Grey Neural Network and Input-Output Combined Forecasting Model and Its Application in Sub-sector Energy Related Carbon Dioxide Emissions Estimation in China

Xiuli Liu[a*], Geoffrey J. D. Hewings[b]
a Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Zhongguancun East Road No.55, Beijing, 100190, China
b Regional Economics Applications Laboratory, University of Illinois, 607 S. Mathews, #318, Urbana, IL 61801, USA

Abstract: The 2007 China energy input-occupancy-output table with 42 sectors was compiled in this paper. Moreover, a grey Neural Network and Input-Output Combined Forecasting Model (GNF-IO) is built to forecast coal, crude oil and natural gas that consumed by 42 industries in China. These are then applied to estimate carbon dioxide emissions related with coal, crude oil and natural gas consumed by 42 industries in China in 2010. According to the analyses and estimation results, the sub-sectors energy conservation policy recommendations were presented.

1 Introduction

As one of the two largest emitters of CO_2 in the world today, China has and will continue to receive more and more pressures to reduce GHG emissions (He et al., 2007). On the Copenhagen Climate Summit in 2009, China proposed a carbon emission reduction of 40%-45% by 2020 based on the 2005 carbon emission level. China's coal-based energy consumption structure determines more than 75% greenhouse gas emissions in China

*Corresponding Author: Xiuli Liu, Tel: +86-10-62545830; fax: +86-10-62541823; e-mail: xiuli.liu@amss.ac.cn

comes from the energy consumption. According to the statistics of CDIAC (2002), approximately 77.9% of total energy-related CO_2 emissions in China were from coal combustion, 19.8% from petroleum, and 2.3% from natural gas.

The authorities commented that the heavy task of carbon emissions reduction in China will be broken down to specific industries in 2010. However, there is no solid index which could be used to determine sub-sector carbon emission reduction tasks[†].

To estimate three types of fossil fuels coal, crude oil and gas consumption and resulting CO_2 emissions by each industry could be an effective factor to determine sub-sector carbon emission reduction tasks.

Hitherto, there have been many studies which focused on the future energy requirements and CO_2 emissions in China. At the national level, van Vuuren et al. (2003) employed the model IMAGE/TIMER to develop a set of energy and emission scenarios for China between 1995 and 2100. Chen (2005) used the model MARKAL-MACRO to generate China's reference scenario for future energy development and carbon emission through the year 2050. Crompton and Wu (2005) applied Bayesian vector autoregressive methodology to forecast China's energy consumption through the year 2010. Other similar works include Lu and Ma (2004), Zheng et al. (2005), etc. Shi and Zhao (1999) projected China's total energy

consumption in 2005 and 2015. They considered transportation and residential sectors will likely be the sectors contributing to China's increased energy consumption in the future. Several earlier studies have estimated the historical trends of energy demand and/or the associated GHG emissions in China's road transport sector and the future trends under different policy scenarios (He et al., 2005; K. He, H. Huo, et al., 2005; Wang et al., 2007; Yan and Crookes, 2007b; Zhang, 2004). The differences in the forecasts presented in these studies are attributable to differences in the data sets and forecasting techniques used. However, these studies failed to provide reliable historical trends and forecast results of energy related CO_2 emission by sector in the system. Combined forecasting method combine many single forecasting model and get a new model that include kinds of forecasting news from different forecasting model, which is fit for complex systems with incomplete information especially.

In the first part of this paper, the Grey Neural Network and Input-Output Combined Forecasting Model (GNF-IO) will be built and the model captures coal, crude oil and natural gas related CO_2 emissions. Based on the 2007 China energy input-occupancy-output table, consumption structure of 3 kinds of primal energy among 42 industries are also evaluated, which are combined with the development planning of renewable energy. By applying the GNF-IO model, a reliable coal, crude oil and natural gas consumption volume and the related CO_2 emissions

volume by China's 42 sectors up to 2010 will be provided. According to the analysis and estimation results, the sub-sectors energy conservation policy recommendations will be presented.

The second part of the paper analyzes consumption structure of 3 kinds of primal energy among 42 industries in China, which is followed by the third part topic on the GNF-IO Model. The fourth and fifth parts are kinds of primal energy consumption forecast with GNF-IO model and sub-sectors carbon dioxide emissions estimation for kinds of energy consumption. Finally, the sixth part provides conclusions with policy suggestions.

2. Consumption structure: 3 types of primary energy among 42 industries

With the energy consumption statistics data In China Energy Statistics Yearbook 2008 and the China 2007 input-output table, the China energy input-occupancy-output table in 42 sectors was compiled. Sector classifications should refer to Appendix 1. By applying this table, the consumption structure of 3 kinds of primary energy by sector in China in 2007 were analyzed (See Figure. 1).

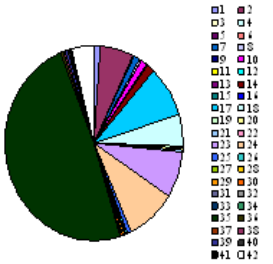

Figure.1(a) Coal consumption structure by sector

Figure.1(b) crude oil consumption structure by sector

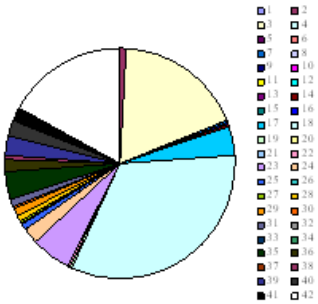

Figure.1(c) Gas consumption structure by sector

As shown in Figure.1(a), the distribution of coal consumption in China's various industries was very different in 2007: electricity, heat production and supply consumed most coal, accounted for 48.7% of the total coal consumption; ferrous metal smelting and rolling processing industry consumed 8.8% of the total coal consumption; petroleum processing, coking and nuclear fuel processing industry consumed 8.7%, non-metallic mineral products industry consumed 7.7%, coal mining and dressing consumed 6%, and living consumed 4% of the total coal consumption.

As illustrated in Figure.1(b), it was clear that 86.5% of China's crude oil was consumed by oil processing, coking and nuclear fuel processing industry and 8.4% of crude oil was consumed by Raw Chemical Materials and Chemical Products industry.

Figure.1(c) depicts evidences in 2007 that 33% of natural gas was consumed in raw chemical materials and chemical products industry, 17.8% of natural gas was consumed by oil and natural gas mining industry, and 17.0% was consumed by living.

3. Consumption structure change of coal, crude oil and gas among 42 industries in China from 2003 to 2007

Based on the consumption data during 2003-2007 of the primal energy coal, crude oil and natural gas in China Energy Statistical Yearbook 2004-2008, divided and re-combined their sector classifications into the same with the Attachment 1. The correlation analysis between any two years of three kinds of primal energy consumption structure among 42 sectors in 2003, 2005, 2006 and 2007 could be referred through Tab.1 to Tab.3.

Table. 1 Correlation coefficient between any two years of coal consumption structure among 42 sectors in 2003, 2005, 2006 and 2007

Year	2003	2005	2006	2007
2003	1			
2005	0.9998	1		
2006	0.9996	0.9998	1	

2007	0.9994	0.9996	0.9999	1

Table. 2 Correlation coefficient between any two years of crude oil consumption structure among 42 sectors in 2003, 2005, 2006 and 2007

Year	2003	2005	2006	2007
2003	1			
2005	0.9907	1		
2006	0.9887	0.9998	1	
2007	0.9886	0.9998	0.9999	1

Table.3 Correlation coefficient between any two years of gas consumption structure among 42 sectors in 2003, 2005, 2006 and 2007

Year	2003	2005	2006	2007
2003	1			
2005	0.9914	1		
2006	0.9813	0.996	1	
2007	0.9625	0.9832	0.9935	1

Almost all data in Tables 1-3 are close to 1. It showed that from 2003 to 2007 consumption structure of coal, crude oil and gas among 42 sectors is stable.

4. The Grey Neural Network and Input-Output Combined Forecasting Model (GNF-IO)

Based on the above analysis, by combining the advantages of GM(1, 1) (Deng Julong, 1989), WPGM(1, 1)（JiPeirong, et al., 2000）, pGM(1, 1) (Lai Zhikun et al., 2003) and BP neural network (Wen Xin et al., 2003), a

new gray neural network and input-output analysis combined forecasting model was proposed, in which the predicting results of three gray prediction models were used as the neural network's inputs, and the original sequence was used as the output of the neural network. The neural network was trained to get the optimal structure, weights and thresholds (Figure.4 shows the model structure). The combined model integrates the advantages of three models in the gray system theory, combining the predict results to the grey neural network. Using the function approximation properties of neural network, achieve the best fit between the predicted and observed values.

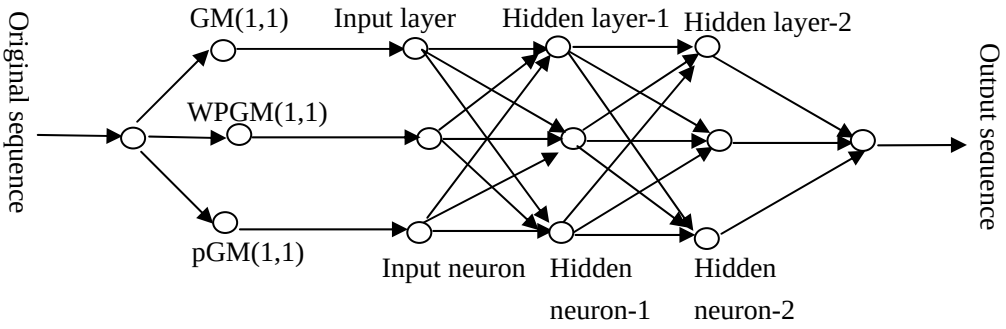

Figure.4 Topology structure of GNF-IO Model

Set m as the original data sequence, set n as the forecasting sequence. Two hidden layer structure of the four layer neural network is (p, q), where p represents the number of the first hidden layer, q denotes number of the second hidden layer. The steps of the GNF-IO model are as follows:

Step 1: To one data sequence, applied GM (1, 1), WPGM (1, 1), pGM (1, 1) to get m simulation values and n forecasting values.

Step 2: Use the simulation value of the three grey models as the input

vector of BP neural network, use initial data sequence as the output vector of the BP neural network, set the network structure (p,q) as (1,1), begin network training, and record total error E of the sample set of the corresponding network structure.

Step 3: Increased p and q by 1 respectively, until p=q=8 (Use the nodes number calculated from empirical formula [p,q]= $\sqrt{0.43r^2+0.12s^2+2.54r+0.77s+0.35}+0.51$ as the median number, where p,q are nodes of hidden layer, r,s are nodes number of input layer and output layer(Lei Wang&Hengshen Yao, 2005)).

Step 4: Selected the corresponding (p, q) of the minimum values among 7 values of E above, set it as (p^0, q^0).

Step 5: In accordance with the structure of (p^0, 1), (p^0, 2)…… (p^0, 7), (q^0, 1), (q^0, 2)…… (q^0, 7), obtained 14 E by Step 2, selected the corresponding (p, q) of the minimum values among 14 values of E above, set it as (p^1, q^1).

Step 6: Use three groups of n predicted values in the Step 1 as input values, simulate the original sequence according to (p^1, q^1) network structure, and get n outputs, which are forecasting results of GNF-IO.

5. Kinds of Primal Energy Consumption Forecast with GNF-IO model

5.1Assumptions

China has announced a development plan for renewable energy, which

determined the target that renewable energy accounted for 10% of the total primal energy consumption by 2010, and accounted for 15% by 2020. By the end of 2006, the total renewable energy consumption was 200 million tons of standard coal (not including the traditional use of biomass) in China, account for about 8% of the total primary energy consumption, rose 0.5% from 2005, which has taken a solid step to the 2010 renewable energy target. In the paper, the renewable energy is assumed to account for 10% of the total primal energy consumption in China in 2010.

Tables 1-3 show that from 2003 to 2007 consumption structure of coal, crude oil and gas among 42 sectors is stable. It is assumed that the consumption structure of primal energy among 42 sectors in 2010 is similar with that of 2007.

5.2 Model Application

First, used 1990-2004 the primary energy coal, oil and natural gas consumption data in China, applied GM(1,1), WPGM(1,1), pGM(1,1) model to simulate energy consumption volume in China, then applied GNF model to simulate the same data sequence, four kinds of simulation results from four models can be obtained. From the relative error of the four models (Figure 5) and model checking (Table 4), it can be seen that the error of the Grey prediction models is much greater than that of GNF model, at some point, the accuracy of Grey prediction models is instability. The simulation accuracy of GNF model was significantly better than the

single grey model.

Next, the analysis applies four models to forecast energy consumption data in year 2005, 2006 and 2007 and checked the forecast error (see Figure.5), at the same time applied other combined forecasting methods and compared their forecasting error (See Table 5). Figure.5 and Table 5 show that the forecast error of the GNF model is smallest; the average forecast error is only 0.27%. To sum up, the GNF model was greatly improved in simulation and prediction performance. As a result, based on 1990-2007 the primary energy coal, oil and natural gas consumption data in China, with model GNF, the three kinds of primary energy consumption in 2010 in China should be predicted as shown in Table 6.

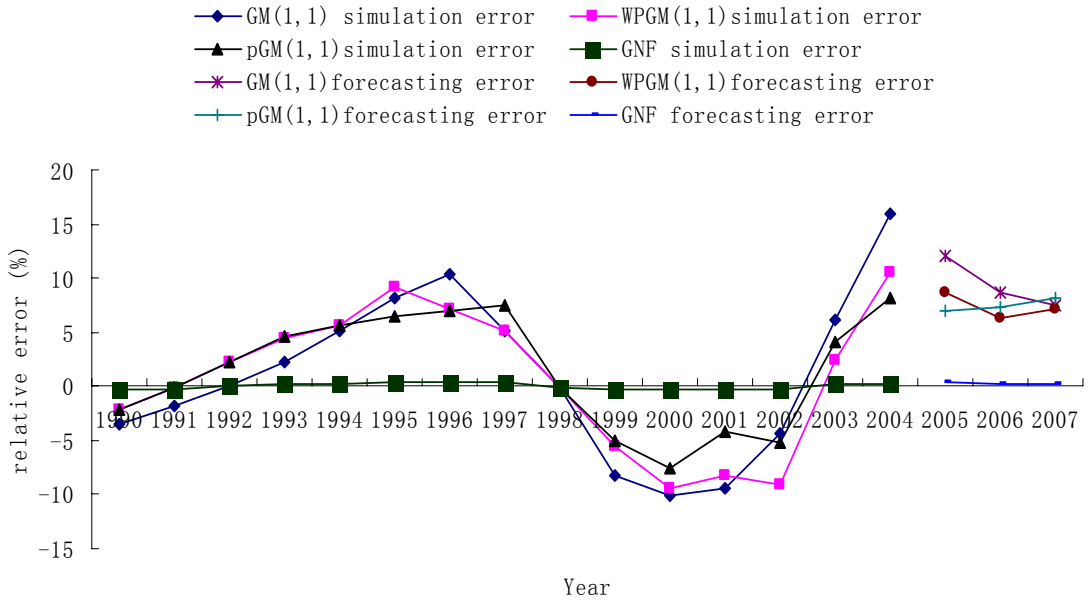

Figure.5 Errors of different models

Table.4 Model testing and assessing

Model	Small Error Probability (p)	Assess criteria of p	Mean Square Error Ration (c)	Assess criteria of c	Accuracy level

GM(1,1)	0.94	0.80-0.95	0.3712	0.35-0.5	Qualified
WPGM(1,1)	1.00	>0.95	0.0571	<0.35	Good
pGM(1,1)	1.00	>0.95	0.0552	<0.35	Good
GNF	1.00	>0.95	0.0029	<0.35	Good

Table.5 Errors of different combination models (%)

Year	GNF	GM-PLS	ARMA
2004	0.29	8.9	2.7
2005	0.31	15.8	10.3
2006	0.26	10.7	15.6
2007	0.21	15.5	18.9

Table.6 Prediction results of energy consumption in China in 2010 (Unit: million tones coal equivalent (MtCE))

Year	Coal	Crude Oil	Gas	Renewable Energy
2010	2045.79	627.54	87.03	306.71
ratio	66.7%	20.5%	2.8%	10%

Table 6 shows the ratio of coal in the total primal energy consumption fell from 68.7% in 2008 to 66.7% in 2010. According to Keii's projection (Keii, 2000), the share of coal as a primary energy over total energy consumption will decline over time. Coal will account for about 65% of China's primary energy by 2010. Our result has the same direction with Keii’s and is 1.7% higher. Table 7 shows that in 2009, 51.3% of crude oil consumed in China was imported. In 2010, crude oil consumption will be increased. Compare Table 6 and Table 7, there maybe 340MtCE crude oil need to be imported to China in 2010. This would be challenging for both China and the rest of the world.

Table.7 Primal energy production in 2009 in China (MtCE)

Year	**Coal**	**Crude Oil**	**Gas**
2009	2960	270	110

the year-on-year growth rate	12.7%	-0.4%	7.7%
Import ratio		51.3%	

6. Sub-sectors carbon dioxide emissions estimation for types of primal energy consumption

Based on the 2007 China energy input-holding-output table, applied emission factors for types of energy that IPCC used in compiling inventories of greenhouse gas emissions in China, carbon dioxide emissions of 42 industrial sectors in 2010 came from coal, oil and natural gas consumption in China were estimated with equation (1) (Results are shown in Table 8).

$$C_{ij} = E_i * b_{ij} * f_i \quad (1)$$

where C_{ij} is the CO_2 emission from sector j for it consumed energy i, E_i is the total consumed volume of energy i, b_{ij} is the ratio of consumed energy i by sector j to the total amount of energy i, f_i is the emission factor of energy i.

Table 8 shows the top 5 industries that carbon dioxide emissions from coal consumption: electricity, heat production and supply, ferrous metal smelting and rolling processing industry, petroleum processing, coking and nuclear fuel processing industry, non-metallic mineral products industry, coal mining and dressing.

The top 5 industries that carbon dioxide emissions from oil consumption

are as follows: petroleum processing, coking and nuclear fuel processing industry, transport, storage and post, raw chemical materials and chemical products, agriculture and other services.

The top 5 industries that carbon dioxide emissions from natural gas consumption are as follows: raw chemical materials and chemical products, oil and natural gas mining, living consumption, non-metallic mineral products industry, petroleum processing, coking and nuclear fuel processing industry.

The top 5 industries that carbon dioxide emissions from all kinds of energy consumption are as follows: electricity, heat production and supply, petroleum processing, coking and nuclear fuel processing industry, ferrous metal smelting and rolling processing industry, non-metallic mineral products industry, raw chemical materials and chemical products. The top 5 industries that carbon dioxide emissions due to total energy consumption are similar to the top 5 industries of carbon dioxide emissions generated by coal consumption.

Table.8 Carbon dioxide emissions of 42 industrial sectors in China by types of energy consumption in 2010 (Unit: a hundred million ton)

Sector Code	From Coal Consumption	Ratio	From Oil Consumption	Ratio	From Natural Gas Consumption	Ratio	From Three Kinds of Energy Consumption	Ratio

1	60.99	1.1%	46.98	4.0%	0.00	0.0%	107.97	1.5%
2	345.00	6.0%	2.09	0.2%	1.61	1.0%	348.71	5.0%
3	8.91	0.2%	37.37	3.2%	30.16	17.8%	76.44	1.1%
4	2.95	0.1%	0.96	0.1%	0.01	0.0%	3.92	0.1%
5	2.40	0.0%	0.43	0.0%	0.01	0.0%	2.84	0.0%
6	15.17	0.3%	1.62	0.1%	0.01	0.0%	16.80	0.2%
7	51.83	0.9%	3.04	0.3%	0.61	0.4%	55.49	0.8%
8	17.97	0.3%	0.83	0.1%	0.20	0.1%	18.99	0.3%
9	2.84	0.0%	0.19	0.0%	0.10	0.1%	3.13	0.0%
10	56.40	1.0%	2.49	0.2%	0.22	0.1%	59.11	0.8%
11	5.05	0.1%	1.11	0.1%	0.04	0.0%	6.19	0.1%
12	2.21	0.0%	0.74	0.1%	0.01	0.0%	2.96	0.0%
13	9.87	0.2%	0.74	0.1%	0.06	0.0%	10.67	0.2%
14	79.76	1.4%	1.48	0.1%	0.20	0.1%	81.44	1.2%
15	0.95	0.0%	0.38	0.0%	0.08	0.0%	1.41	0.0%
16	0.44	0.0%	0.45	0.0%	0.00	0.0%	0.89	0.0%
17	498.38	8.7%	601.91	51.7%	7.06	4.2%	1107.34	15.7%
18	295.27	5.2%	68.84	5.9%	55.81	33.0%	419.92	6.0%
19	15.11	0.3%	0.53	0.0%	0.38	0.2%	16.02	0.2%
20	20.02	0.4%	1.22	0.1%	0.12	0.1%	21.36	0.3%
21	9.57	0.2%	0.88	0.1%	0.14	0.1%	10.59	0.2%
22	5.89	0.1%	1.65	0.1%	0.22	0.1%	7.76	0.1%
23	441.61	7.7%	19.05	1.6%	9.41	5.6%	470.08	6.7%
24	505.42	8.9%	7.03	0.6%	3.86	2.3%	516.31	7.3%
25	58.96	1.0%	3.52	0.3%	1.53	0.9%	64.01	0.9%
26	7.20	0.1%	2.13	0.2%	0.27	0.2%	9.60	0.1%
27	8.97	0.2%	2.34	0.2%	0.72	0.4%	12.02	0.2%

28	12.03	0.2%	1.23	0.1%	1.07	0.6%	14.32	0.2%
29	19.24	0.3%	3.00	0.3%	1.94	1.1%	24.18	0.3%
30	3.63	0.1%	2.03	0.2%	0.49	0.3%	6.14	0.1%
31	3.48	0.1%	2.09	0.2%	1.89	1.1%	7.46	0.1%
32	0.52	0.0%	0.33	0.0%	0.03	0.0%	0.88	0.0%
33	13.13	0.2%	0.52	0.0%	0.02	0.0%	13.66	0.2%
34	0.16	0.0%	0.06	0.0%	0.00	0.0%	0.22	0.0%
35	2781.92	48.7%	35.71	3.1%	6.80	4.0%	2824.43	40.1%
36	34.14	0.6%	0.64	0.1%	2.79	1.7%	37.57	0.5%
37	0.81	0.0%	0.13	0.0%	0.02	0.0%	0.96	0.0%
38	15.90	0.3%	13.02	1.1%	0.54	0.3%	29.46	0.4%
39	21.48	0.4%	219.48	18.9%	4.70	2.8%	245.66	3.5%
40	23.03	0.4%	18.55	1.6%	3.90	2.3%	45.49	0.6%
41	20.18	0.4%	46.65	4.0%	3.30	2.0%	70.12	1.0%
42	230.21	4.0%	10.58	0.9%	28.71	17.0%	269.49	3.8%
Sum up	5709	100%	1164	100%	169	100%	7042	100%

The energy-related carbon dioxide emissions volume in China in 2010 estimated by EIA is 7546 million tons. It's 504 million tons (7.2%) remarks greater than this result. The main reason of this outcome is that the primal energy consumption data is from the China Statistics Book, which is different from the EIA, their assumptions are fundamentally different and finally their models include different approaches.

7. Conclusions and policy suggestions

In comparison with earlier established studies, this paper provided a more reliable estimation by employing a plausible approach to calculate the CO_2 emission that comes from three types of primal energy consumed by each industry, estimated data which has been tested and verified to ensure its reliability. The paper used more up to date different energy type's data, and incorporating China's recent efforts to promote alternative energies.

Tab.5 shows that the energy efficiency work of coal can be focused on electricity, heat production and supply, ferrous metal smelting and rolling processing industry, petroleum processing, coking and nuclear fuel processing industry. The energy efficiency work of crude oil can be focused on petroleum processing, coking and nuclear fuel processing industry, raw chemical materials and chemical products. Sub-sector CO2 emission volume could be referred to determine sub-sector CO2 emission reduction tasks.

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Appendix 1. Sector code and its corresponding name of 2007 China energy input-holding-output table with 42 sectors

Sector Code	Sector Name	Sector Code	Sector Name	Sector Code	Sector Name
1	Agriculture	15	Printing and Record Medium Reproduction Industry	29	Transport Equipment
2	Coal Mining and Dressing	16	Educational and Sports Goods	30	Electrical Machinery and Equipment
3	Oil and Natural Gas Mining	17	Petroleum processing, coking and nuclear fuel processing	31	Communications equipment, computers and other electronic equipment

			industry		manufacturing
4	Ferrous mineral mining	18	Raw Chemical Materials and Chemical Products	32	Instruments, Cultural and Office Machinery
5	Non-ferrous mineral mining	19	Pharmaceutical Industry	33	Arts and crafts and other manufacturing
6	Non-metallic Minerals and Other Mining and Dressing	20	Chemical fiber manufacturing industry	34	Waste and scrap
7	Food processing and food manufacturing	21	Rubber Products	35	Electricity, heat Production and Supply
8	Beverage Manufacturing	22	Plastic Products	36	Gas Production and Supply
9	Tobacco industry	23	Non-metallic mineral products industry	37	Water Production and Supply
10	Textile	24	Ferrous metal smelting and rolling processing industry	38	Construction industry
11	Textile and Apparel, Footwear and Headgear	25	Non-ferrous metal smelting and rolling processing industry	39	Transport, storage and post
12	Leather, fur, feathers (down) and its products	26	Fabricated metal products	40	Wholesale, retail trade and accommodation, catering industry
13	Wood processing and furniture manufacturing	27	General Equipment	41	Other services
14	Paper and Paper Products	28	Special Equipment	42	Living consumption