

Climate Policy Uncertainty and Its Impact on Energy Structure Transition

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Abstract:

With the frequent occurrence of extreme weather, the transformation of energy structure plays an important role in the green and low-carbon development of China's economy and society. This paper empirically examines the impact and mechanisms of climate policy uncertainty on China's energy structure transition at the provincial level. The results show that climate policy uncertainty significantly inhibits energy structure transition. For each one standard deviation increase in the climate policy uncertainty index, the energy structure transition decreases by about 9.4% of a standard deviation. Mechanism analysis shows that climate policy uncertainty hinders the development of industrial structure, thereby impeding energy structure transition. Meanwhile, this adverse effect is weakened as the attention to environmental governance significantly increases. Heterogeneity analysis indicates that the impact of climate policy uncertainty is more pronounced in regions with lower levels of economic development and industrialization. The findings suggest that governments should pay attention to climate policy uncertainty and alleviate the dilemma of energy structure transition by creating more stable expectations for climate policies.

Keywords:

Climate Policy Uncertainty, Energy Structure, Climate Change, Low-Carbon Economy, Carbon Neutrality

1. Introduction

Global economic development is driven by energy [1]. However, population growth, industrialization and urbanization have led to excessive energy consumption. The excessive burning of fossil fuels, as one of the key energy sources, is an important source of greenhouse gas emissions and environmental pollution. Rapid economic expansion is accompanied by increased CO₂ emissions and global climate change, thus causing serious climate and environmental problems. Balancing economic growth with climate change governance has become a key challenge. To effectively cope with the pressure of environmental pollution control, achieve deep emission reduction targets and promote the decarbonization of the global energy system, countries are actively promoting a fundamental reshaping of the energy system – from a traditional fossil-fuel-dependent system to a green renewable-energy-dominated system. This has become a strategic consensus of the international community [2]. China's resource endowment of being relatively rich in coal but short of oil and gas determines that its energy consumption pattern presents a “one large and three small”

pattern of coal, oil, gas and non-fossil energy [3]. China's energy consumption structure urgently needs to shift from "coal-dominated" and "fossil-energy-dominated" to clean and low-carbon. During the 11th Five-Year Plan period, China incorporated energy intensity reduction into its national strategic goals for the first time to break the dual dilemma of energy constraints and environmental pollution in economic development. By the 13th Five-Year Plan period, this was further upgraded to a "dual control" mechanism for total energy consumption and intensity. The report of the 20th National Congress of the Communist Party of China, while continuing the total control framework, clearly proposes a strategic transformation from energy "dual control" to carbon emission "dual control".

As a responsible major country, China has established a "1+N" policy system for carbon peaking and carbon neutrality [4] and has elevated active participation in global climate governance to a national strategic level. However, because the timing, intensity and details of policies are difficult for micro agents to fully anticipate, climate policies exhibit significant uncertainty. That is, climate risks include not only physical risks caused by climate change, but also climate transition risks caused by frequently introduced and changing climate policies. Represented by the Climate Policy Uncertainty Index (CPU), studies show that China's CPU index has been rising rapidly in recent years.

Against the background of continuously increasing energy consumption demand, people are paying more attention to research on climate policy uncertainty and energy transition, especially in emerging markets characterized by dynamic and rapid transition to a net-zero economy. Firm-level studies include: climate policy uncertainty affects corporate tax avoidance behavior [5], reduces corporate investment efficiency [6], and firms tend to adopt more conservative investment strategies to reduce potential risks. CPU also significantly increases firms' bond financing costs, manifested as significantly higher bond credit spreads for firms with high climate policy sensitivity [7]. Ren et al. (2024) highlight the trend of financialization, suggesting that CPU is harmful to corporate financialization. Climate policy uncertainty also significantly inhibits corporate green and low-carbon innovation, becoming a "stumbling block" leading to the reduction of such innovation [8]. Climate policy uncertainty also has macroeconomic effects. Zhang et al. (2024) study the impact of climate risk on the risk co-movement of China's new energy industry chain and its time-varying mechanism [9]. Guo et al. (2022) argue that climate policy uncertainty is a potential influencing factor for changing energy demand, adversely affecting natural gas and oil prices [10]. Existing research on the impact of climate policy uncertainty mostly focuses on its specific effects on fossil fuel and clean energy markets. However, these studies usually only use the share of renewable energy and energy price changes as indicators to measure energy transition, ignoring the core feature that energy transition is essentially a process where the economic system shifts from relying on a specific energy technology system to a new one. Moreover, the CPU index originally developed by Gavrilidis (2021) [11] is based on U.S. newspapers, and due to regional differences, selected keywords such as "White House" and "Congress" are not fully applicable to China. Research on the mechanisms, transmission paths and mitigating factors of CPU remains relatively scarce.

The marginal contributions of this paper are as follows: First, it reveals the mechanism by which climate policy uncertainty inhibits energy structure transition, identifies the "dual mediation" transmission path of green finance and industrial

structure, and proposes buffering strategies from the dual perspectives of local government environmental governance attention and public participation in environmental concerns, clarifying the micro-mechanisms of CPU's impact on energy transition. Second, compared with previous energy transition studies that usually measure only from the single perspective of energy asset prices or carbon emissions, this paper selects the Energy Consumption Structure Dual Substitution Index (ECT) to comprehensively measure the internal optimization of fossil energy, i.e., the substitution of oil and gas for coal and the substitution of non-fossil energy for fossil energy. Meanwhile, it adopts a localized Climate Policy Uncertainty Index (CPU), breaking through the measurement limitations of existing studies that rely on European and American media or social platforms. Third, it fills the research gap at the provincial level. Previous studies have verified the impact at the national and firm levels. This paper further studies the impact of provincial CPU on ECT, conducting dynamic analysis based on China's provincial multi-dimensional data, because although the central government is the main body for formulating climate policies, local governments are the main implementers of policies, which is of great research significance.

2. Theoretical Analysis and Research Hypotheses

Frequent extreme climate events cause major disruptions and disturbances to people's production and life, and may trigger a series of economic ripple effects. Against the backdrop of continued global economic development, the World Economic Forum's Global Risks Report 2023 points out that failure of climate action will be a major risk factor in the next decade. To address climate change, countries around the world actively participate in global climate governance by formulating and implementing a series of relevant policies. The Kyoto Protocol and the Paris Agreement are important milestones in climate governance, providing a basis for the global low-carbon energy transition [12].

2.1. Climate Policy Uncertainty and Energy Structure Transition

Climate policy uncertainty refers to the degree of ambiguity and unpredictability of government policies and regulations that address climate change mitigation and adaptation due to potential policy or regulatory changes. Frequent extreme weather and climate change drive government policy adjustments, and governments must balance economic growth with carbon emission reductions, inevitably leading to fluctuations in climate policy uncertainty, which greatly affects the implementation and effectiveness of climate policies, and thus may significantly impact energy policies and environmental sustainability processes [13,14]. On the one hand, high policy volatility often leads to agency problems, causing information asymmetry between the government and firms. The government, as a policy maker in the process of energy structure transition, finds it difficult to accurately grasp the actual situation and needs of firms, resulting in policies that are not precise or difficult to implement, as well as resource misallocation and rising corporate compliance costs, hindering the adjustment and transformation of the energy structure [15]. On the other hand, climate policies can play an environmental regulatory role, increasing firms' carbon emission costs, internalizing the negative externalities of pollution emissions on the environment, prompting firms to adjust their decisions and improve energy technology to reduce environmental pollution. Furthermore, continuously changing climate policies, due to a lack of continuity and stability, increase the value of the

waiting option, which in turn intensifies the uncertainty of the business environment by affecting labor supply, capital allocation and production decisions. Therefore, firms may adopt a cautious attitude in decision-making, postpone clean technology and equipment upgrades, adopt a “wait-and-see” attitude, maintain current fossil fuel production processes and delay transition actions until more information is available for decision-making [16]. Insufficient policy forward-looking will simultaneously hinder macro governance effectiveness and micro agent adaptability, forming a systemic resistance to energy structure transition.

Thus, this paper proposes Hypothesis H1: Climate policy uncertainty inhibits energy structure transition.

2.2. Climate Policy Uncertainty, Industrial Structure and Energy Structure Transition

Industrial structure reflects the pollution intensity of production activities and directly affects pollution intensity and environmental quality [24]. On the one hand, climate policy uncertainty encourages fossil fuel dependence and inhibits corporate investment and innovation. To avoid uncertainty risks, firms cut R&D expenditure, especially investment in green innovation, slowing technological upgrading and the process of industrial technology upgrading and low-carbon transition, thereby affecting the optimization of industrial structure. On the other hand, climate policy uncertainty affects resource allocation efficiency [25], causing unstable market expectations, leading capital to flow to relatively stable, low-risk areas rather than being allocated based on industrial development potential and actual demand, affecting the coordinated development of various industries within the industrial structure.

Industrial structure upgrading helps reduce energy intensity, optimize energy structure, promote clean energy technology progress, and reduce the proportion of high-energy-consuming and high-polluting industries in the economy [26]. Industrial structure determines the industrial energy consumption structure. Industrial structure upgrading and energy structure transition are interdependent, collectively promoting the carbon output efficiency of various socio-economic sectors, and the regional energy consumption structure also tends to become clean and low-carbon.

Thus, this paper proposes Hypothesis H2: Climate policy uncertainty inhibits energy structure transition by hindering industrial structure upgrading.

2.3. The Moderating Role of Environmental Governance Attention

Local governments, as practitioners of top-level design and managers of local systems, bear the dual responsibility of green economic development and environmental pollution control, and play a key role in formulating urban-scale emission reduction targets and low-carbon economic strategies [27]. Local governments usually use fiscal means and mandatory environmental regulation measures for environmental governance. On the one hand, in regions with high attention to environmental governance, local governments establish strict environmental standards and energy use restrictions. High-polluting and high-energy-consuming enterprises face great compliance pressure in their daily production and operation [28]. To internalize the cost of environmental regulations, these enterprises invest in energy-saving technologies and clean energy to reduce energy intensity and meet environmental requirements. On the other hand, in regions with strict

environmental regulations, enterprises are more adapted to high-intensity environmental requirements, have more accurate expectations and coping capabilities regarding market changes and policy uncertainty, and reduce the impact of CPU on energy structure transition by formulating long-term strategies adapted to different policy environments.

Thus, this paper proposes Hypothesis H3: The degree of attention to environmental governance positively moderates the inhibiting effect of climate policy uncertainty on energy structure transition.

3. Research Design

3.1. Model Specification

To explore the impact of climate policy uncertainty on energy structure transition, this paper constructs the following model:

$$ECT_{i,t} = \alpha_1 + \beta_1 CPU_{i,t} + \gamma_1 control_{i,t} + \varphi_i + \omega_t + \varepsilon_{i,t} \quad (1)$$

where $ECT_{i,t}$ represents the energy structure transition of province i in year t ; $CPU_{i,t}$ represents the climate policy uncertainty of province i in year t , and its coefficient β_1 is the main focus; $control_{i,t}$ is a set of control variables at the provincial level; φ_i and ω_t are province fixed effects and year fixed effects, capturing time-invariant regional characteristics and time factors common to all provinces respectively; $\varepsilon_{i,t}$ is the random error term.

3.2. Definition of Key Variables

3.2.1. Dependent Variable

Energy structure transition is a complex systematic project, the essence of which is the process of optimizing the allocation of various dominant energies through dynamic adjustment. Because different energy sources have significant differences in carbon emission intensity and production characteristics, the evolution of energy consumption structure directly affects total regional carbon emissions. Currently, accelerating the dual substitution process of “oil and gas for coal, and non-fossil energy for fossil energy” has become a key path to promote the transformation of energy consumption patterns from high-pollution, high-carbon to clean and low-carbon, and is also a strategic choice for building a modern energy system. Based on the dual substitution characteristics of energy consumption transition and referring to the research method of Li et al. (2022) [32], this study constructs an Energy Consumption Structure Dual Substitution Index (ECT). The construction process is as follows: First, the measurement units of various energy consumptions are unified using standard coal conversion coefficients. Second, two key indicators are constructed respectively: 1) Oil-Gas Substitution Index (OGS), i.e., the ratio of the combined share of oil and gas consumption to coal consumption, reflecting the degree of internal structural optimization within traditional fossil energy; 2) Clean Energy Substitution Index (CES), i.e., the ratio of non-fossil energy consumption share to fossil energy consumption share, measuring the low-carbon transition process of the energy system. The geometric mean of the above two indices is calculated to obtain the dual substitution index that comprehensively reflects the degree of energy structure transition.

$$ECT = \sqrt{OGS \times CES} = \sqrt{\frac{(E_o + E_g) \times E_n}{E_c \times (1 - E_n)}} \quad (2)$$

where E_c , E_o , E_g , E_n represent the shares of coal consumption, oil consumption, natural gas consumption and non-fossil energy consumption in total energy consumption respectively. The dependent variable is logarithmically transformed.

3.2.2. Explanatory Variable

Regarding the quantification of climate policy uncertainty, existing literature mainly adopts two methodological systems: one is the text analysis method based on traditional media, such as Gavrilidis (2021) [11] who constructed an index by counting the frequency of climate policy reports in eight major U.S. newspapers; the other is the data mining method based on social media, such as Lee and Cho (2023) [33] who used climate-related tweets on Twitter to construct a China index. However, the former mainly reflects U.S. policy characteristics, while the latter suffers from sample bias due to the restricted use of Twitter in China. This paper uses the China provincial climate policy uncertainty index (CPU) constructed by Ma et al. (2023) [35] to measure the level of climate policy uncertainty in China's provincial administrative regions. This measurement method overcomes the shortcomings of insufficient local applicability of foreign indices and limited representativeness of social media data.

The specific method uses manual auditing and the deep learning algorithm MacBERT model, based on over 1.7 million articles from six mainstream Chinese newspapers including People's Daily, Guangming Daily, Economic Daily, Global Times, Science and Technology Daily, and China News Service, and extracts information related to climate policy and uncertainty. It includes six main steps: data collection, data cleaning, manual auditing, model construction, index calculation and verification. The provincial-level CPU index for China from 2003 to 2022 is constructed.

3.2.3. Control Variables

This paper selects a series of control variables at the provincial level, including economic development level (PGDP), measured by per capita GDP; government intervention level (GIL), expressed as the ratio of fiscal expenditure to regional GDP; openness degree (FDI), measured by actual foreign direct investment; transportation infrastructure level (TIL), expressed as the logarithm of highway mileage; energy structure (EI), expressed as the ratio of electricity consumption to total regional electricity consumption; population density (DENS), expressed as urban population density; R&D intensity (RD), expressed as the ratio of internal R&D expenditure to regional GDP.

3.2.4. Data Sources and Description

This paper uses macro panel data of 30 provinces in China from 2003 to 2022 as the research sample. Due to serious data missing for Tibet, Hong Kong, Macao and Taiwan, they are not included in the study. Raw data mainly come from the CSMAR database, EPS data platform, China Energy Statistical Yearbook, China Environmental Statistical Yearbook and statistical yearbooks of various provinces. After interpolation and winsorizing the main continuous variables at the upper and lower 0.5%, the descriptive statistics of each variable are shown in Table 1.

Table 1. Descriptive statistics of main variables.

Variable	Observations	Mean	SD	Min	Max
ECT	600	5.570	0.407	4.846	7.146
CPU	600	1.814	0.699	0.477	3.978
PGDP	600	1.190	0.786	0.285	4.934
GIL	600	0.219	0.0973	0.0792	0.643
FDI	600	0.309	0.358	0.00763	1.711
DENS	600	450.7	657.2	7.393	3,926
TIL	600	11.35	0.892	8.640	12.98
EI	600	0.0333	0.0234	0.00308	0.108
IL	600	8.808	1.743	3.892	12.40
RD	600	0.0151	0.0112	0.00175	0.0683
ECI	600	1.078	0.715	0.166	4.553

4. Empirical Results Analysis

4.1. Baseline Regression Analysis

Table 2 reports the baseline regression results of climate policy uncertainty and energy transition. Column (1) shows the univariate regression result, indicating a significant negative correlation between climate policy uncertainty (CPU) and energy structure transition (ECT). Column (2) adds control variables and controls for year fixed effects only. Column (3) adds province fixed effects based on column (2). The sign and significance of CPU remain largely unchanged. The above analysis indicates that climate policy uncertainty has a significant inhibiting effect on energy structure transition. Hypothesis H1 is verified.

Table 2. Baseline regression analysis.

	(1)	(2)	(3)
	ECT	ECT	ECT
CPU	-0.049*** (-2.729)	-0.049** (-2.741)	-0.055*** (-3.268)
PGDP		0.269*** (13.909)	0.267*** (5.363)
GIL		-0.049 (-0.505)	0.178 (1.037)
FDI		0.182*** (4.538)	-0.075 (-1.103)
TIL		-0.243*** (-14.824)	-0.071** (-2.126)
EI		0.616*** (9.562)	0.922*** (7.665)
IL		0.020* (1.946)	-0.031 (-1.582)
DENS		-0.010*** (-14.126)	0.009 (0.933)
RD		-0.557*** (-6.343)	0.843*** (3.050)
CONS	5.660*** (168.354)	7.797*** (57.636)	5.940*** (14.616)
Province Fixed	control	uncontrol	control
Year Fixed	control	control	control
Observations	600	600	600
r2	0.903	0.720	0.925

*Note: t-values in parentheses; *, **, *** indicate significance at the 10%, 5% and 1% levels respectively.*

This paper further examines the economic significance of the impact of CPU on ECT. After fully controlling for various influencing factors, the coefficient of climate policy uncertainty is -0.055. The standard deviation of the CPU index is 0.6989, and that of the ECT index is 0.4074. Thus, the economic significance of the model is about 9.4% ($| -0.055 | \times 0.6989 / 0.4074 \times 100\%$). This means that for each one standard deviation increase in the climate policy uncertainty index, energy structure transition decreases by about 9.4% of a standard deviation, indicating a fairly substantial economic significance. The significant increase in adjusted R^2 from column (1) to column (3) suggests that the selected control variables are reasonable.

4.2. Robustness Tests

4.2.1. Replacing the Core Variable of Energy Structure Transition

Referring to Feng et al. (2022) [34], the energy intensity indicator (ECI) is used as an alternative measure of energy structure transition. Energy intensity represents total energy consumption per unit of GDP and is a negative indicator of energy transition. The results of the alternative test are reported in column (4) of Table 3, showing a significant positive correlation, indicating that higher CPU leads to higher energy intensity and thus lower energy transition levels, consistent with the baseline regression results.

4.2.2. Replacing the Core Variable of Climate Policy Uncertainty

Referring to Hoang et al. (2022) [16], the one-year lagged annual climate policy uncertainty index (LCPU) is used as a proxy for climate policy uncertainty. Column (5) of Table 3 reports the results, with the coefficient of LCPU significantly negative, confirming the baseline conclusion.

4.2.3. Quantile Regression

Following Zhang et al. (2024) [28], panel quantile regression is used to test whether there are significant structural changes in the marginal effect of CPU at different ECT levels. The 0.2, 0.5 and 0.85 quantiles are considered. The regression results are shown in columns (1), (2) and (3) of Table 3. The increase in CPU has a significant positive effect on all three quantiles (i.e., negative effect on ECT), indicating that CPU inhibits ECT in both high- and low-level regions.

Table 3. Robustness tests.

	(1)	(2)	(3)	(4)
	ECT	ECT	ECT	ECI
CPU	-0.046***	-0.034**	-0.044**	0.222***
	(-2.754)	(-2.253)	(-2.015)	(6.384)
Control variable	control	control	control	control
Province Fixed	control	control	control	control
Year Fixed	control	control	control	control
Observations	600	600	600	600
r2	0.729	0.760	0.777	0.719

	(5)	(6)
	ECT	ECT

CPU		-0.063***
		(-3.516)
LCPU	-0.036**	
	(-2.350)	
Control variable	control	control
Province Fixed	control	control
Year Fixed	control	control
Observations	570	520
r2	0.926	0.924

Note: *t*-values in parentheses; *, **, *** indicate significance at the 10%, 5% and 1% levels respectively.

4.2.4. Alternative Sampling Method

Differences at the regional administrative level cannot be ignored. The four municipalities directly under the central government (Beijing, Shanghai, Tianjin, Chongqing) are excluded, and the baseline regression is repeated. Column (6) of Table 3 shows that after excluding these municipalities, the estimated coefficient is -0.063, significant at the 1% level.

5. Further Analysis

5.1. Mechanism Analysis

The above research shows that climate policy uncertainty significantly inhibits energy consumption transition, but the specific mechanisms are not yet explored. Based on the theoretical analysis, this section examines the mechanisms from the perspectives of industrial structure and environmental governance attention.

5.1.1. Mediating Effect of Industrial Structure

The rationalization of industrial structure (RIS) is constructed following Deng et al. (2020) [38]:

$$RIS_{i,t} = 1 - \frac{1}{3} \sum_{i=1}^3 \left| \frac{Y_{i,t}}{Y_t} - \frac{L_{i,t}}{L_t} \right| \quad (3)$$

where $RIS_{i,t}$ represents the industrial structure rationalization index. $\frac{Y_{i,t}}{Y_t}$ represents the share of the three industries in total output, and $\frac{L_{i,t}}{L_t}$ represents the share of employment in the three industries in total employment. The absolute difference $\frac{Y_{i,t}}{Y_t} - \frac{L_{i,t}}{L_t}$ measures the degree of coupling between output structure and employment structure. The larger this value, the more the economy deviates from an equilibrium state. Therefore, a larger value of $RIS_{i,t}$ indicates a better match between input and output in the economy, i.e., a higher degree of rationalization.

The regression results are shown in the two columns of Table 4. Column (1) shows that the regression coefficient of CPU is significantly negative, indicating that CPU reduces the level of RIS. Column (2) shows that the coefficient of RIS is significantly positive, indicating that RIS promotes ECT. Hypothesis H2 is verified.

Table 4. Mediation effect.

	(1)	(2)
	RIS	ECT
CPU	-0.024***	
	(-4.178)	
GFI		
RIS		0.718***
		(2.701)
Sobel		0.129***
Province	control	control
Year	control	control
N	489	489
r2	0.646	0.871

Note: *t*-values in parentheses; *, **, *** indicate significance at the 10%, 5% and 1% levels respectively.

5.1.2. Moderating Effect of Environmental Governance Attention

Following Lin and Cheung (2024) [41], the sample is divided into two groups based on the average value of energy conservation and environmental protection expenditure. Table 5 columns (1) and (2) report the regression results for the high-attention group and the low-attention group respectively. The estimated coefficient of CPU in the high-attention group is -0.040, and in the low-attention group is -0.062, both significant. The inhibiting effect of CPU is significantly larger in the low-attention group, indicating that active government strategies moderate the impact, and higher government attention weakens the inhibition effect. Hypothesis H3 is verified.

Table 5. Moderating effect.

	High level of emphasis on environmental governance	Low level of emphasis on environmental governance
	(1) ECT	(2) ECT
CPU	-0.040**	-0.062**
	(-2.390)	(-2.312)
CPU×public		
Control variable	control	control
Province	control	control
Year	control	control
N	281	197
r2	0.944	0.951

Note: *t*-values in parentheses; *, **, *** indicate significance at the 10%, 5% and 1% levels respectively.

5.2. Heterogeneity Analysis

Given the unbalanced economic development across regions in China, this section further verifies whether the main results differ by regional economic development level, industrialization level, etc.

5.2.1. Heterogeneity by Regional Economic Development Level

GDP is used as a measure of economic development level, and the sample is divided into two groups based on the mean of GDP. Table 6 columns (1) and (2) show that the coefficients of CPU are both significantly negative. The absolute value of the coefficient in column (1) is smaller than that in column (2), indicating that the

inhibiting effect of CPU on energy structure transition is more pronounced in regions with lower economic development levels.

5.2.2. Heterogeneity by Industrialization Level

The sample is divided into high and low industrialization level groups based on the share of industrial value added in regional GDP. Table 6 columns (3) and (4) show that both coefficients are significantly negative, and the absolute value of the coefficient in the high industrialization group is smaller than that in the low industrialization group, indicating that the inhibiting effect of CPU is reduced in regions with high industrialization levels.

Table 6. Heterogeneity analysis.

	Economically Developed	Economically Less Developed	Low Industrialization	High Industrialization
	(1) ECT	(2) ECT	(3) ECT	(4) ECT
CPU	-0.062**	-0.128***	-0.069***	-0.057**
	(-2.303)	(-5.700)	(-3.271)	(-2.181)
Control variable	control	control	control	control
Province	control	control	control	control
Year	control	control	control	control
N	299	298	279	319
r ²	0.810	0.933	0.955	0.940

Note: *t*-values in parentheses; *, **, *** indicate significance at the 10%, 5% and 1% levels respectively.

6. Conclusion and Policy Implications

Based on panel data of 30 provinces in China from 2003 to 2022, and building on previous research findings and theoretical analysis, this paper empirically examines the impact of climate policy uncertainty (CPU) on energy structure transition and its mechanisms. The main conclusions are as follows:

Climate policy uncertainty significantly inhibits energy structure transition. This inhibitory effect remains significant after a series of robustness tests, including alternative measurements of key variables, endogeneity tests, and policy shocks. The mediation mechanism is significant: climate policy uncertainty hinders the development of industrial structure, thereby impeding energy structure transition. Moderating effect analysis shows that the degree of attention to environmental governance significantly moderates the inhibiting effect of climate policy uncertainty on energy transition. Proactive local government actions can alleviate the negative impact of climate policy volatility on energy transition. Heterogeneity analysis indicates that in regions with lower levels of economic development and industrialization, the hindering effect of climate policy uncertainty on energy transition is more pronounced.

Based on the above findings, this paper proposes the following policy implications:

First, build a stable and transparent climate policy system. Policymakers should enhance the forward-looking and coherent nature of climate policies to reduce expectation disorders caused by frequent adjustments. This can be achieved by legislating medium- and long-term emission reduction targets and establishing a

transition period mechanism for policy adjustments, thereby reducing corporate compliance costs and wait-and-see tendencies.

Second, governments should strike a balance between environmental improvement and economic growth. They should strengthen the dual-drive of industrial structure upgrading and promote the low-carbon transformation of industrial structures. In highly industrialized regions, priority should be given to supporting clean technology substitution, while in less industrialized regions, the development of the digital economy and low-carbon service industries should be encouraged. Resource allocation should be optimized through the coordination of industrial policies and carbon allowance trading. Governments should establish long-term mechanisms to ensure sustained and stable growth of local environmental protection expenditure, so as to meet the investment needs commensurate with the actual requirements of local environmental protection and economic development. On the supply side: through fiscal subsidies, tax incentives, policy preferences and other incentive mechanisms, enterprises should be encouraged to increase R&D investment in low-carbon and energy-saving technologies. Increasing government subsidies can effectively reduce the costs and risks of green production for enterprises, improve economic expectations, and thereby stimulate the production and sale of green products. On the demand side: governments can send clear signals to the market through demand-pull measures such as pollution control investment and green procurement, guiding social capital toward low-pollution, low-energy enterprises and energy transition sectors.

Third, local governments need to focus on improving the legal and regulatory framework in the fields of energy conservation and environmental protection. They should fill institutional gaps, formulate or revise environmental regulations and policies, and increase penalties for environmental pollution, thereby guiding enterprises to increase environmental capital investment. Standard constraints should be strengthened. In practice, by strictly enforcing energy standards and energy efficiency labeling systems, local governments can further urge high-energy-consumption and high-emission enterprises to optimize production methods, improve energy utilization efficiency, actively adopt clean energy, and accelerate the completion of low-carbon energy transition.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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