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Impact Evaluation of Industrial Energy Consumption Based on Input-output Complex Network

Ren Zhou, Xinhua Wang*

College of Finance and Economics, College of Economics and Management, Shandong University of Science and Technology, Qingdao 266590, China

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Abstract

Target control and industrial transfer are important methods to regulate energy conservation and emission reduction in the region, so measuring the influence of each industry to energy consumption is the basis of regional industrial structure adjustment. Firstly, an energy flow network model is constructed based on the theory of Industrial Complex Network. It describes the mutual input and consumption of material and energy among industrial sectors. Then, the index system is designed to evaluate the influence of each industry on energy consumption in the economic system. According to the evaluation, methods are searched for to regulate energy-saving and emission-reducing on the industrial level. Based on the data of Shandong Province, the strategies of energy saving and emission reduction are put forward: research and develop new technologies; Sort management, focusing on the control of "key industries", and paying attention to the industries that consume less energy but relevant more with others appropriately; Rational layout industry, optimize industrial structure and so on.

Keywords: energy consumption; energy flow network; Shandong province; evaluation of industrial impact;

1. Introduction

Industrial transfer is an important method to realize the rational distribution of productive forces and the coordinated development of the region. With the influence of the pressure of energy conservation and emissions reduction, many economic developed areas limit the development of the industry with high energy consumption and high pollution, so more and more such industries were transferred to less developed area. How to adjust regional industrial structure? Domestic and foreign scholars have studied the influence of industrial structure on energy consumption.

Watanabe analyzed the impact of changes in industrial structure on energy consumption to 20% [1]. Ang [2], Hasanbeigi et al. [3], Choi and Ang [4] concluded that the change of the industrial structure in different periods contribute different to energy consumption by LMDI. Lu confirmed that the total amount of energy consumption is highly correlated with the industrial structure by regression analysis [5]; Zhang and Huang confirmed that economic structure dominated by second industries has an accelerating effect on energy consumption [6]. Yin et al. constructed VECM and found that the changes in energy consumption and industrial structure present a positive correlation in the long run, and the development of the second and tertiary industries has a significant impact on the increase of energy consumption [7]. Most of these studies are based on the three industry divisions, but in fact there are thousands of floor links between the sub sectors, and the energy consumption level varies greatly. It is very important to analyze the impact of changes in the structure of industry segments on energy consumption.

In the late twentieth century, complex networks were applied to the field of social science. More and more scholars combine input-output theory with complex network theory to study industrial association. In foreign countries, of professor Campbell [8], the professor of Washington University introduced graph theory into industrial association research firstly; Schnabl [9], Aroche [10], Morillas et al. used different quantitative methods to determine the threshold and extract strong correlation, and construct their respective industrial complex network models [11]. Mcnemey et al. built industrial networks based on input-output data from more than 20 countries and found that they have similar associations [12]. In China, Zhao et al. constructed a graph model of industry association structure using the WI index to study the industry supply chain and related structure of Shandong province [13]. Chen et al. used the industry complex network theory to study the side effect of industry [14]. Sun and Wang [15] and Wang and Sun [16] compared the industrial correlation of Beijing Tianjin and Hebei, and identified their key industry.

From the existing research results, the modeling and optimization of industrial related networks using input-output table has made great progress. However, using complex networks to analyze energy flow and evaluate the impact of energy consumption in subdivision industries is not deep enough. Therefore, this paper uses the input-output table and the industrial energy consumption data of Shandong province, constructs the energy consumption flow network model and the industrial energy consumption

* Corresponding author e-mail: zwhx741@sina.com.

influence evaluation system, and looks for the road of industrial development under the premise of energy saving and emission reduction.

2. Theoretical Model and Research Method

An energy flow network model is constructed based on the theory of Industrial Complex Network. It describes the mutual input and consumption of material and energy among industrial sectors. Then, the index system is designed to evaluate the influence of each industry on energy consumption in the economic system. After that, using entropy weight method to determine the index weight.

2.1. Construction of energy flow associated network model

With each industry sector as the node, the amount of energy invested and consumed by the industrial sector as a link, according to the input-output relation of energy consumption among industries, a complex network model with energy flow relationship is established. The point set V is used to represent the industrial sector set, and the edge set L represents the inter industry input-output relation. The weight set W represents the weights of each edge, that is, the relationship of input and output between the industries [17]. The network graph T = (V, L, W). The edge set L embodied energy flow relationship between the industry, if the industry i invest energy to industrial j, then there is an edge Lij from i to j; if no energy is invested from industry i to industry j, Lij does not exist. Because the energy input from industry i to industry j does not necessarily exist when the energy input from industry j to industry i exists, lij≠lji. The energy input weights from industry i to industry j is marked on each side in the figure as Wij. The inter industry input-output is different, so Wij ≠ Wji. Since most industry sectors have mutual input and mutual consumption, Lij and Lji may exist simultaneously. So, the complex network is asymmetrical, directed with multiple edges possibly.

2.2. The index to evaluate the influence of each industry to energy consumption

Based on the statistical index properties of the complex network, four types of indicators are set including breadth of node, depth of node, spread degree of node and dominant degree of node, to analyze the energy consumption influence of the node from forward, backward and integrated three angles.

1. Breadth index of node

It describes the ability of the target node to affect other nodes directly. 3 indexes including forward, backward and integrated breadth index are set to describe the node range directly pushed, pulled and related strongly. The forward breadth of nodes describes the number of strongly related nodes that are directly affected by the active supply or passive demand, and is expressed by in-degree centrality [18-20]. The backward breadth of nodes describes the number of backward strong connected nodes, which is directly affected by the passive supply or the active demand, and is expressed by out-degree centrality. The comprehensive breadth of nodes describes the number of forward or backward strongly connected nodes that are directly affected by the supply and demand relationship. It can be measured by the sum of in-degree centrality and out-degree centrality. The higher the 3 indexes, the stronger the width of the associated nodes. If $d_I(n_i)$ represents in-degree centrality, $d_O(n_i)$ represents out-degree centrality, then $d_I(n_i)=\sum_{j=1}^{g} x_{ji}$, $d_O(n_i)=\sum_{j=1}^{g} x_{ij}$.

x_{ij} represents the weight value of the effective connection between n_i and n_j, and g represents the number of sectors.

2. Depth of node

Depth of node describes how the target node transfers its affection directly and indirectly to other nodes via network association. 3 indexes including forward, backward and integrated depth index are set. The forward depth describes the degree to which nodes extend forward through the supply chain. It can be calculated by reciprocal of out closeness centrality. Out closeness centrality can be calculated by the reciprocal of the sum of the shortcuts from the destination node to all other nodes along the direction of the network edge.

The backward depth describes the degree to which nodes extend backward progressively through the demand chain. It can be calculated by reciprocal of in closeness centrality. In closeness centrality can be calculated by the reciprocal of the sum of the shortcuts from the destination node to all other nodes inverse the direction of the network edge. The integrated depth describes the degree to which the nodes extend forward or backward through the supply chain or demand chain, which is calculated by the sum of the forward depth and the backward depth. The higher the 3 indexes, the stronger the individual depth of nodes. If $C_c(n_i)$ represents closeness centrality, then $C_c(n_i)=\frac{g-1}{\sum_{j=1}^{g} d(n_i,n_j)}$.

$d(n_i,n_j)$ represents the shortest path from n_i to n_j.

3. Spread of node

Spread of node describes the potential level of the target nodes. 3 indexes are set up: forward spread, backward spread and complete spread. Forward spread is calculated by Katz horizontal influence, (the row sum of network adjacency matrix or flow matrix). Backward spread degree is calculated by Katz vertical influence, (the column sum of network adjacency matrix or flow matrix). Integrated spread degree describes the sum of Katz horizontal influence and Katz vertical influence. The higher the three indexes, the greater the spread of nodes.

4. Dominance of node

Dominance of node describes the degree to which nodes control other nodes. 2 indexes, node relation dominance and node flow dominance, are used to describe the degree of node control to other nodes and traffic flow. The dominance of node relation represents the relation control ability of nodes on the whole network. If a node is in many other nodes on the path through the interactive network, so it occupies an important position, can affect other nodes through energy transfer control, in the middle of the central node of the relation between dominant degree [21]. The node flow dominance describes the network path where the nodes interact with each other, and the degree of control of the energy transfer between other nodes is expressed by the center of the flow. The higher the 2 indexes, the stronger the dominance of nodes. If $C_B(n_i)$ represents betweenness centrality, then $C_B(n_i)=\frac{\sum_{j<k} g_{jk}(n_i)/g_{jk}}{(g-1)(g-2)/2}$.

g_{jk} represents the number of shortest paths associated with energy flows between industries j and k, $g_{jk}(n_i)$ represents how many ni industry is contained in the shortest energy flow path connecting industries j and k.

2.3. Index weight determination

In order to understand the influence of each department more clearly, the index weight is determined by entropy weight method. The forward impetus, the backward pulling power and the comprehensive influence are evaluated respectively.

According to the variability of indexes, entropy weights determine the weights of indexes. The weighting steps are as follows:

First of all, data standardization processing.

Suppose there are n indicators $X_1, \ldots, X_n$, among $X_j = \{x_{1j}, x_{2j}, x_{3j}, \ldots x_{ij}\}$, x_{ij} Represents indicator j of industry I, then the standardized value of each index is $x_{ij}^* = \frac{x_{ij} - x_{\min j}}{x_{\max j} - x_{\min j}}$.

Then, calculate the information entropy of each index.

According to information theory, Information entropy is $E_j = \frac{-\sum_{i=1}^{n} P_{ij} \ln(P_{ij})}{\ln(n)}$, among which, if $P_{ij} = \frac{x_{ij}^*}{\sum_{i=1}^{n} x_{ij}^*}$, let $\lim_{P_{ij} \to 0} P_{ij} \ln(P_{ij}) = 0$.

Finally, the weight of each index is determined $W_j = \frac{1 - E_j}{n - \sum_{i=1}^{n} E_j}$, $Score = \sum w_j x_{ij}^*$

3. Results

Based on the data of Shandong Province, the complex network model of energy flow is constructed, the sub-index of energy flow influence is calculated, and the energy flow influence of each industry is evaluated.

3.1. Data sources and processing

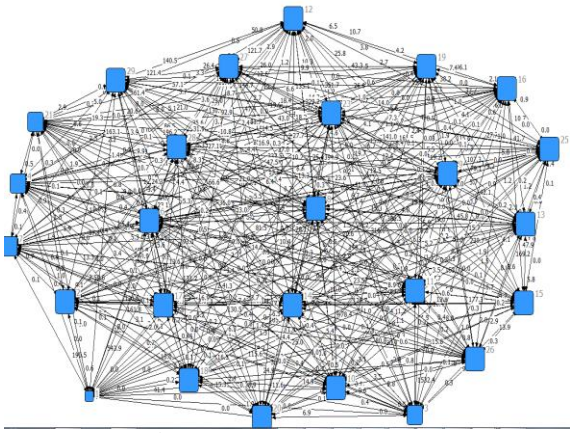

Figure 1. energy flow associated 2 mode network diagrams

The construction of the complex network model requires data of input-output table and energy consumption table. The design department of them are not unified, so in order to facilitate the analysis and comparison, based on the input-output table and the energy consumption table of Shandong in 2012, the energy consumption table and input-output table of 29 sectors are merged, and the energy input and output table of the department is calculated on this basis [22]. The energy consumption data of each industry sector in 2012 were obtained from the statistical yearbook in 2013, and the industrial energy consumption matrix was calculated according to the direct industrial consumption coefficient. To facilitate observation, a network diagram (**Fig. 1**) is constructed. In **Fig. 1**, the point set V consists of 29 industry sectors with input-output relationships. The size of the node represents the magnitude of the degree. The industry code is marked on the right side of the node. The energy flow between nodes is marked on the line. The industry code is shown in **Table 1**.

Table 1. Industry code

code	industry	code	industry
1	Agriculture, forestry, animal husbandry and fishery	16	General purpose equipment manufacturing
2	Coal mining and cleaning	17	Transportation equipment manufacturing
3	Oil and gas extraction	18	Electrical machinery and equipment manufacturing
4	Metal mining industry	19	Communications equipment, computers and other electronic equipment manufacturing
5	Non-metal mining and other mining industry	20	Instrument and culture office machinery manufacturing
6	Food manufacturing and tobacco processing industry	21	Crafts and other manufacturing industries
7	Textile industry	22	waste
8	Textile, clothing, shoes and caps, leather, down and its products	23	The production and supply of electricity and heat
9	Wood processing and furniture manufacturing	24	Gas production and supply
10	Paper making, printing and the manufacturing of stationery and sports goods	25	Water production and supply
11	Petroleum processing, coking and nuclear fuel processing	26	Construction industry
12	Chemical industry	27	Transportation, ware-housing and postal services
13	Non-metallic mineral manufacturing	28	Wholesale & retail, accommodation catering
14	Metal smelting and rolling industry	29	Other social services
15	Metal products		

3.2. Industry energy flow influence index calculation

According to the formula in 2.1 and industry energy flow matrix, using UCINET software, the indicators are calculated to analyze the impact of energy flow in each industry, as shown in Table 2.

To see the effect of each industry more clearly, a scatter plot is plotted, as shown in **Fig. 2**.

Table 2. comprehensive analysis index of node influence.

code	breadth			depth			spread			dominance	
	Forward breadth	Backward breadth	Comprehensive breadth	Forward depth	Backward depth	Comprehensive depth	Forward spread	Backward spread	Complete spread	Relational dominance	Flow dominance
1	1.43	0.38	1.81	0.029	0.026	0.055	0.022	0.006	0.028	0.231	10.785
2	1.79	0.667	2.457	0.032	0.034	0.067	0.029	0.011	0.04	2.078	3.294
3	1.896	0.423	2.319	0.030	0.028	0.058	0.030	0.007	0.037	0.203	3.459
4	1.631	0.153	1.784	0.034	0.021	0.055	0.027	0.002	0.029	0.382	0.477
5	0.438	0.075	0.513	0.034	0.029	0.063	0.007	0.001	0.008	2.409	0.704
6	0.862	1.307	2.169	0.034	0.025	0.059	0.014	0.020	0.034	1.479	7.128
7	0.725	1.043	1.768	0.033	0.033	0.067	0.011	0.016	0.027	2.257	3.484
8	0.446	0.139	0.585	0.034	0.036	0.070	0.007	0.002	0.009	4.416	2.024
9	0.244	0.223	0.467	0.032	0.034	0.067	0.004	0.003	0.007	3.189	1.477
10	0.919	1.062	1.981	0.034	0.036	0.070	0.014	0.017	0.031	4.416	3.460
11	1.866	2.381	4.247	0.031	0.036	0.067	0.030	0.037	0.067	1.473	2.975
12	4.836	6.208	11.044	0.036	0.036	0.071	0.079	0.102	0.181	6.933	20.788
13	1.11	2.729	3.839	0.034	0.034	0.069	0.018	0.043	0.061	5.505	9.365
14	3.85	8.146	11.996	0.033	0.036	0.069	0.062	0.133	0.195	5.336	10.719
15	0.518	0.652	1.17	0.033	0.036	0.069	0.008	0.011	0.019	5.336	3.046
16	1.304	0.565	1.869	0.036	0.036	0.071	0.021	0.009	0.03	6.933	5.429
17	0.644	0.33	0.974	0.033	0.036	0.069	0.010	0.005	0.015	5.336	1.901
18	0.874	0.595	1.469	0.036	0.036	0.071	0.014	0.010	0.024	6.933	3.095
19	0.206	0.093	0.299	0.033	0.036	0.069	0.003	0.001	0.004	4.831	1.662
20	0.22	0.017	0.237	0.029	0.036	0.065	0.004	0.000	0.004	0.74	1.258
21	0.118	0.065	0.183	0.032	0.036	0.068	0.002	0.001	0.003	2.685	1.543
22	0.231	0.018	0.249	0.026	0.023	0.050	0.004	0.000	0.004	0	0.786
23	1.919	1.745	3.664	0.029	0.036	0.065	0.031	0.027	0.058	0.617	5.761
24	0.046	0.056	0.102	0.032	0.030	0.063	0.001	0.001	0.002	1.465	0.901
25	0.063	0.087	0.15	0.030	0.036	0.066	0.001	0.001	0.002	1.088	1.283
26	0.093	0.442	0.535	0.031	0.033	0.065	0.001	0.007	0.008	1.15	1.984
27	1.376	1.613	2.989	0.032	0.036	0.068	0.022	0.026	0.048	2.6	12.668
28	0.813	0.579	1.392	0.032	0.036	0.068	0.013	0.009	0.022	2.685	10.188
29	1.955	0.63	2.585	0.030	0.036	0.066	0.031	0.010	0.041	2.294	14.210

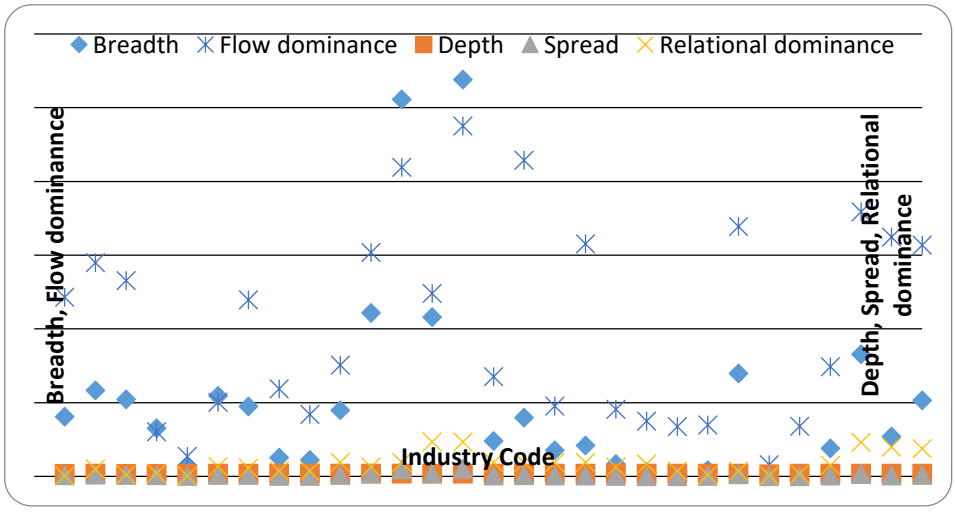

Figure 2. Index of node influence.

As can be seen from **Fig. 2**, among the chemical industry, metal smelting and rolling processing industry, non-metallic mineral products industry, transportation, warehousing, postal service, the indicators are in the top 10. While among waste, gas production and supply, water production and supply, instrument and culture office machinery manufacturing, non-metallic minerals and other mineral extraction and construction industry, the indicators are in the latter 10.

Most of the indexes in chemical industry, metallurgy and materials industry, transportation, machinery, production and supply of electronic equipment manufacturing industry and electric power are higher, especially the influence degree, and they have greater dominance, which is the main driving force of economic development in Shandong [23]. It shows that industry is the main industry of energy consumption and occupies a central position. The manufacturing industry is relatively mature, a relatively complete industrial chain, chemical industry, metallurgy, energy and raw materials have certain comparative advantages, but economic development is constrained by energy and resources.

The industries such as transportation, warehousing, postal services, other social services, wholesale and retail, accommodation, catering have strong impact, which means that traditional advantages of the third industry are flourishing, largely contributing to other industries and impacting the economy. But other social services are integrated data from multiple departments, and restricted by data acquisition, so they cannot fully analyze the specific circumstances of each department.

3.3. Comprehensive analysis of energy flow influence among industries

The comprehensive analysis of energy flow influence among industries is developed from three aspects: forward thrust force analysis, backward pull force analysis and comprehensive influence force analysis.

1. Forward thrust of energy flow

The weights of Forward breadth, Forward depth and Forward spread are 0.511621, 0.0748 and 0.413579 respectively by entropy weight method. The forward force of the energy flow obtained from the weighted sum of the normalized values of each index is shown in the last column of Table 3.

From the angle of forward force, all the indexes in chemical industry, metal smelting and rolling processing industry, electricity & heat production and supply industry, petroleum and natural gas exploitation industry, petroleum processing, coking and nuclear fuel processing, coal mining and cleaning industry are more than 0.9, far higher than 0.58 of the average. These industries are basic industries in the national economy, and the development of economy will drive the energy consumption of these industries to increase significantly. Take the chemical industry for example, if the final demand of each sector of the national economy grows by 1 unit, the energy consumption of the chemical industry will be increased by 2.5 times. Therefore, the industry should strengthen technological innovation and improve energy efficiency. Not only should they maintain a certain economic scale to meet the needs of the national economic development, but they also should not cause waste of energy.

Table 3. Calculation table of forward force

Code	Forward breadth (0.511621)	Forward depth (0.0748)	Forward spread (0.413579)	Forward force
1	0.731618	0.002169	0.009099	0.742886
2	0.915802	0.002394	0.011994	0.930189
3	0.970033	0.002244	0.012407	0.984685
4	0.834454	0.002543	0.011167	0.848164
5	0.22409	0.002543	0.002895	0.229528
6	0.441017	0.002543	0.00579	0.449351
7	0.370925	0.002468	0.004549	0.377943
8	0.228183	0.002543	0.002895	0.233621
9	0.124836	0.002394	0.001654	0.128883
10	0.47018	0.002543	0.00579	0.478513
11	0.954685	0.002319	0.012407	0.969411
12	2.474199	0.002693	0.032673	2.509564
13	0.567899	0.002543	0.007444	0.577887
14	1.969741	0.002468	0.025642	1.997851
15	0.26502	0.002468	0.003309	0.270797
16	0.667154	0.002693	0.008685	0.678532
17	0.329484	0.002468	0.004136	0.336088
18	0.447157	0.002693	0.00579	0.45564
19	0.105394	0.002468	0.001241	0.109103
20	0.112557	0.002169	0.001654	0.11638
21	0.060371	0.002394	0.000827	0.063592
22	0.118184	0.001945	0.001654	0.121784
23	0.981801	0.002169	0.012821	0.996791
24	0.023535	0.002394	0.000414	0.026342
25	0.032232	0.002244	0.000414	0.03489
26	0.047581	0.002319	0.000414	0.050313
27	0.70399	0.002394	0.009099	0.715483
28	0.415948	0.002394	0.005377	0.423718
29	1.000219	0.002244	0.012821	1.015284

2. Analysis of pulling force after flow

The weights of Backward breadth, Backward depth and Backward spread were determined by entropy weight method as 0.473245, 0.052171 and 0.474583 respectively. The backward pulling force of the energy flow obtained from the weighted sum of the normalized values of each index is shown in the last column of Table 4.

From the backward pulling power angle, all the indexes in metal smelting and rolling processing industry, chemical industry, non-metallic mineral products industry, petroleum processing, coking and nuclear fuel processing and manufacturing are more than 1, far higher than the average level, which means they have great influences on other industries. If the eventual use of each of these sectors grows by 1 unit, it will produce more the demand for other sectors of the national economy, resulting in a substantial increase in energy consumption. Take metal smelting and rolling processing industry as an example, a unit of final demand growth will promote the entire national economy energy consumption increased by 3.92 times.

Therefore, in order to save energy, the excessive growth of these industries should be appropriately controlled, and substantial increase in energy consumption also should be avoided so as not to have a great influence on the whole national economy. At the same time, these departments use policies incentives and technological advances to improve energy efficiency and reduce energy consumption per unit of output.

Table 4. calculation table of backward pulling force.

Industry	Backward breadth (0.473245)	Backward depth (0.052171)	Backward spread (0.474583)	Backward pulling force
&1	0.179833	0.001356	0.002848	0.184037
2	0.315655	0.001774	0.00522	0.322649
3	0.200183	0.001461	0.003322	0.204966
4	0.072407	0.001096	0.000949	0.074451
5	0.035493	0.001513	0.000475	0.037481
6	0.618532	0.001304	0.009492	0.629328
7	0.493595	0.001722	0.007593	0.50291
8	0.065781	0.001878	0.000949	0.068608
9	0.105534	0.001774	0.001424	0.108731
10	0.502586	0.001878	0.008068	0.512533
11	1.126797	0.001878	0.01756	1.146235
12	2.937907	0.001878	0.048408	2.988192
13	1.291486	0.001774	0.020407	1.313667
14	3.855056	0.001878	0.06312	3.920054
15	0.308556	0.001878	0.00522	0.315655
16	0.267384	0.001878	0.004271	0.273533
17	0.156171	0.001878	0.002373	0.160422
18	0.281581	0.001878	0.004746	0.288205
19	0.044012	0.001878	0.000475	0.046365
20	0.008045	0.001878	0	0.009923
21	0.030761	0.001878	0.000475	0.033114
22	0.008518	0.0012	0	0.009718
23	0.825813	0.001878	0.012814	0.840505
24	0.026502	0.001565	0.000475	0.028541
25	0.041172	0.001878	0.000475	0.043525
26	0.209174	0.001722	0.003322	0.214218
27	0.763345	0.001878	0.012339	0.777562
28	0.274009	0.001878	0.004271	0.280158
29	0.298145	0.001878	0.004746	0.304769

3. Comprehensive influence analysis of energy flow

Finally, the comprehensive influence of energy flow was analyzed, and the weights of Comprehensive Breadth, Comprehensive depth, Complete spread, Relational dominance, Flow dominance were 0.344592, 0.024065, 0.341423, 0.201428, 0.088492 respectively, the weighted summation of the normalized values of each index has a combined effect as shown in Table 5.Calculate the power flow impact as shown in the last column of Table 5.

From the angle of comprehensive influence, all the indexes in chemical industry, metal smelting and rolling processing industry, other social services, transportation and storage sector, non-metallic mineral products industry are much higher than the average level and have great influence on other industries.

As shown in **Fig. 3**, the dominance index makes the third industry and the first industry more influential, indicating that they are in the network path of the interaction between the nodes in the second industry and largely control energy transmission degree of the second industry nodes. The development of these industries will affect the development of the second industry; therefore, these industries should be developed moderately.

Table 5. Calculation chart of comprehensive influence

Industry	Comprehensive Breadth (0.285209)	Comprehensive depth (0.037602)	Complete spread (0.300492)	Relational dominance (0.138667)	Flow dominance (0.238029)	Comprehensive influence
1	0.516227	0.002068	0.008414	0.032032	2.567146	3.125888
2	0.700757	0.002519	0.01202	0.28815	0.784069	1.787515
3	0.661399	0.002181	0.011118	0.028149	0.823343	1.526191
4	0.508812	0.002068	0.008714	0.052971	0.11354	0.686105
5	0.146312	0.002369	0.002404	0.334049	0.167573	0.652706
6	0.618617	0.002219	0.010217	0.205088	1.696673	2.532814
7	0.504249	0.002519	0.008113	0.312971	0.829294	1.657147
8	0.166847	0.002632	0.002704	0.612353	0.481771	1.266308
9	0.133192	0.002519	0.002103	0.442209	0.351569	0.931594
10	0.564998	0.002632	0.009315	0.612353	0.823581	2.01288
11	1.211281	0.002519	0.020133	0.204256	0.708137	2.146327
12	3.149843	0.00267	0.054389	0.961378	4.948154	9.116434
13	1.094916	0.002595	0.01833	0.763362	2.229145	4.108347
14	3.421362	0.002595	0.058596	0.739927	2.551436	6.773916
15	0.333694	0.002595	0.005709	0.739927	0.725037	1.806962
16	0.533055	0.00267	0.009015	0.961378	1.292261	2.798379
17	0.277793	0.002595	0.004507	0.739927	0.452494	1.477316
18	0.418971	0.00267	0.007212	0.961378	0.736701	2.126932
19	0.085277	0.002595	0.001202	0.6699	0.395605	1.154579
20	0.067594	0.002444	0.001202	0.102614	0.299441	0.473295
21	0.052193	0.002557	0.000901	0.372321	0.367279	0.795252
22	0.071017	0.00188	0.001202	0	0.187091	0.26119
23	1.045004	0.002444	0.017429	0.085558	1.371287	2.521721
24	0.029091	0.002369	0.000601	0.203147	0.214464	0.449673
25	0.042781	0.002482	0.000601	0.15087	0.305392	0.502125
26	0.152587	0.002444	0.002404	0.159467	0.47225	0.789152
27	0.852488	0.002557	0.014424	0.360534	3.015355	4.245359
28	0.39701	0.002557	0.006611	0.372321	2.425043	3.203542
29	0.737264	0.002482	0.01232	0.318102	3.382397	4.452565

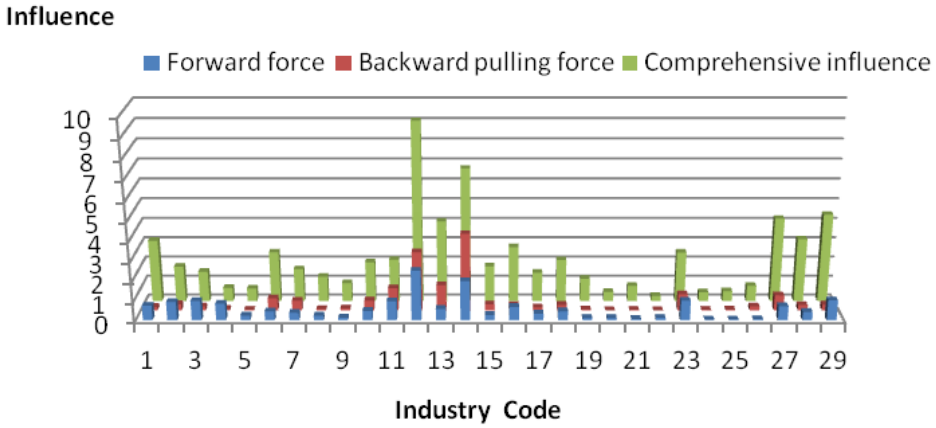

Figure 3. Energy flow influence of industry.

4. Conclusions and Policy Recommendations

Through the complex network analysis of energy input and output, we can see that the interaction between industries is frequent, the energy flow is active, and the network is closely linked, which provides the following inspiration for energy conservation and emission reduction policy formulation:

1. Rational distribution of industries and optimization of industrial structure

The optimization of industrial structure is the process of promoting the rationalization and development of industrial structure. The rational coordination of industrial structure requires not only the balance among industries, but also the strong complementarity and mutual transformation ability among industries. The high coordination among industries can improve the quality of industrial structure aggregation, curb the waste of energy, and improve the overall the effect of energy saving and emission reduction so as to realize the rationalization of industrial structure under certain economic conditions and ensure the coordination and sustainability of economic growth.

By studying the complex network of input and output flow we can see that industries are closely related with each other. The regional layout of any industry will affect other enterprises. Therefore, we should have a reasonable industrial layout, maximize the energy efficiency of the industry in the region energy flow, and make energy flow smoothly to reduce pollution emissions, assemble industries that can flow closely together, and optimize the overall allocation of resources.

2. classification management, focusing on controlling the key industries, and paying attention to the industries with less energy consumption but great relevance

By analyzing the influence of the nodes, the forward driving force and the backward pulling force are defined". Focus on control of the node with frequent and large energy flow. Prescribe the right medicine when making a policy.

The key sectors, such as chemical industry, metal smelting and rolling processing industry, petroleum processing, coking and nuclear fuel processing industry, which have both high "forward driving force" and "backward pulling power", not only made great contribution to the regional economic growth, but also caused a great deal of energy consumption. If these departments continue to develop at a high speed, they will drive the energy consumption of other departments to increase by a big margin, and the growth in the final demand for other sectors will also lead to an increase in energy consumption in such industries. So, in the process of adjusting industrial structure we should not only consider appropriate controls on the scale of these industries, optimize the internal structure of the industry through technological innovation and eliminating backward production capacity, but also protect proportion of these industries so as to avoid affecting economic development.

Some energy industries and basic industries, such as agriculture, forestry, animal husbandry and fishery; coal mining and cleaning industry; oil and natural gas extraction industry; metal mining industry, which have small "forward driving force" and "backward pulling force", are the energy output in the whole economy system. They transfer more energy consumption to maintain a certain economic scale to meet the needs of economic development. The eventual increase in demand from other sectors will lead to an increase in energy consumption in these sectors. But the expansion of these industries has a relatively small impact on the energy consumption of the entire economic system, we can strengthen technological innovation to ensure that energy waste is not caused by large-scale expansion

For other hi-tech industries and service industries, such as general purpose, special equipment manufacturing; instrument manufacturing; other manufacturing; metal products; electricity, thermal production and supply; construction; which have small "forward driving force" and big "backward pulling force", although the output of energy consumption is small, the demand for energy consumption is not small. Its energy consumption comes from the upstream sector of the industry chain, namely energy industry, basic industry and so on. This shows that in the economic chain, departments located upstream of the industry chain shift their energy consumption to the downstream sectors of the industry chain through intermediate inputs. Meanwhile, departments located downstream of the industry chain also meet their own end demand by net input from upstream sectors. Proper controls should be taken on the scale of such industries and we should optimize the industrial structure by eliminating backward production capacity and encouraging technological innovation to prevent a significant increase in energy consumption in other industries. The energy sector has undertaken a large amount of energy consumption for other sectors and is a key sector of the economic system. It is vital to improve energy efficiency and increase the use of low-carbon energy. The development of low-carbon energy is of great significance for achieving the goal of energy conservation and emission reduction.

In some departments, neither "forward driving force" nor "backward pulling force" is large, such as gas, water production and supply industry; accommodation and catering; whose energy consumption is not high. Their investment in energy consumption of other industries is not much, either. However, they relate to all sectors of the national economy and have more indirect energy consumption, and proper control is also necessary.

In conclusion, considering the transformation of industrial structure and energy saving and emission reduction, we should not simply consider the energy consumption and emission intensity of each industry, but comprehensively. Direct energy consumption and emission intensity in some industries may be low, but the total energy consumption and emission intensity are not low, so when the industrial structure was transformed into a low-powered industry, it is likely to reduce energy consumption per unit of GDP without reducing the energy consumption across the entire economy, because there is a problem of energy transfer within the industrial structure. Simply limiting the development of high-energy industries may reduce the energy consumption and emission intensity, but at the same time it may also pose a threat to other industries.

3. Actively develop new technologies

For those highly spreading and dominant industries, such as the chemical industry, metal smelting and rolling processing industry, non-metallic mineral products industry, we should increase technology investment, actively develop energy-saving and energy-reducing consumption and clean production technologies and improve energy efficiency.

4. Optimize the industrial cluster and enhance the competitiveness of the cluster

Regional industrial competitiveness, optimization of industrial structure and the development and policy induction of industrial clusters should be based on the internal division of labor. Through cluster analysis, we study the relationship between division of labor and cooperation in industry and then formulate industrial cluster policy, cultivate, optimize and even rebuild the industrial chain to form the optimal economic development path for the region.

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