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The Impact of Energy Intensity on Environmental Inequity

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Abstract

With the determination of carbon neutrality target, energy structure has become an important indicator to measure regional pollution emissions. In order to study the impact of energy intensity on environmental inequity, this paper uses threshold model to study the impact of energy intensity change on environmental inequity based on the panel data of 30 provinces from 2000 to 2020.The results show that there is a non-linear U-shaped relationship between energy intensity and environmental inequity. With the increase of energy intensity, the impact of energy intensity on environmental inequity does not play the role of mitigation, but more significantly aggravates the degree of environmental inequity.

Keywords: energy intensity, environmental equity, threshold effect

1. Introduction

Due to the development of the socialist market economy, the increase of resource consumption, global warming, energy and environmental protection problems are increasingly severe, and the inequality of the social environment also arises. After the reform and opening up, with the huge demand for economic development and the high-tech bias to energy, the eastern coastal economy of China has been able to develop rapidly, and some regions have achieved the state of aggregation saturation, related the value of production factors is also increasing, the environmental carrying capacity of the eastern region has a certain limit, and due to a series of factors such as the difference of resource endowment and environmental problems in each region, the industry began to transfer from the eastern region to the central and western regions. To a certain extent, these industrial transfers have improved the industrial chain and organizational structure in the central and western regions, and promoted regional economic development. However, due to the regional differences in environmental regulation, the change of regional development strategy, and the rapid renewal of industrial cycle in the eastern region, most of the industrial types transferred out of the eastern region are characterized by high input, high consumption and high pollution. These industrial transfers bring serious environmental problems to the central and western regions, and the problem of environmental injustice also arises. After the 18th National Congress of the Communist Party of China, the Chinese government has paid more attention to the importance of sustainable development and introduced a series of policies and measures. Various regions have implemented stricter environmental control. According to the 2018 Global Environmental Performance Index survey bulletin, China's environmental performance index has ranked 120 out of 180 participating countries and regions, indicating that China's environmental quality has become a more urgent social development issue. The current social contradiction focuses on the contradiction between unbalanced and inadequate development, and the issue of environmental injustice will inevitably hinder the resolution of the current contradiction. The complex environmental inequity coupled with the goal of carbon neutrality makes the Chinese government in urgent need of a set of theoretical support to solve the problem of environmental inequity in China.

After entering the stage of reform and opening up, China has achieved remarkable achievements in economic development, but behind these economic development is achieved through the path of high input, high consumption and high pollution. The extensive economic development mode of three high levels needs a large amount of support from energy and resources as the foundation, as the basic guarantee of strategic resources and economic operation. The role of energy in economic development is reflected in all aspects of production and life. In some countries, energy is even considered as the lifeblood of the country. It can be seen that energy is an important driving force for economic growth. However, the country's high dependence on energy also has a negative impact on the economy and ecological environment, and is not conducive to sustainable development. Data show that China has the highest consumption of primary energy in the world. In 2020, China's primary energy consumption was 145.46 exajoules, with a year-on-year growth of 2.4%. In terms of total energy consumption, China has a large energy consumption, but the energy utilization efficiency is relatively low, and the non-renewable high-pollution energy such as coal is the main source of consumption. In addition, the use of clean energy in China is lower than the level of developed countries. At present, under the dual carbon target, although the energy structure of some developed first-tier cities has gradually shifted to clean energy, most areas still use coal and other main energy input factors. The power source of some so-called new energy vehicles is also the power supply mode of thermal power generation, which has three high levels. The relationship between energy and economic development has not been properly handled from the root. The three-high economic development mode leads to frequent haze weather and continuous decline of environmental quality. Therefore, reducing the energy intensity, improving the energy structure and dealing with the environmental inequity between regions have far-reaching significance for China's economic development at the present stage.

2. Literature Review

Energy intensity, also known as energy intensity, generally refers to the level of energy consumption per unit of GDP. It is the main indicator of energy efficiency, that is, the total amount of fuel consumed to produce a unit of economic output. The lower the energy intensity is, the higher the energy efficiency is, which better reflects the dependence degree of energy consumption in the national economy. It is generally expressed in the form of total fuel consumption per unit multiplied by gross domestic product, and the unit is "tce/ ten thousand yuan". Yu Wenyi et al (Yu Wen-yi, Zhang Jia-luan & Zhang Lei, 2021). Starting from the goal of reducing energy consumption per unit GDP, this paper puts forward a scientific and technological path to reduce energy intensity by taking Guangdong Province as the research object. Geng Wen-xin et al (GenG W X & FAN Y., 2021). From the perspective of carbon trading market, this paper links carbon trading policy with energy intensity and studies the relationship between them. Wang Lianghu. (Wang Lianghu & Wang Zhao, 2020) Taking the Yangtze River Economic Belt as the research object, the research on the convergence of energy intensity is discussed. It can be seen that most of the research on energy intensity is related to carbon trading and scientific and technological progress, while the research on the relationship between energy intensity and environmental equity is still blank, and the relevant nationwide empirical research is also few.

The definition of environmental equity, also known as environmental equality, originated from the civil rights movement in the United States in pursuit of fairness in the black society's garbage stacking; The definition of environmental equality requires that the benefits of all groups in the environment must be equal, and stipulates that the costs borne by different groups in the environment must be equal, and the theme of the benefits obtained in the environment and the costs borne by the deterioration of the environment must be the same. To further divide environmental equity, equity can be divided into intergenerational level and intergenerational level, Wu Cuifang et al (WU Cuifang, YAO Zhilun, LI Yuwen & ZHONG Fanglei, 2009). According to Wu, environmental equity refers to the burden of environmental pollution in different regions, groups or between generations. It can be studied from the burden population and the working population, and the intra-generational equity and intergenerational equity are considered comprehensively. Page first proposed the equality between generations, followed by Weiss (Weiss E B., 1984). On this basis, he proposed the theory of intergenerational equality, arguing that environmental unfairness refers to the inequality between different generations. The academic community believes that in terms of priority, the priority of intra-generational equity is higher than that of intergenerational equity, so this paper chooses to replace intra-generational equity as the explanatory variable of environmental equity. In the literature on environmental justice, the academic community mainly studies from the perspective of ethics and law, but lacks the research from the perspective of economy. Currently, scholars mainly discuss whether the environmental responsibility should be different in different regions due to heterogeneity, Li Xuejiao et al. (Li, X. & He, A. et al., 2016) Research on the inequality of interests caused by pollution transfer between urban and rural areas, Sun Yuchun et al. (Sun Y C, Chang X Y. et al., 2016) This paper studies the ecological invasion caused by transnational pollution transfer. In terms of constructing environmental equity index, there is no unified index for relevant environmental equity research. The existing literature mainly focuses on the environmental Gini coefficient, but the contribution coefficient used by various studies is different. (Wang Jinnan, Lu Yuantang, Zhou Jinsong, Li Yong & Cao Dong, 2006) Using the Gini coefficient based on regional output value for measurement and analysis, Zhong Xiaoqing et al. (ZHONG X Q, ZHANG W M & Li M M., 2008) Using the environmental Gini coefficient based on ecological capacity to measure environmental inequity. In terms of studying the relationship between pollution transfer and environmental equity, the existing literature lacks discussion on the interaction mechanism between the two, and there is a lack of empirical research. The research objects also focus on some areas such as Beijing-Tianjin- Hebei region, Ding Guanqi (DING G Q., 2021). This paper studies the relationship between the transfer of highly polluting industries and environmental inequity from the Beijing-Tianjin- Hebe i region, which lacks the overall perspective of the whole country and is not universal.

3. Research Design

3.1 Data Sources

This paper takes 30 provinces and regions in China as the research objects, and the time span is selected from 2000 to 2020 (Tibet, Hong Kong, Macao and Taiwan are excluded due to the lack of data).

3.2 Measurement of Environmental Inequity

3.2.1 Introduction of Measurement Methods

According to the principle of Gini coefficient, if the proportion of the total pollutant emissions caused by a region in the national total is equal to the proportion of the GDP output value contributed by the region in the total GDP output value, then the pollution emission is fair, and the economic contribution coefficient is constructed as follows

$$GCC_i = \frac{P_i}{P} \Big/ \frac{G_i}{G} \tag{1}$$

In Equation (1), and represent the pollutant discharge and output value of region i, and represent the pollutant discharge and output value of the whole country respectively. If GCC_i > 1, it indicates that the proportion of the total amount of pollutants emitted in a region is greater than the proportion of the GDP output value that contributes to the output, indicating that the fairness of this region is poor, and the greater the value is, the worse the fairness is.

Similarly, considering the population factor, the following population bearing coefficient is constructed:

$$PUC_i = \frac{P_i}{P} \Big/ \frac{N_i}{N} \tag{2}$$

In Equation (2), and represent the pollutant emissions and population of region i, and represent the pollutant emissions and population of the whole country, respectively. If GBC_i> 1, it indicates that the proportion of pollution emitted in a region is greater than the proportion of population, indicating that the fairness of this region is poor, and the greater the value is, the worse the fairness is.

According to Zhong Xiaoqing (ZHONG X Q, ZHANG W M & Li M M., 2008). According to the estimation requirements of ecological capacity proposed by Zhong, the forest area index of the region is selected to construct the green burden coefficient:

$$GBC_i = \frac{P_i}{P} \Big/ \frac{S_i}{S} \tag{3}$$

In Equation (3), and represent the pollutant emissions and forest area of region i, and represent the pollutant emissions and population of the whole country, respectively. If GBC_i> 1, it indicates that the proportion of pollution emitted in a region to the total is greater than the proportion of population to the total, indicating that the fairness of this region is poor, and the greater the value is, the worse the fairness is.

3.2.2 Combination Empowerment Index Weight Determination Method

When multiple indicators are used to comprehensively evaluate a target, it is often necessary to determine the evaluation weight of each indicator according to the importance level of each indicator. The higher the weight is, the higher the importance is. The methods for determining the weight are divided into subjective weighting method, objective weighting method and combined weighting method. In general, the three methods have their own advantages and disadvantages. The core of subjective weighting method is to assign weights according to subjective experience, which has strong subjectivity. The advantage is that it can determine weights purposefully and intentionally, but the objectivity is poor. The objective weighting method emphasizes the use of mathematical tools and other objective methods, the corresponding statistical processing of the data, and finally determine the weight of the index, which does not shift with the subjective will of people, but can not be well added to the purpose and intention of the weighting, and has strong objectivity, including principal component analysis method, mean square error weight method, entropy weight method, etc. The combined weighting method combines the weights obtained by the subjective and objective weighting to obtain the final weight result. It not only makes full use of the mathematical statistics method, gives full play to the objectivity, but also fully reflects the subjective experience of the decision maker, so it is a combination of the subjective and objective weighting method. To sum up, this paper selects the combined weighting method to determine the weight of indicators, and selects the weighting coefficient for control. The weighting formula is as follows:

$$w = \gamma\alpha + (1-\gamma)\beta$$

Among them, the weighting coefficient $\gamma \in [0,1]$, α is the weight determined by the analytic hierarchy process, and β is the weight determined by the entropy weight method, and the weighting coefficient selected in this paper is 0.5.

3.2.3 Analytic Hierarchy Process Index Weight Analysis

According to the relative importance comparison between two indicators given by experts, the weight value can be obtained after calculation and processing. The importance scale table is introduced, and the scale from 1 to 9 represents the relative importance between any two indicators.

Table 1. Analytic Hierarchy Process (AHP) scale and meaning

Scaling	Meaning
1	The ith factor is as important as the JTH factor
3	The ith factor is slightly more important than the JTH factor

5	Factor i is significantly more important than factor j
7	Factor i is strongly more important than factor j
9	Factor i is extremely more important than factor j
2,4,6,8	In between the above adjacent cases

Construct the matrix according to the importance scale given by the expert:

$$A=\begin{bmatrix} 1 & 4 & 5 \\ 1/4 & 1 & 2 \\ 1/5 & 1/2 & 1 \end{bmatrix} \quad (4)$$

The weight vector of criterion layer is obtained by feature vector normalization:

$$w=\begin{bmatrix} 0.6807 \\ 0.2014 \\ 0.1179 \end{bmatrix} \quad (5)$$

3.2.4 Index Weight Analysis of Entropy Weight Method

In order to eliminate the influence of dimension, the range transformation method is used to carry out dimensionless processing. The specific operations are as follows:

For positive indicators with higher values, the better, let $y_{ij} = \dfrac{x_{ij} - x_{\min(j)}}{x_{\max(j)} - x_{\min(j)}}$ (6)

For a negative indicator with a smaller value that is better, let $y_{ij} = \dfrac{x_{\max(j)} - x_{ij}}{x_{\max(j)} - x_{\min(j)}}$ (7)

For the index value it is best to be at [g1j, g2j] between moderate indicators, let

$$\begin{cases} 1-\dfrac{g_{1j} - x_{ij}}{\max(g_{1j} - x_{\min(j)}, x_{\max(j)} - g_{2j})} & (x_{ij} < g_{1j}) \\ 1 & (g_{1j} < x_{ij} < g_{2j}) \\ 1-\dfrac{x_{ij} - g_{2j}}{\max(g_{1j} - x_{\min(j)}, x_{\max(j)} - g_{2j})} & (x_{ij} > g_{2j}) \end{cases} \quad (8)$$

After processing as required, all indicators will be between 0 and 1.

The process of entropy weight method to determine the weight of all levels of indicators is as follows:

First, calculate the proportion or probability of the index value of period i under the JTH index:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (9)$$

Second, calculate the entropy value of the JTH index:

$$e_j = -k\sum_{i=1}^{n} (p_{ij} \ln p_{ij}) \quad (10)$$

Of which:

$$k = \frac{1}{Ln(n)}$$

(n is the number of samples), k > 0

Third, calculate the difference coefficient of the JTH index, and the calculation formula of the difference coefficient is as follows:

$$h_j = 1 - e_j \quad (11)$$

Fourth, calculate the weight of the JTH indicator:

$$w_j = \frac{h_j}{\sum_{j=1}^{n} h_j} \quad (12)$$

According to the entropy weight method, the following weight results are obtained:

Table 2. Calculation results of entropy weight method

Total index	Secondary metrics	Information entropy redundancy	Coefficient of difference	Weight
	GCC	0.8590	0.1410	0.3327
EII	PUC	0.8666	0.1334	0.3319
	GBC	0.8608	0.1392	0.3354

According to the subjective and objective empowerment results, the determined combination empowerment results are as follows:

Table 3. Calculation results of combined weighting method

Total index	Evaluation factors	Ahp is used to calculate the weights	The entropy weight method calculates the weights	Final weight
	GCC	0.6807	0.3327	0.50670
EII	PUC	0.2014	0.3319	0.26665
	GBC	0.1179	0.3354	0.22665

Therefore, the environmental unfairness index can be written as follows:

$$EII = \alpha \text{gcc} + \beta \text{ puc} + \gamma \text{ gbc} \quad (13)$$

$$\alpha + \beta + \gamma = 1$$

3.2.5 Measurement and Calculation of Pollution Equivalent Number

Due to the different types of pollutants, the impact on human and natural environment is also different. Therefore, according to the principle of scientific, reasonable, normalized treatment and operation, all kinds of pollutants are discharged according to the toxicity of organisms, the degree of harm to the ecological environment and the cost of treatment and regulation. The pollution equivalent obtained by treatment is an equivalent index of harmful equivalent, toxic equivalent and cost equivalent. For example, 1 pollution equivalent =1kgCOD=0.0005kg mercury =0.95kg nitrogen oxide, then it can be considered that the harmful pollution and treatment cost generated by 1kgCOD and 0.0005kg mercury and 0.95kg nitrogen oxide are basically the same, so the above pollutants can be unified as one pollution equivalent. In this paper, according to the pollution scale issued by the Environmental Protection Tax Law of the People's Republic of China, the variable pollution equivalent number APX is introduced:

$$APX_i = \frac{Q_i}{W_i} \quad (14)$$

APX_i is the pollution equivalent number of pollutant i, dimensionless, Q_i is the emission of pollutant i, in kg, W_i is the pollution equivalent value of pollutant i, in kg.

The following table is obtained by calculating the pollution equivalent according to the selected representative pollutants:

Table 4. Pollution equivalent value of pollutants

Pollutants	Pollution is worth its weight
Chemical oxygen demand (COD)	1

Sulfur dioxide (SO2)	0.95
Soot	2.18

3.3 Spatio-Temporal Evolution Characteristics of Environmental Inequity

According to the above calculation method, the scores of environmental inequity coefficients of 30 provinces and cities in China are obtained.

Table 5. Scores of environmental inequity coefficients

Region	Economic contribution coefficient					Coefficient of population contribution					Green burden coefficient				
	2000	2005	2010	2015	2020	2000	2005	2010	2015	2020	2000	2005	2010	2015	2020
Beijing	0.31	0.14	0.13	0.13	0.11	0.96	0.82	0.71	0.56	0.51	4.80	4.13	3.67	2.96	2.75
Tianjin	0.80	0.63	0.64	0.57	0.60	1.63	1.26	1.13	1.46	1.25	24.25	18.76	16.71	21.52	18.58
Hebei	1.59	1.49	1.55	1.45	1.41	1.41	1.40	1.41	1.32	1.37	3.99	3.95	3.98	3.71	3.85
Shanxi	2.63	2.87	2.96	2.76	2.57	1.92	2.46	2.40	2.32	2.41	4.16	5.35	5.24	5.04	5.24
Inner Mongolia	1.94	2.20	2.67	2.55	2.64	1.61	1.58	1.62	1.73	1.92	0.26	0.25	0.26	0.27	0.31
Liaoning	1.17	1.14	1.14	1.13	1.30	1.67	1.46	1.45	1.29	1.17	2.02	1.77	1.74	1.54	1.39
Ji Lin	1.14	1.29	0.91	1.21	1.29	0.95	0.85	0.83	0.78	0.82	0.49	0.44	0.43	0.40	0.42
Heilongjiang	0.74	0.83	0.76	0.99	1.13	0.71	0.67	0.70	0.68	0.70	0.21	0.20	0.20	0.20	0.20
Shanghai	0.37	0.28	0.27	0.28	0.30	1.42	1.26	1.09	1.01	0.93	168.19	153.87	135.77	129.03	122.57
Jiangsu	0.61	0.63	0.63	0.59	0.60	0.91	1.08	0.96	1.06	1.05	11.99	14.27	12.68	13.99	13.86
Zhejiang	0.60	0.54	0.57	0.58	0.59	1.02	1.01	1.11	0.97	0.97	1.20	1.19	1.32	1.16	1.18
Anhui	0.80	0.92	0.96	0.93	0.97	0.53	0.51	0.53	0.55	0.57	1.34	1.31	1.36	1.40	1.46
Fujian	0.33	0.42	0.51	0.50	0.60	0.47	0.47	0.48	0.52	0.51	0.29	0.29	0.30	0.32	0.32
Jiangxi	0.95	1.02	1.02	1.24	1.14	0.59	0.52	0.54	0.63	0.65	0.36	0.33	0.33	0.39	0.41
Shandong	1.06	0.88	0.87	0.84	0.76	1.26	1.33	1.23	1.18	1.07	7.68	8.12	7.54	7.18	6.53
Henan	1.20	1.17	0.92	1.13	1.25	0.82	0.79	0.80	0.77	0.81	4.02	3.89	3.93	3.78	3.97
Hubei	0.94	0.93	0.81	0.93	0.86	0.75	0.78	0.82	0.75	0.75	1.19	1.22	1.29	1.17	1.17
Hunan	1.19	1.44	1.48	1.36	1.25	0.83	0.91	0.96	0.91	0.95	0.88	0.96	1.02	0.96	1.00
Guangdong	0.36	0.45	0.46	0.46	0.42	0.57	0.55	0.59	0.68	0.74	0.83	0.80	0.87	1.01	1.11
Guangxi	2.87	3.11	3.20	2.95	2.90	1.61	1.45	1.46	1.70	1.69	1.08	0.98	0.99	1.15	1.14
Hainan	0.37	0.32	0.32	0.31	0.28	0.32	0.24	0.27	0.23	0.23	0.21	0.16	0.18	0.15	0.15
Chongqing	1.26	1.57	1.68	1.64	1.58	1.03	0.95	1.70	1.47	1.38	2.23	2.03	3.59	3.07	2.87
Sichuan	1.56	1.53	1.50	1.36	1.26	0.94	0.97	0.86	1.08	1.05	0.75	0.74	0.66	0.82	0.79
Guizhou	3.31	2.63	2.45	2.42	2.36	1.16	1.29	1.16	1.01	0.93	1.45	1.61	1.46	1.27	1.18
Yunnan	1.01	1.02	1.14	1.10	1.11	0.62	0.59	0.54	0.54	0.53	0.24	0.22	0.20	0.21	0.20
Shaanxi	1.97	1.69	1.49	1.50	1.40	1.25	1.15	1.22	1.14	1.19	0.95	0.87	0.92	0.85	0.88
Gansu	1.74	1.98	2.41	2.31	2.02	0.94	0.85	0.76	0.84	0.86	1.09	1.00	0.88	0.97	0.99
Qinghai	0.98	1.59	2.11	2.08	2.54	0.64	0.51	0.52	0.55	0.75	0.15	0.12	0.12	0.13	0.17
Ningxia	5.06	4.27	4.12	3.80	3.65	3.46	3.31	2.92	2.88	2.26	6.60	6.39	5.69	5.66	4.48
Xinjiang	0.87	1.26	1.24	1.52	1.56	0.82	0.86	0.97	0.98	1.09	0.44	0.46	0.52	0.54	0.60

A value greater than 1 in the table means a lack of fairness in the region, and a larger value means a worse fairness. Taking the data of Shanghai in 2020 as an example, the economic coefficient is 0.3, the population coefficient is 0.93, and the green coefficient is 122.57. It can be seen that Shanghai is in compliance with environmental fairness in terms of economic contribution coefficient and population burden coefficient. However, the fairness in terms of green burden coefficient is poor, which is caused by Shanghai's large economic contribution, low population burden and great pressure on ecological capacity nationwide.

According to the determination of environmental inequity index, the level of inequity in 30 provinces and regions from 2000 to 2020 can be calculated as follows:

Table 6. Scores of environmental inequity index in 30 provinces

Regions	2000	2005	2010	2015	2020
Beijing	1.5	1.28	1.13	0.9	0.84
Tianjin	6.33	4.9	4.37	5.62	4.85
Hebei	2.09	2.07	2.1	1.96	2.02
Shanxi	2.79	3.59	3.46	3.22	3.3
Inner Mongolia	1.47	1.43	1.44	1.46	1.58
Liaoning	1.5	1.32	1.31	1.19	1.11
Ji Lin	0.94	0.85	0.84	0.83	0.9
Heilongjiang	0.61	0.59	0.62	0.62	0.65
Shanghai	38.69	35.38	31.22	29.66	28.16
Jiangsu	3.27	3.89	3.45	3.8	3.76
Zhejiang	0.85	0.84	0.91	0.78	0.79
Anhui	0.85	0.82	0.86	0.89	0.93
Fujian	0.36	0.36	0.37	0.41	0.41
Jiangxi	0.72	0.65	0.66	0.78	0.79
Shandong	2.61	2.77	2.57	2.48	2.24
Henan	1.74	1.69	1.72	1.65	1.72
Hubei	0.95	0.97	1.04	0.95	0.96
Hunan	1.02	1.14	1.22	1.17	1.21
Guangdong	0.52	0.5	0.54	0.62	0.68
Guangxi	2.13	1.93	1.95	2.32	2.31
Hainan	0.32	0.24	0.27	0.24	0.24
Chongqing	1.42	1.29	2.26	1.94	1.83
Sichuan	1.21	1.22	1.08	1.37	1.32
Guizhou	2.31	2.58	2.35	2.05	1.92
Yunnan	0.73	0.71	0.66	0.67	0.66
Shaanxi	1.55	1.41	1.48	1.37	1.4
Gansu	1.38	1.28	1.15	1.28	1.3
Qinghai	0.7	0.55	0.56	0.59	0.82
Ningxia	4.98	4.72	4.18	4.11	3.25
Xinjiang	0.76	0.81	0.92	0.93	1.06

The corresponding environmental inequity index of the four economic zones is obtained:

Table 7. Environmental inequity index scores of the four regions

Region	2000	2005	2010	2015	2020
Northeast Region	3.05	2.95	3.46	3.94	6.09
Eastern Region	56.54	44.63	24.27	20.43	12.49
Central Region	8.07	8.89	8.23	8.6	8.2
Western Region	18.65	18.81	20.37	21.31	17.34

4. Empirical Analysis

4.1 Construction of Econometric Model

1) Benchmark panel model

According to the theoretical analysis, the model is set as follows:

$$eii_{it} = \alpha_i + \gamma_1 energy_{it} + \gamma_2 er_{it} + \gamma_3 rgdp_{it} + \gamma_4 insa_{it} + \gamma_5 insr_{it} + \gamma_6 green_{it} + \gamma_7 fdi_{it} + \varepsilon_{it}$$

After logarithmic processing, the model is set as follows:

$$\ln eii_{it} = \alpha_i + \gamma_1 lnenergy_{it} + \gamma_2 lner_{it} + \gamma_3 lnrgdp_{it} + \gamma_4 lninsa_{it} + \gamma_5 lninsr_{it} + \gamma_6 lngreen_{it} + \gamma_7 lnfdi_{it} + \varepsilon_{it}$$

2) Variable selection

a) Explained variable. The explained variable in this paper is the environmental inequity index (eii), which is measured by the comprehensive evaluation coefficient of, which better reflects the degree of environmental inequity between regions.

b) Explanatory variables. The explanatory variables in this paper are energy intensity (energy)

c) and environmental regulation intensity (er).

d) Control variables. Per capita income (rgdp), industrial optimization (insa), industrial rationalization (insr), ecological capacity (green) and foreign investment (fdi) were selected.

In order to further test whether environmental regulation has nonlinear moderating effect, this paper constructs the following panel threshold model:

$$eiiit = \alpha i + \gamma 1\ rgdpit + \gamma 2\ insait + \gamma 3\ insrit + \gamma 4\ greenit + \gamma 5\ fdiit + \mu 1\ energyit \cdot I(erit \le \rho) + \mu 3\ energyit \cdot I(erit > \rho) + \varepsilon it$$

Where, energy is the core explanatory variable affected by the threshold variable, er is the threshold variable, is the threshold value to be estimated, and I(·) is the indicator function, which takes the value of 1 when the corresponding conditions are met, and 0 otherwise. ρ Considering that there may be multiple thresholds, the multiple threshold model is constructed as follows:

$$eiiit = \alpha i + \gamma 1\ rgdpit + \gamma 2\ insrit + \gamma 3\ greenit + \gamma 4\ insrit + \gamma 5\ fdiit + \mu 1\ energyit \cdot I(erit \le \eta 1) + \mu\ 2energyit \cdot I(\eta 1 < erit \le \eta 2) + \mu\ 3energyit \cdot I(erit > \eta 3) + \varepsilon it$$

4.2 Main Variables and Their Implications

4.2.1 Explained Variables

The explained variable in this paper is environmental inequity index (eii). In order to comprehensively consider the economic, population and ecological factors, the three indexes of economic, population and ecological coefficient are comprehensively evaluated to obtain the environmental inequity index.

4.2.2 Explanatory Variables

In order to study the impact of energy intensity on environmental equity, this paper selects energy intensity (energy) and environmental regulation intensity (er) as explanatory variables, Shen Kunrong et al. (Shen, K., Jin, & Fang, X., 2017) The study found that there is a certain relationship between environmental regulation and pollution transfer, and pollution transfer will inevitably lead to environmental equity problems. Therefore, this paper selects environmental regulation intensity as the explanatory variable, referring to Qin Bingtao. (Qin B T & Ge L M., 2018) The index of relative environmental regulation intensity proposed by Qin is calculated by relative environmental regulation intensity, which is the completed amount of pollution investment in each region/the completed amount of pollution investment in China.

4.2.3 Control Variables

Per capita income (rgdp), industrial optimization (insa), industrial rationalization (insr) and ecological capacity (green) were selected as control variables. Among them, rgdp represents the per capita output value of the region, Chen Shiyi (Chen S Y & Chen D K., 2018). The variable of per capita income is introduced to study the high quality economic development and the haze environment problem. On this basis, the per capita output value is replaced by insa, which represents the degree of industrial optimization and dysprosia Wang. (WANG Di & TANG Maogang, 2019) On this basis, this paper selects the degree of industrial optimization as the control variable, and the specific value is calculated as the added value of the tertiary industry/the added value of the secondary industry. Insr represents the degree of industrial rationalization, referring to Gan et al (GAN Chunhui, ZHENG Ruogu & Yu Para-shi, 2011). Insr represents the degree of industrial rationalization calculated by Equation (15), and green represents the index of ecological capacity. Because it is difficult to accurately calculate and evaluate the ecological capacity, we refer to Zhong Xiaoqing according to the simple and applicable principle of index selection of economic evaluation method. (ZHONG X Q, ZHANG W M & Li M M., 2008) According to the method of scholars, the index of forest area was selected as the index of ecological capacity.

$$insr_i = \sum_{i=1}^{n} (\frac{Y_i}{Y}) \ln(\frac{Y_i}{L_i} / \frac{Y}{L}) \quad (15)$$

4.3 Descriptive Statistics

Table 8. Descriptive statistics

Variable	N	Mean	p50	SD	Min	Max
lne**i**	630	0.324	0.258	0.778	1.705	3.655
lnenergy	630	4.588	4.572	0.597	2.956	6.115
lner	630	0.463	0.349	1.056	6.295	1.674
lnrgdp	630	0.919	1.083	0.852	1.294	2.803
lninsa	630	0.0710	0.0300	0.372	0.658	1.667
lninsr	630	0.659	0.440	0.878	5.298	0.778
lngreen	630	5.893	6.210	1.437	0.637	7.869
lnfdi	630	9.915	9.935	1.535	6.087	13.570

4.4 Parameter Estimation Results

When the intensity of environmental regulation is at different levels, it will have different impacts on regional output value and industrial structure. Then, is the impact of energy intensity, the core variable, on environmental inequity linear? The above analysis cannot reflect the possible nonlinear relationship, so the square term of core variable is introduced on the basis of the benchmark panel model, and the model is as follows:

$$\text{lneii}_{it} = \alpha_i + \gamma_1 lnenergy_{it} + \gamma_2 lnenergy^2{}_{it} + \gamma_3 lner_{it} + \gamma_3 lnrgdp_{it} + \gamma_4 lninsa_{it} + \gamma_5 lninsr_{it} + \gamma_6 lngreen_{it} + \gamma_7 lnfdi_{it} + \varepsilon_{it}$$

Table 9. Parameter estimation results

	lneii	lnenergy	lnener~2	lnrgdp	lngreen	lninsr	lninsa	lnfdi
lneii	1							
lnenergy	0.276***	1						
lnenergy2	0.276***	1.000***	1					
lnrgdp	0.074*	-0.781***	-0.781***	1				
lngreen	-0.562***	0.0460	0.0460	-0.225***	1			
lninsr	-0.076*	0.615***	0.615***	-0.710***	0.531***	1		
lninsa	-0.194***	-0.360***	-0.360***	0.371***	-0.263***	-0.468***	1	

lnfdi	-0.00700	-0.504***	-0.504***	0.374***	-0.248***	-0.518***	-0.118***	1

It can be seen that after considering the squared term of energy intensity, the coefficient of the squared term is significantly positive at the level of 1%, indicating that there is a U-shaped feature between energy intensity and environmental inequity. When the logarithm of energy intensity is to the left of the inflection point, improving energy intensity will reduce the degree of environmental inequity from the macro level. At this time, the promoting effect of energy intensity on environmental equity is greater than the inhibiting effect, and the marginal promoting effect is decreasing, while the inhibiting effect is increasing. At the micro level, when the energy consumption per unit output value of local enterprises increases, the income effect it brings is greater than the substitution effect of pollution control, thus increasing energy intensity and reducing environmental inequity, corresponding to the early stage of regional industrial development. When the logarithm of energy intensity is on the right side of the inflection point, the improvement of energy intensity will increase the degree of environmental inequity from the macro level. At this time, the inhibitory effect of energy intensity on environmental equity is greater than the promotion effect, and the marginal inhibitory effect is decreasing, while the marginal promotion effect is increasing. At the micro level, when the energy consumption per unit output value of local enterprises increases, the substitution effect of pollution control is greater than the income effect, thus increasing the energy intensity and improving the degree of environmental inequity, which corresponds to the later stage of regional industrial development, which is consistent with China's development entering the stage of high-quality development.

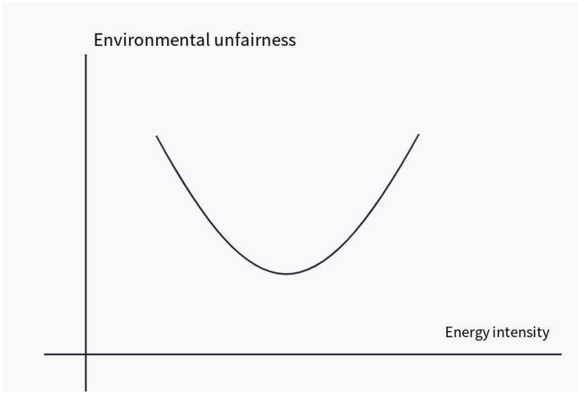

Figure 1. U-shaped diagram of environmental inequity and energy intensity

4.5 Threshold Quantity Determination and Estimation

The stata tool was used to estimate the model under the setting of single threshold, double threshold and triple threshold successively, and the F-statistic was calculated. The Bootstrap method was used to repeat the sampling 300 times to obtain the P value.

Table 10. Threshold estimation results

Model	F-value	P-value	Number of sampling	Critical value		
				1%	5%	10%
Single threshold	27.79	0.0467	300	34.1673	25.4568	22.0916
Double threshold	20.48	0.0367	300	23.5984	18.9876	16.3080
Triple threshold	6.58	0.6533	300	32.2889	21.8583	16.9786

The threshold estimation results are obtained with the help of stata tool. Table 10 shows the estimation results from single threshold test to triple threshold test. The corresponding F values and P values of the threshold estimation results of the three threshold models are different. It can be found that the F-statistic corresponding to the results of the single threshold test is 27.79, which is higher than the critical value of 25.4568 at the significance level of 5%, and the P value is 0.0467, indicating that the single threshold passes the test at the significance level of 5%, that is, the threshold effect exists. The F value of the double threshold test result was 20.48, which was higher than the critical value of 18.9876 at the 5% significance level, and the P value was 0.0367, indicating that the double threshold passed the 5% significance level test, that is, there was a double threshold effect. The F value and P value of the triple threshold test did not pass the value at the significance level, that is, there was no triple threshold effect. According to the above results, the double threshold effect is better than the single threshold effect. Therefore, this paper uses the double threshold model to conduct relevant empirical analysis.

In order to further show the determination process of the threshold value, the results in the following figure are obtained by means of LR statistics. The threshold value and confidence interval are clearly shown in Figures 2 to 3 through the likelihood ratio function diagram. Figure 2 shows the case of a single threshold value, the vertical axis is the value of the likelihood ratio function, the horizontal axis is the threshold parameter, the dotted line represents the likelihood ratio critical value of 7.35 on the 95% confidence interval, and all the likelihood values less than 7.35 constitute the confidence interval, and the minimum point 0.0653 is determined as the first threshold value.

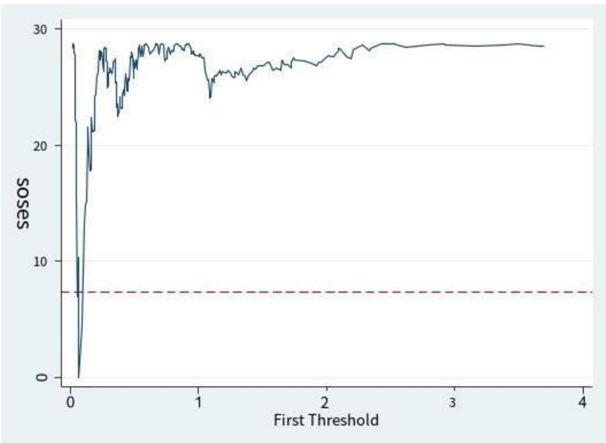

Figure 2. First Threshold

In Figure 2, the first threshold value and confidence interval of LR statistics are shown

Figure 3 shows the second stage of the threshold search process. After fixing the first threshold value, the second threshold value of the likelihood ratio function on the 95% confidence interval is 0.6732.

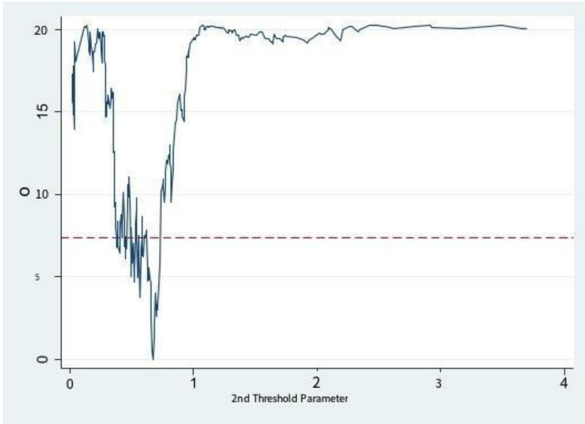

Figure 3. Second threshold value and confidence interval of LR statistics

The estimated values and corresponding confidence intervals of the two thresholds are obtained as follows:

Table 11. Threshold estimation results

	Threshold estimates	95% confidence interval
η_1	0.0653	[0.0512, 0.0739]
η_2	0.6732	[0.6424, 0.6769]

4.5.1 Analysis of Model Estimation Results

After determining the number of thresholds through the search process, the empirical model is set as follows:

$$eiiit = \alpha i + \gamma 1\ rgdpit + \gamma 2\ insrit + \gamma 3\ greenit + \gamma 4\ insrit + \gamma 5\ fdiit + \mu 1\ energyit \cdot I(erit \leq \eta 1) + \mu\ 2energyit \cdot I(\eta 1 < erit \leq \eta 2) + \mu\ 3energyit \cdot I(erit > \eta 2) + \varepsilon it$$

And the logarithm is taken to obtain the following model:

$$lneii_{it} = \alpha_i + \gamma_1 lnrgdp_{it} + \gamma_2 lninsr_{it} + \gamma_3 lngreen_{it} + \gamma_4 lninsr_{it} + \gamma_5 lnfdi_{it} + \mu_1 lnenergy_{it} \cdot I(er_{it} \leq \eta_1) + \mu_2 lnenergy_{it} \cdot I(\eta_1 < er_{it} \leq \eta_2) + \mu_3 lnenergy_{it} \cdot I(er_{it} > \eta_2) + \varepsilon_{it}$$

Considering the possibility of heteroscedasticity in provincial data series, the processing method of robust standard deviation is adopted in model estimation, and the estimation results are shown in Table 12.

Table 12. Variable estimation results

Variables	Estimated coefficient	Robust standard deviation	T-value	P-value
lnrgdp	0.514 ***	0.043	11.83	0.000
lninsa	0.230 ***	0.069	3.35	0.001
lninsr	0.130 ***	0.036	3.61	0.000
lngreen	-1.121***	0.073	-15.46	0.000
lnfdi	-0.039 ***	0.015	-2.68	0.008
lnenergy(er≤0.0653)	0.457***	0.081	5.63	0.000
lnenergy(0.0653<er<0.6732)	0.533***	0.078	6.79	0.000
lnenergy(er≥0.6732)	0.559***	0.078	7.18	0.000

According to the threshold values obtained above, the environmental regulation levels of all provinces and cities from 2000 to 2020 can be divided into three relative intervals: low level, medium level and high level. It can be seen from the table that under different interval levels of environmental regulation, the estimated coefficients are significantly different, and all are positive at the significance level of 1%, indicating that within the sample interval of this paper, there is a positive correlation between energy intensity and environmental inequity. Within a certain interval, the higher the energy intensity is, the higher the index of environmental inequity will be. However, this positive correlation is not a simple linear relationship. This aggravation changes with the change of environmental regulation intensity. Within the three intervals of environmental regulation intensity, the corresponding estimated coefficient increases from 0.457 to 0.559, that is, the coefficient of energy intensity aggravating environmental inequity is not constant, but there is an obvious threshold effect. When the environmental regulation intensity reaches a certain threshold value, the aggravation degree of energy intensity on environmental inequity is gradually increasing.

4.5.2 Further Discussion

According to the regression results, the influence of control variables on environmental unfairness can also be analyzed. According to the above estimated results, the following conclusions can be drawn: (1) there is a significant positive correlation between lnrgdp and lneii, which indicates that the increase of per capita GDP will aggravates the degree of regional environmental inequity. (2) There is a significant positive correlation between lninsa and lneii, indicating that the improvement of industrial optimization will aggravates the degree of regional environmental inequity. (3) There is a significant positive correlation between lninsr and lneii, indicating that the improvement of industrial rationalization will aggravate the degree of regional environmental inequity. (4) There is a significantly negative correlation between lngreen and lneii, indicating that the improvement of ecological capacity will reduce the degree of regional environmental inequity. (5) There is a significantly negative correlation between lnfdi and lneii, indicating that the increase of foreign capital investment will reduce the degree of regional environmental inequity.

5. Conclusions and Policy Recommendations

5.1 Research Conclusions

With the increasingly severe global environmental problems, “pollution paradise” and other environmental inequities have emerged in the process of development. Under the requirements of carbon emission reduction, the Chinese government has increasingly paid attention to the control of energy consumption per unit GDP. In order to study the relationship between energy intensity and environmental inequities, this paper selected 30 provinces in China from 2000 to 2020 as the research objects. In order to study the relationship between energy intensity and environmental inequity, this paper constructs an index system for measuring environmental inequity, calculates the environmental inequity in four regions, and makes an empirical analysis of energy intensity and environmental inequity, and discusses their mechanism of action.

The results show that: (1) From 2000 to 2020, the environmental equity in the eastern region is poor, but the environmental equity in the eastern region is gradually improving, and the environmental inequity index shows a trend of rapid decline; The changes of environmental inequity index in northeast, central and western regions were relatively flat. (2) Among the four regions, the eastern region has the worst environmental inequity, followed by the western region, the central region and the northeastern region. The national ranking of environmental equity is as follows: the northeastern region has the fairest environment, the central region has the fairest environment, the western region has the worst environmental equity, and the eastern region has the worst environmental equity. (3) There is a nonlinear U-shaped relationship between energy intensity and environmental inequity. When the logarithmic value of energy intensity is to the left of the inflection point, increasing energy intensity will reduce the degree of environmental inequity from the macro level. At this stage, the promoting effect of energy intensity on environmental equity is greater than the inhibiting effect, and the marginal promoting effect is decreasing, while the inhibiting effect is increasing. At the micro level, when the energy consumption per unit output value of local enterprises increases, the income effect it brings is greater than the substitution effect of pollution control, thus increasing energy intensity and reducing environmental inequity, corresponding to the early stage of regional industrial development. When the logarithm of energy intensity is on the right side of the inflection point, increasing energy intensity will increase the degree of environmental inequity from the macro level. At this stage, the inhibitory effect of energy intensity on environmental equity is greater than the promotion effect, and the marginal inhibitory effect is decreasing, while the marginal promotion effect is increasing. At the micro level, when the energy consumption per unit output value of local enterprises increases, the substitution effect of pollution control brought by it is greater than the income effect, thus increasing the energy intensity and improving the degree of environmental inequity, corresponding to the later stage of regional industrial development. (4) According to the threshold value, the environmental regulation level of all provinces and cities from 2000 to 2020 can be divided into three relative ranges: low level, medium level and high level. The study finds that with the increase of energy intensity, the impact of energy intensity on environmental inequity does not play a due role in alleviating, but more significantly aggravates the degree of environmental inequity. The aggravation of environmental inequity changes with the change of environmental regulation intensity. Within the three ranges of environmental regulation intensity, the aggravation degree of energy intensity on environmental inequity is gradually increased.

5.2 Policy Recommendations

This paper enriches the research on energy intensity and provides some data support for the construction of environmental inequity index by calculating the environmental inequity index of each province and city, as well as the empirical research on energy intensity and environmental inequity. Based on the above research, the following suggestions are given:

First, according to the trend chart of environmental inequity index of all provinces and cities from 2000 to 2020, although the environmental inequity index in the eastern region shows a downward trend, the level of inequity is still at a high level. It is suggested to strengthen the environmental control in the eastern region, so as to reduce the proportion of green burden coefficient in the environmental inequity index. It is suggested to strengthen environmental management and control in eastern China to reduce the proportion of green burden coefficient in environmental unfairness index.

Secondly, China has entered the stage of high-quality development, and the relationship between energy intensity and environmental inequity index has been at the right end of the U-shaped curve. Governments at all levels should accelerate the implementation of the dual carbon target, reduce the energy intensity index, actively invest in the research and development of new energy, and shift to the stage of low-energy development.

Thirdly, at the present stage, China's contradictions focus on unbalanced and inadequate development, and environmental injustice will inevitably hinder the resolution of the contradictions at the present stage. Therefore, regional governments should actively cooperate to avoid ignoring the development of the results, and strengthen the coordinated development of all regions to promote common prosperity.

Fourthly, under the establishment of the dual carbon target, all regions and local industries should carry out close cooperation to control the pollution emissions of high-polluting industries, rather than taking economic indicators as the only indicators, properly promote the orderly implementation of the carbon trading market, so that industries with low energy intensity and low pollution emissions can enjoy more economic dividends, promote fair and positive benign competition, and promote the fair development of the environment.

Fifthly, after 2015, the eastern region is no longer the region with the most serious environmental fairness, while the western region has become the region with the highest environmental inequity index. The western region should reasonably control the structure type of industrial transfer, gradually improve the local energy consumption structure, reduce the energy intensity, and vigorously promote the expansion of forest cultivated land.

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