



## Green Technology Innovation and Financial Performance: Roles of Executive Green Perception and Carbon Performance

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### Abstract

Existing research on the linkage mechanisms among green technology innovation (GTI), executive green perception (EGP), carbon performance (CP), and financial performance (FP), particularly systematic investigations within the context of China's high-carbon industries, remains insufficient. To address this gap, this study explored the pathway through which GTI influences FP, as well as the mediating effect of EGP and the moderating effect of CP. Grounded in stakeholder theory and innovation diffusion theory, an integrated analytical framework was developed and tested using panel data from listed companies in China's coal, energy, and manufacturing sectors spanning 2015 to 2023 (N = 11,302). The analysis employed a two-way fixed effects model. The results revealed that GTI significantly and positively impacts FP ( $\beta = 0.199, p < 0.01$ ), with EGP serving a partial mediating role in this relationship. Furthermore, CP positively moderates the connection between GTI and FP ( $\beta = 0.096, p < 0.01$ ). The key innovation of this research is its unique simultaneous examination of both mediating and moderating mechanisms within a single model. The approach provides a deeper theoretical explanation and practical managerial insights for utilizing green innovation to enhance financial outcomes in high-carbon transitional settings.

### Keywords:

Green Technology Innovation;  
Financial Performance;  
Executive Green Perception;  
Carbon Performance; China.

### Article History:

Received:	07	December	2025
Revised:	23	February	2026
Accepted:	06	March	2026
Published:	01	April	2026

## 1- Introduction

Technological revolutions have led to an environmental crisis that many are describing as marked by "high resource consumption and high carbon emissions," which places global corporate development in a time of long-term challenges stemming from climate change, resource issues, and environmental pollution [1-3]. In this context, green technology innovation has emerged as one of the key routes organizations can take to achieve sustainability goals while at the same time remaining competitive economically [4-6]. However, as environmental pressures intensify and stakeholder expectations evolve, organizations face increasingly urgent strategic decisions regarding investment in green technology innovation. Such investments are no longer solely about meeting regulatory requirements, as they also relate to securing a social license to operate, achieving a competitive advantage, and ensuring long-term organizational viability. It, then, raises a critical and ongoing debate: Does green technology innovation genuinely enhance financial performance, or

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DOI: <https://doi.org/10.28991/ESJ-2026-010-02-022>

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might it instead reduce profitability? This question is especially significant for managers who must justify substantial investments in green initiatives to shareholders primarily focused on financial returns.

The findings in the green technology innovation to financial performance relationship studies are mixed. Research suggests in some studies that green technology innovation lessened costs related to environmental issues, created new market opportunities, and competitive advantage that improved financial performance [3, 7-10]; nevertheless, other research has threshold effects that trigger a positive impact on financial performance once investment exceeds that threshold level [11, 12], whereas other research provides U-shaped and/or negative [13-16]. All the empirical findings essentially lead to a key question: under what conditions and through which mechanisms does green technology innovation enhance financial performance? The mixed findings in the existing literature suggest that this relationship is neither uniform nor straightforward but instead contingent on multiple factors. Variations may arise across industries due to differences in technological intensity, institutional environments, firm-specific characteristics, and entrepreneurial behavior. The implementation, integration, and management of green innovations within organizations may also influence financial outcomes. Moreover, the benefits of such innovations may emerge only under certain temporal or strategic conditions, shaping when and how financial returns are realized. Given the limited empirical evidence in this area, and assuming the validity of theoretical arguments supporting a generally positive relationship, further investigation into these contextual domains and related scenarios is both necessary and timely.

We suggest understanding these mixed findings may lie in two contingencies. First, it may be that executives play an important role in the transmission mechanism of these results. As strategic decision officers, the environmental awareness of executives and their conscious prioritization of sustainability issues have a bearing on how effectively green technology investment is adopted and utilized in business strategies [17, 18]. Investment in green innovation among firms stimulates executive attention to environmental issues [19, 20]. In turn, this executive attention influences how resources are allocated and the extent to which green initiatives are incorporated into firm-level core strategies [21]. Executives with additionally stronger green perception, for instance, can more successfully convert green technologies to market advantages, cost efficiencies, and brand value [22]. It is thus possible that executive green perception helps identify why green innovation is successful in some firms and not in other firms. Two distinct pathways may explain how the mediating mechanism operates. One pathway suggests that executives with stronger green perceptions are more inclined to adopt environmentally oriented strategies that enhance corporate reputation and brand value, thereby attracting sustainability-conscious investors and customers [23]. Another pathway indicates that heightened environmental perception strengthens corporate social responsibility activities and overall ESG performance. Improved ESG performance can, in turn, expand access to financing, reduce capital costs, and enhance talent attraction, ultimately contributing to superior operational performance [7, 23-25].

Second, a firm's carbon management capabilities may influence its ability to financially benefit from adopting green innovation. Companies with strong carbon performance, for instance, typically have well-developed environmental management systems, established stakeholder trust, and recognized green credentials [26, 27]. These capabilities enable firms to transform green innovations into tangible returns, such as reduced operational expenses, improved reputation, increased investor confidence, and greater market acceptance [27]. On the other hand, companies that demonstrate poor carbon performance may be skeptical of green innovations at all, or possibly as "greenwashing," thus eliminating the thoughts of financial benefits from green innovation [28]. Evidence in the energy sector suggests that when firms have strong carbon performance, the positive link between green innovation and financial performance is significantly enhanced [28]. Thus, carbon performance is a boundary condition that delineates when and for which firms' green technology innovation furthers a firm's financial outcome. For China, the world's largest manufacturing economy and carbon emitter, green technology innovation has become a highly salient issue. More than half of the energy consumed in China can be attributed to the manufacturing sector [29], which has had significant economic impacts related to resource depletion and pollution [30]. Thus, in recent years, the Chinese government has set ambitious "dual carbon" goals (e.g., reach carbon peak by 2030 and carbon neutrality by 2060), indicating that green transformation is both necessary and allowed to happen, particularly for industries that are high in carbon, such as manufacturing, coal, and energy [31]. However, the pathway of how green technology innovation leads to financial performance in China's unique setting (i.e., state-owned structures, government-led environmental policies, and fast-changing markets) remains largely unknown [32].

Despite growing scholarly interest in these relationships, several critical research gaps remain. Much of the existing literature focuses on the direct effects of green innovation on firm performance [7-10], but the underlying mechanisms through which this relationship unfolds remain insufficiently examined. Although some studies acknowledge the role of managerial cognition [22, 33], systematic analysis of executive environmental perception as a mediating mechanism is still limited. In addition, the boundary conditions under which green technology innovation translates into financial benefits are not well understood. Prior findings are inconsistent, ranging from positive linear relationships [7-9] to threshold effects [11] and U-shaped patterns [13, 14], indicating that important contextual contingencies may have been overlooked. Furthermore, although China is the world's largest carbon emitter and has introduced ambitious "dual carbon" targets [31], empirical research integrating executive cognition with carbon management capabilities in high-

carbon industries remains scarce. Recent studies accentuate the complexity of the environmental performance–financial performance nexus [24, 25], yet relatively few investigations have examined how these mechanisms operate within regulatory-intensive and state-influenced contexts, where pressures for green transformation are particularly pronounced.

This study, thus, addresses these gaps by developing an integrated framework that jointly examines the mediating and moderating mechanisms linking green technology innovation to financial performance. Using extensive panel data from China's coal, energy, and manufacturing sectors, which together account for more than 50% of national energy consumption [29], the study provides systematic evidence on how, when, and why green technology innovation generates financial value in high-carbon transitional contexts. The current study, therefore, has the potential to enhance understanding of the relationship between green technology innovation and firm performance in several significant ways. It offers novel empirical evidence from China's high-carbon industries, an inadequately examined yet essential context. Prior research reports mixed findings on the financial outcomes of green innovation, and this study examines how and to what extent green technology innovation influences firm performance under conditions of intensive carbon pressure. The study also contributes to theory through clarification of the mechanisms linking green technology innovation to performance. Rather than offering descriptive explanations alone, it examines how executive green perception shapes firms' strategic use of green technology innovation as a mediating process. The analysis further identifies carbon performance as a key moderating factor, showing that the financial returns from green technology innovation depend on firm-level carbon outcomes and contextual conditions. Integration of mediating and moderating mechanisms within a unified analytical framework generates practical insights for non-state managers seeking to maximize returns on green innovation investments, as well as for government agencies aiming to accelerate green transformation in energy-intensive industries.

## 2- Underpinning Theories and Hypothesis Development

### 2-1- Theoretical Framework

This study draws on Stakeholder Theory and Innovation Diffusion Theory to explain the interrelationships among green technology innovation, executive green perception, carbon performance, and firm financial performance. Stakeholder Theory helps explain the link between green technology innovation and corporate outcomes, as interactions with key stakeholders motivate firms to allocate resources toward green technology research and development [34]. Executive green perception captures the extent to which executives are attuned to the environmental demands of stakeholders. The stronger the executive green perception, the more likely they are to incorporate stakeholder views into strategic decision-making [35]. It identifies executive green perception as a mediating mechanism that links stakeholder pressures with green innovation investments, shaping strategic actions and enhancing financial outcomes. In a similar way, carbon performance can influence evaluations from key stakeholders such as government regulators, investors, or the general public [36]. Superior carbon performance generates evidence for stakeholders that a firm's green innovation initiatives in the environment are "authentic" and "effective" [37]. The literature on carbon performance also suggests that firms with superior carbon performance are positioned to translate green innovation investments into financial returns, suggesting a moderating effect.

Innovation Diffusion Theory [38] complements Stakeholder Theory by clarifying how innovations are adopted and implemented within organizations. Strategic decision-makers, in the forms of executives, will influence whether innovations in green technology are effectively adopted given executive understanding of the environment and understanding the prioritization of the environment by the organization [39]. The mediating role of executive green perception becomes evident, as executives with a stronger understanding of environmental issues are more likely to act as champions of green innovation and translate their intentions into effective implementation. Relative to Innovation Diffusion Theory, observability of innovation can enhance legitimacy and acceptance of the innovation in question. Once organizations demonstrate strong carbon performance based on publicly reported carbon performance, stakeholders are more likely to consider these green innovations as credible actions, thus increasing the positive impact of these innovations on financial performance [40, 41]. Thus, carbon performance acts as a visible signal to proactively build trust between a stakeholder and an organization, strengthening the relationship between green technology innovation and financial performance.

The two theories form a coherent theoretical framework that supports the modeling of the interrelationships examined in this study. Stakeholder theory explains why firms pursue green innovation as well as the reasons why executive perception and carbon performance are important in these pursuits. Innovation Diffusion Theory explains how innovations are adopted (through executive championing of innovations) or when innovations were most efficacious (to the extent that innovations are visible to stakeholders in terms of their carbon performance). The theoretical frameworks are integrated with the proposed analytical model, in which green technology innovation enhances financial performance through the mediating role of executive green perception, and carbon performance serves as a signaling condition that strengthens the credibility and effectiveness of innovation outcomes reflected in financial performance.

## ***2-2-Green Technology Innovation on Financial Performance***

Environmental issues on a global scale have garnered attention from both academics and widespread consideration amongst businesses and policymakers [42]. Study of the relationship between green technology innovation and financial performance may provide some reasonable recommendations to business managers when engaging in sustainable development [43]. More entrepreneurs are beginning to understand the necessity of having environmental issues at the forefront of grand conception of the business. As a result of this, business managers are becoming more concerned with financial performance along with contributions to their business profit and society and the environment [44].

Despite the increasing interest of research and academia, the relationships between performance capitalism, for example, financial performance, and green technology innovation continues to yield conflicting empirical studies. In the bulk of studies, researchers find a positive linear relationship [8, 9, 45]. Greater investment in green innovation is often associated with improved financial performance, but some studies identify a more complex U-shaped relationship. In other words, the financial impact of corporate green technology innovation will not always be a linear relationship [13, 14, 46-48]. These findings suggest that investments into green innovation may lead to marginal benefit, little benefit, or even negative benefit for financial performance before significant benefits accrue. Other research studies have found that of innovation investment on financial performance follows a threshold effect indicating financial performance only becomes positive, once innovation investment yields a certain critical threshold level [11]. Other research presents other contradictory findings identifying either a negative relationship [15], or inverted U-shaped relationship [13, 14] between green technology innovation and financial performance where too much green innovation does not yield profitability in the enterprise.

Stakeholder theory explains how firms differ in their use of green technology innovation to respond to stakeholder demands and advance social responsibility initiatives [49]. Such a perspective helps explain why some firms are better able than others to generate financial returns from investments in green technology [50].

Within the dynamic context of China's high-carbon industries, where regulatory requirements and environmental pressures are high, we expect a positive influence of green technology innovation on financial performance. In this case, we would expect green technology innovation to benefit financial performance through reducing compliance costs, building corporate reputation and creating competitive advantages. Therefore, our hypothesis is:

***H1:*** Green technology innovation positively affects financial performance.

## ***2-3-Mediating Role of Executive Green Perception***

The differing evidence concerning the relationship between green innovation and financial performance suggests that this association takes place through a number of mediating variables rather than relationships based on direct effects [51, 52]. We contend that executive green perception has a strong mediating role in regard to effects on financial performance from green technology innovation. Executive green perception is conceptually distinct from ESG in several important respects. ESG orientation reflects organization-level commitments that are manifested in formal policies and reporting frameworks [7, 49], whereas executive green perception captures the cognitive awareness and environmental beliefs formed by individual executives prior to strategic decision-making. Similarly, environmental strategy refers to deliberate and formalized action plans implemented at the organizational level [30], while executive green perception represents the antecedent perceptions and attentional focus that precede strategy formulation.

Drawing on innovation diffusion theory [38], individual perception represents a critical initial stage in determining whether innovation is translated into organizational strategy. The text-based measurement approach captures executives' expressed environmental awareness through narrative disclosures in annual reports, reflecting genuine cognitive attention and priority setting rather than symbolic reporting or strategic positioning.

As the primary decision-makers of enterprises, executives inherently take responsibility for both the extent to which green technology investments generate financial performance and the way in which that financial performance is generated. The decision for investment in green technology innovation will spur, at the parent-level, an increase in executive attention to environmental factors and a parent-level commitment to sustainability at the organizational/enterprise level context [38, 53, 54]. The increase in built factors will specifically influence resource allocation choices, market orientation activities, and risk options related to the effective implementation of a green strategy [54, 55]. Executives with higher environmental perceptions are more prepared to develop a network of green technology capabilities, in terms of garnering market space, cost savings, and brand value as an outcome of their unique green technology success [56]. Executives with higher environmental perceptions will also facilitate the balancing act between sustainability, represented by long-term goals and objectives, and short-term profitability, which will in turn contribute to overall improved corporate performance [57, 58].

Overall, there is empirical evidence that supports this mediation process. Chen & Chang [22] showed that executive green perception mediated green innovation and organizational performance relationship. Yabing et al. [33] and Meiting

et al. [59] found executive green perception influences economic performance and environmental performance through resource allocation decisions. Wang et al. [60] verified the mediating role of executive green perception in the green innovation and environmental regulation relationship in the service sector. These studies imply that green technology innovation is insufficient alone as a factor for financial performance as it is contingent on whether executives have acknowledged its strategic importance and have embedded it into their organizational practice.

Overall, our theorizing suggests that executive green perceptions may explain some of the reasons why some firms are able to successfully transform investments in green technology into financial returns while others do not. Green technology innovation raises executive cognizance of opportunities and risks associated with the environment and will influence strategic decision making and resource allocation that produces ultimately positive financial performance. Therefore:

**H2:** Executive green perception mediates the relationship between green technology innovation and financial performance.

#### ***2-4- Moderating Role of Carbon Performance***

Aside from executive green perception as a mediating mechanism, it is plausible that the financial performance, resulting from the implementation of green technology innovation, can also be dependent on a firm's carbon management capabilities. We argue that carbon performance exerts a boundary condition to identify when and which firms will translate green technology innovation into financial performance benefits.

More precisely, carbon performance—measured through emissions management and carbon effectiveness—reflects an organization's readiness and capability to generate financial returns from green innovation [61]. Firms with high carbon performance have established strong environmental management capabilities, as well as developed stakeholder trust and credible green credentials [62, 63]. As a result, they are better positioned to translate green technologies into financial returns through multiple channels. First, high carbon performance enables cost reductions through energy savings and lower compliance risks [64, 65]. Second, it signals authenticity to stakeholders, as investments in green technologies reduce skepticism related to greenwashing [66]. Third, strong carbon performance enhances corporate reputation and strengthens investor confidence, which typically leads to valuation premiums [67].

The logic of moderation is supported. Evidence in the OECD suggests that green technology innovation lowers emissions to a greater degree with more economic returns when firms can capitalize on existing environmental management competencies [68, 69]. Research in the energy industry suggests that the relationship between technology innovation and financial performance is enhanced where carbon performance is high relative to firms with lower carbon performance [27, 28]. Barbaglia et al. [70] produced evidence of indications that carbon management moderated the connection between carbon risk and corporate performance- this is further confirming that carbon capabilities are significant strategic resource to enhance value from the team's environmental investments.

The moderating mechanism happens through stakeholder perceptions of credibility. That is, firms with high carbon performance, when they invest and commit to green technology innovation, are likely to have their stakeholders perceive that the innovation is a real investment, not simply symbolic positioning. Further, this credibility leads to heightened acceptance from stakeholders, bolstering investor support and increasing customer loyalty, which serves to optimize financial return from the green innovation. In contrast, firms with low carbon performance may not fully realize benefits from the investment in green technologies because stakeholders would likely be skeptical of their commitment to the environment.

Therefore, the carbon performance should enhance the relational positive impact of green technology innovation on financial performance; thus, we predict that carbon performance would moderate the positive return from green technology innovation. Therefore:

**H3:** Carbon performance positively moderates the relationship between green technology innovation and financial performance.

### **3- Material and Methods**

#### ***3-1-Sample and Data Sources***

To ensure the industry-specificity of the research, this study examines listed companies from China's coal, energy, and manufacturing sectors during 2015-2023, based on the National Bureau of Statistics' industry classification (GB/T 4754-2017). After excluding delisted firms, ST firms, and observations with missing data, the final sample comprises 11,302 firm-year observations from 3,718 companies.

### 3-2- Variable Measurement

Consistent with previous studies, we measured the key variables as follows. Financial performance (FP) was measured as Return on Assets (ROA), or operating income divided by total assets [47]. Green technology innovation (GTI) was measured as the natural logarithm of green patent applications plus one [71-73]. The logarithmic transformation addressed the right-skewed nature of the patent counts as well as the presence of zero values.

Executive green perception (EGP) was measured as a text analysis of the firm's annual report, the natural logarithm of keyword frequency for 19 environment-related keywords [17]. Several factors support the validity of our EGP measurement approach in addressing concerns regarding symbolic reporting. First, prior studies demonstrate that text analysis of environmental keywords in the Management Discussion and Analysis (MD&A) section can effectively capture managers' genuine attentional focus [17]. Executives' perception frames and attention allocation shape how issues are interpreted and prioritized, thereby influencing whether they are subsequently translated into formal strategies. Recurrent and salient environmental expressions in managerial narratives therefore reflect underlying cognitive attention rather than merely ex post strategic outcomes.

Second, EGP is measured using narrative sections that require direct executive involvement, rather than standardized and formulaic CSR disclosures. Third, the significant association between EGP and subsequent GTI investment ( $\beta = 0.101$ ,  $p < 0.01$  in Model 3) provides evidence of convergent validity, as purely symbolic disclosures lacking substantive commitment would be unlikely to predict actual innovation investment. Similarly, the robustness of the empirical results across alternative model specifications further alleviates concerns regarding symbolic reporting. Finally, within China's regulatory environment, false or misleading environmental claims are subject to penalties under the Environmental Protection Law of the People's Republic of China, which weakens firms' incentives to engage in purely symbolic environmental disclosure.

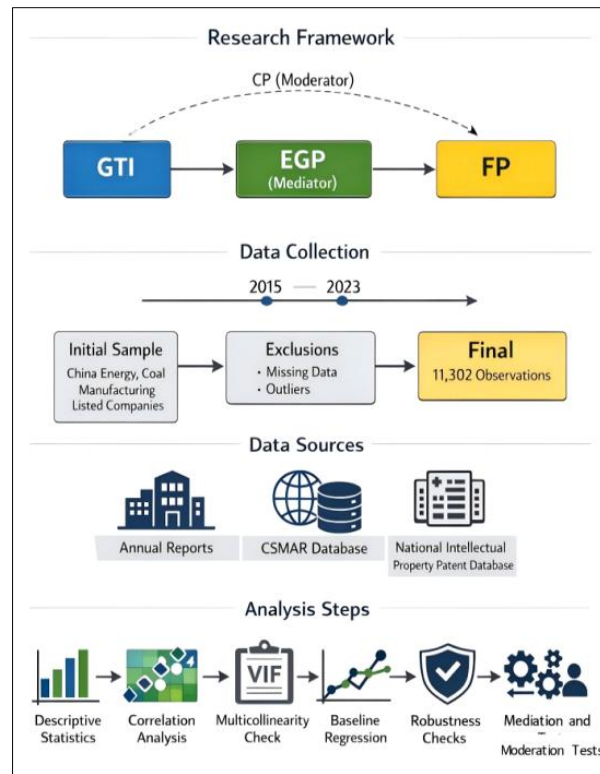
Carbon performance (CP) was operationalized as the reciprocal of carbon emissions per million yuan of sales (sales/carbon emissions). The higher the value, the better the carbon performance [74-77]. Based on both theoretical and practical considerations, the reciprocal of carbon emissions per million yuan of sales is adopted as the measure of carbon performance. The intensity-based indicator captures carbon efficiency in a manner consistent with the value-creation logic emphasized in stakeholder theory [34]. Unlike absolute emission measures, an intensity-based metric accounts for firm-size heterogeneity and allows meaningful comparisons across firms of different scales within the sample [74-77]. Compared with alternative denominators such as total assets, a sales-based measure more directly reflects firms' carbon management capability, as sales revenue represents productive output. The indicator has also been validated in prior research examining the relationship between carbon performance and firm performance in the context of global warming and climate change [26-28, 75-77].

We included several control variables to account for other firm characteristics associated with financial performance: total asset turnover rate, fixed asset growth rate, CEO duality, ownership concentration (the largest shareholder's shareholding ratio), current asset ratio, total asset growth rate, and firm age, which we measured in years since listing [17, 78-83]. Year and industry dummy variables are included to account for time and industry fixed effects. Table 1 presents variable definitions and measurement formulas.

**Table 1. Variables and Method of measurement**

	Variable	Notations	Method of measurement
Dependent Variable	Finance performance	FP	Return on Assets (ROA).
Independent Variable	Green technology Innovation	GTI	$\ln(\text{green patent applications} + 1)^*$
Mediating Variable	Executive green perception	EGP	The natural logarithm of the frequency of keywords
Moderating Variable	Carbon performance	CP	The reciprocal of carbon emissions per million yuan of sales (Sales / Carbon Emission).
Control Variables	Total asset turnover rate	TAT	$\text{Operating income} / ((\text{Total assets at end of period} + \text{Total assets at beginning of period}) / 2)$ .
	Fixed asset growth rate	Fix	$(\text{Net fixed assets at end of period} - \text{Net fixed assets at beginning of period}) / \text{Net fixed assets at beginning of period} \times 100\%$ .
	CEO duality	Dual	1 if the chairman is also the CEO, 0 otherwise.
	First major shareholder's shareholding ratio	Top1	Shareholding ratio of the largest shareholder.
	Current asset ratio	Cr	Current assets / Total assets.
	Total asset growth rate	Tagr	$(\text{Total assets at end of period} - \text{Total assets at beginning of period}) / \text{Total assets at beginning of period} \times 100\%$ .
	Listing year	Inage	$\ln(\text{Current year} - \text{Year of listing})$ .
	Year	Year	Year dummy variable
	Industry	Ind	Industry dummy variables

\* Note:  $\ln$  indicates the natural logarithm.



**Figure 1. Research methodology flowchart**

Figure 1 illustrates the sequential research process, beginning with the theoretical integration of Stakeholder and Diffusion theories, moving through the rigorous exclusion of outliers from the 11,302 observations, and concluding with the multi-stage mediation and moderation testing.

### 3-3-Model

We employ ordinary least squares (OLS) regression with time and industry two-way fixed effects to test our hypotheses. The analysis includes descriptive statistics, correlation analysis, and multicollinearity diagnostics (VIF tests).

#### Model 1: Direct Effect (H1)

To test H1 regarding the direct relationship between green technology innovation and financial performance:

$$ROA_{i,t} = \beta_0 + \beta_1 * GTI_{i,t} + \beta_2 * Cr_{i,t} + \beta_3 * TAT_{i,t} + \beta_4 * Fix_{i,t} + \beta_5 * Inage_{i,t} + \beta_6 * Tagr_{i,t} + \beta_7 * Top1_{i,t} + \beta_8 * Dual_{i,t} + \sum Year + \sum IND \quad (1)$$

where,  $ROA_{i,t}$  is the dependent variable (financial performance),  $GTI_{i,t}$  is the independent variables (green technology innovation), and  $Cr_{i,t}$ ,  $TAT_{i,t}$ ,  $Fix_{i,t}$ ,  $Inage_{i,t}$ ,  $Tagr_{i,t}$ ,  $Top1_{i,t}$ ,  $Dual_{i,t}$  are the control variables. The subscript  $i$  represents firms,  $t$  represents years,  $\sum Year$  represents year fixed effects, and  $\sum IND$  represents industry fixed effects. In the model,  $\beta_0$  denotes the intercept, and  $\beta_1$  through  $\beta_n$  represent the regression coefficients associated with the explanatory variables.

#### Models 2-4: Mediation Effect (H2)

To test H2 regarding the mediating role of executive green perception, we follow the stepwise approach of Wen & Ye [84]:

$$ROA_{i,t} = \beta_0 + \beta_1 * EGP_{i,t} + \beta_2 * Cr_{i,t} + \beta_3 * TAT_{i,t} + \beta_4 * Fix_{i,t} + \beta_5 * Inage_{i,t} + \beta_6 * Tagr_{i,t} + \beta_7 * Top1_{i,t} + \beta_8 * Dual_{i,t} + \sum Year + \sum IND \quad (2)$$

$$EGP_{i,t} = \beta_0 + \beta_1 * GTI_{i,t} + \beta_2 * Cr_{i,t} + \beta_3 * TAT_{i,t} + \beta_4 * Fix_{i,t} + \beta_5 * Inage_{i,t} + \beta_6 * Tagr_{i,t} + \beta_7 * Top1_{i,t} + \beta_8 * Dual_{i,t} + \sum Year + \sum IND \quad (3)$$

$$ROA_{i,t} = \beta_0 + \beta_1 * GTI_{i,t} + \beta_2 * EGP_{i,t} + \beta_3 * Cr_{i,t} + \beta_4 * TAT_{i,t} + \beta_5 * Fix_{i,t} + \beta_6 * Inage_{i,t} + \beta_7 * Tagr_{i,t} + \beta_8 * Top1_{i,t} + \beta_9 * Dual_{i,t} + \sum Year + \sum IND \quad (4)$$

where,  $EGP_{i,t}$  is the mediator variable. In the model,  $\beta_0$  denotes the intercept, and  $\beta_1$  through  $\beta_n$  represent the regression coefficients associated with the explanatory variables.

Model (2) examines the effect of the mediator (EGP) on the dependent variable (ROA). Model (3) tests the effect of the independent variable (GTI) on the mediator (EGP). Model (4) includes both GTI and EGP to assess partial or full mediation.

### Model 5: Moderation Effect (H3)

To test H3 regarding the moderating role of carbon performance, we include an interaction term between GTI and CP:

$$ROA_{i,t} = \beta_0 + \beta_1 * GTI_{i,t} + \beta_2 * CP_{i,t} + \beta_3 * CP_{i,t} * GTI_{i,t} + \beta_4 * Cr_{i,t} + \beta_5 * TAT_{i,t} + \beta_6 * Fix_{i,t} + \beta_7 * Inage_{i,t} + \beta_8 * Tagr_{i,t} + \beta_9 * Top1_{i,t} + \beta_{10} * Dual_{i,t} + \sum Year + \sum IND \quad (5)$$

where,  $CP_{i,t}$  is Moderator variable, The  $CP_{i,t} * GTI_{i,t}$  is the interaction term. The coefficient  $\beta_3$  captures the moderating effect of carbon performance on the relationship between green technology innovation and financial performance.

Even though two-way fixed effects account for time-invariant firm heterogeneity and common temporal shocks, potential endogeneity concerns remain, particularly the possibility of reverse causality in which stronger financial performance enables greater investment in green technology innovation. Several considerations help mitigate this concern in the present context. Green technology innovation typically involves substantial lead times associated with research and development activities as well as patent approval processes, which creates temporal separation between innovation efforts and subsequent financial outcomes. The sample also concentrates on high-carbon industries subject to stringent regulatory pressures [31], where green innovation is largely driven by compliance requirements rather than discretionary investments funded by prior profitability. In addition, prior studies conducted in comparable settings suggest that the dominant causal direction runs from green technology innovation to financial performance rather than the reverse [7-9]. Nevertheless, the cross-sectional time-series design does not fully eliminate endogeneity concerns, and any causal interpretations should therefore be made with appropriate caution.

## 4- Results and Discussion

### 4-1- Descriptive Statistics

Table 2 presents the descriptive statistics for the variables. The mean ROA is 3.4429 with a standard deviation of 5.9279, showing significant profitability differences among companies. The minimum value is -20.3135, indicating losses, while the maximum is 18.8943, representing high-profit firms. The mean GTI is 1.2221 with a standard deviation of 1.35 and a range of 0-7.3045, with a right-skewed distribution, indicating most companies have low GTI. The average CP is 0.7688, but a maximum of 36.6064 suggests some companies have outstanding carbon performance. The average EGP is 1.3088 with a standard deviation of 0.9162, indicating little variation in EGP across firms.

**Table 2. Descriptive Analysis**

Variable	Obs	Mean	Std. dev.	Min	Max
ROA	11,302	3.4429	5.9279	-20.3135	18.8943
GTI	11,302	1.2221	1.3500	0.0000	7.3045
CP	11,302	0.7688	1.0611	0.0000	36.6064
EGP	11,302	1.3088	0.9162	0.0000	5.4116
Cr	11,302	0.5338	0.1741	0.1173	0.8751
TAT	11,302	0.6050	0.3372	0.1130	2.1082
Fix	11,302	0.1293	0.3349	-0.3622	2.0184
Inage	11,302	2.4640	0.6190	0.6931	3.4012
Tagr	11,302	0.1212	0.2212	-0.2660	1.2176
Top1	11,302	32.3478	14.2252	8.2600	70.3300
Dual	11,302	0.2683	0.4431	0.0000	1.0000

### 4-2- Correlation Analysis

Table 3 shows the Pearson correlation results. GTI is positively correlated with ROA at a 5% significance level, correlation coefficient 0.021, suggesting that improving GTI may enhance FP, supporting Hypothesis 1. Additionally, EGP is positively correlated with ROA at the 1% level, correlation coefficient 0.028. Interestingly, CP initially shows a negative correlation with FP, with a coefficient of -0.044 at the 1% significance level. These findings align with prior research on environmental investments in capital-intensive industries [42, 43], where upfront costs precede long-term benefits. Carbon performance investments function more as strategic positioning, yielding returns through multiple channels: future energy savings, reduced compliance costs from avoiding increasingly stringent environmental regulations and carbon taxes, enhanced brand reputation, and strengthened customer loyalty. Realizing these benefits requires an extended time horizon. This mismatch in “time windows” is a significant reason for the observed negative correlation, which will be further discussed in Section 5.

**Table 3. Correlation Analysis**

	ROA	GTI	CP	EGP	Cr	TAT	Fix	lnage	Tagr	Top1	Dual
ROA	1										
GTI	0.021**	1									
CP	-0.044***	-0.01	1								
EGP	0.028***	0.164***	0.066***	1							
Cr	0.103***	-0.014	0.037***	-0.221***	1						
TAT	0.166***	0.056***	-0.003	0.086***	0.204***	1					
Fix	0.122***	0.025***	-0.003	-0.031***	-0.038***	-0.065***	1				
lnage	-0.068***	0.175***	0.175***	0.201***	-0.138***	0.126***	-0.185***	1			
Tagr	0.305***	0.037***	-0.087***	-0.062***	0.074***	-0.060***	0.397***	-0.244***	1		
Top1	0.145***	0.060***	-0.066***	0.055***	-0.036***	0.085***	0.001	-0.044***	-0.005	1	
Dual	0.001	-0.033***	0.009	-0.093***	0.056***	-0.046***	0.059***	-0.195***	0.068***	-0.058***	1

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

\*, \*\*, and \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

To avoid multicollinearity issues in analyzing the relationship between GTI, EGP, CP, and FP, a VIF test was conducted. The mean VIF value of 1.12 is well below the critical value of 5, indicating no multicollinearity problem.

#### 4-3- Benchmark Regression

The results of the benchmark regression, which tests H1, are reported in Table 4. The results show that green technology innovation (GTI) has a statistically significant and positive impact on financial performance (ROA), with a coefficient of 0.199 ( $p < 0.01$ ), supporting stakeholder value creation [34, 35] and corroborating previous studies showing a positive impact [7-9]. Thus, a one-unit increase in GTI is associated with a 0.199 percentage point increase in ROA after controlling firm characteristics including asset turnover, fixed asset growth, ownership structure, and age of firm. indicating that firms with higher levels of green technology innovation exhibit superior financial performance.

From a practical perspective, the finding indicates that investments in green technologies, including cleaner production processes, energy-saving technologies, and low-carbon innovations, can be translated into tangible financial returns. For managers, GTI should be regarded as a value-enhancing strategic investment rather than merely a compliance or environmental responsibility initiative. The magnitude of the effect ( $\beta = 0.199$ ) implies that a one-unit increase in the logarithm of green patent applications corresponds to approximately a 0.2 percentage point improvement in ROA. Given the sample mean ROA of 3.44%, this represents a meaningful economic impact. Moreover, comparing effect sizes across control variables reveals that GTI's contribution to financial performance is comparable to established drivers such as asset turnover and ownership concentration, emphasizing green innovation's strategic importance as a performance determinant in high-carbon industries. Overall, the results offer strong support for H1, indicating that green technology innovation positively influences financial performance in China's high-carbon sectors. These findings establish a foundation for subsequent analysis and hypothesis development.

**Table 4. Analysis of Benchmark Regression Results**

	(Model 1) ROA
GTI	0.199*** (4.748)
Cr	4.215*** (11.522)
TAT	3.903*** (22.346)
Fix	0.384** (2.344)
lnage	-0.439*** (-4.545)
Tagr	7.796*** (30.639)
Top1	0.050*** (13.331)
Dual	0.004 (0.033)
_cons	-2.955*** (-8.618)
N	11297.000
r2	0.215
F	302.725

*t* statistics in parentheses;

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

#### 4-4- Robustness Checks

To verify the robustness of our main results, this research includes three different tests of robustness. We first replace the independent variable (GTI) with the natural log of total number of green invention patent applications as an alternative measure of green technology innovation [83]. Next, we replace the dependent variable (ROA) with the market-to-book ratio to provide a market-based measure of financial performance [85]. Finally, we re-estimate our benchmark regression with industry-clustered standard errors to account for the possibility of correlation within industries [86].

The results from our robust tests are presented in Table 5. In our first specification with the alternative measure of GTI, we obtain a coefficient of 0.225 ( $p < 0.01$ ). In the second specification with the market-to-book ratio as the dependent variable, we obtain a coefficient of 0.041 ( $p < 0.01$ ). In the third specification with the industry-clustered standard errors, we obtain a coefficient of 0.199 ( $p < 0.01$ ). In all three specifications, we find a statistically significant positive effect of GTI on financial performance at the 1% level. The consistent positive and statistically significant effects across all three specifications and estimation methods provides support for the robustness of our main finding that green technology innovation positively impacts financial performance and for H1. Given the capital-intensive nature of high-carbon industries where asset bases significantly influence profitability metrics, we verify our findings using the market-to-book ratio as an alternative performance measure. Column 2 of Table 5 demonstrates that GTI maintains a significant positive effect ( $\beta = 0.041$ ,  $p < 0.01$ ) on this market-based indicator. The consistent positive relationship across both accounting-based (ROA) and market-based (MBratio) measures confirms that green innovation enhances multiple dimensions of financial performance. The market-to-book ratio captures investors' forward-looking expectations of future cash flows, suggesting that capital markets recognize and value green innovation efforts beyond current accounting returns. Market validation is particularly important in high-carbon industries undergoing green transformation, where stakeholders increasingly scrutinize environmental commitments.

Further comparison of effect sizes across different model specifications indicates that the economic contribution of GTI is comparable to, and in some cases exceeds, that of several conventional firm-level determinants. This highlights the relative importance of green innovation as a key performance driver in high-carbon industries.

The robust test results strengthen confidence in the causal relevance of GTI and suggest that its financial benefits are persistent rather than confined to specific model settings.

**Table 5. Results of Regression Analysis for Robustness Test**

	(1) ROA	(2) MBratio	(3) ROA
GTI	0.225*** (4.789)	-	-
Cr	4.170*** (11.413)	-0.211*** (-14.689)	4.215*** (3.895)
TAT	3.912*** (22.413)	0.001 (0.157)	3.903*** (5.653)
Fix	0.383** (2.335)	-0.013** (-1.968)	0.384*** (3.029)
lnage	-0.436*** (-4.523)	0.051*** (13.377)	-0.439* (-1.867)
Tagr	7.815*** (30.747)	-0.040*** (-4.033)	7.796*** (14.695)
Top1	0.050*** (13.313)	0.000*** (3.016)	0.050*** (6.703)
Dual	-0.001 (-0.009)	-0.018*** (-3.867)	0.004 (0.018)
GTI	-	0.041*** (24.898)	0.199*** (2.833)
_cons	-2.886*** (-8.413)	0.546*** (40.587)	-2.955*** (-2.880)
N	11297.000	11297.000	11297.000
r2	0.215	0.404	0.215
F	302.784	170.396	83.047

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

#### 4-5-Heterogeneity Analysis

To determine whether the impact of green technology innovation on financial performance differs across contexts, we examine heterogeneity based on industry characteristics. Table 6 shows results across industries with varying technological intensity and pollution levels. We find substantial heterogeneity in the GTI-performance relationship, with green technology innovation showing the greatest positive effect in the most polluting industries ( $\beta = 0.359$ ,  $p < 0.01$ ), in non-high-tech firms ( $\beta = 0.278$ ,  $p < 0.01$ ), in high-tech firms ( $\beta = 0.197$ ,  $p < 0.01$ ), and in the least polluting industries ( $\beta = 0.146$ ,  $p < 0.01$ ). A comparison of effect sizes across models indicates that the economic contribution of GTI is substantially stronger in pollution-intensive industries. Notably, the effect of GTI on ROA in heavy-polluting firms is more than twice that observed in non-heavy-polluting firms, suggesting that the financial returns to green technology innovation are highly context-dependent and amplified under stricter environmental constraints.

From a practical standpoint, these coefficients imply that, holding other factors constant, a one-unit increase in GTI generates a significantly larger improvement in return on assets for firms operating in pollution-intensive sectors. This pattern suggests that green technology innovation enables heavy-polluting firms to realize tangible economic benefits through emission reductions, enhanced resource efficiency, and lower regulatory compliance costs.

For non-high-tech firms, the relatively larger GTI coefficient ( $\beta = 0.278$ ) indicates that green innovation may serve as a strategic substitute for technological disadvantages by improving production efficiency, strengthening regulatory legitimacy, and facilitating access to policy support. In contrast, although high-tech firms also benefit from green innovation ( $\beta = 0.197$ ), their marginal financial gains are comparatively smaller, possibly because these firms already operate closer to the technological frontier and exhibit higher baseline innovation efficiency.

Overall, the heterogeneity analysis demonstrates that green technology innovation generates disproportionately higher financial returns in industries subject to stricter environmental regulation and greater pollution pressures. The results stress the strategic role of green technology innovation as a mechanism for enhancing firm performance, particularly among firms in high-pollution sectors undergoing green transformation.

**Table 6. Heterogeneity Analysis by Industry Characteristics**

	High tech level enterprises	Non-high-tech enterprises	Heavy polluting enterprises	Non heavy polluting enterprises
	ROA	ROA	ROA	ROA
GTI	0.197*** (4.173)	0.278*** (2.959)	0.359*** (4.639)	0.146*** (2.936)
Cr	4.808*** (11.324)	3.109*** (4.246)	1.029 (1.589)	5.572*** (12.473)
TAT	3.530*** (17.527)	5.131*** (14.614)	2.614*** (9.631)	4.898*** (21.702)
Fix	0.462** (2.514)	0.219 (0.600)	-0.086 (-0.292)	0.555*** (2.838)
lnage	-0.621*** (-5.532)	0.206 (1.070)	0.001 (0.004)	-0.693*** (-5.995)
Tagr	7.802*** (27.389)	7.585*** (13.287)	9.580*** (19.564)	7.164*** (24.117)
Top1	0.047*** (10.507)	0.061*** (8.246)	0.024*** (3.635)	0.059*** (12.748)
Dual	0.004 (0.032)	0.096 (0.379)	0.065 (0.294)	0.050 (0.372)
_cons	-2.784*** (-7.141)	-4.431*** (-6.060)	-0.970 (-1.502)	-3.983*** (-9.859)
N	8391.000	2897.000	3580.000	7709.000
r2	0.220	0.219	0.185	0.248
F	232.279	76.441	78.793	242.693

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

The above research results indicate that the value-creation effect of green technology innovation is not uniform across firms but is contingent on industry characteristics and regulatory environments. Building on this contextual evidence, the following section further examines the internal mechanisms and boundary conditions, specifically executive green perception and carbon performance, that shape how green innovation is translated into financial outcomes.

#### *4-6-Mediating Effect of Executive Green Perception and Moderating Effect of Carbon Performance*

Table 7 presents the mediation and moderation analysis results corresponding to Models 2-5 specified in Section 3.3. The concluding analyses explored mediation (models 2-4, H2) and moderation (model 5, H3). Using Wen & Ye's [84] stepwise method, we examined executive green perception's mediating role. The model 2 results indicated executive green perception significantly and positively predicted ROA ( $\beta = 0.234$ ,  $p < 0.01$ ). The effect is larger than the direct impact of GTI in Model 4 (0.179). The result suggests that leaders' psychological commitment and strategic awareness may exert a stronger influence on ROA than technology alone. Furthermore, model 3 results revealed that green technology innovation has a significant, positive effect on executive green perception ( $\beta = 0.101$ ,  $p < 0.01$ ), further demonstrating that green technology innovation fosters executive environmental awareness. As firms engage in green R&D, the leadership team becomes more environmentally literate, which in turn helps them manage resources more efficiently. Model 4 tested, simultaneously, green technology innovation and executive green perception, which continued to have a positive and significant relationship with ROA ( $\beta = 0.179$  and  $\beta = 0.194$ ,  $p < 0.01$ ). The direct effect of green technology innovation on ROA dropped from 0.199 in model 1 to 0.179 in model 4, yet remains significant in model 4, suggesting partial mediation and indicating that executive green perception is an important mechanism that connects green technology innovation to financial performance, thus supporting H2. The results indicate that for green technology innovation to maximize ROA, it must influence the executive suite's mindset. When leaders perceive "green" as a core value, they are more likely to align marketing, operations, and supply chains with that innovation, leading to better financial performance.

Overall green technology innovation does not automatically translate into profit through technology alone. Instead, a significant portion of the value is unlocked through the stockholders and Innovations Diffusion Theory, where the technology reshapes executive green perceptions, leading to more effective environmental strategy execution, which subsequently enhances financial performance.

The moderation analysis is found in model 5 (H3), which included carbon performance as the moderating variable and tested the interaction effect, using  $GTI \times CP$ . The results showed the interaction term has a positive and significant coefficient ( $\beta = 0.096$ ,  $p < 0.01$ ), indicating carbon performance moderates the positive relationship between green technology innovation and financial performance. Firms with high carbon performance potentially gain an additional 0.096-unit increase in ROA for each unit of GTI. The results indicate that carbon performance provides another platform for firms to leverage prior investments in green innovation by optimizing the direct translation of investment into return for green innovation.

The direct effect of carbon performance on ROA is negative ( $\beta = -0.157$ ,  $p < 0.10$ ), suggesting potential upfront costs for advisor-related carbon management. In business terms, this represents the "compliance burden." Improving carbon performance, such as installing scrubbers or hiring carbon auditors, is an expensive upfront investment that initially drags down ROA. Nonetheless, the interaction effect suggests that the enhanced pay-off of green technology innovation is compounded with carbon performance, thus supporting H3.

These results reveal a synergistic relationship between operational environmental outcomes and technological innovation. While improving carbon performance imposes upfront costs that initially drag down ROA ( $\beta = -0.157$ ,  $p < 0.10$ ), representing investments in emission control equipment, energy management systems, and carbon monitoring infrastructure, the positive interaction term ( $\beta = 0.096$ ,  $p < 0.01$ ) demonstrates that these investments create a "complementary asset" structure. Firms with superior carbon management systems possess the organizational infrastructure, technical expertise, and stakeholder credibility to more efficiently leverage new green technologies, thereby amplifying the financial returns from innovative investments.

The economic interpretation is informative. Firms with high carbon performance achieve an additional 0.096-unit increase in ROA for each unit increase in green technology innovation, beyond the baseline direct effect. Carbon performance therefore does not generate value independently and may initially suppress profitability due to associated compliance and management costs. Instead, carbon performance functions as a value-enhancing condition that amplifies the financial returns of green innovation. The pattern reconciles the seemingly divergent direct and interaction effects, indicating that carbon management is costly in the short term yet strategically necessary, as it creates the conditions under which green technology innovation can be effectively translated into financial gains.

From a managerial perspective, this suggests firms should view carbon performance improvements and green technology investments as integrated strategic initiatives rather than independent activities. The synergy between these two dimensions means that firms investing in green innovation without corresponding carbon management capabilities may fail to realize full financial benefits, while firms improving carbon performance without concurrent innovation investments bear costs without commensurate returns.

**Table 7. The Mediating Role of EGP and the Moderating Role of CP**

	(Model 2)	(Model 3)	(Model 4)	(Model 5)
	ROA	EGP	ROA	ROA
EGP	0.234*** (3.761)	-	0.194*** (3.084)	-
Cr	4.227*** (11.529)	-0.448*** (-8.176)	4.302*** (11.730)	4.225*** (11.549)
TAT	3.937*** (22.577)	0.071*** (2.725)	3.889*** (22.268)	3.893*** (22.290)
Fix	0.401** (2.447)	-0.001 (-0.023)	0.385** (2.345)	0.382** (2.327)
lnage	-0.388*** (-4.063)	0.078*** (5.375)	-0.454*** (-4.697)	-0.438*** (-4.540)
Tagr	7.872*** (31.007)	0.015 (0.401)	7.793*** (30.639)	7.795*** (30.634)
Top1	0.052*** (13.662)	0.002*** (2.903)	0.050*** (13.247)	0.050*** (13.338)
Dual	0.020 (0.171)	-0.074*** (-4.260)	0.018 (0.157)	0.002 (0.020)
GTI	-	0.101*** (16.136)	0.179*** (4.232)	0.127** (2.524)
CP	-	-	-	-0.157* (-1.713)
GTI*CP	-	-	-	0.096*** (2.612)
_cons	-3.221*** (-9.193)	1.155*** (22.480)	-3.179*** (-9.074)	-2.835*** (-8.105)
N	11297.000	11297.000	11297.000	11297.000
r2	0.215	0.263	0.216	0.216
F	301.451	59.582	270.349	242.984

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

#### 4-7-Discussion

The research demonstrates a significant positive impact of green technology innovation on financial performance ( $\beta = 0.199$ ,  $p < 0.01$ ). Regardless of the alternative models employed, our findings consistently support the positive impact of green technology innovation, aligning with the results of prior studies [8, 9, 45]. The study finds evidence of the positive financial effect operating via multi-path mechanisms compatible with stakeholder theory [34, 35]. Environmental regulations compel energy-intensive industries to adopt green technologies, while government subsidies allow firms implementing innovative technologies to reduce their innovation costs [87-89]. Government support is only one aspect of market-level mechanisms; this framework also encompasses the green premiums generated by pro-environmental consumer behavior [48] and collaborations with supply chain partners that lower compliance costs. Green technology innovation enables firms to offer differentiated products, thereby capturing greater market share and enhancing pricing power. More importantly, by leveraging innovation to meet or exceed environmental regulatory requirements in advance, firms can avoid substantial carbon taxes, environmental fines, and the risks of legal litigation.

Conversely, other studies have identified the presence of threshold effects [11] or an inverted U-shaped relationship [13, 14]. Given the heterogeneity of research contexts, the impact of green technology innovation on industry remains inconclusive when considering initial investment costs; at this stage, such technologies may even constitute a structural barrier [11]. However, as green technologies mature, firms can naturally achieve economies of scale, enhance operational efficiency, and ultimately reduce costs [38]. Regarding the inverted U-shaped relationship, the logic posits that during the nascent stages of innovation, firms can easily capture "low-hanging fruit" by optimizing processes and improving resource utilization [14]. In this phase, the economic returns from innovation significantly outweigh R&D expenditure, leading to an upward trend in financial performance. Nevertheless, as the intensity of green innovation deepens, firms transition into the development of cutting-edge technologies characterized by prolonged cycles and high uncertainty. The substantial capital commitment required creates a formidable "crowding-out effect," diverting funds originally intended for core business expansion. Consequently, this leads to a decline in marginal returns, resulting in an overall inverted U-shaped trajectory between green technology innovation and financial performance.

Furthermore, the heterogeneity analysis shows GTI influences improvements to financial performance strongest in heavily polluting industries ( $\beta = 0.359$ ,  $p < 0.01$ ) with the highest pressures towards improving green technology innovation due to direct environmental regulations as evidence that aspects of industry contextualization and research contribute to our study [30, 90].

Beyond the direct impact of Green Technology Innovation (GTI) on financial performance, Executive Green Perception (EGP) emerges as a pivotal mediating mechanism, aligning with findings from prior research [22, 33, 59, 60]. In contrast to previous studies, this research offers a novel theoretical perspective by drawing upon Innovation Diffusion Theory [34, 38]. It provides fresh insights and empirical evidence suggesting that specific groups or individuals make adoption decisions based on their cognitive structures regarding innovation. EGP operates through pro-environmental business strategies, which, analogous to social signaling mechanisms, enhance corporate reputation [58], while the EGP reduces the cost of capital required to achieve financial performance gains [7, 23].

Furthermore, our results are consistent with Stakeholder Theory [35, 49]. By elucidating this mechanism within a high-carbon context and quantifying the mediation proportion, these findings extend the scope of earlier research [22, 33, 59]. Critically, our study indicates that green technology innovation alone is insufficient; executives must recognize its strategic significance and actively advocate for its implementation. Our interpretation also reconciles previous contradictory findings [14, 45], where the sequential relationship between green innovation and performance effects appeared inconsistent, a discrepancy that may be attributed to varying levels of executive environmental awareness.

Carbon performance is important for moderating the boundary condition of the GTI-performance link ( $\beta = 0.096$ ,  $p < 0.01$ ) and offers support for the extension of previous studies on synergies [27, 28]. This study extends prior research by shifting the focus from symbolic to substantive environmental outcomes. Earlier scholarships posited that firms with superior environmental performance command higher levels of institutional legitimacy; within this framework, a robust environmental reputation (e.g., high ESG ratings) serves as a signal to attract investors, thereby enhancing financial performance through the reduction of financing costs. In contrast, the present study utilizes carbon performance as a direct output metric. This approach quantifies a firm's functional capability to translate technological inputs into tangible emission reduction outcomes, rather than merely relying on external perceptions of environmental stewardship. A position consistent with stakeholder theory [35, 37], along with the diffusion theory construct "observability" [38, 40, 41]. Strong carbon performance, for example, indicates authenticity [38, 91, 92], provides cost-efficiencies [27, 68-70] and positively influences investor confidence [41, 93]. The negative direct effect of carbon performance ( $\beta = -0.157$ ,  $p < 0.10$ ) reflects, on the surface, the costs associated with upfront high carbon industry costs [29, 44], particularly when customers do not possess preferences toward green. Although companies may incur upfront costs associated with carbon performance, the positive moderation of carbon performance indicates the potential benefits an extended green management strategy may have toward green innovation in the long-term to produce environmental responsibility that is competition advantageous [27, 41]. The results of this article help to clarify the earlier summarization of findings: carbon management supply costs upfront but provide value creation long-term through green innovation.

In total, our findings help illustrate how financial performance can be appropriately optimized through accommodating technological investment, strategic commitments, leadership, and carbon management. Our framework expands stakeholder theory [34, 35] and the Innovation Diffusion Theory [38], to show how these three areas create interdependent systems that provide a virtuous cycle—GTI creates a demonstrated result, and develops executive cognitive capacities of strategic commitment, which generates financial performance through cost efficiency and positioning in the market sector. A strong carbon performance that is mutable becomes additive [68, 69, 91-94] and reductive of the financial risk [26, 27], while poor carbon performance negates overall green innovation through undermining the linkage to stakeholder trust. In doing this, as noted previously, our conceptual lens demonstrates that the seemingly contradictions identified [13-15, 46-48] are illuminated. Studies that show weak or negative relationships of green innovation performance presumably involved companies where executive cognitions were poor regarding stakeholder connectivity, or their frameworks were lost due to carbon performance signaling. Our framework shows how green innovation has financial outputs based both on internal (executive cognition) and external (carbon performance) indicators, and demonstrates heterogeneity in studies and builds theory, by representing the conditions in which, and the way, green innovation creates value.

Our findings from China's high-carbon industries may differ in other contexts in several important ways. Regarding industry context, high-carbon industries face substantially stronger regulatory pressures and stakeholder scrutiny [20, 21, 31], amplifying both the costs and financial benefits of green innovation. In low-carbon industries where environmental compliance costs are lower and baseline emissions are minimal, the direct effect of GTI on financial performance might be weaker but potentially more linear, lacking the upfront cost barriers observed in capital-intensive sectors. The moderating effect of carbon performance would likely be less pronounced in industries where carbon management is peripheral rather than central to stakeholder evaluation and regulatory compliance. Regarding institutional context, China's unique characteristics shape our findings in specific ways. The strong government environmental mandates and 'dual carbon' policy framework [31] create powerful institutional pressures that drive green innovation adoption regardless of immediate profitability concerns. China's high prevalence of state ownership (as shown in our heterogeneity analysis, Table 6) means many firms face softer budget constraints and can absorb upfront carbon management costs more readily than purely market-driven enterprises. In Western market economies with stronger consumer environmental consciousness, the mediating role of executive green perception might be less critical as market mechanisms directly reward green innovation. On the contrary, in contexts with weaker environmental regulations, the financial benefits of green innovation might materialize more slowly and depend more heavily on voluntary market differentiation strategies.

## 5- Conclusions

Integrating Stakeholder Theory and Innovation Diffusion Theory, this research investigates the mechanism through which Green Technology Innovation (GTI) influences financial performance. Specifically, the study examines the mediating role of Executive Green Perception (EGP) and the moderating influence of Carbon Performance (CP). Leveraging an extensive panel dataset comprising 11,302 firm-year observations of Chinese listed companies in the coal, energy, and manufacturing sectors from 2015 to 2023, we employ a two-way fixed-effects model to control for industry-specific and time-variant factors. The empirical results demonstrate that GTI exerts a significant positive effect on financial performance ( $\beta = 0.199$ ,  $p < 0.01$ ), suggesting that sustainable research and development creates tangible economic value even in heavy-polluting industries. Furthermore, the results reveal that EGP acts as a partial mediator ( $\beta = 0.179$ ,  $p < 0.01$ ), indicating that GTI reshapes the cognitive structures of the upper echelon, which subsequently optimizes strategic resource allocation. Furthermore, CP serves as a positive moderator ( $\beta = 0.096$ ,  $p < 0.01$ ), implying that superior carbon management acts as a "multiplier" that amplifies the returns on green investment. Synthetically, these findings suggest that the successful translation of green innovation into financial performance is not automatic; it necessitates a holistic approach that integrates technological investment, strategic leadership focus, and robust carbon management. This study reconciles prior contradictory findings by demonstrating that executive advocacy and operational carbon efficiency are essential boundary conditions. For policymakers and managers in high-carbon sectors, these results underscore the importance of shifting from symbolic environmental compliance to substantive technological and cognitive transformation to achieve sustainable competitive advantage.

This study provides a nuanced explanation for the inconsistent and often contradictory conclusions prevalent in extant literature regarding the "green technology innovation-performance" nexus. By incorporating Executive Green Perception (EGP) as a mediator and Carbon Performance (CP) as a moderator, we demonstrate that the financial dividends of Green Technology Innovation (GTI) are not realized automatically. Rather, the efficacy of green innovation is maximized only when it is supported by proactive managerial advocacy and a robust carbon management infrastructure. Based on these empirical findings, several critical policy implications emerge. First, policymakers should transition from merely incentivizing innovation "inputs", such as research and development tax credits or general expenditure grants, to rewarding quantifiable environmental "outputs," specifically substantial improvements in carbon performance. Our results indicate that substantive carbon reduction serves as a critical catalyst for institutional financial viability, providing a more reliable indicator of long-term value than raw research and development spending alone. Furthermore, given the significant mediating role of EGP, government agencies should implement environmental literacy and strategic training programs tailored for corporate boards and senior management. Such initiatives are essential to ensure that green subsidies and technological assets are effectively translated into coherent strategic actions rather than being treated as isolated, fragmented technical projects. Most crucially, the study underscores the necessity for differentiated green financial instruments specifically tailored for high-carbon industries. These instruments should be designed to help firms overcome the formidable "threshold costs" and structural inertia associated with the initial stages of a green transition. By facilitating access to sustainability-linked loans or specialized green bonds, regulators can help high-carbon enterprises achieve the economies of scale necessary to bridge the gap between high-cost innovation and sustained profitability.

### 5-1-Limitations of the Study

This study has some limitations. First, the external validity of this study is clearly limited. Given that the sample originates solely from China's high-carbon industries (coal, energy, and manufacturing), the applicability of conclusions to low-carbon sectors or less capital-intensive industries remains open to debate. Furthermore, China's unique institutional context, characterized by strong state ownership, government-led environmental policies, and rapid regulatory changes, may limit generalizability to market-driven economies in Europe and North America where different incentive structures and stakeholder dynamics prevail. Second, the study's institutional setting is unique to China and involves state ownership and government-driven policies, therefore it may not apply to Western market economies. Third, although patents can serve as a measure of green innovation, it is limited in that it cannot capture minor improvements that are not based on a patent or organizational innovations, both have been considered in green innovation literature. Fourth, by applying fixed effects to substantiate endogeneity, the cross-sectional, time-series design of the study does not allow for full causality. Fifth, while our two-way fixed effects approach addresses several endogeneity sources, we cannot fully rule out reverse causality between financial performance and green innovation. Future research employing instrumental variable approaches, natural experiments, or longer-lagged specifications would strengthen causal inference. Despite this limitation, our theoretical framework, institutional context (regulatory-driven innovation), and consistency with prior research [7-9] support the proposed causal direction.

Finally, even though we provide comprehensive theoretical justification for the negative direct effect of carbon performance on financial performance (Section 4.6), our analysis does not include subgroup analyses that could further validate this finding across different firm characteristics. Specifically, testing whether the negative cost burden of carbon management ( $\beta = -0.157$ ,  $p < 0.10$ ) varies systematically across firms with different levels of green innovation intensity,

ownership structures, or financial slack would strengthen our complementary assets interpretation. For instance, we hypothesize that the negative effect would be more pronounced in firms with low GTI (where carbon management yields no synergistic benefits) and attenuated or reversed in high-GTI firms (where complementarity effects materialize). Such conditional analysis would directly test whether carbon performance transitions from cost burden to value driver only when coupled with green innovation but was beyond the scope of the current study given sample size considerations when creating multiple cross-classified subgroups. Future research examining these boundary conditions would provide more granular insights into the optimal sequencing and bundling of green investments.

### ***5-2- Future Research***

Future research can extend the understanding in multiple ways. First, it would be useful to examine additional mediating mechanisms, involving green supply chain collaboration, organizational learning, or dynamic capabilities, to develop a more holistic understanding of the transmission mechanisms. Second, longitudinal studies would help clarify how the relationships between the antecedents and consequences of innovation evolve across technology maturity. Third, exploring heterogeneity in the carbon performance-financial performance relationship through targeted subgroup analyses would validate and extend our complementary assets framework. Specifically, future studies should test whether the negative direct effect of carbon performance varies across: (1) green innovation intensity levels, directly testing our hypothesis that the cost burden is most severe in low-GTI firms where carbon management lacks synergistic benefits, while potentially neutral or positive in high-GTI firms where complementarity effects materialize; (2) financial resource availability, examining whether financially constrained firms face more pronounced negative effects due to inability to absorb upfront carbon management investments; (3) ownership structures, investigating whether state-owned enterprises can more readily absorb short-term profitability reductions given softer budget constraints and longer investment horizons; and (4) industry regulatory stringency, testing whether firms in heavily regulated sectors face different cost-benefit dynamics. Such conditional analyses would identify the precise boundary conditions under which carbon management transitions from financial burden to strategic enabler, providing actionable guidance for managers regarding optimal timing and sequencing of green investments. Fourth, machine learning approaches, employing data from different types of sources, e.g., patent text, energy consumption, and government indicators, would help to identify nonlinearities and threshold effects. Lastly, Cross-national comparative studies would test whether our framework holds across different institutional contexts, particularly examining how varying levels of environmental regulation stringency, state ownership prevalence, and green finance market development influence the relationships among GTI, EGP, CP, and financial performance. Moreover, extending the framework to low-carbon industries or service sectors would clarify whether our findings represent industry-specific dynamics or generalizable mechanisms of green value creation.

## **6- Declarations**

### ***6-1- Author Contributions***

Conceptualization, Y.L., P.L., and M.S.; methodology, Y.L. and P.L.; formal analysis, Y.L. and P.L.; investigation, Y.L.; data curation, Y.L.; writing—original draft preparation, Y.L. and P.L.; writing—review and editing, P.L., M.S., W.D., and R.A.; visualization, Y.L.; supervision, P.L.; project administration, P.L.; funding acquisition, P.L. All authors have read and agreed to the published version of the manuscript.

### ***6-2- Data Availability Statement***

The data presented in this study are available on request from the corresponding author.

### ***6-3- Funding***

This research was supported by the International Mobility Fund for Research Collaboration, provided by Walailak University, Thailand.

### ***6-4- Institutional Review Board Statement***

Ethical review and approval were waived for this study by the Human Research Ethics Committee of Walailak University (Certificate No. WUEC-25-327-01, approved on 3 September 2025) as the research utilizes secondary data from publicly available sources and does not involve direct human participation or primary data collection from human subjects.

### ***6-5- Informed Consent Statement***

Not applicable.

### ***6-6- Conflicts of Interest***

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

## 7- References

- [1] Yakovleva, O., Slyusar, V., Kushnir, O., & Sabovchyk, A. (2021). New trends in scientific and technological revolution (STR) and transformation of science and education systems in the paradigm of sustainable development. *E3S Web of Conferences*, 277, 06006. doi:10.1051/e3sconf/202127706006.
- [2] Zhu, Y., Hu, Y., & Zhu, Y. (2024). Can China's energy policies achieve the "dual carbon" goal? A multi-dimensional analysis based on policy text tools. *Environment, Development and Sustainability*, 1-40. doi:10.1007/s10668-024-05190-4.
- [3] Liu, L., Feng, A., & Liu, M. (2024). The effect of green innovation on corporate financial performance: Does quality matter? *Finance Research Letters*, 62, 105255. doi:10.1016/j.frl.2024.105255.
- [4] Wang, W., & Yang, X. (2025). Driving green technology innovation: The impact of environmental policies on manufacturing. *Journal of Innovation and Knowledge*, 10(2), 100684. doi:10.1016/j.jik.2025.100684.
- [5] Li, W., Xu, X., Huang, S., Cheng, T., Liu, M., & Zhang, C. (2023). Assessment of green technology innovation on energy-environmental efficiency in China under the influence of environmental regulation considering spatial effects. *Scientific Reports*, 13(1), 20789. doi:10.1038/s41598-023-47786-2.
- [6] Li, H., Liu, J., & Wang, H. (2024). Impact of green technology innovation on the quality of regional economic development. *International Review of Economics and Finance*, 93, 463–476. doi:10.1016/j.iref.2024.05.017.
- [7] Wu, L., Wang, C., Ren, H., & Zhang, W. (2024). How does executive green cognition affect enterprise green technology innovation? The mediating effect of ESG performance. *Heliyon*, 10(14), e34287. doi:10.1016/j.heliyon.2024.e34287.
- [8] Xia, D., & Wang, X. Q. (2021). The synergetic impact of environmental and innovation information disclosure on corporate financial performance: An empirical study based on China coal listed companies. *Technovation*, 100, 102179. doi:10.1016/j.technovation.2020.102179.
- [9] Blum-Kusterer, M., & Hussain, S. S. (2001). Innovation and corporate sustainability: An investigation into the process of change in the pharmaceuticals industry. *Business Strategy and the Environment*, 10(5), 300–316. doi:10.1002/bse.300.
- [10] Liu, M., Liu, L., & Feng, A. (2024). The Impact of Green Innovation on Corporate Performance: An Analysis Based on Substantive and Strategic Green Innovations. *Sustainability (Switzerland)*, 16(6), 2588. doi:10.3390/su16062588.
- [11] Guo, C., Wang, Y., Hu, Y., Wu, Y., & Lai, X. (2024). Does smart city policy improve corporate green technology innovation? Evidence from Chinese listed companies. *Journal of Environmental Planning and Management*, 67(6), 1182-1211. doi:10.1080/09640568.2022.2157708.
- [12] Wang, F. (2023). The intermediary and threshold effect of green innovation in the impact of environmental regulation on economic Growth: Evidence from China. *Ecological Indicators*, 153, 110371. doi:10.1016/j.ecolind.2023.110371.
- [13] Deng, X., & Li, L. (2020). Promoting or inhibiting? The impact of environmental regulation on corporate financial performance—An empirical analysis based on China. *International Journal of Environmental Research and Public Health*, 17(11), 3828. doi:10.3390/ijerph17113828.
- [14] Zhang, Y., Wei, J., Zhu, Y., & George-Ufot, G. (2020). Untangling the relationship between Corporate Environmental Performance and Corporate Financial Performance: The double-edged moderating effects of environmental uncertainty. *Journal of Cleaner Production*, 263, 121584. doi:10.1016/j.jclepro.2020.121584.
- [15] Baah, C., Opoku-Agyeman, D., Acquah, I. S. K., Agyabeng-Mensah, Y., Afum, E., Faibil, D., & Abdoulaye, F. A. M. (2021). Examining the correlations between stakeholder pressures, green production practices, firm reputation, environmental and financial performance: Evidence from manufacturing SMEs. *Sustainable Production and Consumption*, 27, 100–114. doi:10.1016/j.spc.2020.10.015.
- [16] Batool, F., Alhidary, I. A., Boda, J. R., Alwadi, B. M., Khudoykulov, K., & Haseeb, M. (2025). Balancing Sustainability and Profitability: The Financial Effect of Green Innovation in Chinese High-Pollution Industries. *Sustainability (Switzerland)*, 17(8), 3610. doi:10.3390/su17083610.
- [17] Su, X., Xu, A., Lin, W., Chen, Y., Liu, S., & Xu, W. (2020). Environmental leadership, green innovation practices, environmental knowledge learning, and firm performance. *Sage Open*, 10(2), 2158244020922909. doi:10.1177/2158244020922909.
- [18] Cao, H., & Chen, Z. (2019). The driving effect of internal and external environment on green innovation strategy-The moderating role of top management's environmental awareness. *Nankai Business Review International*, 10(3), 342–361. doi:10.1108/NBRI-05-2018-0028.
- [19] Liu, T., & Cao, X. (2025). RETRACTED ARTICLE: Going Green: How Executive Environmental Awareness and Green Innovation Drive Corporate Sustainable Development. *Journal of the Knowledge Economy*, 16(2), 6577-6604. doi:10.1007/s13132-024-01788-1.

- [20] Chen, Y. S., Chang, T. W., Lin, C. Y., Lai, P. Y., & Wang, K. H. (2016). The influence of proactive green innovation and reactive green innovation on green product development performance: The mediation role of green creativity. *Sustainability (Switzerland)*, 8(10), 966. doi:10.3390/su8100966.
- [21] Liang, M., Cao, H., & Wang, X. (2022). Senior executives' environmental awareness, dynamic capabilities and corporate green innovation performance: moderating effect of environmental uncertainty. *Science and Technology Management Research*, 42(4), 209-216.
- [22] Chen, Y. S., & Chang, C. H. (2013). The Determinants of Green Product Development Performance: Green Dynamic Capabilities, Green Transformational Leadership, and Green Creativity. *Journal of Business Ethics*, 116(1), 107–119. doi:10.1007/s10551-012-1452-x.
- [23] Su, L., & He, Y. (2024). ESG Performance, Executive Green Cognition, and Corporate Financial Performance. *Communication of Finance and Accounting*, 23, 49-53.
- [24] Chen, X., Lakkanawani, P., Suttipun, M., Swatdikun, T., & Huang, S. Z. (2024). Green Technology Innovation and Corporate Reputation: Key Drivers of ESG and Firm Performance. *Emerging Science Journal*, 8(6), 2501–2518. doi:10.28991/ESJ-2024-08-06-021.
- [25] Lapinskienė, G., Gedvilaitė, D., Liučvaitienė, A., & Peleckis, K. (2023). How Does Environmental Data from ESG Concept Affect Stock Returns: Case of the European Union and US Capital Markets. *Emerging Science Journal*, 7(2), 410–427. doi:10.28991/ESJ-2023-07-02-08.
- [26] Meng, X., Gou, D., & Chen, L. (2023). The relationship between carbon performance and financial performance: evidence from China. *Environmental Science and Pollution Research*, 30(13), 38269–38281. doi:10.1007/s11356-022-24974-7.
- [27] Yan, J., Zhou, H., Mu, J., Zhang, Y., & Rahman, A. (2022). The synergistic effect of carbon performance and technological innovation on corporate financial performance. *Frontiers in Psychology*, 13, 1060042. doi:10.3389/fpsyg.2022.1060042.
- [28] Zhang, J., & Ke, H. (2022). The moderating effect and threshold effect of green finance on carbon intensity: From the perspective of capital accumulation. *Complexity*, 2022(1), 4273691. doi:10.1155/2022/4273691.
- [29] Xu, R., & Lin, B. (2017). Why are there large regional differences in CO2 emissions? Evidence from China's manufacturing industry. *Journal of Cleaner Production*, 140, 1330–1343. doi:10.1016/j.jclepro.2016.10.019.
- [30] Kraus, S., Rehman, S. U., & García, F. J. S. (2020). Corporate social responsibility and environmental performance: The mediating role of environmental strategy and green innovation. *Technological Forecasting and Social Change*, 160, 120262. doi:10.1016/j.techfore.2020.120262.
- [31] NDRC. (2021). Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy. National Development and Reform Commission (NDRC), Beijing, China. Available online: [https://en.ndrc.gov.cn/policies/202110/t20211024\\_1300725.html](https://en.ndrc.gov.cn/policies/202110/t20211024_1300725.html) (accessed on March 2026).
- [32] Schiederig, T., Tietze, F., & Herstatt, C. (2012). Green innovation in technology and innovation management—an exploratory literature review. *R&d Management*, 42(2), 180-192. doi:10.1111/j.1467-9310.2011.00672.x.
- [33] Yabing, L., Yue, X., & Zhen, Z. (2023). The relationship between executives' green perception and firm performance in heavy-pollution industries: a moderated mediating effect model. *Science & Technology Progress and Policy*, 40(7), 113-123. doi:10.6049/kjbydc.2022030266.
- [34] Dangelico, R. M., & Vocalelli, D. (2017). “Green Marketing”: An analysis of definitions, strategy steps, and tools through a systematic review of the literature. *Journal of Cleaner Production*, 165, 1263–1279. doi:10.1016/j.jclepro.2017.07.184.
- [35] Parmar, B. L., Freeman, R. E., Harrison, J. S., Wicks, A. C., Purnell, L., & de Colle, S. (2010). Stakeholder Theory: The State of the Art. *Academy of Management Annals*, 4(1), 403–445. doi:10.5465/19416520.2010.495581.
- [36] Testa, F., Iraldo, F., & Daddi, T. (2018). The Effectiveness of EMAS as a Management Tool: A Key Role for the Internalization of Environmental Practices. *Organization and Environment*, 31(1), 48–69. doi:10.1177/1086026616687609.
- [37] Cho, C. H., Freedman, M., & Patten, D. M. (2012). Corporate disclosure of environmental capital expenditures: A test of alternative theories. *Accounting, Auditing and Accountability Journal*, 25(3), 486–507. doi:10.1108/09513571211209617.
- [38] Lee, J. W. (2024). Diffusion of innovations. *Encyclopedia of Sport Management*. Free Press, New York, United States. doi:10.4337/9781035317189.ch157.
- [39] Wang, D., Luo, Y., Hu, S., & Yang, Q. (2022). Executives' ESG cognition and enterprise green innovation: Evidence based on executives' personal microblogs. *Frontiers in Psychology*, 13, 1053105. doi:10.3389/fpsyg.2022.1053105.
- [40] Delmas, M. A., & Burbano, V. C. (2011). The drivers of greenwashing. *California Management Review*, 54(1), 64–87. doi:10.1525/cm.2011.54.1.64.

- [41] Downar, B., Ernstberger, J., Reichelstein, S., Schwenen, S., & Zaklan, A. (2021). The impact of carbon disclosure mandates on emissions and financial operating performance. *Review of Accounting Studies*, 26(3), 1137–1175. doi:10.1007/s11142-021-09611-x.
- [42] Su, W., Guo, C., & Song, X. (2022). Media coverage, Environment Protection Law and environmental research and development: evidence from the Chinese-listed firms. *Environment, Development and Sustainability*, 24(5), 6953–6983. doi:10.1007/s10668-021-01735-z.
- [43] Frempong, M. F., Mu, Y., Adu-Yeboah, S. S., Hossin, M. A., & Adu-Gyamfi, M. (2021). Corporate sustainability and firm performance: the role of green innovation capabilities and sustainability-oriented supplier–buyer relationship. *Sustainability (Switzerland)*, 13(18), 10414. doi:10.3390/su131810414.
- [44] Akbar, A., Jiang, X., Qureshi, M. A., & Akbar, M. (2021). Does corporate environmental investment impede financial performance of Chinese enterprises? The moderating role of financial constraints. *Environmental Science and Pollution Research*, 28(41), 58007–58017. doi:10.1007/s11356-021-14736-2.
- [45] Chen, S. (2026). Research on the Relationship Between Green Innovation, Carbon Performance, and Financial Performance in Manufacturing. *Economics & Business Management*, 4(2), 102. doi:10.63313/ebm.2027.
- [46] Pessoa, G., Kosov, M., Ponkratov, V., Volkova, M., Durmanov, A., Shkalenko, A., & Elyakov, A. (2025). The Green Transition Paradox Across Natural Resource-Rich Economies: Evidence from Brazil, Russia, and Uzbekistan. *Emerging Science Journal*, 9(2), 851–867. doi:10.28991/ESJ-2025-09-02-018.
- [47] Riillo, C. A. F. (2017). Beyond the question “Does it pay to be green?”: How much green? and when? *Journal of Cleaner Production*, 141, 626–640. doi:10.1016/j.jclepro.2016.09.039.
- [48] Jin, Z., & Xu, J. (2020). Impact of environmental investment on financial performance: Evidence from Chinese listed companies. *Polish Journal of Environmental Studies*, 29(3), 2235–2245. doi:10.15244/pjoes/111230.
- [49] Weng, H. H. R., Chen, J. S., & Chen, P. C. (2015). Effects of green innovation on environmental and corporate performance: A stakeholder perspective. *Sustainability (Switzerland)*, 7(5), 4997–5026. doi:10.3390/su7054997.
- [50] Cupertino, S., Vitale, G., & Riccaboni, A. (2020). Sustainability and short-term profitability in the agri-food sector, a cross-sectional time-series investigation on global corporations. *British Food Journal*, 123(13), 317–336. doi:10.1108/BFJ-02-2021-0154.
- [51] Baah, C., Agyabeng-Mensah, Y., Afum, E., & Lascano Armas, J. A. (2024). Exploring corporate environmental ethics and green creativity as antecedents of green competitive advantage, sustainable production and financial performance: empirical evidence from manufacturing firms. *Benchmarking: An International Journal*, 31(3), 990-1008. doi:10.1108/BIJ-06-2022-0352.
- [52] Xiaodan, L. (2023). Research on the Impact of Green Innovation on New Ventures Performance. *Academic Journal of Business and Management*, 5(27), 39-45. doi:10.25236/AJBM.2023.052707.
- [53] Xu, L., Li, C., Zhang, X., & Zhao, X. (2025). Under the "Dual-Carbon" Goal: Green Credit Policy and High-Quality Enterprise Development in China. *Green and Low-Carbon Economy*, 3(2), 121-132. doi:10.47852/bonviewGLCE42022548.
- [54] Liu, Y., & Chen, Y. (2024). Executives’ green cognition and corporate green innovation: evidence from China. *Total Quality Management and Business Excellence*, 35(9–10), 1054–1075. doi:10.1080/14783363.2024.2352577.
- [55] Noman, B. A., & Ayesh, S. (2020). Managerial Cognition: A Review and Reconceptualisation. *International Journal of Business Society*, 4(9), 198–209. doi:10.30566/ijo-bs/2020.36.
- [56] Wang, Y., & Liu, Y. (2024). Can the Top Management Team’s Environmental Attention Promote Corporate Green Innovation? *Sustainability (Switzerland)*, 16(8), 3495. doi:10.3390/su16083495.
- [57] Tang, Y., Katsikas, E., Koufopoulos, D. N., Fygkioris, M., Grose, C., Chantziaras, A., & Athanasiadis, K. A. (2024). An empirical study on the relationship between executive team heterogeneity and corporate innovation. *Scientific Research Management*, 29(6), 10–13. doi:10.22495/cgpmpp1.
- [58] Sun, J. (2025). Does Executives’ Green Cognition Improve Corporate Environmental Performance? – The Moderating Role of Corporate Governance. *Polish Journal of Environmental Studies*, 34(6), 7391–7410. doi:10.15244/pjoes/192562.
- [59] Meiting, M. A., Xiaojie, W. U., & Xiuqiong, W. A. N. G. (2023). Technological imprint of top management team and ambidextrous green innovation of firms: mediating effect of environmental attention. *Journal of Systems & Management*, 32(5), 976.
- [60] Wang, D., Tarasov, A., & Zhang, H. (2023). Environmental regulation, innovation capability, and green total factor productivity of the logistics industry. *Kybernetes*, 52(2), 688-707. doi:10.1108/K-04-2022-0591.
- [61] Ju, W., & Jin, S. (2024). The impact of green innovation on the carbon performance of Chinese manufacturing enterprises: Moderating role of internal governance. *Heliyon*, 10(10), e31272. doi:10.1016/j.heliyon.2024.e31272.

- [62] Zeng, S. X., Meng, X. H., Yin, H. T., Tam, C. M., & Sun, L. (2010). Impact of cleaner production on business performance. *Journal of Cleaner Production*, 18(10–11), 975–983. doi:10.1016/j.jclepro.2010.02.019.
- [63] ISO. (2015). ISO 14001:2015 — Environmental management systems — Requirements with guidance for use. International Organization for Standardization, Geneva, Switzerland.
- [64] Sun, Y., Jiang, J., & Zhang, X. (2024). Effective carbon cost constraints: Unity of environmental effectiveness, cost effectiveness, and incentive effectiveness. *Bulletin of Chinese Academy of Sciences*, 39(8), 1365–1374. doi:10.16418/j.issn.1000-3045.20230825002.
- [65] The State Council of the People’s Republic of China. (2022). Comprehensive Work Plan for Energy Conservation and Emission Reduction during the 14th Five-Year Plan. General Office of the National Development and Reform Commission, Beijing, China.
- [66] Hu, J., Liu, X., Zhao, Y., & Li, Y. (2025). The Impact of Environmental Information Disclosure on Corporate Resilience. *Journal of Financial Risk Management*, 14(04), 593–609. doi:10.4236/jfrm.2025.144031.
- [67] Xie, Z., Wang, J., & Zhao, G. (2022). Impact of Green Innovation on Firm Value: Evidence from Listed Companies in China’s Heavy Pollution Industries. *Frontiers in Energy Research*, 9, 806926. doi:10.3389/fenrg.2021.806926.
- [68] Álvarez-Herránz, A., Balsalobre, D., Cantos, J. M., & Shahbaz, M. (2017). Energy Innovations-GHG Emissions Nexus: Fresh Empirical Evidence from OECD Countries. *Energy Policy*, 101, 90–100. doi:10.1016/j.enpol.2016.11.030.
- [69] Ganda, F. (2019). The impact of innovation and technology investments on carbon emissions in selected organisation for economic Co-operation and development countries. *Journal of Cleaner Production*, 217, 469–483. doi:10.1016/j.jclepro.2019.01.235.
- [70] Barbaglia, L., Croux, C., & Wilms, I. (2020). Volatility spillovers in commodity markets: A large t-vector autoregressive approach. *Energy Economics*, 85, 104555. doi:10.1016/j.eneco.2019.104555.
- [71] Han, S., Zhang, Z., & Yang, S. (2022). Green finance and corporate green innovation: based on China’s green finance reform and innovation pilot policy. *Journal of Environmental and Public Health*, 2022(1), 1833377. doi:10.1155/2022/1833377.
- [72] Fan, M., Yang, P., & Li, Q. (2022). Impact of environmental regulation on green total factor productivity: A new perspective of green technological innovation. *Environmental Science and Pollution Research*, 29(35), 53785–53800. doi:10.1007/s11356-022-19576-2.
- [73] Anwar, R., & Malik, J. A. (2020). When Does Corporate Social Responsibility Disclosure Affect Investment Efficiency? A New Answer to an Old Question. *SAGE Open*, 10(2), 1–14. doi:10.1177/2158244020931121.
- [74] Clarkson, P. M., Li, Y., Richardson, G. D., & Vasvari, F. P. (2008). Revisiting the relation between environmental performance and environmental disclosure: An empirical analysis. *Accounting, Organizations and Society*, 33(4–5), 303–327. doi:10.1016/j.aos.2007.05.003.
- [75] He, Y., Tang, Q., & Wang, K. (2016). Carbon performance versus financial performance. *China Journal of Accounting Studies*, 4(4), 357–378. doi:10.1080/21697213.2016.1251768.
- [76] Le, H., & Nguyen-Phung, H. T. (2024). Assessing the impact of environmental performance on corporate financial performance: A firm-level study of GHG emissions in Africa. *Sustainable Production and Consumption*, 47, 644–654. doi:10.1016/j.spc.2024.04.024.
- [77] Busch, T., Bassen, A., Lewandowski, S., & Sump, F. (2022). Corporate Carbon and Financial Performance Revisited. *Organization and Environment*, 35(1), 154–171. doi:10.1177/1086026620935638.
- [78] Stoffels, J. D., Cunningham, D. C., Meiburg, C. O., & Walker, M. C. (1981). Cases on Financial Institutions. *The Journal of Finance*, 36(3), 751. doi:10.2307/2327536.
- [79] Walsh, P. P., Murphy, E., & Horan, D. (2020). The role of science, technology and innovation in the UN 2030 agenda. *Technological Forecasting and Social Change*, 154, 119–129. doi:10.1016/j.techfore.2020.119957.
- [80] Duchin, R., Gilbert, T., Harford, J., & Hrdlicka, C. (2017). Precautionary Savings with Risky Assets: When Cash Is Not Cash. *Journal of Finance*, 72(2), 793–852. doi:10.1111/jofi.12490.
- [81] Lin, C., Ma, Y., Malatesta, P., & Xuan, Y. (2013). Corporate ownership structure and the choice between bank debt and public debt. *Journal of Financial Economics*, 109(2), 517–534. doi:10.1016/j.jfineco.2013.03.006.
- [82] Goldfarb, A., & Tucker, C. (2019). Digital economics. *Journal of Economic Literature*, 57(1), 3–43. doi:10.1257/jel.20171452.
- [83] Kocaarslan, B., & Soytaş, U. (2019). Dynamic correlations between oil prices and the stock prices of clean energy and technology firms: The role of reserve currency (US dollar). *Energy Economics*, 84, 104502. doi:10.1016/j.eneco.2019.104502.
- [84] Wen, Z., & Ye, B. (2014). Analyses of Mediating Effects: The Development of Methods and Models. *Advances in Psychological Science*, 22(5), 731. doi:10.3724/sp.j.1042.2014.00731.

- [85] Fama, E. F., & French, K. R. (1993). Common risk factors in the returns on stocks and bonds. *Journal of Financial Economics*, 33(1), 3–56. doi:10.1016/0304-405X(93)90023-5.
- [86] Petersen, M. A. (2009). Estimating standard errors in finance panel data sets: Comparing approaches. *Review of Financial Studies*, 22(1), 435–480. doi:10.1093/rfs/hhn053.
- [87] Liu, C. (2025). Analyzing the Efficiency and Optimization Strategies of Rural-Urban Integration Driven by Digital Economy Based on Spatial Econometric Models. *International Journal of Computer Information Systems and Industrial Management Applications*, 17, 30-30. doi:10.70917/ijcisim-2025-0307.
- [88] Ma, X., & Xue, Y. (2023). How does carbon emission trading scheme affect enterprise green technology innovation: evidence from China's A-share non-financial listed companies. *Environmental Science and Pollution Research*, 30(13), 35588-35601. doi:10.1007/s11356-022-24768-x.
- [89] Tian, H., Lin, J., & Jiang, C. (2022). The Impact of Carbon Emission Trading Policies on Enterprises' Green Technology Innovation—Evidence from Listed Companies in China. *Sustainability (Switzerland)*, 14(12), 7207. doi:10.3390/su14127207.
- [90] Li, G., Yang, J., Chen, D., & Hu, S. (2017). Impacts of the coming emission trading scheme on China's coal-to-materials industry in 2020. *Applied Energy*, 195, 837–849. doi:10.1016/j.apenergy.2017.03.115.
- [91] Xu, Y., Ge, W., Liu, G., Su, X., Zhu, J., Yang, C., ... & Ran, Q. (2023). The impact of local government competition and green technology innovation on economic low-carbon transition: new insights from China. *Environmental Science and Pollution Research*, 30(9), 23714-23735. doi:10.1007/s11356-022-23857-1.
- [92] Liu, R., Rahman, M. R. C. A., & Jamil, A. H. (2025). Leveraging Environmental Regulation: How Green Innovation Moderates the Relationship Between Carbon Information Disclosure and Firm Value. *Sustainability (Switzerland)*, 17(6), 2597. doi:10.3390/su17062597.
- [93] Perdichizzi, S., Buchetti, B., Cicchiello, A. F., & Dal Maso, L. (2024). Carbon emission and firms' value: Evidence from Europe. *Energy Economics*, 131, 107324. doi:10.1016/j.eneco.2024.107324.
- [94] Adu, D. A., Flynn, A., & Grey, C. (2023). Carbon performance, financial performance and market value: The moderating effect of pay incentives. *Business Strategy and the Environment*, 32(4), 2111–2135. doi:10.1002/bse.3239.