

Do government subsidy policies promote the energy transition resilience of enterprises? Empirical evidence from China

Yuanke Zhao 

*School of Humanities and Foreign Languages,
Qingdao University of Technology, Qingdao, China*

Chen Yang

*School of Mechanics Civil Engineering and Architecture,
Northwestern Polytechnical University, Xian, China, and
School of Public Administration, Hohai University, Nanjing, China*

Guoqing Shi

School of Public Administration, Hohai University, Nanjing, China, and

Shusheng Yang

*School of Humanities and Foreign Languages,
Qingdao University of Technology, Qingdao, China*

Abstract

Purpose – Energy transition resilience (ETR) captures enterprises' capacity to maintain sustainability during low-carbon transitions. This paper aims to construct a comprehensive ETR evaluation index system and examines how government subsidies affect enterprises' ETR.

Design/methodology/approach – This study uses panel data from 2013 to 2023 on small and medium-sized enterprises listed on China's A-share SME and ChiNext boards to construct a comprehensive ETR evaluation index system. Econometric models are used to empirically test the impact of government subsidies on enterprises' ETR, while further analysing the mediating role of financing constraints, the threshold moderating effect of environmental regulations and heterogeneity across ownership, region and industry.

Findings – The results indicate that: government subsidies significantly enhance enterprises' ETR; the resource-based and signalling functions of government subsidies improve ETR by easing financing constraints; environmental regulations exert a countervailing moderating effect on the relationship between



© Yuanke Zhao, Chen Yang, Guoqing Shi and Shusheng Yang. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at <http://creativecommons.org/licenses/by/4.0/>

Funding: This work was supported by the Postgraduate Research and Practice Innovation Program of Jiangsu Province No. KYCX_0912; Fundamental Research Funds for the Central Universities No. B240205044; Fundamental Research Funds for the Central Universities No. D5000240157; Key Research Project of the National Foundation of Social Science of China No. 21&ZD 183.

Declaration of competing interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

government subsidies and ETR, displaying a single threshold; and government subsidies have a stronger positive effect on ETR among non-state-owned enterprises, eastern enterprises and manufacturing enterprises.

Practical implications – The findings offer empirical support for governments to optimise subsidy policies and improve environmental regulation systems. They also provide decision-making references for enterprises to enhance ETR and achieve sustainable energy transition, contributing to the joint promotion of energy transformation and the “dual carbon” goals at both governmental and enterprise levels.

Originality/value – This paper is among the earliest attempts to systematically construct a comprehensive evaluation index system for enterprises’ ETR, filling a gap in the existing literature. It innovatively reveals the mechanisms of government subsidies from the perspectives of resource-based theory, signalling theory and threshold moderation, providing new empirical evidence on the relationship between subsidy policies and ETR.

Keywords Subsidy policies, Energy transition, Resilience, Financing constraints

Paper type Research paper

1. Introduction

As global climate change intensifies and natural resources become increasingly scarce, the energy transition has emerged as a pivotal pathway towards green development and sustainable economic growth. China, as the world’s largest emitter of greenhouse gases, continues to exhibit an energy structure and demand profile heavily reliant on traditional fossil fuels (Gu *et al.*, 2024). The Paris Agreement stipulates that global net-zero carbon emissions should be achieved by 2050, a target that requires the concerted efforts of enterprises, governments and all sectors of society (Wang and Lo, 2021). As the primary creators of socio-economic wealth, enterprises are the foremost consumers of resources and energy, as well as the largest contributors to pollution and carbon emissions (Maia and Garcia, 2023). At the same time, as the main users of energy and drivers of technological innovation, enterprises’ capacity to respond and adapt to the energy transition process is directly linked to the extent to which transition goals are achieved. Under such conditions, enterprises’ ability to withstand shocks, adapt to changing environments and sustain transformation trajectories over time becomes critical (Roemer and Haggerty, 2022). Consequently, resilience has emerged as a key concept for understanding how enterprises survive and thrive amid the risks and uncertainties associated with energy transition.

The concept of resilience originated in ecology, where it was initially used to describe the capacity of an ecosystem to recover and adapt after disturbance (Herman *et al.*, 2011). It was subsequently introduced into the social sciences to analyse how enterprises and individuals respond to uncertain, complex and dynamic risks. In the context of energy systems, energy transition resilience (ETR) is defined as the ability of an energy system to sustain long-term operational stability (Williams *et al.*, 2017; Zhang *et al.*, 2024a). At the enterprise level, ETR refers to their comprehensive ability to maintain operational stability, foster technological innovation and achieve green development when confronted with the challenges of high investment, substantial risk and uncertainty inherent in the energy transition (Gatto *et al.*, 2023; Roemer and Haggerty, 2022). While conventional literature frequently evaluates enterprise environmental strategies through the lenses of environmental performance or green innovation capability, these constructs primarily capture static outcomes or isolated dimensions of enterprise behaviour. Specifically, environmental performance typically functions as a trailing indicator of realised ecological footprints (Ismail *et al.*, 2026), whereas green innovation capability highlights discrete technological inputs and research efforts rather than systemic adaptability (Shah *et al.*, 2026). Furthermore, although the broader concept of organisational resilience addresses a enterprise’s general capacity to withstand macro-crises such as financial distress or supply chain disruptions (Yao and Li, 2026), it inherently lacks the focus required to address the profound environmental-specificity, high sunk costs and structural uncertainties unique to the low-carbon

paradigm shift. In contrast, ETR provides a distinctive analytical lens for understanding how enterprises navigate the uncertainties inherent in energy transition (Zhang *et al.*, 2024b). It focuses on the process where enterprises continuously adjust and reorganise their resources through dynamic mechanisms to maintain a long-term trajectory of transition in the face of external regulatory shocks and internal disruptions. By uniquely integrating this resilience perspective with the complex context of energy systems, it offers valuable insights for enterprises seeking to understand how to navigate the green transition.

Existing evidence suggests that enterprise energy transition produce spillover effects that give rise to asymmetric costs and benefits across enterprises during the transition process (Liu *et al.*, 2024). Moreover, as the process is relatively lengthy and fraught with high risks, enterprises' intrinsic motivation to transition may be weakened (Liu *et al.*, 2019). Consequently, it is insufficient to rely solely on market forces to drive the energy transition, and thus appropriate fiscal policies support from the government becomes indispensable. Among fiscal tools, government subsidies serve as an effective means of providing short-term economic compensation and enhancing enterprises' long-term ETR (Sun *et al.*, 2022). Firstly, subsidies can strengthen the economic resilience of enterprises' energy transition by lowering the initial costs of adopting clean energy technologies and implementing energy-saving measures (Wang *et al.*, 2020). Such cost reductions facilitate enterprises' adaptation to evolving energy policies and shifting market demands, thereby enhancing adaptability during the transition process. Moreover, subsidies can effectively alleviate the financing pressures encountered during the energy transition, thereby improving capital liquidity and financial stability (Sun *et al.*, 2022). Secondly, subsidies can encourage enterprises to increase investment in research and development (R&D) of renewable energy and clean technologies, thus promoting technological innovation (Peng and Liu, 2018). Bai *et al.* (2019) noted that subsidies primarily exert their influence by easing financing constraints and increasing R&D investment.

Despite the growing consensus on the necessity of fiscal intervention to mitigate the asymmetric costs and uncertainties of energy transition (Liu *et al.*, 2024), the nexus between government subsidies and ETR remains underexplored. Firstly, while substantial progress has been made in quantifying green performance and innovation, there is an absence of a standardised, multi-dimensional measurement for ETR at the enterprise level. Current metrics predominantly capture static, realised outcomes (Aldieri *et al.*, 2021), failing to assess resilience as a holistic capacity encompassing resource reconfiguration and shock absorption. Secondly, although subsidy policies are recognised for easing financing constraints and signalling market legitimacy, the internal mechanisms through which it translates into long-term resilience remain largely obscured. Thirdly, there is limited empirical evidence regarding the interaction between subsidies and external institutional pressures. The question of how environmental regulations set critical boundaries for subsidy effectiveness remains unanswered. Although the Chinese Government has set a carbon neutrality target for 2060, the current composition of energy enterprises remains heavily dependent on traditional fossil fuels and there is insufficient understanding of how these enterprises can develop resilience in transitioning towards green and low-carbon energy. Analysing the relationship between government subsidy policies and enterprises' ETR is therefore essential for the effective implementation of the energy transition and the achievement of green, low-carbon development. Building on this context, the present study seeks to address the following research questions:

- RQ1. Do government subsidy policies significantly improve enterprises' ETR?
- RQ2. Through which mechanisms do government subsidies influence ETR?
- RQ3. Do the effects of subsidies on ETR differ across enterprise types?

This study makes several contributions. Firstly, it constructs a comprehensive evaluation index system for enterprises' ETR, thereby providing a foundation for advancing quantitative research in this field. Secondly, drawing on the resource and signal-based attributes of government subsidies, it examines the mechanisms through which subsidies affect ETR, using financing constraints as a mediating variable and environmental regulation as a moderating variable to explore the interactions between different policy instruments. Finally, it conducts a multi-faceted heterogeneity analysis across enterprise attributes, regions and industries to identify variations in the effects of subsidies, offering evidence-based insights for policymakers seeking to enhance subsidy policies.

The rest of the paper is structured as follows: Section 2 presents a literature review of the study and proposes theoretical hypotheses. Section 3 introduces the research methodology and data sources. Section 4 analyses the research results. Section 5 discusses the results in depth. Section 6 concludes with policy implications.

2. Theoretical analysis and research hypotheses

2.1 *Impact of government subsidy policies on enterprises' energy transition resilience*

As an external third-party actor to enterprises and investors, the government can effectively reduce the economic costs incurred by enterprises during the energy transition through financial subsidies, thereby enhancing enterprises' ETR. Firstly, the energy transition generates significant positive externalities, the spillover effects of which compel enterprises to bear substantial costs while making it difficult for them to capture corresponding benefits (Noseleit, 2018). By providing subsidies, the government internalises these externalities, compensates for funding gaps in enterprise transformation and ensures sustained investment in green and low-carbon projects, thereby strengthening their ability and resilience in the transition process. Secondly, subsidies can stimulate technological innovation and enhance enterprises' dynamic capabilities. The energy transition involves high technological barriers and considerable uncertainty, which may cause enterprises to slow innovation when facing financial pressures during R&D (Ghisetti *et al.*, 2017). As non-repayable financial support, subsidies not only increase cash flow but also significantly reduce the marginal cost of innovation and the risk of failure caused by uncertainty, thereby boosting both resilience and competitiveness. Finally, subsidies can ease financial constraints arising from information asymmetry. Energy transition projects often entail long payback periods, making it difficult for enterprises to secure adequate funding from capital markets (Hall *et al.*, 2017). Moreover, to maintain a favourable public image and continue receiving subsidies, enterprises often disclose more environmental information (Zeng *et al.*, 2012). This behaviour strengthens trust between enterprises and capital markets, further alleviating financing constraints and promoting improvements in enterprises' ETR:

H1. Government subsidies help promote enterprises' ETR.

2.2 *The mediating role of financing constraints*

Alleviating financing constraints serves as a critical mechanism through which government subsidies enhance enterprises' ETR. Under the institutional pressure of environmental regulation, energy transition requires enterprises to undertake investments in green R&D (Yu *et al.*, 2021). However, information asymmetry and long payback periods often make external financiers reluctant to provide sufficient capital, thereby intensifying enterprises' financing constraints and weakening their capacity to sustain transition-oriented activities (Wang *et al.*, 2025). Government subsidies as a policy-induced resource endorsement

mechanism that alleviates financing constraints through two theoretically distinct but complementary attributes. Firstly, from a resource attribute-based perspective, subsidies increase enterprises' financial slack, reduce the marginal cost of transition investment and improve their flexibility in allocating resources to green innovation and technological upgrading (Mazzucato and Semieniuk, 2018), thereby enabling enterprises to absorb financial pressure and maintain investment continuity during the transition process (Yang *et al.*, 2019). Secondly, the signalling attribute of subsidies refers to their certification function in capital markets (Ilmanen, 2011). In contexts of information asymmetry, subsidies indicate that a enterprise's transition strategy is aligned with government policy priorities and has received a certain degree of public endorsement, which improves the enterprise's perceived legitimacy, reduces investors' risk perceptions and enhances its access to external financing (Wang *et al.*, 2022). Therefore, the resource attribute primarily relaxes internal capital constraints, whereas the signalling attribute improves the external financing environment by reducing information asymmetry and strengthening market confidence. By integrating these two mechanisms, government subsidies mitigate financing constraints through both an internal resource channel and an external legitimacy channel, thereby strengthening enterprises' resilience ability to absorb shocks:

- H2. From the perspective of the resource and signalling attributes of government subsidies, such subsidies can enhance enterprises' ETR by alleviating financing constraints.

2.3 The moderating role of environmental regulations

As an important policy tool for driving energy transition, environmental regulations not only directly influence enterprise behaviour but also moderate the relationship between government subsidies and enterprises' ETR. When regulatory intensity remains below a critical threshold, the institutional pressure is relatively moderate, serving as a constructive catalyst to overcome uncertain risk without paradoxically depleting enterprise resilience (Dragomir and Dragomir, 2020). Within this initial regime, subsidies and regulations operate complementarily: regulatory mandates guide enterprise awareness towards green practices, while subsidies act as a vital financial buffer to offset initial compliance expenditures (Panaiotov, 1994), thereby maintaining a stable and positive impact on enterprises' ETR. However, once the intensity of environmental regulations crosses a critical structural threshold, a distinctive regime shift occurs wherein the compliance cost effect overshadows the innovation offset effect. Under hyper-strict regulatory regimes, the exorbitant cost of immediate compliance severely drains corporate financial resources (Li *et al.*, 2019). Driven by short-term survival imperatives and cost-minimisation strategies (Gunningham *et al.*, 2005), enterprises are forced to adopt defensive operational postures. Consequently, rather than routing government subsidies into long-term, high-risk strategic energy transition, enterprises may divert these public funds to address immediate, rigid regulatory penalties or superficial end-of-pipe treatments. This resource reallocation and crowding-out effect in the post-threshold regime ultimately leads to a weakening of the facilitative impact of government subsidies on enterprises' ETR:

- H3. Environmental regulations exert a moderating effect on the relationship between government subsidies and enterprises' ETR, such that the positive effect of subsidies on ETR weakens after regulatory intensity crosses a critical threshold. The theoretical analysis of this study is shown in Figure 1.

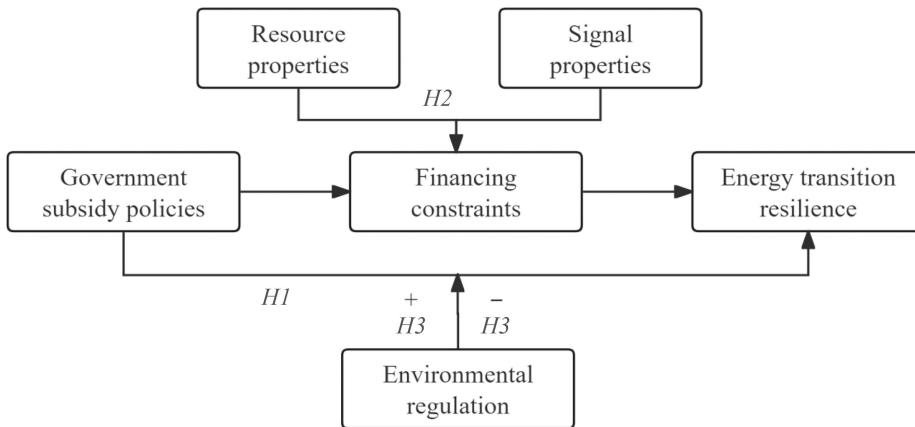


Figure 1. Theoretical analytical framework

3. Methodology and data sources

3.1 Sample and data sources

This study uses panel data listed on China's A-share SME Board and ChiNext Board over the period 2013–2023. Government subsidies are more likely to generate observable marginal effects among SMEs because these enterprises typically operate under stronger resource constraints, higher financing frictions and technological uncertainty than large state-owned enterprises (Sun *et al.*, 2022; Zhang *et al.*, 2024a). In contrast, large state-owned enterprises are shielded by soft budget constraints, preferential access to state-controlled financial resources and the simultaneous pursuit of commercial policy mandates, which may attenuate their sensitivity to marginal subsidy changes (Wang *et al.*, 2022). Non-listed enterprises are excluded because comparable, audited and longitudinal data on subsidies and energy transition related indicators are often unavailable or less reliable, which would undermine measurement consistency (Shao and Wang, 2023; Oum *et al.*, 2014). By focusing on the sample enterprises, which are more concentrated in entrepreneurial and green transition related sectors, the study examines a setting in which subsidies, financing constraints, environmental regulations and responses to ETR.

Data on government subsidies and control variables are primarily obtained from the WIND database, with missing values supplemented using the CSMAR database. Information on financing constraints is sourced from the CSMAR database, while data on environmental regulations are derived from the China Statistical Yearbook. Data on clean energy patent applications are obtained from the CNRDS database. To minimise the influence of outliers and ensure data reliability, the following procedures are applied:

- financial and real estate enterprises are excluded;
- enterprises designated as “ST” or “*ST” during the sample period are removed; and
- all continuous variables are Winsorised at the 1% and 99% percentiles.

After data processing, the final sample comprises 6,336 enterprise-year observations from 792 enterprises.

3.2 Variable selection and definition

3.2.1 *Dependent variable: Enterprises' energy transition resilience.* At present, methods for measuring enterprises' ETR remain in the developmental stage. To comprehensively and objectively assess enterprises' ETR, this study uses a composite indicator system. Drawing on the methodological frameworks of Hansen (1999) and He et al. (2021), and integrating the China Enterprise Green Development Report No.1 (2015) with the United Nations Sustainable Development Goals 7 and 13, we construct a multi-dimensional evaluation system comprising four first-level indicators and 14 s-level indicators, as presented in Table 1:

- (1) *Operational resilience:* Operational resilience reflects an enterprise's top-level design in the clean energy transition, encompassing strategic planning, cultural development and social responsibility. Enterprises must adapt to external challenges by revising strategies and corporate culture in rapidly changing markets and technological environments, thereby strengthening adaptability and competitiveness (Teece et al., 1997). Fostering a green culture and setting environmental objectives are critical to enhancing enterprises' ETR (Hart and Dowell, 2011). Moreover, enterprise social responsibility can improve societal recognition, secure external support for the clean energy transition and mitigate policies and market uncertainties (Carroll, 1991; He et al., 2021).
- (2) *Production resilience:* Production resilience represents the "hard power" of enterprises' clean energy transition, capturing their ability to shift from fossil fuel-based production to clean energy-based processes. It measures performance in energy conservation, emissions reduction, resource-use efficiency and economic output growth (Zahoor et al., 2022). Clean production equipment and intangible assets serve as critical competitive advantages and pillars of production resilience (de Lima E Silva and Silva, 2024).
- (3) *Innovation resilience:* Innovation resilience reflects enterprises' capacity to improve adaptability and competitiveness through R&D and technological innovation in the energy transition. The number of clean technology patents is widely recognised as a key measure of innovation capacity (Johnstone et al., 2010). Horbach (2008) observed that R&D investment in the clean energy transition can significantly strengthen technological innovation and market competitiveness. Doran and Ryan (2016) further demonstrated that a higher proportion of R&D personnel correlates with greater transition efficiency and resilience.
- (4) *Environmental resilience:* Environmental resilience refers to the ability of enterprises to minimise their environmental impact by controlling pollutant emissions and improving resource-use efficiency during the clean energy transition. Ambec and Lanoie (2008) found that investments in environmental protection and pollution control not only reduce environmental burdens but also enhance production efficiency. Domenech and Davies (2011) highlighted that comprehensive utilisation of solid waste substantially contributes to resource conservation and cost control, indicating that environmental governance capability is directly linked to an enterprise's sustainable development potential in the energy transition.

This research constructs the above comprehensive evaluation indicator system and uses the hierarchical analysis method to determine the weight of each indicator. The specific operational steps are as follows:

Table 1. Comprehensive evaluation index system for enterprises' ETR

Primary indicators	Secondary indicators	Evaluation content	Type
Operational resilience	Transition management strategy	Clean energy contingency mechanisms; clean energy management systems; ISO14001 certification	Qualitative
	Corporate transition culture	Clean transition philosophy; green energy targets; clean transition education and training	Qualitative
	Responsibility for transition	Honours and awards related to clean energy; records of environmental violations; special actions for clean transition	Qualitative
Production resilience	Clean energy production	Efficiency of clean energy use; awareness of clean energy production; incentives for clean production	Quantitative
	Clean equipment output	Ratio of revenue from clean equipment to fixed assets	Quantitative
Innovation resilience	Intangible asset ratio	Ratio of intangible assets to total assets	Quantitative
	Economic benefit growth	Growth in operating income from clean production	Quantitative
Environmental resilience	Proportion of R&D personnel	Proportion of R&D staff engaged in energy transition	Quantitative
	R&D investment ratio	Proportion of R&D investment related to energy transition	Quantitative
	Number of clean patent applications	Number of patent applications related to clean technologies	Quantitative
	Compliance in pollutant emissions	Incidents of environmental emergencies; compliance in pollutant emissions	Qualitative
	Air pollutant reduction and transition governance	Actions and awareness related to air pollution control during transition	Qualitative
	Waste water reduction and transition governance	Actions and awareness related to wastewater control during transition	Qualitative
	Solid waste utilisation and disposal	Actions taken for the comprehensive utilisation and disposal of solid waste	Qualitative

- Establishment of the hierarchical structure model and judgment matrix. A questionnaire was developed using a 1–9 scale, and 12 experts were invited to evaluate the correlation factors of each indicator level.
- *Consistency testing and weight calculation:* Out of the 12 questionnaires, 2 were discarded as their consistency ratios (CR) exceeded the acceptable threshold. For the 10 retained valid questionnaires, the CR values for all judgment matrices ranged from 0.012 to 0.078, which are strictly below the critical threshold of 0.10, confirming the logical consistency of the experts' assessments.
- *Quantification of qualitative indicators:* To ensure analytical transparency and replicability, the seven qualitative secondary indicators were transformed into quantifiable scores through content analysis. A standardised three-point scale are used based on the disclosure and implementation of policies. The detailed scoring criteria are documented in [Appendix](#).
- *Linear normalisation of data:* All indicator values were transformed into dimensionless standardised data to ensure comparability and methodological rigour.
- *Weighted calculation:* Enterprises' ETR was computed by applying the corresponding weights to each indicator, after which the natural logarithm was taken to ensure analytical robustness and mitigate the influence of extreme values. The log-transformed ETR aims to capture relative improvements in enterprise ETR while aligning with the incremental nature of enterprises' transition processes. To support the multi-dimensional ETR construct, a PCA was performed. The KMO value of 0.782 and a significant Bartlett's test ($p < 0.01$) confirmed the validity of the factor structure, with the four dimensions accounting for 74.3% of the total variance.

3.2.2 Independent variable: Government subsidies. Following the disclosure of government subsidy items in the notes to the consolidated financial statements of listed companies, this study aggregates the total value of all government subsidies received during the period as the initial value. Given the potentially large magnitude of subsidies and the existence of observations with zero subsidies, and to ensure both data integrity and operability, we follow the approach of [Bai et al. \(2019\)](#) and [Lu et al. \(2022\)](#) by adding 1 to the initial value before applying the natural logarithm transformation.

3.2.3 Mediating variable: Financing constraints. Referring to [Schauer et al. \(2019\)](#), this study uses the FC index to measure financing constraints. The FC index is a composite indicator derived from multi-dimensional data and model fitting to assess the difficulties enterprises face in securing financing. A higher FC index value indicates more severe financing constraints.

3.2.4 Moderating variable: Environmental regulations. Drawing on the methods of [Hou et al. \(2018\)](#) and [Ouyang et al. \(2020\)](#), environmental regulation intensity is measured as the ratio of industrial pollution control investment to the added value of the secondary industry.

3.2.5 Control variables. To minimise the influence of confounding factors on the regression results, we follow the approach of [Shen et al. \(2017\)](#) and [Shao and Wang \(2023\)](#) by controlling for enterprise age, asset liability ratio, cash flow, ownership structure, equity concentration, fixed asset ratio, return on total assets and the marketisation index. [Table 2](#) presents the specific definitions and calculation methods of all variables.

Table 2. Variable definition

Variable type	Name	Definition	Measurement method
Dependent variable	InETR	ETR of enterprises	Logarithm of the enterprise's ETR index
Independent variable	Sub	Government subsidies	Logarithm of (government subsidies + 1)
Mediating variable	FC	Financing constraints	FC index
Moderating variable	ER	Environmental regulation	(Investment in industrial pollution control/value added of secondary industry) × 100
Instrumental variable	Submean	Industry-level average of government subsidies	Tertile average of government subsidies at the industry level
Proxy variable	Creia	Number of clean energy patent applications	Logarithm of (total clean energy patent applications + 1)
Control variables	Age	Enterprise age	Logarithm of (Enterprise's founding year + 1)
	Lev	Leverage ratio	Ratio of total liabilities to total assets at year-end
	Cash	Cash flow	Ratio of cash flow from operating activities to total assets
	Soe	Ownership type	Takes value 1 if state-owned or state-controlled, 0 otherwise
	Equity	Ownership concentration	Shareholding ratio of the largest shareholder
	Fas	Fixed asset ratio	Ratio of fixed assets to total assets at year-end
	Roa	Return on total assets	Net profit divided by average total assets
	Market	Marketisation index	Marketisation index in the "China provincial marketisation index report"

3.3 Model setting

3.3.1 Baseline regression model. To test research *H1* and evaluate the impact of government subsidies on enterprises' ETR, this study constructs the following baseline regression model incorporating a two-way fixed effects specification:

$$\ln ETR_{it} = \alpha_0 + \alpha_1 Sub_{it} + \alpha_2 \sum Control_{it} + \sum u_i + \sum Year + \varepsilon_{it} \quad (1)$$

Among them, *i* represents the enterprise, *t* represents the year. $\ln ETR_{it}$ represents enterprises' ETR *i* in year *t*. Sub_{it} measures the government subsidies obtained by enterprise *i* in year *t*. $Control_{it}$ represents the above control variables. u_i and *Year* represent firm and year fixed effects. ε_{it} is the random disturbance term. α_0 is the constant term, α_1 is the coefficient corresponding to government subsidies and α_2 is the coefficient corresponding to control variables.

3.3.2 Mediating effect model. To test research *H2* and assess the mediating role of financing constraints in the relationship between government subsidies and enterprises' ETR, Model (2) is constructed on the basis of the baseline Model (1):

$$FC_{it} = b_0 + b_1 Sub_{it} + b_2 \sum Control_{it} + \sum u_i + \sum Year + \varepsilon_{it} \quad (2)$$

Among them, FC_{it} represents the financing constraints faced by enterprise *i* in year *t*. If the coefficient α_1 in Model (1) is significant and the coefficient b_1 in Model (2) is also significant, it indicates that there is an intermediary effect of financing constraints.

3.3.3 *Moderating effect model.* To test research *H3*, this study incorporates environmental regulations as a moderating variable and introduces an interaction term between environmental regulations and government subsidies to construct Model (3):

$$\ln ETR_{it} = c_0 + c_1 Sub_{it} + c_2 ER_{it} + c_3 ER_{it} \times Sub_{it} + c_4 \sum Control_{it} + \sum u_i + \sum Year + \varepsilon_{it} \quad (3)$$

At the same time, to verify that different levels of environmental regulation may lead to differences in enterprises' ETR, we used environmental regulation as a threshold variable and adopted the threshold regression model proposed by Hansen (1999) to construct Model (4):

$$\ln ETR_{it} = d_0 + d_1 Sub_{it}(ER_{it} \leq \theta_1) + d_2 Sub_{it}(ER_{it} > \theta_1) + d_3 \sum Control_{it} + \sum u_i + \sum Year + \varepsilon_{it} \quad (4)$$

Among them, θ_1 is the corresponding environmental regulation threshold value. d_1 is the coefficient of the impact of government subsidies on enterprises' ETR when $ER_{it} \leq \theta_1$. d_2 is the coefficient of the impact of government subsidies on enterprises' ETR when $ER_{it} > \theta_1$. When $d_1 \neq d_2$, it indicates that there is a threshold effect, otherwise there is no threshold effect. The multiple threshold model setting is consistent with the single threshold model setting.

4. Results

4.1 Descriptive statistical analysis

Table 3 shows the descriptive statistical analysis of the variables. The results show that the minimum value of enterprises' ETR is 0.197, the maximum is 0.631 and the mean is 0.395. This suggests substantial variation in ETR among the sample enterprises, indicating an overall unbalanced distribution. Government subsidies have a standard deviation of 1.283 and a median of 15.110, reflecting notable disparities in the amounts received by different enterprises. Financing constraints range from a minimum of 0.021 to a maximum of 0.933, with a mean of 0.568, indicating that while the severity of constraints varies considerably across enterprises, most enterprises experience relatively pronounced financing limitations. For environmental regulations, the minimum observed value is 0.012 and the maximum is

Table 3. Descriptive statistics of variables

Variable	No.	Mean	Median	Standard deviation	Min.	Max.
ETR	6,336	0.395	0.363	0.077	0.197	0.631
Sub	6,336	15.05	15.11	1.283	12.23	19.19
Submean	6,336	15.05	15.01	0.498	14.68	17.21
Creia	6,336	0.440	0	0.831	0	3.466
FC	6,336	0.568	0.623	0.276	0.021	0.933
ER	6,336	0.197	0.149	0.136	0.012	0.691
Age	6,336	2.833	2.763	0.279	2.064	3.499
Lev	6,336	0.348	0.327	0.135	0.041	0.796
Cash	6,336	0.041	0.039	0.061	-0.131	0.278
Soe	6,336	0.128	0	0.298	0	1
Equity	6,336	0.307	0.297	0.123	0.087	0.678
Fas	6,336	0.198	0.176	0.127	0.004	0.559
Roa	6,336	0.046	0.045	0.061	-0.271	0.213
Market	6,336	7.836	7.951	1.325	3.890	10

0.691, again indicating marked regional differences in regulatory intensity. The remaining control variables also display substantial variation, suggesting heterogeneity in enterprise characteristics within the sample.

4.2 Measurement of enterprises' energy transition resilience

This study first measures and analyses enterprises' ETR. Figure 2 illustrates the trend in the average ETR of all sample enterprises from 2013 to 2023. Overall, the results reveal an upward trajectory: enterprises' ETR remained relatively stable between 2013 and 2016, followed by a marked increase from 2016 to 2023. As the energy transition has progressed, enterprises have responded positively by adopting cleaner energy sources and promoting low carbon development, thereby enhancing their ETR (Maia and Garcia, 2023).

This study further examined the average ETR trends of enterprises by ownership type and industry classification. As shown in Figure 3, the average ETR of state-owned enterprises is consistently higher than that of non-state-owned enterprises. Similarly, manufacturing enterprises exhibit significantly higher ETR levels compared with their non-manufacturing counterparts. This finding underscores the heterogeneous resilience-building capacity of enterprises under varying ownership and sectoral pressures.

4.3 Base regression results

Firstly, to address concerns of multi-collinearity, we conducted a VIF test. The overall mean VIF is 1.67, and the maximum value is 4.07. All VIF values are less than 10, indicating that there is no serious multi-collinearity issue among the variables. The first column of Table 4 shows results before control variables are included, while the second column shows results after control variables are included. To formally justify this model specification, a Hausman test is conducted. The result rejects the null hypothesis of the random effects model

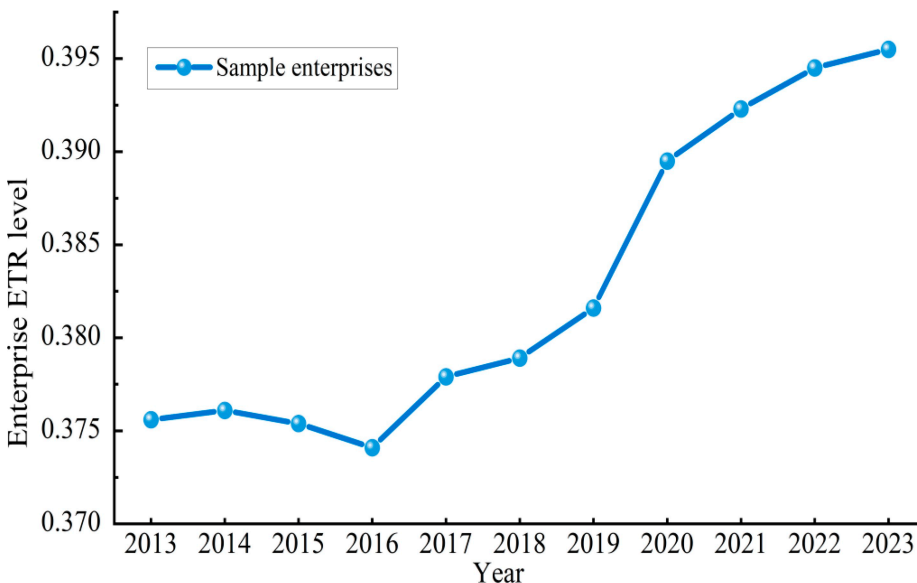


Figure 2. ETR trends in sample enterprises

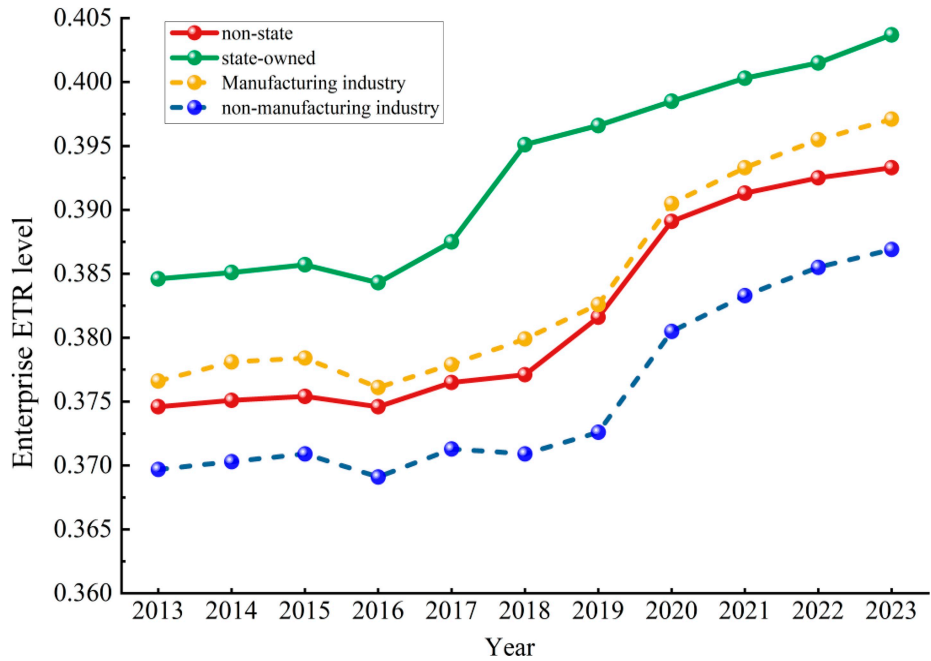


Figure 3. ETR trends in enterprises with different ownership structures and industries

Table 4. Impact of government subsidies on enterprises' ETR

Variables	InETR (1)	InETR (2)
Sub	0.042*** (0.002)	0.036*** (0.002)
Lev		0.001 (0.017)
Age		0.051*** (0.010)
Cash		0.193*** (0.045)
Soe		0.049*** (0.009)
Equity		−0.067*** (0.020)
Fas		0.175*** (0.024)
Roa		0.298*** (0.046)
Market		0.004** (0.002)
Constant term	−2.105*** (0.037)	−2.226*** (0.048)
Firm FE	Yes	Yes
Year FE	Yes	Yes
N	6336	6336
R ²	0.114	0.134

Note(s): Significance at the 5 and 1% levels is denoted by ** and ***, respectively. Robust standard errors are reported in parentheses

($p < 0.01$), statistically validating the necessity of using the firm fixed effects framework. In both models, the estimated coefficients for government subsidies are significantly positive at the 1% level, indicating that a 1% increase in government subsidies is associated with an approximately 0.036% increase in enterprises' ETR. The findings suggest that subsidies reduce the marginal cost of transition, share the risks associated with uncertainty in R&D and innovation activities related to green transition, enhance enterprises' adaptability in energy transition. These results provide empirical support for *H1*.

Regarding the control variables, the estimated coefficients for Age, Cash, Soe, Roa, Fas and Market are all significantly positive. Increases in Cash and Roa signal strong operational performance, enabling enterprises to invest more in clean energy transition projects. A higher Fas implies that enterprises possess more advanced machinery, equipment and technological capacity, which facilitates green and low carbon production processes. By contrast, the coefficient for Equity is significantly negative, indicating that higher ownership concentration is detrimental to enterprises' ETR. From a governance perspective, excessive ownership concentration may intensify principal-agent conflicts, enabling controlling shareholders to prioritise short-term financial returns over long-term strategic investments (Shao and Wang, 2023). Furthermore, existing studies suggest that highly concentrated ownership structures tend to suppress enterprises' risk-taking and green innovation incentives, thereby weakening environmental performance and long-term resilience (Bai *et al.*, 2019; Ge, 2023).

4.4 Robustness and endogeneity tests

4.4.1 Robustness test. To establish the reliability of our baseline findings, three rigorous robustness checks are performed. Firstly, we use an alternative measure for the dependent variable. Specifically, the total number of clean energy patent applications (calculated as the natural logarithm of the sum of clean energy invention and utility model applications, plus one) serves as a proxy for enterprises' ETR. As shown in Column (1) of Table 5, the coefficient of government subsidies remains significantly positive at the 1% level.

Secondly, enterprises with ongoing clean transition projects or products, as well as sufficient innovation resources, may have a greater likelihood of being selected as subsidy recipients, which could bias the regression results (Jiang *et al.*, 2023). This raises the possibility of reverse causality between government subsidies and enterprises' ETR, as subsidies may enhance ETR while higher ETR could also affect subsidy allocation, leading to potential endogeneity. To address both reverse causality and the time lagged effects of subsidies, the regression was re-estimated using lagged government subsidies as the independent variable. Column (2) of Table 5 shows that the coefficient of lagged government subsidies remains significantly positive at the 1% level, further supporting the robustness of *H1*.

Finally, to ensure our baseline findings are not driven by the subjectivity of the AHP, we perform additional robustness checks using two alternative weighting approaches to reconstruct the ETR index. Firstly, we use the equal weighting method to objectively assign weights. Secondly, the entropy weight method is used, whereby all 14 sub-indicators are assigned the same weighting. The coefficient for government subsidies remains significantly positive under both alternative weighting schemes, further confirming the robustness of our results.

4.4.2 Instrumental variable test. This study follows Peng and Liu (2018) and selects two instrumental variables: the industry level mean of government subsidies and its lagged value. The industry level mean reflects the government's allocation decisions at the sectoral level and is not directly related to the ETR of individual enterprises, yet it is highly correlated with

Table 5. Robustness and endogeneity tests

Variables	Replace the dependent variable Creia (1)	Independent variable lagged one period lnGTD (2)	Equal weight ETR ETR_equal (3)	Entropy weight ETR ETR_entropy (4)	Submean (5)	Instrumental variable regression L.Submean (6)
Sub	0.116*** (0.008)		0.052*** (0.003)	0.050*** (0.003)	0.049*** (0.010)	0.062*** (0.014)
L.Sub		0.038*** (0.002)				
Constant term	-1.734*** (0.168)	-2.290*** (0.054)	-2.205*** (0.172)	-2.187*** (0.169)	-2.225*** (0.179)	-2.503*** (0.063)
Control variables	Control	Control	Control	Control	Control	Control
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	6,336	5,808	6,336	6,336	6,336	5,808
R ²	0.111	0.151	0.136	0.136	0.138	0.137

Note(s): Significance at the 1% levels is denoted by ***. Robust standard errors are reported in parentheses

the subsidies received by each enterprise within the industry. This satisfies the relevance and exogeneity conditions for valid instrumental variables (Imbens, 2014).

Using these instruments, Model (1) was re-estimated via the 2SLS method. Columns (5) and (6) of Table 5 present the results. The tests confirm the absence of weak instruments and reject the null hypothesis of under-identification. The 2SLS results are consistent with the baseline regression, with the coefficient for government subsidies remaining significantly positive at the 1% level. Moreover, the coefficient magnitude is larger than in the baseline model, suggesting that endogeneity was present and that the use of instrumental variables effectively mitigates its impact on the estimates.

4.5 Mechanism analysis

4.5.1 Analysis of the mediating effect of financing constraints. To align with modern causal mediation standards (Imai et al., 2010), we assess the indirect effect of subsidies on ETR through financing constraints. Following the recommendations of Shaver (2005) and Rucker et al. (2011) for mediating effect analysis, it is necessary to first assess the relationship between the independent variable and the mediating variable. Accordingly, a regression based on Model (2) was conducted. The results show that the estimated coefficient of government subsidies on financing constraints is significantly negative at the 1% level. This implies that a unit increase in subsidies meaningfully relaxes the financing constraints an enterprise faces, freeing up critical capital specifically for green technology investments.

To formally quantify the causal mediation channel, the Bootstrap method was applied to estimate the indirect effect (Table 6). The results indicate that the 95% confidence interval for the indirect effect is [0.021, 0.034], which does not include zero. This statistically significant indirect effect confirms that financing constraints act as a vital transmission mechanism. Economically, this mechanism holds high practical significance: under the resource attribute of subsidies, the government directly injects liquidity to share the heavy capital burdens of energy transition. Concurrently, under the signalling attribute, receiving a subsidy conveys a positive signal to external markets, functionally multiplying an enterprise's capacity to attract outside investment. This robust causal pathway continues to support *H2*.

4.5.2 Analysis of the moderating effect of environmental regulations. This study further examines the moderating role of environmental regulations in the relationship between government subsidies and enterprises' ETR. The results, presented in Column (2) of Table 7, show that the estimated coefficient of government subsidies is significantly positive at the 1% level, whereas the interaction term between environmental regulations and government subsidies is significantly negative at the 5% level. The opposite signs of these coefficients indicate that environmental regulations exert a significant negative moderating effect on the impact of government subsidies on enterprises' ETR, thereby supporting *H3*.

Table 6. Bootstrap mediation test

Effect	Coefficient	Bootstrap 5,000	Bootstrap 5,000	<i>p</i> -value
		times 95% CI	times 95% CI	
		Lower limit	Upper limit	
Indirect effect Sub→FC→InETR	0.023	0.021	0.034	0.001
Direct effect Sub→InETR	0.038	0.034	0.042	0.001
Total effect	0.061	0.055	0.076	0.001

Table 7. Results of mediation and moderation effect tests

Variables	Mediation effect		Moderation effect	
	FC (1)	(2)	InETR (3)	(3)
Sub	−0.058*** (0.002)	0.038*** (0.002)	0.035*** (0.002)	
ER		−0.021 (0.021)		
ER × Sub		−3.933** (1.743)		
Alt_ER			−0.012 (0.015)	
Alt_ER × Sub			−2.845** (1.231)	
Constant term	1.934*** (0.042)	−2.208*** (0.049)	−2.156*** (0.021)	
Control variables	Control	Control	Control	
Firm FE	Yes	Yes	Yes	
Year FE	Yes	Yes	Yes	
N	6,112	6,336	6,301	
R ²	0.550	0.146	0.145	

Note(s): Significance at the 5 and 1% levels is denoted by ** and ***, respectively. Robust standard errors are reported in parentheses

Furthermore, we use the criterion of “whether an enterprise was designated as a key pollution monitoring enterprise in a given year” as a proxy indicator for environmental regulation, to more accurately reflect the regulatory pressure at the enterprise level. The re-estimated results in Column (3) of [Table 7](#) demonstrate that the micro-level interaction term remains significantly negative at the 5% level. While subsidies promote resilience, stringent environmental regulations crowd out these benefits by drastically increasing short-term compliance costs ([Shen et al., 2017](#)). Under such conditions, sample SMEs may reallocate government subsidies away from long-term resilience-building activities towards immediate compliance needs. As a result, subsidies intended for the energy transition may be diverted towards end of pipe treatments rather than towards R&D and innovation in clean energy products, thereby weakening the positive influence of government subsidies on enterprises’ ETR.

4.5.3 Threshold test of environmental regulations. While the preceding analysis confirms a negative moderating effect, it remains unclear whether this effect is distinctly non-linear based on regulatory stringency. To investigate this, environmental regulations are treated as a threshold variable, and a bootstrap method is applied to test for threshold effects following the methodology of [Hansen \(2000\)](#). As shown in [Table 8](#), environmental regulations pass the single-threshold test with athreshold value of 0.203, whereas the double- and triple-threshold tests lack statistical significance ($p > 0.1$).

[Figure 4](#) presents the LR plot with environmental regulations as the threshold variable, where the minimum point of the LR statistic corresponds to the estimated threshold value. When $ER \leq 0.203$, the estimated coefficient for government subsidies is 0.011 and is significant at the

Table 8. Threshold estimation test results

Variables	Threshold type	F-value	p-value	Critical value			Threshold value	Confidence interval	
				10%	5%	1%			
ER	Single threshold	67.53	0.007	47.223	53.741	63.565	0.203	0.2025	0.2043

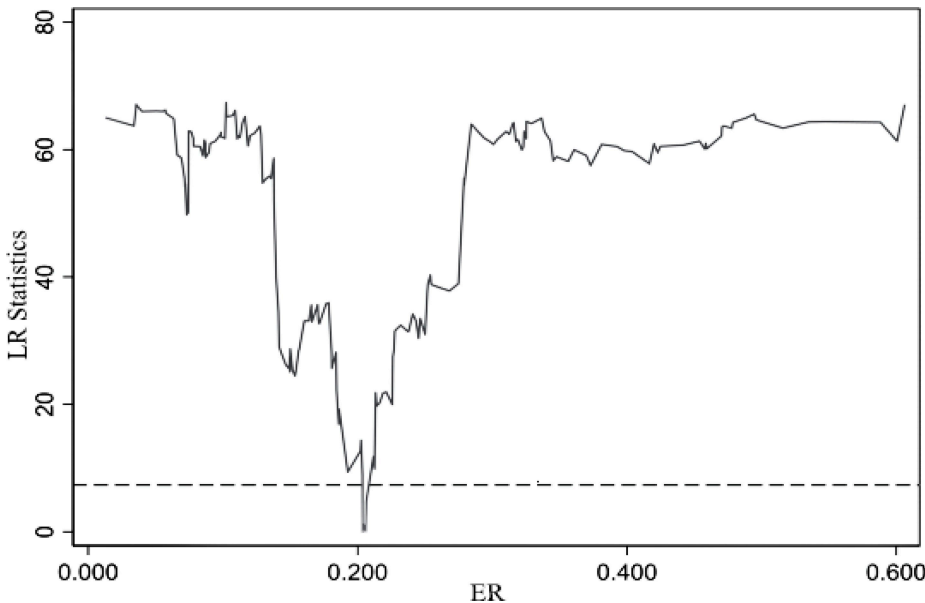


Figure 4. LR diagram of environmental regulations as threshold variables

1% level. When $ER > 0.203$, the estimated coefficient for government subsidies is 0.009; while still significant at the 1% level, the coefficient has decreased, indicating that as the level of environmental regulation increases, the role of government subsidies in promoting corporate green transition gradually diminishes. When environmental regulations are moderate, they may synergise with subsidies to encourage green innovation. In practical terms, this threshold effect signifies that subsidies yield the highest real-world returns in environments with manageable regulatory burdens. Once regulatory stringency crosses the critical threshold (0.203), enterprises are forced into a reactive, survival-oriented resource allocation strategy. Consequently, financial subsidies originally intended for foundational clean energy transitions are “crowded out” and immediately diverted into short-term, end-of-pipe treatments to maintain legitimacy and avoid severe regulatory penalties. Further sample analysis reveals that 63.7% of observations fall below the threshold of 0.203, while 36.3% are above it. This implies that for the majority of sampled enterprises, regulations remain within a tolerable range where government subsidies continue to play a meaningful practical role in advancing ETR.

4.6 Heterogeneity analysis

- *Heterogeneity by property rights:* The nature of property rights directly influences enterprises’ business objectives, resource allocation and technological innovation behaviour. Prior studies indicate that state-owned enterprises are more inclined to accept and implement government policy directives due to their alignment with policy orientations, and thus may receive greater resource support and preferential treatment during the energy transition (Zhu *et al.*, 2022). In contrast, non-state-owned enterprises rely more heavily on market incentives and tend to achieve transition goals through innovation and efficiency improvements, exhibiting greater

market sensitivity and flexibility (Li *et al.*, 2017). Accordingly, this study first conducts heterogeneity tests for enterprises with different ownership structures.

- *Heterogeneity by region:* Significant disparities exist in China's regional economic development. Owing to their higher levels of economic growth and stronger fiscal capacity, eastern regions invest far more in environmental governance than central and western regions. The financial strength and environmental awareness of local governments play a critical role in shaping enterprises' energy transitions. Research has shown that higher local government expenditure on pollution control increases the likelihood that local enterprises will receive subsidies to support clean energy transition activities (Yu *et al.*, 2020). This leads to marked differences in enterprises' ETR across regions. Therefore, we perform heterogeneity tests for enterprises operating in regions with different economic and environmental profiles.
- *Heterogeneity by industries:* Industries enterprises differ substantially in resource consumption and production modes, which, in turn, affect the role of subsidies in enhancing ETR. Manufacturing enterprises depend more heavily on policy support owing to their complex production processes and heavy environmental compliance burdens. Existing research suggests that enterprises in the manufacturing sector are more inclined to use government subsidies to promote the R&D and application of clean energy technologies, thereby accelerating the transition process (Liu and Liang, 2013). In contrast, non-manufacturing enterprises may face different regulatory pressures and transition pathways. Consequently, we conduct heterogeneity tests across manufacturing and non-manufacturing sectors.

Table 9 presents the results of the three heterogeneity analyses. The findings indicate that government subsidies significantly enhance enterprises' ETR regardless of ownership structure, with the estimated coefficients for both non-state and state-owned enterprises being positive and significant at the 1% level (Columns 1 and 2). Notably, the coefficient for non-state-owned enterprises (0.036) is slightly higher than that for state-owned enterprises (0.033). In practical economic terms, this suggests that the heightened market sensitivity of non-state-owned enterprises enables them to translate subsidies into transition outcomes marginally more efficiently. Geographically, while government subsidies substantially promote ETR across all areas, the effect is distinctly more pronounced for enterprises in the eastern region (0.038) compared with those in the central and western regions (0.023). An equivalent subsidy grant yields a substantially higher return on ETR in the east, likely due to better supporting infrastructure and local fiscal strength. Subsidies facilitate ETR across industry types (Columns 5 and 6). However, a one-standard-deviation increase in subsidies yields a roughly 5.2% increase in ETR for manufacturing enterprises, compared with only 2.7% for non-manufacturing enterprises. This markedly stronger economic effect underscores the heavy reliance of resource-intensive manufacturing sectors on targeted policy support to overcome the substantial capital barriers associated with green technological transition.

5. Discussions

Firstly, based on the baseline regression analysis, this study demonstrates that government subsidies significantly enhance enterprises' ETR. While much of the existing literature examines policy incentives through the narrow lenses of isolated green technologies or static environmental compliance (Bai *et al.*, 2019; Liu *et al.*, 2020), this study centres its analysis on resilience – a more integrative and dynamic enterprise attribute. Responding to contemporary debates in organisational resilience theory (Folke *et al.*, 2010; Linnenluecke, 2017), our findings suggest that ETR transcends mere adaptive capability the incremental

Table 9. Heterogeneity test results

Variables	Non-state- owned InETR (1)	State- owned InETR (2)	Eastern region InETR (3)	Central and Western regions InETR (4)	Manufacturing sector InETR (5)	Non-manufacturing sector InETR (6)
Sub	0.036*** (0.002)	0.033*** (0.002)	0.038*** (0.002)	0.023*** (0.004)	0.041*** (0.003)	0.021*** (0.002)
Constant term	-2.278*** (0.050)	-1.944*** (0.166)	-2.237*** (0.051)	-1.711*** (0.111)	-2.347*** (0.061)	-1.835*** (0.071)
Control variables	Control	Control	Control	Control	Control	Control
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	5413	923	4902	1434	4210	2126
R ²	0.132	0.243	0.145	0.185	0.144	0.164
Note(s): Significance at the 1% levels is denoted by ***. Robust standard errors are reported in parentheses						

adjustment of operational routines to absorb short-term shocks. Instead, ETR fundamentally represents a transformative capability, entailing a proactive reconfiguration of an enterprise's core technological paradigm and energy architecture. These findings echo [Liu et al. \(2019\)](#), who suggest that subsidies can substantially mitigate the risks enterprises face during energy transition, particularly in technology and capital intensive sectors, by easing pressures from financial markets. This study further argues that subsidies perform a dual function: they act as positive policy signals that enhance investor confidence in clean energy and sustainable production initiatives, and they alleviate financing constraints. This dual role enables enterprises to access resources more flexibly and to build capabilities more effectively, thereby improving ETR. In addition, the study empirically validates the internal mechanisms through which government subsidies enhance ETR, specifically through the resource attribute and the signalling attribute in mitigating financing constraints. Rather than merely inducing short-term subsidy behaviours, these mechanisms structurally cultivate long-term organisational adaptability. From the perspective of dynamic capabilities theory, subsidies provide an ex-ante "resource buffer" that shields long-term eco-innovation from short-term cash-flow volatility ([Shao and Chen, 2022](#)). Concurrently, the signalling attribute conveys favourable expectations to external investors, lowering external capital costs and mitigating information asymmetry ([Polzin et al., 2017](#)). Crucially, the process of acquiring and deploying public funds drives internal integration and external legitimization ([Peng and Liu, 2018](#)), triggering organisational learning. Consequently, the internalised green knowledge and upgraded competencies remain embedded within the firm, permanently elevating its capacity to dynamically allocate resources under future institutional uncertainties. Moreover, this study finds that the effect of government subsidies on ETR is positive and larger when ER is below the threshold (0.203), and weakens substantially when ER is above it. When regulation intensity remains relatively low, moderate environmental constraints act synergistically with subsidies, motivating enterprises to improve energy efficiency and adopt cleaner production practices ([Zhang et al., 2024b](#)). However, once regulation exceeds a critical threshold, the resulting cost burdens precipitate a severe crowding-out effect. This weakening mechanism is fundamentally rooted in the financial frictions' characteristic of SMEs. While regulatory pressure can theoretically stimulate green innovation, capturing these benefits necessitates substantial, irreversible ex-ante capital commitments. This study indicates that SMEs, constrained by a lack of financial slack, cannot absorb such regulatory shocks. To avert immediate regulatory penalties, these liquidity-constrained enterprises are structurally compelled to divert government subsidies away from long-term, resilience-building strategic innovations towards non-productive, immediate compliance overheads. This finding significantly refines the boundary conditions of the Porter hypothesis ([Porter and Linde, 1995](#); [Zhang and Chen, 2022](#)) and contributes to the global discourse on state-led eco-innovation ([Mazzucato, 2015](#)). Rather than a universal innovation offset, we demonstrate that the capacity of environmental regulation to complement is highly contingent upon enterprise-level financial capabilities. Excessively stringent regulation applied to highly constrained enterprises triggers a forced shift from strategic innovation to myopic compliance, thereby attenuating the resilience-building effects of government support. Furthermore, the heterogeneity analysis shows that government subsidies have a stronger positive effect on ETR among non-state-owned enterprises, eastern enterprises and manufacturing enterprises. One explanation is that non-state-owned enterprises, with greater market sensitivity and flexibility in resource acquisition, are more adept at converting subsidies into drivers of clean production and green innovation

(Noseleit, 2018). Similarly, the eastern region's more developed market mechanisms, industrial networks and innovation ecosystems, together with the manufacturing sector's urgent demand for energy efficiency and technological upgrading, amplify the resource and signalling effects of subsidies. Globally, highly flexible, market-responsive firms often display superior capacity in translating public matching funds into commercialised clean-tech outputs compared to highly bureaucratised entities (Johnstone *et al.*, 2017). These findings are consistent with Ma *et al.* (2021), who argue that in regions with strong institutional foundations and mature markets, the marginal effects of policy incentives are more pronounced. Industry characteristics also shape how subsidies are absorbed and transformed into resilience outcomes. Finally, several limitations should be acknowledged, which offer avenues for future research. Firstly, large state-owned enterprises may be less sensitive to subsidies due to distinct operational mandates, whereas traditional energy enterprises facing structural rigidity might require regulatory compulsion beyond financial incentives. In addition, unlisted enterprises with stricter capital constraints could benefit more significantly from subsidies. Future research could extend the analysis to SOEs, non-listed enterprises and traditional energy enterprises to examine whether the subsidy and ETR relationship varies across ownership forms, listing status and sectoral regimes. Secondly, although a composite index enables a comprehensive assessment of ETR, potential subjective measurement errors cannot be entirely ruled out. Future research could refine the ETR index by incorporating additional objective indicators as global carbon accounting data improves. Thirdly, the current analysis is based solely on objective data and does not account for internal organisational factors such as psychological or cultural resilience. Integrating both subjective managerial surveys and objective measures in future research could yield a more holistic understanding of enterprise resilience in the context of the global energy transition.

6. Conclusions and policy implications

Using panel data from A-share SME Board and ChiNext-listed companies between 2013 and 2023, this study main findings are as follows:

- Government subsidies significantly promote enterprises' ETR.
- Mechanism analysis shows that the resource and signalling attributes of subsidies enhance ETR by alleviating financing constraints.
- Environmental regulations have a counter regulatory effect on the impact of government subsidies on enterprises' ETR, with evidence of a single threshold effect. As regulation intensity increases, the positive effect of subsidies on ETR diminishes; when the regulatory burden exceeds the threshold, this effect weakens substantially.
- Heterogeneity analysis reveals that government subsidies have a stronger positive effect on ETR among non-state-owned enterprises, eastern enterprises and manufacturing enterprises. Based on these findings, the following policy recommendations are proposed:

Firstly, establish differentiated subsidy strategies based on firm capacity and regulatory intensity. Phase out direct subsidies for capable enterprises in favour of R&D tax relief and performance monitoring, while increasing financial support for weaker firms. Adjust subsidies dynamically with environmental regulation: raise amounts or extend cycles in high-pressure regions, and link eligibility to measurable green progress.

Secondly, improve policy transparency and coordination with financial institutions. Strengthen information-sharing mechanisms to guide external capital into transition activities, and establish communication channels between finance departments and banks to reinforce the resource and signalling functions of subsidies, lowering barriers to market-based transition financing.

Thirdly, adopt a dual-track framework accounting for ownership, industry and regional heterogeneity. Use market-based incentives for agile SMEs, and combine subsidies with mandatory emissions targets and structural reforms for large traditional incumbents with soft budget constraints. Regionally, guide eastern enterprises towards higher ETR while enabling central and western regions to catch up through cross-regional learning and central-government transfer payments.

Data availability

The data for all analyses reported in the manuscript is available on request.

References

- Aldieri, L., Gatto, A. and Vinci, C.P. (2021), "Evaluation of energy resilience and adaptation policies: an energy efficiency analysis", *Energy Policy*, Vol. 157, p. 112505.
- Ambec, S. and Lanoie, P. (2008), "Does it pay to be green? A systematic overview", *The Academy of Management Perspectives*, pp. 45-62.
- Bai, Y., Song, S., Jiao, J. and Yang, R. (2019), "The impacts of government R&D subsidies on green innovation: evidence from Chinese energy-intensive firms", *Journal of Cleaner Production*, Vol. 233, pp. 819-829.
- Carroll, A.B. (1991), "The pyramid of corporate social responsibility: toward the moral management of organizational stakeholders", *Business Horizons*, Vol. 34 No. 4, pp. 39-48.
- De Lima E Silva, Y.C. and Silva, M.E.A. (2024), "Optimal environmental policy and business cycles: an analysis using an e2-dsge model", *Renewable Energy*, Vol. 237, p. 121696.
- Domenech, T. and Davies, M. (2011), "Structure and morphology of industrial symbiosis networks: the case of kalundborg", *Procedia – Social and Behavioral Sciences*, Vol. 10, pp. 79-89.
- Doran, J. and Ryan, G. (2016), "The importance of the diverse drivers and types of environmental innovation for firm performance", *Business Strategy and the Environment*, Vol. 25 No. 2, pp. 102-119.
- Dragomir, V.D. and Dragomir, V.D. (2020), "Theoretical aspects of environmental strategy", *Corporate Environmental Strategy: theoretical, Practical, and Ethical Aspects*, pp. 1-31.
- Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T. and Rockström, J. (2010), "Resilience thinking: integrating resilience, adaptability and transformability", *Ecol Soc*, Vol. 15 No. 4.
- Gatto, A., Drago, C., Panarello, D. and Aldieri, L. (2023), "Energy transition in China: assessing progress in sustainable development and resilience directions", *International Economics*, Vol. 176, p. 100450.
- Ge, T. (2023), "Rising energy inequity and its driving factors to approach a just energy transition in China", *Environmental Impact Assessment Review*, Vol. 103, p. 107231.
- Ghisetti, C., Mancinelli, S., Mazzanti, M. and Zoli, M. (2017), "Financial barriers and environmental innovations: evidence from eu manufacturing firms", *Climate Policy*, Vol. 17 No. sup1, pp. S131-S147.
- Gu, J., Li, Y., Hong, J. and Wang, L. (2024), "Carbon emissions cap or energy technology subsidies? Exploring the carbon reduction policy based on a multi-technology sectoral dsge model", *Humanities and Social Sciences Communications*, Vol. 11 No. 1, pp. 1-17.

- Gunningham, N.A., Thornton, D. and Kagan, R.A. (2005), "Motivating management: corporate compliance in environmental protection", *Law and Policy*, Vol. 27 No. 2, pp. 289-316.
- Hall, S., Foxon, T.J. and Bolton, R. (2017), "Investing in low-carbon transitions: energy finance as an adaptive market", *Climate Policy*, Vol. 17 No. 3, pp. 280-298.
- Hansen, B.E. (2000), "Sample splitting and threshold estimation[J]", *Econometrica*, Vol. 68 No. 3, pp. 575-603.
- Hansen, B.E. (1999), "Threshold effects in non-dynamic panels: estimation, testing, and inference", *Journal of Econometrics*, Vol. 93 No. 2, pp. 345-368.
- Hart, S.L. and Dowell, G. (2011), "Invited editorial: a natural-resource-based view of the firm: fifteen years after", *J Manage*, Vol. 37 No. 5, pp. 1464-1479.
- He, L., Sun, Y., Xia, Y. and Zhong, Z. (2021), "Construction of a green development performance index of industrial enterprises: based on the empirical study of 458 listed industrial enterprises in China", *Ecological Indicators*, Vol. 132, p. 108239.
- Herrman, H., Stewart, D.E., Diaz-Granados, N., Berger, E.L., Jackson, B. and Yuen, T. (2011), "What is resilience? ", *The Canadian Journal of Psychiatry*, Vol. 56 No. 5, pp. 258-265.
- Horbach, J. (2008), "Determinants of environmental innovation—new evidence from German panel data sources", *Research Policy*, Vol. 37 No. 1, pp. 163-173.
- Hou, J., Teo, T.S., Zhou, F., Lim, M.K. and Chen, H. (2018), "Does industrial green transformation successfully facilitate a decrease in carbon intensity in China? An environmental regulation perspective", *Journal of Cleaner Production*, Vol. 184, pp. 1060-1071.
- Ilmanen, A. (2011), *Expected Returns: An Investor's Guide to Harvesting Market Rewards*, John Wiley and Sons.
- Imai, K., Keele, L. and Tingley, D. (2010), "A general approach to causal mediation analysis", *Psychological Methods*, Vol. 15 No. 4, pp. 309-334, doi: [10.1037/a0020761](https://doi.org/10.1037/a0020761), PMID: 20954780.
- Imbens, G. (2014), *Instrumental Variables: An Econometrician's Perspective*, National Bureau of Economic Research.
- Ismail, I.J., Changalima, I.A. and Kimario, H.F. (2026), "When does supply chain management collaborative innovation improve SMEs' environmental performance? The moderating role of collaborative innovation networks", *Strategic Business Research*, Vol. 2 No. 1, p. 100168.
- Jiang, Z., Xu, C. and Zhou, J. (2023), "Government environmental protection subsidies, environmental tax collection, and green innovation: evidence from listed enterprises in China", *Environmental Science and Pollution Research*, Vol. 30 No. 2, pp. 4627-4641.
- Johnstone, N., Haščič, I. and Popp, D. (2010), "Renewable energy policies and technological innovation: evidence based on patent counts", *Environmental and Resource Economics*, Vol. 45 No. 1, pp. 133-155.
- Johnstone, P., Stirling, A. and Sovacool, B. (2017), "Policy mixes for incumbency: exploring the destructive recreation of renewable energy, shale gas 'fracking', and nuclear power in the United Kingdom", *Energy Research and Social Science*, Vol. 33, pp. 147-162.
- Li, H., Zhu, X., Chen, J. and Jiang, F. (2019), "Environmental regulations, environmental governance efficiency and the green transformation of China's iron and steel enterprises", *Ecological Economics*, Vol. 165, p. 106397.
- Li, M.H., Cui, L. and Lu, J. (2017), "Varieties in state capitalism: outward FDI strategies of Central and local state-owned enterprises from emerging economy countries", *State-Owned Multinationals: Governments in Global Business*, Springer, pp. 175-210.
- Linnenluecke, M.K. (2017), "Resilience in business and management research: a review of influential publications and a research agenda", *International Journal of Management Reviews*, Vol. 19 No. 1, pp. 4-30.

- Liu, H. and Liang, D. (2013), "A review of clean energy innovation and technology transfer in China", *Renewable and Sustainable Energy Reviews*, Vol. 18, pp. 486-498.
- Liu, J., Yin, Y. and Yan, S. (2019), "Research on clean energy power generation-energy storage-energy using virtual enterprise risk assessment based on fuzzy analytic hierarchy process in China", *Journal of Cleaner Production*, Vol. 236, p. 117471.
- Liu, J., Zhao, M. and Wang, Y. (2020), "Impacts of government subsidies and environmental regulations on green process innovation: a nonlinear approach", *Technology in Society*, Vol. 63, p. 101417.
- Liu, Y., Cheng, J. and Dai, J. (2024), "Harnessing digital transformation for green innovation in energy transition: a study on R&D investments and spatial spillover in China", *Econ Chang Restruct*, Vol. 57 No. 1, p. 13.
- Lu, S., Li, S. and Zhou, W. (2022), "Does government subsidy stimulate or shackle new energy industry efficiency? Evidence from China", *Environmental Science and Pollution Research*, Vol. 29 No. 23, pp. 34776-34797.
- Ma, Y., Zhang, Q. and Yin, Q. (2021), "Top management team faultlines, green technology innovation and firm financial performance", *Journal of Environmental Management*, Vol. 285, p. 112095.
- Maia, R.G.T. and Garcia, K.C. (2023), "What they say, what they do and how they do it: an evaluation of the energy transition and GHG emissions of electricity companies", *Energy Policy*, Vol. 174, p. 113462.
- Mazzucato, M. (2015), *The Green Entrepreneurial State*, Routledge, pp. 134-152.
- Mazzucato, M. and Semieniuk, G. (2018), "Financing renewable energy: who is financing what and why it matters", *Technological Forecasting and Social Change*, Vol. 127, pp. 8-22.
- Noseleit, F. (2018), "Renewable energy innovations and sustainability transition: how relevant are spatial spillovers?", *Journal of Regional Science*, Vol. 58 No. 1, pp. 259-275.
- Oum, S., Narjoko, D. and Harvie, C. (2014), "Constraints, determinants of sme innovation, and the role of government support", *ERIA Discussion Paper Series*, Vol. 10, pp. 1-38.
- Ouyang, X., Li, Q. and Du, K. (2020), "How does environmental regulation promote technological innovations in the industrial sector? Evidence from Chinese provincial panel data", *Energy Policy*, Vol. 139, p. 111310.
- Panaiotov, T. (1994), *Economic Instruments for Environmental Management and Sustainable Development*, UNEP Nairobi, Kenya.
- Peng, H. and Liu, Y. (2018), "How government subsidies promote the growth of entrepreneurial companies in clean energy industry: an empirical study in China", *Journal of Cleaner Production*, Vol. 188, pp. 508-520.
- Polzin, F., Sanders, M. and Täube, F. (2017), "A diverse and resilient financial system for investments in the energy transition", *Current Opinion in Environmental Sustainability*, Vol. 28, pp. 24-32.
- Porter, M.E. and Linde, C.V.D. (1995), "Toward a new conception of the environment-competitiveness relationship", *Journal of Economic Perspectives*, Vol. 9 No. 4, pp. 97-118.
- Roemer, K.F. and Haggerty, J.H. (2022), "The energy transition as fiscal rupture: public services and resilience pathways in a coal company town", *Energy Research and Social Science*, Vol. 91, p. 102752.
- Rucker, D.D., Preacher, K.J., Tormala, Z.L. and Petty, R.E. (2011), "Mediation analysis in social psychology: current practices and new recommendations", *Social and Personality Psychology Compass*, Vol. 5 No. 6, pp. 359-371.
- Schauer, C., Elsas, R. and Breitkopf, N. (2019), "A new measure of financial constraints applicable to private and public firms", *Journal of Banking and Finance*, Vol. 101, pp. 270-295.
- Shah, S.F.A., Pan, H., Cui, Z., Yang, W. and Ye, L. (2026), "Driving green innovation in SMEs: the mediating role of digital green supply chains and complementary capabilities", *Technology in Society*, Vol. 87, p. 103383.

- Shao, K. and Wang, X. (2023), "Do government subsidies promote enterprise innovation? – Evidence from Chinese listed companies", *Journal of Innovation and Knowledge*, Vol. 8 No. 4, p. 100436.
- Shao, Y. and Chen, Z. (2022), "Can government subsidies promote the green technology innovation transformation? Evidence from Chinese listed companies", *Economic Analysis and Policy*, Vol. 74, pp. 716-727.
- Shaver, J.M. (2005), "Testing for mediating variables in management research: concerns, implications, and alternative strategies", *Journal of Management*, Vol. 31 No. 3, pp. 330-353.
- Shen, J., Wei, Y.D. and Yang, Z. (2017), "The impact of environmental regulations on the location of pollution-intensive industries in China", *Journal of Cleaner Production*, Vol. 148, pp. 785-794.
- Sun, Y., Guan, W., Cao, Y. and Bao, Q. (2022), "Role of green finance policy in renewable energy deployment for carbon neutrality: evidence from China", *Renewable Energy*, Vol. 197, pp. 643-653.
- Teece, D.J., Pisano, G. and Shuen, A. (1997), "Dynamic capabilities and strategic management", *Strategic Management Journal*, Vol. 18 No. 7, pp. 509-533.
- Wang, F., Wang, Y. and Zhang, Z. (2025), "The effect of green finance on corporate biodiversity risks", *International Review of Financial Analysis*, Vol. 108, p. 104718.
- Wang, H., Qi, S., Zhou, C., Zhou, J. and Huang, X. (2022), "Green credit policy, government behavior and green innovation quality of enterprises", *Journal of Cleaner Production*, Vol. 331, p. 129834.
- Wang, R., Hsu, S., Zheng, S., Chen, J. and Li, X.I. (2020), "Renewable energy microgrids: economic evaluation and decision making for government policies to contribute to affordable and clean energy", *Applied Energy*, Vol. 274, p. 115287.
- Wang, X. and Lo, K. (2021), "Just transition: a conceptual review", *Energy Research and Social Science*, Vol. 82, p. 102291.
- Williams, T.A., Gruber, D.A., Sutcliffe, K.M., Shepherd, D.A. and Zhao, E.Y. (2017), "Organizational response to adversity: fusing crisis management and resilience research streams", *Academy of Management Annals*, Vol. 11 No. 2, pp. 733-769.
- Yang, X., He, L., Xia, Y. and Chen, Y. (2019), "Effect of government subsidies on renewable energy investments: the threshold effect", *Energy Policy*, Vol. 132, pp. 156-166.
- Yao, L. and Li, J. (2026), "Resilience of inter-organizational innovation collaboration in turbulent times: a behavioral theory of the firm perspective", *Journal of Business Research*, Vol. 211, p. 116191.
- Yu, C., Wu, X., Zhang, D., Chen, S. and Zhao, J. (2021), "Demand for green finance: resolving financing constraints on green innovation in China", *Energy Policy*, Vol. 153, p. 112255.
- Yu, F., Wang, L. and Li, X. (2020), "The effects of government subsidies on new energy vehicle enterprises: the moderating role of intelligent transformation", *Energy Policy*, Vol. 141, p. 111463.
- Zahoor, Z., Khan, I. and Hou, F.J. (2022), "Clean energy investment and financial development as determinants of environment and sustainable economic growth: evidence from China", *Environmental Science and Pollution Research*, Vol. 29 No. 11, pp. 16006-16016.
- Zeng, S.X., Xu, X.D., Yin, H.T. and Tam, C.M. (2012), "Factors that drive Chinese listed companies in voluntary disclosure of environmental information", *Journal of Business Ethics*, Vol. 109 No. 3, pp. 309-321.
- Zhang, S. and Chen, W. (2022), "Assessing the energy transition in China towards carbon neutrality with a probabilistic framework", *Nature Communications*, Vol. 13 No. 1, p. 87.
- Zhang, Z., Luo, C., Zhang, G., Shu, Y. and Shao, S. (2024a), "New energy policy and green technology innovation of new energy enterprises: evidence from China", *Energy Economics*, Vol. 136, p. 107743.

Zhang, Z., Wu, H., Zhang, Y., Hu, S., Pan, Y. and Feng, Y. (2024b), "Does digital global value chain participation reduce energy resilience? Evidence from 49 countries worldwide", *Technological Forecasting and Social Change*, Vol. 208, p. 123712.

Zhu, M., Qi, Y. and Hultman, N. (2022), "Low-carbon energy transition from the commanding heights: how state-owned enterprises drive china's wind power 'miracle'", *Energy Research and Social Science*, Vol. 85, p. 102392.

Further reading

Chen, R., Zhang, Q. and Wang, J. (2025), "Impact assessment of green finance reform on low-carbon energy transition: evidence from china's pilot zones", *Environmental Impact Assessment Review*, Vol. 110, p. 107654.

Appendix

Table A1. Scoring criteria for qualitative indicators of ETR

Primary dimension	Secondary indicator	Evaluation elements	Operationalised scoring and coding rules
Operational resilience	Transition management strategy	Clean energy contingency mechanisms; clean energy management systems; ISO14001 certification	• 2 points: The enterprise has established a specialised clean energy/sustainability management committee, possesses valid ISO14001 environmental management certification and discloses institutionalised clean energy contingency mechanisms • 1 point: The enterprise has obtained ISO14001 certification or mentions a transition strategy, but lacks a dedicated management committee or explicit contingency mechanisms • 0 points: No strategic management or certification regarding clean transition is disclosed
	Corporate transition culture	Clean transition philosophy; green energy targets; clean transition education and training	• 2 points: The enterprise explicitly integrates a clean transition philosophy into its core corporate values, sets quantified green energy consumption/generation targets and provides documented transition training programs for employees • 1 point: The enterprise expresses a general philosophy of green growth or transition, but lacks quantified targets or verified employee training data • 0 points: No mention of green transition culture, targets or educational training
Environmental resilience	Compliance in pollutant emissions	Incidents of environmental emergencies; compliance in pollutant emissions	• 1 point: Full compliance with national and local pollutant emission standards throughout the year, with 0 recorded environmental emergency incidents • 0 points: Presence of any administrative penalties for exceeding emission standards, or the occurrence of an environmental safety accident
	Air pollutant reduction and transition governance	Actions and awareness related to air pollution control during transition	• 2 points: The enterprise discloses specific technical upgrades (e.g. advanced desulfurisation, denitrification or dust removal facilities) and presents quantitative metrics or targeted investment for air pollutant reduction

(continued)

Table A1. Continued

Primary dimension	Secondary indicator	Evaluation elements	Operationalised scoring and coding rules
	Wastewater reduction and transition governance	Actions and awareness related to wastewater control during transition	• 1 point: The enterprise expresses qualitative awareness and programmatic commitment to air pollution control but lacks specific technical upgrade details or quantitative tracking • 0 points: No disclosure regarding air pollution control or waste gas governance • 2 points: The enterprise provides detailed disclosure on wastewater treatment facilities, operational water-recycling rates or the implementation of Zero Liquid Discharge technologies
	Solid waste utilisation and disposal	Actions taken for the comprehensive utilisation and disposal of solid waste	• 1 point: The enterprise textually states its adherence to wastewater reduction awareness but lacks specific disclosures on recycling facilities or water-saving outcomes • 0 points: No disclosure regarding wastewater management or transition governance • 2 points: The enterprise systematically discloses circular economy initiatives, detailing specific recycling pathways, safe disposal protocols or quantified solid waste comprehensive utilisation rates • 1 point: The enterprise mentions basic solid waste sorting and legal disposal protocols without systematic circular economy or advanced utilisation initiatives • 0 points: No disclosure regarding solid waste utilisation or disposal practices

Corresponding author
Chen Yang can be contacted at: chen.yang@nwpu.edu.cn