energies

Article

Can the Relationship between Atmospheric Environmental Quality and Urban Industrial Structure Adjustment Achieve Green and Sustainable Development in China? A Case of Taiyuan City

Xi Zhang [1], Jiayu Zheng [2,*] and Ligang Wang [2,*]

[1] School of Economics, Beijing Technology and Business University, Beijing 100048, China; zhangxi@btbu.edu.cn
[2] School of Economics and Management, University of Chinese Academy of Sciences, Beijing 100190, China
* Correspondence: zhengjiayuzjy@126.com (J.Z.); tyzfwlg@163.com (L.W.)

Abstract: Atmospheric environmental quality affects the high quality and sustainable development of the economy. The optimisation and upgrading of the industrial system are important to improve the operation efficiency of the economy and society. Firstly, this paper constructs the theoretical analysis framework of coupling and coordination between the atmospheric environment system and the industrial system and analyses the internal mechanism of the interaction and coordinated development of the two systems. Then, it puts forward the combination of the coupling coordination model and the VAR model (Vector autoregressive model) and presents the analysis and evaluation method of the relationship between them from the two perspectives of "static" and "dynamic". Finally, the empirical study is conducted in Taiyuan, a resource-based city in China. The results show that: (1) The two systems in Taiyuan have an obvious interaction and develop in the direction of benign coupling. (2) The impact of the two systems on each other is mainly in the medium and long term and dominated by the role of the atmospheric environment system on the industrial system. This study provides a theoretical framework and evaluation methods for evaluating and analysing the relationship between the urban atmospheric environment system and the industrial system in China, and then provides suggestions for policymaking.

Keywords: atmospheric environmental quality; industrial structure; Taiyuan city; coupling coordination model; VAR model

Citation: Zhang, X.; Zheng, J.; Wang, L. Can the Relationship between Atmospheric Environmental Quality and Urban Industrial Structure Adjustment Achieve Green and Sustainable Development in China? A Case of Taiyuan City. *Energies* **2022**, *15*, 3402. https://doi.org/10.3390/en15093402

Academic Editors: Junpeng Zhu, Xinlong Xu and Luigi Aldieri

Received: 14 April 2022
Accepted: 3 May 2022
Published: 6 May 2022

1. Introduction

Atmospheric environmental quality is the key index to measure economic quality and sustainable development. After experiencing rapid industrialisation, China is also facing problems, such as environmental pollution restricting economic development, and endangering health. As early as 1982, China promulgated the standards and specifications for evaluating atmospheric environmental quality, which were revised and improved in 1996, 2000, and 2012. Existing studies have conducted rich research on atmospheric environmental quality evaluation methods. The main methods and models include the RBF (Radial Basis Function) network analysis method [1,2], the fuzzy mathematics method [3], the set pair analysis method [4], the grey clustering method [5], the AHP model (Analytic Hierarchy Process) [6,7], the DPSIR model (Drive-Pressure-State-Impact-Response model) [8,9], etc. Lu et al. [10] studied and analysed that under the new air quality evaluation standards, the atmospheric environment of more than 70% of prefecture-level cities in China is overloaded. The improvement of environmental carrying capacity is very urgent. Dong et al. [11] analysed China's atmospheric environmental quality from 2015 to 2019 according to the data of monitoring stations and found that China's air quality index and the concentration of six types of pollutants were significantly improved during the study sample period. The study pointed out that PM2.5 (particulate matter) is the most important pollutant affecting China's air quality. As people pay more and more attention to environmental issues, the Chinese government has adopted a positive action plan to promote the governance of the atmospheric environment. In 2013, the action plan for preventing and controlling air pollution was issued, which made specific action guidelines for "winning the Blue-Sky Protection Campaign". In 2018, the three-year action plan for winning the Blue-Sky Protection Campaign was further released to deepen the governance of end problems. The plan aims to improve air quality in key areas through coordinated control of multiple pollutants. Based on the quasi-natural experimental method, Wu and Yin [12] found that the implementation of the action plan can improve the atmospheric quality through the impact on the industrial structure, especially in resource-based cities. The study emphasises that compared with the development of the advanced industrial structure, the rationalisation of the industrial structure plays a more obvious role in improving air quality. Only when the adjustment of industrial structure is compatible with the overall characteristics of the region can the policy really play a role.

Industrial structure adjustment is an important way to optimise economic and social factors. William Petty first put forward the theory of industrial structure, while Clark revealed the evolution law of industrial structure. How to measure the change in industrial structure and whether the adjustment is reasonable is a more concerning issue in the research of industrial structure adjustment. Fu [13] took the proportion of three industries as the corresponding weight of each industry and aggregated it to build an advanced index of industrial structure. Gan et al. [14] took the ratio of the tertiary industry to the secondary industry to measure the upgrading of the industrial structure. However, relevant studies believe that it is too one-sided to measure the rationality of the industrial structure from the change of the proportion of three industries. Liu [15] believes that the rationality evaluation system of industrial adjustment should have the functions of judgment, selection, control, guidance, and early warning, and should follow the principles of scientificity, comprehensiveness, independence, feasibility, and stability. Based on the above functions and principles, 5 primary indicators, 13 secondary indicators, and 37 tertiary indicators are selected to build an evaluation system for industrial structure rationalisation. In empirical research, most choices are mainly measured by constructing the ratio of the output value of various industries to labour productivity [16–18].

How to coordinate the relationship between the upgrading of the industrial structure and the improvement of atmospheric environmental quality is a very important issue for China in the green transition period. Many scholars have also carried out research on this issue. Zhang et al. [19] used the SDA method (structural decomposition analysis method) to evaluate China's economic development during the Eleventh Five Year Plan period. They pointed out that if China does not change its economic structure and development model, it may not be able to fulfil its commitment to reduce the emission of industrial air pollutants. Zhang et al. [20] found that the adjustment of the industrial structure had a positive impact on reducing carbon emissions based on the econometric model. Among them, the reduction of the proportion of energy-intensive secondary industry and the optimisation of energy structure have a particularly obvious effect on improving atmospheric environmental quality [21,22]. Ding et al. [23] have tried to analyse the relationship between industrial structure and the atmospheric environment through an integrated and systematic method. They constructed the PSR-LQI (pressure–state–response and level–quality–innovation model) index evaluation system and presented the corresponding evaluation results. Zheng et al. [24], based on the threshold model and the empirical analysis of China's provincial panel data, found that the impact of the industrial structure on pollutant NOx and PM2.5 is divided into three stages, while the impact mechanism of pollutant SO_2 is two stages. The adjustment of the industrial structure can improve the impact of economic development on air pollution. Zhou et al. [25] pointed out that the strictness of environmental supervision helps to optimise the industrial structure and then improve the quality of the atmospheric environment. Relevant studies also show that the impact of the industrial structure on atmospheric environmental quality is long-term and increases with time [26].

What is the relationship between atmospheric environmental quality and industrial structure adjustment? How important is the adjustment of the industrial structure to improve atmospheric environmental quality? What difficulties are faced in the process of improving atmospheric environmental quality through industrial structure adjustment? Previous studies have fully analysed the single system of atmospheric environmental or industrial systems and used the econometric model to empirically test and evaluate the relationship between them. Many studies have also mentioned the long-term nature, dynamic interaction, and segmentation of the relationship between the two systems [24–26]. However, the existing studies mainly analyse the relationship between the two systems from the perspective of a single system or comparative static and have not been able to analyse the dynamic process of the interaction between the two systems and present an intuitive evaluation of the coupling and coordination between the two systems. The development of the atmospheric environmental system has experienced a strategic change from the total amount control of single pollutants to the quality improvement of multi-pollutant collaborative control. To maintain the sustainable development of its own system, it needs to maintain coordination with other economic and social subsystems through continuous optimisation. On the other hand, after transforming the industrial structure level from low to high level, the industrial system needs to consider the rationalisation within the system. After reaching coordination and balance within the system, it will develop in the direction of rationalisation among systems. The development between the two systems can be roughly divided into three stages: the low-level coupling and coordination stage, the mutual running in and coordination stage, and the high-level coupling and coordination stage. In the first stage, the atmospheric environment system has constraints on the industrial system, and the industrial system cooperates with the realisation of the governance goal of the atmospheric environment system. In the second stage, the regulation of the atmospheric environment system on the industrial system is gradually optimised. The optimisation and improvement of the industrial system will promote and guide the improvement of the atmospheric environment system. In the third stage, the two systems maintain benign coupling and need coordination, and jointly develop in the direction of sustainability. For the leapfrogging of different stages and the drive of the system itself, the systems will also affect each other. The strategic improvement of the atmospheric environment system will enhance the optimisation requirements of the industrial system, and the improvement of the matching and adaptability of the industrial system will also enhance its impact on the atmospheric environment system. Of course, due to the complexity of the urban development model, the industrial system and atmospheric environment system may not only promote each other's leap forward, but also regress. Therefore, this paper constructs the analysis framework of coupling and coordination between the atmospheric environment system and the industrial system. As shown in Figure 1, it analyses the internal and external evolution processes of the two systems in the interaction process from the theoretical level, and then uses the coupling and coordination model and the VAR model for empirical analysis.

There are three main contributions of this paper. Firstly, it constructs the theoretical analysis framework of coupling and coordination between the atmospheric environment system and the industrial system and clarifies the internal mechanism of the interaction and coordinated development of the two systems. Secondly, the coupling coordination model and the VAR model are combined to test the relationship between them from the perspectives of "static" and "dynamic", which not only provides an overall intuitive evaluation of the relationship between them, but also analyses the dynamic process of interaction. Thirdly, as a resource-based city in China, Taiyuan is typical and representative. This paper selects the data of Taiyuan for the empirical test, provides an analytical framework and comprehensive evaluation method for evaluating the situation of the two systems of the city, and provides support for government departments to formulate policies and evaluate the effectiveness and rationality of urban policies.

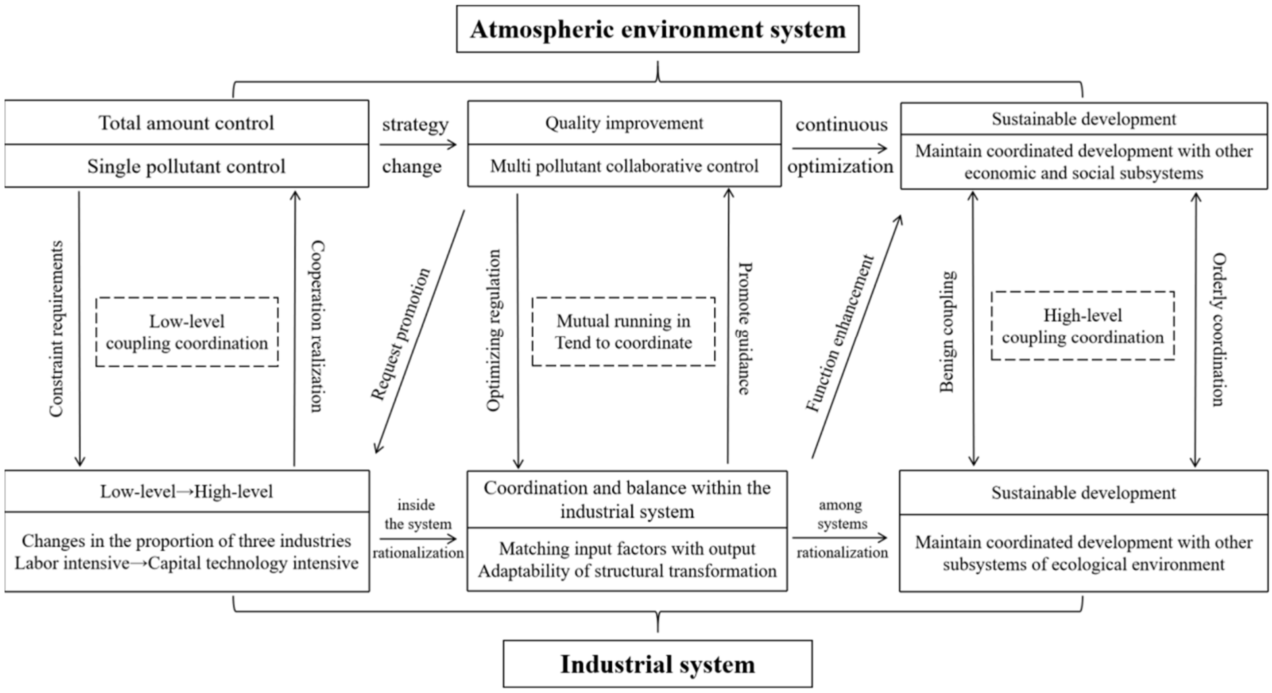

Figure 1. Analysis framework of coupling and coordination between the atmospheric environment system and the industrial system.

2. Study Area

Taiyuan is the capital city of Shanxi Province in China (as shown in Figures 2 and 3). The terrain is surrounded by mountains in the east, west, and north. The central and southern part is the Fenhe River valley plain. The whole terrain is high in the north and low in the south, in the shape of a dustpan. Therefore, the average ground wind speed is small, the static wind frequency is high, and the precipitation is scarce, which is unfavourable to the city's diffusion of air pollutants.

Figure 2. Location of the study area in China.

Figure 3. Location of the study area in Shanxi Province.

As a typical resource-based city, Taiyuan has a special industrial structure. The industry is mainly heavy. Coal mining and combustion greatly impact the quality of the atmospheric environment. Taiyuan has also actively adjusted and upgraded its industrial structure for many years. As shown in Figure 4, the proportion of primary industry in Taiyuan is relatively small and in a downward trend, and the proportion of secondary industry and tertiary industry shows a "K" trend. After 2009, the tertiary industry became the leading industry in Taiyuan, basically maintaining a stable industrial pattern of "tertiary, secondary, and primary industry", reflecting the industrial structure characteristics of urbanisation. However, from 2013 to 2020, the air quality ranking of Taiyuan was always in the lower position of the environmental air quality ranking of national key cities. The poor atmospheric environmental quality has become an important factor restricting the development of Taiyuan.

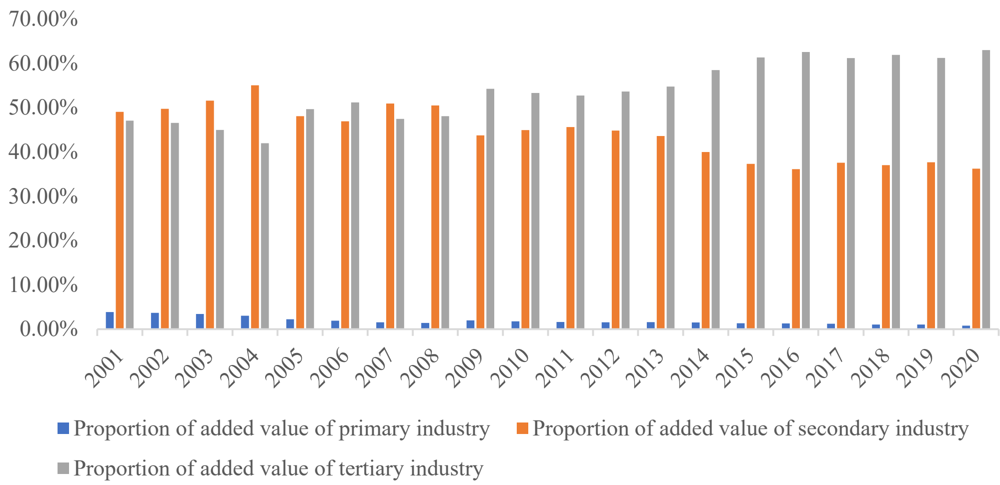

Figure 4. Changes in the proportion of three industries in Taiyuan over the years.

3. Methods and Data

The coupling coordination model provides an intuitive measurement and evaluation of whether the system elements can interact and the overall coordinated development. The VAR model can measure the size and continuous influence of the interaction of elements between systems in the process of dynamic development. Referring to the practice of Liao et al. [27], this paper combines the two models to comprehensively analyse the coupling and internal mechanisms between atmospheric environmental quality and urban industrial structure adjustment in Taiyuan from the perspectives of "static" and "dynamic". This section will specifically introduce the above models and the required data.

3.1. Coupled Coordination Model

Coupling originates from the physical concept, which refers to the phenomenon that two or more systems and their elements affect each other and finally achieve synergy through interaction. The coupling degree in the model reflects the degree of mutual dependence and restriction between systems. The coupling coordination degree reflects the degree of benign coupling between systems in their interaction. The more obvious the trend of orderly development between systems, the greater the index.

For the comprehensive system composed of the atmospheric environment subsystem and the urban industry subsystem, subsystem i has n indicators, which are $x_1, x_2, \cdots, x_n$. In order to eliminate the influence of dimensionality, the indicators need to be standardised before using these indicators to construct the comprehensive index of subsystem i. Referring to the existing research methods, this paper used the range method to process the data. When using this method, it needs to distinguish and process according to the positive and negative contributions of the index to the system. The greater the x_{ij} value, the better the system function. It is called the positive index, and Formula (1) is used for standardisation. The smaller x_{ij} value indicates the better system function, which is called the negative index, and Formula (2) is used for standardisation. The specific formulae are as follows:

$$\text{Positive index}: \ d_{ij} = \left(x_{ij} - x_{ijmin}\right) / \left(x_{ijmax} - x_{ijmin}\right) \tag{1}$$

$$\text{Negative index}: \ d_{ij} = \left(x_{ijmax} - x_{ij}\right) / \left(x_{ijmax} - x_{ijmin}\right) \tag{2}$$

where d_{ij} is the standardised value of system i index j, $0 \leq d_{ij} \leq 1$. x_{ijmax} is the maximum value of system i index j, x_{ijmin} is the minimum value of system i index j, and x_{ij} is the value of system i index j.

The comprehensive index of the atmospheric environment subsystem and the industrial subsystem is based on the weighted synthesis of the contribution of all indicators in each system to the subsystem, and its calculation formula is:

$$U_i = \sum_{j=1}^{n} w_{ij} \cdot d_{ij} \tag{3}$$

where w_{ij} is the weight of index j of system i, where $w_{ij} \geq 0$ and $\sum w_{ij} = 1$. The weight corresponding to each index reflects the ability of the index to provide comprehensive information about the subsystem, so it needs to be determined according to the amount of information contained in the index. The principal component analysis method can effectively deal with the influence of information repetition and interaction between different indicators. Therefore, this method is also used in this paper. Through principal component analysis, the corresponding variance value of each index is obtained as the weight of the corresponding value index, and then the comprehensive index of each system and the coupling degree, C, between systems are calculated.

The calculation formula of coupling degree is as follows:

$$C = \left[\frac{\prod_i^m U_i}{\left(\frac{1}{m}\sum_i^m U_i\right)^m} \right]^{\frac{1}{m}} \tag{4}$$

where m is the number of subsystems. Since the number of subsystems of the atmospheric environment and the urban industrial structure integrated system constructed in this paper is 2, $m = 2$. Therefore, the above coupling calculation formula is simplified as follows:

$$C = \sqrt{\frac{U_1 U_2}{\left(\frac{U_1+U_2}{2}\right)^2}} = \frac{2\sqrt{U_1 U_2}}{U_1 + U_2} \tag{5}$$

where U_1 and U_2 are the comprehensive indexes of the atmospheric environment and the industrial subsystem, respectively. The value of C is between 0 and 1. The greater the value of C, the closer the relationship between systems. Referring to the median segmentation method adopted by most studies, it can be divided into the following four stages, listed in Table 1.

Table 1. Median segmentation of coupling degree.

C	Corresponding Stage
$0 < C \leq 0.3$	Low-level coupling
$0.3 < C \leq 0.5$	Antagonistic stage
$0.5 < C \leq 0.8$	Running in stage
$0.8 < C \leq 1$	High-level coupling

However, the coupling index only reflects the function degree of the two systems. In order to account for the respective development of the two systems, it is necessary to further study whether the two systems are coordinated. Coordination is used to measure the degree of harmony of each subsystem. There is a close relationship between the industrial and the atmospheric environment subsystems. On the one hand, the atmospheric environmental carrying capacity requires the optimisation and upgrading of the industrial structure, and the atmospheric environmental quality will react to the process of industrial structure adjustment. On the other hand, the adjustment of the industrial structure not only needs to realise the healthy and sustainable development of the industrial system, but also needs to match with the carrying capacity of the atmospheric environment. The coupling coordination degree can better evaluate the coordination degree of the interaction coupling between industrial structure adjustment and atmospheric environmental quality improvement. The calculation formula is:

$$T = \alpha U_1 + \beta U_2 \tag{6}$$

$$D = \sqrt{C \times T} \tag{7}$$

where D is the coupling coordination degree, C is the coupling degree, and T is the comprehensive coordination index of the industry and the atmospheric environment, reflecting the overall synergistic effect or contribution of industrial structure adjustment and atmospheric environment quality improvement. α and β are the weights of the two systems. This paper believes that the improvement of the atmospheric environment is as important as the optimisation and upgrading of the industrial structure, so $\alpha = \beta = 0.5$.

When the D value is larger, it shows that the coordinated development of the two systems is better. According to the judgment method of existing research [28], the coordination can be divided into ten stages according to the coupling coordination degree, D, as shown in Table 2.

Table 2. Coupling coordination level segmentation.

D	Coordination Level
[0, 0.1)	Extremely uncoordinated
[0.1, 0.2)	Seriously uncoordinated
[0.2, 0.3)	Moderately uncoordinated
[0.3, 0.4)	Slightly uncoordinated
[0.4, 0.5)	On the verge of uncoordinated
[0.5, 0.6)	Barely coordinated
[0.6, 0.7)	Slightly coordinated
[0.7, 0.8)	Moderately coordinated
[0.8, 0.9)	Well-coordinated
[0.9, 1]	Quality coordinated

Considering the availability of data and indicators' comprehensive information-carrying capacity, this paper constructs a comprehensive evaluation index system, as shown in Table 3. Relevant data can be obtained from the official website of the Taiyuan Bureau of Statistics (http://stats.taiyuan.gov.cn, accessed on 5 March 2022).

Table 3. Comprehensive evaluation index system.

Coupling Systems	Indicators	Unit	Indicators Direction
Atmospheric environment system	Industrial sulphur dioxide emissions	10,000 tonnes	−
	Industrial smoke (powder) dust emission	10,000 tonnes	−
	Days with air quality above grade II	day	+
Industrial system	Rationalisation of industrial structure (ISR)	/	−
	Advanced industrial structure (ISH)	/	+
	Comprehensive utilisation rate of general industrial solid waste	%	+
	Total investment in fixed assets	100 million yuan	+

For the evaluation indicators of the atmospheric environment system, China mainly evaluates the atmospheric environment by monitoring the concentration of six types of pollutants (including PM10, PM2.5, O3, NO_2, SO_2, and CO) and the air quality index (AQI) in practice. However, because some data are difficult to obtain, this paper selects three indicators: industrial sulphur dioxide emission, industrial smoke (powder) dust emission, and days with air quality above grade II.

As for the evaluation indicators of the industrial structure system, the upgrading of the industrial structure aims to measure the degree of the evolution of the industrial structure from low-level to high-level. This paper constructs the following indicators based on the idea of Fu [13]:

$$ISH_t = (q_{2t} + q_{3t}) \times \frac{q_{3t}}{q_{2t}} \tag{8}$$

where q_{2t} and q_{3t}, respectively, represent the proportion of the secondary and tertiary industries in Taiyuan's GDP in the t period.

The rationalisation of the industrial structure is to consider the coordination between different industries, the adaptability between input factors and output, and the adaptability of structural transformation ability. The existing studies mostly use the structural deviation degree improved by Gan et al. [14] based on the Theil index. This method was also used in this paper. The specific calculation formula is:

$$ISR_t = \sum_{j=1}^{3} (q_{jt}) ln \frac{Y_{jt}/Y_t}{L_{jt}/L_t} \tag{9}$$

where q_{it} indicates the proportion of the j industry in the region's GDP during the t period, Y_{jt} refers to the gross domestic product of the j industry in Taiyuan during the t period, and L_{jt} refers to the number of employees in the j industry in Taiyuan during the t period. Y_t and L_t, respectively, represent the regional GDP (Gross domestic product) and total employment of Taiyuan in the t period. The closer ISR is to 0, indicating the closer the industrial structure is to the equilibrium state, the more reasonable the industrial structure is.

Referring to the index construction of the industrial rationalisation system by Liu [15], the comprehensive utilisation rate of general industrial solid waste reflects the improvement of factor utilisation within the industry. The total investment in fixed assets is a strategic plan reflecting the industry's long-term development. Therefore, this paper selected the above four indicators as the evaluation indicators of the industrial system.

3.2. VAR Model

The coupling coordination model can conduct an intuitive evaluation of the coupling coordination of the two systems from a comparative static point of view, and the VAR model is an econometric model used to estimate the dynamic relationship of joint endogenous variables. The model is established according to the statistical characteristics of the data without setting any constraints in advance. Each variable in the system is regarded as endogenous, and the lag term of all variables is included in the constructed function model. The VAR model is mainly used to analyse the response of interconnected time-series systems under the dynamic impact of system variables. The analysis of the model is mainly to observe the impulse response function and variance decomposition of the system. The former refers to the system's response to a random impact of one of the variables and how long this response will last. The latter is an important method to judge the dynamic correlation between economic series variables. In essence, it decomposes the prediction mean square error of the system into the contribution of the shocks of various variables in the system. Through the Granger causality test, we can analyse the causal effect of variables in time. This paper used the VAR model to analyse the dynamic action of the atmospheric environment system and the industrial system in Taiyuan. The specific model is constructed as follows:

$$\begin{cases} y_{1t} = \alpha_{10} + \gamma_{11} y_{1,t-1} + \ldots + \gamma_{1p} y_{1,t-p} + \beta_{11} y_{2,t-1} + \ldots + \beta_{1p} \beta_{2,t-p} + \varepsilon_{1t} \\ y_{2t} = \alpha_{20} + \gamma_{21} y_{1,t-1} + \ldots + \gamma_{2p} y_{1,t-p} + \beta_{21} y_{2,t-1} + \ldots + \beta_{2p} \beta_{2,t-p} + \varepsilon_{2t} \end{cases} \quad (10)$$

where y_1 and y_2 are the comprehensive indexes of the atmospheric environment system and the industrial structure system, respectively. p represents the lag order, t represents the time, γ and β represent the regression coefficient, α represents the intercept term, and ε represents the residual term.

4. Results and Discussion

4.1. Descriptive Statistics

The original data of various indicators of the Taiyuan atmospheric environment system and the industrial system can be obtained from the official website of the Taiyuan Bureau of Statistics. Among them, the number of days with air quality above grade II, the upgrading of the industrial structure, and the total investment in fixed assets include the data for 20 years, from 2001 to 2020. Industrial sulphur dioxide emission, industrial smoke (powder) dust emission, and the comprehensive utilisation rate of general industrial solid waste cover 15 years of data, from 2003 to 2017. The data of industrial structure rationalisation include the data for 16 years, from 2003 to 2018, as shown in Table 4. Considering the amount of information and availability of data, this paper finally selected the data from 2003 to 2017 for empirical analysis. Due to the different dimensions of the above data, the range method was used to standardise the above data. According to the positives and negatives of the index, we used Formulas (1) and (2) to deal with it, respectively. The results are shown in Table 5.

Table 4. Descriptive analysis of each index.

System	Indicators	Observed Value	Mean	SD	Min	Max
Atmospheric environment system	Days with air quality above grade II	20	228.8	59.10	120	324
	Industrial sulphur dioxide emissions	15	100,576	49,399	9759	183,656
	Industrial smoke (powder) dust emission	15	44,052	15,140	17,086	72,171
Industrial system	Advanced industrial structure (ISH)	20	1.232	0.325	0.739	1.726
	Rationalisation of industrial structure (ISR)	16	0.024	0.01	0.009	0.039
	Comprehensive utilisation rate of general industrial solid waste	15	0.488	0.0519	0.422	0.560
	Total investment in fixed assets	20	978.0	610.2	122.7	2028

Table 5. Standardised treatment results.

Year	Days with Air Quality above Grade II	Industrial Sulphur Dioxide Emissions	Industrial Smoke (Powder) Dust Emission	Advanced Industrial Structure (ISH)	Rationalisation of Industrial Structure (ISR)	Comprehensive Utilisation Rate of General Industrial Solid Waste	Total Investment in Fixed Assets
2003	0.117	0.011	0.000	0.106	0.139	0.059	0.000
2004	0.383	0.000	0.102	0.000	0.185	0.059	0.072
2005	0.512	0.191	0.285	0.279	0.788	0.177	0.128
2006	0.611	0.316	0.420	0.340	0.761	0.131	0.163
2007	0.660	0.443	0.469	0.184	0.975	0.000	0.204
2008	0.864	0.481	0.573	0.206	1.000	0.380	0.273
2009	0.827	0.536	0.609	0.492	0.608	0.462	0.317
2010	0.877	0.514	0.678	0.440	0.688	0.730	0.390
2011	0.901	0.434	0.508	0.410	0.812	0.784	0.450
2012	1.000	0.471	0.546	0.453	0.000	0.839	0.612
2013	0.000	0.545	0.638	0.513	0.169	0.892	0.804
2014	0.216	0.575	0.231	0.722	0.308	0.946	0.846
2015	0.420	0.684	0.684	0.910	0.250	1.000	0.999
2016	0.432	0.966	0.913	1.000	0.173	0.660	1.000
2017	0.080	1.000	1.000	0.896	0.298	0.039	0.417

4.2. Evaluation Results of Coupling Coordination Model

Since the indexes selected in this paper are inter-related and the information covered is overlapped, this paper adopted the principal component analysis method to extract the information contributed by each index to each subsystem, determine the corresponding weight coefficient of each index according to the component matrix and corresponding variance (see Table 6), and then calculate the comprehensive index of the atmospheric environment system and the industrial system according to Formula (3). The comprehensive index of atmospheric environmental and industrial systems, coupling degree, coupling coordination degree, comprehensive coordination index, and corresponding coupling coordination stages of the two systems are shown in Table 7 and Figure 5.

Table 6. Corresponding weight of each index.

System	Indicators	Weight Coefficient
Atmospheric environment system	Days with air quality above grade II	0.278
	Industrial sulphur dioxide emissions	0.333
	Industrial smoke (powder) dust emission	0.389
Industrial system	Advanced industrial structure (ISH)	0.328
	Rationalisation of industrial structure (ISR)	−0.054
	Comprehensive utilisation rate of general industrial solid waste	0.352
	Total investment in fixed assets	0.374

Table 7. Coupling and coordination of the atmospheric environment system and the industrial system in Taiyuan.

Year	Atmospheric Environment System U1	Industrial System U2	Coupling Degree, *C*	Comprehensive Coordination Index, T	Coupling Coordination Degree, *D*	Coupling Stage	Coordination Stage
2003	0.036	0.048	0.991	0.205	0.451	High level	Verge of uncoordinated
2004	0.146	0.037	0.806	0.303	0.494	High level	Verge of uncoordinated
2005	0.317	0.159	0.944	0.488	0.679	High level	Slightly coordinated
2006	0.439	0.177	0.906	0.555	0.709	High level	Moderately coordinated
2007	0.514	0.084	0.694	0.547	0.616	Running in	Slightly coordinated
2008	0.623	0.249	0.904	0.660	0.773	High level	Moderately coordinated
2009	0.645	0.410	0.975	0.726	0.841	High level	Well-coordinated
2010	0.679	0.510	0.990	0.771	0.874	High level	Well-coordinated
2011	0.592	0.535	0.999	0.751	0.866	High level	Well-coordinated
2012	0.647	0.673	1.000	0.812	0.901	High level	Quality coordinated
2013	0.430	0.774	0.958	0.776	0.862	High level	Well-coordinated
2014	0.342	0.869	0.900	0.778	0.837	High level	Well-coordinated
2015	0.611	1.011	0.969	0.900	0.934	High level	Quality coordinated
2016	0.797	0.925	0.997	0.928	0.962	High level	Quality coordinated
2017	0.744	0.448	0.969	0.772	0.865	High level	Well-coordinated

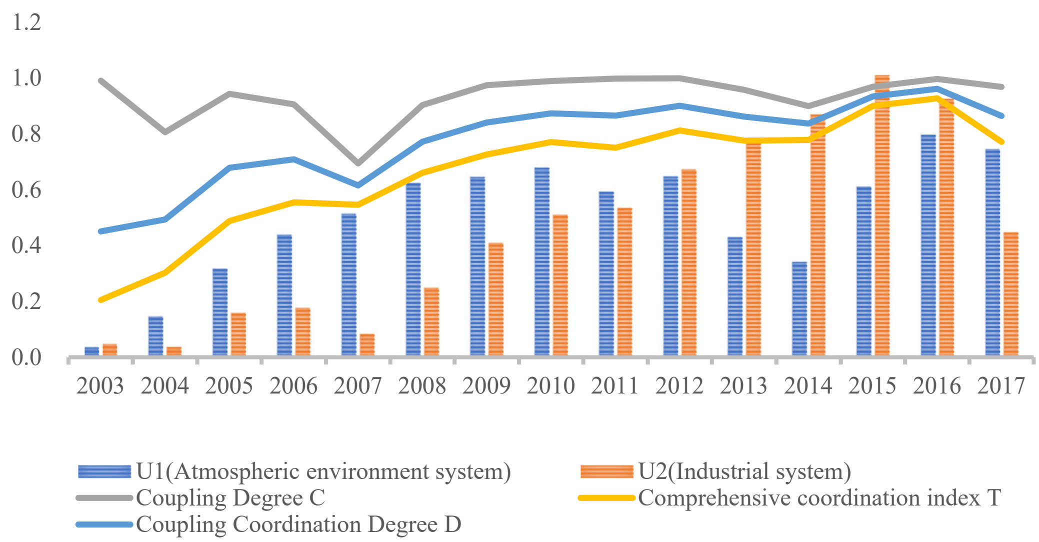

Figure 5. Coupling and coordination trends of the atmospheric environment system and the industrial system in Taiyuan from 2003 to 2017.

It can be seen from the chart that the atmospheric environment of Taiyuan is systematically rising. From 2003 to 2010, it maintained a rapid upward trend, and the comprehensive index increased from 0.036 to 0.679, indicating the continuous improvement of atmospheric quality. However, the composite index fell in shock, and fell to 0.342 in 2014. This is mainly because China revised the ambient air quality standard (GB 3095-2012) in 2012 and adopted more stringent standards. After four years of adjustment and adaptation to the new standard, the development of the atmospheric environment system in Taiyuan showed an upward trend again, and the comprehensive index reached 0.797.

In terms of the industrial system, the comprehensive index of the industrial system basically maintained an upward trend from 2003 to 2015, rising from 0.048 to 1.011. Taiyuan's industrial structure has experienced the transformation from "secondary, tertiary, and primary" to "tertiary, secondary, and primary". The advanced index of the industrial structure continued to rise. However, the rationalisation index fluctuated, which reflects that the matching degree of elements in Taiyuan's industrial system and the internal optimisation of the three industries are important factors affecting the development of the system. After 2015, the decline of the comprehensive index of the industrial system also reflects this situation to a certain extent. After 2017, Taiyuan also began to publish relevant statistical data of strategic emerging industries and high-tech industries to refine and analyse the development quality within the industry.

The coupling degree, C, of the two systems fluctuated greatly before 2009 and became stable and close to 1 after 2009, indicating that the interaction between the atmospheric environment system and the industrial system is obvious. The coupling and coordination dispatching, D, maintained an upward trend, indicating that the two systems were developing in the direction of benign coupling. The coordination of the two systems has experienced the process of "uncoordinated—primary coordination—moderately coordinated—well-coordinated—quality coordination", indicating that the development between the systems tends to be gradually synchronised. However, it is also noted that the coupling coordination degree of the two systems slightly fluctuated, which reflects that the two systems in Taiyuan are currently in the transitional stage of "mutual running in and tend to coordination—high-level coupling coordination" in the above theoretical analysis framework.

4.3. Results of the VAR Model

The coupling and coordination model mainly measured and evaluated the annual coupling and coordination of the atmospheric environment and industrial systems from a static perspective. In this section, the VAR model was used to analyse the interaction force and continuous influence between the two systems. The specific steps and results were analysed as follows.

4.3.1. Decision Lag Order

To estimate the VAR model, we first needed to determine the lag order, p, of the model according to the information criterion. According to the results in Table 8, the lag order of this model is 4.

Table 8. Decision lag order.

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	5.754				0.0017	−0.6825	−0.7280	−0.6101
1	14.611	17.714	4	0.001	0.0007	−1.5656	−1.7024	−1.3486
2	21.750	14.279	4	0.006	0.0005	−2.1364	−2.3644	−1.7747
3	29.907	16.314	4	0.003	0.0003	−2.8923	−3.2115	−2.3859
4	38.754	17.693 *	4	0.001	0.0003 *	−3.7735 *	−4.1839 *	−3.1224 *

Note: * indicates the lag order selected by the corresponding information criterion.

4.3.2. Stationary Test

In order to ensure the stability of the model, it was also necessary to test the stationarity of the model. As shown in Figure 6, all unit roots were in the unit circle, indicating that the model is stable.

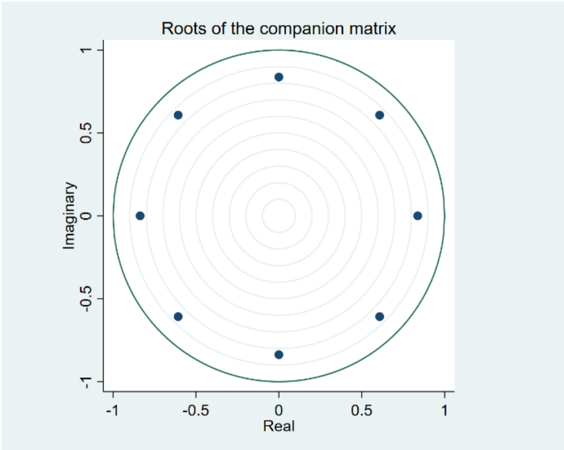

Figure 6. Stationary test.

4.3.3. Granger Causality Test

The Granger test can analyse the causal relationship and action direction of variables in time. It can be seen from Table 9 that the comprehensive index of the atmospheric environment system is the Granger cause of the comprehensive index of the industrial system, and the assumption that the comprehensive index of the industrial system is not the Granger cause of the comprehensive index of the atmospheric environment system cannot be rejected. This is consistent with the optimisation requirements of the industrial system for the strategic improvement of the atmospheric environment system mentioned in the theoretical analysis framework of this paper. From the results of coupling and coordination, it can be seen that the development synchronisation of the two systems in Taiyuan needs to be strengthened. Therefore, Taiyuan should continue to optimise its industrial system, so as to enhance its role in the atmospheric environment system.

Table 9. Granger causality test results.

Hypothesis	chi2	df	df_r	Prob > chi2	Conclusion
U2 is not the Granger cause of U1	0.961	1	8	0.3558	Cannot reject
U1 is not the Granger cause of U2	25.872	1	8	0.0009	Reject

4.3.4. Impulse Response

Since the VAR model contains many parameters, it cannot directly explain the economic meaning of parameters, so it is mainly analysed through the impulse response. Figure 7 shows the impulse response of the Taiyuan atmospheric environment system comprehensive index U1 and the industrial system comprehensive index U2. The horizontal axis represents the lag order of impact (unit: year), and the vertical axis represents the response value of relevant variables. It can be seen from the figure that when the comprehensive index U1 of the atmospheric environment system was used as the pulse variable, the comprehensive index U2 of the industrial system fluctuated significantly during phases 3–5, which shows that the optimisation of the atmospheric environment system will have a positive impact on the industrial system in the medium and long term. When the industrial system comprehensive index U2 was used as the impulse response variable, the atmospheric environment system comprehensive index U1 had positive benefits in phases 3–5, but the benefits were small.

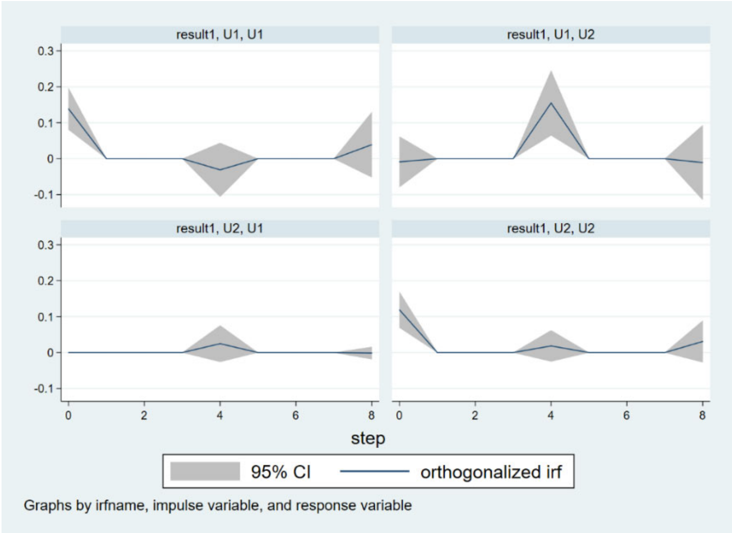

Figure 7. Impulse response.

4.3.5. Variance Decomposition

Variance decomposition can explain the contribution of each variable shock in the system. It can be seen from Figure 8 that the change of the atmospheric environment system mainly came from its own change impact, which is consistent with the practice in China. The governance and improvement of the atmospheric environment system are mainly regulated by administrative means. In the short term, the change of the industrial system is attributed to itself, but in the long term, it is jointly affected by its own change and the impact of the change of the atmospheric environment system. In phases 1–4, the contribution rate of the impact of the industrial system itself to its variance was close to 1, but it dropped to 37% in the subsequent phases. In comparison, the explanation degree of the change of the atmospheric environment system U1 to the industrial system U2 reached 63%.

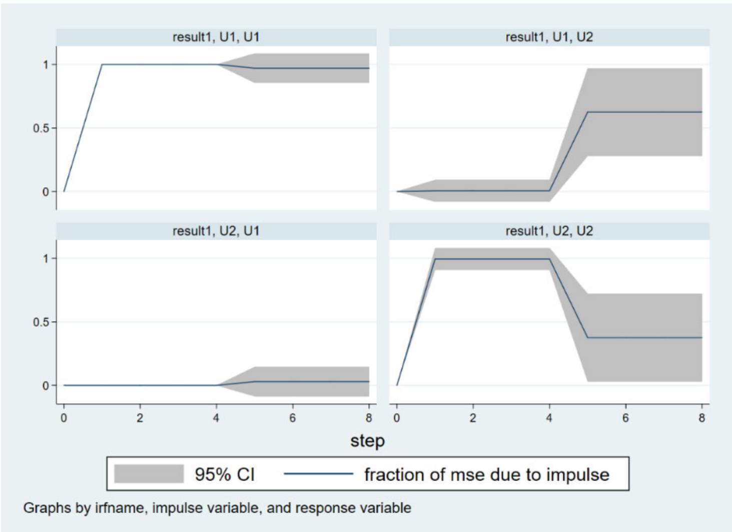

Figure 8. Variance decomposition.

5. Conclusions

The quality of the atmospheric environment affects the high-quality and sustainable development of the economy, and the optimisation and upgrading of the industrial system is an important way to improve the efficiency of economic and social operations. Analysing the relationship and interaction between the two systems is significant in promoting the coordinated development of the environment and economy. By constructing the theoretical analysis framework of coupling and coordination between the atmospheric environment system and the industrial system, this paper clarified the two systems' internal mechanisms of the interaction and coordinated development. Then, it put forward the combination of the coupling coordination model and the VAR model and provided the analysis and evaluation method of the relationship between them from the two perspectives of "static" and "dynamic".

The atmospheric environmental quality is an important factor affecting the development of Taiyuan. For many years, Taiyuan has also been committed to adjusting the industrial structure to make the industrial development adapt to the local environmental carrying capacity. Therefore, based on the theoretical analysis framework and the proposed evaluation method, this paper empirically analysed the data of the typical resource-based city Taiyuan from 2003 to 2017. The results show that: (1) Based on the results of the coupling coordination model, the interaction between the two systems in Taiyuan was obvious and developed towards benign coupling. However, there were still fluctuations in some years, reflecting that the two systems are still in the transition stage of "mutual running in and tend to coordination—high-level coupling coordination". (2) According to the results of the VAR model, the impact of the two systems on each other was mainly in the medium and long term and dominated by the effect of the atmospheric environment system on the industrial system.

Based on the above analysis results, the following policy implications can be obtained. Firstly, Taiyuan should continue to maintain the coordination and sustainability of atmospheric environmental governance and industrial structure adjustment. It should promote and maintain the synchronous and orderly development between the two systems. Secondly, it should be optimised from within the industrial system to improve the scientificity and effectiveness of industrial policies, so as to enhance its internal and external benefits, and then promote the sustainable development of the two systems in Taiyuan and make the two systems enter a high-level coupling and coordinated development stage. Thirdly, when formulating and evaluating urban environmental and industrial policies, central government departments should fully consider the particularity of different urban development stages and the long-term effect of policies so as to avoid "one size fits all" and short-sighted behaviour.

This paper presented an analysis framework and long-term evaluation method of the relationship between the urban atmospheric environment system and the industrial system, which provides theoretical and methodological guidance for policymakers to evaluate relevant policies. However, because some data cannot be obtained through public channels, only the evaluation results of Taiyuan from 2003 to 2017 were presented. Relevant policy departments can conduct the internal evaluation with reference to the methods proposed in this paper and take measures according to the latest situation of the two systems. On the other hand, this paper's evaluation and analysis methods were mainly studied from the macrosystem level. In the future, we can further analyse the response of micro-subjects (such as enterprises) to different types of environmental regulation and industrial structure adjustment policies in different stages, find the action mechanism at the micro-level, and then provide more targeted policy suggestions. In addition, in recent years, the COVID-19 pandemic has had a significant impact on all economies in the world, and the global health crisis has become an external factor that cannot be ignored. The impact of this factor on the atmospheric environment industry coupling system proposed in this paper will be worthy of more extensive and in-depth research in the future.

Author Contributions: Conceptualisation, X.Z. and L.W.; methodology, J.Z.; software, J.Z.; validation, X.Z., J.Z. and L.W.; formal analysis, X.Z., J.Z. and L.W.; investigation, J.Z.; resources, J.Z. and L.W.; data curation, J.Z. and L.W.; writing—original draft preparation, J.Z. and L.W.; writing—review and editing, X.Z., J.Z. and L.W.; visualisation, J.Z.; supervision, X.Z.; project administration, X.Z.; funding acquisition, X.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 72003009.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The sources of relevant data acquisition have been described in the text.

Acknowledgments: The authors dedicate their earnest gratitude to the editor and the anonymous reviewers for their active comments, which improved the quality of the manuscript.

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

References

1. Cao, A.; Tian, L.; Cai, C.; Zhang, S. The research and prediction of atmospheric pollution based on wavelet and RBF neural network. *J. Syst. Simul.* **2006**, *18*, 1411–1413.
2. Nouri, A.; Lak, M.G.; Valizadeh, M. Prediction of PM2.5 Concentrations Using Principal Component Analysis and Artificial Neural Network Techniques: A Case Study: Urmia, Iran. *Environ. Eng. Sci.* **2021**, *38*, 89–98. [CrossRef]
3. Yang, W.; Li, L. Fuzzy mathematics-based comprehensive evaluation of atmospheric environmental quality in Huaian. *Clim. Environ. Res.* **2009**, *14*, 451–454.
4. Xing, Y.; Wang, X.; Hang, D. Set pair analysis for regional atmospheric environmental risk assessment. *China Env. Ment. Sci.* **2016**, *36*, 634–640.
5. Feng, S.; Song, Z.; Wang, H. Evaluation of atmospheric environment quality for resource type cities based on Grey cluster method. *Earth Environ.* **2015**, *43*, 345–349.
6. Jiang, C.Y.; Zhang, X.; Hu, L.; Wang, Q.; Zhang, W.J. Application of AHP Method in Evaluation of Atmospheric Environment Comprehensive Quality in Xi'an. *Adv. Mater. Res.* **2012**, *347–353*, 2054–2057. [CrossRef]
7. Lv, W.; Ji, S. Atmospheric environmental quality assessment method based on analytic hierarchy process. *Discret. Contin. Dyn. Syst. S* **2019**, *12*, 941–955. [CrossRef]
8. Zebardast, L.; Salehi, E.; Afrasiabi, H. Application of DPSIR framework for integrated environmental assessment of urban areas: A case study of Tehran. *Int. J. Environ. Res.* **2015**, *9*, 445–456.
9. Cao, Y.; Bian, Y. Improving the ecological environmental performance to achieve carbon neutrality: The application of DPSIR-Improved matter-element extension cloud model. *J. Environ. Manag.* **2021**, *293*, 112887. [CrossRef]
10. Lu, Y.; Jiang, H.; Liu, N.; Cheng, X.; Ye, W. The carrying capacity assessment of the national atmospheric environment based on the new air quality standards. *Environ. Monit. China* **2017**, *33*, 65–72.
11. Dong, J.; Chen, X.; Cai, X.; Xu, Q.; Guan, Y.; Li, T.; Liu, S.; Chen, F. Analysis of the temporal and spatial variation of atmospheric quality from 2015 to 2019 based on China atmospheric environment monitoring station. *J. Geo Inf. Sci.* **2020**, *22*, 1983–1995.
12. Wu, Z.; Yin, Y. Has the air pollution prevention and control action completed the "blue sky protection campaign" of resource-based cities? *Ind. Econ. Res.* **2022**, *1*, 43–56. (In Chinese)
13. Fu, L. An empirical study on the relationship between the upgrading of China's industrial structure and economic growth. *Stat. Res.* **2010**, *27*, 79–81. (In Chinese)
14. Gan, C.; Zheng, R.; Yu, D. The impact of China's industrial structure change on economic growth and fluctuation. *Econ. Res. J.* **2011**, *46*, 4–16+31. (In Chinese)
15. Liu, S. Study on the construction of evaluation index system for the rationalisation of industrial structure. *Sci. Technol. Manag. Res.* **2011**, *31*, 66–69. (In Chinese)
16. Zhou, X.; Zhang, J.; Li, J. Industrial structural transformation and carbon dioxide emissions in China. *Energy Policy* **2013**, *57*, 43–51. [CrossRef]
17. Zhu, B.; Zhang, M.; Zhou, Y.; Wang, P.; Sheng, J.; He, K.; Wei, Y.; Xie, R. Exploring the effect of industrial structure adjustment on inter-provincial green development efficiency in China: A novel integrated approach. *Energy Policy* **2019**, *134*, 110946. [CrossRef]
18. Wan, L.; Zheng, Q.; Wu, J.; Wei, Z.; Wang, S. How does the ecological compensation mechanism adjust the industrial structure? Evidence from China. *J. Environ. Manag.* **2021**, *301*, 113839. [CrossRef]
19. Zhang, W.; Wang, J.; Zhang, B.; Bi, J.; Jiang, H. Can China Comply with Its 12th Five-Year Plan on Industrial Emissions Control: A Structural Decomposition Analysis. *Environ. Sci. Technol.* **2015**, *49*, 4816–4824. [CrossRef]
20. Zhang, J.; Jiang, H.; Liu, G.; Zeng, W. A study on the contribution of industrial restructuring to reduction of carbon emissions in China during the five Five-Year Plan periods. *J. Clean. Prod.* **2018**, *176*, 629–635. [CrossRef]
21. Cheng, X.; Fan, L.; Wang, J. Can energy structure optimisation, industrial structure changes, technological improvements, and central and local governance effectively reduce atmospheric pollution in the Beijing-Tianjin-Hebei area in China? *Sustainability* **2018**, *10*, 6443. [CrossRef]
22. Wang, S.; Li, C.; Zhou, H. Impact of China's economic growth and energy consumption structure on atmospheric pollutants: Based on a panel threshold model. *J. Clean. Prod.* **2019**, *236*, 117694. [CrossRef]

23. Ding, L.; Chen, K.; Hua, Y.; Dong, H.; Wu, A. Investigating the relationship between the industrial structure and atmospheric environment by an integrated system: A case study of Zhejiang, China. *Sustainability* **2020**, *12*, 12783. [CrossRef]
24. Zheng, Y.; Peng, J.; Xiao, J.; Su, P.; Li, S. Industrial structure transformation and provincial heterogeneity characteristics evolution of air pollution: Evidence of a threshold effect from China. *Atmos. Pollut. Res.* **2020**, *11*, 598–609. [CrossRef]
25. Zhou, Q.; Zhong, S.; Shi, T.; Zhang, X. Environmental regulation and haze pollution: Neighbor-companion or neighbor-beggar? *Energy Policy* **2021**, *151*, 112183. [CrossRef]
26. Wang, W.; Han, Y. An empirical analysis of the impact of the evolution of industrial structure on the ecological environment in Anhui province. *Stat. Decis.* **2017**, *8*, 142–145. (In Chinese)
27. Liao, K.-C.; Yue, M.-Y.; Sun, S.-W.; Xue, H.-B.; Liu, W.; Tsai, S.-B.; Wang, J.-T. An Evaluation of Coupling Coordination between Tourism and Finance. *Sustainability* **2018**, *10*, 2320. [CrossRef]
28. Li, Y.; Li, Y.; Zhou, Y.; Shi, Y.; Zhu, X. Investigation of a coupling model of coordination between urbanisation and the environment. *J. Environ. Manag.* **2012**, *98*, 127–133. [CrossRef]