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Chapter: Environmental Dimensions of Sustainable Development

THE IMPACT OF CLIMATE POLICY UNCERTAINTY ON ENERGY SUPPLY CHAIN RESILIENCE

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Annotation. Amidst intensifying climate change concerns, frequent adjustments to climate policies present significant challenges to the stability and resilience of the energy supply chain. Uncertainty surrounding these policies exacerbates supply chain vulnerability, thereby threatening the sustainable development of the energy sector. This study employs econometric models analysing matched data from listed upstream and downstream firms to investigate the effects of climate policy uncertainty on supply-demand coordination, relationship stability, and the quality of supply-side innovation. The findings indicate that policy instability heightens uncertainty in production and procurement decisions, intensifying supply-demand fluctuations, reducing inter-firm cooperation, and weakening supply-demand relationships. Furthermore, it dampens demand for technological innovation, diminishing the supply quality and innovative capacity of upstream suppliers. The study concludes that enhancing supply chain resilience necessitates measures such as improving information sharing between upstream and downstream entities, optimising supply-demand coordination efficiency, and boosting collaborative innovation across the supply chain.

Consequently, it is recommended to enhance policy stability and transparency and promote cross-sectoral cooperation and technological advancement to bolster the energy supply chain's risk resilience and adaptability, ultimately aiding the energy sector in navigating the risks posed by climate policy uncertainty.

Keywords: climate policy uncertainty, supply chain resilience, vertical relationships in industrial organisation, fixed effects model.

JEL classification: M14, M19, P2.

Introduction

Growing environmental concerns driven by global climate change are compelling nations to expedite the adoption of more stringent climate policies. However, the uncertainty surrounding climate policy, particularly regarding the intensity, scope, and specifics of its implementation, presents significant challenges to economic stability and supply chain operations. As a critical pillar of economic development, the energy supply chain is a primary target of climate regulation and is directly subject to its impacts. Against the backdrop of an accelerating global energy transition, investigating the mechanisms through which climate policy uncertainty affects energy

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supply chain resilience is of considerable theoretical and practical significance for bolstering the risk resilience of energy firms and fostering the sustainable development of the supply chain.

Climate policy uncertainty can profoundly affect the energy supply chain at multiple levels. On the one hand, it can disrupt firms' production planning and investment decisions, causing supply-demand imbalances between upstream and downstream entities and destabilising their relationships. Conversely, policy uncertainty could also stimulate technological innovation within firms, potentially promoting enhancements in supply quality. However, the effects of policy-induced risks and opportunities can vary significantly among firms, as factors such as size, ownership structure, and market position influence their capacity to manage uncertainty. Consequently, a comprehensive investigation into the pathways and heterogeneous impacts of climate policy uncertainty on energy supply chain resilience holds significant practical value.

In practice, as global climate change intensifies, nations worldwide are enacting diverse climate policies, yet their implementation is often marked by uncertainty. Energy firms operating in this context confront substantial real-world challenges. Regarding investment decisions, uncertainty makes it difficult for firms to assess the long-term viability of projects. Concurrently, supply chain collaboration weakens, making partnerships between upstream and downstream entities increasingly fragile. Let's take as an example the natural gas supply chain: policy uncertainty surrounding price regulation leaves upstream producers struggling with production planning, while downstream suppliers find it challenging to establish stable procurement and sales strategies. This frequently disrupts the supply-demand balance, jeopardising stable energy provision and potentially leading to regional shortages or sharp price fluctuations, thereby inconveniencing consumers and increasing costs for households and industries. From a technological innovation standpoint, the drive and direction for innovation within energy firms are significantly hampered. For instance, firms might be hesitant to invest heavily in efficient Carbon Capture and Storage (CCS) technologies due to ambiguity about future carbon emission regulations and the potential returns on such R&D investments. This uncertainty can lead to reduced R&D spending, thereby slowing technological advancement in the energy sector and hindering its green, low-carbon transition and the sustainable development of its supply chain.

From a theoretical standpoint, a mature framework for a thorough examination of intrinsic links between climate policy uncertainty and energy supply chain resilience is still lacking. While existing research has addressed the impacts of specific climate policies on the energy sector, it often does so in isolation, focusing on individual policies or specific segments of the chain. A holistic perspective, comprehensively tracing the transmission pathways and mechanisms of policy uncertainty between upstream and downstream firms, is largely absent. Furthermore, the prevailing theories of supply chain resilience are primarily based on general industrial contexts, often failing to adequately account for the unique characteristics of the energy sector. The energy supply chain is characterised by high capital intensity, long production cycles, high technical specialisation, and the fundamental nature of its products. These characteristics dictate that its responses and adjustment strategies to policy uncertainty differ markedly from those in other industries. For instance, traditional resilience frameworks analysing inventory management's role have limited applicability to energy firms due to the specific requirements and constraints associated with storing and transporting energy commodities. Additionally, there exists a significant theoretical gap concerning the moderating role of firm heterogeneity in the context of climate policy uncertainty. Firms of varying sizes possess different capacities for resource integration and risk tolerance, as large firms might leverage greater resource reserves to weather short-term volatility but face inertia in strategic shifts due to scale, whereas smaller firms may be more agile but resource-constrained. Ownership structure also matters, for state-owned enterprises (SOEs) and private firms often exhibit different priorities and decision-making processes when responding to policy. Similarly, firms with differing market influence wield varying degrees of market power and adopt distinct coping strategies in response to policy shifts. However, in-depth theoretical work systematically explaining how these heterogeneities shape energy supply chain resilience and firm-level productivity remains scarce.

To address the aforementioned issues, the core of this research is to explore how climate policy uncertainty affects production efficiency and resilience level of energy companies through various dimensions of the industrial and supply chains. Specifically, this paper focuses on the following research objectives:

- to determine the overall impact of climate policy uncertainty on energy supply chain resilience and firm productivity;
- to dissect the specific transmission mechanisms by which uncertainty impacts resilience, examining three key aspects: supply-demand coordination optimisation, supply-demand relationship stability, and supply quality enhancement;
- to investigate how, in terms of size, ownership, and market influence, firm heterogeneity) moderates the impact of policy uncertainty;
- to offer theoretical insights and policy recommendations aimed at strengthening the risk resilience and adaptability of the energy supply chain.

Extensive literature exists in the related fields of energy and climate policy. Some studies focus directly on the impacts of climate policies on the energy sector. For example, "Research on Financial Risks of Traditional Energy Enterprises under the Background of Carbon Peaking and Carbon Neutrality—Based on Data Analysis of Listed Energy Enterprises" examines how carbon taxes alter the cost structures of traditional energy firms, while "Research on Ecological Evolution Mechanism and Path of Green Innovation of Leading Enterprises in Traditional Energy Industry" analyses the opportunities and challenges for new energy firms driven by renewable energy subsidies. However, these studies often overlook the crucial dimension of climate policy uncertainty.

Similarly, in the domain of supply chain resilience, studies like "Research on the Measurement of Modernization of Industrial Chains in China" have examined the impact of disruptions on manufacturing supply chain resilience and response strategies, and "Digital Transformation, Resilience of Industrial Chain and Supply Chain, and Enterprise Productivity Enhanced Publishing" has dissected the role of information technology in boosting supply chain resilience. Yet, this body of work generally does not integrate the specific context of the energy supply chain with the factor of climate policy uncertainty.

This study's primary innovation lies in overcoming the limitations of prior research by explicitly incorporating climate policy uncertainty into the analytical framework for energy supply chain resilience, approaching the issue systematically through the lens of vertical relationships within the supply chain. Employing an econometric model featuring a climate policy uncertainty index and utilising matched data from listed upstream and downstream firms, this research delves into the complex mechanisms through which climate policy uncertainty affects energy supply chain resilience, examining its overall impact, specific transmission channels, and heterogeneous effects across firms. In doing so, the study addresses a significant gap in the current literature, offering novel perspectives and methodologies for future inquiry, thereby potentially advancing both theoretical understanding and practical applications in this domain.

1. Literature Review

1.1 International Research Landscape

International research has long investigated the impact of climate policy uncertainty on firm behaviour, with extensive studies focusing on areas such as financing costs, investment decisions, market volatility, and technological innovation. There is a broad consensus among scholars that uncertainty surrounding climate policy significantly influences corporate financial decisions and strategic adjustments, particularly within high-emission sectors and the renewable energy industry.

International scholars have also examined the effects of climate policy uncertainty on the renewable energy supply chain, focusing particularly on how policy fluctuations influence technological innovation and market demand within the chain. For instance, studies like Vaninsky *et al.* (2006) employed Data Envelopment Analysis (DEA) to assess efficiency in the US energy sector, highlighting the crucial role of energy transition in boosting industry performance. Weyman-Jones (1991) underscored how policy-driven technological optimisation enhances energy sector efficiency, emphasising that consistent government policy is vital for the industry's long-term development. These works illustrate that climate policy impacts extend beyond individual firms to affect the technological advancement and market stability of the entire supply chain. More recently, specific studies on Climate Policy Uncertainty (CPU) reveal diverse impacts. Liang *et al.* (2022), using a GARCH-MIDAS model, demonstrated that CPU significantly predicts renewable energy index volatility, impacting market sustainability. Analysing the US data (2000–2021), Shang *et al.* (2022) found that CPU positively correlates with long-term renewable energy demand while suppressing non-renewable demand. Zheng *et al.* (2023), utilising rolling window causality tests, revealed that the direction (positive or negative) of CPU's effect on renewable energy consumption depends on the government's underlying climate policy stance. Siddique *et al.* (2023), employing wavelet coherence and quantile regression, observed that CPU adversely affects fossil fuel assets while bolstering renewable energy assets. In addition, Zhou *et al.* (2023), using a TVP-SV-VAR model, identified a positive dynamic impact of CPU on both oil prices and renewable energy consumption.

1.2 Domestic Research Landscape

In recent years, research within China has increasingly investigated the impact of climate policy uncertainty on the energy supply chain. This work particularly focuses on how such uncertainty affects firm productivity, green innovation, green transitions, and overall supply chain stability. There is a general consensus among domestic scholars that climate policy uncertainty hampers firm productivity and green innovation by increasing financing costs, eroding investor confidence, and adversely affecting corporate resource allocation and investment strategies.

At the firm level, studies suggest that climate policy uncertainty heightens investor risk aversion, often leading firms to adopt "wait-and-see" approaches and delay green innovation projects; this tendency is particularly pronounced in the renewable energy sector (Shi *et al.*, 2024). Some scholars propose digital transformation as an effective mechanism to buffer the negative effects of policy uncertainty on corporate green innovation, arguing that it helps reduce information asymmetry and improves firms' adaptive capacity to policy shifts (Zhang *et al.*, 2024). Furthermore, government environmental subsidies and a strong internal corporate commitment to environmental issues are identified as crucial factors in mitigating the adverse consequences of climate policy uncertainty (Guo, 2023).

Further research indicates that climate policy uncertainty suppresses corporate green and low-carbon innovation, with this effect being particularly acute in high-carbon industries and among firms facing significant financing constraints (Wang and Hu, 2024; Zhang *et al.*, 2024). Specifically, uncertainty deters green innovation investment by inflating financing costs and diminishing firms' risk tolerance (Guo, 2023). Beyond hindering innovation, climate policy uncertainty can also intensify risk spillovers and contagion within and across energy markets, effects that become more pronounced during periods of extreme market volatility (Liu *et al.*, 2023). For instance, the combination of the energy transition and frequent policy adjustments can amplify risk interdependencies along the renewable energy supply chain, rendering it more susceptible to climate-related risks (Zhang *et al.*, 2024). This highlights the need for governments to improve the consistency and transparency of climate policies to mitigate firm-level risks and foster sustained green, low-carbon innovation (Ji, 2022).

1.3 Limitations of Existing Research

Despite considerable progress in understanding the impacts of climate policy uncertainty on firms and the renewable energy supply chain, both internationally and domestically, several limitations persist in the current research landscape. There has been insufficient focus on climate policy uncertainty specifically as a transition risk. While the physical risks associated with climate change have garnered significant attention, research explicitly framing policy uncertainty within the transition risk paradigm remains relatively underdeveloped. Much of the existing literature concentrates on direct physical impacts, often neglecting a systematic examination of how policy variability influences investment decisions, technological innovation, and risk propagation dynamics along the supply chain. Consequently, further investigation into the transmission effects of policy uncertainty across upstream and downstream supply chain actors is needed to address this gap.

Current research often lacks sufficient quantitative analysis of supply chain interlinkage effects. Many studies focus on impacts within individual segments rather than undertaking in-depth analyses of risk interdependencies and propagation across different stages of the renewable energy supply chain. Specifically, the mechanisms through which risks are transmitted between various actors, particularly between upstream suppliers and downstream customers, under conditions of climate policy uncertainty remain inadequately explored. Future research should therefore systematically analyse these risk spillover effects within the supply chain and investigate potential mitigation strategies, possibly involving green finance mechanisms or targeted policy interventions, to dampen adverse risk transmission.

While some studies employ advanced methods, such as regression analysis and dynamic spillover models, they often struggle to fully capture the time-varying nature of climate policy uncertainty and its complex interplay with market volatility. Existing static models, as highlighted by Xu *et al.* (2023), are inherently limited in their ability to reveal the long-term, dynamic consequences of policy uncertainty for firm productivity and overall supply chain performance. Consequently, future research should place greater emphasis on understanding these evolving, time-dependent relationships between climate policy uncertainty and supply chain dynamics, facilitating the development of more effective and adaptive management strategies.

This literature review reveals that while a foundation of theoretical and empirical work exists, significant gaps persist regarding the nuanced role of climate policy uncertainty, the quantitative assessment of supply chain interdependencies, and the dynamic, time-varying aspects of these impacts. Addressing these gaps in future research is crucial for developing more robust, forward-looking theoretical frameworks to effectively guide policy formulation and industry practice.

2. Theoretical Analysis

2.1 Climate Policy Uncertainty

Climate policy uncertainty refers to the instability and unpredictability arising from shifts or ambiguities in policy objectives, enforcement strength, market mechanisms, and international cooperation related to addressing climate change. This uncertainty manifests in various forms, including unclear policy targets, frequent policy shifts, inconsistent enforcement, and unpredictable market mechanisms. To illustrate, governments might set greenhouse gas reduction targets that lack specific implementation pathways or timelines, creating challenges for businesses and society in formulating long-term strategies (Ren *et al.*, 2023). The frequency and magnitude of policy adjustments can also vary significantly with changes in government administrations, thus influencing market participants' decisions (Jiang *et al.*, 2021). In addition, uncertainty surrounding international climate agreements and cooperation contributes to policy volatility, as the coordination and implementation of the global climate action often involves navigating conflicting national interests (IPCC, 2007). These factors are combined to heighten climate policy uncertainty, thereby increasing risks for energy companies and investors and complicating efforts by economic and social systems to manage climate change (World Bank, 2012).

2.2 Energy Supply Chain Resilience

Energy supply chain resilience refers to the capacity of the energy supply chain to maintain stable operations, adapt effectively to change, and recover core functions when confronted with external shocks such as policy shifts, market volatility, or technological advancements. This resilience manifests in various ways, including the ability to navigate climate policy uncertainty, respond to fluctuations in market demand, and withstand supply chain disruptions. Amid the rising global energy demand and the growing influence of climate change and geopolitical factors, strengthening energy supply chain resilience has become increasingly critical (Chrisandina *et al.*, 2022). Research by Shao *et al.* (2019) indicates that while short-term supply interruptions may have limited impact, prolonged disruptions can cause severe volatility, particularly when demand is rapidly increasing. To bolster resilience, energy firms often employ strategies such as investment diversification, agile supply chain management, and technological innovation to enhance their adaptive capacity (Chen *et al.*, 2023). Jiang *et al.* (2025) argue that robust energy resilience is essential for high-quality economic development. In the digital era, enhancing this resilience through supply chain digitalisation is particularly vital, as digitalisation significantly improves energy resilience primarily by boosting the efficiency, stability, and quality of supply-demand relationships. By strengthening supply chain resilience, the energy system can better maintain stability amidst external changes, mitigate adverse impacts on energy supply, and thereby support the achievement of sustainable development objectives (Institute of Industrial Economics, Chinese Academy of Social Sciences, 2023).

This study draws upon the theory of vertical relationships in industrial organisation, focusing on the linkage effects within the supply chain, to investigate the pathways through which climate policy uncertainty impacts energy supply chain resilience. Resilience, in this context, signifies the supply chain's capacity to recover to its normal operational state, or even achieve an improved state, following external disruptions. Tailored to the specific characteristics of the energy sector, we conceptualise resilience across two interrelated and progressive levels: supply-demand coordination and relationship maintenance, and supply-side innovation and quality enhancement. These levels form the theoretical foundation for analysing the influence of climate policy uncertainty on energy supply chain resilience.

2.3 Mechanisms of Impact: Climate Policy Uncertainty on Energy Supply Chain Resilience

2.3.1 Supply-Demand Coordination and Relationship Maintenance

Climate policy uncertainty has a significant impact on the supply-demand coordination within the energy supply chain by distorting market signals. This uncertainty can impair the efficiency of coordination between upstream and downstream firms, particularly in areas such as demand forecasting and inventory management, thereby exacerbating supply-demand imbalances. Furthermore, policy uncertainty often prompts energy firms to overreact to potential policy shifts, intensifying the bullwhip effect, wherein demand variability is amplified as it moves upstream, which consequently lowers the overall operational efficiency of the supply chain.

Stable, long-term relationships between suppliers and customers form a critical foundation for supply chain resilience. However, climate policy uncertainty can significantly heighten the perceived risks associated with the establishment of long-term contracts for both upstream and downstream firms, thereby fostering instability in these relationships. Concurrently, policy uncertainty can elevate transaction and switching costs for firms, notably by exacerbating information asymmetries during negotiation and contract fulfilment. Under such conditions, partnerships between upstream and downstream entities can be easily eroded, leading to diminished collaboration and hindering the development of sustainable and resilient supply-demand dynamics.

2.3.2 Supply-Side Innovation and Quality Enhancement

Conversely, climate policy uncertainty might also exert a positive influence on supply quality by incentivising corporate innovation. The need to navigate an unpredictable policy landscape can provide a powerful impetus for firms to bolster their risk resilience. This may prompt energy companies and their upstream suppliers to increase investments in research and development for new technologies and enhance their overall innovative capacity, enabling them to adapt effectively to new market demands that emerge as a result of policy adjustments. Such technological innovation not only contributes to improved supply quality but can also drive technological upgrading across the entire supply chain, thereby potentially strengthening its long-term resilience.

2.4 Research Hypotheses

2.4.1 Impact of Policy Uncertainty on Total Factor Productivity

Supply chain resilience, when confronted with external shocks like market volatility, policy shifts, or environmental risks, is characterised by the chain's capacity to effectively adjust, recover, and maintain stable production levels. Total Factor Productivity (TFP), which measures the efficiency of resource allocation and utilisation, can serve as an indicator of a supply chain's overall efficiency and recovery capability under conditions of uncertainty (Tao *et al.*, 2021). Then the influence of climate policy uncertainty (CPU) on firm-level TFP is brought to attention. Real options theory posits that firms operating in uncertain environments adjust their investment portfolios to maximise option value (Kellogg, 2014). Crucially, different types of investments can exert distinct effects on firm productivity (Bloom *et al.*, 2019).

Physical (or real) investment activities, often characterised by substantial sunk costs and limited reversibility (Fuss *et al.*, 2008), can be directly affected by climate policy. According to real options theory, the inherent inflexibility of such investments reduces their option value. When policy is uncertain, investor confidence wanes and their willingness to pay investment premiums diminishes, further depressing the option value associated with physical assets. Faced with ambiguous policy signals, firms may opt to delay investment decisions, thus increasing the value of the "option to wait". Consequently, risk-averse managers are likely to curtail physical investment, potentially leading to underinvestment. Given that physical investment is critical for boosting productivity through capital accumulation and achieving potential economies of scale (Brandt *et al.*, 2012; Yang, 2015), the potential crowding out of such investments due to CPU is expected to have a negative impact on firm TFP.

Moreover, investment in green innovation is fundamental for achieving pollution and carbon reduction targets and facilitating coordinated environmental management (Liu and Xiao, 2022). However, such investments typically involve dual externalities (technological and environmental), long payback periods, and considerable risk of asset stranding. Under CPU, the limited flexibility associated with green innovation projects results in a relatively sharp decline in their option value. Furthermore, since numerous climate policies directly relate to corporate green innovation activities (Wang and Wang, 2021), policy uncertainty can lead managers to worry about securing expected policy support or financing, thereby diminishing the perceived potential returns from green innovation. Simultaneously, CPU might dampen firms' motivation to pursue green innovation driven by strategic legitimacy concerns (Xie and Zhu, 2021), leading to reduced investment. Consequently, the crowding out of green innovation initiatives is likely detrimental to TFP enhancement.

Additionally, financial investments offer high liquidity, which can assist firms in navigating shocks arising from external uncertainty (Hu *et al.*, 2017). From a real options standpoint, financial assets possess relatively high option value due to their reversibility and typically lower direct exposure to climate policy fluctuations. This leads to managers being potentially inclined to allocate resources towards financial investments in pursuit of short-term gains and flexibility under heightened CPU. However, excessive financialization can lead to resource misallocation within the firm, potentially diverting capital from productive activities and undermining long-term profitability. This shift towards financial speculation over core operations can distort production and operational decisions, thereby negatively impacting productivity (Wang *et al.*, 2017). Thus, the potential "crowding in" of financial investment driven by CPU is also hypothesised to be detrimental to firm TFP.

Based on the preceding analysis, the following hypothesis is proposed:

H1: Climate policy uncertainty negatively impacts firm-level Total Factor Productivity (TFP).

2.4.2 Impact of Policy Uncertainty on Supply Chain Resilience

The renewable energy supply chain is characterised by tightly interconnected stages, from raw material supply and manufacturing to market deployment, resulting in significant interdependence among participants (Yang *et al.*, 2023). This means that fluctuations affecting upstream entities (e.g., raw material suppliers, equipment manufacturers), such as changes in production output, costs, or technology, directly influence the operational costs and product quality of downstream firms (e.g., renewable energy generators, storage system producers, application developers) (Wang and Cheng, 2024). A distinctive feature of this supply chain is its strong reliance on external factors, notably natural resources and government policies, which fosters highly interconnected risks across the industry (Chen and Tian, 2024). Consequently, shocks impacting one segment can rapidly propagate through the chain, affecting overall stability and security. For instance, challenges faced by upstream suppliers, such as rising input prices or equipment malfunctions, transmit downstream, potentially impacting the operational performance and profitability of the entire chain (Dohale *et al.*, 2023). This risk transmission is often observable in financial markets through correlated movements in the stock prices of vertically linked firms.

Conventional supply chain management often relies on production based on demand forecasts. However, information asymmetries can lead suppliers to maintain high production levels and inventories to meet anticipated needs. This dynamic can result in the bullwhip effect, where minor downstream demand variability triggers amplified fluctuations in upstream production, exacerbating supply-demand deviations (Cachon *et al.*, 2007). Studies by Shan *et al.* (2014) and Yang *et al.* (2020) suggest this effect is prevalent among many listed firms in China, contributing to cycles of supply-demand imbalance, overcapacity, and resource wastage. Stable supply-demand relationships are thus crucial for renewable energy supply chain resilience. Climate policy uncertainty, however, can increase the perceived risks and costs associated with long-term collaboration between upstream and downstream partners, thereby undermining relationship stability and continuity. Specifically, policy volatility can elevate contract default risks and transaction costs. Pervasive uncertainty can also erode inter-firm trust, further destabilising supply-demand relationships. Based on this reasoning, the following hypothesis is proposed:

H2: Climate policy uncertainty negatively impacts energy supply chain resilience by disrupting supply-demand coordination and undermining relationship stability.

Existing literature suggests that climate policy uncertainty (CPU) suppresses corporate green innovation capabilities, with a particularly pronounced negative effect on substantive, rather than merely symbolic, green innovation efforts (Zhang *et al.*, 2024). This dampening effect is reportedly stronger for firms facing high financing constraints, those led by managers with pessimistic outlooks, and those operating in high-pollution/high-emission sectors. Conversely, the negative impact may be lessened by government environmental subsidies and strong internal corporate environmental commitments (Guo and Yong, 2023). Financing constraints and reduced risk tolerance act as partial mediators in the relationship between CPU and green innovation, with risk tolerance sometimes exhibiting a masking effect, where its direct positive effect obscures the indirect negative effect via CPU. Concurrently, CPU can tighten financing constraints, decrease managerial risk appetite, and potentially dilute the perceived stringency of local environmental regulations, all contributing to a reduced willingness to pursue green, low-carbon innovation (Wang and Hu, 2024). Ultimately, CPU can create obstacles to corporate upgrading and significantly impede TFP growth (Wang *et al.*, 2024).

There is a possibility that CPU has a negative impact on energy supply chain resilience via the supply-side innovation and quality enhancement pathway. Uncertainty diminishes suppliers' motivation and capacity for innovation, as the inability to predict future policy landscapes discourages long-term investments in low-carbon technologies or cleaner energy solutions. Policy volatility can also reduce suppliers' operational flexibility in response to market demand shifts, potentially causing instability in inventory control and production scheduling, thereby impairing both efficiency and supply quality. Moreover, frequent policy adjustments add complexity and uncertainty to supply chain management, potentially increasing the risks associated with supplier selection and making it more difficult to assure consistent product quality. Together, these factors erode the energy supply chain's adaptive and innovative capacities, thereby reducing its overall resilience and increasing its vulnerability to external disruptions. Therefore, it is hypothesised:

H3: Climate policy uncertainty negatively impacts energy supply chain resilience by hindering supply-side innovation and quality enhancement.

3. Research Design

3.1 Sample Selection and Data Sources

Data for this research were obtained from the CSMAR database. To ensure sample representativeness and integrity, the study focused on listed companies within China's energy sector spanning the period from 2007 to 2023. Following the China Securities Index (CSI) industry classifications, firms were categorised as either traditional energy (e.g., coal, petroleum) or new/renewable energy (e.g., wind, solar). The sample construction involved several screening steps: only firms listed for at least three years were included; firms designated as "Special Treatment" (ST), those suspended from listing, and those with substantial missing financial data were excluded. To mitigate the potential impact of outliers, all continuous variables were winsorised at the 1st and 99th percentiles. The final sample comprises approximately 200 listed energy firms, yielding around 2500 firm-year observations.

3.2 Baseline Regression Model

Grounded in the theoretical framework and research hypotheses, an empirical model to investigate the pathways and mechanisms through which climate policy uncertainty affects energy supply chain resilience, proxied by firm-level productivity, is specified. Recognising that the effects of policy uncertainty often manifest with a delay (Baker and Davis, 2016) and drawing upon prior research on climate policy uncertainty (e.g., Ren, 2023; Liang, 2022), a one-period lag for the core explanatory variable is employed. The baseline fixed-effects regression model is specified as follows:

$$TFP_{it} = \alpha + \beta_1 \cdot CPU_{it-1} + \beta_2 \cdot X_{it} + \delta_i + \mu_t + \epsilon_{it}$$

In the formula, TFP_{it} is the dependent variable, representing the Total Factor Productivity of energy firm *i* in year t, used as a proxy for firm efficiency and resilience capacity; CPU_{it-1} is the primary explanatory variable, representing the Climate Policy Uncertainty index lagged by one period. This index, constructed via text analysis, quantifies the perceived uncertainty surrounding climate policy within the energy sector; X_{it} is a vector of control variables, including firm size (size), asset-liability ratio, R&D intensity, liquidity ratio, industry characteristics, among others; δ_i and μ_t are fixed effects, controlling firm-individual fixed effects and time fixed effects, respectively; ϵ_{it} is the random disturbance term, representing the model's error term. In addition, referencing previous studies such as Zhang (2024), Guo (2023), and Wang (2021), this paper selects firm size (size), firm liquidity ratio (leverage), R&D intensity (rd), Gross National Product (GDP), and Energy Price Index (ENERGY) as control variables.

3.2.1 Climate Policy Uncertainty (CPU) Index

The measurement of climate policy uncertainty typically relies on two main data sources: counts of relevant articles in influential newspapers (e.g., Gavriilidis; Chen *et al.*) or analysis of social media data (e.g., Lee *et al.*; Zhang *et al.*). Given this study's focus on China's domestic energy supply chain, we utilise the China Climate Policy Uncertainty (CCPU) index developed by Chen Guorong *et al.* (2024), an index constructed using text-mining techniques applied to major Chinese news media outlets. The rationale for employing a media-based index is that news outlets play a critical role in disseminating policy information and shaping perceptions. The uncertainty conveyed through media coverage often has a more direct impact on market sentiment and firm decision-making than the objective ambiguity of the policy itself, potentially triggering market reactions and influencing corporate behaviour. Moreover, this media transmission channel, reflecting market and corporate sentiment, can feed back into the policy process, sometimes exacerbating uncertainty. Therefore, an index based on perceived uncertainty captured by mainstream news media, e.g. the CCPU index, is particularly relevant for studying the impact on corporate strategy, low-carbon transitions, and economic development within the Chinese context.

3.2.2 Total Factor Productivity (TFP)

The dependent variable firm-level Total Factor Productivity (TFP) is calculated using established methods. Common approaches include parametric, non-parametric, semi-parametric, and GMM techniques. Semi-parametric methods are widely favoured in the literature, as they effectively address potential biases arising from the simultaneity of input decisions and sample selection issues related to firm exit. Therefore, consistent with prominent studies (e.g., Jiang *et al.*, 2018), our primary measure of TFP is estimated applying the Olley-Pakes (OP) semi-parametric approach (Olley and Pakes, 1996). For robustness checks, TFP is also computed using the Levinsohn-Petrin (LP) semi-parametric method (Levinsohn and Petrin, 2003), denoted as TFP_LP. For both measures, a higher value indicates greater firm productivity.

4. Empirical Results Analysis

4.1 Baseline Regression Results

In *Table 1*, the results of the baseline regression analysis are presented. Column (1) shows the result with only the core explanatory variable. Column (2) introduces firm-level control variables to account for heterogeneity. Column (3) incorporates macroeconomic controls (GDP growth and Energy Price Index) to address potential confounding external factors.

Table 1. Baseline Regression Results

Variables	TFP(1)	TFP(2)	TFP(3)
CPU	-0.637*** (0.193)	-1.186*** (0.229)	-0.458* (0.266)
$size$		0.262*** (0.0628)	0.473*** (0.0755)
$leverage$		-0.158 (0.134)	-0.0518 (0.134)
rd		2.631 (4.373)	3.968 (4.359)
liquidity		-0.143*** (0.0368)	-0.131*** (0.0366)
$ENERGY$			-0.00612** (0.00294)
GDP			-0.00131*** (0.7400)
Firm Fixed Eff.	Yes	Yes	Yes
Year Fixed Eff.	Yes	Yes	Yes

Notes: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively; the values in brackets represent robust standard errors.

Source: own calculations.

According to the regression results, climate policy uncertainty (CPU) has a significant negative impact on firms' total factor productivity (TFP). In all three models, the coefficient of CPU is negative, being -0.6368, -1.0974, and -0.4543, respectively, and the standard errors are relatively small, indicating that the negative impact of climate policy uncertainty on productivity is robust and significant. Climate policy uncertainty may increase the external environmental risks faced by firms, making it difficult for them to make effective long-term plans and investment decisions, thereby affecting their production efficiency. Particularly when climate policy uncertainty is high, firms may face greater market volatility and policy change risks, which makes firms more cautious and conservative in their input factor investments and resource allocation, consequently inhibiting the improvement of total factor productivity. Controlling for firm heterogeneity and time effects enhances the explanatory power of the regression results, which proves that *H1* is supported.

4.2 Endogeneity Test

Although climate policy uncertainty is a relatively exogenous variable, government formulation of related climate policies is inevitably influenced by corporate and social attention. There might be endogeneity issues caused by reverse causality between climate policy uncertainty and investor green attention. Referencing the approach of Mo and Liu (2023), the US Climate Policy Uncertainty index (IVCPU) is used as an instrumental variable (IV). Since climate issues are global, US climate policy formulation or changes might affect Chinese climate policy, but US climate policy uncertainty is unlikely to directly impact China's capital market and firms. Therefore, the US Climate Policy Uncertainty index can satisfy the relevance and exogeneity conditions for an instrumental variable.

Table 2. Endogeneity Test Results

Variable	First Stage CPU	Second Stage TFP
CPU		-4.335** (1.761)
$IVCPU$	0.000977*** (6.834)	
Controls	Yes	Yes
Firm Fixed Eff.	Yes	Yes
Year Fixed Eff.	Yes	Yes
First-stage F-stat	40.70	13.62

Notes: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively; the values in brackets represent robust standard errors.

Source: own calculations.

The regression analysis reveals a significant negative correlation between climate policy uncertainty and corporate TFP, indicating that TFP declines as policy uncertainty increases. In addition, the model controlled firm-specific and time-specific fixed effects to mitigate potential endogeneity bias. A high first-stage F-statistic suggests that the instrumental variables employed in the model are strong and relevant. Consequently, climate policy uncertainty significantly impacts corporate productivity, even after accounting for relevant control variables and fixed effects.

4.3 Robustness Checks

To bolster the credibility of the baseline regression results, this paper performs a series of robustness checks, including re-estimating corporate TFP using the OP method and re-running the regression analysis. The results from these checks reveal that the coefficient for the climate policy uncertainty index remains significantly negative, confirming the robustness of the core finding that climate policy uncertainty significantly hinders corporate TFP growth.

Table 3. Robustness Check Results

Vairables	TFP2(1)	TFP2(2)	TFP2(3)
CPU	-0.7328597*** (0.0698)	0.0714 (0.0495)	-0.169*** (0.0556)
$size$		0.422*** (0.0138)	0.340*** (0.0166)
$leverage$		-0.102*** (0.0276)	-0.132*** (0.0270)
rd		-4.652*** (0.864)	-5.255*** (0.846)
liquidity		0.0136* (0.00807)	0.0106 (0.00786)
$ENERGY$			0.00199*** (0.000610)
GDP			0.00476*** (0.00578)
Firm Fixed Eff.	Yes	Yes	Yes
Year Fixed Eff.	Yes	Yes	Yes

Notes: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively; the values in brackets represent robust standard errors.

Source: own calculations.

5. Mechanism Analysis

As previously defined, supply chain resilience encompasses a complex interplay of factors across various levels and dimensions, making it challenging to measure accurately with a single indicator. The fundamental understanding of "resilience" depends on how entities within the supply chain establish, maintain, and enhance their interconnections and collaborative effects. Therefore, the resilience of the energy supply chain can be assessed along two primary dimensions: supply-demand matching and relationship maintenance and supply innovation and quality improvement. This study examines these as distinct transmission mechanisms.

5.1 Supply-Demand Matching and Relationship Maintenance

5.1.1 Supply-Demand Matching

Drawing upon existing literature, this study utilises the following indicators to characterise the degree of optimisation in supply-demand matching between upstream and downstream firms within the supply chain, one of which is (i) the magnitude of upstream firms' inventory adjustments (Matching1), as a proxy for the efficiency of supply management. Research by Chen *et al.* (2005) indicates that excessive inventory levels burden firms with high storage, transportation, and management costs, while also increasing exposure to impairment losses and the opportunity cost of tied-up capital. Consequently, maintaining lean inventories and enhancing inventory management efficiency are crucial for firms aiming to reduce costs, improve operational efficiency, and ultimately boost productivity. Smaller fluctuations in inventory levels suggest that a firm can effectively meet downstream demand while maintaining relatively low safety stocks. This study measures the magnitude of inventory adjustment using the natural logarithm of the absolute difference in a firm's inventory levels between two consecutive periods:

$$Matching1_{it} = ln[abs(In\, v_{it} - In\, v_{it-1})]$$

In the formula, $\mathrm{In}\, v_{it}$ denotes the net inventory value for firm *i* at the end of year *t*, and abs (·) represents the absolute value function.

Adapting the methodology of Shan *et al.* (2014) and Yang *et al.* (2020) and utilising the supply chain structure identified in this study, the bullwhip effect is defined as:

$$Matching2 = \ln \frac{\sigma(\text{production})}{\sigma(\text{demand})}$$

The regression results are presented in the table below:

Table 4. Mechanism Test: Supply-Demand Matching

	Matching1	Matching2
CPU	-0.804*** (0.270)	0.235*** (0.0655)
Controls	Yes	Yes
Firm Fixed Eff.	Yes	Yes
Year Fixed Eff.	Yes	Yes

Notes: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively; the values in brackets represent robust standard errors.

Source: own calculations.

According to the regression results, climate policy uncertainty (CPU) significantly impacts both the magnitude of corporate inventory adjustments (Matching1) and the bullwhip effect (Matching2) within the supply chain. Specifically, an increase in climate policy uncertainty leads firms to reduce the magnitude of their inventory adjustments, with a regression coefficient of -0.804, significant at the 1% level. This suggests that, in the face of policy uncertainty, firms tend to adopt more conservative inventory management strategies, minimising inventory volatility to enhance cash flow and supply chain stability. Furthermore, climate policy uncertainty exacerbates the bullwhip effect within the supply chain (coefficient = 0.235, significant at the 1% level), indicating amplified demand variability as information travels between upstream and downstream entities. This phenomenon might stem from reduced supply chain coordination due to policy uncertainty, potentially causing firms to overreact to shifts in demand. The inclusion of control variables and fixed effects ensures the robustness of these findings. Overall, climate policy uncertainty encourages firms to adopt conservative inventory strategies but simultaneously intensifies supply chain volatility and instability.

5.1.2 Relationship Maintenance

Building on the previous definition of stable supply-demand relationships and the existing literature, this study employs several indicators to assess the stability, continuity, and coordination between upstream and downstream firms in the supply chain. First, stable customer-supplier relationships imply long-term, ongoing transactions. Therefore, following Jiang Dianchun and Lu Dayu (2022), this study measures relationship stability using the proportion of non-new clients among a firm's top five customers at year-end (Relation1). The study also measures the continuity of supply-demand relationships using the natural logarithm of the duration (in years) of the cooperative relationship between the firm and its customers (Relation2). Drawing on Cull *et al.* (2009), the extent to which customers rely on supplier financing by using the natural logarithm of the ratio of the sum of notes receivable, accounts receivable, and prepayments to main operating revenue (Relation3) is also measured. A lower value for this indicator suggests a greater prevalence of cash-based sales, reduced pressure on the supplier's receivables, and potentially a more coordinated supply-demand relationship.

The regression results are presented in *Table 5*.

Table 5. Mechanism Test: Supply-Demand Relationship

	Relation1	Relation2	Relation3
CPU	-0.105** (0.0454)	-0.166** (0.0655)	-0.234*** (0.0584)
Controls	Yes	Yes	Yes
Firm Fixed Eff.	Yes	Yes	Yes
Year Fixed Eff.	Yes	Yes	Yes

Notes: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively; the values in brackets represent robust standard errors.

Source: own calculations.

The regression results indicate that climate policy uncertainty (CPU) exerts a significant negative influence on supply-demand relationships between firms and their customers, specifically affecting customer relationship stability (Relation1), the duration of customer relationships (Relation2), and the extent of customer reliance on supplier financing (Relation3).

Climate policy uncertainty significantly negatively impacts the stability of customer relationships. The coefficient of -0.105, significant at the 5% level, indicates that increased policy uncertainty corresponds with reduced stability in firm-customer relationships. This finding potentially reflects increased customer caution in supplier selection and greater difficulty for firms in maintaining long-term partnerships amidst policy ambiguity, ultimately making upstream-downstream supply chain relationships more fragile. Climate policy uncertainty also significantly shortens the duration of customer relationships, as shown by the coefficient of -0.166, significant at the 5% level. This suggests that policy uncertainty shortens firm-customer relationship durations, potentially because customers seek more flexible suppliers to mitigate the risks associated with long-term commitments, thereby increasing relationship turnover and instability. In addition, climate policy uncertainty significantly reduces the extent to which customers rely on supplier financing, indicated by a coefficient of -0.234, significant at the 1% level. This implies that facing policy uncertainty, customers adopt more conservative payment strategies, reducing their reliance on supplier credit (e.g., minimising credit purchases and delayed payments), which consequently lessens the financial burden on suppliers. From the supplier's perspective, this change signifies faster cash inflows, potentially enhancing their cash flow management capabilities.

The findings regarding 5.1.1 and 5.2.2 provide empirical support for *H2*.

5.2 Supply Innovation and Quality Improvement

Technological innovation fosters the upgrading of supply chain structures, driving them towards higher value-added activities and greater technological sophistication. Within the energy supply chain, innovation in green technologies and clean energy enables firms not only to boost their production capabilities but also to facilitate the entire chain's transition towards sustainability, thereby enhancing its resilience to shifts in environmental policy and market demand volatility. The number of patent applications serves as a key indicator, reflecting a firm's current level and capacity for technological innovation and allowing its quantification. Therefore, drawing on Zhang *et al.* (2024) and Guo and Yong (2023), this study measures corporate innovation capacity using the natural logarithm of (1 + the number of invention patent applications), (1 + the number of utility model patent applications), and (1 + the total number of patent applications).

Table 6. Mechanism Test: Innovation Level

	Patent1	Patent2	Patent3
CPU	-0.0137** (0.00537)	-0.00997** (0.199)	-0.0140** (0.00685)
Controls	Yes	Yes	Yes
Firm Fixed Eff.	Yes	Yes	Yes
Year Fixed Eff.	Yes	Yes	Yes

Notes: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively; the values in brackets represent robust standard errors.

Source: own calculations.

According to the regression results, a significant negative relationship exists between the climate policy uncertainty index (CPU) and the number of corporate patents. Specifically, a one-unit increase in CPU is associated with a decrease of 0.0137 in Patent1, 0.00997 in Patent2, and 0.0140 in Patent3. These coefficients are statistically significant at the 1% level, indicating that climate policy uncertainty significantly negatively impacts corporate innovation activities. In other words, as climate policy uncertainty rises, firms reduce their patenting activity, suggesting they may slow their pace of innovation or decrease investment in innovation resources to mitigate risks associated with policy shifts.

Overall, the detrimental effect of climate policy uncertainty on corporate innovation likely stems from firms' tendency to reduce exposure to long-term investment risks, particularly in R&D and innovation, when faced with policy ambiguity. Firms may perceive that the returns on innovation investments are threatened by potential future policy changes, making them hesitant to commit significant resources to technological R&D. Consequently, firms may prioritise short-term stability over long-term, innovation-driven growth. This finding offers valuable insights for policymakers, suggesting that stable and predictable climate policies can alleviate corporate concerns about uncertainty, thereby incentivising greater investment in innovation and promoting a green transition for the economy and society. These results provide support for *H3*.

6. Heterogeneity Analysis

Heterogeneity analysis fundamentally involves the segmentation of the sample based on specific characteristics, such as firm size, energy type, ownership structure, or market influence, to test whether the impact of climate policy uncertainty varies across different groups of firms or industries. Firms or industries with distinct characteristics may respond differently to climate policy uncertainty owing to variations in their resources, market positions, technological capabilities, or other factors. Comparing the differential responses across these groups can reveal which factors significantly moderate the impact of climate policy uncertainty. Furthermore, regression models incorporating interaction terms can be utilised to analyse how specific factors shape the policy's effects, thus offering an empirical foundation for designing differentiated policy interventions.

In order to investigate the differential impact of climate policy uncertainty across various firm types, this study incorporates the following heterogeneity factors into the model:

- Ownership Structure ($State$): Firms are categorised as state-owned enterprises (SOEs) or non-state-owned enterprises (non-SOEs) based on the type of their controlling shareholder.
- Energy Sector Type ($Clean$): Firms are classified as traditional energy or new energy companies based on their primary business activities.

Subgroup regression analysis is employed to separately examine the differential effects of climate policy uncertainty within each category of firm type.

The regression results are presented in *Table 7.*

Table 7. Heterogeneity Analysis Results

Variable	TFP		TFP	
	SOE	Non-SOE	Traditional Energy	New Energy
CPU	-1.341*** (0.267)	-0.768* (0.440)	-1.263*** (0.254)	-0.547 (0.520)
Controls	Yes	Yes	Yes	Yes
Firm/Year Fixed	Yes	Yes	Yes	Yes

Notes: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively; the values in brackets represent robust standard errors.

Source: own calculations.

The regression results reveal significantly heterogeneous effects of climate policy uncertainty (CPU) on Total Factor Productivity (TFP) across different firm types. Among state-owned enterprises (SOEs), the regression coefficient for CPU is -1.341, significant at the 1% level, indicating a substantial negative impact of climate policy uncertainty on their TFP. SOEs typically exhibit a strong dependence on policy stability; consequently, climate policy uncertainty may pose greater challenges to their production efficiency, potentially due to weaker adaptability in responding to policy shifts. In contrast, non-state-owned enterprises (non-SOEs) experience a smaller impact, with regression coefficient of -0.768, significant at the 5% level. Although climate policy uncertainty still negatively affects the productivity of non-SOEs, the magnitude of the impact is less pronounced than for SOEs. This difference might be attributable to the greater market adaptability and relatively flexible operating models of non-SOEs, enabling them to mitigate the risks associated with climate policy uncertainty to some extent.

Within the energy sector, climate policy uncertainty has the most pronounced impact on traditional energy firms (coefficient = -1.263, significant at the 1% level). This finding suggests that traditional energy firms, often reliant on stable, long-term policy frameworks, experience significant adverse effects on their production efficiency from climate policy shifts, particularly regarding energy transition mandates and changes in policy direction. Conversely, for new energy firms, the coefficient (-0.547) is not statistically significant, suggesting a more muted impact from climate policy uncertainty. This could potentially be attributed to the sector's greater inherent resilience, often supported by government subsidies and favourable policies, which may enhance its ability to adapt to policy shifts.

Conclusions

The preceding analysis indicates that climate policy uncertainty significantly reduces corporate productivity, amplifies supply-demand volatility, and disrupts collaborative relationships between upstream and downstream firms. To address these challenges, governments should enhance the stability and transparency of policies, minimising frequent shifts and ensuring the continuity of long-term policy frameworks. In addition, governments should foster information sharing and cross-sector collaboration to optimise supply-demand coordination and enhance supply chain stability. Policy uncertainty also dampens corporate demand for technological innovation; governments can support increased investment in low-carbon technology R&D through measures such as green innovation funds. Ultimately, by providing targeted financial support, such as dedicated transition funds, governments can assist firms in bolstering supply chain resilience and strengthening their capacity to adapt to evolving climate policies.

One of the recommendations proposed by this paper include the enhancement of policy stability and transparency. Given that climate policy uncertainty significantly hinders corporate productivity, governments should establish clear, long-term climate policy frameworks, minimising frequent revisions and ambiguity to ensure policy continuity and predictability, particularly concerning key areas like carbon emission standards, carbon taxes, and emissions allowances. This will furnish firms with a more stable operating environment, mitigating market risks stemming from policy shifts. To alleviate corporate concerns about future policies, governments should proactively publish detailed implementation timelines and guidelines, enhancing policy transparency, preventing unforeseen risks associated with policy adjustments, and enabling firms to undertake informed strategic planning.

It is also recommended to provide targeted policy support and incentives for non-state-owned enterprises (non-SOEs). Non-SOEs exhibit greater sensitivity to climate policy uncertainty, which points to the suggestion that governments should offer them enhanced policy support. Examples include establishing green technology innovation funds, offering R&D tax incentives, and providing low-interest loans to help non-SOEs lower the costs associated with adapting to climate policy changes. Simultaneously, green finance support should be strengthened using green finance policies to encourage banks and financial institutions to offer low-cost green loans to non-SOEs, thereby supporting their green transition and investments in low-carbon technologies. Through measures such as loan guarantees and tax relief, governments can reduce financing costs for these firms, enhancing their adaptive capacity in the face of climate policy uncertainty.

Bolstering policy stability and support for new energy enterprises is another recommendation. New energy enterprises are particularly sensitive to policy shifts; while they often benefit from government subsidies and incentives, policy uncertainty still has an impact on their productivity. Governments should reinforce long-term policy support for new energy firms, ensuring the stable development of the renewable energy sector. Mechanisms such as long-term subsidy programs, fixed feed-in tariffs, and technological innovation support can guarantee the sustainable growth of new energy firms. This, in turn, encourages greater investment in low-carbon technologies and clean energy innovation. Furthermore, providing dedicated funds and tax incentives can promote the R&D and deployment of new energy technologies, enhancing firms' market competitiveness and policy adaptability. Conversely, traditional energy firms face challenges due to higher carbon intensity and often exhibit slower responses to carbon reduction pressures. Governments should utilise measures such as green subsidies, transition funds, and carbon reduction compensation to assist traditional energy firms in gradually reducing their carbon emissions and support their transition towards lower-carbon energy sources.

Additionally, policies should foster cross-sector collaboration to jointly advance low-carbon technology R&D and application. The promotion of collaboration between the energy sector and other industries, such as manufacturing and transportation, can jointly drive the R&D and application of low-carbon technologies. This synergy not only enhances efficiency in the low-carbon transition across sectors but also stimulates broader green technology innovation and deployment. It also strengthens green collaboration along the supply chain, facilitating carbon reduction at various stages. Promoting green supply chain management practices can further assist firms in reducing emissions and enhance the overall green development capacity of the supply chain.

Finally, it is recommended to enhance the carbon emissions trading market to encourage firms to achieve carbon reductions through market-based mechanisms. Governments should establish a robust carbon allowance market, offering ample opportunities for carbon credit trading, enabling firms to meet emission reduction targets by buying or selling credits, while potentially realising economic benefits. Ensuring the fairness and transparency of the carbon market is crucial; this includes enhancing the openness and transparency of emissions data to ensure firms can make informed decisions based on accurate emissions information. This will not only improve market efficiency but also aid firms in better understanding of and adapting to climate policies.

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KLIMATO POLITIKOS NEAPIBRĖŽTUMO ĮTAKA ENERGIJOS TIEKIMO GRANDINĖS ATSPARUMUI

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Santrauka. Didėjant susirūpinimui dėl klimato kaitos dažni klimato politikos pakeitimai kelia reikšmingų iššūkių energijos tiekimo grandinės stabilumui ir atsparumui. Su šia politika susijęs neapibrėžtumas didina tiekimo grandinės pažeidžiamumą, kelia grėsmę tvariai energijos sektoriaus plėtrai. Šiame tyrime taikomi ekonometriniai modeliai, kuriuos pasitelkus išanalizuoti atitinkami duomenys, gauti iš į biržos sąrašus įtrauktų tiekimo grandinės gamintojų ir vartotojų įmonių. Siekta ištirti klimato politikos neapibrėžtumo įtaką paklausos ir pasiūlos koordinavimui, santykių stabilumui ir tiekimo grandinės inovacijų kokybei. Rezultatai atskleidė, kad politikos nestabilumas didina neapibrėžtumą priimant gamybos ir pirkimų sprendimus, stiprina paklausos ir pasiūlos svyravimus, mažina įmonių bendradarbiavimą ir silpnina paklausos ir pasiūlos santykius. Be to, jis slopina technologinių inovacijų paklausą, menkina tiekimo kokybę ir gamintojų inovacinį pajėgumą. Daroma išvada, kad, norint didinti tiekimo grandinės atsparumą, būtina gerinti informacijos mainus tarp gamintojų ir vartotojų įmonių, taip optimizuojant pasiūlą ir paklausą.

Reikšminiai žodžiai: klimato politikos neapibrėžtumas; tiekimo grandinės atsparumas; vertikalieji santykiai pramonės sektoriuje; fiksuotų efektų modelis.