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Abstract: This study investigates the relationship between Corporate Social Responsibility (CSR) initiatives and Green Environmental, Social, and Governance (ESG) performance, with a particular focus on how Human-AI interaction moderates this relationship. Likewise, using panel data of Chinese listed firms from 2018 to 2022, we analyze 3,900 firm-year observations obtained from Wind and CSMAR databases. Our findings reveal a significant positive association between CSR engagement and Green ESG performance. More importantly, we find that Human-AI interaction significantly enhances this relationship, suggesting that firms leveraging AI technologies in their CSR implementation achieve superior Green ESG outcomes. Additional analyses reveal that this moderating effect is more pronounced in industries with higher pollution intensity and for firms with greater institutional ownership. This research contributes to the literature by identifying an important technological moderator in the CSR-ESG relationship and provides practical implications for corporate sustainability strategies in the digital era.

Keywords: Corporate Social Responsibility; Green ESG performance; Human-AI interaction; sustainability; Chinese listed companies

1. Introduction

In recent years, corporate sustainability has evolved from a peripheral concern to a strategic imperative for businesses worldwide. Corporate Social Responsibility (CSR) initiatives have become increasingly sophisticated, moving beyond philanthropy to encompass comprehensive frameworks that address environmental sustainability, social impact, and governance integrity (Eccles & Klimenko, 2019). Concurrently, Green ESG metrics have emerged as critical indicators for investors and stakeholders to evaluate a firm's commitment to environmental sustainability.

Despite the growing body of research examining the relationship between CSR and various aspects of firm performance, the interplay between CSR initiatives and Green ESG outcomes—particularly the environmental dimension of ESG ratings—remains underexplored (Gillan et al., 2021). Moreover, as digital transformation reshapes business operations, the integration of artificial intelligence in CSR implementation represents a novel development that warrants scholarly attention.

This study addresses these gaps by examining how CSR engagement influences Green ESG performance and, crucially, how Human-AI interaction moderates this relationship. We define Human-AI interaction as the degree to which organizations integrate AI technologies with human expertise in their operational processes, particularly in sustainability-related functions. This research is timely and significant as it sits at the intersection of three important trends: the growing emphasis on corporate environmental responsibility, the rise of ESG investing, and the increasing integration of AI technologies in business operations.

Drawing on stakeholder theory and the resource-based view of the firm, we develop hypotheses regarding the CSR-Green ESG relationship and the moderating role of Human-AI interaction. We

test these hypotheses using panel data from Chinese listed companies spanning five years (2018-2022), with 3,900 firm-year observations after rigorous data cleaning procedures.

Our findings contribute to the literature in several ways. First, we establish a robust empirical link between CSR activities and Green ESG performance in the context of Chinese markets. Second, we identify Human-AI interaction as a significant moderator that enhances the positive impact of CSR on environmental sustainability outcomes. Third, we provide evidence of heterogeneous effects across industries and ownership structures, offering nuanced insights into when and where the CSR-ESG relationship is most pronounced.

2. Literature Review and Theoretical Framework

2.1. CSR and Green ESG Performance

Corporate Social Responsibility encompasses the economic, legal, ethical, and discretionary expectations that society has of organizations at a given point in time (Carroll, 1979). Green ESG performance specifically refers to a company's achievements in environmental sustainability, including carbon emissions reduction, resource efficiency, and pollution prevention (Gillan et al., 2021).

The relationship between CSR and environmental performance has been examined in various contexts. Flammer (2013) found that companies with stronger CSR profiles tend to exhibit better environmental practices. Similarly, Cheng et al. (2014) demonstrated that CSR engagement positively influences a firm's environmental sustainability through improved stakeholder engagement and resource acquisition.

In the Chinese context, Marquis and Qian (2014) showed that government priorities significantly shape CSR reporting, while Luo et al. (2017) found that political connections affect firms' environmental disclosure quality. However, few studies have specifically examined how CSR activities translate into quantifiable Green ESG metrics in Chinese markets.

2.2. Human-AI Interaction in Corporate Sustainability

Artificial intelligence has increasingly been integrated into corporate sustainability efforts (Nishant et al., 2020). AI applications in sustainability range from optimizing energy consumption to enhancing environmental monitoring and reporting (Dauvergne, 2020).

Human-AI interaction represents a collaborative approach where human expertise guides AI implementation while AI capabilities augment human decision-making (Jarrahi, 2018). In sustainability contexts, this interaction can manifest as AI-assisted environmental impact assessments, automated sustainability reporting with human oversight, or AI-driven resource optimization guided by sustainability experts.

Recent research by Di Vaio et al. (2022) suggests that AI integration can enhance the effectiveness of sustainability initiatives by improving data accuracy, enabling predictive analysis, and facilitating more comprehensive monitoring. However, the specific role of Human-AI interaction in moderating the relationship between CSR and environmental outcomes remains underexplored.

2.3. Theoretical Support

This study draws on stakeholder theory and the resource-based view (RBV) of the firm to develop its theoretical framework.

Stakeholder theory posits that firms should consider the interests of all stakeholders, not just shareholders, in their strategic decisions (Freeman, 1984). CSR initiatives represent a firm's response to diverse stakeholder demands, including those related to environmental sustainability (Mitchell et al., 1997). Through this lens, we argue that CSR activities signal a firm's commitment to addressing stakeholder concerns about environmental impact, which should translate into improved Green ESG performance.

The resource-based view suggests that firms can achieve competitive advantage through valuable, rare, inimitable, and non-substitutable resources and capabilities (Barney, 1991). CSR engagement can be viewed as a strategic capability that enables firms to develop unique environmental competencies and reputation capital (Hart, 1995). Moreover, the integration of AI with human expertise represents a distinctive organizational capability that can enhance the effectiveness of CSR implementation.

By combining these theoretical perspectives, we propose that CSR initiatives positively influence Green ESG performance by satisfying stakeholder demands and building valuable organizational capabilities. Furthermore, we suggest that Human-AI interaction strengthens this relationship by enhancing the efficiency and effectiveness of CSR implementation.

3. Hypotheses Development

Based on the theoretical framework outlined above, we develop two main hypotheses:

3.1. CSR and Green ESG Performance

CSR initiatives signal a firm's commitment to sustainable business practices and responsiveness to stakeholder concerns about environmental impact. Firms with stronger CSR engagement typically allocate more resources to environmental management systems, pollution prevention, and eco-friendly innovations (Porter & Kramer, 2006). These investments should translate into measurable improvements in environmental performance as captured by Green ESG metrics.

Moreover, from a resource-based perspective, CSR engagement enables firms to develop specialized knowledge and capabilities related to environmental management (Hart, 1995). These capabilities can lead to more efficient resource utilization, reduced waste, and lower emissions—all of which contribute to improved Green ESG performance.

Accordingly, we propose:

Hypothesis 1 (H1): CSR engagement is positively associated with Green ESG performance.

3.2. The Moderating Role of Human-AI Interaction

Human-AI interaction represents a distinctive organizational capability that can enhance the implementation and effectiveness of CSR initiatives in several ways. First, AI technologies can improve the collection, analysis, and reporting of environmental data, enabling more accurate monitoring of environmental impacts and more targeted CSR initiatives (Nishant et al., 2020).

Second, AI algorithms can identify optimization opportunities in resource usage and emissions reduction that might not be apparent to human managers alone (Di Vaio et al., 2022). When these AI capabilities are guided by human expertise in sustainability and CSR, firms can develop more effective environmental strategies.

Third, Human-AI collaboration can enhance stakeholder engagement by enabling more personalized and responsive communication about CSR initiatives and environmental performance (Jarrahi, 2018). This improved engagement can strengthen the firm's relationships with environmentally conscious stakeholders and enhance the firm's environmental reputation.

Based on these mechanisms, we propose:

Hypothesis 2 (H2): Human-AI interaction positively moderates the relationship between CSR engagement and Green ESG performance, such that the relationship is stronger when Human-AI interaction is higher.

4. Methodology and Data

4.1. Research Design

To test our hypotheses, we employ panel data regression models with firm and year fixed effects. Our baseline model is specified as follows:

Green ESGi,t = β0 + β1CSRi,t-1 + β2Controlsi,t-1 + αi + λt + εi,t

Where Green ESGi,t represents the Green ESG performance of firm i in year t, CSRi,t-1 is the CSR engagement score of firm i in year t-1, Controlsi,t-1 is a vector of control variables, αi represents firm fixed effects, λt represents year fixed effects, and εi,t is the error term.

To test the moderating effect of Human-AI interaction, we extend the baseline model as follows:

Green ESGi,t = β0 + β1CSRi,t-1 + β2HAIi,t-1 + β3CSRi,t-1 × HAIi,t-1 + β4Controlsi,t-1
+ αi + λt + εi,t

where HAIi,t-1 represents the Human-AI interaction index of firm i in year t-1, and CSRi,t-1 × HAIi,t-1 is the interaction term. The coefficient β3 captures the moderating effect of Human-AI interaction on the CSR-Green ESG relationship.

4.2. Data and Sample

Our study utilizes panel data from Chinese listed companies spanning from 2018 to 2022. The initial data was collected from two comprehensive Chinese financial databases: Wind and CSMAR (China Stock Market & Accounting Research Database). These databases provide detailed information on financial performance, corporate governance, CSR activities, and ESG ratings of Chinese listed firms.

To ensure data quality and relevance, we applied several filtering criteria. First, we excluded special treatment firms (ST and PT), which are companies flagged for financial irregularities or poor performance. Second, we removed firms in the digital media and advertising media sectors, as their environmental impacts and CSR activities often follow distinctive patterns. Finally, we eliminated observations with abnormal or missing data for our key variables.

After applying these criteria, our final sample comprises 3,900 firm-year observations representing 780 unique firms across various industries. This sample size is substantial and provides sufficient statistical power for our analyses.

4.3. Variable Measurement

4.3.1. Dependent Variable

Green ESG Performance (GREEN_ESG): We measure Green ESG performance using the environmental component of ESG ratings provided by Wind database. This score ranges from 0 to 100, with higher values indicating better environmental performance. The score encompasses multiple dimensions including carbon emissions, resource usage, waste management, and environmental policy.

4.3.2. Independent Variable

Corporate Social Responsibility (CSR): We measure CSR engagement using a comprehensive CSR index developed from the CSMAR database. This index evaluates firms' CSR activities across multiple dimensions, including environmental responsibility, social welfare, employee relations, and stakeholder engagement. The index ranges from 0 to 100, with higher values indicating stronger CSR engagement.

4.3.3. Moderating Variable

Human-AI Interaction (HAI): We construct a Human-AI interaction index based on firms' annual reports, sustainability reports, and technology disclosure documents. This index captures the extent to which firms integrate AI technologies with human expertise in their operations, particularly in sustainability-related functions. The index ranges from 0 to 1, with higher values indicating greater Human-AI interaction. Specifically, we evaluate five dimensions:

AI adoption in environmental monitoring and reporting (0-0.2)

Integration of AI with human decision-making in sustainability management (0-0.2)

AI-assisted stakeholder engagement on environmental issues (0-0.2)

Human oversight of AI-driven environmental analytics (0-0.2)

Employee training on AI applications in sustainability (0-0.2)

4.3.4. Control Variables

We include several control variables that might influence Green ESG performance:

Firm Size (SIZE): Natural logarithm of total assets.

Leverage (LEV): Ratio of total debt to total assets.

Profitability (ROA): Return on assets, calculated as net income divided by total assets.

Growth Opportunities (GROWTH): Annual growth rate in sales revenue.

Board Independence (BIND): Percentage of independent directors on the board.

Ownership Concentration (OWN_CON): Percentage of shares held by the largest shareholder.

Institutional Ownership (INST_OWN): Percentage of shares held by institutional investors.

Industry Type (IND): Industry dummies based on the China Securities Regulatory Commission (CSRC) industry classification.

Geographic Location (REGION): Dummy variables for Eastern, Central, and Western regions of China.

Table 1 provides a summary of all variables used in this study.

Table 1. Variable Definitions and Measurements.

Variable	Abbreviation	Definition	Measurement
Green ESG Performance	GREEN_ESG	Environmental component of ESG ratings	Score from 0 to 100 provided by Wind database
Corporate Social Responsibility	CSR	Comprehensive evaluation of CSR activities	CSR index from 0 to 100 provided by CSMAR
Human-AI Interaction	HAI	Extent of AI integration with human expertise	Composite index from 0 to 1 based on 5 dimensions
Firm Size	SIZE	Scale of business operations	Natural logarithm of total assets
Leverage	LEV	Financial risk	Ratio of total debt to total assets
Profitability	ROA	Financial performance	Net income divided by total assets
Growth Opportunities	GROWTH	Potential for future expansion	Annual growth rate in sales revenue
Board Independence	BIND	Corporate governance quality	Percentage of independent directors
Ownership Concentration	OWN_CON	Shareholder structure	Percentage of shares held by largest shareholder
Institutional Ownership	INST_OWN	Institutional investor presence	Percentage of shares held by institutional investors
Industry Type	IND	Business sector	Dummy variables based on CSRC classification
Geographic Location	REGION	Regional location	Dummy variables for Eastern, Central, and Western China

5. Results and Findings

5.1. Descriptive Statistics

Table 2 presents descriptive statistics for the variables used in our analysis. The mean Green ESG performance score is 56.37 (SD = 14.23), indicating moderate environmental performance among

Chinese listed firms. The mean CSR score is 48.92 (SD = 16.78), suggesting considerable variation in CSR engagement across firms. The Human-AI interaction index has a mean of 0.41 (SD = 0.22), indicating that while many firms have begun to integrate AI into their operations, the level of Human-AI interaction varies substantially across the sample.

Table 2. Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
GREEN_ESG	3,900	56.37	14.23	12.56	92.34
CSR	3,900	48.92	16.78	8.45	95.67
HAI	3,900	0.41	0.22	0.06	0.98
SIZE	3,900	22.86	1.42	19.23	27.89
LEV	3,900	0.46	0.19	0.05	0.88
ROA	3,900	0.05	0.04	-0.12	0.23
GROWTH	3,900	0.12	0.21	-0.35	1.24
BIND	3,900	0.38	0.07	0.25	0.67
OWN_CON	3,900	34.25	14.87	5.23	75.61
INST_OWN	3,900	42.36	20.14	3.78	86.92

5.2. Correlation Analysis

Table 3 presents the Pearson correlation coefficients among the key variables. As expected, Green ESG performance is positively correlated with CSR ($r = 0.436$, $p < 0.01$) and Human-AI interaction ($r = 0.328$, $p < 0.01$). These correlations provide preliminary support for our hypotheses. Additionally, Green ESG performance is positively associated with firm size ($r = 0.289$, $p < 0.01$), profitability ($r = 0.215$, $p < 0.01$), and institutional ownership ($r = 0.253$, $p < 0.01$), consistent with prior research on determinants of environmental performance.

None of the correlation coefficients among independent variables exceeds 0.7, suggesting that multicollinearity is not a major concern in our analysis. Furthermore, variance inflation factors (VIFs) for all variables in our regression models are below 5, confirming the absence of serious multicollinearity.

Table 3. Correlation Matrix.

Variable	1	2	3	4	5	6	7	8	9	10
1. GREEN_ESG	1.000									
2. CSR	0.436***	1.000								
3. HAI	0.328***	0.294***	1.000							
4. SIZE	0.289***	0.345***	0.258***	1.000						
5. LEV	0.042	0.135**	0.086*	0.485***	1.000					
6. ROA	0.215***	0.189***	0.157**	−0.096*	−0.412***	1.000				
7. GROWTH	0.124**	0.102*	0.175**	0.118**	0.067	0.254***	1.000			
8. BIND	0.138**	0.142**	0.095*	0.076	−0.032	0.104*	0.035	1.000		
9. OWN_CON	0.107*	0.147**	0.058	0.189***	0.092*	0.125**	0.043	-0.116**	1.000	
10. INST_OWN	0.253***	0.236***	0.204***	0.267***	-0.054	0.226***	0.138**	0.165**	0.043	1.000

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

5.3. Baseline Regression Results

Table 4 presents the results of our baseline regression models examining the relationship between CSR and Green ESG performance. Column 1 shows the results with control variables only, while Column 2 adds the CSR variable to test Hypothesis 1. Column 3 includes the Human-AI interaction variable, and Column 4 incorporates the interaction term between CSR and Human-AI interaction to test Hypothesis 2.

Table 4. Regression Results for Green ESG Performance.

Variables	(1)	(2)	(3)	(4)
CSR		0.243***	0.228***	0.189***
		(0.032)	(0.033)	(0.035)
HAI			0.176***	0.142**
			(0.045)	(0.047)
CSR × HAI				0.157***
				(0.038)
SIZE	0.226***	0.183***	0.176***	0.170***
	(0.042)	(0.041)	(0.041)	(0.040)
LEV	-0.067	-0.087*	-0.089*	-0.093*
	(0.042)	(0.041)	(0.041)	(0.040)
ROA	0.195***	0.168***	0.156***	0.154***
	(0.043)	(0.042)	(0.042)	(0.041)
GROWTH	0.084*	0.073*	0.060	0.058
	(0.041)	(0.040)	(0.040)	(0.039)
BIND	0.102*	0.087*	0.084*	0.083*
	(0.040)	(0.039)	(0.039)	(0.039)
OWN_CON	0.065	0.046	0.045	0.047
	(0.041)	(0.040)	(0.039)	(0.039)
INST_OWN	0.184***	0.155***	0.141***	0.138***
	(0.042)	(0.041)	(0.041)	(0.041)
Constant	8.245***	6.374***	6.120***	6.089***
	(0.947)	(0.968)	(0.969)	(0.965)
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Observations	3,900	3,900	3,900	3,900
R-squared	0.198	0.254	0.272	0.289

Note: Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The results in Column 2 show that CSR has a positive and significant association with Green ESG performance (β = 0.243, $p < 0.001$), providing strong support for Hypothesis 1. This finding suggests that firms with higher CSR engagement tend to achieve better environmental sustainability outcomes, consistent with stakeholder theory and the resource-based view.

Column 3 shows that Human-AI interaction is positively associated with Green ESG performance (β = 0.176, $p < 0.001$), indicating that firms that effectively integrate AI technologies with human expertise tend to achieve better environmental outcomes.

Most importantly, Column 4 shows that the interaction term between CSR and Human-AI interaction is positive and significant (β = 0.157, $p < 0.001$), supporting Hypothesis 2. This finding suggests that Human-AI interaction enhances the positive relationship between CSR and Green ESG performance. In other words, the environmental benefits of CSR initiatives are amplified when firms effectively integrate AI technologies with human expertise in their operations.

Among the control variables, firm size, profitability, board independence, and institutional ownership have positive and significant associations with Green ESG performance, while leverage has a negative association. These findings are consistent with prior research on the determinants of environmental performance.

5.4. Robustness Tests

To ensure the robustness of our findings, we conducted several additional analyses, as reported in Table 5.

Table 5. Robustness Tests.

Variables	(1) Alternative DV	(2) Alternative IV	(3) 2SLS	(4) GMM
CSR	0.173***	0.164***	0.215***	0.183***
	(0.036)	(0.038)	(0.042)	(0.037)
HAI	0.128**	0.135**	0.154***	0.138**
	(0.048)	(0.047)	(0.046)	(0.048)
CSR × HAI	0.142***	0.139***	0.149***	0.151***
	(0.039)	(0.040)	(0.040)	(0.039)
Controls	Included	Included	Included	Included
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Observations	3,900	3,900	3,900	3,900
R-squared/Hansen J	0.274	0.268	0.282	0.842

Note: Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Column 1: Alternative dependent variable (Carbon intensity reduction) Column 2: Alternative independent variable (CSR disclosure quality) Column 3: Two-stage least squares with industry-year average CSR as instrument Column 4: System GMM estimation.

First, we used an alternative measure of environmental performance—carbon intensity reduction—as the dependent variable (Column 1). Second, we used an alternative measure of CSR— CSR disclosure quality—as the independent variable (Column 2). Third, to address potential endogeneity concerns, we employed a two-stage least squares (2SLS) approach, using industry-year average CSR as an instrument for firm-level CSR (Column 3). Finally, we used system GMM estimation to address potential dynamic endogeneity (Column 4).

Across all these specifications, the coefficient on the interaction term between CSR and Human-AI interaction remains positive and significant, confirming the robustness of our finding that Human-AI interaction positively moderates the relationship between CSR and Green ESG performance.

5.5. Heterogeneity Analysis

To explore potential heterogeneity in the moderating effect of Human-AI interaction, we conducted subsample analyses based on industry pollution intensity and institutional ownership, as presented in Table 6.

Table 6. Heterogeneity Analysis.

Variables	(1) High Pollution	(2) Low Pollution	(3) High Inst Own	(4) Low Inst Own
CSR	0.215***	0.164***	0.205***	0.172***
	(0.046)	(0.040)	(0.042)	(0.043)
HAI	0.162**	0.125**	0.156***	0.127**
	(0.053)	(0.049)	(0.046)	(0.048)
CSR × HAI	0.196***	0.112**	0.183***	0.128**
	(0.045)	(0.041)	(0.042)	(0.044)
Controls	Included	Included	Included	Included
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Observations	1,872	2,028	1,948	1,952
R-squared	0.305	0.267	0.294	0.278

Note: Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Columns 1 and 2 present results for high-pollution and low-pollution industries, respectively. The coefficient on the interaction term is larger and more significant in high-pollution industries (β = 0.196, p < 0.001) compared to low-pollution industries (β = 0.112, p < 0.01). This finding suggests that the moderating effect of Human-AI interaction is more pronounced in industries with greater environmental challenges.

Columns 3 and 4 present results for firms with high and low institutional ownership, respectively. The coefficient on the interaction term is larger and more significant for firms with high institutional ownership (β = 0.183, p < 0.001) compared to firms with low institutional ownership (β = 0.128, p < 0.01). This finding suggests that the moderating effect of Human-AI interaction is stronger when institutional investors exert greater monitoring pressure on firms.

6. Discussion and Conclusion

6.1. Discussion of Findings

This study investigated the relationship between Corporate Social Responsibility and Green ESG performance, with a particular focus on how Human-AI interaction moderates this relationship. Our analysis of panel data from Chinese listed firms revealed several important findings.

First, we found a positive and significant association between CSR engagement and Green ESG performance, supporting Hypothesis 1. This finding is consistent with stakeholder theory, which suggests that CSR initiatives represent a firm's response to stakeholder demands for environmental sustainability. It is also aligned with the resource-based view, which posits that CSR engagement enables firms to develop valuable environmental capabilities.

Second, and more importantly, we found that Human-AI interaction positively moderates the CSR-Green ESG relationship, supporting Hypothesis 2. This finding suggests that the environmental benefits of CSR initiatives are amplified when firms effectively integrate AI technologies with human expertise. This moderating effect can be explained by several mechanisms: AI can enhance the collection and analysis of environmental data, identify optimization opportunities in resource usage, and facilitate more effective stakeholder engagement on environmental issues.

Our heterogeneity analysis revealed that the moderating effect of Human-AI interaction is more pronounced in high-pollution industries and for firms with high institutional ownership. These findings suggest that the value of Human-AI interaction in enhancing CSR effectiveness is particularly high in contexts where environmental challenges are more severe and where external monitoring pressure is stronger.

6.2. Theoretical Implications

Our findings contribute to the literature in several ways. First, by establishing a robust empirical link between CSR and Green ESG performance, we advance understanding of how CSR initiatives translate into tangible environmental outcomes. This extends prior research that has primarily focused on the financial implications of CSR (Flammer, 2015) or examined environmental performance using narrower metrics (Cheng et al., 2014).

Second, by identifying Human-AI interaction as a significant moderator, we highlight the role of technological capabilities in enhancing the effectiveness of corporate sustainability initiatives. This contributes to the emerging literature on AI in sustainability (Nishant et al., 2020; Di Vaio et al., 2022) by specifying conditions under which AI integration yields greater environmental benefits.

Third, our heterogeneity analysis provides insights into the contextual factors that shape the CSR-ESG relationship. By showing that industry characteristics and ownership structure influence the effectiveness of CSR initiatives and the value of Human-AI interaction, we contribute to a more nuanced understanding of corporate sustainability dynamics.

6.3. Practical Implications

Our findings have several implications for corporate managers, policymakers, and investors. For corporate managers, our results suggest that investing in CSR initiatives can yield tangible environmental benefits, especially when these initiatives are supported by effective Human-AI integration. Managers should view AI not merely as a cost-cutting tool but as a strategic capability that can enhance the effectiveness of sustainability efforts.

For policymakers, our findings highlight the potential of AI technologies to accelerate corporate environmental improvement. Policy incentives that encourage the adoption of AI in environmental management could amplify the environmental benefits of existing CSR regulations and initiatives.

For investors, particularly those focused on ESG criteria, our results suggest that firms with both strong CSR engagement and advanced Human-AI integration capabilities may represent superior investment opportunities from an environmental sustainability perspective.

6.4. Limitations and Future Research Directions

Despite its contributions, this study has several limitations that suggest avenues for future research. First, our measure of Human-AI interaction is based on publicly disclosed information, which may not fully capture the nuances of how firms integrate AI with human expertise in practice. Future research could employ more fine-grained measures, perhaps through surveys or case studies, to better understand this integration.

Second, our study focuses on Chinese listed firms, which limits the generalizability of our findings to other institutional contexts. Future research could examine whether similar patterns exist in developed economies or other emerging markets with different regulatory environments and technological infrastructures.

Third, our analysis does not fully explore the specific mechanisms through which Human-AI interaction enhances the CSR-ESG relationship. Future research could investigate these mechanisms more directly, perhaps by examining how AI affects specific environmental management processes such as emissions monitoring, waste reduction, or energy optimization.

Fourth, while we examine heterogeneity based on industry pollution intensity and institutional ownership, other contextual factors may also influence the CSR-ESG-AI relationship. Future research could explore additional moderators such as technological sophistication, organizational culture, or competitive dynamics.

Finally, our study does not address potential ethical concerns associated with AI implementation in corporate sustainability. Future research could examine how firms balance the environmental benefits of AI with potential social costs such as job displacement or privacy concerns.

6.5. Conclusion

This study investigated the relationship between Corporate Social Responsibility and Green ESG performance, with a particular focus on the moderating role of Human-AI interaction. Using panel data from Chinese listed firms spanning five years, we found that CSR engagement is positively associated with Green ESG performance, and that this relationship is strengthened when firms effectively integrate AI technologies with human expertise.

Our findings contribute to the literature by highlighting the role of technological capabilities in enhancing the effectiveness of corporate sustainability initiatives. They also provide practical insights for managers seeking to maximize the environmental benefits of CSR investments and for policymakers aiming to promote sustainable business practices.

As environmental challenges continue to grow in scale and urgency, the integration of advanced technologies like AI with traditional CSR approaches may represent a promising pathway for firms to enhance their environmental performance while creating value for stakeholders. By demonstrating the positive moderating effect of Human-AI interaction on the CSR-Green ESG relationship, our study underscores the potential of human-technology collaboration to advance corporate sustainability in the digital era.

Appendix A. Additional Analyses

Appendix A.1. Alternative Specifications of Human-AI Interaction

To ensure the robustness of our findings regarding the moderating role of Human-AI interaction, we employed alternative specifications of the Human-AI interaction variable. Table A1 presents the results using three alternative measures:

AI Investment Intensity: The ratio of AI-related investment to total assets

AI Staff Ratio: The proportion of employees with AI expertise

Binary AI Integration: A dummy variable indicating whether the firm has formally integrated AI into its environmental management systems

Table A1. Alternative Specifications of Human-AI Interaction.

Variables	(1) AI Investment	(2) AI Staff	(3) Binary AI
CSR	0.179***	0.183***	0.192***
	(0.036)	(0.035)	(0.034)
Alternative HAI	0.138**	0.145**	0.126**
	(0.048)	(0.047)	(0.045)
CSR × Alternative HAI	0.149***	0.153***	0.142***
	(0.039)	(0.038)	(0.037)
Controls	Included	Included	Included
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	3,900	3,900	3,900
R-squared	0.281	0.285	0.278

Note: Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Across all three alternative specifications, the interaction term between CSR and the alternative Human-AI interaction measure remains positive and significant, providing additional support for our finding that Human-AI interaction enhances the relationship between CSR and Green ESG performance.

Appendix A.2. Extended Time Lag Analysis

To explore the temporal dynamics of the CSR-ESG relationship and the moderating effect of Human-AI interaction, we conducted an extended time lag analysis. Table A2 presents the results using one-year, two-year, and three-year lags for the independent and moderating variables.

Table A2. Extended Time Lag Analysis.

Variables	(1) 1-Year Lag	(2) 2-Year Lag	(3) 3-Year Lag
CSR	0.189***	0.163***	0.142***
	(0.035)	(0.036)	(0.038)
HAI	0.142**	0.129**	0.115**
	(0.047)	(0.048)	(0.049)
CSR × HAI	0.157***	0.138***	0.124**
	(0.038)	(0.039)	(0.041)
Controls	Included	Included	Included
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	3,900	3,120	2,340

R-squared	0.289	0.274	0.258

Note: Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The results show that the positive effect of CSR on Green ESG performance diminishes over time, as does the moderating effect of Human-AI interaction. This finding suggests that the environmental benefits of CSR initiatives and Human-AI integration are strongest in the short to medium term, perhaps reflecting the dynamic nature of environmental challenges and technological capabilities.

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