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Research on the Correlation Between Energy Reform and City Development Based on Cointegration and Causality Analysis - Part 2 Interpretative Structure Model and Panel Data Regression Model

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Abstract: This article builds a model of energy-city development correlation, and factors for energy systems to drive city development. It also analyzes the corresponding indicators and determines the intercorrelation between the indicators. In the end, the article collects and categorizes energy, industry, environment, and other representative indicators from prefecture-level cities in China, and analyzes the factors affecting energy and city development based on the panel data regression model.

1 Introduction

From the perspective of a city, the energy system is a sub-system of the city. It constitutes a part of the city's infrastructure to assist the economic, social, livelihood, and cultural development[1]. With the transformation and upgrading of city development and the in-depth advancement from the energy revolution, the innovation and transformation of a city's energy system can lead to the more comprehensive development of various elements of a city, and the energy system will transform from a guaranteed supply to be the driving force for development[2]. Only after the energy-city development correlation, such as the internal connection between the energy system and urban systems, the interface elements between the energy system and city development, and the coordinated development path of energy and cities are clarified, can the key elements of energy-driven city development be identified[3]. Thus providing practical energy solutions for breaking the bottleneck of city development. It is therefore necessary to conduct in-depth research into the energy-city development correlation[4].

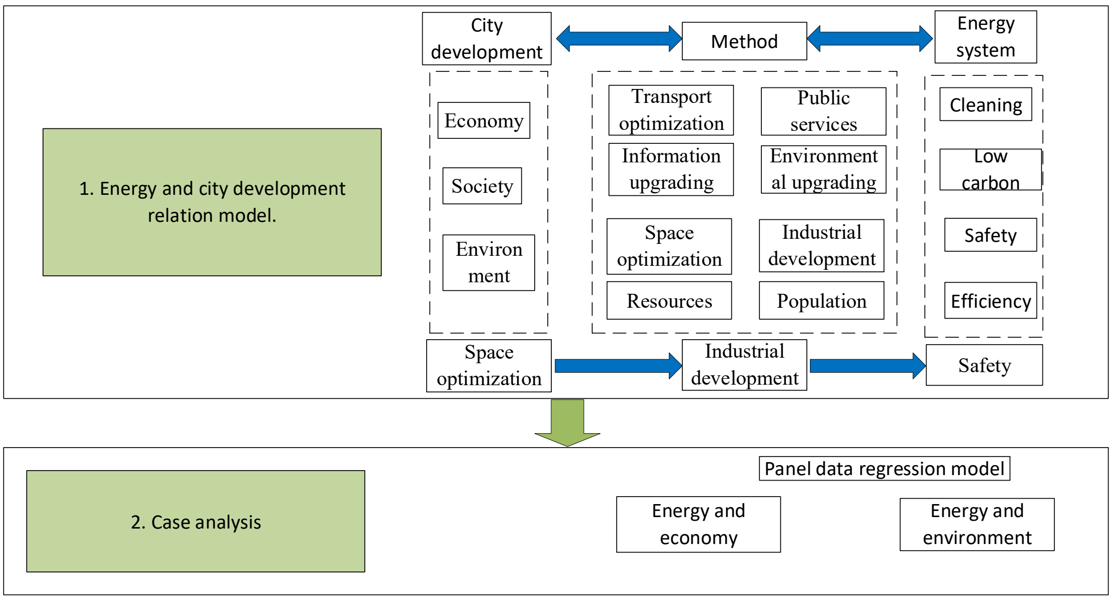

Figure 1 Idea map for Research on Energy-city Correlation model

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Firstly, this article constructs an analysis model of the relationship between city and energy, untangles the binary relationship between energy and urban subsystems at the micro level, defines some indicators used to describe urban development and energy system. From the perspective of intermediate medium, it takes medium as the development goal of urban system, and explores the relationship between energy and other systems under different objectives.

Secondly, this paper conducts quantitative analysis on the key factors of energy influencing urban development.It selects 35 cities at prefecture level and above as the research object, collects and sorts out the statistical data of energy, industry, environment and other dimensions of representative indicators in recent years.Then it constructs the panel data regression model, and analyzes the influencing factors of energy and the above urban development indicators.

2 Analysis of Key Factors that Affect Cities when Implementing Energy Reform

2.1 Interpretative Structural Model

The structural model is used to describe the correlation between system factors via a graph to represent a model of the system as a collection of factors[5]. Through the structural model, it is possible to analyze the reasonableness of element selection and to analyze the influence of the elements on the system and their correlation to the overall system[6]. The structural model can perform quantitative analysis through structural models on systematic evaluation, decision-making, planning, and target determination, yet only the qualitative analyses can be made based on human experience, intuition, or inspiration from the past[7-8].

2.2 Factor Identification

The article targets the correlation between cities and energy. Through research into relevant literature, coupled with existing research results on the factors affecting city and energy development, the following specific factors were determined.

Energy factors: energy cost optimization (101), energy supply guarantee (102), low-carbon energy development (103), clean energy utilization (104), efficient system improvements (105), energy market construction (106), energy-product innovation (107), production layout optimization (108), energy development (109), source-network-load-storage coordination (110), energy reserve optimization (111), network transportation capacity improvement (112), multi-energy complementary coordination (113), smart energy regulation (114), multi-energy system integration (115), digital energy transformation (116), and improvements to service efficiency (117), universal service guarantee(118).

Traffic factors: green and low-carbon transportation (201), convenient and unobstructed travel (202), economical and efficient logistics (203), optimization of road network facilities (204), clean energy alternatives (205), intensive transportation sharing (206), intelligent transportation networking (207).

Information factors: data system construction (301), availability of information facilities (302), development of an information-economy (303), information network coverage (304), popularization of IoT terminals (305), data center construction (306), data resource application (307), information industry integration (308).

Spatial factors: Residents' job-housing balance (401), intensive use of space (402), green and intelligent buildings (403), building energy conservation and environmental protection (404), spatial overall planning (405), development intensity red line (406), smart buildings promotion (407), green building application (408), coordinated urban and rural development(409).

Resource factors: energy resource utilization (501), land resource utilization (502), and water resource utilization (503).

Demographic factors: wage increase (601), population density control (602), human capital improvement (603), and guaranteed quality of life (604).

Industrial factors: industrial cluster development (701), upgrading of the industrial structure (702), green industrial transformation (703),reduction of industrial water consumption(704).

Public service factors: optimization of the business environment (801), public service guarantee (802), and improvement of government affairs (803).

Environmental factors: improvement to the air quality (901), water and soil pollution control (902), solid waste treatment (903), and reduction of pollution emissions (904).

2.3 Adjacent Construction

For the interpretative structural model of key energy factors influencing cities studied in this article, after the set of main factors affecting the development of cities and energy was defined, it was necessary to clarify the other factors directly affected by each factor, and then establish a direct correlation between the factors and establish a model, which was the basis for establishing the adjacency matrix. To determine how and which factors directly affected other factors, this paper referred to characteristics of new towns, existing research from other literature, and expert experience. As shown in the following table, a correlation between each influencing factor and its direct influence is explained. With the development of cities and energy, as well as the progress of technology and policies, the influence of certain factors may change, but the main correlation structure between various factors will not be affected.

The factors that directly influence traffic factors are shown in the following table.

Table 1 Factors that Directly Influence Traffic

City System	City Indicators	Influencing Factors
Traffic optimization	(201)	(205)、(206)
	(202)	(206)
	(203)	(207)、(204)、(205)、(206)
	(204)	(305)
	(205)	(101)、(103)
	(206)	(307)
	(207)	(307)、(305)

The factors that directly influence information networks are shown in the following table.

Table 2 Factors Directly Influencing Information Networks

City System	City Indicators	Influencing Factors
Information upgrades	(301)	(307)、(304)、(305)
	(302)	(306)、(304)、(305)
	(303)	(308)、(207)、(407)
	(304)	(102)、(101)
	(306)	(102)、(101)
	(307)	(306)、(304)
	(308)	(307)

The factors that bear a direct influence on spatial orientation and usage are shown in the following table.

Table 3 Factors that Directly Influence Spatial Orientation and Usage

City System	City Indicators	Influencing Factors
Space utilization	(401)	(701)
	(402)	(405)
	(403)	(404)、(407)
	(404)	(408)
	(405)	(406)
	(406)	(103)、(104)
	(407)	(305)、(304)
	(408)	(103)

The factors that directly influence resources are shown in the following table.

Table 4 Factors that Directly Influence Resources

City System	City Indicators	Influencing Factors
Resource utilization	(501)	(103)、(104)
	(502)	(405)
	(503)	(704)

The factors that directly influence industry are shown in the table below.

Table 5 influencing Factors for Industry

City System	City Indicators	Influencing factors
Industrial development	(701)	(203)、(101)、(409)
	(702)	(308)
	(703)	(104)、(101)

The factors that directly influence demographics are shown in the following table.

Table 6 Factors that Influence Population Demographics

City System	City Indicators	Influencing Factors
Population Upgrade	(601)	(702)、(409)
	(602)	(409)
	(603)	(604)

The factors that directly influence public services are shown in the following table.

Table 7 Factors that Directly Influence Public Services

City System	City Indicators	Influencing Factors
Public service	(801)	(102)、(101)
	(802)	(409)、(307)
	(803)	(307)

The factors that directly influence the environment are shown in the following table.

Table 8 Factors that Directly influence the Environment

City System	City Indicators	Influencing Factors
Environmental upgrade	(901)	(904)
	(902)	(904)、(903)
	(904)	(703)、(702)、(104)、(103)、(205)、(206)

The factors that directly influence energy are shown in the following table.

Table 9 Factors that Directly Influence Energy

Energy System	Energy Indicator	Influencing Factors
Energy system	(101)	(106)、(105)、(107)、(109)、(117)
	(102)	(111)、(112)
	(103)	(113)、(108)、(110)
	(104)	(106)、(107)
	(105)	(108)、(113)、(114)
	(106)	(115)
	(107)	(116)、(115)
	(108)	(115)
	(109)	(107)、(106)
	(110)	(114)
	(111)	(108)
	(112)	(114)、(113)
	(113)	(115)
	(114)	(116)
	(118)	(108)
	(117)	(107)、(106)

2.4 Analysis of Key Factors

2.4.1 The Goal of Traffic Optimization

When taking traffic optimization as the goal, three target factors, namely green and low-carbon transportation, convenient and smooth travel and economic and efficient logistics, are set up. According to the analysis steps, a hierarchical deconstruction chart with the goal of traffic optimization is obtained, as shown in Figure 2.

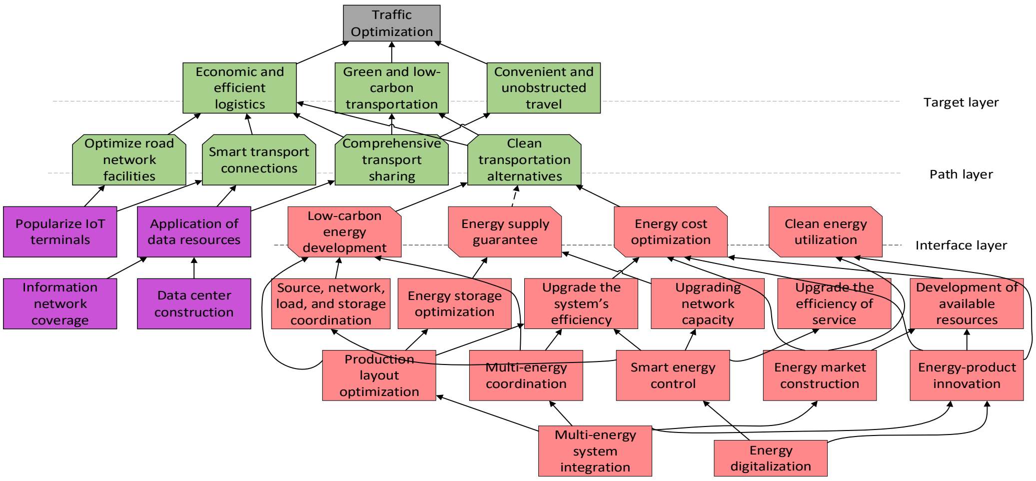

Figure 2 Deconstructed Hhierarchical Diagram that Targets Traffic Optimization

As shown in the above figure: 1) While targeting traffic optimization, the energy system will directly affect clean transportation alternatives through two indicators, energy cost optimization and low-carbon energy development, and indirectly affect clean alternatives through the indicator, energy supply guarantee. 2) Clean transportation alternatives and comprehensive transportation sharing can directly promote green and low-carbon level of transportation. They work jointly with the optimization of road network facilities and intelligent transportation networks to improve logistics economically and efficiently. 3) The development of information systems, including data center construction, information network coverage, and data resource applications, the popularization of IoT terminals, and data resource applications can promote the intelligence of transportation systems, improve transportation efficiency, and further reduce logistics costs. 4) Multi-energy system integration, and energy digital transformation, etc., affect energy efficiency through production layout optimization, smart energy regulation, etc., thereby optimizing costs, improving efficiency and promoting clean transportation.

2.4.2 Targeted Industrial Development

When taking the industrial development as the goal, three target factors are set up, i.e. upgrading of industrial institutions, development of industrial clusters and green transformation of industries. According to the analysis steps, a hierarchical deconstruction chart with industrial development as the goal is obtained, as shown in Figure 3.

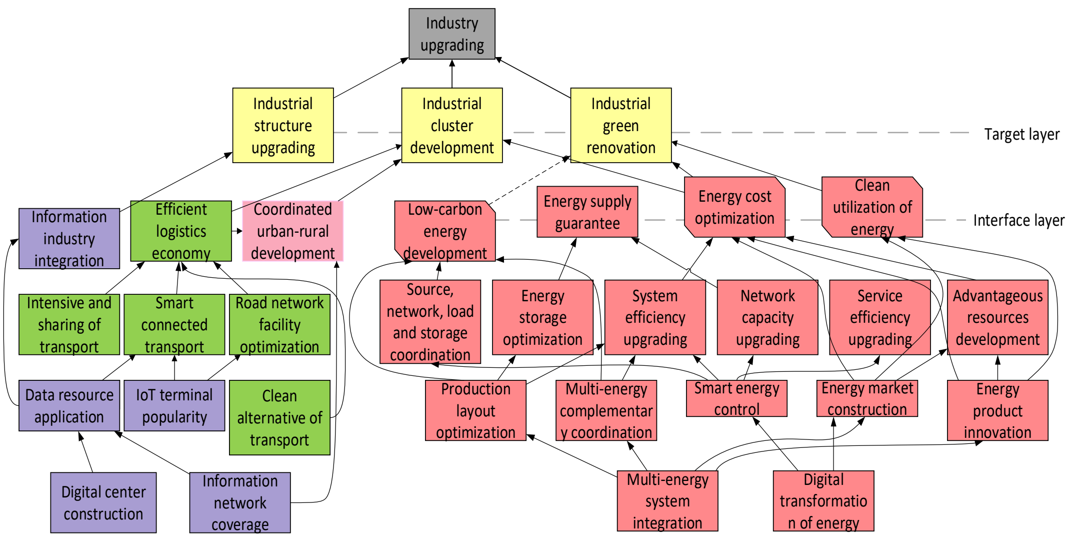

Figure 3 Hierarchical deconstruction diagram targeting industrial development

As shown in the diagram: 1) Targeting the industrial upgrading, the energy system will directly affect the industrial green transformation substitution and industrial cluster development through two interface indicators of energy cost optimization and energy clean utilization, and indirectly affect the green transformation and replacement through one interface index of low-carbon energy development. 2) The development of information systems, including data center construction, information network coverage, data resource applications, popularizing IoT terminals, and data resource applications, can promote the integration of the information industry and optimize industrial structure. 3) The development of the transportation system, including comprehensive transportation sharing, intelligent transportation network connection, road network facility optimization, and traffic clean substitution, can improve logistics economy and promote the development of industrial clusters. 4) Measures such as multi-energy system integration and energy digitalization will affect energy efficiency through production layout optimization, smart energy regulation, etc., thereby optimizing costs, improving efficiency, and promoting green industry.

3 Panel Data Regression Analysis

This chapter selects 35 prefecture-level or larger cities in China as research subjects. Thenit collects and categorize data from indicators of energy, industry, environment, and other factors from the past ten years,.It builds a panel data regression model and analyzes the factors affecting energy and the above-mentioned indicators of a city's development.

3.1 Regression Model for Panel Data

Panel data regression analysis refers to a statistical method for analyzing the relationship using data with two dimensions of time and cross-section[9]. Many relevant events can be found by analyzing the panel and cross-sectional data[10]. Therefore, the time of the panel data sample not only allows us to consider time sequence factors when examining the correlation between different variables, and eliminates the problem of inversion of cause and effect, but also allows us to discover the dynamic trend of changes[11].

The general formula for panel data regression model is:

$$y_{it} = \alpha_i + \sum_{k=1}^{k} \beta_{ki} x_{kit} + u_{it} \quad (1)$$

Where, i=1,2,..., N represents N individuals; t=1,2,... ,T, representing T periods; y_{it} is the interpreted variable, representing the observable value of i-th individual in period t; x_{kit} is the interpretative variable, representing the observable value of k-th interpretative variable for the individual i in period t; β_{ki} is the estimated parameters; u_{it} is a stochastic disturbance, and α_i is individual heterogeneity.

3.2 Data Selection and Arrangement

This article selects the statistical data from 35 cities in China, such as per capita GDP, energy intensity, electrification level, SO_2 emissions, and other indicators from the past 10 years. The data was sourced from China Statistical Yearbook, China City Statistical Yearbook, Government Work Reports, and other government department data, literature from the China Electricity Council, power websites, and authoritative journals, etc.

For this analysis, the cities were classified. Developed cities include Shanghai, Chongqing, Xi'an, Hefei, Chengdu, Beijing, Tianjin, Hangzhou, Ningbo, Shaoxing, Nanjing, Yangzhou, Changzhou, Quanzhou, Guangzhou, Changsha, etc., Under-developed cities include Tongchuan, Baoji, Weinan, Yan'an, Yulin, Wuhu, Fuyang, Jiaxing, Huzhou, Taizhou, Putian, Zhuhai, Zhanjiang, Maoming, Xiangtan, Yueyang, Changde, Zhangjiajie, Loudi, etc.

3.3 Analysis Results

(1) Per capita GDP and electrification level

The mathematical expression for the panel data regression model of GDP per capita and electrification level is as follows:

$$GDP_{it} = c_i + \beta_{1i} Electricity_{it} + u_{it} \quad (2)$$

Where, i=1,2,... ,N represents N individuals; t=1,2,... , T, representing T period; GDP_{it} is the interpreted variable, which represents the observable value of GDP for the i-th city in period t; $Electricity_{it}$ is the interpretative variable, representing the electrification level of the i-th city in period t; β_{1i} is the estimated power coefficient; u_{it} is a stochastic disturbance, and c_i is the heterogeneity of the individual.

The statistical analysis results are as follows:

Table 10 Regression Results Where the Dependent Variable was per capita GDP and the Independent Variable was Electrification Level

	Constant		Power factor	
	Regression value	P check value [1]	Regression value	P check value [1]
All cities	15071	0.0001	2920.9	0.0000
Developed city	-45702	0.0012	8029.0	0.0000
Underdeveloped city	11706	0.0014	2644.6	0.0000

Note: P check value indicates the significance of the regression coefficient, and 0.01 indicates that it is significant at the 1% statistical level.

The results show that the coefficient of the electrification level variable is significantly positive, that is, the urban electrification level is significantly positively correlated with per capita GDP. The benchmark regression coefficient for all cities is 2920.9, the regression coefficient for developed cities is 8029.0, which is greater than the regression coefficient for all cities, and the regression coefficient for underdeveloped cities is 2644.6, which is less than the regression coefficient for all cities, and they are all significant at the 1% statistical level.

Based on the above analysis, the following conclusions can be drawn. In developed cities, electricity consumption has a significant driving effect on the city's GDP. By substituting electricity for high energy consumption industries and upgrading processes, developing low energy consumption, low electricity consumption, and high value-added industries, restricting and transferring industries with high energy consumption, high power consumption, and low value-added industries, the electrification level can be enhanced, and the quality of urban economic development can be further upgraded.

(2) SO_2 emissions and energy intensity

The mathematical expression of the panel data regression model for urban SO_2 emissions and energy intensity is as follows:

$$SO_{2_{it}} = c_i + \beta_{1i} EnergyIntensity_{it} + u_{it} \quad (3)$$

Where, i=1, 2, ... , N represents N individuals; t=1,2,... , T, represents T periods; $SO_{2_{it}}$ is the interpreted variable, representing the observable value of SO_2 emission from the ith city in period t; $EnergyIntensity_{it}$ is the interpretative variable, representing the observed value of energy intensity in period t for the ith city. β_{2i} is the strength parameter to be estimated; u_{it} is a stochastic disturbance, c_i is individual heterogeneity. The results of the statistical analysis are as follows:

Table 11 Regression Results Where Urban SO2 Emissions is the Dependent Variable and Energy Intensity is the Independent Variable

	Constant		Strength factor	
	Regression value	P check value	Regression value	P check value
11 Observation cities	4.0693	0.0000	1.1968	0.0000

The 11 observation cities included Shanghai, Chongqing, Xi'an, Hefei, Chengdu, Beijing, Tianjin, Hangzhou, Nanjing, Guangzhou, and Changsha, all of which are relatively developed cities. The statistical results showed that the coefficient of the energy intensity variable was significantly positive, that is, the urban energy intensity is significantly positively correlated with urban SO_2 emissions. The benchmark regression coefficient of 11 observable cities was 1.1968, which is significant at the 1% statistical level.

Based on the above analysis, the following conclusions can be drawn.With the development of a city, the intensity of energy consumption is too high and goes beyond the environment's load capacity, thus exerting an impact on environmental indicators. To implement green development targets in urban planning, it is necessary to strengthen "dual control" energy and total coal consumption to force a batch of backward enterprises, eliminate backward production capacity, reduce excessive production capacity, and promote the green development of key energy-intensive industries. The focus should be placed on four major areas of industry, construction, transportation, and public institutions, to increase energy conservation efforts and improve energy efficiency within these key industries.

4 Conclusion

Through the analysis of the deconstruction and interpretive structure models for urban function, the energy in urban support systems has both direct and indirect correlation paths with the various subsystems of cities. The direct correlation, the energy system serves city development by ensuring energy supply, drives city development by optimizing energy costs, and leads green urban development through clean alternative and low-carbon transformation. The indirect correlation, the energy system is deeply integrated with information and transportation systems, and the two-way flow and sharing of information, traffic flow, and energy flow will jointly support the development of other subsystems. The integrated development of infrastructure will be the focus of future urban construction. According to the panel data analysis, the development of electrification is the core driving force to promote sustainable development of cities, especially developed cities. The industrial structure of developed cities is relatively mature. Through electric energy alternatives and technologically upgrading high energy consumption industries, low energy consumption and high value-added industries can be developed, and high energy consumption and low value-added industries are restricted and transferred, so the quality of economic development can be further improved. Less developed cities offer lower wages and have relatively abundant resources such as land. By undertaking labor-intensive and resource-intensive industries, the industrial structure can be continuously optimized to ensure the sustainable development of the urban economy.

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