

Article

Does Fossil Energy Spatial Mismatch Hurt Economic Growth? Evidence from China and the Moderating Role of New Energy Development

Buchen Wu ¹, Jingjing Qian ² and Yue Li ^{2,*}

¹ School of Public Policy & Management, China University of Mining and Technology, Xuzhou 221116, China; bcwu001@sina.com

² School of Business Administration, Shandong Technology and Business University, Yantai 264005, China; 2024410125@sdtbu.edu.cn

* Correspondence: 201813685@sdtbu.edu.cn; Tel.: +86-17660628701

Abstract

Based on China's provincial panel data from 2000 to 2022, this paper constructs a measurement model of the spatial misallocation of fossil energy and investigates its impact on regional economic development, its transmission mechanism, as well as the moderating effect of new energy development. The results show that: (1) Spatial misallocation of fossil energy significantly hinders economic development, and this conclusion is robust under a variety of robustness checks; (2) The inhibitory effect of fossil energy spatial misallocation on economic development is most pronounced in the central region, regions with insufficient energy allocation, and in the context of coal misallocation; (3) New energy development not only exerts a positive driving effect on economic development, but also weakens the negative impact of fossil energy misallocation; after crossing a critical threshold, its effect shifts from inhibition to promotion; (4) Fixed-asset investment, industrial structure, and energy efficiency play negative mediating roles. The negative indirect effects of these three variables superimpose on the negative direct effect of fossil energy spatial misallocation, further strengthening the impediment to economic development. This study provides a basis for optimizing fossil energy allocation and promoting the coordinated development of traditional and new energy sources.

Keywords: fossil energy spatial mismatch; economic development; new energy development; moderating effect; mediating effect



Academic Editor: Charisios Achillas

Received: 22 April 2026

Revised: 22 June 2026

Accepted: 23 June 2026

Published: 26 June 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

Energy is the material basis and core driving force for the sustainable development of the national economy. Rational spatial allocation of energy factors is an important prerequisite for improving resource utilization efficiency and promoting high-quality economic development [1]. Since the reform and opening-up, China's economy has achieved leapfrog growth, with its total GDP ranking second in the world for a long time, creating remarkable economic development achievements. However, relying on the extensive growth model of "high investment, high energy consumption, and high pollution" for a long time [2,3], China's economic development has accumulated deep-seated problems such as tightening resource constraints, unbalanced regional development, and distorted factor allocation [4,5], which have become key constraints on economic transformation,

upgrading, and high-quality development. As the main body of China's energy consumption structure, fossil energy has long supported the rapid economic growth. Nevertheless, affected by the superposition of multiple factors such as differences in natural resource endowments, government intervention in resource allocation, and asynchronous evolution of production and consumption centers, its spatial allocation is facing a severe mismatch dilemma, which has become an important bottleneck restricting the improvement of energy factor utilization efficiency and economic development quality [6].

China's fossil energy resources present a spatial pattern of "rich in the west and poor in the east, abundant in the north and scarce in the south", while energy consumption demand is highly concentrated in the economically developed eastern and southern coastal areas. The energy development strategy of "restricting the east, stabilizing the central region, and developing the west" formulated by the government has further accelerated the spatial agglomeration of fossil energy production capacity in western resource-rich regions. Taking coal, a typical fossil energy, as an example, the proportion of coal output in Inner Mongolia, Shanxi, and Shaanxi in the national total output rose from 32.76% in 2000 to 71.78% in 2023, an increase of 39 percentage points. In contrast, more than 50% of China's terminal fossil energy consumption is concentrated in the southeast coastal areas, resulting in a distance of 1000 to 3000 km between energy production bases and load centers, prominent contradictions in the reverse distribution of production and consumption, and increasingly prominent fossil energy spatial mismatch [7]. This problem not only causes significant losses in cross-regional energy transportation and conversion but also distorts energy price signals and resource allocation directions, thereby significantly hindering the high-quality development of the regional economy. Against the background of a deepening global low-carbon development consensus and China's firm implementation of the "dual carbon" goal [8], energy transition centered on the development and utilization of new energy has become an inevitable choice to optimize the energy structure and solve the problem of fossil energy factor distortion. Different from the highly concentrated spatial distribution of fossil energy, new energy has the natural advantages of relatively balanced distribution and wide coverage, providing a new path to alleviate fossil energy spatial mismatch and its negative economic effects [9]. Therefore, exploring the impact of fossil energy spatial mismatch on economic development from the perspective of energy transition and clarifying the moderating role of new energy development in this impact process has important practical and theoretical significance for optimizing the spatial allocation of energy factors, promoting the coordinated development of energy and economy, and accelerating the realization of high-quality economic development.

Against the aforementioned realistic background, existing literature has explored the measurement, driving factors, and risk mechanisms of energy security levels. Prior studies have thoroughly analyzed the spatial-temporal distribution characteristics of energy security [10] and the implementation effects of relevant policies [11]. Through cross-country comparisons, scholars have identified disparities in energy security rankings among EU nations [12], as well as differences in resilience to external shocks across G7 economies [13]. In terms of influencing factors, the clean energy transition [14], digital finance [15], energy storage technologies [16] and green trade [17] are widely recognized as boosters for enhancing energy security, while geopolitical conflicts are proven to form a bidirectional negative causal cycle with energy security risks [18]. Further research on energy security risks reveals that, beyond the conventional strategy of energy structure diversification [19], natural resource endowments [20] and the development of the digital economy [21]—especially digital inclusive finance—act as core variables for mitigating energy security hazards [22].

Regarding the drivers of the energy transition, academics have conducted in-depth analyses from perspectives including the digital economy and green finance. On one hand, digital transformation and artificial intelligence serve as new engines for improving resource allocation efficiency [23]; empirical evidence verifies their functioning through three channels: optimizing resource allocation, fostering technological innovation, and advancing industrial structure upgrading. On the other hand, green finance accelerates energy structure transition by easing financing constraints [24], with particularly pronounced effects observed in resource-dependent cities [25].

From the specific perspective of resource allocation, spatial imbalance between supply and demand is a major inducement to the aforesaid security risks. Therefore, research on energy mismatch has always been a research hotspot in the fields of energy economics and resource allocation [6]. Existing studies have defined the connotation of energy mismatch from the perspective of factor distortion, divided it into two categories: connotative and denotative, and formed a variety of measurement methods represented by the production function method, the frontier technology analysis method, and the shadow price measurement method [26–28]. In terms of the impact of energy mismatch, scholars have conducted in-depth research on the dimensions of energy efficiency, total factor productivity, and environmentally sustainable development. It is generally believed that energy mismatch significantly reduces energy utilization efficiency [29], inhibits the improvement of total factor productivity [30], and exacerbates environmental problems such as carbon emissions and haze [31,32], thereby restricting sustainable economic development. On the basis of general energy mismatch research, the research on fossil energy spatial mismatch has gradually attracted attention [9]. However, most existing studies focus on the evaluation of fossil energy spatial mismatch and its impact on the environment, with insufficient exploration of the impact on regional economic development. Especially under the background of China's vigorous promotion of the energy transition, research on how new energy development moderates the economic effects of fossil energy spatial mismatch remains in the exploratory stage, lacking empirical tests and multidimensional heterogeneity analyses based on long-term panel data. In addition, existing studies have not systematically sorted out the transmission path of fossil energy spatial mismatch affecting economic development, and whether fixed asset investment, industrial structure, and energy efficiency play a mediating role still needs more sufficient empirical evidence.

In response to the above research gaps, this paper takes 30 provinces in China from 2000 to 2022 as research samples to systematically explore the impact of fossil energy spatial mismatch on regional economic development, the moderating effect of new energy development, and the internal transmission path. The marginal contributions of this paper are mainly reflected in three aspects: First, from the perspective of spatial allocation, based on the HK model and Cobb–Douglas production function, a fossil energy spatial mismatch measurement model with both mismatch degree and mismatch direction is constructed to calculate the fossil energy spatial mismatch index of China's provinces in a long period, enriching the measurement system of fossil energy spatial mismatch; Second, it reveals the marginal weakening mechanism of new energy development on the negative economic effect of fossil energy spatial mismatch, and conducts multi-dimensional heterogeneity analysis from three dimensions: regional difference, mismatch direction difference and fossil energy type difference, clarifying the heterogeneous moderating characteristics of new energy development, making up for the deficiency of existing research on the moderating factors of the economic effect of fossil energy spatial mismatch; Third, the Bootstrap method is used to empirically test the mediating effect of fixed asset investment, industrial structure and energy efficiency in the relationship between fossil energy spatial mismatch and economic development, constructing a complete analysis framework of “fossil en-

ergy spatial mismatch—mediating variable—economic development”, and deepening the understanding of the internal transmission mechanism of fossil energy spatial mismatch affecting economic development.

The follow-up structure of this paper is as follows: The first part is literature review and theoretical hypotheses, sorting out existing research results, and putting forward theoretical hypotheses by analyzing the impact mechanism of fossil energy spatial mismatch on economic development and the moderating mechanism of new energy development; The second part is research design, covering key variable measurement, empirical model construction, variable index design and data source description; The third part is empirical result analysis, verifying the direct impact of fossil energy spatial mismatch on economic development through benchmark regression, and conducting robustness and endogeneity tests on the results; The fourth part is heterogeneity analysis and moderating effect test, carrying out multi-dimensional heterogeneity analysis and verifying the moderating effect of new energy development and its heterogeneous characteristics; The fifth part is mediating effect test, identifying the key transmission path of fossil energy spatial mismatch affecting economic development; Finally, it is research conclusions and policy suggestions, summarizing the main research conclusions and putting forward targeted policy suggestions combined with the research results.

2. Materials and Methods

2.1. Literature Review

Factor mismatch is a core problem restricting the improvement of resource allocation efficiency and high-quality economic development, and has always been a research hotspot in the field of economic theory. As a typical form of factor mismatch, energy mismatch is defined as an economic phenomenon in which the actual allocation state and utilization efficiency of energy factors deviate from Pareto optimality due to price distortion, institutional constraints, spatial distribution imbalance, and other factors [33]. Its research paradigm is derived from the classical resource mismatch analysis framework. Existing studies divide energy mismatch into two categories: connotative and denotative. Connotative energy mismatch is reflected in the non-optimal allocation of energy factors among different enterprises and industries, leading to significant heterogeneity in the marginal output of energy; Denotative energy mismatch means that even if the marginal output of energy of each economic subject tends to be consistent, the total output can be improved through the optimization and adjustment of energy spatial allocation. The measurement of energy mismatch is the basis of relevant empirical research. Existing measurement methods are expanded based on the resource mismatch measurement framework, forming three mainstream methods with their own characteristics: The production function method, represented by the Cobb–Douglas production function [34], can fit the actual production process without complex cost data, and is the most widely used method in provincial and industrial energy mismatch measurement; Frontier technology analysis methods, including Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA) and other methods, do not need to preset function forms, effectively reducing model setting bias and subjective interference, but it is difficult to accurately quantify the distortion degree of a single energy factor among different production units [35]. The shadow price measurement method can completely map the energy pricing process and take into account external factors such as environmental costs, with unique advantages in econometric analysis and efficiency decomposition, but its application is limited by the difficulty of parameter estimation and the availability of microdata [36].

A comprehensive comparison reveals that Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) primarily focus on evaluating efficiency frontiers, making

them unable to directly measure factor price distortion coefficients. Although the shadow price method can estimate the marginal abatement cost of energy and the value of environmental externalities, its application is constrained by difficulties in parameter estimation, strict functional form assumptions, and the availability of micro-level data. While the production function approach can intuitively estimate the relative degree of distortion, it is limited by rigid functional assumptions and struggles to incorporate undesirable outputs. As research deepens, machine learning methods such as Random Forests and Neural Networks have begun to be applied to energy misallocation measurement. These approaches can relax functional-form assumptions to a certain extent; however, their interpretability and underlying economic-theoretical foundations still require further refinement.

In the evaluation of the impact of energy mismatch, existing literature has conducted in-depth research around three core dimensions: energy efficiency, total factor productivity, and environmentally sustainable development. In terms of energy efficiency, it is widely recognized in academia that energy misallocation exerts a significant inhibitory effect on energy utilization efficiency [32]. On the one hand, the failure of energy factors to flow toward entities with optimal production efficiency leads to inefficient consumption and massive waste of energy resources. On the other hand, the resulting price distortions not only discourage corporate R&D investment in energy-saving technologies but also elevate financing costs for non-energy-related enterprises, creating a dual constraint that further hinders regional improvements in energy efficiency [37]. Furthermore, empirical studies have demonstrated that inter-provincial energy price distortions exhibit spatial spillover and early-warning effects, jointly shaping the overall level of regional energy efficiency [38]. However, there is a notable divergence in the literature regarding the directional impact of factors influencing energy misallocation. Regarding environmental regulation, some scholars argue that it can effectively alleviate energy misallocation, with superior governance outcomes for over-allocation compared to under-allocation [32]. Conversely, industry-level empirical research indicates that energy intensity or environmental regulation policies may actually exacerbate the degree of energy misallocation [39]. Additionally, the rebound effect driven by technological progress has been confirmed as a primary cause of aggravated energy under-allocation [32], whereas eliminating energy price distortions and advancing market-oriented factor reforms are considered critical pathways for enhancing energy utilization efficiency [37].

In terms of total factor productivity, Considerable divergences exist in research on how energy misallocation transmits impacts to productivity. At the industrial level, energy misallocation significantly depresses firm and industrial total factor productivity (TFP) [39]. This inhibitory impact is far more severe in high-energy-consuming heavy chemical industries than in the light industry and the service sector; fully rectifying energy price distortion can markedly raise TFP within heavy industry segments [40]. At the city level, energy misallocation is a major contributor to losses in industrial green total factor productivity (GTFP), though disagreements remain over its transmission pathways. Some studies highlight that energy misallocation curbs GTFP growth by stifling technological innovation and obstructing the optimization of energy consumption structures [41]. Other research points out that energy structure transformation itself may intensify factor allocation distortion, and its suppression of productivity growth mainly stems from scale effects rather than technology effects [42].

In terms of environment and sustainable development, Substantial conflicts appear among research conclusions in this strand. Most scholars conclude that energy misallocation undermines corporate environmental performance: by dragging down energy utilization efficiency, it worsens air quality [43,44], exacerbates haze pollution [45], and elevates carbon emissions [46,47], thereby imposing constraints on regional sustainable

economic development. In contrast, several studies identify a nonlinear relationship between the two variables. Specifically, factor market distortion and environmental pollution follow a significant inverted U-shaped curve as firms elevate their technological innovation capacity [48]. Additional analysis reveals regionally heterogeneous impacts of energy price distortions on air quality, with stronger adverse influences in eastern China relative to central and western regions [45]. Moreover, other scholars examine the magnitude and direction of energy misallocation, documenting uneven distortion levels across fossil fuel varieties: price distortions for coal and oil are substantially larger than those for natural gas [41]. Excessive energy allocation reduces carbon emission efficiency, while inadequate energy allocation helps improve carbon emission efficiency [44].

With the deepening of energy mismatch research, scholars' research perspective has gradually shifted from general energy mismatch at the industrial and enterprise levels to the more China-specific research topic of specific energy spatial mismatch. Fossil energy spatial mismatch is the concrete manifestation of energy mismatch in the spatial dimension, specifically referring to the phenomenon of low cross-regional allocation efficiency of energy factors, high transportation loss, and distorted price signals caused by the spatial separation of fossil energy production centers and consumption centers affected by resource endowments [7,9], industrial layout, policy regulation, and other factors. Existing studies have conducted preliminary exploration around the measurement and impact of fossil energy spatial mismatch. However, there are still obvious research gaps in existing studies: First, the internal transmission mechanism of fossil energy spatial mismatch affecting economic development is not systematically sorted out, and there is a lack of empirical tests based on large-sample panel data on whether fixed asset investment, industrial structure and energy efficiency are key mediating variables between the two; Second, under the background of energy transition, research on the moderating effect of new energy development on the economic effect of fossil energy spatial mismatch is still in the exploratory stage, the specific mechanism of new energy development alleviating the negative effect of fossil energy spatial mismatch has not been revealed, and there is a lack of multi-dimensional heterogeneity analysis to clarify the regional and mismatch direction differences in the moderating effect; Third, existing studies pay insufficient attention to the differences in economic effects of spatial mismatch of different types of fossil energy (coal, oil, natural gas), and fail to accurately identify the impact characteristics of spatial mismatch of different fossil energy.

Based on this, on the basis of existing research, this paper incorporates new energy development into the analysis framework of fossil energy spatial mismatch and economic development, systematically explores the economic effect, transmission path of fossil energy spatial mismatch and the moderating mechanism of new energy development, and conducts heterogeneity analysis from three dimensions: region, mismatch direction and energy type, in order to make up for the deficiencies of existing research and enrich the research system of fossil energy spatial mismatch.

2.2. Impact Mechanism and Theoretical Hypotheses

2.2.1. Impact of Fossil Energy Spatial Mismatch on Economic Development and Mediating Mechanism

Energy is the basic production factor for China's national economic development, and its spatial allocation directly affects resource utilization efficiency and regional economic development quality [49,50]. Fossil energy spatial mismatch has a significant inhibitory effect on economic development through price signal distortion, resource allocation imbalance, production efficiency reduction, etc., and this effect will form a transmission effect through three mediating variables: fixed asset investment, industrial structure, and energy efficiency. Based on this, the core hypothesis is put forward:

Hypothesis 1. *At the national level, fossil energy spatial mismatch has a significant inhibitory effect on economic development.*

(1) Mediating Effect of Fixed Asset Investment

Fossil energy spatial mismatch causes double distortions in the efficiency and structure of fixed asset investment, thereby forming a negative transmission to economic development. On the one hand, the price signal distortion caused by fossil energy spatial mismatch makes resources excessively agglomerate in inefficient and high-energy-consuming industries, crowding out fixed asset investment in high-potential industries such as high-tech and high-end manufacturing, resulting in “low-end locking” of investment structure; On the other hand, the spatial imbalance of fossil energy supply increases the uncertainty of enterprise operation, and energy-dependent enterprises are difficult to accurately predict energy costs and supply stability, thereby reducing the willingness to invest in fixed assets, resulting in “effective insufficiency” of investment scale. Reasonable fixed asset investment is the core engine to promote the improvement of production capacity and the cultivation of new drivers of economic growth. The inefficient investment and structural imbalance caused by the mismatch will directly weaken the pulling effect of fixed asset investment on economic development. Based on this, it is put forward:

Hypothesis 2a. *Fixed asset investment plays a significant negative mediating role between fossil energy spatial mismatch and economic development.*

(2) Mediating Effect of Industrial Structure

Fossil energy spatial mismatch will solidify and even aggravate industrial structure imbalance, hinder the process of industrial structure upgrading and rationalization, and thereby restrict economic development. For regions rich in fossil energy production, the low-cost energy advantage brought by spatial mismatch easily makes them fall into the “resource dependence trap” [51], over-developing high-energy-consuming and low-value-added energy mining and processing industries, crowding out development resources and space for emerging industries, leading to simplification and a low-end industrial structure [52]. For regions with concentrated fossil energy consumption, the increase in energy costs caused by spatial mismatch will form cost constraints on the development of manufacturing and service industries, inhibiting industrial upgrading and business innovation. The optimization of industrial structure is the core driving force for high-quality economic development. The imbalance and blocked upgrading of the industrial structure will directly weaken the resilience and potential of economic development. Based on this, it is put forward:

Hypothesis 2b. *Industrial structure plays a significant negative mediating role between fossil energy spatial mismatch and economic development.*

(3) Mediating Effect of Energy Efficiency

Fossil energy spatial mismatch directly inhibits the improvement of energy efficiency across three dimensions: energy utilization, technological innovation, and transmission loss, thereby exerting a negative impact on economic development. First, enterprises in regions rich in fossil energy production lack the motivation for energy-saving technology R&D and equipment renewal due to low-cost access to energy, maintaining high-energy-consuming production models, resulting in low energy utilization efficiency; Second, regions with concentrated fossil energy consumption are vulnerable to unstable energy supply, leading to inefficient operation of production equipment and further reducing energy utilization

efficiency; Third, the spatial separation of fossil energy production and consumption centers leads to a large number of cross-regional energy transportation demands, causing huge losses in energy transmission and conversion processes, and pushing up the overall operating cost of the energy system. The improvement of energy efficiency is a key path to achieving economic quality and efficiency improvement. Low energy efficiency means low utilization efficiency of production factors, which will directly increase economic operation costs and reduce output benefits. Based on this, it is put forward:

Hypothesis 2c. *Energy efficiency plays a significant negative mediating role between fossil energy spatial mismatch and economic development.*

2.2.2. Moderating Mechanism of New Energy Development

New energy has the natural characteristics of balanced spatial distribution, clean sustainability, and diverse utilization scenarios [53], which is a sharp complement to the spatial mismatch pattern of “production in the west and demand in the east” of fossil energy. Its development can alleviate the inhibitory effect of fossil energy spatial mismatch on economic development through three mechanisms: spatial reconstruction, structural optimization, and efficiency improvement, forming a significant moderating effect. The specific analysis is as follows:

(1) Spatial Reconstruction Mechanism: Shortening the Spatial Distance between Energy Supply and Demand

The widely distributed characteristic of new energy resources can reconstruct the geographical connection between energy production and consumption, break the solidified pattern of “production in the west and demand in the east” of fossil energy, and alleviate fossil energy mismatch from the spatial dimension. Western resource-rich regions can rely on the advantages of wind and solar resources to build large-scale wind and photovoltaic bases, realize local consumption of “west power for west use”, and replace part of cross-regional fossil energy transmission demand; Eastern consumption-concentrated areas can use building roofs, industrial parks and other scenarios to promote distributed new energy projects, forming an energy supply system of “near production and near consumption”, reducing dependence on external fossil energy input. At the same time, the spatial layout characteristics of new energy will also promote the reconstruction and upgrading of industrial layout, realize the in-depth spatial matching of “energy-industry”, smooth the regional development gap caused by the separation of fossil energy production and marketing, and further alleviate the negative economic effect of spatial mismatch.

(2) Structural Optimization Mechanism: Reducing Dependence on Fossil Energy

The development of new energy can enrich the types of energy supply, promote the transformation of the energy consumption structure from fossil energy-based to diversified and clean, reduce the dependence of economic development on fossil energy, and thereby weaken the impact of fossil energy spatial mismatch. On the one hand, the increase in the proportion of new energy in the energy consumption structure directly reduces the demand for fossil energy such as coal and oil, reducing the impact of energy supply fluctuations caused by fossil energy spatial mismatch on economic development; On the other hand, the introduction of new energy makes the energy market competition more sufficient, promotes energy prices to more reasonably reflect their scarcity and environmental costs, corrects the price signal distortion caused by fossil energy mismatch, and improves the overall allocation efficiency of energy factors.

(3) Efficiency Improvement Mechanism: Reducing Cost Loss Caused by Mismatch

The development of new energy can reduce the explicit transportation costs and implicit risk losses caused by fossil energy spatial mismatch through technological innovation and model optimization, and improve the overall allocation efficiency of the energy system. New energy consumption models such as direct green power supply and “source-grid-load-storage” integration reconstruct the energy supply link, greatly compress intermediate transportation links, and reduce the costs and losses of cross-regional fossil energy transportation; The coordinated development of new energy storage technology and UHV channels not only alleviates the volatility and intermittency of new energy, but also makes up for the lack of energy peak regulation capacity caused by fossil energy spatial mismatch, reducing the risk of energy supply and demand imbalance. The improvement of energy system efficiency can effectively offset the efficiency loss caused by fossil energy spatial mismatch, thereby alleviating its inhibitory effect on economic development.

(4) Risk Constraint Mechanism: Rising Adaptation Costs for System Operation

The moderating effect of new energy development does not always mitigate the inhibitory influence of energy misallocation on economic development across all scenarios; under specific restrictive conditions, there exists a risk that it may amplify the adverse impacts of misallocation.

On the one hand, for regions with weak energy system regulation capacity or tight supply constraints, the inherent volatility and intermittency of new energy power generation will greatly raise the complexity of grid operation and standby costs without sufficient energy storage facilities or peak-shaving resources. When the guaranteed capacity of fossil energy is limited, such instability may instead magnify security risks in energy supply, thereby intensifying the economic constraints caused by misallocation.

On the other hand, during periods of strained factor resources or transitional adaptation, large-scale integration of new energy may trigger fierce competition for land, capital, and other production factors, generating a crowding-out effect on investments in traditional high-efficiency energy. Moreover, fossil energy peak-regulation capacity reserved to stabilize fluctuations in new energy output will temporarily lower the overall operational efficiency of the energy system. Short-term transition costs stemming from technical adaptation and matching expenses may offset the benefits brought by new energy within a certain timeframe. Based on this, the core hypothesis is put forward:

Hypothesis 3. *New energy development exerts a significant moderating effect on the spatial misallocation of fossil energy and economic development. The direction and magnitude of this moderating effect depend on the comprehensive outcome generated by the superposition of multiple mechanisms.*

2.2.3. Heterogeneity Hypotheses

Considering the significant differences in resource endowments, economic development levels, industrial structures, and new energy development foundations among regions in China, the economic effects of fossil energy spatial mismatch and the moderating effect of new energy development both have heterogeneous characteristics. Based on this, it is put forward:

Hypothesis 4. *The inhibitory effect of fossil energy spatial mismatch on economic development has significant heterogeneity;*

Hypothesis 5. *The moderating effect of new energy development has significant heterogeneity.*

Based on the above analytical perspectives, this paper constructs the theoretical framework illustrated in Figure 1.

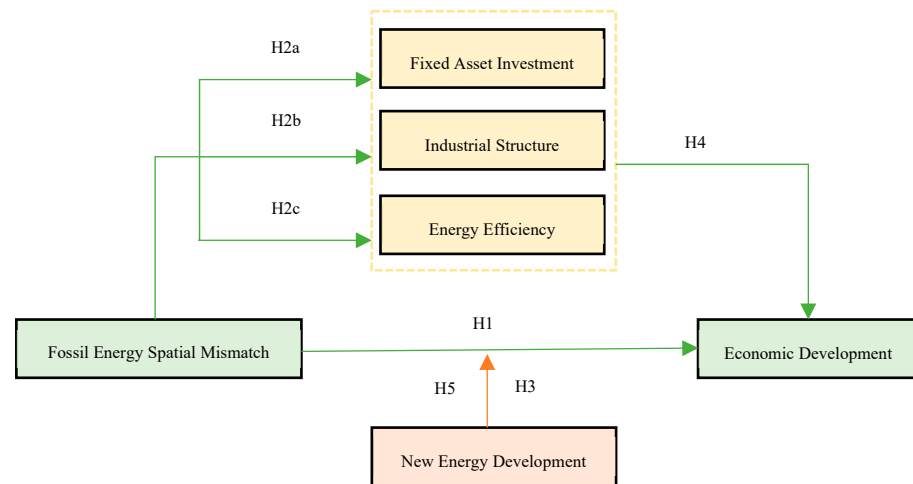


Figure 1. Theoretical framework.

3. Research Design

3.1. Measurement of Key Variables

3.1.1. Measurement of Fossil Energy Spatial Mismatch

On the basis of defining the connotation of spatial misallocation of fossil energy, this paper draws on the resource misallocation analytical framework (HK model) proposed by Hsieh and Klenow (2009) [30], and constructs a measurement model based on the Cobb–Douglas (C-D) production function. This model can quantify both the magnitude and direction of spatial fossil energy misallocation. The core logic of the model is as follows: in an ideal, perfectly competitive market, production factors ought to flow to regions with the highest marginal output until the marginal output of factors is equalized across all regions. Nevertheless, institutional barriers or market segmentation will distort factor prices and make the actual allocation deviate from the optimal equilibrium. Accordingly, the degree of resource misallocation can be inferred inversely by measuring the extent of factor price distortion.

(1) Construction of the Theoretical Model and Setting of Price Distortion

Assume that the total output S of province S in year S is jointly determined by three production factors: capital (K), labor (L), and fossil energy (E). The production process follows a constant-returns-to-scale Cobb–Douglas (C-D) production function:

$$Y_{it} = AK_{it}^{\beta_{Ki}} L_{it}^{\beta_{Li}} E_{it}^{\beta_{Ei}} \quad (1)$$

where Y_{it} denotes the total output value of province i in year t ; A represents the technological level; K_{it} , L_{it} and E_{it} stand for the input volumes of capital, labor, and fossil energy, respectively; β_{Ki} , β_{Li} , and β_{Ei} are the output elasticities of the three factors, reflecting their respective contribution ratios to output. Meanwhile, we assume $\beta_{Ki} + \beta_{Li} + \beta_{Ei} = 1$, meaning the production function exhibits constant returns to scale. The aggregate national production function can be derived by summing the production functions of all provinces.

To quantify the degree of deviation of resource allocation, we introduce the concept of distortion tax (τ) to characterize factor price distortions. Specifically, the prices of the three production factors faced by province i are $(1 + \tau_{Ki}) \cdot PK$, $(1 + \tau_{Li}) \cdot PL$, and $(1 + \tau_{Ei}) \cdot PE$. PK , PL , and PE represent the undistorted prices of capital, labor, and fossil energy, while τ_{Ki} , τ_{Li} , and τ_{Ei} denote the distortion tax rates of corresponding factors in province i . When $\tau > 0$, the factor is subject to tax burdens or allocation barriers; when $\tau < 0$, the factor receives subsidies.

We assume the national price index (P) equals 1, and the total supply of each production factor in every period is exogenously given, satisfying the following constraints:

$$Y = \sum_{i=1}^N p_i Y_i \quad (2)$$

$$s.t. \frac{\partial Y}{\partial Y_i} = P_i \quad (3)$$

$$P = \sum_{i=1}^N p_i \quad (4)$$

$$K = \sum_{i=1}^N K_i, L = \sum_{i=1}^N L_i, E = \sum_{i=1}^N E_i \quad (5)$$

According to the research of Chen and Hu [54], the absolute distortion coefficient of fossil energy price can be defined as:

$$\gamma_i = \frac{1}{1 + \tau_E} \quad (6)$$

where γ_i is the absolute distortion coefficient of fossil energy price, and τ_E is the “distortion tax”.

(2) Calculation of Relative Price Distortion Coefficient

When determining cross-regional factor allocation, the relative, rather than absolute, degree of factor price distortion matters more. Moreover, absolute distortion coefficients cannot be measured with real data, whereas relative distortion coefficients can be recovered, making relative price distortion far more empirically relevant. Therefore, this paper calculates the relative price distortion degree γ_i of fossil energy via the following formula:

$$\hat{\gamma}_i = \frac{\frac{E_i}{E}}{\frac{s_i \beta_{E_i}}{\beta_E}} \quad (7)$$

$$s_i = \frac{p_i Y_i}{Y} \quad (8)$$

$$\beta_E = \sum_{i=1}^N s_i \beta_{E_i} \quad (9)$$

where E_i/E is the actual share of fossil energy consumption of province i in the national total fossil energy consumption. Based on the prior assumption that the price index $P = 1$, s_i can be simplified to output share $s_i = Y_i/Y$, representing the proportion of province i 's output in the national total output. β_E denotes the output-weighted average energy contribution elasticity, and $s_i \beta_{E_i} / \beta_E$ is the theoretical fossil energy consumption share of province i under efficient allocation. $\hat{\gamma}_i$ captures the deviation between actual fossil energy consumption and efficient consumption volume for province i , the spatial misallocation degree of fossil energy:

If $\hat{\gamma}_i = 1$, the province's energy allocation is relatively efficient;

If $\hat{\gamma}_i > 1$, the province suffers excessive energy allocation;

If $\hat{\gamma}_i < 1$, the province faces insufficient energy allocation.

(3) Parameter Estimation and Model Illustration

As implied by the theoretical framework above, calculating the fossil energy spatial misallocation degree $\hat{\gamma}_i$ requires prior estimation of the fossil energy output elasticity β_{E_i}

for each province. Drawing on Bai Junhong, we adopt a constant-returns-to-scale C-D production function incorporating fossil energy inputs. We take the natural logarithm of both sides and add individual fixed effects μ_i and time fixed effects ϑ_t :

$$\ln\left(\frac{Y_{it}}{L_{it}}\right) = \ln A + \beta_K \ln\left(\frac{K_{it}}{L_{it}}\right) + \beta_E \ln\left(\frac{E_{it}}{L_{it}}\right) + \mu_i + \vartheta_t + \varepsilon_{it} \quad (10)$$

This paper measures the fossil energy spatial mismatch index of 30 provinces in China from 2000 to 2022. Due to space limitations, this paper selects the years 2010, 2014, 2016, 2019, 2020, 2021, and 2022 to disclose the degree of energy mismatch in each province (Table 1).

Table 1. Mismatch of energy space in different provinces during special years.

Provinces	2010	2014	2016	2019	2020	2021	2022	Mean
Beijing	1.3729	1.5523	1.5421	1.5920	1.5809	1.5833	1.8825	1.3651
Tianjin	0.5151	0.6327	0.7341	0.7140	0.7359	0.7075	0.7912	0.5964
Hebei	−0.5971	−0.5824	−0.6078	−0.5872	−0.5740	−0.5769	−0.5530	−0.5498
Shanxi	−0.8487	−0.8571	−0.8576	−0.8590	−0.8578	−0.8586	−0.8330	−0.8217
Inner Mongolia	−0.6358	−0.6066	−0.6195	−0.7003	−0.7245	−0.7159	−0.7194	−0.5944
Liaoning	−0.0451	0.0179	−0.0555	−0.1356	−0.1636	−0.2081	−0.2341	−0.0324
Jilin	−0.3048	−0.2220	−0.0292	−0.0467	−0.0309	−0.0435	−0.0237	−0.1951
Heilongjiang	0.1379	0.1829	0.2656	0.2553	0.2533	0.2313	0.2565	0.2050
Shanghai	1.4831	1.6411	1.6290	1.7467	1.7691	1.7780	1.7220	1.5488
Jiangsu	0.9856	0.9594	0.9372	1.0261	1.0816	1.0965	1.0072	1.0184
Zhejiang	0.8834	0.8159	0.7308	0.7356	0.7474	0.7272	0.4582	0.8064
Anhui	−0.2150	−0.2358	−0.2434	−0.2185	−0.2088	−0.2188	−0.2509	−0.2178
Fujian	1.0272	0.9678	1.0665	1.0515	1.0378	0.9809	0.9802	1.0695
Jiangxi	0.0727	0.0024	−0.0284	0.0068	0.0147	0.0016	0.0054	0.0500
Shandong	0.0298	0.1185	0.0444	0.0957	0.1286	0.1337	0.0345	0.0967
Henan	−0.6025	−0.5725	−0.5466	−0.4941	−0.4850	−0.4861	−0.5156	−0.5483
Hubei	−0.4713	−0.4108	−0.3710	−0.3521	−0.3991	−0.3820	−0.2755	−0.4014
Hunan	−0.2462	−0.1296	−0.0703	−0.0295	−0.0131	−0.0254	0.5784	−0.0696
Guangdong	1.8765	1.8593	1.7805	1.7836	1.7760	1.7412	1.7613	1.8566
Guangxi	−1.4150	−1.4054	−1.3909	−1.3819	−1.3836	−1.0261	−1.0246	−1.3971
Hainan	0.1855	0.0125	−0.0492	−0.1036	−0.1082	−0.1064	−0.0901	0.0982
Chongqing	−0.1166	0.0444	0.2204	0.2123	0.2206	0.1999	0.4615	0.0884
Sichuan	−0.3610	−0.3020	−0.2398	−0.2270	−0.2212	−0.2365	−0.2458	−0.2750
Guizhou	−1.2373	−1.2555	−1.2791	−1.3008	−1.3073	−1.3038	−1.3077	−1.2985
Yunnan	−1.0851	−1.0863	−1.0878	−1.0897	−1.0898	−1.0869	−1.0845	−1.0942
Shaanxi	−0.6901	−0.6984	−0.7142	−0.7137	−0.7161	−0.7255	−0.7436	−0.6789
Gansu	−0.8361	−0.8451	−0.8360	−0.8394	−0.8362	−0.8388	−0.8416	−0.8212
Qinghai	−1.0908	−1.0708	−1.0711	−1.0756	−1.0762	−1.0753	−1.0771	−1.1039
Ningxia	−1.0723	−1.0627	−1.0572	−1.0460	−1.0433	−1.0397	−1.0412	−1.0869
Xinjiang	−0.8724	−0.9148	−0.9193	−0.9225	−0.9228	−0.9250	−0.9258	−0.8711

According to Table 1, the overall trend of the mean distribution for each province and city shows significant regional differences, revealing the unbalanced state of the distortion degree of fossil energy spatial allocation across the country. Specifically, regions with a mean close to 0 indicate that their fossil energy allocation is relatively reasonable with low distortion, while regions with a mean significantly deviating from 0 reveal obvious fossil energy allocation distortion. Further detailed analysis shows that China's provinces and cities can be divided into two major regions according to the degree of distortion of fossil energy allocation: regions with excessive fossil energy allocation and regions with insufficient fossil energy allocation. The former mainly includes many provinces in the central, western, and northeastern regions, such as Tianjin, Hebei, Shanxi, etc. These regions generally have a mean less than 0, indicating that energy supply exceeds actual demand, resulting in excessive allocation. This phenomenon may be related to the

abundant fossil energy resources, relatively lagging economic development, and single energy consumption structure in these regions. On the contrary, the latter is concentrated in the eastern and southern coastal economic zones, such as Beijing, Shanghai, Guangdong, and other provinces, with a mean greater than 0, indicating that fossil energy supply cannot meet the rapidly growing economic demand, resulting in insufficient allocation.

At the provincial level, the degree of distortion of fossil energy allocation in different regions shows distinctive characteristics. Taking Beijing and Shanghai as examples, as China's economic centers, the fossil energy allocation distortion degree of these two cities has always remained at a high level, with a mean greater than 0, indicating that their fossil energy allocation is seriously insufficient, and further optimization is needed to meet the high demand for economic development. As a major economic province and energy-consumption province, Guangdong also has a high degree of fossil energy allocation distortion and faces the challenge of insufficient energy allocation. In contrast, some provinces in the central, western, and northeastern regions, such as Shanxi and Inner Mongolia, are facing the dilemma of excessive fossil energy allocation due to abundant fossil energy resources.

3.1.2. Measurement of Economic Development Level

This paper adopts the indicator system constructed by Sun Hao [55] to measure the high-quality economic development index. Taking the new development philosophy of innovative, coordinated, green, open, and shared development proposed by General Secretary Xi Jinping at the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China as the theoretical foundation for establishing the high-quality economic development indicator system, this system assesses high-quality economic development from two dimensions: the process and outcomes of economic growth.

To calculate the high-quality economic development index, all indicators first require dimensionless processing, followed by weighting in accordance with standardized rules. The detailed calculation procedures for the high-quality economic development index of each provincial region are outlined below:

(1) Dimensionless standardization of indicators.

To eliminate the dimensional bias of diverse evaluation indicators, normalization is conducted on all indicator datasets. The standardization formulas for positive indicators and negative indicators are specified in Equation (11) and Equation (12), respectively.

$$X_{ij} = \frac{x_{ij} - x_{ijmin}}{x_{ijmax} - x_{ijmin}} \quad (11)$$

$$X_{ij} = \frac{x_{ijmax} - x_{ij}}{x_{ijmax} - x_{ijmin}} \quad (12)$$

where i denotes each indicator, j represents each provincial administrative region, x_{ij} is the raw data of indicator i for province j , x_{ijmin} and x_{ijmax} refer to the minimum and maximum values of x_{ij} , respectively, and X_{ij} stands for the standardized value of indicator i for province j .

(2) Determine indicator weights.

The indicator system is constructed in line with the new development philosophy, where the five dimensions of innovation, coordination, green development, openness, and shared development carry equal importance. This paper adopts the equal-weighting method for weight assignment.

(3) Calculate the composite index.

The linear weighted summation method is employed to compute the high-quality economic development index, as shown in Formula (13).

$$Q_j = \sum_{i=1}^{i=18} (X_{ij} \times \omega_i) \quad (13)$$

wherein, Q_j denotes the high-quality economic development index of province j , and ω_i represents the weight of indicator i .

3.2. Model Construction

3.2.1. Evaluation Model of the Impact Effect of Fossil Energy Production Capacity Spatial Agglomeration on Economic Development Level

According to the research results and conclusions on the influencing factors of economic development, taking fossil energy spatial mismatch as the explanatory variable, a benchmark regression model of fossil energy spatial mismatch on economic development is constructed, with the formula as follows:

$$ED_{i,t} = \alpha + \beta SM_{i,t} + \gamma X_{i,t} + \mu_i + \vartheta_t + \varepsilon_{i,t} \quad (14)$$

where ED is the economic development level of a province (municipality, autonomous region); SM is the fossil energy spatial mismatch level, that is, the core explanatory variable; i is the region, t is the time, X is the control variable set; α is the parameter to be estimated; μ_i and ϑ_t are factors that do not change with region and time, and ε it is the random disturbance term.

3.2.2. Evaluation Model of the Moderating Effect of Energy Transition on the Economic Development Impact of Fossil Energy Production Capacity Spatial Agglomeration

According to theoretical analysis, new energy development alleviates the inhibitory effect of fossil energy spatial mismatch on economic development by shortening the distance between energy supply and demand, reducing the cost loss of fossil energy mismatch, and reducing dependence on fossil energy. In order to verify the moderating effect of new energy development on the economic effect of fossil energy spatial mismatch, this paper introduces the interaction term between new energy development level and fossil energy spatial mismatch into the previous model to analyze the moderating role of new energy development level, and constructs the econometric model as follows:

$$ED_{i,t} = \alpha + \beta_1 SM_{i,t} + \beta_2 TJ_{i,t} + \beta_3 SM_{i,t} \times TJ_{i,t} + \gamma X_{i,t} + \mu_i + \vartheta_t + \varepsilon_{i,t} \quad (15)$$

development level by subtracting hydropower generation and thermal power generation from total power generation, and taking the logarithm. The data comes from the China Electric Power Statistics Yearbook and BJX Power Network. Considering data availability, when exploring the moderating effect of the new energy development level, the sample period is selected as 2004–2022.

3.3. Variable Description and Index Design

3.3.1. Explained Variable

Referring to the practice of Sun Hao [38], based on the new development concept, an economic development index system is constructed to measure the economic development level (ED) from five aspects: innovative development (ID), coordinated development (CD), green development (GD), open development (OD), and shared development (SD). The specific index system is shown in Table 2.

Table 2. Economic development indicator system. The abbreviations used in the table represent the following variables: ID stands for Innovative Development, CD for Coordinated Development, GD for Green Development, OD for Open Development, SD for Shared Development, and R&D for Research and Development.

First-Level Indicator	Second-Level Indicator	Third-Level Indicator	Indicator Calculation	Positive/Negative
ED	ID	GDP Growth Rate	Regional GDP Growth Rate (%)	+
		R&D Investment Intensity	R&D Expenditure of Industrial Enterprises above Designated Size/Regional GDP	+
		Investment Efficiency	Incremental Capital-Output Ratio (ICOR) = Investment Rate/Regional GDP Growth Rate	−
		Technology Transaction Activity	Technology Transaction Volume/Regional GDP	+
	CD	Demand Structure	Total Retail Sales of Consumer Goods/Regional GDP	+
		Urban-Rural Structure	Urbanization Rate (%)	+
		Industrial Structure	Increase in the Share of Tertiary Industry in Regional GDP	+
		Government Debt Burden	Government Debt Balance/Regional GDP	−
	GD	Energy Consumption Elasticity Coefficient	Energy Consumption Growth Rate/Regional GDP Growth Rate	−
		Wastewater per Unit Output	Total Wastewater Discharge/Regional GDP	−
		Exhaust Gas per Unit Output	Sulfur Oxide Emissions/Regional GDP	−
	OD	Foreign Trade Dependence	Total Import and Export Volume/Regional GDP	+
		Foreign Investment Ratio	Actually Utilized Foreign Investment/Regional GDP	+
		Marketization Degree	Regional Marketization Index	+
	SD	Labor Remuneration Ratio	Labor Remuneration/Regional GDP	+
		Residents' Income Growth Elasticity	Growth Rate of Per Capita Disposable Income of Residents/Regional GDP Growth Rate	+
		Urban-Rural Consumption Gap	Per Capita Consumption Expenditure of Urban Residents/Per Capita Consumption Expenditure of Rural Residents	−
		Ratio of People's Livelihood Fiscal Expenditure	The proportion of local fiscal expenditure on education, medical and health care, housing security, social security, and employment in the local fiscal budget expenditure	+

3.3.2. Core Explanatory Variable

The calculation process of the fossil energy spatial mismatch (FESM) index is as mentioned above.

3.3.3. Control Variables

Drawing upon relevant literature, we selected financial development level (FD), internet penetration rate (IPR), population density (PD), degree of opening up (OPEN), technological progress (TP), and infrastructure (INF) as control variables to empirically examine the effects of influencing factors on the economic development index. Specifically, financial development level is measured by the ratio of total deposits and loans to GDP, reflecting the scale and vitality of regional financial resources; the internet penetration rate is calculated as the proportion of internet users to the total resident population, indicating the coverage of digital infrastructure; population density is derived by dividing the year-end resident population by the provincial area, representing the intensity of regional population agglomeration; the degree of opening up is measured by the proportion of total import and export volume to GDP, depicting the degree of economic external orientation; technological progress is represented by the number of authorized invention patents, re-

flecting the regional innovation output capacity; and infrastructure is measured by per capita road construction area, reflecting the supply level of transportation infrastructure. Detailed variable descriptions and indicator designs are presented in Table 3.

Table 3. Control variable description and data source. The abbreviations used in the table represent the following variables: FD stands for financial development level, IPR for internet penetration rate, PD for population density, OPEN for openness, TP for technological progress, and INF for infrastructure construction.

Variable Name	Representative Indicator	Data Source
FD	Total deposits and loans/GDP	Statistical Yearbooks of Each Province
IPR	Number of internet users/Total permanent resident population	Statistical Yearbooks of Each Province
PD	Year-end permanent resident population/Provincial area	China Statistical Yearbook
OPEN	Total import and export volume/GDP	Wind Database, Statistical Yearbooks of Each Province
TP	Number of invention patents granted	National Bureau of Statistics of China
INF	Per capita road construction area	National Bureau of Statistics of China

3.3.4. Moderating Variable

The new energy development level (NEDL) is represented by new energy power generation. Since total power generation, hydropower generation, and thermal power generation are the main disclosed data, this paper measures the new energy development level (NEDL) by subtracting hydropower generation and thermal power generation from total power generation and taking the logarithm. The data comes from the China Electric Power Statistics Yearbook and BJX Power Network. Considering data availability, when exploring the moderating effect of new energy development level (NEDL), the sample period is selected as 2004–2022.

3.4. Data Sources and Descriptive Statistics

This paper uses panel data of 30 provinces and cities in China from 2000 to 2022 for empirical analysis. Considering data availability, Hong Kong, Macao, Taiwan, and Xizang are not included. The descriptive statistics of each variable are shown in Table 4.

Table 4. Descriptive statistics. The abbreviations used in the table represent the following variables: ED stands for economic development level, FESM for fossil energy spatial mismatch, FD for financial development level, IPR for internet penetration rate, PD for population density, OPEN for openness, TP for technological progress, INF for infrastructure construction, and NEDL for new energy development level.

Variable	Sample Size	Mean	Minimum	Maximum	Standard Deviation
ED	690	0.5115	0.3760	0.6300	0.0511
FESM	690	−0.1085	−1.7649	2.1111	0.8615
FD	690	3.0280	1.4128	7.6095	1.0935
IPR	690	0.4215	0.0400	0.9000	0.2035
PD	690	5.4339	1.9682	8.2817	1.2754
OPEN	690	0.2874	0.0071	1.6682	0.3261
TP	690	20,019.9100	36.0000	242,551.0000	37,276.8300
INF	690	13.6667	3.9000	28.0000	5.2687
NEDL	570	0.0655	−0.0011	0.6691	0.0847

Table 4 reports the descriptive statistics of the main variables. The spatial mismatch of fossil energy has a mean value of −0.1085 and a standard deviation of 0.8615, with a maximum of 2.1111 and a minimum of −1.7649. This reveals substantial disparities in the degree of fossil energy spatial mismatch across Chinese provinces during the sample

period, reflecting a prominent spatial imbalance between fossil energy production and consumption nationwide. Economic development level yields a mean of 0.5115 and a relatively small standard deviation of only 0.0511, indicating that provincial economic development levels are closely distributed with modest cross-provincial gaps. The values of the remaining control variables all fall within reasonable ranges. Wherein, the technological progress indicator is measured by the number of authorized invention patents in each province. Since the absolute value of this variable is much larger than that of the other control variables, we take the natural logarithm of this variable in the regression analysis to ensure the robustness of the model's estimation.

4. Result Analysis

4.1. Benchmark Regression Results

In order to gradually observe the impact of each control variable on the correlation effect between FESM (fossil energy spatial mismatch) and ED (economic development), eliminate the influence of collinearity, and according to the Hausman test results, this paper selects the fixed effect model for empirical analysis by gradually adding control variables. The regression results are shown in Table 5.

Table 5. The Impact of spatial mismatch of fossil energy on the economic development level.

Variable	ED	ED	ED	ED	ED	ED	ED
FESM	−0.0164 *** (−9.76)	−0.0312 *** (−3.84)	−0.0206 ** (−3.08)	−0.0242 *** (−3.64)	−0.0248 *** (−3.89)	−0.0250 *** (−3.94)	−0.0165 ** (−2.65)
FD		−0.2370 *** (7.38)	−0.0048 (−0.30)	0.0170 (1.03)	0.0234 (0.19)	−0.0012 (−0.07)	−0.0124 (−0.80)
IPR			0.1530 *** (7.81)	0.1490 *** (7.60)	0.1440 *** (7.66)	0.1370 *** (6.14)	0.0738 *** (6.14)
PD				0.4280 *** (4.83)	0.6850 *** (7.44)	0.5900 *** (6.12)	0.6140 *** (6.60)
OPEN					0.1040 *** (7.44)	0.1200 *** (8.04)	0.1180 *** (8.15)
TP						0.0304 *** (3.05)	0.0357 *** (3.70)
INF							0.0650 *** (7.15)
Constant	0.5100 *** (6.10)	0.6830 *** (8.33)	0.4480 *** (9.86)	0.6270 *** (5.77)	0.8420 *** (7.52)	0.8460 *** (7.70)	0.9340 *** (9.59)
Regional Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Time Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Observations	690	690	690	690	690	690	690
R ²	0.4107	0.4330	0.6978	0.7419	0.7367	0.7339	0.8100

Notes: ** $p < 0.05$, *** $p < 0.01$. The values in parentheses are t-statistics.

At the national level, the regression coefficient of spatial mismatch of fossil energy on the economic development level is -0.0165 and significant at the 5% statistical level. This implies that a one-unit increase in the degree of fossil energy spatial mismatch leads to an average 0.0165-unit decline in economic development level. It demonstrates that spatial distortion in energy resource allocation has become a critical bottleneck restricting regional economic growth, and that its adverse impacts pose realistic and pressing challenges.

The coefficient of financial development level on economic growth is negative yet statistically insignificant. A plausible explanation is that excessive financialization diverts financial resources toward speculative financial markets rather than the real economy. This tendency easily fuels financial bubbles, whose burst would severely undermine economic stability and expansion. The regression coefficient of the internet penetration rate stands at 0.0738, significant at the 1% level. This indicates that improved internet infrastructure effectively mitigates information asymmetry and boosts resource allocation efficiency, acting as a core driving force for economic growth in the digital economy era. Population density

carries a coefficient of 0.6140, significant at the 1% level, which reflects that scale effects and knowledge spillovers generated by population agglomeration still deliver strong support for economic growth at the current development stage. The openness degree yields a coefficient of 0.1180, significant at the 1% level, revealing that integration into the global division of labor, alongside foreign capital attraction and technology spillovers, remains a vital external engine propelling high-quality domestic economic development. Technological progress has a coefficient of 0.0357, significant at the 1% level, verifying that technological innovation, as the primary productive force, continuously injects endogenous growth momentum into the economy. Infrastructure construction shows a coefficient of 0.0650, significant at the 1% level. This suggests that upgraded transportation, communication, energy, and other infrastructure not only directly stimulate investment but also indirectly empower coordinated regional economic development by cutting transaction costs and enhancing factor mobility.

4.2. Robustness Test

To ensure the robustness of the above research conclusions, this paper conducts result tests through core variable substitution, shortening the sample period, and winsorization.

4.2.1. Core Variable Substitution

The robustness test is conducted by means of core variable substitution. The proxy for economic development level is substituted with per capita GDP, and we run a national-level regression between per capita GDP and spatial mismatch of fossil energy, with results displayed in Table 6. The regression coefficient of spatial mismatch of fossil energy on per capita GDP is -0.0679 and is significantly negative at the 1% level, indicating that each one-unit increase in the degree of fossil energy spatial mismatch leads to an average decrease of approximately 0.0679 units in per capita GDP. Even after changing the measurement indicator of economic development, energy allocation distortion still restrains residents' wealth accumulation and economic growth by hindering the efficient flow of factors, which verifies the robustness of the previous baseline findings.

Table 6. Results of robustness tests.

Variable	Core Variable Replacement	Shortened Sample Period		Winsorization
		2000–2011	2012–2022	
FESM	-0.0679^{***} (-5.11)	-0.0041^{***} (-3.70)	-0.0092^{***} (4.99)	-0.0209^{***} (-3.31)
Constant	0.576^{***} (9.33)	0.6739^{***} (10.40)	0.7331^{***} (8.52)	0.9310^{***} (9.87)
Controls	YES	YES	YES	YES
Regional Fixed Effects	YES	YES	YES	YES
Time Fixed Effects	YES	YES	YES	YES
Observations	690	360	330	690
R ²	0.8327	0.7544	0.6824	0.7280

Notes: *** $p < 0.01$. The values in parentheses are t-statistics.

4.2.2. Shortening the Sample Period

This paper mainly focuses on the impact of fossil energy spatial mismatch on economic development. Considering that before 2012, it was a period of rapid development of fossil energy, and the development of various regions was relatively balanced. After 2012, especially coal supply was in surplus, and the state began to promote supply-side structural reform, and the trend of coal production capacity agglomeration accelerated, further improving the level of supply and demand mismatch among regions. Therefore, the sample time period is adjusted to 2000–2011 to re-conduct empirical estimation. To ensure the robustness of the

test results, the measurement results of 2012–2022 are also listed. The results are shown in Table 6. The regression coefficients of fossil energy spatial mismatch on economic development level are -0.0041 and -0.0092 , respectively, which are significant at the 1% level, indicating that fossil energy spatial mismatch hinders economic development level. This demonstrates that the adverse impact of energy misallocation on the economy persists in both the early balanced development stage and the later structural adjustment stage. Although the marginal impact fluctuates across periods, its inhibitory effect on economic growth remains unchanged, confirming the consistency of our conclusions across different time windows.

4.2.3. Winsorization

To avoid interference of extreme values on the regression results, the sample data corresponding to various variables are measured after 1% winsorization. The results are shown in Table 6. The regression coefficient of fossil energy spatial mismatch on economic development level is -0.0209 , which is significantly negative at the 1% level, indicating that fossil energy spatial mismatch hinders economic development level. The inhibitory effect of energy allocation distortion on economic growth is not driven by a small number of extreme observations but is derived from the overall sample distribution, which further confirms the reliability of our research conclusions.

In summary, the tests through core index substitution, shortening the sample period, and winsorization are consistent with the benchmark regression results, indicating that the research conclusions are robust.

4.3. Endogeneity Test

To avoid endogeneity of core explanatory variables leading to deviation of estimation results, this paper re-estimates the impact of core explanatory variables on economic development level (ED) by using the instrumental variable method. Since unobserved factors have an impact on the current year, but have little impact on the previous one, two or three years, and have low correlation with random disturbance terms, the lagged one to three periods of core explanatory variables are selected as instrumental variables. The results are shown in Table 7. The p -values of Kleibergen-Paap rk LM statistics are all less than 0.01, indicating that there is no under-identification problem of instrumental variables. The Kleibergen-Paap rk Wald F statistic values are all greater than the critical value of 12.83 at 15%, which can reject the null hypothesis of “weak instrumental variables”. After overcoming the endogeneity problem, the impact of fossil energy spatial mismatch (FESM) on the economic development level is still significant and negative, indicating that the conclusion of this paper is always valid whether considering endogeneity or not.

Table 7. Sub-dimensions of institutional quality of empirical results.

Variable	First Stage	Second Stage
FESM		-0.0149^{***} (-9.03)
FESM_1	-0.8819^{***} (-24.71)	
FESM_2	0.3552^{***} (8.26)	
FESM_3	-0.4446^{***} (-17.32)	
Controls	YES	YES
Constant	0.0557^{***} (23.31)	0.5258^{***} (36.77)
Observations	600	600
R ²	0.9932	0.7860
Kleibergen-Paap rk LM p -value		0.0000
Kleibergen-Paap rk Wald F-statistic		387.1800

Notes: *** $p < 0.01$. The values in parentheses are t-statistics.

4.4. Heterogeneity Analysis

4.4.1. Regional Heterogeneity Analysis

Considering the differences among different regions, different mismatch directions, and different types of fossil energy, in order to more accurately measure the economic effect of fossil energy spatial mismatch (FESM), heterogeneity tests are carried out from three aspects: region, mismatch direction, and fossil energy type, in order to improve the practical guiding significance of the research.

We conduct grouped regressions divided by Eastern, Central, and Western regions, and the results are shown in Table 8. The coefficient of spatial mismatch of fossil energy on economic development level is -0.0217 and significant at the 5% level for the Eastern region; -0.0526 and significant at the 1% level for the Central region; and -0.0112 with no statistical significance for the Western region. This indicates that fossil energy spatial mismatch generally exerts an inhibitory effect on regional economies, yet the magnitude of this restraint varies across areas. The Central region suffers the strongest inhibitory impact, followed by the Eastern region, while the Western region experiences the weakest restraint. Potential underlying reasons are as follows:

Table 8. Heterogeneity analysis of the impact of spatial mismatch of fossil energy on economic development level: Regional difference.

Variable	Eastern Region	Central Region	Western Region
FESM	-0.0217^{**} (-3.08)	-0.0526^{***} (-4.30)	-0.0112 (-0.91)
Constant	0.9390^{***} (7.42)	0.8620^{***} (5.01)	1.5020^{***} (9.26)
Controls	YES	YES	YES
Regional Fixed Effects	YES	YES	YES
Time Fixed Effects	YES	YES	YES
Observations	253	184	253
R ²	0.6897	0.7135	0.7094

Notes: $** p < 0.05$, $*** p < 0.01$. The values in parentheses are t-statistics.

First, the Central region exhibits the highest sensitivity to energy misallocation due to a rigid industrial structure and imperfect resource allocation mechanisms. In terms of economic features, the Central region serves as a national base for energy and raw materials, as well as an agglomeration hub for heavy chemical industries, featuring a heavily industrialized structure with strong reliance on high-carbon energy and low energy substitution elasticity. Existing spatial energy misallocation not only raises factor input costs but also transmits cost pressures along upstream and downstream industrial chains, exacerbating production volatility. Institutionally, this region is in a critical phase of dual transition for both energy and industrial structures, where market-oriented resource allocation mechanisms remain immature and administrative directives still dominate resource scheduling to a large extent. Such non-market regulation reduces resource allocation efficiency and amplifies the adverse shocks of energy misallocation on economic growth, resulting in the most pronounced inhibitory effect.

Second, the Eastern region leverages a diversified industrial structure and mature market-oriented mechanisms to form an effective risk buffer. Although the Eastern region relies heavily on imported energy and is theoretically more vulnerable to external supply shocks, empirical results reveal a milder inhibitory impact compared with the Central region. This advantage stems primarily from its highly diversified economic structure and sophisticated factor allocation systems. On the one hand, the Eastern region boasts large shares of service and high-tech industries, whose energy consumption per unit of GDP is markedly lower than that of Central and Western areas. This low-energy-consumption trait

lessens the marginal dependence of economic growth on fossil fuels, thereby mitigating the negative impacts of misallocation. On the other hand, the Eastern region features a high degree of marketization; its well-developed factor markets can rapidly redirect resources via price signals, and robust logistics networks plus financial instruments alleviate risks stemming from energy misallocation. Additionally, the region's sound energy reserve and emergency dispatch systems institutionally stabilize economic disruptions caused by supply fluctuations.

Third, the Western region has a relatively small economic aggregate, with industrial sectors mostly centered on energy export or primary resource processing. The absolute economic losses triggered by energy misallocation account for a minor share of its macroeconomic indicators, leading to a statistically weak impact. Furthermore, as a national ecological security barrier and strategic backup zone for energy, the Western region receives substantial fiscal transfer payments and ecological compensation funds from the central government. This robust external institutional support effectively fills local fiscal gaps and partially offsets the adverse effects of inefficient internal resource allocation, weakening the apparent inhibitory influence of energy misallocation on local economic development.

4.4.2. Heterogeneity Analysis of Energy Allocation Direction

According to the division of fossil energy spatial mismatch (FESM) direction, based on the average data of fossil energy spatial mismatch regions, regions with an average fossil energy spatial mismatch degree greater than 0 are regions with insufficient energy allocation, and regions with an average fossil energy spatial mismatch degree less than 0 are regions with excessive energy allocation. Stata 15 is used for data processing. The results are shown in Table 9.

Table 9. Heterogeneity analysis of the impact of spatial mismatch in fossil energy on economic development level: Mismatch direction difference.

Variable	Regions with Insufficient Energy Allocation	Regions with Excessive Energy Allocation
FESM	−0.0272 ** (−3.25)	−0.0023 (−0.22)
Constant	0.9090 *** (6.56)	0.8230 *** (10.39)
Controls	YES	YES
Regional Fixed Effects	YES	YES
Time Fixed Effects	YES	YES
Observations	276	414
R ²	0.7077	0.6496

Notes: ** $p < 0.05$, *** $p < 0.01$. The values in parentheses are t-statistics.

The results demonstrate that the inhibitory effect of fossil energy spatial mismatch on economic development is more significant in regions with insufficient energy allocation. Specifically, the regression coefficient of energy misallocation is −0.0272 and significant at the 5% level in under-allocated fossil energy regions, indicating that energy shortages impose tangible constraints on local economic growth. This occurs mainly because such regions depend heavily on external energy supplies, and their industrial layouts are highly reliant on incoming fossil fuels. When spatial misallocation drives up energy acquisition costs or creates supply instability, production factor prices surge, generating a notable crowding-out effect that hinders capital accumulation and industrial upgrading.

In contrast, the adverse impact of misallocation on economic development is statistically insignificant in regions with excessive fossil energy allocation. This phenomenon is underpinned by unique resource endowments and institutional buffering mechanisms in

these areas. For one thing, acting as national strategic energy reserve bases, these regions host large energy industrial clusters. Their robust resource extraction and processing capacity act as an economic stabilizer, effectively offsetting efficiency losses stemming from poor outward transportation or insufficient local consumption. For another, institutional dividends, including national ecological compensation schemes and fiscal transfer payments, alongside agglomeration effects from linked upstream and downstream industries, endow these regions with strong economic resilience. They can absorb negative shocks from distorted resource allocation to a certain degree, weakening the visible inhibitory effect of misallocation on overall macroeconomic performance.

4.4.3. Heterogeneity Analysis of Fossil Energy Types

Taking economic development level (ED) as the explained variable, coal, oil, and natural gas spatial mismatch are selected as explanatory variables respectively to explore the heterogeneous impact of spatial mismatch of different fossil energy types on economic development. Stata 15 is used for data processing. The results are shown in Table 10.

Table 10. Heterogeneity analysis of the impact of spatial mismatch of fossil energy on economic development level: Energy type difference.

Variable	Coal Spatial Mismatch	Oil Spatial Mismatch	Natural Gas Spatial Mismatch
FESM	−0.0700 *** (−3.22)	−0.0169 (−0.89)	−0.0297 (−1.36)
Constant	0.9064 *** (18.93)	0.9360 *** (19.12)	0.9525 *** (18.52)
Controls	YES	YES	YES
Regional Fixed Effects	YES	YES	YES
Time Fixed Effects	YES	YES	YES
Observations	690	690	690
R ²	0.6632	0.6583	0.6588

Notes: *** $p < 0.01$. The values in parentheses are t-statistics.

For coal, the coefficient of its spatial mismatch on economic development level is −0.0700 and significant at the 1% level, meaning coal spatial mismatch exerts a marked inhibitory effect on economic growth. For oil, the coefficient of spatial mismatch is −0.0169 without statistical significance. For natural gas, the coefficient stands at −0.0297 and is also insignificant. Such heterogeneity mainly stems from disparities in the inherent attributes of different energy varieties and their underlying market mechanisms:

First, high logistics costs and rigid constraints for coal magnify losses caused by misallocation. China's coal reserves follow a pattern of "abundant reserves in the north, scarce reserves in the south", while major consumption hubs are concentrated in the southeast coastal regions. This reversed layout of production and consumption makes long-distance transportation a necessity. As a low-value bulk commodity, coal bears far higher transportation costs per unit of calorific value than oil and gas, and its transport capacity is heavily reliant on railways. When spatial mismatch arises, exorbitant logistics expenses rapidly erode corporate profits. Restricted by bottlenecks in railway transport capacity, market-based adjustments cannot be deployed quickly, thereby delivering substantial adverse shocks to coal-reliant heavy industrial sectors.

Second, the fluidity and mature market mechanisms of oil and gas cushion the impacts of misallocation. By contrast, oil and natural gas are primarily transported via pipelines and ocean shipping; their physical forms grant them superior fluidity and flexible deployability. Especially with the advancement of nationwide interconnected oil and gas pipeline networks and diversified import channels, oil and gas enjoy a high degree of market-oriented

allocation. Price signals can guide cross-regional resource flows to effectively stabilize supply risks originating from uneven geographic distribution. Furthermore, oil and gas are mostly consumed as chemical feedstocks or clean fuel at the terminal end, carrying a certain degree of energy-substitution elasticity, which further weakens the marginal inhibitory effect of spatial mismatch on the overall economy.

4.5. Moderating Effect Test

Taking economic development level (ED) as the explained variable, fossil energy spatial mismatch (FESM) as the explanatory variable, new energy development level (NEDL) as the moderating variable, and the interaction term between fossil energy spatial mismatch and new energy development level to measure the moderating effect, Stata 15 is used to process the data. The results are shown in Table 11.

Table 11. Results of the regulatory effect of new energy development.

Variable	National	Eastern Region	Central Region	Western Region	Insufficient Regions	Excessive Regions
FESM	−0.0064 * (−1.96)	−0.0048 *** (−3.37)	−0.0658 (−1.17)	−0.1680 ** (−3.11)	−0.0835 * (−2.28)	−0.0604 * (−2.44)
NEDL	0.0579 *** (6.02)	0.0580 *** (3.95)	0.2140 *** (3.50)	0.2780 *** (4.31)	0.1500 *** (3.72)	0.1460 *** (7.00)
Interaction Term	0.0028 *** (3.12)	−0.0446 ** (−2.93)	0.0861 (1.35)	0.2030 *** (3.68)	−0.1050 ** (−2.85)	0.0913 *** (4.70)
Constant	0.7200 *** (8.94)	0.7260 *** (5.73)	0.1270 *** (4.67)	0.8030 *** (4.52)	0.5810 *** (9.45)	0.6480 *** (5.24)
Controls	YES	YES	YES	YES	YES	YES
Regional Fixed Effects	YES	YES	YES	YES	YES	YES
Time Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	570	209	152	209	228	342
R ²	0.5854	0.7837	0.7145	0.6994	0.5189	0.6857

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The values in parentheses are t-statistics.

At the national level, the coefficient of the interaction term is 0.0028 and significant at the 10% level, indicating that the inhibitory effect of fossil energy spatial mismatch on economic development gradually weakens as the development level of new energy rises. Once the development level of new energy exceeds the threshold value of 2.29, the impact even shifts from inhibition to promotion. This finding verifies the double dividend hypothesis and the energy system resilience theory. Under the traditional development model, the spatial distribution pattern of fossil fuels leads to exorbitant transportation costs and allocation distortions. In contrast, new energy features wide geographical availability and decentralized access, breaking the spatial lock-in effect imposed by natural resource endowments. When new energy accounts for a certain share in the energy mix, it not only directly reduces reliance on cross-regional fossil fuel deployment via substitution effects and cuts frictional costs generated by long-distance transportation, but also strengthens the risk resistance capacity of the energy system by diversifying supply entities. It further transforms the resource curse originally triggered by misallocation into growth momentum for the green transition [56].

Nevertheless, this moderating effect presents obvious heterogeneous characteristics across different regions. In the Western region, the coefficient of the interaction term is 0.2030 and is significantly positive, demonstrating a strong positive moderating effect. This aligns with the theories of multi-energy complementation and resource advantage transformation. As the national clean energy base, the Western region is endowed with abundant wind and solar resources. The high-level development of new energy does not merely substitute fossil energy; instead, it generates synergistic effects with fossil fuels. Relying on extra-high-voltage (EHV) transmission corridors, the Western region realizes

on-site conversion and outward delivery of energy value, greatly mitigating efficiency losses caused by sole dependence on coal transportation. As a result, the adverse impacts of misallocation are rapidly offset and converted into driving forces for economic growth [57].

By contrast, the interaction coefficient for the Eastern region is -0.0446 and significantly negative, showing distinctive characteristics of a transition pain period. In line with the theory of systematic complexity in the energy transition, the Eastern region acts as a high-load center with extremely high stability requirements for its energy system. In the early stage of transition, large-scale integration of new energy raises system volatility. To stabilize such fluctuations, reserved or expanded fossil energy peak-shaving capacity is often required, which instead increases the complexity and operating costs of the system in the short run. In addition, tightening constraints on land, capital, and other production factors in the East may trigger a crowding-out effect during new energy infrastructure construction. Consequently, within a specific phase, new energy development fails to alleviate and, to some extent, amplifies the economic constraints arising from fossil energy spatial mismatch [58].

The interaction coefficient of the Central region is positive yet statistically insignificant, reflecting its status as a transitional zone in energy transformation. The region possesses certain absorption potential for new energy while undergoing adaptive adjustments to its institutional environment, so the moderating effect has not been fully unlocked.

Further analysis based on energy allocation patterns shows that in regions with excessive fossil energy allocation, the interaction term coefficient is 0.0913 and significantly positive, meaning new energy development effectively cushions the negative impacts of misallocation. This benefits from robust industrial foundations and institutional buffering mechanisms in these areas. For one thing, abundant fossil energy reserves serve as natural peak-shaving support to offset the intermittency of new energy. For another, such regions commonly receive national ecological compensation and fiscal transfer payments, whose institutional dividends offset part of the costs from market distortion.

In regions with insufficient energy allocation, however, the interaction coefficient stands at -0.1050 and is significantly negative, exposing severe coordination conflicts between energy supply and demand. For energy-deficient areas, the primary bottleneck remains insufficient total energy supply. Though new energy is intended to fill supply gaps, the volatility of renewable power increases system vulnerability amid existing fossil energy misallocation. Per energy security theory, when fossil fuel supply cannot be guaranteed, heavy reliance on unstable power sources magnifies supply risks and introduces greater uncertainty for corporate production, worsening the economic drag caused by misallocation. This indicates that for energy-short regions, relying solely on new energy cannot resolve misallocation automatically; lacking sufficient system regulation capacity may even trigger a negative moderating effect.

5. Mediating Effect Test

The previous paper has analyzed in detail the paths of fossil energy spatial mismatch (FESM) affecting economic development (ED), including fixed asset investment (FAI), industrial structure (IS), and energy efficiency (EE). The commonly used path test models mainly include the stepwise regression method, the Sobel mediating effect test method, and the Bootstrap method. Through comparison, the Bootstrap method does not rely on the normal distribution assumption, has high test accuracy, is suitable for complex models, has higher statistical power, and can effectively solve the problems of variable measurement error and multiple mediating models. Therefore, this paper adopts the Bootstrap method to carry out the mediating effect test. With Bootstrap = 5000 and 95% confidence interval as the test standard, the specific results are shown in Table 12.

Table 12. Mediation effect test results. If the interval (Boot LLCI, Boot ULCI) does not contain 0, it indicates that the result is significant at the 95% confidence level; otherwise, it is not significant.

Variable	Effect	Effect Size	Standard Error	Boot LLCI	Boot ULCI
FESM	Direct Effect	−0.0091	0.0022	−0.0135	−0.0048
Fixed Asset Investment	Indirect Effect	−0.0016	0.0016	−0.0026	−0.0004
Industrial Structure		−0.0009	0.0020	−0.0015	−0.0002
Energy Efficiency		−0.0025	0.0011	−0.0056	−0.0013

5.1. Mediating Effect of Fixed Asset Investment

As shown in Table 12, the mediating effect value of fossil energy spatial mismatch acting on economic development through fixed asset investment is −0.0016, and does not contain 0 in the 95% confidence interval, indicating that fixed asset investment plays a significant negative mediating role between fossil energy spatial mismatch and economic development. Fossil energy spatial mismatch will distort energy price signals and resource allocation directions. Energy-surplus regions may attract a large number of inefficient and high-energy-consuming industrial investments due to low-cost energy, while energy-deficient regions will inhibit high-quality industrial investments due to energy constraints, resulting in the overall “inefficiency” and “mismatch” of fixed asset investment. Such inefficient investment cannot be effectively transformed into economic growth momentum, but instead forms resource waste, so the indirect effect of fixed asset investment is negative.

5.2. Mediating Effect of Industrial Structure

As shown in Table 12, the mediating effect value of fossil energy spatial mismatch acting on economic development through industrial structure is −0.0009, and does not contain 0 in the 95% confidence interval, indicating that industrial structure plays a significant negative mediating role between fossil energy spatial mismatch and economic development. Fossil energy spatial mismatch will solidify and even aggravate industrial structure imbalance. Energy-rich regions are prone to fall into “resource dependence”, over-developing high-energy-consuming and low-value-added energy-dependent industries, crowding out resources and development space for emerging industries, leading to blocked industrial structure upgrading. The simplification and low-end of industrial structure will weaken the resilience and potential of economic development, thereby exerting a negative transmission on economic development, so the indirect effect of industrial structure is negative.

5.3. Mediating Effect of Energy Efficiency

As shown in Table 12, the mediating effect value of fossil energy spatial mismatch acting on economic development through energy efficiency is −0.0025, and does not contain 0 in the 95% confidence interval, indicating that energy efficiency plays a significant negative mediating role between fossil energy spatial mismatch and economic development. Fossil energy spatial mismatch will directly inhibit the improvement of energy efficiency. Enterprises in energy-surplus regions lack the motivation for technological innovation and energy-saving transformation due to low-cost access to energy, maintaining high-energy-consuming production models; energy-deficient regions may cause production interruption or inefficient operation of equipment due to unstable energy supply. Both situations make energy efficiency at a low level. Low energy efficiency means low utilization efficiency of production factors, which will directly increase economic operation costs and reduce output benefits, and finally form a negative indirect effect through the path of “mismatch → efficiency decline → economic obstruction”.

The negative indirect effects of fixed asset investment, industrial structure, and energy efficiency, and the negative direct effect of fossil energy spatial mismatch form a “superposition effect”, jointly strengthening the hindering effect of fossil energy spatial mismatch on economic development, and also confirming the necessity of optimizing fixed asset investment structure, promoting industrial upgrading, and improving energy efficiency simultaneously to correct energy mismatch.

It should be noted that in accordance with the principle of effect decomposition, the total effect consists of the direct effect and the mediating effect. The coefficient of -0.0165 for fossil energy spatial mismatch in the benchmark regression denotes the overall total effect of the model. Although the absolute coefficients of each mediating path are relatively modest (for instance, the effect of the industrial structure channel stands merely at -0.0009), this does not imply weak economic influence. As fossil energy spatial mismatch acts as a macro structural variable, its cumulative transmission effects via fixed asset investment, industrial structure, and energy efficiency exert substantial impacts in the long run. In particular, these three mediating variables constitute the core internal mechanisms through which energy mismatch hinders economic development. This empirical finding verifies that distortions in resource allocation are transmitted to macroeconomic performance gradually through multiple micro-level channels, which offers explicit microscopic mechanism evidence for interpreting the economic consequences of fossil energy spatial mismatch.

6. Research Conclusions and Recommendations

6.1. Conclusions and Discussion

This paper uses provincial panel data from 2000 to 2022, selects financial development level, internet penetration rate, population density, openness, technological progress and infrastructure construction as control variables, and evaluates the impact effect of fossil energy spatial mismatch on economic development; On this basis, the moderating effect model is used to analyze the moderating effect of energy transition on the relationship between fossil energy spatial mismatch and economic development, and the mediating effect model is used to further test the action path of fossil energy spatial mismatch affecting economic growth. The results show that: (1) From a national perspective, fossil energy spatial mismatch has a significant inhibitory effect on the economic development level. (2) From a regional perspective, the impact of fossil energy spatial mismatch on the economic development level has significant regional heterogeneity. Among them, the economic effect of fossil energy spatial mismatch is the most significant in the central region, followed by the eastern region, and insignificant in the western region; From the perspective of mismatch direction, the economic effect of fossil energy spatial mismatch is significant in regions with insufficient energy allocation and insignificant in regions with excessive energy allocation; From the perspective of energy type, coal spatial mismatch has the most significant inhibitory effect on economic development, while oil and natural gas have no significant inhibitory effect on economic development. (3) New energy development level plays a role in promoting economic development, and new energy development has a marginal weakening mechanism on the negative economic effect of fossil energy spatial mismatch, that is, with the improvement of new energy development level, the hindering effect of fossil energy spatial mismatch on economic development gradually weakens and turns from inhibition to promotion, and the moderating effect of new energy development is heterogeneous. (4) Fixed asset investment, industrial structure, and energy efficiency have significant negative mediating effects in the relationship between fossil energy spatial mismatch and economic development.

First, this paper incorporates fossil energy misallocation and economic development into a unified research framework, expanding studies concerning the economic conse-

quences of fossil energy misallocation. Existing literature on fossil energy misallocation is abundant, yet it mostly concentrates on its driving factors, misallocation degree evaluation, and environmental impacts, while discussions regarding its influences on the regional economy remain relatively scarce. Specifically, in terms of policy intervention, although Jiang et al. argued that environmental regulation can remarkably alleviate energy misallocation [32], other scholars proposed that energy intensity policies may instead exacerbate energy distortion [39]. Regarding spatial distribution characteristics, academic circles have reached a relatively consistent conclusion on the degree of energy price distortion: the distortion level is lower in Eastern China and higher in Central and Western China [41]. Moreover, a broad consensus exists that fossil energy misallocation aggravates environmental pollution.

Second, this study systematically sorts out the transmission paths through which spatial mismatch of fossil energy affects economic development. Prior studies reveal that energy misallocation restrains the growth of green total factor productivity (GTFP) by lowering resource allocation efficiency, curbing technological innovation, and obstructing the optimization of energy consumption structure [41]; meanwhile, it degrades environmental quality by reducing energy utilization efficiency [43], ultimately forming rigid constraints on the sustainable development of regional economies. A consensus has not been reached among scholars on the mediating effect of technological innovation between energy misallocation and its economic and environmental outcomes. Most studies hold that technological innovation acts as a negative mediator between energy misallocation and environmental pollution [43]. In contrast, Liu and Qiu found that the relationship between energy misallocation and environmental pollution follows an inverted-U-shaped curve as the level of technological innovation improves [48].

Third, this paper explores the moderating effect of new energy development on the nexus between spatial mismatch of fossil energy and economic development. In-depth investigations into the boundary conditions and contextual factors shaping the impact effects of energy misallocation are still insufficient in the extant literature. Some existing research, from the perspective of technological change, verified that the energy internet exerts a negative moderating effect on the relationship between energy misallocation and carbon emissions [46]. Other institutionally oriented studies found that local corruption intensifies the inhibitory impact of labor resource misallocation on green total factor productivity [59].

6.2. Recommendations

Based on the above conclusions, in order to alleviate the inhibitory effect of fossil energy spatial mismatch on economic development and promote high-quality regional economic development, it is necessary to coordinate the spatial allocation of fossil energy, focus on optimizing the energy layout in the central and eastern regions, strengthen the precise allocation of coal to break the mismatch dilemma; Implement regional differentiated regulation strategies, implement precise policies for different regions and different mismatch types, and take into account the impact heterogeneity; Accelerate the development of new energy, improve supporting infrastructure, promote its coordinated development with fossil energy, and strengthen its marginal weakening effect on the negative effect of fossil energy mismatch and positive driving effect on the economy; Smooth the mediating transmission paths of fixed asset investment, industrial structure and energy efficiency, and weaken the negative mediating effect by optimizing investment structure, promoting industrial upgrading and improving energy efficiency; At the same time, improve the supporting guarantee system, incorporate relevant control variables into policy considerations, strengthen financial, technological, infrastructure and other supports, ensure the

implementation of various policies, and promote the coordinated development of regional economy and energy system.

7. Limitations and Future Research

7.1. Limitations

7.1.1. Measuring Fossil Energy Misallocation

This paper adopts the Cobb–Douglas production function to quantify the degree of fossil energy misallocation. This method fits real production processes well, does not require complex cost data, and is the most widely adopted approach for measuring energy misallocation at provincial and industrial levels, enabling direct estimation of factor price distortion coefficients. Nevertheless, it bears inherent limitations. First, the elasticity of substitution is fixed at one, which fails to reflect the actual substitution relationships between energy, capital, and labor. Second, it imposes restrictive functional-form assumptions that technological progress follows Hicks' neutrality, which is inconsistent with biased technological progress observed in real production activities. Third, it struggles to incorporate undesirable outputs such as carbon emissions, making it difficult to account for environmental externalities.

7.1.2. Data Availability

Due to limited access to official statistics on new energy power generation, this study adopts an indirect measurement method to construct the corresponding indicator. Specifically, official statistical yearbooks mainly publish total power generation, hydropower generation, and thermal power generation. Therefore, this paper uses the residual value after subtracting hydropower and thermal power generation from the total power generation as a proxy variable for new energy power generation to measure the development level of regional new energy.

7.1.3. Applicability of Research Conclusions

It should be clarified that our empirical analysis relies on Chinese provincial panel data spanning 2000 to 2022. While our conclusions hold valid for China's institutional context, caution is warranted when extrapolating these findings to countries with drastically different institutional environments, energy market structures, or factor allocation mechanisms. Further cross-country research is needed in the future to test the external validity and contextual boundaries of the effects identified in this paper.

7.2. Directions for Future Research

Future research can focus on optimization strategies and correction mechanisms for the spatial allocation of energy. This paper mainly examines the economic consequences of energy misallocation, and subsequent studies can further unpack the black box of "correction", with an emphasis on exploring how institutional and mechanism innovations can alleviate energy misallocation. This will not only help resolve the spatial imbalance between energy supply and demand at the source but also provide theoretical support and practical guidance for establishing a modern energy system that is clean, low-carbon, safe, and efficient.

Author Contributions: Writing—Original Draft Preparation, Software, Data Curation, Formal analysis, B.W.; Writing—Review and Editing, J.Q.; Conceptualization, Methodology, Writing—Review and Editing, Y.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the Natural Science Foundation of Shandong Province (Project No. ZR2025MS1153).

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

Acknowledgments: The authors would like to sincerely appreciate the valuable comments and suggestions provided by the anonymous reviewers and the journal editors, which greatly improved the quality of this manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Ullah, S.; Lin, B. Natural resources, renewable energy-environment nexus for Pakistan: A policy perspective. *Resour. Policy* **2024**, *90*, 104788. [\[CrossRef\]](#)
2. Kang, J.J.; Yu, C.Y.; Xue, R.; Yang, D.; Shan, Y.L. Can regional integration narrow city-level energy efficiency gap in China? *Energy Policy* **2022**, *163*, 112820. [\[CrossRef\]](#)
3. Zhang, H.Q.; Yang, F.; Chandio, A.A.; Liu, J.; Twumasi, M.A.; Ozturk, I. Assessing the effects of internet technology use on rural households' cooking energy consumption: Evidence from China. *Energy* **2023**, *284*, 128726. [\[CrossRef\]](#)
4. Bian, Y.J.; Ma, X.Y. Dynamic evolution and influencing factors of internal and external synergy in China's energy industry: From the perspective of industrial chain. *Sustain. Futures* **2024**, *8*, 100360. [\[CrossRef\]](#)
5. Dong, Z.J.; Ding, H.; Yu, X.Y.; Zhou, D.Q. Analyzing the dynamic effect of energy endowment-demand distortion on sustainable development: Insights from China's regional disparity. *J. Environ. Manag.* **2024**, *366*, 121647. [\[CrossRef\]](#) [\[PubMed\]](#)
6. Hu, J.Z.; Du, J.T.; Shi, Y.S.; Chen, X.L.; Deng, X.Z.; Song, M.L. Energy mismatch in Chinese industrial enterprises: A stochastic frontier approach. *Sustain. Futures* **2025**, *10*, 100946. [\[CrossRef\]](#)
7. Zhang, S.Q.; Meng, L.S.; Li, Y. The impact of spatial agglomeration on energy production capacity on regional energy efficiency. *China Popul. Resour. Environ.* **2021**, *31*, 58–66.
8. Zhang, S.L.; Wang, Y.; Hao, Y.; Liu, Z.W. Shooting two hawks with one arrow: Could China's emission trading scheme promote green development efficiency and regional carbon equality? *Energy Econ.* **2021**, *101*, 105412. [\[CrossRef\]](#)
9. Li, Y.; Yu, X.Y. Coal production capacity spatial agglomeration, new energy development and carbon emissions: An empirical analysis based on panel threshold model. *Dongyue Trib.* **2026**, *47*, 126–137. [\[CrossRef\]](#)
10. Wang, F.R.; Zhuang, L.; Cheng, S.S.; Zhang, Y.; Cheng, S.L. Spatiotemporal variation and convergence analysis of China's regional energy security. *Renew. Sustain. Energy Rev.* **2024**, *189*, 113923. [\[CrossRef\]](#)
11. Zhang, Y.L.; Gnangoin, T.Y. Energy security, energy consumption, and stringent climate policy in European Union countries: Is environmental tax effective? *Energy Strategy Rev.* **2026**, *63*, 102045. [\[CrossRef\]](#)
12. Ivashko, T.; Simakhova, A.; Soliakov, V.; Choroszczak, J. Clustering EU Member States by Energy Security Level Using Kohonen Maps. *Energies* **2025**, *18*, 4750. [\[CrossRef\]](#)
13. Fan, Y.; Chang, T.Y.; Ranjbar, O. Analyzing the degree persistence of shocks to energy security of the G7 countries: Evidence using panel SPSM-quantile unit root test. *Econ. Anal. Policy* **2024**, *82*, 389–399. [\[CrossRef\]](#)
14. Khan, K.; Khurshid, A.; Cifuentes-Faura, J.; Dai, X.J. Does renewable energy development enhance energy security? *Util. Policy* **2024**, *87*, 101725. [\[CrossRef\]](#)
15. Wang, J.Q.; Xie, X.X.; Chen, T.Q. How does digital finance promote energy security? Evidence from China. *Environ. Dev. Sustain.* **2025**, 1–27. [\[CrossRef\]](#)
16. Wang, X.L.; Wang, D.; Zhao, Y.M. Energy storage technology innovation, performance appraisal pressure of officials and energy security: An empirical study in the context of energy transition. *Renew. Energy* **2025**, *251*, 123482. [\[CrossRef\]](#)
17. Li, J.M.; Dong, J.J.; Liu, G.X.; Taghizadeh-Hesary, F. Can green trade development promote energy security in China? The role of financial development. *Econ. Anal. Policy* **2024**, *84*, 1840–1858. [\[CrossRef\]](#)
18. Tao, M.M.; Roubaud, D.; Grebnevych, O. A systematic risk spillover perspective for modelling China's energy security: Firm-level evidence. *J. Environ. Manag.* **2025**, *373*, 123650. [\[CrossRef\]](#) [\[PubMed\]](#)
19. Fan, Y.; Chang, T.Y.; Ranjbar, O. Energy security and energy mix diversification nexus in the OECD countries. *Econ. Anal. Policy* **2024**, *84*, 2071–2085. [\[CrossRef\]](#)
20. Chen, Z.Y.; He, M.; Ali, M. Natural Resources and Geopolitical Risk Impact on Energy Security Risk: The Role of Renewable Energy Consumption and Foreign Direct Investment. *Nat. Resour. Forum* **2026**, *50*, 967–979. [\[CrossRef\]](#)
21. Li, J.J.; Wang, Y.; Su, E.D. Digital economy and energy security risk: Global impacts and mechanisms. *Appl. Econ.* **2026**, 1–17. [\[CrossRef\]](#)
22. Sun, X.Y.; Ullah, S.; Sher, F. How do digital financial inclusion, ICT diffusion, and education affect energy security risk in top energy-consuming countries? *Energy Environ.* **2026**, *37*, 439–456. [\[CrossRef\]](#)
23. Qi, S.Z.; Wang, X.W.; Li, K. Smarter and cleaner energy transition: Exploring how digitalization affects energy efficiency with greening as a moderator. *Energy* **2026**, *342*, 139617. [\[CrossRef\]](#)

24. Zheng, J.H.; Niu, H.; Lo, K.V.; Guo, M.Y. Breaking the resource curse: The impact of green finance on the energy transition of resource-based cities. *Energy Policy* **2026**, *214*, 115245. [\[CrossRef\]](#)
25. Xu, W.H.; Yuan, Q.X.; Chen, N.X.; Ye, J. Green Finance and Energy Structure Transition: Evidence from China. *Sustainability* **2025**, *17*, 4838. [\[CrossRef\]](#)
26. Chen, M.J.; Heerink, N.; Zhu, X.Q.; Feng, S.Y. Do small and equally distributed farm sizes imply large resource misallocation? Evidence from wheat-maize double-cropping in the North China Plain. *Food Policy* **2022**, *112*, 102350. [\[CrossRef\]](#)
27. Yu, C.H.; Wu, X.Q.; Lee, W.C.; Zhao, J.S. Resource misallocation in the Chinese wind power industry: The role of feed-in tariff policy. *Energy Econ.* **2021**, *98*, 105236. [\[CrossRef\]](#)
28. Yu, C.H.; Zhao, J.; Qin, P.; Wang, S.S.; Lee, W.C. Comparison of misallocation between the Chinese thermal power and hydropower electricity industries. *Econ. Model.* **2022**, *116*, 106007. [\[CrossRef\]](#)
29. Zhang, Y.; Hu, S.; Chen, L.Q. Internet technology adoption and firm energy efficiency: Evidence from China. *Technol. Forecast. Soc. Change* **2024**, *201*, 123214. [\[CrossRef\]](#)
30. Hsieh, C.T.; Klenow, P.J. Misallocation and manufacturing TFP in China and India. *Q. J. Econ.* **2009**, *124*, 1403–1448. [\[CrossRef\]](#)
31. Chen, F.L.; Wang, M.C.; Pu, Z.N. The impact of technological innovation on air pollution: Firm-level evidence from China. *Technol. Forecast. Soc. Change* **2022**, *177*, 121521. [\[CrossRef\]](#)
32. Jiang, T.Y.; Cao, C.; Lei, L.Y.; Hou, J.; Yu, Y.; Jahanger, A. Temporal and spatial patterns, efficiency losses and impact factors of energy mismatch in China under environmental constraints. *Energy* **2023**, *282*, 128875. [\[CrossRef\]](#)
33. Choi, B. Productivity and misallocation of energy resources: Evidence from Korea's manufacturing sector. *Resour. Energy Econ.* **2020**, *61*, 101184. [\[CrossRef\]](#)
34. Zeng, S.H.; Gu, Y.X.; Su, B.; Li, T.F. Energy consumption transition and green total factor productivity in Chinese prefecture-level cities. *Energy Econ.* **2025**, *142*, 108156. [\[CrossRef\]](#)
35. Jiang, H.M. Energy price distortion and the real trade gains of China's manufacturing industry. *Contemp. Financ. Econ.* **2020**, 116–124. [\[CrossRef\]](#)
36. Yuan, P.; Yang, Y. Factor market distortion and China's economic efficiency. *Econ. Rev.* **2014**, 28–40+51. [\[CrossRef\]](#)
37. Tan, R.; Lin, B.; Liu, X. Impacts of eliminating the factor distortions on energy efficiency—A focus on China's secondary industry. *Energy* **2019**, *183*, 693–701. [\[CrossRef\]](#)
38. Peng, C.; Zhang, J.J.; Xu, Z.Y. Does price distortion affect energy efficiency? Evidence from dynamic spatial analytics of China. *Energies* **2022**, *15*, 9576. [\[CrossRef\]](#)
39. Zhang, J.Y.; Yuan, X.L. Research on the impact of energy distortion on total factor productivity and countermeasures. *Inq. Econ. Issues* **2015**, *11*, 63–71.
40. Yang, M.; Yang, F.X.; Sun, C.W. Factor market distortion correction, resource reallocation and potential productivity gains: An empirical study on China's heavy industry sector. *Energy Econ.* **2018**, *69*, 270–279. [\[CrossRef\]](#)
41. Sha, R.; Li, J.Y.; Ge, T. How do price distortions of fossil energy sources affect China's green economic efficiency? *Energy* **2021**, *232*, 121017. [\[CrossRef\]](#)
42. Guan, H.J.; Dong, L.Y.; Zhao, A.W. Energy structure dividend, factor allocation efficiency and regional productivity growth—An empirical examination of energy restructuring in China. *Energy Policy* **2023**, *172*, 113307. [\[CrossRef\]](#)
43. Wang, S.H.; Wang, H.K. Factor market distortion, technological innovation, and environmental pollution. *Environ. Sci. Pollut. Res.* **2022**, *29*, 87692–87705. [\[CrossRef\]](#) [\[PubMed\]](#)
44. Yang, F.D.; Yuan, P.; Jiang, G.X. The impact of factor market distortion on firm emissions: Evidence from China. *Pol. J. Environ. Stud.* **2023**, *32*, 4353–4368. [\[CrossRef\]](#) [\[PubMed\]](#)
45. Leng, Y.L.; Du, S.Z. Energy price distortion and haze pollution: Empirical evidence from China. *Ind. Econ. Res.* **2016**, 71–79. [\[CrossRef\]](#)
46. Yang, X.D.; Su, X.F.; Ran, Q.Y.; Ren, S.Y.; Chen, B.; Wang, W.L.; Wang, J.L. Assessing the impact of energy internet and energy misallocation on carbon emissions: New insights from China. *Environ. Sci. Pollut. Res.* **2022**, *29*, 23436–23460. [\[CrossRef\]](#) [\[PubMed\]](#)
47. Guang, F.T.; Deng, Y.T.; Wen, L.; Sharp, B.; Hong, S.F. Impact of regional energy allocation distortion on carbon emission efficiency: Evidence from China. *J. Environ. Manag.* **2023**, *342*, 118241. [\[CrossRef\]](#) [\[PubMed\]](#)
48. Liu, F.; Qiu, S.B. Relations between factor-market distortion and environmental pollution-analysis of intermediate effect based on technological innovation. *Desalination Water Treat.* **2020**, *188*, 303–308. [\[CrossRef\]](#)
49. Andreoni, V. Drivers of coal consumption changes: A decomposition analysis for Chinese regions. *Energy* **2022**, *242*, 122975. [\[CrossRef\]](#)
50. Saqib, N.; Ozturk, I.; Usman, M. Investigating the implications of technological innovations, financial inclusion, and renewable energy in diminishing ecological footprints levels in emerging economies. *Geosci. Front.* **2023**, *14*, 101667. [\[CrossRef\]](#)
51. Auty, R.M. *Sustaining Development in Mineral Economies: The Resource Curse Thesis*, 1st ed.; Routledge: London, UK, 1993.

52. Zhang, W.; Cheng, J.; Liu, X.M.; Zhu, Z.R. Heterogeneous industrial agglomeration, its coordinated development and total factor energy efficiency. *Environ. Dev. Sustain.* **2023**, *25*, 5511–5537. [[CrossRef](#)]
53. Wang, Y.; Zhang, D.Y.; Ji, Q.; Shi, X.P. Regional renewable energy development in China: A multidimensional assessment. *Renew. Sustain. Energy Rev.* **2020**, *124*, 109797. [[CrossRef](#)]
54. Chen, Y.W.; Hu, W.M. Price distortion, factor misallocation and efficiency loss: Theory and application. *China Econ. Q.* **2011**, *10*, 1401–1422. [[CrossRef](#)]
55. Sun, H.; Gui, H.Q.; Yang, D. Measurement and evaluation of high-quality economic development in China's provinces. *Zhejiang Soc. Sci.* **2020**, 4–14+155. [[CrossRef](#)]
56. Makhmudov, N.; Jeon, W. Fossil fuel curse and green transition: The role of renewable energy and green R&D. *Energy Environ.* **2025**. [[CrossRef](#)]
57. Wang, H.; Zhang, Y.Y.; Lin, W.F.; Wei, W.D. Transregional electricity transmission and carbon emissions: Evidence from ultra-high voltage transmission projects in China. *Energy Econ.* **2023**, *123*, 106751. [[CrossRef](#)]
58. Zerrahn, A.; Schill, W.P. Long-run power storage requirements for high shares of renewables: Review and a new model. *Renew. Sustain. Energy Rev.* **2017**, *79*, 1518–1534. [[CrossRef](#)]
59. Hao, Y.; Gai, Z.Q.; Wu, H.T. How do resource misallocation and government corruption affect green total factor energy efficiency? Evidence from China. *Energy Policy* **2020**, *143*, 111562. [[CrossRef](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.