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S.I. : GREENWASHING

Do the greenwashing and corporate social responsibility are significant to mitigate the firm-level emissions: moderating role of environmental, social and governance indicators

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Abstract
This study investigates the impact of corporate strategies, including greenwashing, environmental, social, and governance integration, and corporate social responsibility environments, on sulfur dioxide emission reduction among 653 Chinese enterprises from 2008 to 2022. The research reveals that, while often perceived as superficial, greenwashing indirectly leads to genuine environmental actions under market and regulatory pressures, significantly reducing sulfur dioxide emissions. The interplay between greenwashing and environmental, social, and governance principles further accentuates this effect, as firms align their operations with environmental, social, and governance standards to avoid reputational risks, thereby contributing to emission reduction. The corporate social responsibility environment is also critical to corporate behavior toward sulfur emissions. In corporate social responsibility-oriented settings, firms face heightened expectations and regulatory demands, prompting them to adopt more effective sulfur emission reduction strategies. This study provides a nuanced understanding of the complex dynamics between corporate environmental strategies and actual emission outcomes, offering valuable insights for policymakers and industry stakeholders in guiding corporate behavior toward environmental sustainability.

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Abbreviations

Acronyms	Full form
GHG	Greenhouse gas
CO2	Carbon dioxide
ESG	Environmental, social, and governance
CEO	Chief executive officer
CSR	Corporate social responsibility
CSMAR	China Stock Market & Accounting Research
ST	Special treatment
EMS	Environmental management systems
RD	Research and development

1 Introduction

Environmental problems faced by the world today are diverse and complex, posing significant challenges to the sustainability of our planet. Climate change, driven by human activities such as burning fossil fuels and deforestation, has emerged as one of the most pressing issues (Smith et al., 2019). Rising global temperatures, melting polar ice caps, extreme weather events, and disrupted ecosystems are among the profound impacts of climate change on both natural and human systems. Loss of biodiversity is another critical environmental problem resulting from habitat destruction, pollution, invasive species, and climate change (IPBES, 2019). This loss threatens the delicate balance of ecosystems, reduces ecosystem resilience, and diminishes the availability of essential ecosystem services that humans rely on.

Deforestation, predominantly driven by agricultural expansion, logging, and urbanization, has significant environmental consequences (FAO, 2020). The destruction of forests leads to habitat loss, carbon emissions, and the decline of species dependent on forest ecosystems. Moreover, deforestation disrupts the water cycle and contributes to climate change by reducing the Earth's capacity to absorb and store carbon dioxide. Also, water scarcity has become an increasingly prevalent environmental issue, affecting billions of people worldwide. Population growth, pollution, unsustainable water management practices, and climate change are key factors contributing to the depletion and contamination of freshwater sources (UN, 2018). Water scarcity threatens human health, agricultural productivity, and ecosystems that depend on adequate water supplies. Besides all these issues, pollution in its various forms poses significant risks to human health and the environment. Air pollution from industrial activities, transportation emissions, and burning fossil fuels has detrimental effects on respiratory health and contributes to climate change. Water pollution, caused by improper waste disposal, industrial runoff, and agricultural practices, contaminates freshwater sources and harms aquatic ecosystems. Soil pollution, primarily driven by agrochemicals, industrial waste, and improper waste disposal, degrades soil quality and reduces its capacity to support plant growth and ecosystem functioning (WHO, 2018).

Although these issues are points of concern worldwide, China's greenhouse gas (GHG) emissions have reached alarming levels, making it one of the most significant contributors to global climate change. With its rapidly growing economy and industrial sector, China's emissions have surged over the past few decades. These statistics highlight the urgent need

for mitigation efforts and sustainable practices. China is currently the world's top CO2 emitter, accounting for over 28% of all emissions in 2019, according to the Global Carbon Atlas (Le Quéré et al., 2020). Besides other factors, the country's heavy reliance on coal for energy generation and its extensive industrial activities contribute significantly to its high emissions. Also, burning fossil fuels, particularly coal, is a significant source of China's GHG emissions because the country's coal consumption is substantial, accounting for around half of the global coal consumption (BP, 2020). Hence, the use of coal in power generation, industrial processes, and residential heating drives up emissions levels.

Moreover, China's industrial sector, which encompasses manufacturing, construction, and heavy industries, significantly contributes to GHG emissions. In this sector, the production and processing of raw materials, such as steel and cement, release substantial amounts of CO2 into the atmosphere (Qiu et al., 2020). Consequently, addressing China's emissions is crucial for global climate change mitigation efforts. Although the Chinese government has recognized the urgency and has implemented various measures to curb emissions, such as investing in renewable energy sources, improving energy efficiency, and promoting sustainable practices. Moreover, China has set a target to peak its emissions by 2030 and achieve carbon neutrality by 2060. However, the situation of emissions in China still needs to be revised.

Some studies have used firm-level data to explore factors behind carbon emissions and provide some solutions. In this regard, (Oyewo, 2023) explored how corporate governance can help companies reduce environmental emissions. Their advice is that gender diversity, as well as CEO duality, along with ESG-based compensation, can help companies reduce emissions. Likewise, (Yu et al., 2022) suggest that an emission trading system is an effective tool to help companies reduce emissions and enhance financial performance. According to (Peng et al., 2022), green finance is the most effective way for businesses to lower carbon emissions. Further research (Ding et al., 2020) shows that a carbon tax can reduce businesses' excessive GHG emissions. According to (Forslid et al., 2011), businesses may employ technology to lower their carbon emissions.

Although these studies provide insight into carbon emission and its determinants, it is still unknown how a firm's emission of various other dangerous gasses is affected by its CSR indicators. The theoretical framework posits that a firm's commitment to corporate social responsibility (CSR) plays a pivotal role in shaping its environmental emissions profile, particularly concerning sulfur, nitrogen, and phosphorus (Freeman, 1984). Drawing from stakeholder theory and the resource-based view (Barney, 1991), the extent of CSR engagement influences regulatory compliance, operational efficiency, and technological adoption. A socially responsible firm is likelier to invest in sustainable practices, adopt cleaner technologies, and adhere to stringent environmental regulations (Suchman, 1995). This, in turn, mitigates sulfur, nitrogen, and phosphorus emissions. Furthermore, the framework integrates the legitimacy theory, suggesting that firms engage in CSR to enhance their legitimacy, thus fostering a proactive stance toward emissions reduction.

Greenwashing, a strategy firms employ to project an environmentally responsible image, can paradoxically contribute to reducing sulfur emissions. This phenomenon unfolds as corporations implement superficial eco-friendly measures in pursuing a green facade. However, to maintain credibility in the market and avoid regulatory scrutiny, these firms are often compelled to adopt genuine sustainable practices, including reducing sulfur emissions. Such an approach is supported by the theory of institutional isomorphism (DiMaggio & Powell, 2010), which suggests that organizations conform to societal expectations to gain legitimacy, access to resources, and market advantage. In this context, the external pressure from consumers, investors, and environmental watchdogs catalyzes firms

to undertake substantive environmental measures, including sulfur emission reduction, to align with the eco-conscious market trend. This inadvertent yet positive outcome of greenwashing underscores the complex interplay between corporate image management and environmental responsibility, revealing an unintended pathway toward achieving environmental sustainability goals.

Based on the discussion above, the following are the main contributions of the current study: First off, although earlier research employed firm-level carbon emissions, this analysis used firm-level sulfur, nitrogen, and phosphorus emissions for the first time. For targeted policy interventions, promoting accountability and transparency, allowing performance benchmarking, improving resource allocation and efficiency, and monitoring environmental advancement, it is essential to use firm-level data on sulfur, nitrogen, and phosphorus emissions. Using these data, policymakers, regulators, and businesses may collaborate to develop sustainable and environmentally friendly business practices. Second, this is the first research to examine firm-level emissions using firm-level CSR indicators (CSR, CSDR consumer, CSR environment, and CSR social). A crucial CSR indicator is measuring and tracking a company's carbon footprint. Quantifying the greenhouse gas emissions produced by the firm's operations, supply chain, and product lifecycle is part of this. Understanding their carbon footprint helps businesses locate emission hotspots and adopt focused reduction initiatives.

Additionally, a good CSR indicator for emissions reduction is a company's increase in the proportion of renewable energy in its energy mix. Organizations may migrate to greener energy sources and lessen their dependency on fossil fuels by setting goals for renewable energy consumption or investing in on-site renewable energy generation. Third, the research looks at how corporate directors may control environmental pollutants. According to research, women generally care about and understand the environment more than men. A higher emphasis on sustainability and environmental stewardship may result from the different viewpoints and beliefs that female directors bring to boardroom talks (Galletta et al., 2022). Their viewpoints can affect decisions and encourage a more substantial commitment to reducing emissions.

Hence, the following main points make up the objectives of this research: (i) examine the role of greenwashing in minimizing sulfur emissions, (ii) examine the role of CSR in minimizing sulfur emissions, (iii) examine the role of greenwashing with the moderating role of ESG to minimize sulfur emissions, and (iv) examine the role of the CSR environment in minimizing sulfur emissions.

The article's first section reviews the literature, and then, it moves on to describe the data and variables. The study's methodology is presented in the latter section. The following section presents the findings and analysis and the research's conclusions and recommendations.

2 Literature review

2.1 Firm-level analysis of the environment

Some studies examined the factors and determinants of firm-level emissions. In this regard, Oyewo, (2023) checked the impact of different corporate governance factors on carbon emission performance in multinational firms. Their results prove that the majority of corporate governance indicators show a negative impact on emissions. Also, Yu et al., (2022)

found a positive impact of the carbon trading system on the environment by reducing carbon emissions. Besides this, Wang et al., (2023) investigated if politically connected firms could reduce carbon emissions through this. Their results show that in politically connected firms, the carbon emission level is usually high due to faults in their governance. Along the same line, Alam et al., (2022) used firm-level data from the United States to investigate the impact of cash on carbon emissions. They proved that firms with a high level of cash holdings show a low level of carbon emissions. Hence, cash-rich firms positively impact the environment through lower emissions. Likewise, Liu et al., (2021) found that carbon emissions are low in firms with appropriately set sustainable development goals.

2.2 Impact of greenwashing on the environment

Greenwashing is a term used to describe the practice of companies making false or exaggerated claims about the environmental benefits of their products or services. This literature review aims to analyze the impact of greenwashing on the environment. According to a recent article (Montgomery et al., 2023), greenwashing is becoming more virulent than ever, with a profusion of environmental, social, and governance and net zero commitments becoming fraught. The article suggests that greenwashing can have serious adverse effects on environmental performance. Another study (Yousaf et al., 2023) also found that greenwashing can hurt environmental sustainability thoughts and environmental performance. A systematic literature review (de Freitas Netto et al., 2020) identified the different typologies and characteristics of greenwashing. The review found an increasing interest in greenwashing in the literature, with a peak in 2017. The review also identified the main concepts and forms of greenwashing. Another study by (Pei-yi & Greenwashing, 2020) suggests that environmental disclosure and performance are always low in firms where greenwashing is evident.

2.3 Impact of CSR on the environment

The relationship between CSR and emissions remains a subject of debate in the literature. While some studies suggest that CSR initiatives can reduce emissions, others propose that CSR may inadvertently contribute to increased emissions. For instance, a comprehensive study on greenhouse gas emissions and CSR in the USA, using a dynamic panel model, found mixed results. While some firms with more substantial CSR commitments exhibited lower carbon footprints, the relationship between CSR and emissions varied across industries and contexts (Ahmad et al., 2023). These findings suggest that the impact of CSR on emissions is complex and context-dependent. Considering the presence of emission restrictions, the effects of CSR on emissions become more nuanced. While implementing CSR practices may increase costs for firms, it can also stimulate innovative solutions to comply with emission restrictions effectively. Such initiatives align with the notion that CSR can drive sustainable practices, reducing emissions while meeting regulatory requirements. This highlights the potential of CSR to promote environmental stewardship and mitigate the negative impact of emissions.

CSR is closely linked to sustainable innovation, particularly in industries with high pollution levels. A case study in China's heavy pollution industry reveals that firms embracing CSR practices are more inclined to engage in sustainable innovation. These firms develop and implement environmentally friendly technologies and processes, reducing their overall environmental impact (Yan et al., 2022). This highlights the transformative potential of

CSR to drive positive change and foster sustainability within industries facing significant environmental challenges. Integrating CSR and climate change considerations has implications for firm performance and climate risk management. Studies indicate that incorporating climate change considerations into CSR strategies positively affects overall firm performance, particularly in addressing climate-related risks. Firms that align CSR with climate change initiatives are better positioned to adapt to evolving environmental conditions, mitigate risks, and capitalize on emerging opportunities (Ozkan et al., 2022). This underscores the importance of a comprehensive approach to CSR that accounts for climate risks and enhances overall business resilience. Another study focuses on the effectiveness of solutions. It suggests that effective environmental regulations and eco-innovation are vital in mediating the relationship between CSR and air pollution. CSR initiatives that prioritize environmental stewardship, with robust regulatory frameworks and innovative approaches, can reduce air pollution levels (Jiménez-Parra et al., 2018). This highlights the potential of CSR to mitigate air pollution through a multi-faceted approach.

2.4 ESG and directors' role in the environment

ESG and directors play a significant role in reducing environmental issues. According to (Baratta et al., 2023), environmental emissions can be decreased through effective ESG strategies. Likewise, (Fan et al., 2023) assert that directors, especially female directors, can help firms reduce emissions in Japan. They found a negative impact of directors on emissions. Additionally, (Gull et al., 2023) investigated the direct as well as indirect role of directors on environmental emissions in the United States. Their analysis proved that directors of US firms have not only helped reduce emissions directly but also indirectly mitigated the negative environmental consequences. Also, foreign directors are essential in helping firms combat environmental emissions. (Mardini & Elleuch Lahyani, 2021) investigated this nexus and found that firms with foreign directors perform much better than firms with no foreign directors. Another study by (Konadu et al., 2022) also conducted a study on S&P firms to check if environmental emissions can be reduced through directors. Their results show a significant negative nexus between board gender diversity and corporate emissions.

This literature review clearly shows that no study used firm-level sulfur emission, and all previous studies used carbon emission. Likewise, none of the studies explores the significance of greenwashing to reduce sulfur emissions in China. Additionally, the firm-level CSR indicator (CSR environment) remains to be explored. Hence, the current study is an effort to add new insights to the existing literature using firm-level sulfur emission data from Chinese companies. Also, the impact of greenwashing is explored along with CSR at the firm level. Additionally, the moderating role of ESG and CSR environments still needs to be explored in the existing literature, and we will fill this research gap as well.

3 Data and methodology

Corporate financial information is extracted from the CSMAR (China Stock Market & Accounting Research Database). We can learn about managerial myopia from Hu et al. (2021). We utilize the corporate social responsibility (CSR) rating and five subcategories from Hexun.com as alternative measures to gauge how active businesses are in sustainable growth. This is how the sample gets cleaned: It excludes banking institutions, special

treatment (ST) businesses, and businesses with debt that exceeds their whole assets, to name a few. Due to stricter requirements that may impact their managerial judgment and ESG engagement, ST enterprises have been excluded. This study omits financial institutions due to their unique business models and financial reporting practices, which are not directly comparable with those of non-financial entities. Furthermore, to ensure the inclusion of only financially stable companies which are presumed to be more actively involved in sustainable practices, firms whose debt levels surpass their total assets have been excluded from the sample. This selection criterion is based on the rationale that financially robust companies are more likely to have the resources and inclination to invest in sustainability initiatives. As a result, we have a panel dataset of 653 enterprises that is unbalanced for 2008 through 2022.

4 Theoretical reasoning

4.1 Greenwashing and environment

Greenwashing, in itself, does not directly reduce environmental emissions. Greenwashing is a marketing strategy where a company or organization gives a false impression of its environmental friendliness (Santos et al., 2023). It is a form of spin in which green public relations or marketing is deceptively used to promote the perception that an organization's products, aims, or policies are environmentally friendly when they are not. However, greenwashing can indirectly lead to reduced environmental emissions (Kalesnik et al., 2022). Greenwashing can raise consumer awareness about environmental issues. As consumers become more educated about these issues, they may demand more sustainable products and practices, pushing companies to reduce their emissions.

Similarly, if greenwashing becomes prevalent and publicized, it can lead to stricter regulations and standards for environmental claims. This could force companies to implement the environmentally friendly practices they claim to have, which could reduce emissions. Likewise, if a company falsely advertises its products as green, other companies might respond by making their products more environmentally friendly to gain a competitive edge. This could lead to industry-wide reductions in emissions.

4.2 CSR and environment

Corporate social responsibility (CSR) minimizes environmental emissions and promotes sustainable company practices. By integrating environmental considerations into their business strategies, companies can make meaningful contributions to reducing their environmental impact (Khan et al., 2022). One way CSR proves helpful is through implementing robust environmental management systems (EMS). These systems enable companies to effectively identify, monitor, and manage their environmental impacts. By setting environmental targets, conducting regular assessments, and adopting measures to reduce emissions and waste, companies can track their progress and make continuous improvements (Pasqualini Blass et al., 2017). This approach helps minimize environmental emissions and fosters a culture of sustainability within the organization. Companies can further contribute to emission reduction by emphasizing energy efficiency and transitioning to renewable energy sources. Businesses can significantly reduce their

carbon footprint by investing in energy-efficient technologies, optimizing energy consumption, and supporting renewable energy projects.

4.3 ESG and environment

Environmental, social, and governance (ESG) considerations are instrumental in minimizing environmental emissions and driving sustainable practices within companies. ESG encompasses a broader framework that considers the environmental impact of business operations, social responsibilities toward stakeholders, and sound governance practices. However, when it comes to minimizing environmental emissions, ESG provides a comprehensive approach that integrates environmental concerns into a company's decision-making processes—likewise, the factors of ESG guide companies in assessing and managing their environmental risks and opportunities (Meng & Shaikh, 2023). Hence, companies can identify areas where emissions can be reduced by considering environmental factors, such as climate change, resource efficiency, and pollution. Also, this includes adopting energy-efficient practices, investing in renewable energy sources, implementing waste reduction strategies, and addressing supply chain emissions. It is essential to mention that by integrating ESG into their strategies, companies can align their business goals with environmental sustainability. ESG also plays a crucial role in attracting investors and capital. Investors increasingly consider ESG factors when making investment decisions as they recognize the long-term financial benefits of sustainable practices. This incentivizes companies to take concrete steps to minimize their environmental emissions and demonstrate their commitment to sustainability. By integrating ESG practices, companies can enhance their reputations, access capital from ESG-focused investors, and gain a competitive advantage.

Models:

$$\text{Sulfur}_{it} = \rho_0 + \rho_1 \text{Greenwashing}_{it} + \rho_2 \text{RD}_{it} + \rho_3 \text{Tobin}Q_{it} + \rho_4 \text{Leverage}_{it} + \rho_5 \text{Goodwill}_{it} + \varepsilon_{it} \tag{1}$$

$$\text{Sulfur}_{it} = \rho_0 + \rho_1 \text{CSR}_{it} + \rho_2 \text{RD}_{it} + \rho_3 \text{Tobin}Q_{it} + \rho_4 \text{Leverage}_{it} + \rho_5 \text{Goodwill}_{it} + \varepsilon_{it} \tag{2}$$

$$\text{Sulfur}_{it} = \rho_0 + \rho_1 \text{Greenwashing}_{it} + \rho_2 \text{CSR}_{it} + \rho_3 \text{RD}_{it} + \rho_4 \text{Tobin}Q_{it} + \rho_5 \text{Leverage}_{it} + \rho_6 \text{Goodwill}_{it} + \varepsilon_{it} \tag{3}$$

Sulfur emissions in Chinese firms are the dependent variable of this study. There are two explanatory variables in this study, including CSR and greenwashing. The moderating variable of this study is ESG (Environmental, Social, and Governance). As the environmental, social and governance factors push the firms to enhance the environmental practices to minimize the emissions. However, it is important to use ESG as a moderating variable. The second moderating variable used in this study is CSR environment. Organizations can effectively control environmental emissions by integrating environmental considerations into CSR practices. Such an approach demonstrates a commitment to environmental stewardship, encourages sustainable practices, and promotes continuous improvement. Additionally, the interaction between CSR and the environment fosters innovation, collaboration, and stakeholder engagement, leading to a collective effort to reduce emissions and mitigate environmental impact. There are a few control variables as well used in this study, including research and development (RD), Tobin Q (Market Value of Firm/Replacement Cost of Assets), Leverage (Total Debt/Total Equity), and goodwill.

5 Results

5.1 Descriptive

Table 1 presents the results of descriptive statistics, where goodwill shows the highest mean value and greenwash has the lowest mean. The volatility of goodwill is the highest, but ESG is the least volatile.

Correlation results are presented in Table 2. All variables show a positive correlation with sulfur emissions. The correlation coefficient for goodwill (0.570) is the highest, suggesting that the most significant increase in sulfur emissions is attributed to goodwill. However, the most minor coefficient is for CSR (0.074).

5.2 Hausman test

The Hausman test results in Table 3 indicate that the *p* values for all three models are reported as 0.000, which is less than the conventional significance level of 0.05. This suggests strong evidence to reject the null hypothesis that there is no systematic difference between the coefficients estimated by the models. Hence, the fixed effect model is preferred over the random effect model, as it likely provides more accurate and reliable estimates. Fixed effects models account for time-invariant unobserved factors at the individual or entity level. In contrast, random effects models assume these unobserved factors are random and unrelated to the observed variables.

5.3 Baseline regression

Table 4 presents three models (Model 1, Model 2, and Model 3) for the baseline regression estimation using the fixed effect method. However, it is important to mention here that we have controlled the year and firm effect. Controlling for year and firm effects in regression analysis involves isolating the impact of specific variables by accounting for time-related changes and firm-specific characteristics. This technique, often implemented through fixed-effects models, ensures that the analysis reflects the true relationship between the variables of interest, un-confounded by temporal trends or idiosyncratic firm attributes. The dependent variable in this analysis is sulfur emission, and the table provides the estimated coefficients for various independent variables used in this study. The coefficient estimates for the

Table 1 Descriptive statistics

Variable	Obs	Mean	Std. dev	Min	Max
Sulfur	285	6.954	0.296	6.358	7.403
Greenwash	285	− 2.268	1.398	− 8.198	1.959
ESG	285	− 1.122	0.057	− 1.386	− 0.974
CSR	285	3.077	1.148	− 2.996	4.331
CSR_environment	285	2.550	0.472	1.609	3.178
RD	285	17.216	4.730	0.152	23.449
Tobin*Q*	285	0.290	0.487	− 1.081	1.111
Leverage	285	1.230	0.858	− 1.701	3.305
Goodwill	285	18.734	2.445	10.228	23.385

Table 2 Correlation

	Sulfur	Greenwash	ESG	CSR	CSR_environment	RD	Tobin*Q*	Leverage	Goodwill
Sulfur	1.000								
Greenwash	0.163	1.000							
ESG	0.111	0.075	1.000						
CSR	0.074	−0.105	−0.093	1.000					
CSR_environment	0.155	0.050	−0.101	0.064	1.000				
RD	0.393	0.088	0.053	0.049	0.235	1.000			
Tobin*Q*	0.229	−0.225	0.140	−0.045	−0.214	−0.100	1.000		
Leverage	0.089	−0.182	−0.197	0.347	0.176	0.135	−0.282	1.000	
Goodwill	0.570	0.041	−0.046	0.243	0.370	0.349	−0.178	0.523	1.000

Table 3 Hausman test

Hausman	Model 1	Model 2	Model 3
chi2	48.360	48.170	48.370
p value	0.000	0.000	0.000

The *p* value is less than 0.05: however, the fixed effect method is the appropriate for estimations

Table 4 Baseline regression estimation through fixed effect method

	Model 1	Model 2	Model 3
Greenwash	−0.035		−0.062**
CSR		−0.028	−0.012**
RD	−0.0255**	−0.0267**	−0.0256**
Tobin*Q*	0.191	0.211	0.182
Leverage	0.099	0.104	0.1
Goodwill	0.0896**	0.0886**	0.0908**
Constant	4.740***	4.671***	4.749***

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

independent variable "greenwash" in all three models indicate a negative association with sulfur emissions. However, in Model 1, the coefficient is -0.035, which is insignificant. Similarly, in Model 2, the coefficient is −0.062 at a statistical significance level of 1%. This suggests a stronger negative relationship between greenwashing and sulfur emissions, and a 1% increase in greenwashing reduces sulfur emissions by 0.062%. This result is aligned with the findings of (Zhang et al., 2022). According to them greenwashing is negatively related to environmental performance. However, they study overall pollution levels and do not provide specific information about how greenwashing can affect sulfur emission of firms. The independent variable "CSR" also negatively impacts sulfur emissions. However, the coefficient of CSR is significant in Model 2; it is −0.012, indicating its statistical significance at the 1% level. These results suggest that companies engaging in more corporate social responsibility activities tend to have lower sulfur emissions, and a 1% increase in CSR reduces sulfur emissions by 0.012%. There is no previous study which checks the direct impact of CSR on sulfur emissions; hence, comparison of this research with previous literature is not possible.

"Research and Development" (R&D) also demonstrate a negative association with sulfur emissions across all three models. The coefficient estimates (−0.0255, −0.0267, and −0.0256) are all statistically significant at the 1% level. This suggests that higher investment in research and development is associated with lower sulfur emissions. (Chen et al., 2021) also suggest same conclusion; they analyzed data from Chinese provinces from 2000 to 2016 and revealed a critical link between green R&D activities and the reduction of SO2 emissions. Different categories of R&D, however, demonstrate varied impacts on SO2 emission levels. Notably, R&D focused on utility demonstrates a significantly positive effect in diminishing SO2 emissions. Further investigations, utilizing a panel threshold approach, reveal that the influence of green R&D on SO2 emissions is nonlinear and contingent on the level of technological absorption capacity. However, "Tobin *Q*" represents a measure of the firm's market value, and the coefficients (0.191, 0.211, and 0.182) indicate a positive relationship with sulfur emissions

across all models. However, these coefficients are not statistically significant at conventional levels, suggesting a weak or insignificant association. As far as leverage is concerned, its coefficient is insignificant, which means leverage has no impact on sulfur emissions. Also, the positive coefficients indicate that "goodwill" demonstrates positive associations with sulfur emissions. The coefficient estimates for "goodwill" are statistically significant at the 1% level in all models, indicating a robust positive relationship with sulfur emissions.

5.4 Examining the presence of nonlinear

In Table 5, three models (Model 1, Model 2, and Model 3) are presented to examine the potential nonlinearity effects of certain independent variables on the dependent variable. The linear and squared terms for CSR and greenwash are included in the table to capture potential nonlinear relationships. Also, the variable "Greenwash" is included in all three models, along with its squared term "Greenwash_Square." The dependent variable and the linear term in Model 1 are positively correlated, as shown by the linear term's coefficient of 0.116. However, the squared term's coefficient of 0.015 indicates that it had little to no impact on the dependent variable. This demonstrates that there may not be a substantial nonlinear pattern in the relationship between greenwashing and the dependent variable. The linear term "Greenwash" coefficient for Model 2 is also −0.113, suggesting statistical significance at the 1% level. The negative coefficient indicates the inverse association between greenwashing and the dependent variable. In both models, the squared term "Greenwash_Square" coefficient is small, supporting the idea that the relationship is not significantly nonlinear.

Similarly, the variable "CSR" is examined for nonlinearity using its linear and squared terms. It is evident that in Model 1, the coefficient for "CSR" is 0.0387, indicating a positive relationship that is not statistically significant. Also, the squared term "CSR_Square" has a coefficient of −0.015, suggesting a negligible effect. Likewise, Model 2 shows a negative coefficient (−0.036) for the linear term "CSR" that is statistically significant at the 5% level, implying an inverse relationship between CSR and the dependent variable. The squared term "CSR_Square" has a coefficient of −0.013, indicating no significant nonlinearity.

Table 5 Nonlinearity

	Model 1	Model 2	Model 3
Greenwash	0.116		−0.113**
Greenwash_square	0.015		0.015
CSR		0.0387	−0.036*
CSR_square		−0.015	−0.013
RD	−0.025**	−0.028**	−0.031**
Tobin*Q*	0.182	0.198	0.166
Leverage	0.0911	0.122	0.108
Goodwill	0.0901**	0.0902**	0.0923**
Constant	4.809***	4.657***	4.798***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5.5 Moderating effect of ESG and CSR indicators

Table 6 presents the regression analysis results exploring the moderating effect of ESG (environmental, social, and governance) and CSR (corporate social responsibility) environment on the association between CSR and environmental emissions. The analysis includes the variable "Greenwash" and its interaction term with ESG represented as "Greenwash x ESG." In Model 1, the coefficient for "greenwash" is −0.293, which is statistically significant at the 1% level. This suggests a negative relationship between greenwashing and environmental emissions. The coefficient for the interaction term "Greenwash x ESG" is −0.286, statistically significant at the 1% level. This implies that the negative association between greenwashing and environmental emissions is further moderated by ESG considerations, suggesting that companies with better ESG performance may experience an even more substantial reduction in environmental emissions through greenwashing practices. The variable "CSR" is also included in the analysis along with its interaction term with the CSR environment, represented as "CSR *x* CSR_Environment." In Model 2, the coefficient for "CSR" is −0.012, which is statistically significant at the 1% level. This suggests a negative association between CSR and environmental emissions. The interaction term "CSR *x* CSR_Environment" coefficient is −0.089, statistically significant at the 5% level. This suggests that the negative association between CSR and environmental emissions is further moderated by the CSR environment, indicating that companies operating in a more CSR-friendly environment may experience a more significant reduction in environmental emissions through CSR practices.

6 Discussion

6.1 Examine the role of greenwashing in minimizing sulfur emissions

The effect of greenwashing on sulfur emissions is significant and negative. The reason behind this negative impact is simple. Due to the high level of greenwashing, customers have become aware of the importance of green products. Hence, they demand companies manufacture green products and reduce emissions (Hammami et al., 2018). As consumers become more educated and companies aim to meet new regulatory standards, there could

Table 6 Moderating effect of CSR indicators on the association between CSR and environmental emissions

Greenwash	−0.293**		−0.285***	0.036
Greenwash *x* ESG	−0.286**		−0.279***	
CSR		−0.012**	−0.051**	−0.013***
CSR *x* CSR_environment		−0.089*		−0.0103**
RD	−0.024**	−0.029**	−0.028**	−0.036**
Tobin*Q*	0.169	0.205	0.165	0.175
Leverage	0.105	0.107	0.106	0.103
Goodwill	0.0912**	0.0902**	0.0918**	0.0928**
Constant	4.706***	4.641***	4.711***	4.716***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

be increased competition among businesses to offer genuinely green products and services, leading to industry-wide reductions in emissions.

6.2 Examine the role of greenwashing in interacting with ESG to minimize sulfur emissions

It has been found that when greenwashing interacts with ESG, it significantly reduces sulfur emissions. It is because greenwashing creates an expectation of environmental responsibility (Santos et al., 2023), but without genuine efforts to reduce sulfur emissions, it risks exposing companies to criticism and reputational damage. By integrating ESG principles, companies are held to higher standards of transparency and accountability. This encourages them to align their actions with environmental claims, including reducing sulfur emissions. The integration of ESG ensures that companies are not just making empty promises but are actively working toward sustainable practices. Also, ESG factors serve as performance indicators that assess a company's overall environmental impact (Kocmanová & Dočekalová, 2012). Investors, customers, and other stakeholders increasingly consider ESG ratings when making decisions. Greenwashing may attract short-term attention but lacks substance and fails to demonstrate a genuine commitment to environmental sustainability. By incorporating ESG practices, companies are encouraged to take tangible steps to minimize sulfur emissions, positively impacting their ESG rating and enhancing their credibility with stakeholders.

6.3 Examine the role of the CSR environment in minimizing sulfur emissions

It is noted that CSR helps reduce sulfur emissions because CSR environments often promote and enforce stricter environmental regulations and standards (Lyon & Maxwell, 2008). Companies operating in such environments are more likely to face pressure to comply with stringent emission control measures, including those explicitly targeting sulfur emissions. By aligning their practices with CSR expectations, companies are compelled to adopt technologies, processes, and policies that actively reduce sulfur emissions to meet the regulatory requirements set forth by the CSR environment. Also, CSR environments foster collaboration among industry peers, regulatory bodies, and other stakeholders (Peloza & Falkenberg, 2009). This collaboration facilitates sharing best practices and knowledge of sulfur emission reduction strategies. Companies operating in a CSR environment can learn from one another, exchange ideas, and access resources to develop practical approaches for minimizing sulfur emissions. This collective knowledge-sharing culture promotes continuous improvement and innovation in emission control methods, leading to more successful outcomes in reducing sulfur emissions.

Additionally, CSR environments are characterized by engaged and socially responsible stakeholders actively advocating for sustainable practices (Camilleri, 2017). These stakeholders include consumers, investors, communities, and non-governmental organizations (NGOs). Their expectations and demands for environmental accountability pressure companies to minimize their sulfur emissions. Failing to meet these expectations can result in reputational damage and loss of stakeholder trust. Therefore, companies operating in CSR environments have a strong incentive to prioritize sulfur emission reduction efforts to maintain their reputation and positive relationships with stakeholders. Another reason is that CSR environments promote a holistic approach to sustainability that encompasses economic, social, and environmental dimensions

(Setó-Pamies & Papaoikonomou, 2016). This long-term perspective encourages companies to consider the broader impact of their operations on the environment and society. By incorporating sulfur emission reduction as part of their CSR commitments, companies recognize the importance of mitigating their environmental footprint for the well-being of future generations. They are more likely to invest in technologies, practices, and processes that proactively minimize sulfur emissions and contribute to a cleaner and healthier environment.

6.4 Examine the role of CSR moderating with the CSR environment to minimize sulfur emissions

The CSR (corporate social responsibility) environment acts as a moderating factor in the relationship between CSR and sulfur emissions, influencing the nature and strength of this relationship. A few important reasons for this moderating role are that the CSR environment emphasizes accountability and transparency in corporate practices. Companies operating within this environment are more likely to face scrutiny from stakeholders, including consumers, investors, and regulatory bodies. This heightened accountability creates a more vital link between CSR commitments and sulfur emissions (He & Chen, 2009). Companies that engage in CSR initiatives to reduce sulfur emissions are expected to demonstrate tangible results and transparent reporting. The CSR environment amplifies the importance of fulfilling CSR promises, thus strengthening the relationship between CSR efforts and actual sulfur emission reduction. Likewise, CSR environments often have well-established regulatory frameworks that incentivize and promote sustainable practices. These regulations can include emission limits and requirements for monitoring and reporting sulfur emissions. Companies operating in a CSR environment are more likely to be subject to these regulations, which provide a clear framework for aligning CSR commitments with sulfur emission reduction efforts. The presence of supportive regulations reinforces the relationship between CSR and sulfur emissions by providing a structured environment that encourages and rewards companies for their sustainable actions.

Also, CSR environments foster collaboration among industry peers, stakeholders, and experts in the field of sustainability (Taghian et al., 2015). This collaboration facilitates sharing of best practices, innovative technologies, and research findings related to sulfur emission reduction. Companies operating within a CSR environment have access to a network of knowledge and expertise, enabling them to implement more effective CSR strategies targeted at sulfur emission reduction. The knowledge exchange within the CSR environment strengthens the relationship between CSR initiatives and sulfur emissions by enabling companies to learn from others' experiences and adopt proven practices. Similarly, the CSR environment is characterized by stakeholders with high expectations for environmental responsibility and sustainability (Mutti et al., 2012). These stakeholders, including consumers, investors, and communities, actively seek and support companies demonstrating a commitment to CSR and sustainable practices. In response to stakeholder demands, companies operating in a CSR environment are incentivized to implement robust CSR initiatives that address sulfur emissions. The alignment of stakeholder expectations with CSR efforts strengthens the relationship between CSR and sulfur emissions as companies strive to meet or exceed these expectations.

7 Conclusion

This research, utilizing an unbalanced panel dataset of 653 Chinese enterprises from 2008 to 2022, offers novel insights into the multifaceted influence of corporate strategies on sulfur emissions. It elucidates how greenwashing, while often criticized for its superficiality, inadvertently propels firms toward genuine environmental responsibility, particularly in sulfur emission reduction. This paradoxical outcome highlights the complex dynamics between corporate image and environmental compliance. Moreover, the interaction of greenwashing with environmental, social, and governance (ESG) principles emerges as a pivotal factor. It suggests that when under the scrutiny of ESG standards, firms' superficial green efforts transform into substantive environmental actions, leading to a noticeable decrease in sulfur emissions.

Furthermore, the study underscores the significance of the corporate social responsibility (CSR) environment in shaping corporate behavior toward sulfur emissions. Companies demonstrate a stronger commitment to reducing emissions, driven by regulatory pressures, stakeholder expectations, and collaborative industry practices in contexts where CSR norms are deeply embedded. The CSR environment not only encourages but also amplifies the impact of CSR initiatives on sulfur emission reduction. Scientifically, this research contributes to understanding how external corporate environments and internal strategies collectively influence environmental outcomes. It extends the discourse on greenwashing from a purely critical perspective to a more nuanced understanding of its potential indirect benefits. Additionally, by integrating ESG and CSR frameworks into the analysis of sulfur emission reduction, this study provides a more comprehensive view of the corporate–environmental interface. The findings have implications for policymakers, industry stakeholders, and researchers, offering a deeper understanding of how corporate actions, whether initially superficial or substantively environmental, can be steered toward genuine sustainability goals. This research thus bridges a crucial gap in existing literature, offering a unique perspective on the interplay between corporate green strategies and environmental outcomes in the context of emerging economies like China.

7.1 Policy implications

The findings of this study offer substantial policy implications for China, particularly in steering corporate behavior toward environmental sustainability. The role of greenwashing, initially perceived negatively, can be strategically leveraged by policymakers. By intensifying regulatory standards and consumer awareness, greenwashing can be transformed into a catalyst for genuine green initiatives, thereby reducing sulfur emissions. Policies should encourage transparency and accountability in environmental reporting, nudging companies to align their actual practices with their green claims. Integration of ESG principles into corporate governance can be another focus area. Policymakers can facilitate the adoption of ESG standards across industries, ensuring that firms not only commit to but also act on their environmental responsibilities. This approach could significantly reduce sulfur emissions as companies strive to improve their ESG ratings and meet stakeholder expectations. Furthermore, the establishment and reinforcement of CSR environments are crucial. Policymakers can promote stricter environmental regulations and standards within these environments, creating a conducive setting for companies to adopt sustainable practices. Encouraging collaboration among businesses, regulatory bodies, and other stakeholders

can facilitate knowledge sharing and innovation in emission reduction techniques. Incentives for companies that actively participate in CSR initiatives and demonstrate measurable reductions in sulfur emissions could further motivate firms to engage in sustainable practices.

7.2 Limitation and future direction

This study, like all others, has some restrictions that ought to be addressed in follow-up investigations. It is crucial to recognize that the context and results might only occasionally apply. To validate and generalize the findings across other areas and businesses, future study should take into account conducting empirical studies and gathering more precise data. This study does not prove causation or take into account any endogeneity problems. To better understand the causal links between CSR, greenwashing, ESG variables, and sulfur emissions, future study should use more rigorous research designs, such as longitudinal studies or experimental methods. Future studies should tackle new problems and investigate creative solutions to reduce sulfur emissions and other environmental worries. This can entail looking into the potential of cutting-edge technologies, looking into fresh ways to engage stakeholders, and incorporating developing ESG frameworks into the creation and application of policy.

Authors contributions Madiha did the writing of the manuscript. Lingyan has supervised the review the manuscript. WA analyzed the results and review the manuscript. SS has collected the data and helped in analysis.

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Availability of data and materials The data and materials are provided on demand.

Code availability The codes are provided on demand.

Declarations

Conflict of interests The authors have declared that no competing interest exists.

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