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Carbon Emission Trends of Manufacturing and Influencing Factors in Jilin Province, China

YU Chao[1, 2], MA Yanji[1]

(1. *Northeast Institute of Geography and Agroecology*, *Chinese Academy of Sciences*, *Changchun* 130102, *China*; 2. *University of Chinese Academy of Sciences*, *Beijing* 100049, *China*)

Abstract: This paper constructed a carbon emission identity based on five factors: industrial activity, industrial structure, energy intensity, energy mix and carbon emission parameter, and analyzed manufacturing carbon emission trends in Jilin Province at subdivided industrial level through Log-Mean Divisia Index (LMDI) method. Results showed that manufacturing carbon emissions of Jilin Province increased 1.304×10^7 t by 66% between 2004 and 2010. However, 2012 was a remarkable year in which carbon emissions decreased compared with 2011, the first fall since 2004. Industrial activity was the most important factor for the increase of carbon emissions, while energy intensity had the greatest impact on inhibiting carbon emission growth. Despite the impact of industrial structure on carbon emissions fluctuated, its overall trend inhibited carbon emission growth. Further, influences of industrial structure became gradually stronger and surpassed energy intensity in the period 2009–2010. These results conclude that reducing energy intensity is still the main way for carbon emission reduction in Jilin Province, but industrial structure can not be ignored and it has great potential. Based on the analyses, the way of manufacturing industrial structure adjustment for Jilin Province is put forward.

Keywords: manufacturing; carbon emissions; influencing factors; Log-Mean Divisia Index (LMDI); industrial structure adjustment; Jilin Province, China

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1 Introduction

The problems of CO_2 emissions and energy consumption have got a lot of attention under the background of climate change in China, and seeking for effective methods to mitigate and adapt the consequences of the climate change is a great challenge (Li and Yuan, 2014; Zhang *et al.*, 2015). Now China has become the world′s second largest economy while carbon emissions increase rapidly and astonishingly. The largest contribution for carbon emissions comes from the industrial sector. In all kinds of industries, energy consumption of manufacturing is more than others. In 2012, manufacturing accounted for 81.5% of total industrial energy consumption. Naturally manufacturing was given an important task of energy saving and reducing emissions.

To reduce manufacturing carbon emissions, firstly we need to know which factor increased carbon emissions. Thus, it is very important to learn how to evaluate the impacts of different factors on carbon emissions. Currently, there are many researches on manufacturing carbon emissions of China, and most of them focus on influencing factors by using Log-Mean Divisia Index (LMDI) method (Dong and Zhang, 2010; Guo, 2010; Pan *et al.*, 2011; Du *et al.*, 2012; Liu *et al.*, 2014; Wang *et al.*, 2014a). Overall, these studies still have the following problems: 1) Re-

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Corresponding author: MA Yanji. E-mail: mayanji@iga.ac.cn

searches for regional manufacturing carbon emissions are very less than that for the whole China. 2) Data collection is not comprehensive. Most of them only considered three main kinds of energy: raw coal, crude oil and natural gas. 3) Analyses at industrial level are not enough. Most of them only compared the difference between sectors not involving some discussions for subdivided industries. 4) Most of them focused on the positive or negative impact of different factors on the carbon emissions. They ignored dynamics of industrial structure and policy implications. In order to understand this, in-depth analyses are need on the whole manufacturing.

However, this problem is more severe in the Northeast Old Industrial Base. We should not only make up for above lacks but also comprehend its development background, which may profoundly affect carbon emission reduction task. As we all know, Northeast Old Industrial Base has formed a heavy industry development pattern for decades, and it leads to unbalance development between light and heavy industry. Furthermore, because of the industrial properties and size of heavy industry, demands for resources and raw materials are enormous, leading natural resources over-exploitation and resulting in serious environmental pollution. So it is very important to find an effective way for carbon emission reduction. However, there are few researches on manufacturing carbon emissions in Northeast China. Unfortunately, these researches still remain some problems mentioned above, such as energy data collection is not enough and analysis on subdivided industries is not in-depth (Li *et al.*, 2013; Tian *et al.*, 2014).

So this paper attempts to make up for the inadequacy of present studies with the manufacturing of Jilin Province. Jilin Province, as a part of the Northeast China and one of the Old Industrial Bases, its industrial development is also facing these issues (Chen and Chen, 2011; Zhang and Zhang, 2011; Zhang *et al.*, 2013). And manufacturing has always been the main thrust of economic growth as well as the lifeblood of Jilin Province′s economy. In 2010, manufacturing value added share of GDP in Jilin Province was 36.1%, which had already surpassed tertiary industry with 35.9%. And in 2012, manufacturing value added reached 4.6 788 × 10^{11} yuan (RMB), increased by 16.2% compared with the last year, accounting for 39.2% of GDP, for 73.4% of secondary industry, and even for 83.8% of industry. So research on manufacturing of Jilin Province could play a reference for other areas in the Northeast Old Industrial Base during this period of economic transition. From another perspective, it could also examine the effect of policy implementation. This study referred to 29 manufacturing industries and 12 kinds of energy sources in Jilin Province. More comprehensive data will give great support for a deeper analysis at subdivided industrial level and help us make more effective and specific suggestions for carbon emission reduction in Jilin Province.

2 Methods and Data

2.1 Methods

2.1.1 Calculation for carbon emissions

We use the following formula to calculate manufacturing carbon emissions in Jilin Province:

$$C^T = \sum_{ij} C_{ij}^T = \sum_{ij} E_{ij}^T \times SCP_j \times CEP_j \tag{1}$$

where i ranges from 1 to 29 (29 manufacturing industries), j ranges from 1 to 12 (12 kinds of energy); C^T is total manufacturing carbon emissions in time T; C_{ij}^T is carbon emissions of energy j in industry i in time T; E_{ij}^T is energy consumption of energy j in industry i in time T; SCP_j and CEP_j are standard coal parameter and carbon emission parameter of energy j, respectively. The calculation process of SCP_j and CEP_j referred to ′2006 IPCC Guidelines for National Greenhouse Gas Inventories′ (Table 1) (IPCC, 2006).

Table 1 Standard coal and carbon emission parameters

Parameter	Raw Coal	Washed Coal	Coke	Coke Oven Gas	Crude Oil	Petrol
Standard coal parameter	0.714	0.900	0.971	5.714	1.429	1.471
Carbon emission parameter	0.756	0.756	0.756	0.355	0.586	0.554
Parameter	**Kerosene**	**Diesel Oil**	**Fuel Oil**	**Liquefied Petroleum Gas**	**Refinery Gas**	**Natural Gas**
Standard coal parameter	1.471	1.457	1.429	1.714	1.571	12.143
Carbon emission parameter	0.574	0.592	0.618	0.504	0.460	0.448

Notes: Unit of standard coal parameter is tce/t or tce/10^4 m^3; Unit of carbon emission parameter is tce/t

2.1.2 Log-Mean Divisia Index analysis

In the field of energy studies, Laspevres index method and Divisia index method are most often used, and both of them are Index Decomposition Analysis (IDA) method. But there are two major problems in the application of these two methods: existence of residual and unable to deal with value zero. In this regard, Ang *et al.* (1998), on the basis of Divisia index method, developed a new LMDI method. Furthermore, for zero problems, Ang *et al.* (1998) had used limit analysis in 8 cases to accommodate the value zero. In practice, it can be replaced by a small positive number (between 10^{-10} and 10^{-20} is available) and will not affect the calculation results (Ang, 2005). LMDI method contains two types: LMDI I and LMDI II. According to the research content in this paper, LMDI I is used (Ang *et al.*, 2003).

We use the following IDA formula to analyzing the trajectory of manufacturing carbon emissions in Jilin Province:

$$C^T = \sum_{ij} C_{ij}^T = \sum_{ij} Q^T \times \frac{Q_i^T}{Q^T} \times \frac{E_i^T}{{Q^T}_i} \times \frac{E_{ij}^T}{E_i^T} \times \frac{C_{ij}^T}{E_{ij}^T} = \sum_{ij} Q^T \times S_i^T \times I_i^T \times X_{ij}^T \times P_{ij}^T \quad (2)$$

where Q^T and Q_i^T are gross industrial output value of the whole manufacturing and gross industrial output value in industry *i* in time *T*, respectively; E^T and E_i^T are total energy consumption and energy consumption in industry *i* in time *T*, respectively. So, we use gross industrial output value in time *T* to describe industrial activity, represented by Q^T; use gross industrial output value proportion of industry *i* in time *T* to describe industrial structure, represented by S_i^T; use energy consumption for every unit of industrial output value in industry *i* in time *T* to describe energy intensity, represented by I_i^T; use each kind of energy proportion in industry *i* in time *T* to describe energy mix, represented by X_{ij}^T; use carbon emissions by each kind of energy consumption in industry *i* in time *T* to describe carbon emission parameter, represented by P_{ij}^T. We chose above five influencing factors, mainly because this decomposition method provides a perfect decomposition formula and the meaning expressed by each factors is consistent with empirical researches. Also this IDA formula in carbon emission influencing factor studies with LMDI method is often used (Ang, 2005).

Then changes in carbon emissions during study period can be decomposed by two ways: multiplicative decomposition and additive decomposition.

The multiplicative decomposition formula is:

$$D = \frac{C^T}{C^0} = D_Q \times D_S \times D_I \times D_X \times D_P \quad (3)$$

where *D* is the ratio between C^T and C^0 (carbon emissions in base year); D_Q, D_S, D_I, D_X and D_P, respectively, donate the effects associated with industrial activity, industrial structure, energy intensity, energy mix, and carbon emission parameter.

The additive decomposition formula is:

$$\Delta C = C^T - C^0 = \Delta C_Q + \Delta C_S + \Delta C_I + \Delta C_X + \Delta C_P \quad (4)$$

where ΔC is the difference between C^T and C^0; D_Q, D_S, D_I, D_X and D_P, respectively, donate the effects associated with industrial activity, industrial structure, energy intensity, energy mix, and carbon emission parameter.

According to Ang (2005), the general formulae for carbon emission decomposition can be summarized as follows:

$$D_{IF} = \exp\left\{ \sum_{ij} \left[\frac{\left(C_{ij}^T - C_{ij}^0\right) / \left(\ln C_{ij}^T - \ln C_{ij}^0\right)}{\left(C^T - C^0\right) / \left(\ln C^T - \ln C^0\right)} \ln \frac{IF^T}{IF^0} \right] \right\} \quad (5)$$

$$\Delta C_{IF} = \sum_{ij} \left(\frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln \frac{IF^T}{IF^0} \right) \quad (6)$$

where, D_{IF} and ΔC_{IF} are the multiplicative and additive decomposition values of one influencing factor, respectively; IF^T is the computation index of one influencing factor, in this paper, it represents Q^T, S_i^T, I_i^T, X_{ij}^T or P_{ij}^T.

2.2 Data source and processing

The strategy of the Northeast China Revitalization was carried out in 2003 and energy data from 2003 were adjusted according to the second national economic census, so our study period started from 2004. In addition, due to a new manufacturing classification standard implemented after 2011, our study period ended in 2010. The statistical yearbooks of Jilin from Jilin Statistics Bureau and China from National Bureau of Statistics in each year are the primary sources (Jilin Statistics Bureau, 2005–2014; National Bureau of Statistics, 2005–2011).

According to formulas (1), (2), (5) and (6), it can be seen that only two kinds of data are necessary. One is E_{ij}^T, and the other one is Q_i^T. All the other computation indexes can be worked out with them. Energy data for E_{ij}^T comes from 'Total Consumption of Energy by Sector (Physical Quantity)' in the statistical yearbooks each year. In this paper, we select 12 kinds of energy, but electric power and heat consumption are not considered (Table 1). There are mainly two reasons for ignoring them. First, the use of electricity and heat does not emit CO_2. Second, although the electricity and heat production does, we cannot know which energy had been consumed and how much the consumption was in the production process. So we can not figure out the carbon emission parameters of electricity and heat. In fact, calculation methods of electric and heat carbon emission parameters are not given in '2006 IPCC Guidelines for National Greenhouse Gas Inventories' (IPCC, 2006). Most studies on manufacturing carbon emissions in China did not consider electric power and heat consumption either. So, we will also follow this practice here.

Economic data for Q_i^T come from 'Indicators on Economic of Industrial Enterprises above Designated Size' in the statistical yearbooks each year. In this paper, we select 29 manufacturing industries. And in order to ensure data comparability, economic data had been adjusted into constant prices according to the 'Ex-Factory Price Indices of Industrial Products' with the base year 2004.

3 Results

3.1 Overall trends in 2004–2010

Manufacturing carbon emissions of Jilin Province increased 1.304×10^7 t by 66% between 2004 and 2010. Based on additive decomposition (Fig. 1), industrial activity increased 3.276×10^7 t of carbon emissions, while industrial structure and energy intensity decreased 4.120×10^6 t and 1.613×10^7 t, respectively, between 2004 and 2010. Based on multiplicative decomposition (Fig. 2), industrial activity increased by 3.57 times, while industrial structure and energy intensity decreased by 0.85 and 0.53 times, respectively, compared 2004; manufacturing carbon emissions totally increased 1.66 times. According to the calculation process, for a certain kind of energy, its carbon emission parameter is a constant. But for a particular industry, due to the energy mix change in each year, its carbon emission parameter will also change correspondingly. In this paper, the calculation results showed that changes of industrial carbon emission parameters were very small which means the influence of carbon emission parameter was very weak. In addition, impact on carbon emissions by energy mix was also not obvious which indicated that industrial carbon emission parameter had changed little during study period. So we will no longer discuss carbon emission parameter below.

Shown in Table 2, there were only six industries that their carbon emissions decreased during study period:

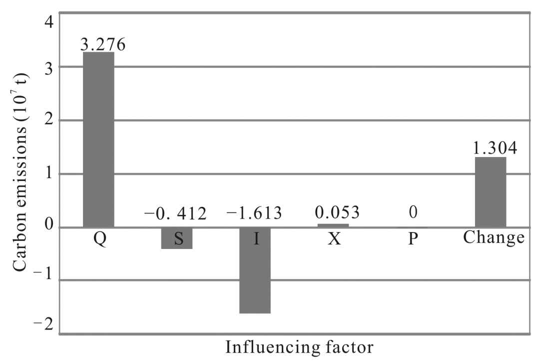

Fig. 1 Results of additive decomposition of carbon emissions for Jilin Province, 2004–2010. Q represents industrial activity; S represents industrial structure; I represents energy intensity; X represents energy mix; and P represents carbon emission parameter

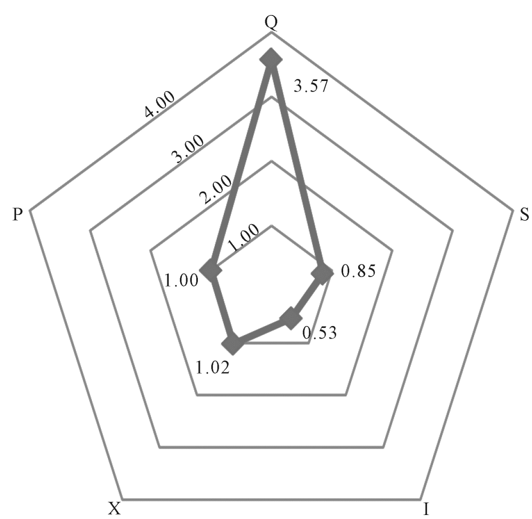

Fig. 2 Results of multiplicative decomposition of carbon emissions for Jilin Province, 2004–2010. Q represents industrial activity; S represents industrial structure; I represents energy intensity; X represents energy mix; and P represents carbon emission parameter

Tobacco processing, *Textile industry*, *Furniture manufacturing*, *Papermaking and paper products*, *Rubber products* and *Transportation equipment*. These six industries accounted for less than 5% of manufacturing carbon emissions. The biggest change of carbon emissions occurred in *Metal products*, increased by 747% between 2004 and 2010. In 2004, 'Million Tons Club', in terms of carbon emissions, had five members, respectively, *Petroleum processing and coking*, *Raw chemical materials and chemical products*, *Nonmetal mineral products*, *Smelting and pressing of ferrous metals* and *Transportation equipment*. Then another two members joined and one member quit the 'Million Tons Club' in 2010. The two members were *Food processing* and *Beverage production*, and carbon emissions of *Food processing* even reached 2.73 × 10^6 t. *Transportation equipment* quit the club because its carbon emissions reduced to 995 000 t, which less than 1 × 10^6 t. Carbon emissions of these seven industries (six members of the club and *Transportation equipment*) totally reached 2.923 × 10^7 t and accounted for 89% of all industries.

3.2 Trends in adjacent year

Further, we also calculated carbon emission differences

Table 2 Results of additive decomposition of carbon emissions in 29 manufacturing industries of Jilin Province, 2004–2010

Manufacturing	Carbon emissions (10^4 t)		Gross industrial output value (10^8 yuan (RMB))		Additive decomposition (10^4 t)			
	2004	2010	2004	2010	Q	S	I	X
Food processing	81.7	273.2	216.3	1191.8	211.44	59.03	–78.77	–0.20
Food production	10.4	18.5	22.3	186.8	17.68	10.49	–20.38	0.35
Beverage production	43.2	112.3	52.2	267.1	95.16	21.22	–49.31	2.04
Tobacco processing	1.7	1.2	30.1	95.7	1.80	–0.24	–2.21	0.09
Textile industry	9.1	7.2	30.9	64.0	10.70	–4.87	–7.64	–0.01
Garments and other fiber products	1.0	2.8	9.0	51.2	2.25	0.68	–1.12	0.04
Leather, furs, down and related products	0.2	0.8	1.9	7.2	0.57	0.01	–0.01	0.01
Timber processing, bamboo, cane, palm fiber and straw products	40.5	61.7	56.8	421.8	66.95	33.68	–79.73	0.32
Furniture manufacturing	5.3	3.1	6.5	47.9	5.18	2.59	–9.67	–0.40
Papermaking and paper products	39.4	38.2	21.1	78.0	51.69	–1.10	–51.75	–0.10
Printing and record medium reproduction	1.2	2.8	5.8	28.3	2.57	0.48	–1.48	0.01
Cultural, educational and sports articles	0.1	0.6	0.4	6.7	0.37	0.38	–0.37	0.07
Petroleum processing and coking	165.4	224.5	46.2	71.1	163.13	–110.37	–28.08	35.30
Raw chemical materials and chemical products	754.4	967.4	398.6	888.1	1134.02	–453.09	–471.15	3.26
Medical and pharmaceutical products	24.6	46.4	117.9	585.8	45.72	9.22	–33.49	0.33
Chemical fiber	46.0	53.9	31.1	66.9	66.50	–28.30	–30.22	–0.02
Rubber products	4.0	1.9	10.1	14.6	3.74	–2.70	–3.10	–0.05
Plastic products	2.5	6.5	20.6	94.9	5.57	0.81	–2.51	0.09
Nonmetal mineral products	261.8	493.1	83.0	609.8	485.72	240.41	–492.62	–2.11
Smelting and pressing of ferrous metals	317.3	753.0	178.1	461.1	666.69	–191.48	–54.77	15.29
Smelting and pressing of nonferrous metals metal products	14.1	20.9	50.3	51.1	22.37	–22.13	5.86	0.69
Metal products	2.5	21.3	14.6	163.0	11.02	8.92	–2.70	1.55
Ordinary machinery	15.9	23.4	32.5	241.1	25.21	12.64	–30.29	–0.09
Equipment for special purposes	7.0	20.6	37.0	266.1	16.75	8.00	–11.20	–0.01
Transportation equipment	114.6	99.5	1328.1	4616.9	141.25	–9.34	–143.41	–3.62
Electric equipment and machinery	1.6	8.2	19.7	139.6	5.15	2.41	–1.53	0.57
Electronic and telecommunications equipment	1.9	5.0	21.8	80.6	3.97	–0.08	–1.27	0.49
Instruments, meters, cultural and office machinery	0.5	2.4	7.8	25.6	1.60	–0.17	0.40	0.05
Artwork and other industries	7.9	9.7	3.4	14.2	11.59	0.87	–10.53	–0.08

Notes: Q represents industrial activity; S represents industrial structure; I represents energy intensity; X represents energy mix in adjacent years, and results showed in Fig. 3 and Table 3. Apart from a slight reduction in the period 2008– 2009, carbon emissions increased to varying degrees in each period. But compared with the overall trends, differences in adjacent years show dramatic ups and downs. By observing each factor, industrial activity led a major increase in carbon emissions in each period, and it was fairly stable. There were still not clear changes in energy mix. Energy intensity and industrial structure had obvious changes in each period. The negative effect of energy intensity reached a peak in the period 2008–2009, which largely offsetting carbon emission increase by industrial activity. Energy intensity continually inhibited the increase of carbon emission, but reduction amount had greatly fell, surpassed by industrial structure in the period 2009–2010. Industrial structure is the most complicated factor as the great fluctuation in different periods. If seen from entire time span, no clear rules can be summarized according to its influences on carbon emissions. But if the study period is divided into two parts with a junction year of 2007, we will get some different conclusions. Industrial structure experienced a transition from increasing to decreasing carbon emissions both in these two periods 2004–2007 and 2007–2010. The former transition suggested that this strategy of the Northeast China Revitalization had achieved remarkable results. However, a global financial crisis gave a hard blow to the economy of Jilin Province where *Transportation equipment* was its leading industry. After 2009, it was encouraging to see that the role of industrial structure adjustment appeared once again and was stronger than before, even energy intensity. It also reflects from one side that the potential to curb carbon emissions by industrial structure adjustment is very large.

3.3 Influencing factors

3.3.1 Industrial activity

From 2004 to 2010, gross industrial output value of manufacturing in Jilin Province increased from 2.854×10^{11} to 1.084×10^{12} yuan (RMB) by 279.7% (Fig. 4). Carbon emissions of every industry increased to varying degrees by industrial activity between 2004 and 2010 (Table 2). Impact on *Raw chemical materials and chemical products* was the biggest with 1.134×10^{7} t carbon emission increase. Carbon emissions of *Cultural*, *educational and sports articles* merely increased 3 700 t. Carbon emissions of *Smelting and pressing of ferrous*

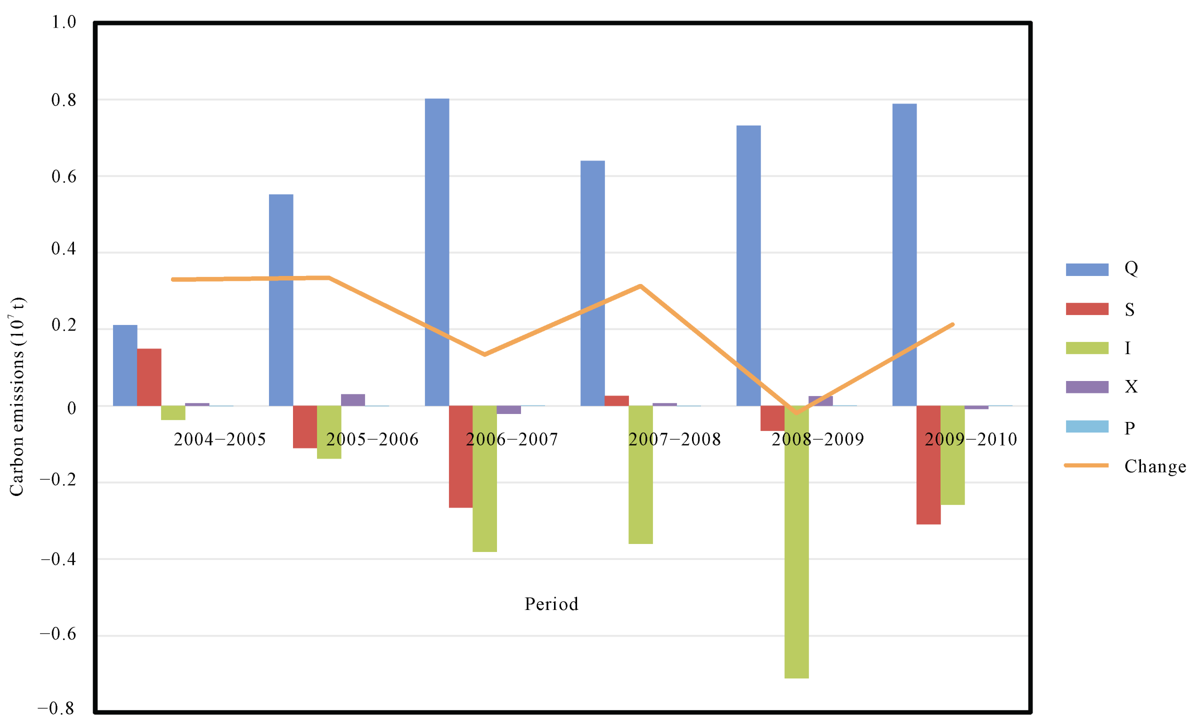

Fig. 3 Results of additive decomposition of carbon emissions for Jilin Province, adjacent years during 2004–2010. Q represents industrial activity; S represents industrial structure; I represents energy intensity; X represents energy mix; and P represents carbon emission parameter

Table 3 Results of additive decomposition of carbon emissions for Jilin Province, adjacent years during 2004–2010 (10^4 t)

Period	Q	S	I	X	P	Change
2004–2005	211.13	148.83	–36.67	6.75	–0.17	329.86
2005–2006	552.31	–110.73	–137.20	30.03	–0.15	334.26
2006–2007	801.85	–265.91	–381.06	–21.19	0.14	133.84
2007–2008	639.72	26.17	–360.02	7.14	–0.21	312.80
2008–2009	731.16	–64.65	–710.74	25.05	0.26	–18.94
2009–2010	787.88	–309.03	–258.46	–7.91	0.02	212.50

Note: Q represents industrial activity; S represents industrial structure; I represents energy intensity; X represents energy mix; and P represents carbon emission parameter

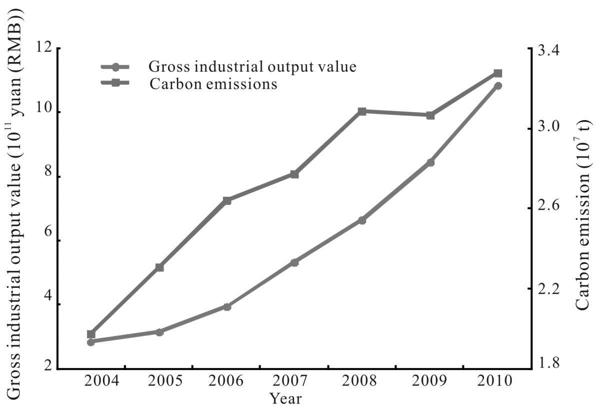

Fig. 4 Gross industrial output value and carbon emissions for Jilin Province, 2004–2010

metals and *Nonmetal mineral products* increased by industrial activity were 6.67 × 10^6 t and 4.86 × 10^6 t, respectively, which ranked second and third in manufacturing of Jilin Province. It was also the main driving force which increased carbon emissions for *Food processing* and *Beverage production* from less than 1 × 10^6 t in 2004 to more than 1 × 10^6 t in 2010.

Zhang *et al.* (2013) concluded that, there is a long-term causal relationship between the economic development and energy consumption in Jilin Province. The economic development is highly depending on the energy while every 1 × 10^8 yuan (RMB) increase of GDP will consume 17 600 t standard coal. Therefore, if we want to reduce carbon emissions, we will have to reduce the consumption of fossil energy. The reduction of fossil energy consumption will largely inhibit the development of resource-based industries, such as *Petroleum processing and coking*. Also, the reality is that resource-based industries account for a large proportion in manufacturing of Jilin Province. From this point, if we blindly limit the development of such industries to reduce carbon emissions, it may be a larger influence on economic growth in Jilin Province.

3.3.2 Industrial structure

Industrial structure decompositions of carbon emissions have both positive and negative values between 2004 and 2010. The positive values means that the proportion of gross industrial output value of some industries increased and industrial structure caused an increase of carbon emissions. In contrast the negative values means the proportion of gross industrial output value of some industries decreased and industrial structure caused a decrease of carbon emissions.

The inhibition of carbon emissions by industrial structure mainly occurred in three industries, namely *Petroleum processing and coking*, *Raw chemical materials and chemical products* and *Smelting and pressing of ferrous metals*. Carbon emission decompositions of industrial structure of them three all surpassed 1 × 10^6 t. Economic proportions of three industries in 2004 were 1.6%, 14.0% and 6.2%, respectively. However, all of them fell 0.7%, 8.2% and 4.3%, respectively in 2010 (Fig. 5). The largest increase in carbon emissions by industrial structure occurred in *Nonmetal mineral products*. Its carbon emissions increased 2.40 × 10^6 t from 2004 to 2010 and economic proportion increased from 2.9% in 2004 to 5.6% in 2010. This rapid growth in *Nonmetal mineral products* was mainly due to a vigorous development in cement industry in recent years and the Northeast China Revitalization policy made a great contribution to this fast development. Jilin Province stimulated its economic growth through a large number of infrastructure constructions, such as urban overpasses, subway, light rail, *etc.*, which directly led to enormous demands for cement since the Northeast China Revitalization.

Besides, it should also be noted that economic proportion of *Food processing* increased greatly between 2004 and 2010. Jilin Province has chosen *Food processing* as a breakthrough point for manufacturing

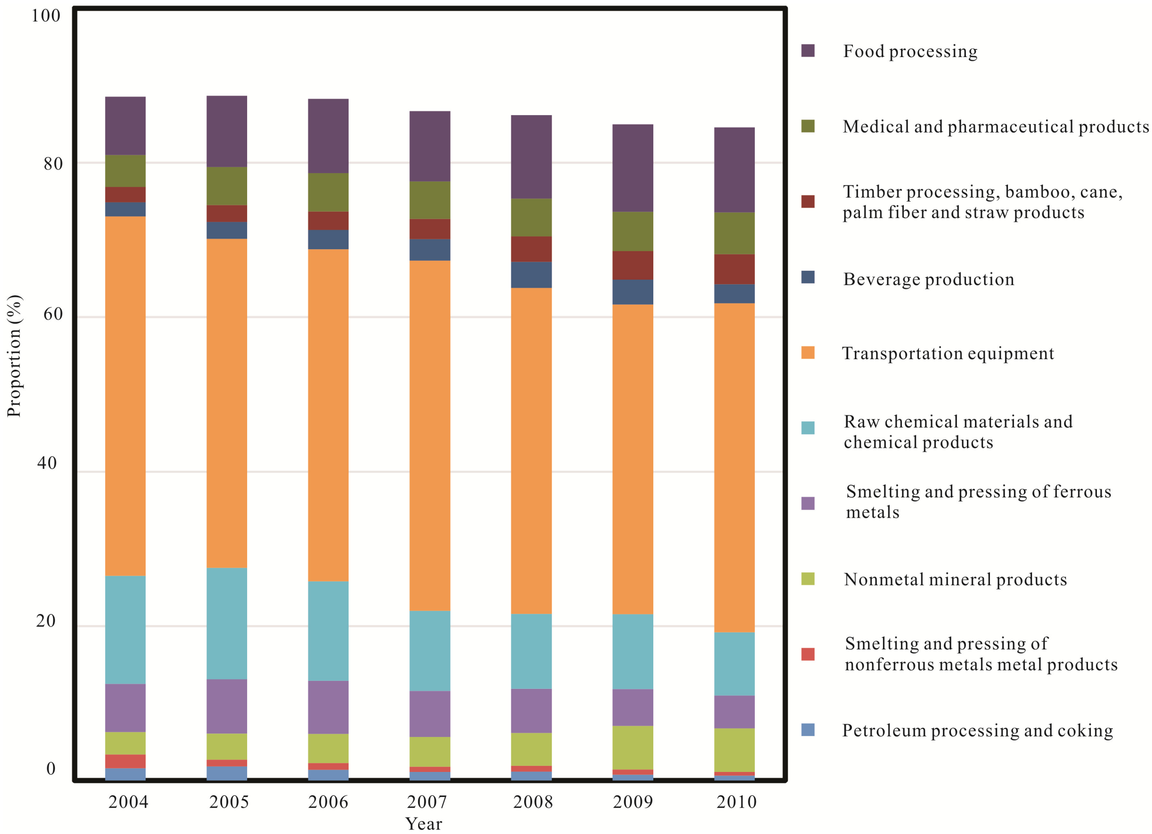

Fig. 5 Cumulative proportion of gross industrial output value of 10 industries for Jilin Province, 2004–2010

development. Making such a choice is mainly because of the geographical location. Jilin Province locates in the world famous Golden Corn Belt and Golden Rice Belt, and it is one of the national commodity grain bases as well as one of the national animal husbandry bases. Therefore, with adequate supply of raw materials assured, Jilin Province has promoted *Food processing* development through expanding enterprise size, enhancing enterprise's modernized level and extending industrial chain.

On the whole, the largest change of economic proportion occurred in *Petroleum processing and coking*, decreasing from 14.0% in 2004 to 8.2% in 2010, followed by *Transportation equipment*. But it can be seen that economic proportion of *Transportation equipment* was still more than 40%, which also played an absolute leading position in manufacturing of Jilin Province. Gross industrial output value of *Transportation equipment* maintained sustained increase with a growth rate close to the provincial level. In addition, Data from 'Ex-Factory Price Indices of Industrial Products' show that, in 2004–2010, *Transportation equipment* was the only industry with a decline in ex-factory price of industrial products year by year which means its production cost fell continually and its sales and profits rose quickly. It can also reflect that *Transportation equipment* had been becoming more and more mature and entering a new period to improve intrinsic quality.

3.3.3 Energy intensity

Energy intensity declined steadily after a slight increase in 2005 as well as carbon intensity which indicated that carbon emissions of every unit of gross industrial output value had been continually decreasing in manufacturing of Jilin Province between 2004 and 2010 (Fig. 6). Except *Smelting and pressing of nonferrous metals metal products* and *Instruments*, *meters*, *cultural and office machinery*, other energy intensity decompositions were all negative (Table 2). So for most manufacturing industries, energy intensity had given a great contribution on the decrease of carbon emissions.

Impact of energy intensity on carbon emission dynamics in *Raw chemical materials and chemical products*, *Nonmetal mineral products* and *Transportation equipment* was larger than others. This is inseparable

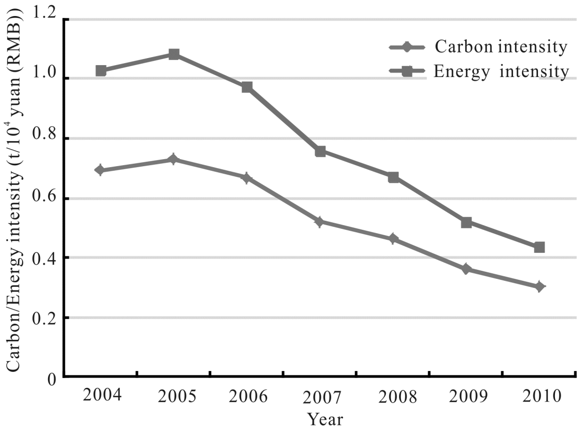

Fig. 6 Energy intensity and carbon intensity for Jilin Province, 2004–2010

from reorganization and restructuring of the large and medium-sized state-owned enterprises and technology and equipment refresh after the implementation of the Northeast China Revitalization. For only two industries of which carbon emission decompositions of energy intensity were positive values, energy consumption of *Instruments*, *meters*, *cultural and office machinery* increased by 359.1% while industrial gross output value increased by 229.3%; energy consumption of *Smelting and pressing of nonferrous metals metal products* increased by 95.1% while industrial gross output value only increased by 1.5%. For the former, energy intensity increase was due to a rapid expansion of industrial scale; for the latter, energy intensity increase was due to the exhaustion of resources resulted in economic growth stagnation.

From the definition we can know that there are three ways to reduce energy intensity. First is to change energy mix and reduce the demand of fossil fuels. For Jilin Province, this issue will be discussed in the next section. Second is the technology advancements. This way is subject to both productivity level and policy support. A sincere cooperation in finance and technology between developing and developed countries is also very important. Furthermore, researches on new technology will inevitably increase costs, and the time from researching to producing is uncertainty, which will further increase the risk for corporations. Third is to stimulate economic growth. The calculation results showed that for energy intensity, a downward trend existed in the whole time, but this downward trend begun to wane. A rapid decline of energy intensity in the early time was mainly due to the resource-based industry upgrading benefitting from the Northeast Revitalization. However, the market of steel, petrochemical and other resource-based industries is down now and it will be more likely to last long. And the worse is that these industries share a large proportion of manufacturing in Jilin Province, which had slowed economic growth. Thus, for Jilin Province, reducing energy intensity should firstly consolidate achievements of resource-based industry upgrading, and then try hard to tap potential of some industries like *Food processing* and *Beverage production* with high carbon emissions but lower energy intensity decomposition relatively.

3.3.4 Energy mix

As shown in Fig. 7, energy consumption of four types (*Raw Coal*, *Washed Coal*, *Coke* and *Crude Oil*) accounted for over 90% of manufacturing. And this proportion was relatively stable, merely increasing 0.85% between 2004 and 2010. However, proportion of their own had been significantly changed. Proportion of *Crude Oil* consumption drastically reduced, from 38.9% in 2004 to 27.8% in 2010. Other three kinds of energy consumption proportion all increased (3.6% for *Raw Coal*, 4.4% for *Coke* and 4.0% for *Washed Coal*, respectively). In general, coal and oil are still the two main kinds of energy for manufacturing of Jilin Province.

When we analyze the impact of energy mix on each industry (Table 2), two of them, *Petroleum processing and coking* and *Smelting and pressing of ferrous metals*, are quite different. In 2004, *Petroleum processing and coking* consumed 407 200 t *of Raw Coal* and 2.21×10^6 t of *Crude Oil*, hardly using *Washed Coal*. In 2010, consumption of *Washed Coal* increased to 1.76×10^6 t instead of 3.868×10^5 t of *Raw Coal* and 6.784×10^5 t of *Crude Oil*. It showed slightly different with *Smelting and pressing of ferrous metals*. There was an obvious rise in energy consumption of all main types in this industry. The different growth degrees led to apparent changes in energy mix.

Seen from Table 1 we can find that carbon emission parameters of fossil energy are certainly higher than others, so the slather use of fossil energy will pose a tremendous pressure on carbon emission reduction. But if we know the development background and total energy mix of Jilin Province, it will help us to deeply understand why energy mix of manufacturing is difficult to change. As shown in Fig. 8, coal resources had maintained a very high proportion, which had been consistently

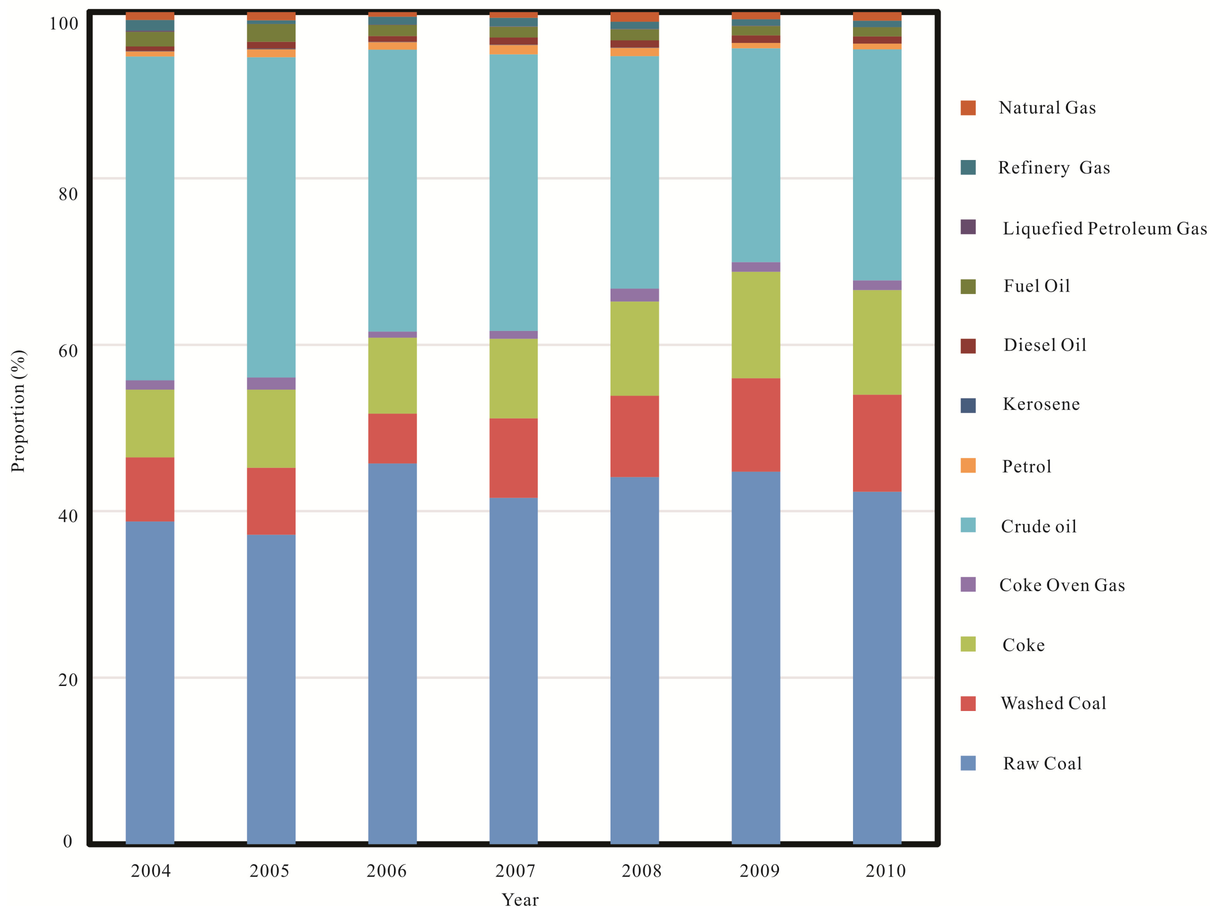

Fig. 7 Energy mix in manufacturing for Jilin Province, 2004–2010

higher than 75% since 2004 in Jilin Province. Furthermore, there are few signs of subsiding. In contrast, proportions of natural gas and hydropower consumption grew very slowly over the past years, only increased 1.2% and 0.2%, respectively. It is more prominent when it compared with the national data. The national data show that proportion of coal consumption had been less than 70% since 2004, and decreased to 66.6% in 2012. The growth rate of natural gas and hydropower was also higher than that in Jilin Province. For China, coal consumption is the dominant carbon emission source and oil consumption takes the second place (Du *et al.*, 2012). Energy mix in China contained a larger share of natural gas, hydro, *etc*. from 2004 to 2010, but this trend does not appear in Jilin Province currently. And the reality is that manufacturing of Jilin Province is using more *Coke* and *Washed Coal*. Indeed more use of *Coke* and *Washed Coal* will improve efficiency of coal consumption, but carbon emission parameter of *Coke* or *Washed Coal* is higher than others' (Table 1). Although the impact of energy mix on carbon emissions is very weak, LMDI analysis results still indicate that it had promoted carbon emission increase in the past years (Fig. 1 and Fig. 2). Therefore, based on the current trend in manufacturing energy consumption of Jilin Province, it is difficult to achieve the goal of carbon emission reduction by changing energy mix.

3.4 Changes in carbon emissions from 2011 to 2013

As a new manufacturing industrial classification standard adopted in 2011, we are not able to make a decomposition analysis including the data of later years. But we can still calculate total carbon emissions of manufacturing from 2011 to 2013. Shown in Table 4, carbon emissions in 2012 decreased for the first time since 2004, with a reduction of 2.08×10^6 t compared with 2011. A series of production safety rectifications for coal enterprises in Jilin Province led a sharp decline in coal production and changed energy mix in 2013. So carbon emissions in 2013 continually decreased to 3.517×10^7 t. As gross industrial output value kept in up, carbon intensity remained a downward trend.

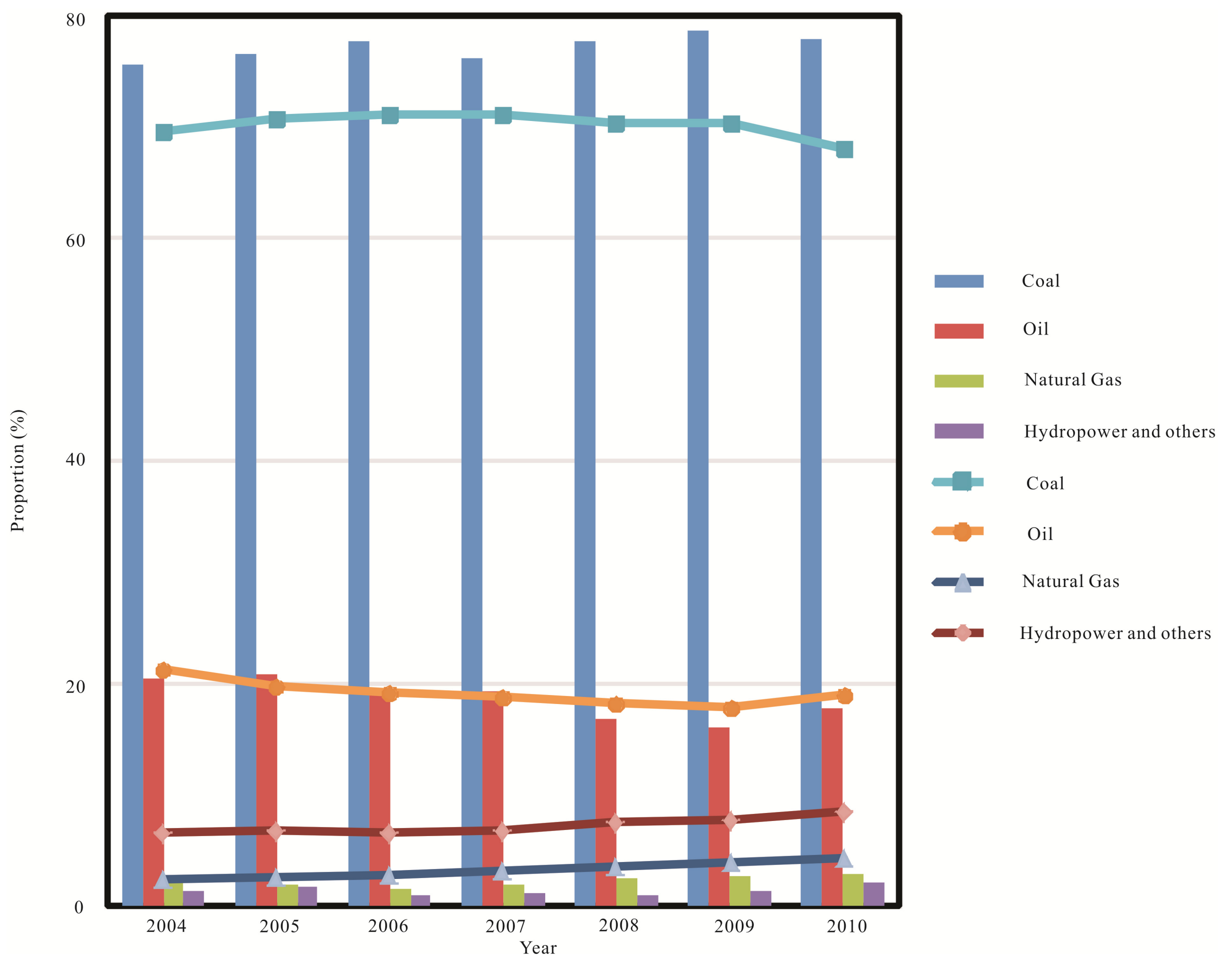

Fig. 8 Energy mix in Jilin Province (line) and China (bar), 2004–2010

Table 4 Carbon emissions, gross industrial output value and carbon intensity for Jilin Province, 2010–2013

Year	Carbon emissions (10^4 t)	Gross industrial output value (10^8 yuan)	Carbon intensity ($t/10^4$ yuan)
2010	3280.07	10 837.07	0.30
2011	4015.57	13 490.52	0.30
2012	3807.61	16 017.26	0.24
2013	3517.01	18 698.20	0.19

Gross industrial output value of every manufacturing increased in varying degrees between 2011 and 2013. *Leather*, *furs*, *down and related products* and *Smelting and pressing of nonferrous metals metal products* had larger increase in gross industrial output value than other industries, increasing by 62.3% and 119.2%, respectively. Because of the short time, changes in industrial structure were not obvious. *Food processing* and *Transportation equipment* made larger changes in economic proportion. For the former, economic proportion increased from 11% in 2011 to 12.7% in 2013; for the latter, it decreased from 39% in 2011 to 35.2% in 2013.

4 Discussion

4.1 Impact of industrial structure

Through the analysis of carbon emission trends by each factor, we have found some different results from previous studies. After learning many scholars' researches, we can see that: 1) In the whole industry, expansion of economic scale was the most important factor for continuous increase of carbon emission and energy intensity was the most important factor to inhibit carbon emissions. Changes of industrial structure and energy mix had few impact and their potentials had not been realized (Shang and Jiang, 2009; Guo, 2010; Wang and He; 2010). 2) In the industrial sector, impact of energy intensity on curbing carbon emissions was more obvious than industrial structure (Liu *et al.*, 2007; Dong and

Zhang, 2010). 3) In the manufacturing sector, the reduction of energy intensity of China′s manufacturing was due to the improvement of energy efficiency (Pan *et al.*, 2011; Hasanbeigi *et al.*, 2013; Zhao *et al.*, 2014; Wang *et al.*, 2014b). These studies have all indicated that in term of carbon emission reduction, energy intensity was more important than industrial structure, and their influences were not at the same level. But for Jilin Province, according to our study, the impact of industrial structure on carbon emissions cannot be ignored, while energy intensity is still the most important factor for inhibiting carbon emissions. As industrial structure was susceptible to the macroeconomic situation and changes of policies constantly depend on the macroeconomic situation, the impact on carbon emissions may lead to positive effects in some years but negative in other years. The analysis of carbon emission between 2004 and 2010 in this paper was the best evidence to get this conclusion (Fig. 3).

Reasons of why industrial structure could give a great contribution to manufacturing carbon emission reduction in Jilin Province can be summarized in three points. First, economic proportion of *Transportation equipment* in Jilin Province was too big which formed a relative single industrial structure and economic growth was highly depended on it. Although its economic proportion in the period 2004–2010 had dropped by 2.9%, it was still over 40%. Due to its huge size, this small change had also given a great impact on industrial structure adjustment in manufacturing. Second, *Petroleum processing and coking*, *Raw chemical materials and chemical products* and *Smelting and pressing of ferrous metals* were special adjustment industries since the Northeast China Revitalization. During the time, their economic proportion dropped significantly and carbon emission decompositions of industrial structure are larger than others′. Third, biological industry in Jilin Province had developed fast in recent years and promoted industrial transformation. Development of biological industry like bioenergy, biomedicine, *etc.*, is itself in line with the low-carbon idea. So combined with the abundant agriculture resources, Jilin Province provided guarantees for the rapid development of *Food processing* and *Medical and pharmaceutical products*, *etc*. Therefore, we have reasons to believe that there is more latent potential to reducing carbon emissions by industrial structure adjustment.

4.2 Trend of manufacturing industrial transformation

The previous analysis has pointed out carbon emissions of those seven industries (six members of the club and *Transportation equipment*) accounted for nearly 90% of all. There is no doubt carbon emission reduction should get to work in these industries. However, all of them have their own character. *Food processing* and *Beverage production* were the industries with high carbon emissions by expansion of economic scale but relatively lower energy intensity decompositions. *Petroleum processing and coking* and *Smelting and pressing of ferrous metals* were the industries with strong impact of industrial structure but weak impact of energy intensity. *Raw chemical materials and chemical products* was the industry that both impacts of industrial structure and energy intensity are strong. Impact of industrial structure on *Nonmetal mineral products* was the largest. For *Transportation equipment*, its carbon emissions had decreased less than 1×10^6 t, industrial structure and energy intensity all had impact on inhibiting carbon emissions. Besides, contribution rate of carbon emission reduction by energy intensity was the highest. Though different factors for different industries have different impacts, updating production technology, improving production added value and reducing unit output energy consumption, are still the main ways to reduce carbon emissions. This just reflects the current development trend of manufacturing—transformation from low-end to high-end manufacturing. In fact, *Transportation equipment* development history in Jilin Province has already confirmed it. No matter development focus which has turned to family car and clean-energy vehicles, or industrial chain which has transformed from parts to whole car production, both of them show that *Transportation equipment* has been moving forward to a high-end manufacturing industry. As a lot of characteristics of high-end manufacturing have been gradually revealed, such as high technology, high added value, low pollution, low emission, *etc.*, it will point out a new direction for manufacturing industrial structure adjustment in Jilin Province.

5 Conclusions and Policy Implications

Based on decomposition analysis of manufacturing carbon emissions in Jilin Province by using LMDI method during the period of 2004–2010, we conclude that: 1) Industrial activity was also the most important factor for the increase of carbon emissions. Its influence was relatively stable and it had maintained a high contribution rate, which means a strong links between economic growth and energy consumption. 2) Energy intensity continually gave a strong impact on inhibiting carbon emissions, but not the entire manufacturing industries, two of them used to be the opposite. 3) Energy mix had limited effects on carbon emissions in all the time, which was closely related to manufacturing characteristics. 4) Industrial structure had experienced an obvious fluctuation, but on the whole, its power had been increased over time and already surpassed energy intensity in one period. Because of macro policies, Jilin Province had achieved obvious results of carbon emission reduction in a short time through industrial structure adjustment. 5) Manufacturing carbon emissions notably decreased for the first time in 2012. Due to the production safety rectifications, carbon emissions continually decreased in 2013. Manufacturing gross industrial output value continually maintained a rapid growth rate, so carbon intensity continually decreased.

Through the empirical research, we find that decreasing energy intensity is still the main way for Jilin Province to reduce carbon emissions, but industrial structure cannot be ignored and it has bigger potential. Thus, based on our analyses, the way of manufacturing industrial structure adjustment can be put forward as follows: 1) To expand economic scale of *Food processing* continually could early form industrial cluster. And then through agglomeration effects, it will promote specialization and improve economic performance as well as reduce energy intensity. 2) Under the background of rapid expansion of *Food processing* and *Beverage production*, *Petroleum processing and coking* and *Smelting and pressing of ferrous metals* should accelerate their industrial transformation by controlling their size and transferring their labors. 3) Because infrastructure construction will promote Jilin's GDP growth in a reasonable period of time, *Nonmetal mineral products* just need to maintain current good situation especially its cement industry. 4) *Raw chemical materials and chemical products* and *Transportation equipment* are still the two leading industries in Jilin Province. These two industries themselves need to be deepened and diversified by adjusting interior enterprise organization structure and extending industrial chain. With enhancing their own innovation ability, they could seizing more market shares and then improve competitiveness of the whole manufacturing.

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