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Research article

Research on the impact of energy transition policies on corporate ESG performance

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ABSTRACT

Energy transition policies are pivotal in fostering green economic growth and addressing environmental pollution. However, their potential negative effects on businesses remain underexplored. This paper examines the impact of energy transition policies on corporate ESG (Environmental, Social, and Governance) performance by leveraging a quasi-natural experiment based on the New Energy Demonstration City (NEDC) policy. Using data from Chinese A-share listed companies from 2009 to 2019 and employing a difference-in-differences (DID) model, this paper finds that the NEDC policy significantly hinders corporate ESG performance. This negative impact is primarily driven by heightened financial constraints, reduced green innovation, and increased bankruptcy risks. Furthermore, the adverse effects are more pronounced in industries characterized by high competition and high pollution. These findings highlight the challenges that energy transition policies pose to corporate sustainability and underscore the need for policymakers to design measures that mitigate these difficulties while advancing environmental objectives.

1. Introduction

The reliance on traditional fossil fuels has been a primary driver of economic growth (Song et al., 2024). However, the extensive utilization of fossil fuels has also led to significant environmental challenges, including climate change and environmental degradation (Mekhilef et al., 2011; Yao et al., 2019). These environmental issues pose substantial risks to labor productivity (Somanathan et al., 2021; Cook and Heyes, 2022), economic growth (Dell et al., 2012; Fang et al., 2024) and public health (Beland and Oloomi, 2019; Agarwal et al., 2021). In response to these pressing concerns, countries worldwide have been actively pursuing energy transition strategies to reduce dependence on fossil fuels and promote cleaner energy sources. As the world's largest energy consumer (Wang et al., 2016), China has implemented a series of policies aimed at facilitating the transition to cleaner energy, reducing carbon emissions, and improving environmental quality. Among these policies, the New Energy Demonstration City (NEDC) policy, introduced by the National Energy Administration (NEA) of China in 2014, stands out, as this policy is more comprehensive and targeted in policy design, and is considered a pivotal component in shaping the trajectory of new energy development in China (Wang and Yi, 2021). Previous research finds that the NEDC policy helps reduce carbon emissions (Gao et al., 2024) and environmental pollution (Guo et al., 2024; Yang et al., 2021b), and enhances green total factor productivity (Yang et al., 2021a) and energy efficiency (Cheng et al., 2023; Zhou et al., 2023), thereby confirming its contribution to achieving environmental goals.

With the increasing recognition of sustainable development, corporations, as important economic entities, have become central to discussions on sustainability. Corporate Environmental, Social, and Governance (ESG) performance, which assesses a firm's performance in environmental protection, social responsibilities, and corporate governance, has emerged as a crucial indicator of corporate sustainability (Zeng et al., 2024). Investors are increasingly factoring ESG performance into their investment decisions (Chen et al., 2024). Existing literature highlights the positive outcomes associated with robust ESG performance, including improved financial performance (Brogi and Lagasio, 2018), reduced default risk (Atif and Ali, 2021), lower cost of capital (Gjergji et al., 2020), and increased firm value (Seok et al., 2024). Given these advantages, it is imperative for firms to prioritize ESG performance and integrate sustainability into their operational strategies.

Several studies have examined the relationship between the NEDC

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policy and corporate ESG performance. For example, Lei (2024) finds that the NEDC policy improves ESG performance, especially among large firms and those in low-carbon industries. Similarly, Zheng et al. (2025) suggests that the NEDC policy enhances ESG performance of energy-intensive firms. However, these studies mainly focus on the incentive effects of the NEDC policy and emphasize its positive impact on businesses, they may overlook the substantial compliance costs and financing challenges that energy transition policies could impose on companies. These burdens, in turn, may undermine the ability of firms to pursue sustainability goals and deteriorate their ESG performance. Therefore, although the relationship between the NEDC policy and ESG performance has been discussed in existing literature, it remains important to revisit this issue from a different perspective, and re-examining this issue can help clarify the broader impact of energy transition policies on businesses and provide more balanced evidence for future policy design.

Using panel data of Chinese A-share listed companies from 2009 to 2019, this paper employs a difference-in-differences (DID) model to estimate the impact of the NEDC policy on corporate ESG performance. The results show that the NEDC policy significantly hinders corporate ESG performance, and this adverse is primarily driven by increased financial constraints, reduced green innovation, and elevated bankruptcy risks. Moreover, heterogeneity analysis reveals that the negative effect of the NEDC policy on corporate ESG performance is more pronounced among firms in high-competition and high-pollution industries.

This paper makes several contributes to the existing literature: (1) This paper contributes to the debate on the relationship between the NEDC policy and corporate ESG performance. Existing studies argue that the NEDC policy improves corporate ESG performance (Lei, 2024; Zheng et al., 2025), but this paper highlights the compliance burdens that the NEDC policy may impose on firms, and suggests that the NEDC policy can negatively impact ESG performance. By focusing on these previously less discussed aspects, this paper provides a more nuanced and balanced understanding of the mixed effects that energy transition policies may have on corporate sustainability. (2) Previous studies suggest that the NEDC policy fosters corporate green innovation (Song et al., 2024; Zhang et al., 2024), but this paper challenges this view by demonstrating that the policy can constrain green innovation, thereby impeding ESG performance. Specifically, the results suggest that the NEDC policy elevates carbon risk of companies, which adversely affect corporate financial performance. The resulting financial pressure will lead to a reduction in R&D expenditures on green innovation, ultimately hindering corporate ESG performance. These findings add to the academic debate on whether energy transition policies promote corporate green innovation. (3) This paper highlights the heterogeneous effects of the NEDC policy on corporate ESG performance across industries with varying characteristics. By identifying that companies in high-competition and high-pollution industries are more adversely affected by the NEDC policy, this paper underscores the need for policymakers to take into account industry-specific constraints and capacities when designing and implementing energy transition policies. By providing evidence of these differences, this paper offers practical implications for more targeted and effective regulatory design.

The reminder of this paper is structured as follows: Section 2 develops the research hypotheses. Section 3 presents the data and methodology. Section 4 outlines the empirical results, including descriptive statistics, baseline results, robustness checks, placebo tests, mechanism analysis, and heterogeneity analysis. Section 5 concludes with a discussion of the key findings and policy implications.

2. Research hypotheses

The NEDC policy is regarded as a critical initiative to accelerate the shift from fossil fuels to renewable energy (Liu et al., 2023). While the NEDC policy yields positive environmental outcomes (Gao et al., 2024; Guo et al., 2024), it may also have adverse effects on corporate sustainability. This paper identifies three underlying mechanisms, including financial constraints, green innovation, and bankruptcy risks, that explains how the NEDC policy may hinder corporate ESG performance.

The NEDC policy aims to promote sustainable energy use and reduce reliance on traditional fossil fuels (Zhou et al., 2023). However, it can also increase corporate carbon risk during the transition from a fossil-based to a low carbon economy (Nguyen and Phan, 2020), exacerbating financial constraints. Specifically, companies with higher carbon risk may incur additional costs in maintaining investor relations due to information asymmetry and reputational concerns (Herbohn et al., 2017), and companies need to make substantial investments in environmental protection to comply with the NEDC policy (Gray and Shadbegian, 2003), these increased costs can reduce future cash flows. Investors also adjust their risk assessments for firms with high carbon risk, further affecting company cash flows (Bolton and Kacperczyk, 2021). The reduced cash flow increases the uncertainty surrounding timely debt repayment (Shu and Tan, 2023), raising corporate default risk (Balachandran and Nguyen, 2018). As a results, banks can incorporate corporate carbon risk into their lending decisions (Nguyen and Shi, 2021), and may respond by increasing interest rates to offset the heightened default risk (Jung et al., 2016). Therefore, the NEDC policy can significantly amplify corporate carbon risk, leading to higher costs and greater financial constraints. This increased financial pressure, in turn, may hinder corporate ESG performance, as companies struggle to allocate sufficient funds to support their ESG initiatives.

While some studies suggest that environmental regulations can encourage firms to innovate in response to public expectations (Chakraborty and Chatterjee, 2017; Valero-Gil et al., 2023), and research has shown that the NEDC policy can effectively promote corporate green innovation (Song et al., 2024; Zhang et al., 2024), this paper argues that the NEDC policy may limit corporate green innovation due to increased financial constraints, ultimately weakening corporate ESG performance. Green innovations are characterized by high risk, long development cycles, and the need for long-lasting financial investments (Xiang et al., 2022). Since lower financial constraints are essential for stable and continuous innovation (Hsu et al., 2014), firms facing significant financial pressure tend to reduce R&D expenditures on green innovations (Zhang and Jin, 2021). Furthermore, green innovation exhibits double externalities, including knowledge spillovers and environmental benefits (Jaffe et al., 2005), which reduce the incentives for firms to engage in green innovations (Fischer and Newell, 2008). Consequently, firms may opt for external technologies (Tomás et al., 2010) or acquire firms with established green patents (Cui et al., 2023) instead of developing their own innovations. Thus, while the NEDC policy may contribute to environmental improvements, the financial constraints it imposes can crowd out R&D expenditures on green innovation, ultimately undermining corporate ESG performance.

In addition to financial constraints and green innovation, bankruptcy risks represent another critical channel through which the NEDC policy impacts corporate ESG performance. Financial distress, a well-recognized precursor to bankruptcy, occurs when companies struggle to meet financial obligations or repay debts (Cho and Hashemi Joo, 2024). Firms in financial distress often face operational instability, which can undermine their long-term commitment to ESG initiatives. The NEDC policy exacerbates corporate carbon risk (Nguyen and Phan, 2020), thereby intensifying financial distress. Specifically, carbon risk can result in additional costs of companies (Gray and Shadbegian, 2003; Herbohn et al., 2017), which strain corporate cash flows (Shu and Tan, 2023), raising the likelihood of financial distress (Adamolekun, 2024). Furthermore, carbon risk can also decrease productivity (Tao and Wu, 2025), further eroding financial stability and pushing firms closer to insolvency (Becchetti and Sierra, 2003). When facing greater financial distress, firms are more likely to prioritize restoring financial equilibrium over other strategic goals (Campbell, 2007), which may lead them to scale back investments in ESG initiatives. This will constraint corporate ESG performance and diminish their capacity for sustainable growth.

Therefore, this paper proposes the following hypotheses.

H1. The NEDC policy significantly undermines corporate ESG performance.

H2. The NEDC policy negatively impacts corporate ESG performance by intensifying financial constraints.

H3. The NEDC policy hinders corporate green innovation, contributing to a decline in corporate ESG performance.

H4. The NEDC policy heightens bankruptcy risks, thereby constraining corporate ESG performance.

3. Research design

3.1. Data

This paper employs a sample of Chinese A-share listed companies from 2009 to 2019, encompassing five years before and after the implementation of the NEDC policy. To avoid the confounding effects of the COVID-19 pandemic on corporate ESG performance, this paper excludes the data from 2020 and beyond. Information on the NEDC policy is sourced from the official website of the National Energy Administration (NEA) of China, the Bloomberg ESG scores are obtained from the Bloomberg ESG database, while other firm-level data is drawn from the CSMAR and CNRDS databases. Then, this paper refines the sample as follows: (1) Companies designated with special treatment (ST) or particular transfer (PT) are excluded to minimize the influence of abnormal financial conditions; (2) Financial firms are omitted due to their adherence to distinct accounting standards; (3) observations with missing data on main variables are removed; and (4) All continuous variables are winsorized at the 1st and 99th percentiles to reduce the impacts of outliers. Consequently, the final dataset comprises 6855 firm-year observations.

3.2. Methodology

3.2.1. Baseline regression model

This paper uses the NEDC policy as a quasi-natural experiment to examine the impact of energy transition policies on corporate ESG performance. Given that the DID model is widely regarded as the most appropriate approach for analyzing quasi-natural experiments (Slaughter, 2001; Hausman and Kuersteiner, 2008; Tu et al., 2019), the empirical model is constructed as follows:

$$ESG_{i,t} = \alpha + \beta Treat_k \times Post_t + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{1}$$

Where i represents the firm, t denotes the year, and k refers to the city. *ESG* denotes corporate ESG performance. Following Huang et al. (2025) and Wei et al. (2025), this paper use the Bloomberg ESG score as a measure of corporate ESG performance, The Bloomberg ESG score ranges from 0 to 100, with higher scores indicating better ESG performance. *Treat* is a dummy variable indicating whether a company is located in a pilot city for the NEDC policy. *Treat* is set to 1, if the company is in a pilot city, which constitutes the treatment group, while *Treat* is set to 0, if the company is in a non-pilot city, which make up the control group. *Post* is a dummy variable indicating whether the year is after 2014, the year the NEDC policy was implemented. *Post* is set to 1, if the year is 2014 or later, while *Post* is set to 0, if the year is before 2014. The coefficient β reflects the effect of the NEDC policy on corporate ESG performance. A significantly negative β indicates that the NEDC policy has a detrimental impact on corporate ESG performance. *Control* represents a set of control variables. Following previous research (Jiang et al., 2024; Cai et al., 2025), this paper controls for a range of firm-level characteristics that may influence ESG performance, including firm age (*AGE*), the proportion of independent directors (*INDE*), financial leverage (*LEV*), operating cash flow (*OCF*), return on assets (*ROA*), firm size (*SIZE*), ownership concentration (*TOP*), and Tobin's Q ratio (*TQ*). A detailed description of the main variables in this paper is provided in Table 1. δ_i denotes the firm fixed effect, μ_t represents the year fixed effect, and $\varepsilon_{i,t}$ refers to the random disturbance term.

3.2.2. Parallel trend test

Since the parallel trend assumption is crucial for the validity of the DID model, this paper follows Serfling (2016) and Dessaint et al. (2017), and adopts an event study approach to examine the dynamic effects of the NEDC policy on corporate ESG performance and test the parallel trend assumption. The empirical model employed is as follows:

$$ESG_{i,t} = \alpha + \sum_{\tau=-5}^{5} \beta_\tau Treat_k \times Year_\tau + \beta_L Treat_k \times Year_L + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{2}$$

where τ denotes the event time related to the NEDC policy, with $\tau = [-5, 5]$. Specifically, $\tau = 0$ corresponds to the year 2014, when the NEDC policy was implemented; $\tau = 1$ indicates one year after the policy (2015); and $\tau = -1$ denotes one year before the policy (2013), which serves as the comparison group. *Year* is a dummy variable indicating whether a given year corresponds to its respective event time. If the year corresponds to the event time, *Year* is set to 1; otherwise, *Year* is set to 0. To address the limited number of observations in earlier periods, this paper follows Greenstone and Hanna (2014) by introducing a dummy variable L, where $L = 1$ if $\tau < -5$, and $L = 0$ otherwise.

3.2.3. Controlling for pre-existing time trend

The event study allows for the identification of the dynamic effects of the NEDC policy on corporate ESG performance. However, if there exists

Table 1
Variable definition.

Variable	Definition
ESG	The Bloomberg's ESG score
Treat	If a company is located in a pilot city for the NEDC policy, it is set to 1; otherwise, it is set to 0
Post	If the year is 2014 or later, it is set to 1; otherwise, it is set to 0
AGE	The logarithm of number of years since the company's listing plus one
INDE	The proportion of independent directors
LEV	The ratio of total liabilities to total assets
OCF	The ratio of net cash flow from operating activities to total assets
ROA	The ratio of net profit to total assets
SIZE	The logarithm of total assets
TOP	The shareholding ratio of the largest shareholder
TQ	The ratio of company market value to total assets
FC	The Kaplan-Zingales index (Kaplan and Zingales, 1997), as a proxy for financial constraints
APP	The logarithm of green patent application volume plus one
AUT	The logarithm of green patent authorization volume plus one
BAN	The Altman's Z-score (Altman, 1968), as a proxy for bankruptcy risks
HHI	The sum of the squared market shares of companies within each industry based on operating revenue
HPI	If a company is a high-pollution industry enterprise, it is set to 1; otherwise, it is set to 0

a pre-policy trend that aligns with the post-policy trend, the impact of the NEDC policy on corporate ESG performance could be overstated. To address this potential pre-existing time trend, this paper follows Moser and Voena (2012) and constructs the empirical model as follows:

$$ESG_{i,t} = \alpha + \beta Treat_k \times Post_t + \beta_1 Treat_k \times Time_t + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{3}$$

Where $Time = [1, 11]$, corresponding to the years 2009–2019. By introducing $Treat \times Time$, this paper controls for the pre-existing time trend and accounts for unobservable factors that change linearly over time at the city level, thereby mitigating potential omitted variable bias.

3.2.4. Alternative dependent variable

For robustness, this paper uses the Huazheng ESG ratings as alternative proxy for corporate ESG performance and constructs the empirical model as follows:

$$HZ_{i,t} = \alpha + \beta Treat_k \times Post_t + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{4}$$

Where *HZ* represents the Huazheng ESG ratings, which consist of nine levels ranging from C to AAA. This paper quantifies these nine levels by assigning scores from 1 to 9, with higher score indicating better ESG performance. The Huazheng ESG ratings are obtained from the Wind database. Since the Huazheng ESG ratings are issued quarterly, this paper adopts the median score to measure a company's annual ESG performance.

3.2.5. Instrumental variable (IV) approach

This paper employs an IV approach to tackle potential endogeneity concerns. Specifically, this paper uses the drainage density of the city where a company is located as the instrument. As cities with higher drainage density can enjoy lower transportation costs, facilitating better economic development, these cities are likely to have more resources to implement energy transition policies. Additionally, economic development brings about carbon emissions and environmental pollution, creating greater pressure to adopt energy transition policies. Furthermore, drainage density is a geographical characteristic, it should be independent of corporate ESG performance. Therefore, drainage density meets both the relevance and exogeneity requirements for a valid IV. As drainage density is constant with time, this paper uses the interaction term between drainage density and *Post* as the instrument for $Treat \times Post$ to avoid absorption by the year fixed effect.

3.2.6. Propensity score matching difference-in-differences (PSM-DID) approach

To address the systematic differences in the changing trends between the treatment and control groups and reduce the estimation error of the DID model, this paper follows Yang et al. (2021b), and adopts a PSM-DID approach. Specifically, this paper first uses all control variables, including *AGE*, *INDE*, *LEV*, *OCF*, *ROA*, *SIZE*, *TOP*, and *TQ*, as covariates, and uses a logit regression model to estimate the propensity scores for the treatment group samples. Then, this paper uses the 1:1 nearest neighbor matching technique to pair treatment and control group samples with the most similar propensity scores. Finally, this paper uses the matched samples and the baseline regression model to re-estimate the impact of the NEDC policy on corporate ESG performance.

3.2.7. Controlling for other policies

The research sample of this paper covers the period from 2009 to 2019, during which several other urban development policies were introduced. These policies may influence corporate ESG performance, potentially confounding the estimated impact of the NEDC policy. Notably, the implementation periods of the Low Carbon City Pilot Policy (LCCPP) and the Smart City Pilot Policy (SCPP) overlap with the research timeframe of this paper. To account for the potential effects of these two policies, this paper constructs the empirical model as follows:

$$ESG_{i,t} = \alpha + \beta Treat_k \times Post_t + \beta_1 LCCPP_{k,t} + \beta_2 SCPP_{k,t} + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{5}$$

Where *LCCPP* is a dummy variable that equals 1 if the city where a company is located implemented the LCCPP policy in a given year and 0 otherwise. Similarly, *SCPP* is a dummy variable that equals 1 if the city where a company is located implements the SCPP policy in a given year and 0 otherwise.

3.2.8. Controlling for greenwashing

Greenwashing is prevalent in China, partly due to the weak enforcement of environmental laws and regulations (Du, 2014). Companies in pilot cities may engage in greenwashing to create the appearance of compliance with the NEDC policy, potentially distorting its estimated impact. To account for this, this paper constructs the empirical model as follows:

$$ESG_{i,t} = \alpha + \beta Treat_k \times Post_t + \beta_1 GWS_{i,t} + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{6}$$

Where GWS denote greenwashing. This paper follows Yu et al. (2020), and constructs a peer-relative greenwashing score as a measure of greenwashing. Specifically, this paper first calculates a normalized measure representing a firm's relative position within its industry based on the distribution of the Bloomberg ESG score. Next, this paper calculates a similar normalized measure using the distribution of the Huazheng ESG ratings. The difference between these two normalized measures serves as a proxy for greenwashing.

3.2.9. Placebo tests

Firstly, this paper conducts a placebo test on policy implementation timing by assuming that the NEDC policy was implemented earlier and constructs the empirical model as follow:

$$ESG_{i,t} = \alpha + \beta Treat_k \times Post_t + \beta_1 Treat_k \times Pre_n + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{7}$$

Where $n = [1, 4]$, corresponding to the assumption that the NEDC policy was implemented n years earlier. *Pre* is a dummy variable indicating whether the year falls within the period from 2014, the actual implementation year of the NEDC policy, to n years before 2014. If the year falls within this period, *Pre* is set to 1; otherwise, it is set to 0. If the coefficients for $Treat \times Pre$ are statistically insignificant while the coefficients for $Treat \times Post$ remain consistent with the baseline results, it suggests that corporate ESG performance did not respond to the NEDC policy before its actual implementation. This finding would indicate that earlier policies did not interfere with the estimated impact of the NEDC policy on corporate ESG performance, thereby enhancing the robustness of the baseline results.

Then, this paper follows Chetty et al. (2009), and conducts a placebo test on policy implementation city. Specifically, this paper randomly assigns the pilot cities of the NEDC policy and assumes that the policy was implemented in these cities in 2014. Using the baseline regression model, this paper then re-estimate the impact of the NEDC policy on corporate ESG performance and records the estimated coefficient and p-value. This procedure is repeated for 500 times. If the resulting coefficients significantly deviate from the baseline results, it suggests that other policies implemented during the same period did not interfere with the baseline results.

3.2.10. Mechanism analysis

This paper suggests that the NEDC policy can significantly hinder corporate ESG performance by exacerbating financial constraints, limiting green innovation, and increasing bankruptcy risks. To further explore the mediating roles of these factors, this paper constructs the empirical models as follows:

$$FC_{i,t} = \alpha + \beta Treat_k \times Post_t + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{8}$$

$$ESG_{i,t} = \alpha + \beta FC_{i,t} + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{9}$$

$$APP_{i,t} = \alpha + \beta Treat_k \times Post_t + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{10}$$

$$ESG_{i,t} = \alpha + \beta APP_{i,t} + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{11}$$

$$AUT_{i,t} = \alpha + \beta Treat_k \times Post_t + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{12}$$

$$ESG_{i,t} = \alpha + \beta AUT_{i,t} + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{13}$$

$$BAN_{i,t} = \alpha + \beta Treat_k \times Post_t + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{14}$$

$$ESG_{i,t} = \alpha + \beta BAN_{i,t} + \gamma Control_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \tag{15}$$

Where *FC* denotes corporate financial constraints. This paper follows Tran et al. (2024) and Haider et al. (2024), and adopts the Kaplan-Zingales (KZ) index (Kaplan and Zingales, 1997) as a proxy for financial constraints, where a higher KZ index indicates greater financial constraints. *APP* represents green patent applications, and *AUT* refers to green patent authorizations. To address the skewness in the distribution of green patent applications and authorizations, this paper measures corporate green innovation using the logarithm of green patent application volume plus one and the logarithm of green patent authorization volume plus one. *BAN* represents corporate bankruptcy risks. This paper follows Adamolekun (2024) and Cho and Hashemi Joo (2024), and employs Altman's Z-score (Altman, 1968) as a proxy for bankruptcy risks. The Altman's Z-sore incorporates various financial indicators, such as profitability, leverage, liquidity, solvency and operational efficiency, to estimate the likelihood of corporate bankrupt (Cho and Hashemi Joo, 2024). A lower Altman's Z-score indicates higher bankruptcy risks.

3.2.11. Heterogeneity analysis

To explore whether the impact of the NEDC policy on corporate ESG performance varies across industries with different characteristics, this paper conducts heterogeneity analysis using sub-sample regressions.

On the one hand, this paper examines whether the impact of the NEDC policy differs by the level of market competition. Market competition is measured using the Herfindahl-Hirschman Index (*HHI*), calculated as the sum of squared market shares of companies within each industry based on operating revenue. A higher *HHI* value indicates lower market competition. The sample is the split at the median *HHI* value: industries with above-median *HHI* form the low-competition group (Low Competition), while those with below-median *HHI* constitute the high-competition group (High Competition). Then, the baseline regression model is applied to each sub-sample to estimate the effect of the NEDC policy on corporate ESG performance. On the other hand, this paper also investigates whether the impact of the NEDC policy varies by industry pollution degree. Companies are classified based on whether they belong to high-pollution industries. If a company operates in a high-pollution industry, *HPI* is set to 1, forming the high-pollution group (HPI); otherwise, *HPI* is set to 0, forming the non-high-pollution group

Table 2
Descriptive statistics.

Variable	N	Mean	Median	SD	Min	Max
ESG	6855	26.18	26.16	7.87	7.85	63.37
Treat	6855	0.18	0	0.38	0	1
Post	6855	0.62	1	0.49	0	1
AGE	6855	2.28	2.48	0.77	0	3.37
INDE	6855	0.37	0.36	0.06	0.31	0.57
LEV	6855	0.49	0.50	0.19	0.07	0.86
OCF	6855	0.06	0.05	0.07	−0.14	0.26
ROA	6855	0.05	0.04	0.05	−0.14	0.22
SIZE	6855	23.13	22.99	1.34	20.48	27.05
TOP	6855	0.38	0.37	0.16	0.08	0.77
TQ	6855	1.94	1.53	1.24	0.87	8.21
FC	6855	1.19	1.47	2.27	−6.25	5.90
APP	6855	0.57	0	1.08	0	7.34
AUT	6855	0.96	0.69	1.24	0	6.90
BAN	6855	5.18	3.06	6.72	0.30	48.70
HHI	6855	0.16	0.10	0.16	0.03	1
HPI	6855	0.29	0	0.45	0	1

Note: This table provides the descriptive statistics for the main variables in this paper, detailing the number of observations (N), mean (Mean), median (Median), standard deviation (SD), minimum value (Min), and maximum value (Max).

Table 3
Baseline results.

Variable	(1)	(2)
	ESG	ESG
Treat × Post	−1.245***	−1.235***
	(0.263)	(0.264)
Constant	26.306***	21.423***
	(0.049)	(3.429)
Observations	6855	6855
Adjusted R^2	0.813	0.814
Controls	NO	YES
Firm FE	YES	YES
Year FE	YES	YES

Note: Standard errors, clustered at the city level, are provided in parentheses. Statistical significance is denoted by ***, **, and * for the 1 %, 5 %, and 10 % levels, respectively.

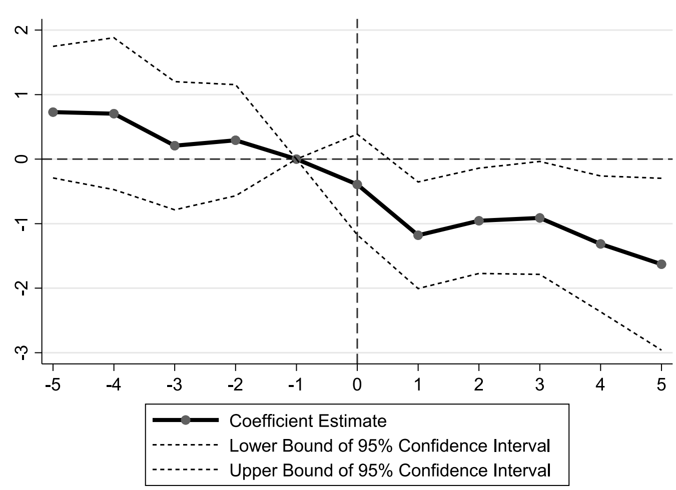

Fig. 1. Parallel trend test. Note: This figure illustrates the dynamic effects of the NEDC policy on corporate EGS performance. The coefficients for *Treat* × *Post* are statistically insignificant before the implementation of the NEDC policy, indicating no significant difference in the pre-policy trends between the treatment and control groups.

(Non-HPI). Then, the baseline regression model is again used to assess the impact of the NEDC policy within these two sub-samples.

4. Empirical results

4.1. Descriptive statistics

Table 2 presents the descriptive statistics for the main variables. The *ESG* variable ranges from 7.85 to 63.37, with a mean of 26.18 and a standard deviation of 7.87. These results indicate that the ESG performance of Chinese listed companies is generally low and shows significant variation across companies. Additionally, the median value of *ESG* is 26.16, which is close to its mean value, suggesting a relatively symmetrical distribution of corporate ESG performance across the sample.

4.2. Baseline results

This paper employs a DID model to explore the impact of the NEDC policy on corporate ESG performance, with the baseline results reported in Table 3. Column (1) presents the regression results without control variables, while Column (2) includes them. The coefficients for *Treat* × *Post* in both columns are significantly negative at the 1 % significance level, indicating that the NEDC policy negatively affects corporate ESG performance, thus supporting Hypothesis H1.

4.3. Robustness checks

4.3.1. Parallel trend test

Fig. 1 illustrates the dynamic effects of the NEDC policy on corporate ESG performance. The coefficients for *Treat* × *Post* are statistically insignificant before the implementation of the NEDC policy, indicating no significant difference in the pre-policy trends between the treatment and control groups. After the implementation of the NEDC policy, the coefficients for *Treat* × *Post* become significantly negative, highlighting the adverse impacts of the NEDC policy on corporate ESG performance. These results provide evidence supporting the parallel trend assumption and reinforce the robustness of the baseline findings.

4.3.2. Controlling for pre-existing time trend

Fig. 1 shows that although the coefficients for *Treat* × *Post* are statistically insignificant before the policy, there is a downward pre-policy trend that align with the trend observed after the policy. This suggests that the baseline results can be overestimated due to this pre-existing time trend. To account for this, this paper controls for the pre-existing time trend and reports the results in Column (1) of Table 4. The coefficient for *Treat* × *Post* is significantly negative at the 5 % significance level, further supporting the robustness of the baseline findings.

4.3.3. Alternative dependent variable

This paper uses the Huazheng ESG ratings as an alternative proxy for corporate ESG performance. The results, presented in Column (2) of Table 4, show that the coefficient for *Treat* × *Post* is significantly negative at the 5 % significance level, confirming the robustness of the baseline findings.

4.3.4. Instrumental variable (IV) approach

This paper uses an IV approach to address potential endogeneity concerns and reports the results in Column (3) of Table 4. The Kleibergen-Paap rk Wald F statistics is 29.789, exceeding the critical value at the 10 % significance level (Stock and Yogo, 2005), confirming the validity of the chosen IV. Furthermore, the coefficient for *Treat* × *Post* is significantly negative at the 5 % significance level, providing additional support for the robustness of the baseline findings.

4.3.5. Propensity score matching difference-in-differences (PSM-DID) approach

To address the systematic differences in the changing trends between the treatment and control groups and reduce the estimation error of the DID model, this paper employs a PSM-DID approach and presents the results in Column (4) of Table 4. The coefficient for *Treat* × *Post* remains significantly negative at the 1 % significance level, which is consistent with the baseline results.

4.3.6. Controlling for other policies

As other urban development policies may affect corporate ESG performance and confound the estimated impact of the NEDC policy, this paper controls for the effects of the LCCPP policy and the SCPP policy, whose implementation periods overlap with the research period, on corporate ESG performance. The results are presented in Column (5) of Table 4. The coefficient for *Treat* × *Post* remains significantly negative at the 1 % significance level, further supporting the baseline findings that the NEDC policy hinders corporate ESG performance.

Table 4
Results of robustness checks.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	ESG	HZ	ESG	ESG	ESG	ESG
Treat × Post	−0.964**	−0.137**	−17.581**	−1.680***	−1.230***	−1.051***
	(0.445)	(0.064)	(6.918)	(0.447)	(0.264)	(0.236)
LCCPP					0.005	
					(0.202)	
SCPP					0.310	
					(0.223)	
Treat × Time	−0.053					
	(0.083)					
GWS						2.020***
						(0.071)
Constant	21.406***	−0.285		7.414	21.202***	14.499***
	(3.427)	(0.663)		(8.310)	(3.443)	(3.135)
Observations	6855	6855	6855	1846	6855	6855
Adjusted R^2	0.814	0.557		0.775	0.814	0.844
Centered R^2			−0.501			
Controls	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
KP-Wald F statistic			29.789			

Note: Standard errors, clustered at the city level, are provided in parentheses. Statistical significance is denoted by ***, **, and * for the 1 %, 5 %, and 10 % levels, respectively.

Table 5
Results of placebo test on policy implementation timing.

Variable	(1)	(2)	(3)	(4)
	ESG	ESG	ESG	ESG
Treat × Post	−1.284***	−1.371***	−1.506***	−1.659***
	(0.291)	(0.336)	(0.394)	(0.518)
Treat × Pre_1	−0.183			
	(0.380)			
Treat × Pre_2		−0.272		
		(0.348)		
Treat × Pre_3			−0.388	
			(0.389)	
Treat × Pre_4				−0.495
				(0.510)
Constant	21.428***	21.423***	21.439***	21.467***
	(3.429)	(3.429)	(3.428)	(3.429)
Observations	6855	6855	6855	6855
Adjusted R^2	0.814	0.814	0.814	0.814
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note: Standard errors, clustered at the city level, are provided in parentheses. Statistical significance is denoted by ***, **, and * for the 1 %, 5 %, and 10 % levels, respectively.

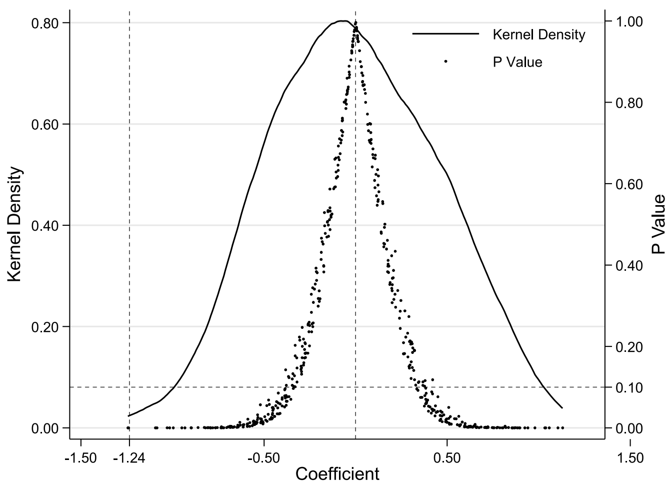

Fig. 2. Placebo test with alternative implementation cities. Note: This figure presents the kernel density curve of the estimated coefficients obtained from the 500 iterations, along with the scatter plot of their corresponding p-values.

4.3.7. Controlling for greenwashing

As greenwashing may confound the estimated impact of the NEDC policy on corporate ESG performance, this paper controls for greenwashing and presents the results in Column (6) of Table 4. The coefficient for *GWS* is significantly positive, confirming the presence of greenwashing. Moreover, the coefficient for *Treat* × *Post* remains significantly negative at the 1 % significance level, which is consistent with the baseline results.

4.4. Placebo tests

4.4.1. Placebo test on policy implementation timing

To ensure that there is no early response of corporate ESG performance to the NEDC policy and that other policies implemented earlier than the NEDC policy do not interfere with its impact, this paper conducts a placebo test on policy implementation timing and presents the results in Table 5. In all columns, the coefficients for *Treat* × *Pre* are statistically insignificant, while the coefficients for *Treat* × *Post* remain significantly negative at the 1 % significance level, which helps confirm the robustness of the baseline findings.

Table 6
Results of mechanism analysis: financial constraints.

Variable	(1)	(2)
	FC	ESG
Treat × Post	0.187***	
	(0.060)	
FC		−0.150***
		(0.053)
Constant	4.336***	21.544***
	(0.969)	(3.428)
Observations	6855	6855
Adjusted R^2	0.850	0.813
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES

Note: Standard errors, clustered at the city level, are provided in parentheses. Statistical significance is denoted by ***, **, and * for the 1 %, 5 %, and 10 % levels, respectively.

4.4.2. Placebo test on policy implementation city

To ensure that other policies implemented during the same period as the NEDC policy do not interfere with the baseline results, this paper conducts a placebo test on policy implementation city. Fig. 2 presents the kernel density curve of the estimated coefficients obtained from the 500 iterations, along with the scatter plot of their corresponding p-values. The kernel density approximates a normal distribution centered around 0, with most of these coefficients being greater than the baseline results, and the majority of p-values exceeding 0.1. These results provide additional evidence supporting the robustness of the baseline findings.

4.5. Mechanism analysis

Previous analyses show that the NEDC policy negatively affects corporate ESG performance. In this section, this paper explores three potential mechanisms that may explain how the NEDC policy influences corporate ESG performance, including financial constraints, green innovation, and bankruptcy risks.

First, this paper examines the mediating effect of financial constraints on the relationship between the NEDC policy and corporate ESG performance, with results presented in Table 6. In Column (1), the coefficient for *Treat* × *Post* is significantly positive, showing that the NEDC policy exacerbates financial constraints. In Column (2), the coefficient for *FC* is significantly negative, demonstrating an inverse relationship between financial constraints and corporate ESG performance. These results suggest that the NEDC policy increases financial constraints, which in turn hampers corporate ESG performance, supporting

Table 7
Results of mechanism analysis: green innovation.

Variable	(1)	(2)	(3)	(4)
	APP	ESG	AUT	ESG
Treat × Post	−0.133***		−0.113**	
	(0.034)		(0.044)	
APP		0.438***		
		(0.097)		
AUT				0.544***
				(0.082)
Constant	−1.358**	21.501***	−5.101***	23.681***
	(0.571)	(3.416)	(0.676)	(3.412)
Observations	6855	6855	6855	6855
Adjusted R^2	0.758	0.814	0.773	0.815
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note: Standard errors, clustered at the city level, are provided in parentheses. Statistical significance is denoted by ***, **, and * for the 1 %, 5 %, and 10 % levels, respectively.

Table 8
Results of mechanism analysis: bankruptcy risk.

Variable	(1)	(2)
	BAN	ESG
Treat × Post	−0.525***	
	(0.192)	
BAN		0.066***
		(0.016)
Constant	15.223***	19.884***
	(3.111)	(3.457)
Observations	6855	6855
Adjusted R^2	0.857	0.813
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES

Note: Standard errors, clustered at the city level, are provided in parentheses. Statistical significance is denoted by ***, **, and * for the 1 %, 5 %, and 10 % levels, respectively.

Hypothesis H2.

Next, this paper explores whether the NEDC policy hinders corporate ESG performance by limiting corporate green innovation. The results are presented in Table 7. In Column (1) and (3), the coefficients for *Treat* × *Post* are significantly negative, indicating that the NEDC policy reduces corporate green innovation. Furthermore, the coefficients for *APP* in Column (2) and for *AUT* in Column (4) are significantly positive, indicating a positive relationship between green innovation and corporate ESG performance. These findings confirm that the NEDC policy limits corporate ESG performance by constraining green innovation, thus supporting Hypothesis H3.

Finally, this paper examining whether bankruptcy risks mediate the relationship between the NEDC policy and corporate ESG performance. The results are reported in Table 8. In Column (1), the coefficient for *Treat* × *Post* is significantly negative, suggesting that the NEDC policy increases corporate bankruptcy risks. In Column (2), the coefficient for *BAN* is significantly positive, indicating that higher bankruptcy risks are associated with lower corporate ESG performance. These findings confirm that bankruptcy risks play a mediating role in the negative impact of the NEDC policy on corporate ESG performance, thereby supporting Hypothesis H4.

The results presented above indicate that the NEDC policy hinders corporate ESG performance by increasing financial constraints, discouraging green innovation, and exacerbating bankruptcy risks. To further verify the mediating roles of these mechanisms, this paper employs a Bootstrap-based mediation analysis to estimate the total effect, direct effect, and indirect effect. The results are shown in Table 9, and the mediating effects are derived using a Bootstrap resampling procedure with 5000 iterations. The estimated direct effect is −1.086, while the total indirect effect amounts to −0.149. The 95 % confidence intervals for both the direct effect and the total indirect effect exclude zero, indicating their statistical significance. Moreover, the 95 % confidence intervals for the indirect effects of all four mediators also exclude zero, further confirming the significant mediating roles of financial constraints, green innovation, and bankruptcy risks in the relationship between the NEDC policy and corporate ESG performance.

Table 9
Results of Bootstrap test.

	Observed Coef.	Bootstrap Std. Err.	Bootstrap 95 % CI	
			Lower	Upper
Gross Effect	−1.23501	0.23275	−1.69119	−0.77883
Direct Effect	−1.08600	0.25461	−1.58503	−0.58697
Indirect Effect (FC)	−0.02597	0.01160	−0.04871	−0.00324
Indirect Effect (APP)	−0.04041	0.01983	−0.07927	−0.00155
Indirect Effect (AUT)	−0.05283	0.02655	−0.10487	−0.00079
Indirect Effect (BAN)	−0.02979	0.01513	−0.05945	−0.00013
Total Indirect Effect	−0.14901	0.03424	−0.21612	−0.08189

Note: This table presents the observed coefficients, the Bootstrap standard errors, and the Bootstrap 95 % confidence intervals of the gross effect, direct effect, and indirect effect.

4.6. Heterogeneity analysis

4.6.1. Market competition

Companies in highly competitive industries are more exposed to market risks and often face difficulties in attracting investor support (Li et al., 2024), which leads to limited resources. When the NEDC policy imposes additional costs, their financial burden intensifies, crowding out their R&D investments in green innovation and raising the risk of financial distress. This, in turn, restricts the ESG performance of these companies. In contrast, companies in less competitive industries encounter fewer market risks and typically have more resources at their disposal. Despite the added costs imposed by the NEDC policy, these companies are less likely to face severe financial constraints. As a results, the extra costs have a less significant impact on their green innovation expenditures and financial stability, resulting in a more moderate effect on their ESG performance. Therefore, the impact of the NEDC policy on corporate ESG performance is expected to be more pronounced in highly competitive industries than in less competitive ones.

To test this hypothesis, this paper conducts a heterogeneity analysis based on market competition. The results are presented in Table 10. The coefficients for *Treat* × *Post* are −1.845 for the high-competition group and −0.677 for the low-competition group. Although both coefficients are significantly negative, the p-value from the Fisher's permutation test is 0.002, indicating a significant difference in the effect of the NEDC policy on ESG performance between highly competitive and less competitive industries. These results confirm that the negative impact of the NEDC policy on corporate ESG performance is more substantial in highly competitive industries.

4.6.2. Degree of pollution

Companies in high-pollution industries encounter greater challenges and attract more scrutiny during the energy transition process. As a result, the NEDC policy imposes a heavier financial burden on these companies, exacerbating their financial constraints, reducing R&D investments in green innovation, and ultimately impairing their ESG performance. In contrast, companies in non-high-pollution industries face less regulatory pressure, and the costs induced by the NEDC policy can be lower compared to those in high-pollution industries, which

Table 10
Results of heterogeneity analysis: market competition.

Variable	(1)	(2)
	High Competition	Low Competition
	ESG	ESG
Treat × Post	−1.845***	−0.677*
	(0.416)	(0.390)
Constant	22.268***	20.616***
	(5.261)	(5.506)
Observations	3395	3392
Adjusted R^2	0.825	0.808
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
Permutation test	0.002***	

Note: Standard errors, clustered at the city level, are provided in parentheses. Statistical significance is denoted by ***, **, and * for the 1 %, 5 %, and 10 % levels, respectively.

Table 11
Results of heterogeneity analysis: degree of pollution.

Variable	(1)	(2)
	HPI	Non-HPI
	ESG	ESG
Treat × Post	−1.856***	−0.986***
	(0.527)	(0.314)
Constant	3.208	23.569***
	(9.375)	(3.993)
Observations	1943	4891
Adjusted R^2	0.822	0.814
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
Permutation test	0.000***	

Note: Standard errors, clustered at the city level, are provided in parentheses. Statistical significance is denoted by ***, **, and * for the 1 %, 5 %, and 10 % levels, respectively.

reduces the likelihood of cutting R&D expenditures in green innovations and lessens the impact on their ESG performance. Therefore, the effect of the NEDC policy on corporate ESG performance is expected to be more significant in high-pollution industries than in non-high-pollution ones.

To examine this hypothesis, this paper conducts a heterogeneity analysis based on the degree of pollution. The results are shown in Table 11. The coefficients for *Treat* × *Post* are −1.856 for the high-pollution group and −0.986 for the non-high-pollution group. While both coefficients are significantly negative, the p-value from the Fisher's permutation test is 0.000, suggesting a significant difference in the impact of the NEDC policy on ESG performance between high-pollution and non-high-pollution industries. These results confirm that the negative impact of the NEDC policy on corporate ESG performance is more pronounced in high-pollution industries.

5. Conclusion

Energy transition policies are vital in fostering green economic development and combating environmental pollution. This paper takes the NEDC policy, introduced in 2014, as a quasi-natural experiment, using data from Chinese A-share listed companies from 2009 to 2019 and employing a DID model to assess the impact of energy transition policies on corporate ESG performance. The findings reveal that the NEDC policy significantly hampers corporate ESG performance. This finding holds up through a range of robustness checks and placebo tests. Mechanism analysis suggests that the policy negatively affects ESG performance by increasing financial constraints, restricting green innovation, and raising bankruptcy risks. Moreover, the heterogeneity analysis shows that the impact of the NEDC policy on corporate ESG performance is more substantial in industries with high competition and high pollution. While energy transition policies can generate positive environmental effects, they may also have adverse implications for corporate sustainability, warranting careful consideration by policymakers.

Compared with previous studies that report positive effects of the NEDC policy on ESG performance (Lei, 2024; Zheng et al., 2025), this paper reaches a different conclusion. One possible reason is that existing studies mainly focus on the incentive effects of the policy and tend to highlight its benefits for corporate sustainability. In contrast, this paper pays more attention to the potential negative effects of the NEDC policy, especially the compliance costs and financial pressures that firms may face during its implementation. These pressures could reduce firms' ability to improve ESG performance. The difference in research focus helps explain why the conclusions of this paper differ from those of previous studies.

Furthermore, this paper provides important theoretical implications. This paper extends the literature on ESG performance and energy transition policies by showing that the impact of such policies on corporate sustainability is not necessarily positive. While prior research primarily emphasizes the incentive effects of energy transition policies, the findings of this paper demonstrate that, under certain conditions, compliance burdens of such policies may outweigh their intended benefits. This offers a more balanced theoretical perspective on how energy transition policies influence firm behavior, suggesting that the pressure induced by energy transition policies can play both enabling and constraining roles in shaping corporate ESG outcomes. This duality highlights the need for theoretical frameworks to better account for the varying conditions under which energy transition policies affect corporate sustainability.

Despite its contributions, this paper has several limitations: (1) This paper focuses exclusively on listed companies due to data availability. However, non-listed firms also constitute a significant part of the economy, and their ESG performance plays an important role in achieving sustainable development. The exclusion of these firms may limit the generalizability of the findings. Future research could explore alternative methods to evaluate the ESG performance of non-listed firms and examine whether energy transition policies have similar effects in that context. (2) This paper identifies three mechanisms through which energy transition policies negatively affect corporate ESG performance, including increased financial constraints, reduced green innovation, and elevated bankruptcy risk. While these mechanisms help explain the observed effects, they may not capture the full range of policy impacts. Future studies could investigate additional potential channels to further clarify the pathways through which energy transition policies influence corporate sustainability.

Based on the findings, this paper offers important policy implications for both policymakers and businesses, aimed at mitigating the adverse effects of energy transition policies on businesses while addressing environmental challenges: (1) For policymakers, addressing the negative impact of energy transition policies on corporate ESG performance requires a more supportive and adaptive approach. First and foremost, expanding access to green financing mechanisms, such as green bonds, sustainability-linked loans, and preferential credit lines, is crucial for helping firms overcome financial constraints. Additionally, policymaker should provide financial incentives, including tax breaks and direct subsidies, to encourage investments in renewable energy, energy efficiency, and pollution reduction technologies. These measures will help companies manage the higher costs associated with transitioning to sustainable practices. Furthermore, policymakers should promote green innovation by offering targeted R&D incentives, such as grants for sustainable technology research, tax deductions for green patents, and subsidies for collaborative innovation projects. Finally, ensuring regulatory flexibility through phased or tiered implementation of energy transition policies would allow firms sufficient time to adapt. This approach should be tailored to the specific needs of different industries, providing a more gradual transition to renewable energy without imposing undue financial pressure. (2) For businesses, especially those in high-competition and high-pollution industries, adapting to energy transition policies requires both strategic investments and operational changes. Firms should prioritize investments in clean technologies and diversify their energy sources to comply with evolving regulations and ensure long-term competitiveness. Companies should also explore green financing options to secure the necessary capital for green projects while alleviating financial constraints. In addition, businesses should invest in workforce upskilling and reskilling programs to help employees develop the skills needed for emerging green industries, such as renewable energy and sustainable technologies. By partnering with educational institutions, companies can better prepare their workforce for these changes, reducing the risks of job displacement and facilitating a smoother transition to greener operations. Lastly, businesses should actively engage in policy dialogues and provide feedback to policymakers on the challenges and opportunities they face during the implementation of energy transition policies. Such engagement will allow companies to influence the design of more effective, industry-specific policies, ensuring that the energy transition remains both feasible and beneficial for all stakeholders involved.

CRediT authorship contribution statement

Zhengge Tu: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Yu Cao:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation. **Gang Ma:** Writing – review & editing, Visualization, Validation, Resources, Methodology, Formal analysis, Data curation. **Mark Goh:** Writing – review & editing, Validation, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Yujia Wang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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Declaration of competing interest

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Data availability

Data will be made available on request.

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