Research on the Impact of Energy Structure on the Resilience of Industrial Chains

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Abstract. Enhancing industrial chain resilience is a core measure to safeguard industrial security and achieve the "dual carbon" goals. As a key driving force for green transformation, energy structure provides an important pathway for improving industrial chain resilience. Based on panel data of China's prefecture-level cities from 2010 to 2021, this paper systematically examines the impact and regional heterogeneity of energy structure on urban industrial chain resilience. The empirical results show that energy structure transformation significantly improves urban industrial chain resilience. Its mechanism lies in that energy structure empowers industrial chain resilience through the mediating effect of optimizing energy utilization efficiency. Heterogeneity analysis reveals that this improvement effect is more significant in resource-based cities and old industrial base cities. The conclusions enrich the research on energy structure and industrial chain resilience, and provide empirical support for local governments to coordinate green transformation and industrial security and formulate differentiated policies.

1 Introduction

1.1 Research Background

Amid global economic uncertainty, geopolitical tensions, and supply chain restructuring, strengthening industrial chain resilience has become a core strategy for securing industrial stability. For China, it is essential to buffer external shocks, safeguard economic security, and advance the “dual carbon” strategy. As China undergoes industrial restructuring and energy revolution, high-carbon industrial chains are constrained by resources, environmental costs, and carbon barriers, making energy structure transformation imperative. Optimizing the energy structure can lower fossil fuel dependence, mitigate supply risks, and boost green innovation. Yet technical gaps, unbalanced development, and weak policy coordination limit its contribution to industrial chain resilience. This paper examines energy structure’s impact on urban industrial chain resilience and heterogeneity, enriching theories and supporting differentiated policy-making for green transition and industrial security.

1.2 Literature Review

Against the dual backdrop of rising global economic uncertainty and accelerated industrial transformation, enhancing industrial chain resilience has become a core issue in ensuring stable economic performance. The diversity and complexity of its influencing factors have sparked extensive academic discussion. Existing studies have explored the mechanisms through which various factors affect industrial chain resilience along two main lines: external environmental drivers and internal governance support. Among them, external influencing factors include the integrated development of digital and real economies (An et al., 2025; Wu et al., 2025)[错误!未找到引用源。错误!未找到引用源。], global heterogeneity in renewable energy supply (Verpoort et al., 2024)[错误!不能识别的开关参数。], low-carbon industrial structure layout (Lichtenberger & Stehrer, 2024)[错误!不能识别的开关参数。], and the design and management of energy-efficient supply chains (Dolgui et al., 2024)[错误!不能识别的开关参数。]. Internal governance factors cover corporate green transformation (Yu & Lin, 2022)[错误!未找到引用源。], technological innovation capability (An et al., 2025)[错误!未找到引用源。], total factor productivity improvement (Wu et al., 2025)[错误!未找到引用源。], and coordinated governance of industrial chains guided by green development (Luo & Ma, 2023)[错误!未找到引用源。]. Collectively, these factors shape the industrial chain’s resistance, recovery, and adaptive capabilities across multiple dimensions.Ma et al.[错误!不能识别的开关参数。] reviewed climate resilience and energy flexibility in industrial systems, noting that energy flexibility is essential for industrial climate resilience and stable operation. Khurshid et al.[错误!不能识别的开关参数。] found that energy transition shapes global industrial resilience via network effects, revealing the indirect impact of energy factors.

1.3 Literature Review

In conclusion, existing studies have examined the economic effects of energy structure and the influencing

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factors of industrial chain resilience from technology, factor allocation, and policy coordination perspectives. However, they have not fully explored whether energy structure can systematically enhance industrial chain resilience or its specific transmission mechanism. The mediating effect of resource allocation efficiency also lacks sufficient empirical verification. Furthermore, the heterogeneous impact of energy structure on industrial chain resilience remains underexplored. Thus, research boundaries and theoretical frameworks need to be expanded and improved to address these gaps.

2 Theoretical Analysis and Research Hypotheses

2.1 Direct Impact Effect

Energy structure optimization serves as an essential driving force that can directly improve the overall resilience of urban industrial chains. On the one hand, a rational and optimized energy structure effectively reduces the industrial system's excessive reliance on high-carbon fossil energy such as coal. By diversifying energy supply sources and reducing the proportion of traditional high-carbon energy consumption, it can significantly mitigate the negative impact of external uncertain risks, including international energy price fluctuations, regional supply disruptions and resource shortage shocks on the stable operation of industrial chains. On the other hand, the large-scale substitution of clean energy can remarkably lower the rigid environmental regulation constraints and green compliance costs faced by industrial enterprises. It helps reduce the pressure of carbon emission reduction and environmental governance in the production and operation process, further enhancing the operational stability and anti-interference ability of the whole industrial chain. Meanwhile, energy structure optimization also promotes the green upgrading of industrial production modes, consolidates the sustainable development capacity of industrial chains, and directly strengthens their ability to resist external shocks and maintain stable operation in the long run. Accordingly, this paper proposes Hypothesis 1: The optimization of energy structure can significantly enhance the comprehensive resilience level of urban industrial chains.

2.2 Indirect Influence Effect

Energy structure transformation can also indirectly enhance industrial chain resilience through the internal mediating pathway of improving energy utilization efficiency. The optimization of energy structure drives the large-scale replacement of traditional fossil energy with clean energy, and meanwhile forces industrial sectors to carry out technological innovation, equipment upgrading and green production transformation. This progressive change effectively improves the overall energy utilization efficiency of industrial activities, remarkably reduces the energy consumption per unit of economic output, curbs inefficient energy waste in the production process, and lowers comprehensive production and operation costs for industrial enterprises. Furthermore, it optimizes the allocation of energy factor resources across different industries and cities, alleviating the mismatch and idle waste of energy resources. The improvement of energy utilization efficiency can further ease the operational cost pressure and resource constraint pressure faced by the industrial chain, significantly strengthen the industrial system's ability to resist external interference, cope with economic fluctuations and recover rapidly after unexpected shocks. Therefore, the whole transmission mechanism realizes the indirect empowerment of industrial chain resilience. On this basis, this paper proposes Hypothesis 2: Energy structure optimization enhances the resilience of industrial chains by promoting the improvement of energy utilization efficiency.

3 Research Design and Conclusions

3.1 Research Design

This paper adopts urban panel data from 2010 to 2021 to construct an empirical research framework. In terms of variable setting, the explained variable is industrial chain resilience (RES), which comprehensively reflects the city's industrial chain risk resistance, recovery capacity and transformation and upgrading level. The core explanatory variable is energy consumption structure (EC), measured by the proportion of coal consumption in total energy consumption. Referring to existing relevant studies, this paper also selects a series of characteristic indicators as control variables, including consumer market size, economic development level, wage level, industrial structure and infrastructure level, so as to eliminate the interference of other urban characteristic factors on the empirical results. The specific definition and measurement method of all variables are shown in **Table 1**. To ensure the robustness and reliability of the empirical regression results, this paper further controls the city fixed effect and year fixed effect to alleviate the endogenous problems caused by unobservable urban individual characteristics and time-varying macroeconomic shocks. On this basis, the benchmark regression, mediating effect test and heterogeneity regression are carried out, and the detailed regression results of each model are reported in **Table 2**. The empirical results verify that energy structure optimization can significantly enhance industrial chain resilience, and there exists an obvious mediating role of energy utilization efficiency. Moreover, the promotion effect presents obvious heterogeneity in resource-based cities and old industrial base cities.

3.2 Empirical Research Conclusions

This paper concludes that energy structure transformation exerts a significant positive promotional effect on the improvement of urban industrial chain resilience. After controlling for urban characteristic variables as well as city and year fixed effects, the empirical results remain robust and credible. The influential mechanism demonstrates that energy structure optimization can effectively elevate energy utilization efficiency, and further strengthen the ability of industrial chains to resist external risks, recover from shocks and achieve iterative upgrading. That is, energy utilization efficiency plays a vital mediating role in the influence process of energy

Table 1. Variable description.

Variable category	Variable name	Variable description
Explanatory variable	Industrial chain resilience (RES)	Evaluation index for constructing the comprehensive resilience level of the industrial chain, encompassing both resilience to recovery and the ability to transform and renew
Explanatory variable	Energy Consumption structure(EC)	Coal consumption/total energy consumption
	Consumer market size	Total retail sales of consumer goods
	Economic development level	Per capita GDP
Control variable	Wage level	The average wage of employees on the job
	Industrial structure	The ratio of the added value of the tertiary Industry to that of the secondary industry
	Infrastructure level	Per capita urban road area
Mediator variable	Energy Utilization Efficiency(SBM)	Measured by the SBM (Slack-Based Measure) model

Table 2. Regression results.

	(1)	(2)	(3)	(4)	(5)	(6)
			Resource-based cities		Old industrial base cities	
			YES	NO	YES	NO
VARIABLES	RES	RES	RES	RES	RES	RES
EC	-0.0249**	-0.0196*	-0.0329**	0.0057**	-0.0320*	-0.0073
	(-2.1868)	(-1.6538)	(-1.9832)	(4.9189)	(-1.9139)	(-1.0331)
SBM		0.0354**				
		(2.1735)				
Constant	0.0198	0.0202	0.2970*	-0.0334	0.2518	-0.1256**
	(0.2111)	(0.2174)	(1.6860)	(-1.0296)	(1.6198)	(-2.2680)
Control Variables	YES	YES	YES	YES	YES	YES
Observations	2,360	2,360	1,441	46	1,541	819
City/Year FE	YES	YES	YES	YES	YES	YES
r2_a	0.816	0.820	0.826	0.672	0.819	0.730
F	2.401	3.773	2.628	.	2.027	4.343
N	2360	2360	1441	46	1541	819

*** p<0.01, ** p<0.05, * p<0.1

structure on industrial chain resilience. Heterogeneity analysis further indicates that the positive empowering effect of energy structure optimization is obviously asymmetric across different city types. Specifically, the improvement impact is more prominent and statistically significant in resource-based cities and old industrial base cities, while the effect is relatively weak or insignificant in other types of cities. This research effectively expands and supplements the theoretical system regarding energy transition and industrial chain resilience. It also provides solid empirical evidence and targeted policy implications for local governments to reasonably adjust energy structure, promote green low-carbon transformation, stabilize industrial operation, and implement differentiated governance strategies to safeguard industrial economic security.

3.3 Policy Recommendations

Based on the empirical conclusions and heterogeneity characteristics of this study, targeted and hierarchical policy recommendations are proposed to coordinate energy structure transformation and industrial chain resilience improvement under the background of dual-carbon goals.

First, local governments should comprehensively promote the low-carbon upgrading of energy structure. It is necessary to steadily reduce the proportion of coal consumption in the total energy consumption, actively develop clean energy such as wind energy, solar energy and natural gas, and accelerate the replacement of fossil energy by renewable energy. By optimizing the energy consumption layout at the city level, the inherent risk vulnerability of high-carbon industrial chains can be fundamentally reduced, and the overall risk resistance capability of urban industrial chains can be consolidated. Second, all regions should take technological innovation as the core starting point to continuously improve energy utilization efficiency. Governments and industrial departments should increase investment in energy-saving and low-carbon technology research and development, promote energy-saving renovation and intelligent transformation of traditional manufacturing and high-energy-consuming industries, and popularize advanced energy management technologies and models. By fully releasing the mediating effect of energy utilization efficiency, the transmission path from energy structure optimization to industrial chain resilience enhancement can be smoothed.

Third, differentiated policy formulation and implementation should be carried out according to urban resource endowments and industrial positioning. Resource-based cities and old industrial base cities should take energy green transformation as a key strategic task, accelerate the withdrawal of backward high-energy-consuming capacity, and foster green and low-carbon emerging industries to release the resilience improvement dividend. For non-resource-based and non-old industrial base cities, it is essential to focus on optimizing industrial layout, strengthening industrial supporting capabilities, and forming a coordinated development pattern of energy transition and industrial chain upgrading. In addition, the central and local governments should strengthen policy guidance, institutional guarantee and inter-regional cooperation, so as to form a long-term mechanism for steadily enhancing industrial chain resilience and ultimately realize the coordinated development of green transformation, energy security and industrial high-quality development.

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