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Sustainable knowledge integration: Enhancing green development resilience

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ABSTRACT

The revised Environmental Protection law (NEPL), enacted in 2015, introduced stricter regulations to address environmental challenges and promote sustainable development. This study investigated the law's impact on enterprise green development resilience (EGDR) through a novel integration of institutional and resource-based theories. Employing the Vertical and Horizontal Slot-Drawing (VHSD) and entropy methods, we developed a comprehensive framework to systematically measure EGDR, capturing both dynamic and structural aspects of resilience. Our findings revealed that, from an institutional perspective, compliance with environmental laws enhances corporate legitimacy and fosters green development. Meanwhile, the resource-based view highlighted how NEPL improves EGDR by promoting green knowledge, stimulating green innovation, offering policy incentives, and easing financial constraints. Notably, the law's effectiveness varies across regions and technological contexts, underscoring significant heterogeneity. These findings uncovered previously unexplored mechanisms linking environmental law enforcement and enterprise resilience, providing actionable insights for policymakers to design more effective environmental strategies. This study contributes to sustainable development research by advancing the understanding of how regulatory frameworks shape green resilience, offering a new lens to examine the interplay between environmental governance and business sustainability.

Introduction

Achieving sustainability is challenging in a changing and complex business environment. Enterprises face various barriers that hinder their progress toward becoming green (Morioka et al., 2017). For example, increasing consumer awareness of green issues requires companies to be agile in responding to changing consumer behaviors (Zhang et al., 2020). This has been a significant learning for Chinese companies. The New Environmental Protection law (NEPL), which came into effect in 2015, marked a significant turning point in China's environmental governance framework. Often referred to as the "toughest environmental protection law in history," the NEPL introduced stringent measures to address serious environmental problems, such as air pollution. To address these pressing challenges, the NEPL incorporated groundbreaking mechanisms for enforcement, including introducing real-time pollution monitoring, raising penalties for non-compliance by 500 percent, and expanding legal accountability for corporate executives. In the first year of implementation, fines totaling approximately 7.8 billion yen (US$1.2 billion) were issued, a 34 percent increase from the previous year. More than 18,000 companies were penalized for violating environmental regulations, and about 3000 facilities were closed for violations. These figures highlight the scope and reach of the NEPL, a regulatory milestone in China's green transformation.

The challenges associated with the implementation of the law show that some companies lacked the financial capital to install costly equipment, while others had insufficient knowledge about green development (Yang et al., 2022). Additionally, some companies were found to have a lack of green-aware talent, weakening their product competitiveness and negatively affecting their market position (Lin & Fan, 2024). Other companies faced criticism for greenwashing rather than pursuing genuine green development. When subjected to such criticism or misunderstandings, companies are urged to quickly adjust and update their programs to become truly sustainable. This report defines the dynamic ability to overcome such challenges as enterprise green development resilience, building on the concepts of green development and organizational resilience. Green development refers to

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socially inclusive and environmentally friendly modes of economic growth, focusing on the efficient use of natural resources, reducing environmental impacts, and minimizing pollution emissions (Gokhale, 2021). While the earlier definition prioritizes outcomes, this study emphasizes the process through which companies implement environmentally sustainable strategies and practices, thereby maximizing economic growth without compromising the environment. With the pressing challenges presented by climate change and stricter environmental regulations (Liu & Cao, 2024), corporations are required to expand their ability to integrate, build, and reconfigure internal and external competencies in a rapidly changing environment (Bocken & Geradts, 2020). The first important dimension of green development resilience is adaptability, which refers to the ability to adjust business models and operations in response to changing market demands, environmental regulations, and climate change impacts (Yasir et al., 2020). The second dimension is the ability to withstand the pressure to green their business activities, whether from the government or the public (Lin & Fan, 2024). The third dimension is having a well-designed risk management system to deal with risks and recover quickly from damages when green development strategies are questioned by the state or public (Settembre-Blundo et al., 2021). In summary, enterprise green development resilience is the ability to adapt, withstand, and recover from challenges during the process of greening business activities. The implementation of the New Environmental Protection law (NEPL) has significantly heightened companies' focus on enhancing their environmental capabilities. Stringent regulations compel firms to swiftly adapt to stricter standards, such as reducing emissions and embracing cleaner technologies. This adaptability is crucial for maintaining competitiveness in a rapidly evolving marketplace. Furthermore, the NEPL has intensified external pressures on companies, including more frequent inspections, higher fines, and rising public expectations for transparency and authenticity in green practices. These pressures particularly challenge the operational sustainability of small and medium-sized enterprises. Simultaneously, the reputational risks associated with regulatory violations or accusations of "greenwashing" underscore the importance of robust risk management systems. Such systems enable companies to mitigate potential damage, respond effectively to unexpected crises, and rebuild public trust as they pursue sustainable development. In this context, the NEPL not only encourages corporate compliance with environmental regulations but also serves as a critical catalyst in building resilience during this process. By strengthening adaptability, resilience, and risk management capabilities, the NEPL lays a solid foundation for companies to thrive amid strict environmental governance frameworks. However, the effectiveness of the New Environmental Protection law (NEPL) and its impacts on corporate resilience have varied significantly across different regions and industries. This study highlights the heterogeneity of these impacts, showing that the regional context and technological readiness of companies significantly influence how they adapt to and benefit from these regulations. The findings suggest that the same regulatory framework may have differing impacts depending on local economic conditions, industrial structures, and levels of environmental awareness, thus providing valuable insights into the varying dynamics of green development resilience across regions and countries.

The remainder of the paper is organized as follows: Section 2 provides a literature review, while Section 3 outlines the research hypotheses based on relevant theories and research objectives. Section 4 details the research methodology, including variables and data sources. Section 5 presents the results of the empirical analysis, and Section 6 discusses and summarizes the findings from both longitudinal and cross-sectional studies.

Literature review

Previous studies have focused on exploring how environmental regulations and laws incentivize enterprises to engage in green development and how they enhance firm resilience. The study by Polzin et al. (2019) revealed that policies promoting renewable energy development influence private entities to invest in new energy. Huang and Lei (2021) and Liu et al. (2022) also revealed that environmental regulations play a role in positively enhancing the negative relationship between CSR and air pollution (Jiménez-Parra et al., 2018). Meanwhile, Tang et al. (2024) found that environmental regulations primarily encourage companies to engage in greenwashing. Zhang and Zhao (2022) highlighted that environmental regulations encourage state-owned companies more than they do non-state-owned companies to engage in strategic-political CSR engagement. To sum up, environmental law encourages businesses to pursue green development primarily by influencing organizational behavior. Existing research has examined how environmental regulations influence business resilience, often through the lens of dynamic capabilities. In this context, resilience refers to firms' adaptive, stress-tolerant capabilities that enable them to respond to regulatory changes (Bocken & Geradts, 2020). For instance, stringent emission reduction targets and waste management standards frequently compel firms to build adaptive capacity (Cheng et al., 2019). In addition, penalties for non-compliance and reputational risks stemming from public scrutiny incentivize firms to develop robust risk management systems to mitigate potential damage (Settembre-Blundo et al., 2021). Conversely, some studies argue that environmental regulations can serve as catalysts for innovation, driving firms to adopt green technologies and streamline operations (Tang et al., 2024). This aligns with the resource-based view (RBV), which suggests that regulations not only impose constraints but also create opportunities for firms to develop unique capabilities—such as green product innovation and sustainable supply chain management—that enhance their competitive advantage (Hart, 1995). However, while numerous studies have investigated the immediate impact of regulations on compliance or innovation outcomes, fewer have systematically explored how environmental regulations shape firms' broader resilience, particularly their capacity to maintain long-term competitiveness under stringent regulatory conditions.

According to institutional theory, external pressures from regulations, laws, and societal norms compel firms to align their behaviors with external expectations to gain legitimacy and sustain operations (DiMaggio & Powell, 1983). Environmental regulations, such as the NEPL, serve as institutional mechanisms to drive businesses toward green development by enforcing compliance and encouraging sustainable practices (Liu et al., 2022; Cheng & Kong, 2022). The NEPL, considered the "most stringent environmental protection law in history," has led to the imposition of strict penalties and numerous transparency measures, increasing public and regulatory scrutiny of firms' environmental performance (Zhou et al., 2021). While studies have highlighted how institutional pressures foster compliance and CSR engagement (Huang & Lei, 2021), they have rarely addressed how these pressures influence firms' resilience in managing shocks and stresses during green transitions. The resource-based view (RBV) suggests that firms' internal resources and capabilities are critical to sustaining competitive advantage, especially when facing external pressures, such as those stemming from environmental regulations (Barney, 2000; Hart, 1995). VRIN resources—those that are valuable, rare, inimitable, and non-substitutable—enable firms to adapt to regulatory challenges and capitalize on green development opportunities (Tang et al., 2024). For instance, investments in green technologies or sustainable supply chains enhance firms' resilience by strengthening their adaptability and innovation (Cheng et al., 2019). However, existing research often overlooks how firms integrate internal resources with external regulatory demands to build resilience, particularly under stringent policies like the NEPL.

Environmental regulations, particularly laws like the NEPL, have been studied extensively for their role in promoting green development by influencing firms' behaviors. Prior research has shown that such regulations drive green technology adoption (Polzin et al., 2019), enhance CSR engagement (Huang & Lei, 2021; Liu et al., 2022), and

align organizational strategies with public and regulatory expectations (Zhou et al., 2021). However, some studies also caution that these regulations may lead to unintended consequences, such as greenwashing, particularly for resource-constrained firms (Tang et al., 2024). While these studies have effectively highlighted the behavioral and strategic changes prompted by environmental laws, their focus remains largely on short-term compliance and innovation outcomes, overlooking the long-term implications for firms' resilience. On the other hand, resilience literature, informed by institutional theory and RBV, provides valuable insights into how firms respond to external shocks and stresses. Institutional theory emphasizes the role of regulatory pressures in compelling firms to adapt and align with external expectations (DiMaggio & Powell, 1983). RBV underscores the importance of leveraging VRIN resources to sustain competitive advantage under external constraints (Barney, 2000). While institutional theory explains why firms respond to regulatory pressures, RBV explores how internal resources enable firms to transform these pressures into opportunities. However, existing studies seldom bridge these two perspectives to explore how environmental laws, like the NEPL, influence the development of enterprise resilience—defined as firms' ability to adapt, withstand, and recover during the process of greening their operations.

This study aims to address a gap in the literature by analyzing data from 683 manufacturing firms over the period spanning 2010 to 2021. It employs both the VHSD model and the entropy method to assess the green development resilience of these firms while utilizing a difference-in-differences (DID) model to examine how NEPL influences their green development resilience. Additionally, by integrating institutional theory with the Resource-Based View (RBV), this study explores the interplay between external regulatory pressure and internal resource mobilization. This approach not only enhances understanding of how NEPL impacts firms' green behaviors but also provides insight into their long-term resilience, thereby contributing to the growing body of research on sustainable development and organizational resilience.

The unique contributions provided by this study can be summarized with the following three points:

- This study introduces the concept of "green development resilience," defined as the ability of enterprises to adapt to, withstand, and recover from external pressures, market changes, and policy or regulatory challenges during the green transformation process. Through quantitative analysis, the study measures the factors influencing green development resilience and proposes a new evaluation framework. It employs a combination of vertical and horizontal sampling (VHSD) and entropy methods to provide empirical support for green development resilience, offering both a theoretical foundation and methodological tools for future research.
- This study provides a comprehensive analysis of the impact of the new environmental protection law (NEPL) on the green development resilience of enterprises and explores the underlying mechanisms. The findings indicate that the NEPL significantly enhances enterprises' green development resilience by increasing compliance pressure, strengthening green innovation capabilities, and improving risk management systems. Additionally, the study highlights how the Law helps enterprises overcome the challenges of green transformation by boosting policy incentives and alleviating financing constraints.
- This study innovatively integrates institutional theory and the Resource-Based View (RBV) to develop a multi-level theoretical framework. Institutional theory explains how the new environmental protection law (NEPL), as an external institutional mechanism, compels enterprises to undergo green transformations. In contrast, the Resource-Based View focuses on how enterprises respond to external pressures and enhance their resilience by leveraging internal resources, such as technology, knowledge, and capital. This dual perspective not only enriches theoretical research on the impact of environmental regulations on corporate behavior but also offers new insights into how companies can achieve green sustainability within a rule-of-law framework.

Theoretical analysis and research hypothesis

Institutional theory and the resource-based view (RBV) offer complementary insights into the dynamics of organizational behaviors and capabilities in response to environmental pressures, including regulations such as the NEPL. Despite their differing perspectives, both frameworks emphasize the ways in which external factors influence organizational practices and competitive advantage. Institutional theory examines how organizations adapt to external norms, laws, and regulations to gain legitimacy and survive (DiMaggio & Powell, 1983). It posits that external institutional pressures compel firms to comply with established rules and practices, thereby shaping their strategic direction, including green initiatives. Conversely, RBV focuses on the internal resources and capabilities that firms possess and how these can be leveraged to sustain competitive advantage (Barney, 2000). From this standpoint, environmental laws like the NEPL present both challenges and opportunities for firms to develop unique resources (e.g., green knowledge, innovation capabilities, and financial resources) that enhance their resilience in pursuing green development. The intersection of these two theories lies in the concept of adaptation: Institutional theory addresses the external pressures driving firms to adopt new practices (e.g., greening), while RBV emphasizes the internal resources and capabilities necessary for firms to effectively respond to these pressures. By integrating these perspectives, this study aims to explore how NEPL impacts both the pressures faced by firms to attain external legitimacy while building their internal capabilities to enhance their adaptive capacity in green development. Specifically, this study investigates how NEPL not only encourages firms to adopt green practices to gain legitimacy (institutional theory) but also examines how firms utilize their internal resources (e.g., green knowledge, innovation capabilities, and financing options) to cope with these regulatory pressures and thrive in the process (RBV).

Direct effects based on institutional theory

Institutional theory is a significant framework for analyzing organizational behavior (Amenta & Ramsey, 2010). It focuses on how firms can better ensure their legitimacy and status by adhering to the norms and rules of the institutional environment, such as laws, government agencies, regulatory structures, and social and cultural practices that create pressure to conform (Dagiliene et al., 2020). Legitimacy refers to stakeholders' evaluation of the appropriateness of business behaviors (Glover et al., 2014). According to Pel et al. (2020) and Bag et al. (2023), institutional theory provides a theoretical perspective for examining how the survival and legitimacy of organizational practices are influenced by factors such as regulation, culture, tradition, history, social environment, and economic incentives. In summary, institutional theory suggests that business decision-making processes and strategies are affected by enduring economic, political, and social pressures as organizations seek to legitimize their practices to survive (Al Nuaimi et al., 2022). Garcia-Martinez et al. (2023) state that public institutions often use the law to create a more responsive and participatory environment, making businesses more environmentally conscious. Therefore, it is reasonable to assume that business practices will be influenced by the NEPL. To legitimize their operations, these firms will adapt their practices to comply with the NEPL (Amenta & Ramsey, 2010). This study argues that these behaviors not only help companies to adopt green practices but also enhance their ability to achieve green growth. Therefore, this study proposes:

Hypothesis. one (H1): The NEPL can positively increase enterprise green development resilience.

Indirect impacts based on resource-based theory

The resource-based view (RBV) suggests that a firm's competitive advantage stems from the unique resources and capabilities it owns and controls (Ozdemir et al., 2023). These include tangible assets such as capital and technical equipment, intangible assets such as knowledge, brands, and patents, and the skills and capabilities to effectively utilize these resources, such as the ability to innovate and finance (Münter, 2024). These resources and capabilities play an indispensable role in enhancing enterprise green development resilience under the Environmental Protection Act, as shown in Fig. 1.

From the RBV perspective, green knowledge serves as a core intangible resource for enterprises. By acquiring and utilizing green knowledge, enterprises can enhance their technical and management capabilities (Shafait & Huang, 2024), thereby improving green development resilience. Green innovation capability is an important resource for enterprises, enabling them to develop new green products and technologies, thereby maintaining market competitiveness and adaptability (Ai et al., 2024). Policy incentives provided by the government, such as tax incentives and subsidies, can be regarded as external resources that effectively support green development (Li et al., 2024). Funds obtained through external financing are key resources that support enterprises in making green investments and conducting research and development to improve green development resilience. Specifically:

- **Green Knowledge.** To comply with environmental regulations, companies often recruit green talent with knowledge of sustainability or train existing employees to rapidly enhance their green knowledge. These talent and training programs not only bring in expertise but also introduce the latest industry practices and innovative ideas (Shaikh et al., 2024). Meanwhile, the environmental awareness of executives is crucial for integrating green elements into daily management and strategy development, ensuring the company has clear goals and pathways for green development (Darvishmotevali & Altinay, 2022; Zheng et al., 2023). Additionally, the rational allocation of monetary resources for the purchase of green equipment and increased investment in green technology research and development are fundamental to the successful implementation of green development initiatives (Khan et al., 2024). These measures significantly enhance the green development resilience of firms by strengthening their green knowledge base and improving their ability to adapt to changes in environmental regulations, enhance innovation, optimize resource allocation, and strengthen their market reputation. Therefore, the implementation of the NEPL not only helps enterprises better meet environmental protection requirements but also enhances their overall competitiveness and sustainable development capability, which is crucial for strengthening enterprise green development resilience.
- **Green Innovation.** Green innovation refers to technological innovation activities that achieve environmental protection and resource conservation while adhering to economic development requirements (Tan & Zhu, 2022). In the face of environmental and resource constraints, technological innovation not only accelerates green development but also enhances enterprises' ability to meet changing requirements quickly, thereby achieving sustainable development (Yu et al., 2024). By introducing and developing new environmental technologies and processes, firms can improve environmental performance, enhance competitiveness, and promote sustainable development. The NEPL prompts firms to increase their investment in green technology innovation and improve their ability to cope with green development through external pressures, such as compliance requirements, policy incentives, and market pressures (Zhang et al., 2024). Green innovation enables enterprises to adapt quickly to regulatory and market changes, continuously improve production processes, increase resource utilization efficiency, and enhance corporate image (Xiang et al., 2022). In summary, the NEPL promotes green technological innovation by enterprises through external pressure and incentives, significantly improving their green development resilience, helping them better cope with environmental and resource constraints, and enhancing their market competitiveness and sustainable development capability.
- **Policy Incentives.** External policy incentives include two major aspects: tax pressure and green subsidies. As a special kind of financial incentive, green subsidies encourage enterprises to make

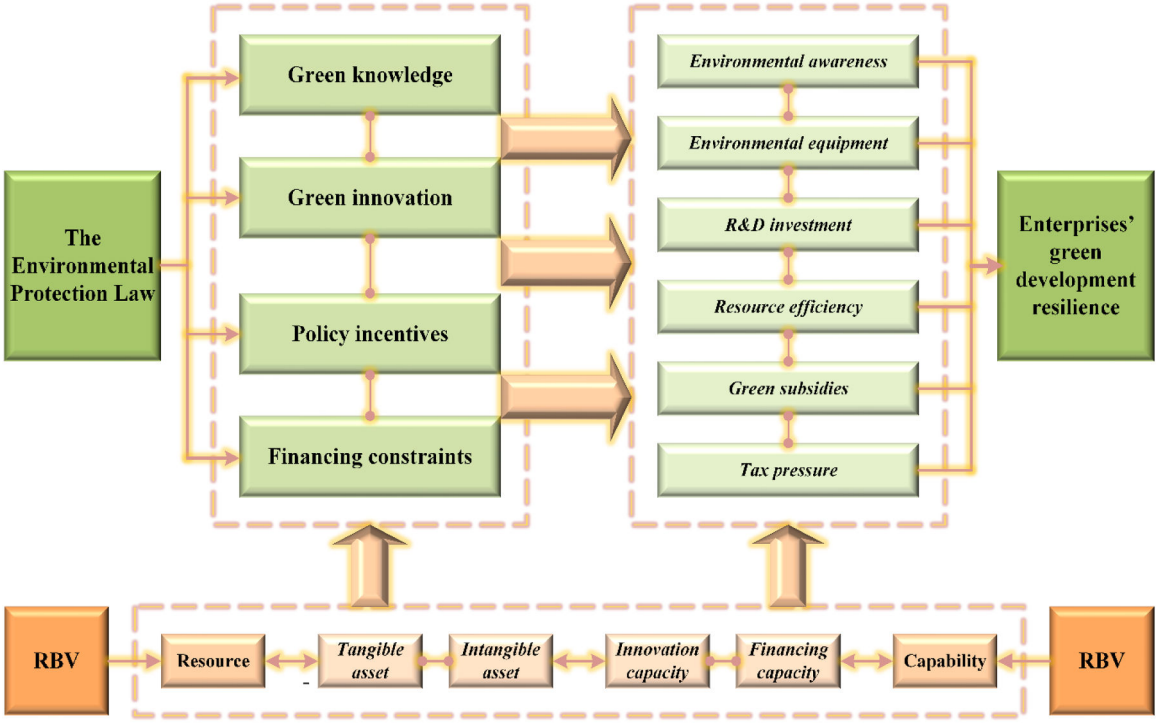

Fig. 1. Conceptual model based on RBV theory.

green investments and innovations by providing financial support, thus reducing the cost of green investment and compelling them to engage in green technology research, development, and application (Liu et al., 2020). For example, the NEPL provides environmental protection subsidies to industrial enterprises to encourage green operations (Zhang et al., 2020). Although environmental protection taxes may inhibit firms' green investments (Yan et al., 2024), tax pressure remains an important force driving firms' green development. Tax pressure motivates firms to standardize their business practices and take proactive environmental measures to avoid potential tax burdens. For example, firms will invest in low-carbon emission projects to reduce emissions and conserve energy. Studies have shown that carbon taxes effectively reduce greenhouse gas emissions and energy consumption (Guo & Zhang, 2023). Through green subsidies and tax pressure, the NEPL can reduce the cost of green investment, incentivize green innovation, regulate environmental protection behaviors, and enhance the market competitiveness of firms, thus significantly improving their green development resilience.

- **Financing Constraints**. Financing constraints refer to potential external and internal factors that limit the number of investment options (Santos & Cincera, 2022). The implementation of the NEPL not only strengthens the regulation of firms but also increases the attractiveness of green projects through policy signaling (Li et al., 2024; Yang et al., 2022). According to signaling theory, public agents can signal to investors that the state supports environmentally friendly industries and firms, leading investors to believe that green projects will receive more policy support, resulting in higher returns and lower risks (Polzin et al., 2019). This signaling attracts more capital to green projects and eases the financing constraints of enterprises. Through these measures, the NEPL enhances the ability of enterprises to obtain funds, reduces the cost of financing, and improves market confidence, thereby significantly increasing enterprise green development resilience.

Based on the above analysis, this paper further proposes the following hypotheses.

Hypothesis. two (H2): The NEPL can increase enterprise green development resilience by increasing their green knowledge base.

Hypothesis. three (H3): The NEPL can increase enterprise green development resilience by increasing their green innovation capacity.

Hypothesis. four (H4): The NEPL can increase enterprise green development resilience through external policy incentives.

Hypothesis. five (H5): The NEPL can increase enterprise green development resilience by alleviating financing constraints.

Methodology

Model specification

In this study, the difference-in-differences (DID) method was chosen because it effectively captures the causal impact of the NEPL on enterprise green development resilience by leveraging temporal and cross-sectional variations. DID is particularly suitable as it controls for unobserved, time-invariant factors and identifies policy effects through a natural experiment framework. In order to test the impact of the NEPL on enterprise green development resilience, using the difference-in-differences method, the baseline regression model was constructed as:

$$grd_{i,t} = a_0 + a_1 nepl_{i,t} + a_2 X_{i,t} + \gamma_i + \vartheta_t + \varepsilon_{i,t} \quad (1)$$

where *grd* denotes the level of enterprise green development resilience; *nepa* denotes policy dummy variables that vary by individual treatment group as well as treatment period, and $nepl_{i,t}$ denotes the average effect of policy shocks. X_{it} denotes the chosen control variables. γ_i denotes time-fixed effects; ϑ_t denotes firms' individual-fixed effects that do not vary over time; and $\varepsilon_{i,t}$ denotes a random disturbance term.

Description of variables and data sources

The screening process for listed companies was as follows: First, exclude ST listed companies. Second, exclude companies listed in the current year, as these companies have a shorter listing period, insufficient historical information, and significant differences in information disclosure compared to other companies. Third, exclude companies with missing data for consecutive years. After this screening, the total number of companies listed was reduced to 683. Considering the availability of data, the selected time period was from 2010 to 2021. Measurement data for relevant indicators of listed companies were sourced from the CSMAR database.

(1) Explained variable

Drawing on scholarly discussions of corporate resilience and sustainable development (Wu & Tham, 2023; Zhang & Xi, 2024), enterprise green development resilience can be defined as the stability and adaptability of firms in the face of environmental pressures, policy changes, and market volatility. Pressure resilience mainly reflects the coping ability and adaptability of enterprises under financial and environmental pressure. State resilience refers to an enterprise's ability to maintain its financial health, operational efficiency, and organizational structure during green development. Response resilience focuses on an enterprise's ability to enhance its green development potential through technological innovation and market response within a changing external environment (shown in Table 1).

In terms of specific methodology, this paper, with reference to Chen and Song (2024), combines the vertical and horizontal slot-drawing (VHSD) method and the entropy value method to assign weights to the stress, situation, and response resilience of enterprise green development resilience, respectively. This combined method fully considers the dynamic and static nature of the indicators, effectively reduces the interference of subjective factors, improves the objectivity and scientific validity of the calculation of indicator weights, and ensures the accuracy and reliability of the assessment results.

(2) Core explanatory variable

The core explanatory variable *nepl* is the cross-multiplier of the dummy variable for the time of publication of the NEPL and the dummy variable for the experimental group. Since the NEPL officially went into effect on January 1, 2015, the time dummy variable takes 1 for the current year of 2015 and subsequent years, and 0 for the reverse. In this paper, a sample of firms from 18 heavy-polluting industries was selected as the experimental group, and non-heavy-polluting firms belonging to the same broad industry category as heavy-polluting industries were included in the control group. Enterprises in the experimental group were taken as 1, and enterprises in the control group were taken as 0.

(3) Mechanism variables

Based on the previous hypothesis, the implementation of the NEPL promotes enterprise green development resilience through four main channels. To this end, the mechanism variables set in this paper include: corporate green perception and resource allocation index; number of green patents and percentage of green patents; green subsidies and tax pressure; and financing constraints and financing costs

(4) Control variables

The control variables selected with reference to the study by Wu & Tham, 2023) are specifically: the natural logarithm of the total assets of the enterprise at the end of the year (*size*); gearing ratio, that is, total liabilities at the end of the year divided by total assets at the end of the year (*lev*); the ratio of net profit to the average balance of total assets (*roa*); book-to-market ratio (*bm*), measured by the ratio of the book value of the firm to its market value; Tobin's Q value (*tobinq*); market capitalization ratio (*pb*); gross profit margin on sales (*grossprofit*); and

Table 1
System of indicators for enterprise green development resilience.

Tier 1	Tier 2	Tier 3	Measurement
Stress resilience	Financial stress resilience	SA Index	Composite index based on specific criteria.
		Debt-to-Asset Ratio	Total Liabilities / Total Assets
		Long-term Debt to Total Assets Ratio	Long-term Debt / Total Assets
		Operating Cost Ratio	Operating Costs / Total Revenue
	Environmental stress resilience	Environmental Regulation Intensity	Proxy variables such as environmental taxes paid or compliance costs.
		Herfindahl-Hirschman Index (HHI)	Sum of the squares of market shares.
Situation resilience	Financial situation resilience	Total Assets	Sum of all current and non-current assets.
		Return on Assets (ROA)	Net Income / Total Assets
	Organizational structural resilience	Board Size	Number of directors.
		Proportion of Independent Directors	Independent Directors / Total Directors
		CEO Duality	1 if CEO is also chairperson, 0 otherwise.
		Organizational Resilience	Composite index or specific metrics.
Response resilience	Market response resilience	Net Profit Growth Rate	(Current Year Net Profit - Previous Year Net Profit) / Previous Year Net Profit
		Institutional Investor Shareholding Ratio	Institutional Shares / Total Shares Outstanding
		Corporate Green Total Factor Productivity	Productivity index incorporating environmental factors
	Innovative response resilience	R&D Investment	Total R&D expenditure
		Green Technology Efficiency Change Index	Change in efficiency scores related to green technologies.
		Green Technology Progress Change Index	Change in technological advancements over time.

firm's years of establishment (*firmage*), expressed as the natural logarithm of the number of years of establishment. All descriptive statistics results of variables shown in Table 2

The correlation analysis results, as shown in Fig. 2, indicate that NEPL is significantly positively correlated with corporate green development resilience at the 1 % significance level, providing initial support for research hypothesis H1. Additionally, significant correlations exist among other major variables, permitting further regression analysis.

Empirical analysis

Benchmark regression results

In order to test research hypothesis H1, the baseline model test was first conducted, and the results are shown in Table 3. Among them, Result 1 in Table 3 does not include any fixed effects or control variables. In Result 2 Table 3, the control variables have been added. Result 3 in Table 3 controls industry and year-fixed effects. From the regression results, it can be seen that regardless of the addition of control variables, or whether or not industry and time-fixed effects are controlled for, the release of the NEPL enhances enterprise green development resilience at the 1 % significance level, providing preliminary evidence of the NEPL's positive effect on enterprise green development resilience.

Table 2
Descriptive statistics results of variables.

Variable	OBS	Mean	Std. dev.	Min	Max
grd	7434	0.337	0.072	0.049	0.625
nepl	7434	0.146	0.353	0.000	1.000
size	7434	22.760	1.397	19.486	28.637
lev	7434	0.439	0.197	0.008	0.946
roa	7434	0.059	0.049	−0.198	0.477
bm	7434	0.650	0.267	0.034	1.559
tobinq	7434	1.986	1.425	0.641	29.167
pb	7434	3.002	2.548	0.108	37.755
grossprofit	7434	0.299	0.169	−0.062	0.975
firmage	7434	2.885	0.368	0.693	3.714
egp	5581	0.908	0.848	0.000	3.828
reop	6751	−0.351	1.586	−5.396	17.194
green1	4321	0.828	1.148	0.000	7.232
green2	4321	0.071	0.167	0.000	1.000
subsidy	7314	3.797	6.238	0.000	21.487
tax	7434	0.010	0.174	−0.242	1.985
kz	7403	0.768	2.290	−9.098	8.260
peg	5654	0.108	0.041	0.000	0.564
region	7434	1.434	0.718	1.000	3.000
tech	7434	0.188	0.391	0.000	1.000

Parallel trend test

The multi-temporal double-difference model needs to pass the parallel trend assumption, i.e., the trend of changes in the enterprise green development resilience in the pilot and non-pilot regions before the implementation of the policy is parallel. Therefore, this study draws on the event study method to conduct the parallel trend test, which is expressed as the equation:

$$grd_{i,t} = \alpha_0 + \prod_{k\geq -5, k\neq -1}^{5} \alpha_k D_{i,t}^{k} + X_{i,t} + \gamma_i + \vartheta_t + \varepsilon_{i,t} \quad (2)$$

where a denotes $D_{i,t}^{k}$ set of dummy variables that take the value of 1 when a policy shock occurs in the province where manufacturing firm i is located in year t and after, while 0 denotes before the policy occurs. The rest of the variables have the same meaning as in Eq. (2). In the regression analysis specific to the parallel trend test, this paper takes k=−1, i.e., 1 year before the establishment of the digital trading platform, as the base period, so the dummy variable $D_{i,t}^{-1}$ is not included in Eq. (2). Finally, the coefficient of α_k can be tested to see whether the parallel trend test is satisfied or not

Considering the data taken from the 6 years before the policy's implementation, this study summarizes the data from these 6 years as −6 periods; since the sample period spans 2010 to 2021 and the implementation of the NEPL occurred in 2015, the maximum number of periods after the implementation of the policy is 5 periods. At the same time, the 5th period before the policy was implemented is used as the base period. The results of the parallel trend test shown in Fig. 3 show that the coefficient estimates for each group before the implementation of the NEPL are not significant. This indicates that there was no difference in enterprise green development resilience between the treatment and control groups before the implementation of the NEPL, which passes the parallel trend test.

Placebo test

(1) Time-placebo test

In order to negate the effect of time on the green development resilience of enterprises in the treatment and control groups, with reference to the results of the parallel trend test, this study advanced the implementation of the NEPL by three years, constructing a spurious policy shock and regressing Eq. (1), with the regression results shown in

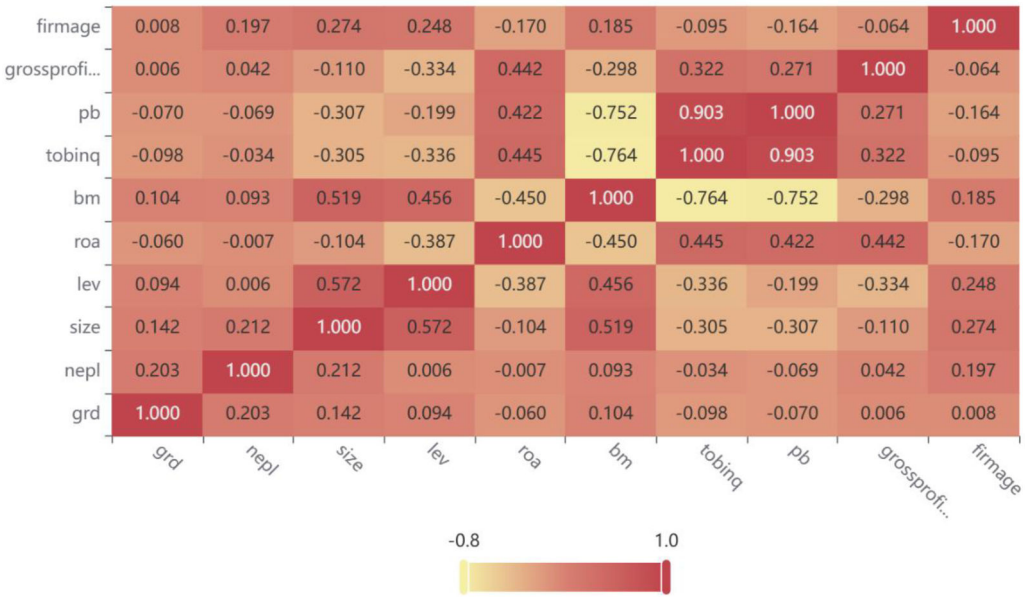

Fig. 2. Correlation Analysis.

Table 3
Benchmark regression results.

Variable	(1)	(2)	(3)
nepl	0.041***	0.039***	0.019***
	(0.002)	(0.002)	(0.003)
size		0.005***	0.011***
		(0.001)	(0.002)
lev		0.007	0.038***
		(0.006)	(0.009)
roa		−0.080***	−0.018
		(0.002)	(0.023)
bm		−0.003	0.017**
		(0.005)	(0.006)
pb		0.004***	0.001
		(0.001)	(0.001)
tobinq		−0.009***	−0.004*
		(0.002)	(0.002)
grossprofit		0.023***	0.004
		(0.006)	(0.011)
firmage		−0.012***	−0.016
		(0.003)	(0.008)
_cons	0.331***	0.257***	0.113*
	(0.001)	(0.018)	(0.053)
Control variable	No	Yes	Yes
Fixed time	No	No	Yes
Fixed firm	No	No	Yes
Sample size	7434	7434	7434

Note: ***, ** and * indicate statistical significance at the 1 %, 5 % and 10 % levels, respectively, and values in parentheses are robust standard errors. Same below.

Fig. 4. The same-time placebo test results show that the average processing effect of the policy was insignificant, which suggests there was no significant difference in the time trend between firms in the treatment group and control group.

(2) Individual placebo test

In this study, we used the individual placebo test to verify the robustness of the causal effect of the NEPL on enterprise green development resilience. Specifically, we conducted a placebo intervention in years when the NEPL policy was not actually implemented or in samples of firms not affected by the policy to test the significance of the policy effect. The results of the individual placebo test showed that in years when the policy was not implemented or in firms not affected by the policy, the NEPL did not have a significant impact on enterprise green development resilience, as shown in Fig. 4. This indicates that the observed policy effect was not due to other unobserved factors or time trends but is attributable to the actual implementation of the NEPL. Therefore, the individual placebo test passed, further supporting the causal interpretation of our empirical results, namely, that the NEPL significantly enhanced enterprise green development resilience.

(3) Mixed placebo test

The mixed placebo test involved random assignment of both time and individual factors. As shown in Fig. 4, the Mixed-Placebo test demonstrates the kernel density distribution of coefficients after 1000 random groupings. This distribution approximates a normal distribution, centering around the value zero. Most of the coefficients are located to the left of the baseline regression coefficient, indicating that the coefficients from random groupings did not hold significant statistical relevance. This supports the reliability of the conclusions drawn from the baseline regression.

Robustness test

(1) Propensity matching score

In this paper, propensity score matching (PSM) was used to construct the sample. After propensity score matching was conducted, a more balanced distribution of the variables between the control group and the test group could be observed, with a deviation of <10 %, while the means between the two groups were not significantly different. The empirical results obtained from the Propensity Score Matching Double Difference (PSM-DID) method, utilizing both the K-order and kernel matching techniques as illustrated in Table 4, demonstrate that the NEPL enhanced enterprise green development resilience. These findings substantiate the efficacy of the NEPL and confirm the robustness of the double difference method.

(2) Research sample adjustment

To assess the robustness of the regression outcomes, this study modified the research sample. Given that the initial sample included municipalities and autonomous regions, where municipalities typically exhibit a higher level of business activity and a predominantly high-tech industrial structure, the NEPL may have a weaker impact on enterprise green development resilience. Consequently, this study initially excluded the samples from municipalities directly under the control of the central government for regression analysis. The modified regression outcomes, as indicated in Table 4, Result 3, remain robust. Furthermore,

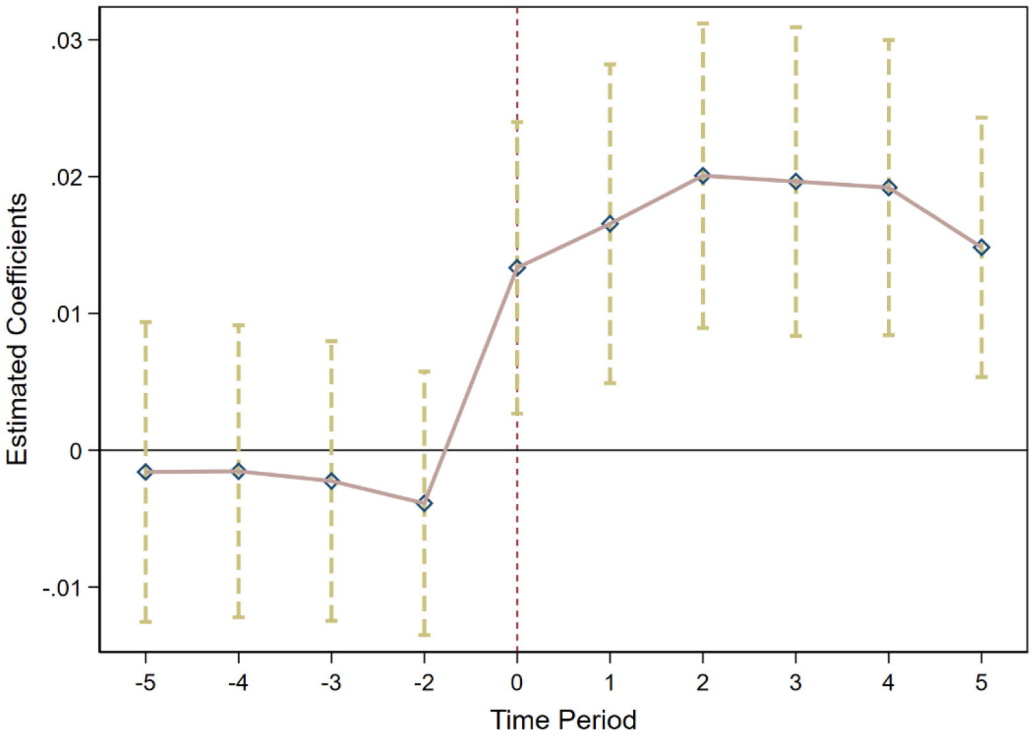

Fig. 3. Parallel trend test.

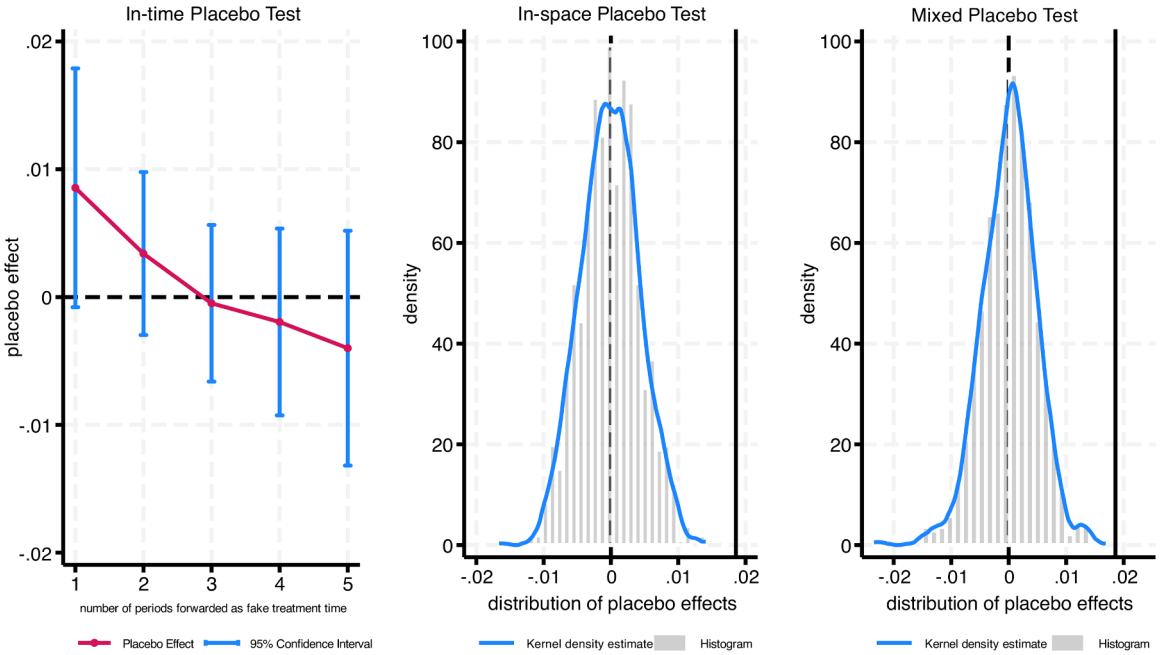

Fig. 4. Placebo test.

considering the potential influence of the 2019 coronavirus pandemic on the study results, the temporal scope was narrowed to the period from 2012 to 2019 for regression analysis, with the outcomes depicted in Table 4, Result 4, still demonstrating significance.

(3) Parallel policy

To ensure the robustness of the estimated impact of the NEPL on enterprise green development resilience, a parallel policy robustness check was conducted. This approach examines whether the observed effects could be confounded by other policies implemented during the same period. The results, shown in the robustness section, reveal a coefficient of 0.019 (significant at the 1 % level), indicating that the NEPL's effect on enterprise green development resilience remained significant even after accounting for the influence of concurrent policies. This finding demonstrates that the observed impact is not merely a reflection of parallel policy effects but is primarily attributable to the NEPL.

Mechanism testing

The findings of this study clearly indicate that the NEPL has greatly

Table 4
Robustness test.

Variables	(1) K-order	(2) Kernel	(3) Exclude Cities	(4) Exclude Time	(5) Parallel Policy
nepl	0.013**	0.019***	0.020***	0.020***	0.019***
	(0.005)	(0.005)	(0.003)	(0.003)	(0.003)
_cons	−0.027	0.055	0.109	−0.012	0.113**
	(0.140)	(0.105)	(0.060)	(0.087)	(0.053)
Control variable	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes	Yes
Obs	3487	7194	5808	4914	7434

contributed to enterprise green development resilience. This section investigated the mechanisms by which the NEPL affects green development resilience, focusing on four key dimensions: Green Knowledge Channels, Green Innovation Channels, Policy Incentive Channels, and Financing Constraints Channels. This study utilized the research methodology pioneered by Farbmacher et al. (2022) and employed a dual machine learning model to uncover the complex mechanisms by which the NEPL has affected enterprise green development resilience. Table 5 presents the detailed results of this mechanism testing, demonstrating the specific ways in which these four dimensions contributed to the observed effects.

(1) Green knowledge channels

The enhancement of green knowledge mechanisms within enterprises is evident from the regression results in Table 5. The indirect effects of resource allocation efficiency and executives' green cognition in the control group are significant at the 10 % and 1 % levels, respectively. These findings suggest that the NEPL enhanced enterprise green development resilience by elevating the level of green cognition internally, thereby confirming research hypothesis H2.

(2) Green innovation channels

The enterprise green innovation mechanisms are reinforced, as demonstrated by the regression results in Table 5. The indirect effect of the overall level of green innovation and the proportion of green innovations in the control group is significant at the 1 % level. This result implies that the NEPL boosted enterprise green development resilience by enhancing their green innovation capabilities, thus supporting research hypothesis H3.

(3) Policy incentive channels

The enterprise green innovation mechanisms benefit from policy incentives, according to the regression results in Table 5. The indirect effects of environmental subsidies and overall taxation in the control group are significant at the 10 % level positively and at the 5 % level negatively. These outcomes indicate that the NEPL fostered enterprise green development resilience by increasing environmental protection subsidies and reducing tax burdens, validating research hypothesis H4.

(4) Financing dynamic channels

The enterprise green innovation mechanisms improve through financial dynamics, as shown by the regression results in Table 5. The indirect effects of both financing constraints and financing costs in the control group are significantly negative at the 1 % level. This finding suggests that the NEPL enhanced enterprise green development resilience by alleviating financing constraints and reducing financing costs, thereby substantiating research hypothesis H5.

Further discussion

(1) Regional heterogeneity

This study examines the different impacts of the NEPL on the enterprise green development resilience of enterprises, which are categorized into eastern, central, and western enterprises. The regression results presented in Table 6 show the different results for these three types of enterprises. The coefficient for eastern enterprises is statistically significant at 0.019, indicating a positive impact of the NEPL on enterprise green development resilience in this region. The significance of the results suggests that the law effectively enhanced green practices among enterprises in the eastern region, which is typically more economically developed. The impact on central enterprises, while positive at 0.013, is not statistically significant. This suggests that while the law had a positive influence on enterprise green development resilience, it was not as pronounced or consistent as in the eastern region. This could be attributed to the varying economic conditions or differing levels of industrial development in the central region. For western enterprises, the coefficient is 0.024 with a standard error of 0.009, and it is also statistically significant. This indicates a strong and positive effect of the NEPL on the enterprise green development resilience in the western region. Given that the western region of China is generally less developed, this significant impact might reflect a substantial governmental and industrial effort to comply with new environmental standards.

(2) Technology heterogeneity

This paper further splits the sample into high-tech and non-high-tech firms. The classification of high-tech and non-high-tech enterprises follows the official high-tech industry directory issued by the Ministry of Science and Technology of China. High-tech enterprises are defined as those engaged in sectors such as information technology, biopharmaceuticals, aerospace, advanced materials, and environmental technology. Non-high-tech enterprises refer to firms operating outside of these high-tech sectors, typically focusing on traditional industries with less emphasis on innovation. As shown in Results 4 and 5 in Table 6, the impact of the NEPL on enterprise green development resilience differs between these two categories. For high-tech firms, the coefficient of the

Table 6
Heterogeneity test.

Variable	(1) East	(2) Mid	(3) West	(4) High-Tech
nepl	0.020***	0.012**	0.022	0.022
	(0.003)	(0.005)	(0.005)	(0.003)
_cons	0.117**	0.124**	0.128**	0.136**
	(0.053)	(0.053)	(0.053)	(0.053)
Control variable	Yes	Yes	Yes	Yes
Fixed time	Yes	Yes	Yes	Yes
Fixed firms	7434	7434	7434	7434

Table 5
Mechanism tests.

Mechanism	Variable	Total effect	Disposition group direct effect	Control group direct effect	Disposition group indirect effect	Control group indirect effect
Green Knowledge	*egp*	0.038***	0.037***	0.037***	0.001	0.001*
	reop	0.037***	0.038***	0.036***	0.001***	0.001
Green Innovation	*green*1	0.045**	0.045***	0.043**	0.002	0.032***
	*green*2	0.225***	0.158*	0.126	0.099***	0.067**
Policy Incentive	*subsidy*	0.038***	0.038***	0.039***	−0.001	0.001*
	tax	0.040***	0.042***	0.041***	−0.001**	−0.002***
Financing Constraints	*kz*	0.039***	0.041***	0.40***	−0.001	−0.002***
	peg	0.045***	0.046***	0.047***	−0.002***	−0.001

main regression is 0.010, but it is not significant. For non-high-tech firms, the coefficient of the main regression is 0.018 and is significant at the 1 % level, indicating that the NEPL had a significant positive impact on the green development resilience of non-high-tech firms.

Conclusions and implications

Conclusions

The Relationship between Environmental Protection Laws and Enterprise Green Development Resilience

The finding showed that the NEPL can enhance enterprise green development resilience, which is consistent with the research findings by Bocken and Geradts (2020) who argued that institutions could act as either barriers or drivers as companies attempt to engage in green innovation. This is the reason why environmental laws are often used to create a more sensitive and engaged setting to increase firms' environmental awareness (Jiménez-Parra et al., 2018). Liu et al. (2022) stated that the driving force for profit-driven companies to engage in green development is environmental regulations and laws, which act as important tools and methods for governments to compel enterprises to carry out green development initiatives. To a large degree, this implies the effectiveness of environmental regulations and laws in encouraging corporations' to protect the environment. For example, resilient corporations can quickly update their business model to generate environmentally-friendly products. In addition, when there is resource depletion, companies with resilience could find alternative solutions to minimize losses due to resource depletion. These initiatives ultimately benefit society in achieving sustainable development. Hence, this study suggests that the implementation of effective environmental protection regulations and laws should be a priority for governments to accelerate the transition into a more sustainable future.

However, the regional heterogeneity test indicated that the impact of the NEPL on companies varies from region to region. The research results indicated that there was a significantly positive relationship with companies in the eastern region, but no such significant relationship could be observed for companies in the western and central regions. This may be because the NEPL was more strictly enacted in the eastern region (Han et al., 2021), noting that this region is typically more economically developed than the other two regions and therefore has greater scope to reduce environmental pollution. Based on this disparity, this study suggests further research is needed to investigate the effectiveness of such laws and regulations in other countries and contexts. The laws have a differing impact on different regions due to various factors, which limits the generalizability of the findings. Additionally, the heterogeneity test on high-tech and non-high-tech companies showed distinct differences. The significant positive impact of the NEPL on non-high-tech companies, compared to high-tech companies may be attributed to several factors. High-tech companies often possess more advanced technologies and greater flexibility in adapting to environmental regulations, thus the Law's impact may not be as pronounced. In contrast, non-high-tech companies typically rely more on traditional processes and may find it more challenging to adapt without significant investment, making the supportive measures of the law more impactful. This distinction underscores the need for tailored policy approaches that consider the specific characteristics and capabilities of different types of companies.

Since the implementation of the Environmental Protection Law in 2015, Chinese-listed companies have increased their environmental investments to promote green transformation. For instance, Baoshan Iron & Steel Co., Ltd. (Baosteel, stock code: 600,019) has established a technology library of the latest commercially viable energy-saving and low-carbon technologies, striving for ultimate energy efficiency across all processes and achieving a cumulative technical energy saving of 460,000 tons of standard coal over five years. Additionally, Baosteel invested in transforming a 430-cubic-meter conventional blast furnace into a hydrogen-rich carbon cycle blast furnace, and on February 15, 2022, commenced the construction of a 1-million-ton hydrogen-based shaft furnace low-carbon metallurgy demonstration project with a total investment of 1.89 billion yuan. These measures have not only reduced the company's carbon emissions but also enhanced its market competitiveness. Meanwhile, Wanhua Chemical Group Co., Ltd. (Wanhua Chemical, stock code: 600,309) has set a carbon emission target of "peaking carbon emissions no later than 2030 and striving to achieve carbon neutrality by 2048." Wanhua Chemical is investing in offshore wind power, onshore wind power, agrivoltaics, aquavoltaics, nuclear power, and other new energy sources to increase clean electricity supply. These efforts have resulted in the obtainment of 32.4 billion kWh of equity power based on shareholding proportions and the achievement of full coverage of clean electricity in Wanhua Chemical's industrial parks in China, aiding the company's low-carbon transformation. These cases demonstrate that stringent environmental regulations can prompt enterprises to increase their environmental investments, promoting green transformation and achieving sustainable development.

In a broader context, this study aligns with research from various regions and countries, including Asian, European, BRICS, ASEAN, and APEC nations, where the impacts of environmental regulations and corporate sustainability have also been explored. Research in Asia, for instance, has emphasized the challenges of enforcing environmental protection laws in rapidly industrializing economies, where cultural factors, such as the prioritization of economic growth over environmental protection, may influence the speed and effectiveness of policy implementation. In many Asian countries, businesses often face a cultural inclination toward short-term economic gains, which do not tend to be in alignment with the long-term nature of sustainability initiatives.

Studies in Europe tend to focus on the integration of green innovation within established regulatory frameworks, where a culture of environmental consciousness and stronger public advocacy for sustainability drive compliance. The European emphasis on corporate social responsibility (CSR) reflects a long-standing cultural commitment to environmental sustainability, which may make firms in these regions more proactive in adopting green technologies.

In BRICS countries, the role of legal enforcement in fostering resilience among businesses is often coupled with the need for economic incentives to support green technologies. However, cultural differences in these countries—where governance structures, business practices, and levels of public engagement with environmental issues vary—can influence how laws are interpreted and enforced. In particular, cultural differences related to government-business relationships and attitudes toward environmental regulation can impact the effectiveness of corporate responses.

Research from ASEAN countries highlights the importance of balancing economic development with environmental sustainability. In these regions, the strong cultural emphasis on community and collective responsibility may encourage companies to integrate green practices, particularly in industries that have direct community impacts. However, the challenge remains in addressing varying cultural attitudes towards environmental stewardship and business competitiveness. APEC nations provide a unique perspective on how trade-related regulations can drive sustainability initiatives across borders. Cultural factors in these regions may shape how companies view environmental regulations not as a burden but as an opportunity for innovation and collaboration. The cultural openness to international cooperation in APEC countries could enhance cross-border efforts to tackle environmental challenges and promote green development.

Additionally, studies on different types of businesses, such as high-tech versus traditional industries, demonstrate that the impact of environmental laws can vary significantly depending on the sector's capacity for innovation and adaptation. High-tech firms, with their culture of innovation, are often more capable of adopting green technologies, while traditional industries may face greater resistance due to deeply rooted business practices and a less flexible cultural approach to change.

How the Environmental Protection Law Helps Enhance Enterprise Green Development Resilience

This study also revealed how the NEPL helps enhance enterprise green development resilience. The NEPL works through four channels, including strategic resources, green innovation, policy incentives, and financing dynamics. These aspects help enterprises grow their experience and knowledge to deal with potential disruptions due to changes in the market environment.

First, when enterprises tried to comply with the NEPL, they would hire talent with green awareness who can assist the organization in strategically greening their businesses. Such research findings are supported by Liu and Cao (2024), who stated that executive environmental awareness is fundamental to an organization's commitment to green development since it motivates companies to build green knowledge that helps them improve their green innovation capabilities and correspondently makes them more agile in perceiving and grasping external opportunities. These efforts ultimately increase their ability to deal with potential opportunities and threats posed by a rapidly changing market environment.

Furthermore, the NEPL enhances enterprise green development resilience by encouraging green innovation. This is consistent with findings by Liu and Cao (2024) that show that pressure from environmental regulations can stimulate businesses to innovate. Every government is active in encouraging companies to adopt green technology innovations that reduce pollution and improve the effectiveness of resource use. Innovation is key to developing resilience as resilient organizations tend to experiment more with new business models, services, or products, thus being sufficiently agile to adapt to unexpected opportunities and challenges (Lin & Fan, 2024). The development of experience and professionalism in green development by companies is a process.

The research results verified that taxation pressure and green subsidies are important mechanisms of the NEPL to increase enterprise green development resilience. This observation is supported by research by Huang and Lei (2021) showing that companies that received economic incentives, such as green subsidiaries, tended to make more green investments, which allowed them to adopt or innovate pollution control technologies. This process empowers companies with the capability to address environmental risks such as air pollution. When corporations perceive the financial benefits of certain projects, they are willing to reconfigure their resources and invest in the development of dynamic capabilities (Bocken & Geradts, 2020). Due to tax pressure, companies are forced to equip themselves with the necessary resources to deal with various environmental protection requirements and can even become proactive in addressing the changing requirements of sustainable development. This is in line with the research findings by Guo and Zhang (2023) who found that carbon taxes can reduce the emission of greenhouse gases.

The NEPL promotes enterprise green development resilience by reducing financing constraints and financial costs. When the NEPL was enacted, those companies engaged in greening their business can meet loose financing constraints and costs, since their programs are government-supported and are therefore more likely to attract cheaper and faster financing (Huang & Lei, 2021). With low financing constraints and costs, enterprises can conduct more green innovation or green research projects, as pointed out by Cecere et al. (2020). In this way, organizations are more likely to engage in green innovation.

Implications for policymakers

Based on the findings, this study recommends that policymakers focus on stimulating green technology innovation by leveraging a combination of environmental regulations and economic incentives. Governments should utilize regulatory tools such as carbon pricing mechanisms, emissions caps, and mandatory green technology adoption requirements, similar to the European Union's Emission Trading System (ETS), to push companies toward greener practices. At the same time, these regulatory pressures should be complemented by economic incentives like green subsidies, tax reductions, and green bonds to offset the costs of green investments. A balanced combination of these tools will not only encourage companies to adopt sustainable practices but also drive innovation in green technologies that will help meet environmental goals more effectively. Additionally, policies should be designed to fit industry-specific needs and regional contexts, recognizing that the effectiveness of regulations may vary depending on local economic conditions and industrial maturity.

While environmental awareness is crucial, companies are profit-driven, and therefore, regulations should be designed to make green transitions financially attractive. Policymakers should recognize that companies are more likely to engage in green development when they perceive the benefits—such as cost savings through energy efficiency or waste reduction—outweigh the short-term costs of compliance. Green technologies like renewable energy and resource-efficient production methods can offer long-term financial gains that balance environmental benefits with profitability. Moreover, to support businesses in this transition, policymakers must reduce financing constraints. This can be done by installing green finance instruments, such as green bonds and green credit funds, which can help companies secure capital for green projects. A combination of financial incentives, reduced capital costs, and regulatory pressure will enable companies to overcome barriers to green development and make sustainable business practices the norm.

Finally, it is important for policymakers to adopt a more holistic approach that involves all relevant stakeholders, including businesses, communities, suppliers, and customers. Policymakers should ensure that the perspectives and concerns of these groups are integrated into the policy-making process through consultation, feedback mechanisms, and collaboration platforms. Involving multiple stakeholders not only helps create more inclusive and effective policies but also ensures smoother implementation and greater long-term success. For example, community support can facilitate the adoption of green policies, while close collaboration with suppliers can help businesses transition to more sustainable supply chains. By addressing the needs and interests of all parties involved, policymakers can create a more comprehensive policy environment that supports businesses and contributes to broader environmental and social goals.

Implications for businesses

Based on the findings of this study, businesses should prioritize green innovation and knowledge accumulation to enhance their green development resilience. This can be achieved by actively investing in the development of green technologies and innovations. Companies should establish dedicated green R&D teams focused on sustainable solutions and collaborate with universities, research institutions, and industry partners. In selecting R&D projects, businesses should target innovations that align with both their environmental goals and business objectives, ensuring they have a meaningful impact on sustainability. It is crucial for companies to choose partners with expertise in green technologies and sustainability, as well as evaluate the effectiveness of these collaborations using performance metrics and milestones. Beyond innovation, businesses should foster a culture of strong environmental awareness at all levels of the organization, particularly among executives. This can be achieved through targeted training programs, leadership development, and incentives for sustainable practices. For example, identifying "green champions" within the company can help lead the charge on environmental goals, ensuring alignment with the company's green practices and engaging staff at all levels. These cultural changes should be regularly evaluated to ensure they align with environmental objectives and that necessary adjustments are made to maintain progress.

Additionally, companies should strategically leverage government incentives such as subsidies, tax reductions, and other financial support programs to ease the financial burden of transitioning to sustainable

operations. To maximize these incentives, businesses must familiarize themselves with the specific programs available, eligibility conditions, and the application processes. Programs like green bonds and low-interest loans can help fund larger-scale sustainability initiatives, while short-term financial incentives provide immediate support. However, businesses should also focus on long-term strategies for improving green capabilities, such as investing in energy efficiency, resource conservation, and waste reduction. Alongside these initiatives, companies must collaborate with key stakeholders, including local communities, suppliers, and customers, to ensure alignment with broader social and environmental goals. Building strong relationships with these groups can help facilitate the adoption of sustainable practices and create more resilient, sustainable business models. To this end, businesses should establish clear communication and feedback mechanisms to ensure effective collaboration and address potential conflicts. Through these strategies, businesses can not only comply with environmental regulations but also position themselves as leaders in the green economy, ensuring long-term success and contributing to broader sustainability objectives.

Limitations of the study

This study has several limitations. First, the time span for data collection is relatively short, which may limit the generalizability of the research results. Organizational resilience in green development may not fully manifest in such a short period, and longer-term studies could provide a more comprehensive view. Future studies could consider collecting data over an extended period, such as 10 years after the enactment of the NEPL, to better capture the long-term effects. Second, this study narrows its focus to the role of resources and innovation in building corporate resilience. Future research should explore a wider range of factors, such as corporate culture, leadership, and external partnerships, to enhance the generality and depth of the findings. Third, this study examines companies only from high-pollution industries, which may limit the applicability of the findings to other sectors. A broader sample across various industries would provide a more holistic understanding of corporate green resilience. Additionally, the study does not account for potential cultural differences that may influence how companies respond to environmental regulations. As noted in previous research, cultural factors, such as collectivism versus individualism, can significantly impact corporate attitudes towards green development. Future studies should consider cross-cultural differences, particularly when comparing companies from different regions or countries, to better understand the validity and applicability of the theoretical framework across diverse cultural contexts. In summary, future research should expand the study time frame, include a broader range of influencing factors, adopt samples from diverse industries, and account for cultural differences to improve the robustness and generalizability of the findings.

CRediT authorship contribution statement

Jingfeng Huang: Writing – review & editing, Writing – original draft, Resources, Project administration, Formal analysis, Data curation, Conceptualization. **Bai Yang:** Formal analysis, Data curation, Conceptualization. **Bing Zhou:** Project administration, Conceptualization. **Bing Ran:** Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

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