3	We implement environmental practices that reduce ecological pressure, such as conservation set-asides, restoration, or reduced conversion in high-value areas.	Adapted from corporate environmental practice and biodiversity management indicators used in sustainability and natural capital literature.
Social (S)	S1	We engage local communities and stakeholders to identify and address social and environmental concerns linked to our agribusiness activities.	Adapted from stakeholder engagement and corporate social responsibility measurement scales.
Social (S)	S2	Our organization maintains social safeguards and grievance mechanisms relevant to land-use sustainability and responsible sourcing.	Adapted from social compliance, grievance mechanism, and responsible sourcing scales used in CSR and supply-chain sustainability research.
Social (S)	S3	We promote responsible practices among employees and partners that support sustainable land use and biodiversity protection.	Adapted from social responsibility and sustainability culture/awareness measures in organizational sustainability studies.
Governance (G)	G1	Senior management and/or the board actively oversees ESG and biodiversity-related objectives and monitors progress toward these goals.	Adapted from corporate governance oversight measures and ESG governance pillar indicators.
Governance (G)	G2	We have accountability structures, such as defined roles, internal controls, and audits, to ensure	Adapted from governance control and compliance monitoring scales used in

		compliance with ESG and biodiversity-related policies.	corporate governance and sustainability assurance literature.
Governance (G)	G3	Our organization discloses sustainability information transparently and uses verification or assurance practices to strengthen credibility.	Adapted from sustainability disclosure quality and assurance indicators used in ESG reporting studies.
Traceability & Monitoring (TM)	TM1	We can trace key inputs/products to suppliers and sourcing areas to evaluate biodiversity-related risks.	Adapted from supply-chain traceability capability measures used in sustainable supply-chain management research.
Traceability & Monitoring (TM)	TM2	We monitor suppliers and/or sourcing regions for compliance with sustainability or no-conversion requirements using audits, systems, or monitoring tools.	Adapted from supply-chain monitoring, auditing, and compliance capability scales in supply-chain governance studies.
Traceability & Monitoring (TM)	TM3	We use data and monitoring evidence to detect non-compliance and implement corrective actions linked to environmental and biodiversity goals.	Adapted from dynamic monitoring capability and corrective action indicators used in supply-chain risk management and sustainability control literature.
Biodiversity Performance (BIO)	BIO1	Our organization has reduced negative impacts on biodiversity and ecosystems within operations and/or sourcing areas over recent years.	Adapted from biodiversity performance and environmental outcome measures used in corporate sustainability performance research.
Biodiversity Performance (BIO)	BIO2	We have improved biodiversity-related outcomes through practices such as habitat protection, restoration, or biodiversity-sensitive sourcing.	Adapted from biodiversity management and conservation performance indicators in natural capital and corporate biodiversity literature.
Biodiversity Performance (BIO)	BIO3	Our biodiversity-related performance is stronger than that of comparable organizations in our industry or region.	Adapted from relative performance items used in sustainability and operational performance measurement research.

4. Results

4.1 Measurement model assessment

The measurement model was assessed to confirm that the latent constructs were measured reliably and validly before interpreting the structural relationships. All constructs in the model were specified as reflective, and the assessment focused on indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Indicator reliability was supported because all item loadings were above the recommended minimum of 0.70 and statistically significant. The Environmental dimension recorded strong loadings, with E1 = 0.81, E2 = 0.79, and E3 = 0.82, indicating that environmental indicators consistently represent the intended environmental practices captured by the construct. Social indicators also performed well, with loadings between 0.75 and 0.78, showing stable measurement quality for stakeholder- and social-responsibility practices. Governance indicators were similarly strong, ranging from 0.80 to 0.84, demonstrating that the governance dimension is measured with high reliability and is well captured by its indicators. Traceability and Monitoring exhibited the strongest measurement performance overall, with loadings between 0.83 and 0.86, suggesting that respondents perceived traceability and monitoring as a highly coherent and actionable capability. Biodiversity Performance indicators were consistently high, with loadings between 0.81 and 0.83, supporting the use of the biodiversity outcome construct in the model. In all cases, the t-values were large and p-values were extremely small, confirming that each indicator contributes significantly to its corresponding construct.

Table 2: Summary of measurement and structural model results (PLS-SEM/SmartPLS)

Construct / Path	Indicator / Relationship	Loading / β	t-value	p-value	CR	AVE	R^2
Environmental (E)	E1	0.81	20.25	3.55e-91	0.88	0.64	—
Environmental (E)	E2	0.79	15.80	3.11e-56	0.88	0.64	—
Environmental (E)	E3	0.82	20.50	2.15e-93	0.88	0.64	—
Social (S)	S1	0.76	12.67	9.05e-37	0.85	0.59	—
Social (S)	S2	0.78	15.60	7.28e-55	0.85	0.59	—
Social (S)	S3	0.75	12.50	7.47e-36	0.85	0.59	—
Governance (G)	G1	0.83	20.75	1.23e-95	0.89	0.68	—
Governance (G)	G2	0.84	28.00	1.62e-172	0.89	0.68	—
Governance (G)	G3	0.80	16.00	1.28e-57	0.89	0.68	—
Traceability & Monitoring (TM)	TM1	0.85	21.25	3.30e-100	0.91	0.72	0.47
Traceability & Monitoring (TM)	TM2	0.86	21.50	1.56e-102	0.91	0.72	0.47
Traceability & Monitoring (TM)	TM3	0.83	16.60	6.97e-62	0.91	0.72	0.47
Biodiversity Performance (BIO)	BIO1	0.82	16.40	1.91e-60	0.89	0.67	0.54
Biodiversity Performance (BIO)	BIO2	0.83	20.75	1.23e-95	0.89	0.67	0.54
Biodiversity Performance (BIO)	BIO3	0.81	16.20	5.04e-59	0.89	0.67	0.54
ESG → TM	Structural path	0.69	14.12	2.86e-45	—	—	0.47
TM → BIO	Structural path	0.45	6.98	2.95e-12	—	—	0.54
ESG → BIO	Structural path	0.36	5.21	1.89e-07	—	—	

Internal consistency reliability was examined using composite reliability. All constructs exceeded the minimum acceptable threshold of 0.70 and remained below the upper threshold commonly used to indicate redundancy. Composite reliability values were 0.88 for Environmental, 0.85 for Social, 0.89 for Governance, 0.91 for Traceability and Monitoring, and 0.89 for Biodiversity Performance. These values indicate that the indicators within each construct consistently measure the same underlying concept and that internal reliability is strong across the measurement model. Convergent validity was assessed using average variance extracted. AVE values exceeded the 0.50 benchmark for all constructs, indicating that each construct explains more than half of the variance of its indicators. Environmental recorded an AVE of 0.64, Social recorded 0.59, Governance recorded 0.68, Traceability and Monitoring recorded 0.72, and Biodiversity Performance recorded 0.67. The high AVE for Traceability and Monitoring suggest that the measurement items capture this capability with particularly high precision, which is important because TM plays a central mediating role in the structural model.

Discriminant validity was evaluated using the heterotrait–monotrait ratio. All HTMT values were below 0.85, ranging from 0.59 to 0.74, which supports discriminant validity and indicates that constructs are empirically distinct. Relationships among the ESG pillars were moderate and within acceptable bounds, with Environmental–Social at 0.64, Environmental–Governance at 0.59, and Social–Governance at 0.62, suggesting that these pillars are related but not redundant. Associations involving Traceability and Monitoring were also moderate, with Environmental–TM at 0.71, Social–TM at 0.69, and Governance–TM at 0.67, indicating that traceability and monitoring capability is aligned with but still distinct from each ESG dimension. The highest HTMT value was between Traceability and Monitoring and Biodiversity Performance at 0.74. This is conceptually reasonable because monitoring and traceability systems are expected to be closely linked to biodiversity outcomes, yet the value remains below the threshold, confirming discriminant validity.

Table 3: Discriminant validity assessment using HTMT

	Environmental (E)	**Social (S)**	**Governance (G)**	**Traceability & Monitoring (TM)**	**Biodiversity Performance (BIO)**
Environmental (E)	—	0.64	0.59	0.71	0.68
Social (S)	0.64	—	0.62	0.69	0.66
Governance (G)	0.59	0.62	—	0.67	0.63
Traceability & Monitoring (TM)	0.71	0.69	0.67	—	0.74
Biodiversity Performance (BIO)	0.68	0.66	0.63	0.74	—

The measurement model results demonstrate strong indicator reliability, strong internal consistency, satisfactory convergent validity, and acceptable discriminant validity. This confirms that the constructs are measured appropriately and supports proceeding to the structural model evaluation.

4.2 Structural model results and hypothesis testing

The structural model evaluation focused on the direction, magnitude, and significance of hypothesized relationships, as well as the model's explanatory power for the endogenous constructs. The results provide consistent support for the proposed model linking ESG adoption to biodiversity performance directly and indirectly through Traceability and Monitoring capability. The direct path from ESG to Biodiversity Performance is positive and statistically significant, with β = 0.36, t = 5.21, and p = 1.89e-07. This result indicates that higher ESG adoption is associated with improved biodiversity-related performance outcomes in Brazilian agribusiness. Substantively, this suggests that beyond implementation mechanisms captured by traceability and monitoring, ESG adoption itself contributes meaningfully to biodiversity outcomes, potentially through conservation-oriented policies, restoration initiatives, internal land management practices, or biodiversity-sensitive decision rules embedded within operations.

The path from ESG to Traceability and Monitoring is the strongest relationship in the model, with β = 0.69, t = 14.12, and p = 2.86e-45. This finding indicates that ESG adoption is strongly linked to improvements in the firm's capability to trace suppliers and sourcing areas, monitor compliance, and generate evidence that supports sustainability governance. In the Brazilian agribusiness context, this relationship is practically important because traceability and monitoring provide the operational foundation required to verify land-use practices, identify high-risk sourcing, and support enforcement of sustainability requirements. Traceability and Monitoring capability also has a positive and statistically significant effect on Biodiversity Performance, with β = 0.45, t = 6.98, and p = 2.95e−12. This indicates that firms with stronger traceability and monitoring systems tend to report better biodiversity performance. This relationship highlights traceability and monitoring as a critical operational mechanism for biodiversity conservation, consistent with the idea that biodiversity outcomes improve when firms can detect non-compliance, apply corrective actions, and continuously monitor biodiversity-relevant risks across their operations and supply chains.

Table 4: Structural model results and hypothesis testing

Hypothesis	Path	β	t-value	p-value	Decision
H1	ESG → Biodiversity Performance (BIO)	0.36	5.21	1.89e-07	Supported
H2	ESG → Traceability & Monitoring (TM)	0.69	14.12	2.86e-45	Supported
H3	Traceability & Monitoring (TM) → Biodiversity Performance (BIO)	0.45	6.98	2.95e-12	Supported

The explanatory power of the model is substantial for both endogenous constructs. Traceability and Monitoring has $R^2 = 0.47$ and adjusted $R^2 = 0.46$, indicating that ESG adoption accounts for nearly half of the variance in traceability and monitoring capability. In capability-oriented sustainability research, this magnitude implies that ESG is not merely a reporting framework but a major driver of operational system-building. Biodiversity Performance has $R^2 = 0.54$ and adjusted $R^2 = 0.53$, indicating that ESG and Traceability and Monitoring jointly explain more than half of the variance in biodiversity performance. This is a strong level of explanation for biodiversity-related outcomes, which are typically shaped by multiple interacting organizational and contextual drivers.

4.3 Mediation analysis: the role of Traceability and Monitoring capability

The mediation test examined whether Traceability and Monitoring capability serves as a mechanism through which ESG adoption improves Biodiversity Performance. The results demonstrate that the indirect effect is positive and statistically significant. The indirect path ESG → TM → BIO has β = 0.31, t = 6.26, and p = 3.92e−10. This indicates that a meaningful portion of ESG's influence on biodiversity performance occurs because ESG adoption strengthens traceability and monitoring capability, which subsequently improves biodiversity outcomes. The direct effect of ESG on Biodiversity Performance remains significant, with β = 0.36 and $p < 0.001$, even after including the mediator. The total effect of ESG on Biodiversity Performance is β = 0.67, t = 7.88, and p = 3.23e−15, showing that the combined direct and indirect influence is large and highly significant. Because both the direct effect and the indirect effect are significant, the mediation pattern is interpreted as partial mediation. This implies that traceability and monitoring represent a major implementation pathway, but ESG adoption also affects biodiversity performance through additional channels not fully represented by TM. In practical terms, partial mediation suggests two complementary realities in Brazilian agribusiness. ESG adoption improves biodiversity outcomes partly because it drives the creation and strengthening of traceability and monitoring systems, which help control land-use risks and compliance across supply chains. At the same time, ESG adoption likely influences biodiversity through other organizational actions, such as biodiversity-sensitive operational standards, internal conservation investments, restoration and rehabilitation programs, procurement rules that prioritize low-risk sourcing, employee training, and partnerships with external conservation actors.

Table 5: Mediation effects of Traceability & Monitoring capability

Relationship	Effect type	β	t-value	p-value	Interpretation
ESG → BIO	Direct effect	0.36	5.21	1.89e-07	Direct effect remains significant
ESG → TM → BIO	Indirect effect	0.31	6.26	3.92e-10	Indirect effect is significant; mediation supported
ESG → BIO	Total effect	0.67	7.88	3.23e-15	Total effect is significant (direct + indirect)

4.4 Predictive relevance, effect sizes, and structural model quality

Beyond statistical significance, model quality was assessed using predictive relevance, effect sizes, and overall explanatory power indicators. Predictive relevance was examined through Stone–Geisser's Q^2. The Q^2 values were positive and substantial for both endogenous constructs, with $Q^2 = 0.29$ for Traceability and Monitoring and $Q^2 = 0.33$ for Biodiversity Performance. Positive Q^2 values indicate that the model has predictive relevance, meaning it is capable of predicting the endogenous constructs beyond purely fitting the observed sample. The higher Q^2 for Biodiversity Performance suggests that the combined predictors provide meaningful predictive capability for biodiversity outcomes, which strengthens the practical value of the model. Effect size analysis clarifies the substantive contribution of each predictor path. The ESG → TM path has $f^2 = 0.39$, which is interpreted as a large effect. This confirms that ESG adoption is a major driver of traceability and monitoring capability and that changes in ESG adoption are associated with sizable changes in monitoring capability. The TM → BIO path has $f^2 = 0.18$, interpreted as a medium effect, indicating that monitoring capability contributes meaningfully to biodiversity performance outcomes. The direct ESG → BIO path has $f^2 = 0.10$, interpreted as a small effect. This suggests that while ESG adoption directly improves biodiversity performance, the most influential mechanism in the model is the capability pathway operating through traceability and monitoring systems.

Together, the R^2, Q^2, and f^2 patterns provide a coherent story. ESG adoption strongly builds implementation capability, implementation capability meaningfully improves biodiversity outcomes, and ESG also exerts an additional direct influence on biodiversity performance through pathways beyond traceability and monitoring.

Table 6: Structural model quality indicators

Model explanatory power and predictive relevance

Endogenous construct	R^2	R^2 adjusted	Q^2 (predictive relevance)	Interpretation
Traceability & Monitoring (TM)	0.47	0.46	0.29	Moderate-to-substantial explained variance; predictive relevance supported
Biodiversity Performance (BIO)	0.54	0.53	0.33	Substantial explained variance; predictive relevance supported

Effect sizes (f^2)

Structural path	f^2 effect size	Interpretation
ESG → TM	0.39	Large effect
TM → BIO	0.18	Medium effect
ESG → BIO	0.10	Small effect

5. Conclusion

This study examined whether ESG adoption improves biodiversity performance in Brazilian agribusiness and whether Traceability and Monitoring capability explains this relationship. Using PLS-SEM results from data collected between May and September 2025 from 500 firms, ESG adoption showed a significant positive direct effect on biodiversity performance and a strong positive effect on traceability and monitoring capability. Traceability and monitoring also significantly improved biodiversity performance and partially mediated the ESG–biodiversity relationship, indicating that ESG delivers biodiversity benefits most effectively when supported by verifiable monitoring and traceability systems. the findings suggest that ESG commitments are more likely to translate into biodiversity conservation outcomes when firms invest in operational governance tools such as supplier mapping, monitoring routines, verification, and corrective action mechanisms. Future studies can strengthen evidence by using longitudinal designs and integrating objective biodiversity indicators such as satellite-based land-cover and habitat integrity measures.

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