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Article

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Using LMDI Approach to Analyze Changes in Carbon Dioxide Emissions of China's Logistics Industry

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Abstract:

Purpose: China is confronting with tremendous pressure in carbon emission reduction. While logistics industry seriously relies on fossil fuel, and emits greenhouse gas, especially carbon dioxide. The aim of this article is to estimate the carbon dioxide emission in China's logistics sector, and analyze the causes for the change of carbon dioxide emission, and identify the critical factors which mainly drive the change in carbon dioxide emissions of China's logistics industry.

Design/methodology/approach: The logarithmic mean Divisia index (LMDI) method has often been used to analyze decomposition of energy consumption and carbon emission due to its theoretical foundation, adaptability, ease of use and result interpretation. So we use the LMDI method to analyze the changes in carbon dioxide emission of China's logistics industry in this paper.

Findings: By analyzing carbon dioxide emission of China's logistics, the results show that the carbon dioxide emission of logistics in China has increased by 21.5 times, from 45.1 million tons to 1014.1 million tons in the research period. The highway transport is the main contributor to carbon dioxide emission in logistics industry. The energy intensity and carbon dioxide emission factors contributed to the reduction of carbon dioxide emission in China's logistics industry in overall study period.

Originality/value: Although a lot of literature have analyzed carbon dioxide emission in many industry sectors, such as manufacturing, iron and steel, pulp and paper, cement, glass industry, and so on. However, few scholars researched on carbon dioxide emission in logistics industry. This is the first study which is in the context of carbon dioxide emission of China's logistics industry.

Keywords: logistics industry in China, carbon dioxide emission, LMDI

1. Introduction

Many studies have suggested that the concentration of greenhouse gases (GHG) in the atmosphere has been increasing as a result of human activities (Loo & Li, 2012), and the high concentration of GHG has caused global warming which was measured by the increase of the Earth's average temperature (Chapman, 2007). It was reported that the average global surface temperature had increased by 0.74°C over the last 100 years (2014), which was caused by the GHG in the atmosphere, due to the consumption of numerous fossil fuels. Intensive use of fossil fuels can be cited as the main reason of the significant increase in anthropogenic GHG that lead to climate change (İpek-Tunç, Türüt-Aşık & Akbostanci, 2009). Carbon dioxide (CO₂) was the most important composition and accounted for about 80% share of the greenhouse effect (Liao, Lu & Tseng, 2011). Figure 1 shows the top five CO₂ emission countries in the world. China has exceed America and become the first source of CO₂ emission since 2007, with 8320.96 million tons carbon (MTC) in 2010, which accounted for 26.2% share of the total CO₂ emission in the world (2014). As a signatory of the United Nations Framework Convention on Climate Change (UNFCCC), China approved the Kyoto Protocol in 2002, and promised that carbon emissions per unit of GDP would be reduced by 40%-45% in 2020 than 2005 in Copenhagen world climate meeting in 2009. It is greatly significant for policy makers to analyze the change in dioxide carbon emission and find the critical factors to achieve the goal of emission reduction.

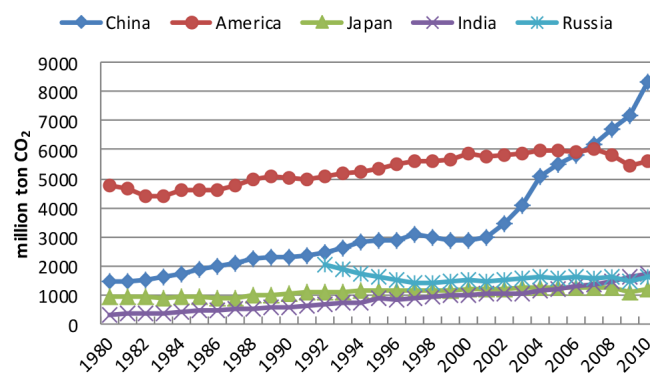


Figure 1. Top five of total CO₂ emission in the world (U.S. Energy Information Administration, EIA, 2012)

Confronted with global warming, CO₂ emission as a main composition of GHG was widely paid attention and researched by most governments, scholars and enterprises in recent years. We can roughly summarize the researches as the following aspects. The first aspect primarily focused on the relationships between energy consumption, CO₂ emission and economic activities in different countries and districts, such as China (Wang, Zhou & Zhou, 2011), Russia (Pao, Yu & Yang, 2011), India (Ghosh, 2010), Europe (Acaravcia & Ozturk, 2010), South Africa (Menyah & Wolde-Rufael, 2010), Turkey (Halicioglu, 2009), and so on. The research results showed there were different causal relationships in different countries. The second aspect was on the forecasting of CO₂ emission. For example, Azadeh, Khakestani and Saberi (2009) forecasted the oil consumption and CO₂ emission in Canada, United States, Japan and Australia during 1990-2005 by using a flexible fuzzy regression algorithm. Olsthoorn (2001) estimated CO₂ emissions from international aviation from 1950 to 2050 through a regression model. Finally, it was case study of CO₂ emission decomposition. For example, Ipek-Tunç et al. (2009) identified the factors that contributed to the changes in CO₂ emissions in agriculture, industry and services. Hammond and Norman (2012) researched on carbon emissions from UK manufacturing between 1990 and 2007. Sheinbaum, Ozawa and Castillo (2010) analyzed energy and CO₂ emission trends of Mexico's iron and steel industry during the period 1970-2006 using Log mean Divisia index; Schmitz, Kamiński, Scalet and Soria (2011) represented a detailed analysis of CO₂ emissions and energy consumption of European glass industry. Xu, Tobias and Eichhammer (2012) analyzed the change of energy consumption and CO₂ emissions in China's cement industry and its driving factors over the period 1990-2009.

As we know, transport is one of main resources of CO₂ emissions. Some research achievements were made. Steenhof, Woudsman and Sparling (2006) analyzed the change in GHG emissions produced by Canada's freight transport using a decomposition analysis framework. Liao et al. (2011) examined CO₂ emissions of truck-only transportation using activity-based emission modeling and compared those with intermodal coastal shipping and truck movements. Fatumata and Lee (2009) compared the energy intensity and CO₂ emission of truck freight in Australia, France, Japan, the United Kingdom and the United States from 1973 to the present, using a bottom-up approach relying on national data. Solís and Sheinbaum (2013) presented a disaggregation of the fuel consumption and its related CO₂ emissions from passenger and freight road transport in Mexico. Zhou, Chung and Zhang (2013) studied CO₂ emissions performance of the transport sector throughout China's 30 administrative regions using Data Envelopment Analysis (DEA) models with different return of scales. Kellner and Igl (2015) examined how the network carbon footprint of a real-world distribution system was affected by the logistics service provider network that was chosen to forward goods from production facilities to customers. Xu and Lin (2015) adopted provincial panel data from 2000 to 2012 and nonparametric additive regression models to examine the key influencing factors of CO₂ emissions in the transport sector in China.

We can find that many research achievements about CO₂ emissions sprang up in different fields from above listed references. However, few scholars researched on carbon dioxide emission in logistics industry. A small quantity of scholars researched CO₂ of logistics. For example, Zajac (2011) presented of the conception of counting the energy consumption of logistics warehouse systems. Tang, Wang, Yan and Hao (2014) examined the issue of cutting emissions by reducing shipment frequency within the framework of periodic inventory review system. Hammami, Nouira and Frein (2014) developed a deterministic optimization model that incorporates carbon emissions in a multi-echelon production-inventory model with lead time constraints. Logistics is a process of planning, implementing and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods and related information from point of origin to point of consumption for the purpose of conforming to customer requirement (Cooper, Lambert & Pagh, 1997). Logistics has played an extremely important role in economic growth in China (Zhang & Peng, 2009; Peng, 2011; Tan, 2003). On the other hand, it is a relatively energy-intensity industry, such as haul trucks, shipping and aircraft, which seriously rely on fossil fuel, and they emit greenhouse gas. Logistics activities accounted for roughly 5.5% share of global GHG emissions, around 90% of which came from transport, and the rest come from warehouses, load and unload (McKinnon, 2012).

There are close correlations between logistics and transportation. However, logistics presents some obvious differences with transportation. Transportation can be known as an important element of logistics. The generalized transportation includes passenger transport and freight transport, but logistics doesn't cover passenger transport.. The paper mainly contributes to reflect changes in carbon dioxide emission of China's logistics from a more extensive perspective, on the basis of transportation, storage, distribution, packaging, et al. It is different with the previous researches which were just based on transportation data, such as passenger transportation, or freight transportation, or the sum of the two. The main purpose of this paper is to: (1) estimate the CO₂ emission in China's logistics sector; (2) analyze the causes for the change of CO₂ emission; (3) identify the critical factors which mainly drive the change in CO₂ emissions of logistics sector in China. The remainder of the paper is organized as follows. Section 2 mainly introduces the decomposition method of carbon dioxide emission and the source of data. Section 3 describes the statistical analysis of carbon dioxide emission in China's logistics industry, and presents the results of carbon dioxide emission decomposition. Section 4 presents the conclusions and some suggestions for sustainable logistics.

2. Methodology

2.1. Decomposition Methods

There are several methods for decomposition analysis of energy consumption and CO₂ emission. Especially, two famous decomposition methods, i.e. structural decomposition analysis (SDA) and index decomposition analysis (IDA), have been widely used, such as Wachsmann, Wood, Lenzen and Schaeffer (2009), Chang, Lewis and Lin (2008), Lise (2006), Akbostanc, Ipek-Tunç and Türüt-Aşık (2011). SDA was based on the input-output model, given to an analytical framework by Leontief (1966). Rose and Casler (1996) reviewed the development of SDA and its relationships to other methodologies, and presented the fundamental principles of alternative approaches. IDA was first used to study the impact of changes in product mix on industrial energy demand (Ang, Zhang & Choi, 1998). Ang (2004) comprehensively compared the two popular index decomposition analysis methods, namely the Laspeyres index decomposition and the Divisia index decomposition, and recommended the log mean Divisia index (LMDI) method for general use due to its theoretical foundation, adaptability, ease of use and result interpretation, along with some other desirable properties in the context of decomposition analysis (Liu, Fan, Wu & Wei, 2007). So we use the LMDI method to analyze the changes in CO₂ emission of China's logistics industry in this paper.

According to the LMDI method firstly introduced by Ang, Zhang and Choi (1998), and the practical guide presented by Ang (2005), the changes in CO₂ emissions from industry may be studied by quantifying the contributions from five different factors: activity effect, structure effect, intensity effect, fuel-mix effect and emission-factor effect. About 90% CO₂ emissions came from transport activity in logistics sector (McKinnon, 2012), so we further to divide the intensity effect into transport intensity effect and energy intensity effect. So we can research the changes in CO₂ emission from logistics industry by quantifying the contributions from the following six different factors: logistics activity (measured by logistics added-value), transport intensity, transport mode shift, energy intensity, fuel mix and CO₂ emission factors. The general index decomposition analysis (IDA) identity may be written as shown in Equation (1). The significance of symbols can be seen in Table 1.

$$C = \sum_{ij} C_{ij} = \sum_{ij} Y \times \frac{Q}{Y} \times \frac{Q_i}{Q} \times \frac{E_i}{Q_i} \times \frac{E_{ij}}{E_i} \times \frac{C_{ij}}{E_{ij}} = \sum_{ij} Y \times T \times S_i \times I_i \times M_{ij} \times U_{ij} \quad (1)$$

| Symbols | Description |
|----------|--|
| i | Transport mode |
| j | Fuel type |
| C | Total carbon dioxide emission in study period |
| Y | Logistics activity, measured by logistics added-value |
| Q | Turnover volume of freight transport |
| Q_i | Freight turnover volume of the i th transport mode |
| E_{ij} | Consumption of fuel j in i th transport mode |
| C_{ij} | Carbon dioxide emission resulting from fuel j in i th transport mode |
| T | $T = Q/Y$, transport intensity |
| S_i | $S_i = Q_i/Q$, transport mode shift |
| I_i | $I_i = E_i/Q_i$, energy intensity |
| M_{ij} | $M_{ij} = E_{ij}/E_i$, fuel mix |
| U_{ij} | $U_{ij} = C_{ij}/E_{ij}$, carbon dioxide emission factor |

Table 1. Significance of symbols

The change of the aggregate carbon dioxide emission in logistics industry from the base year 0 to the target year t , denoted by D_{tot} or E_{tot} , can be decomposed to six affect factors as follows: logistics activity effect (denoted by D_{act} or E_{act}), transport intensity effect (denoted by D_{intt} or E_{intt}), transport mode shift effect (denoted by D_{str} or E_{str}), energy intensity effect (denoted by D_{inte} or E_{inte}), fuel mix effect (denoted by D_{mix} or E_{mix}), CO₂ emission factors effect (denoted by D_{emf} or E_{emf}), as shown in the form of Equation (2) and the additive form of Equation (3).

$$D_{tot} = C^t / C^0 = D_{act} D_{intt} D_{str} D_{inte} D_{mix} D_{emf} \quad (2)$$

$$\Delta C_{tot} = C^t - C^0 = \Delta C_{act} + \Delta C_{intt} + \Delta C_{str} + \Delta C_{inte} + \Delta C_{mix} + \Delta C_{emf} \quad (3)$$

According to the multiplicative and additive decomposition method recommended by Ang (2005), each term of Equations (2) and (3) can be calculated applying the LMDI method, which were shown in Appendix A-Table A1.

2.2. Management of Data

There are no compiled data of logistics industry in the related Chinese yearbooks, but we can find a statistical index in China Statistical Yearbooks and China Transport Yearbooks, which included the related statistical data about transport, storage and communications, we can regard the index as a proximate proxy of logistics industry (Liu & Li, 2007; Zhang & Yu, 2012). In this paper, we use the "top-down" method to calculate CO₂ emissions in logistics industry, which estimates CO₂ emissions on basis of the total amount of fuel consumption. CO₂ emissions of the i th transport mode in year t can be calculated by multiplying fuel consumption

of one fuel type used in the i th transport mode and the CO₂ emission factor of the fuel type j . If different fuels are used in one transport mode, we should summarize the CO₂ emission of different fuel types in the mode (Loo & Li, 2012). For example, the fuel types include coal, diesel and electricity in railway transport mode. The main energy fuels are gasoline and diesel in highway transport mode, and they are jet kerosene and aviation gasoline in the aviation transport. For water transport, the primary fuel is diesel. The energy consumption data of different freight transport modes can be obtained and calculated from China Statistical Yearbook, Yearbook of China Transportation and Communication, Compile of China Aviation Statistics in different stages. Emission factor data came from IPCC Guidelines for National Greenhouse Gas Inventories (2006), as shown in Table 2.

| Fuel type | CO ₂ emission factor (kg/TJ) | Net calorific value (TJ/Gg) | Emission factor (kg CO ₂ /ton fuel) |
|-------------------|---|-----------------------------|--|
| Coal | 96,100 | 18.9 | 1816.29 |
| Jet kerosene | 71,500 | 44.1 | 3153.15 |
| Aviation gasoline | 70,000 | 44.3 | 3101.00 |
| Motor gasoline | 69,300 | 44.3 | 3069.99 |
| Diesel | 74,100 | 43.0 | 3186.30 |

Table 2. CO₂ emission factor by type of transport fuel

Carbon emission coefficients of fuels have changed with an updating in level of fuels. Because of the relatively short study period, these changes of the emission coefficients can be ignored when we analyze the macro changes in CO₂ emission, we assume that the CO₂ coefficients of coal, kerosene, gasoline and diesel are constant. However, CO₂ coefficient of electricity is continuously changing, due to the fuel mix used and technological improvements in the generation of electricity. We use the net standard coal consumption rate (g/kw. h) to describe the energy consumptions which were used to generate one kilowatt hour. We can obtain the data from China Energy Statistical Yearbook. So, the CO₂ emission coefficient is restricted to the impact of changes in electricity emission rate, which is calculated on basis of the individual fuels used in power generation (Liu, Fan, Wu & Wei, 2007; Wang, Zhang & Zhou, 2011).

3. Results and Discussion

3.1. Total CO₂ Emission in Chinese Logistics Industry

Figure 2 presents the trend of total CO₂ emission in China's logistics industry from 1980 to 2010. It's obvious that the CO₂ emission has a continuously raising trend in the study period. It has increased by 21.5 times from 45.1 million tons CO₂ in 1980 to 1014.1 million tons CO₂ in 2010, with the average growth rates was 11.7%, which accounted for 12.2% share of total CO₂

emission of China. The result showed that logistics industry has gradually become one of the leading source of CO₂ emission. The aggregate CO₂ emission in logistics has close relationship with economic growth. Economic growth caused the increasing demand for logistics service, then, logistics activities increased the energy consumption and thus produced more CO₂ emission, especially the transport, which consumed numerous fossil fuels. We can see that the changing trend was a gentle up-incline before 2007, and suddenly became upward sharply after 2007 in the Figure 2. Especially in 2007 and 2008, the change of CO₂ emission were remarkable, with the growth rate of 63.5% and 51.1%, respectively, which resulted from Chinese government's numerous invests on infrastructure for pursuing the continuous economic growth.

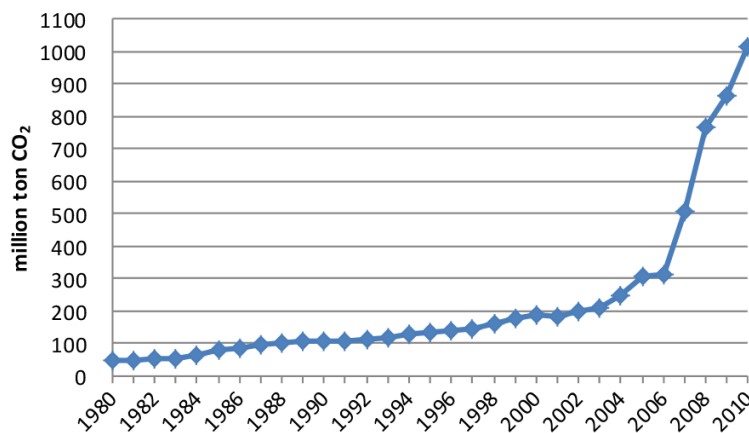


Figure 2. Total CO₂ emission in Chinese logistics industry

We further to analyze the distribution of annual CO₂ emission according to the transport modes to understand the composition of CO₂ emission in logistics industry well. Figure 3 shows the percentages of CO₂ emission in different transport modes in each year from 1980 to 2010. From Figure 3, we can conclude that the highway transport was a main contributor to CO₂ emission, it accounted for 76.8% (or 778.47 million tons CO₂) share of total CO₂ emission in 2010. The reasons were that the demand for highway transport was increasing in recent years due to its convenience and flexibility, and the highway transport mainly relied on the fossil energy. Next to highway transport, waterway transport ranked the second, which accounted for 18.1% (or 183.37million tons CO₂) of total CO₂ emission in 2010, and it is noticed that the statistical data of waterway transport included ocean transport in China Statistical Yearbook. Railway transport ranked the third with reduction from 32.3% share in 1980 to 2.53% in 2010. The main reason is the replacement of the coal-fired steam locomotives with diesel/electric locomotives (Wang, Zhang & Zhou, 2011). The freight aviation transport had small proportion and ranked the fourth, which only accounted for 1.69% share of total CO₂ emission, however, its growth rate was the most obvious, it increased by 89.4 times, from 0.19 million tons CO₂ in 1980 to 17.12 million tons CO₂ in 2010. It may be explained by the changing of production

mode, for example, the Just-In-Time (JIT) requests to reduce the inventory as far as possible, which made promptness of delivery become an important factor. In order to satisfy customer's requirements, more and more suppliers choose the aviation transport due to its quick speed.

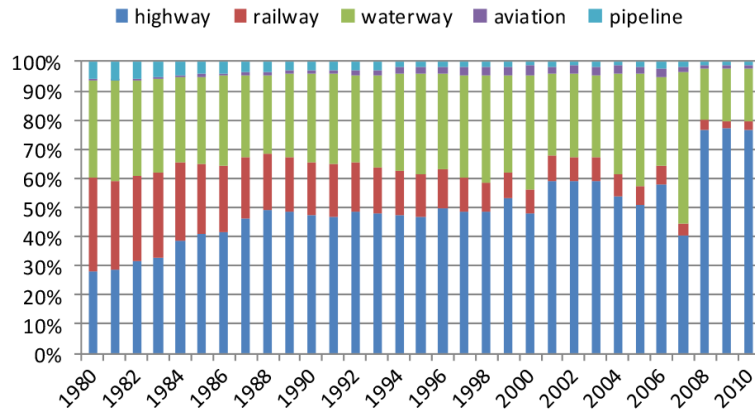


Figure 3. Percentage of CO₂ emission in different transport modes

3.2. Intensity of CO₂ Emission in Logistics Industry

The CO₂ emission intensity of logistics can be defined as the CO₂ emission per unit of logistics output, which can be measured by the added value of logistics and the turnover volume of freight transport. So we analyze the CO₂ emission from two aspects, i.e. CO₂ emission per added value of logistics (million tons CO₂ per billion Yuan) and CO₂ emission per turnover volume of each transport mode (million tons CO₂ per billion km-tons). As shown in Figure 4, it presents the changing trend of CO₂ emission of logistics in China. In general, the CO₂ emission of logistics tends to flat in the period of 1980-2006. However, there were dramatic changes in intensity of CO₂ emission between 2006 and 2010, with increasing from 3.06 million tons CO₂ per billion Yuan in 2006 to 8.74 million tons CO₂ per billion Yuan in 2010 (constant price in 1980). There are some reasons for the obvious changes in intensity of CO₂ emission, for example, Chinese government invested vast funds in infrastructure for economic growth from 2006 to 2010, which boosted the increase of logistics demand rapidly, and it exceeded the technological updating speed for energy conservation and emission reduction. On the other hand, the transport mode obviously changed from lower energy consumption mode to higher energy consumption mode in 2006-2010. The turnover volume ratio of railways to total turnover volume of freight transport decreased from 24.71% in 2006 to 19.49% in 2010; the ratio of highway transport increased from 10.98% in 2006 to 30.59%, especially in 2008, the turnover volume of highway transport increased by 1.89 times than last year, from 1135.5 billion ton-km to 3286.8 billion ton-km. So the economic growth and energy mix are important factors for the changing in intensity of CO₂ emission.

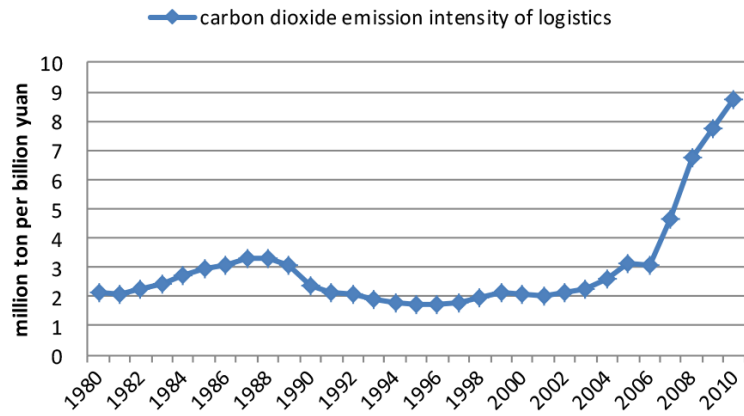


Figure 4. CO₂ emission intensity of logistic industry

As shown in Figure 5, we present the chart of changes in the intensity of CO₂ emission according to transport mode, for comparing the CO₂ emission difference of different transport modes. It is easy to find out that the railway transport owns the lowest CO₂ emission intensity and presents a declining trend, it was because the economies of scale of railway transport increased and steam locomotive was replaced by electric locomotives. The aviation transport has the highest CO₂ emission intensity, due to high energy intensity and less loading capacity, but it is decreasing in recent years, which attributed to the improvement of aviation fuel quality. Next to aviation transport, the CO₂ emission intensity of highway transport was the second and presented an increasing trend in recent years. The diesel and gasoline are important fuel energy of highway transport, which are the main source of CO₂. The sharp increasing of freight transport volume resulted in the increasing of transport intensity, which caused that the increasing of carbon emission exceeded the increasing of logistics output, on the other hand, the continuous use of transportation facility would make the vehicle condition worse, which can increase the emission intensity.

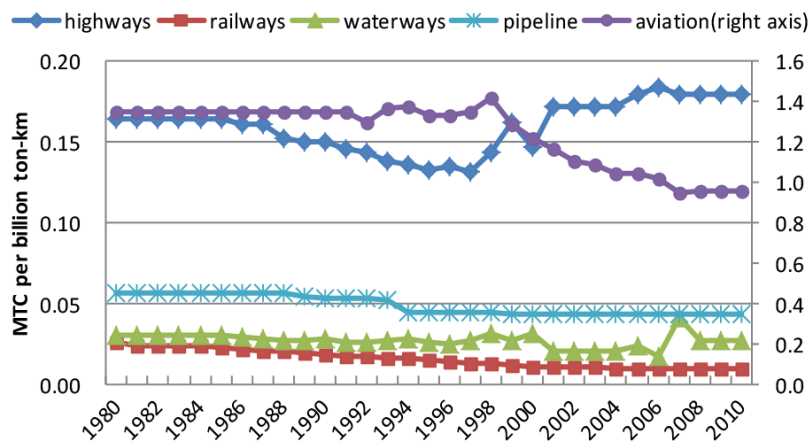


Figure 5. CO₂ emission intensity in different transport modes

3.3. Decomposition Results of CO₂ Emission from Chinese Logistics Industry

In this paper, we used logarithmic mean Divisia index (LMDI) method to explore the multiplicative and additive decomposition of CO₂ emission in China's logistics industry. The decomposition results are based on Equations (2) and (3) and the LMDI formula in Appendix A-Table A1, as shown in Table 3 and Table 4. Figures 6-7 showed the radar charts for multiplicative decomposition and the bar charts for additive decomposition of CO₂ emission in logistics industry by using the numerical results presented in Tables 3-4, respectively.

| | Dtot | Dact | Dintt | Dsrt | Dinte | Dmix | Demf |
|-----------|--------|-------|-------|-------|-------|-------|-------|
| 1980-1990 | 2.359 | 2.083 | 1.025 | 1.260 | 0.870 | 1.009 | 0.999 |
| 1990-2000 | 1.756 | 1.903 | 0.868 | 1.093 | 0.955 | 1.020 | 0.998 |
| 2000-2005 | 1.642 | 1.095 | 1.614 | 0.929 | 0.962 | 1.041 | 0.999 |
| 2005-2010 | 3.308 | 1.182 | 1.468 | 1.832 | 1.021 | 1.022 | 0.998 |
| 1980-2010 | 22.495 | 3.314 | 1.729 | 2.005 | 0.947 | 2.076 | 0.997 |

Table 3. Multiplication decomposition of CO₂ emission in logistics industry

| | ΔCtot | ΔCact | ΔCintt | ΔCstr | ΔCinte | ΔCmix | ΔCemf |
|-----------|---------|---------|---------|---------|---------|---------|--------|
| 1980-1990 | 61.270 | 52.385 | 1.770 | 16.489 | -9.949 | 0.614 | -0.039 |
| 1990-2000 | 80.352 | 91.902 | -20.154 | 12.649 | -6.637 | 2.837 | -0.245 |
| 2000-2005 | 119.834 | 21.976 | 115.751 | -17.786 | -9.451 | 9.676 | -0.331 |
| 2005-2010 | 707.602 | 98.889 | 227.156 | 357.898 | 12.130 | 12.635 | -1.108 |
| 1980-2010 | 969.058 | 372.969 | 170.351 | 216.454 | -17.053 | 227.328 | -0.992 |

Table 4. Additive decomposition of CO₂ emission in logistics industry

3.3.1. Total Change in Carbon Dioxide Emission Between 1980 and 2010

Figures 6-7 describe the results of the multiplicative and additive decomposition analyses of logistics industry in China. According to the analysis, we can conclude that the total CO₂ emission had changed greatly, with the accumulated increasing of 969.1 million tons CO₂ emission from 1980 to 2010, and logistics activity, transport intensity, transport mode shift and fuel mix are important factors in increasing the CO₂ emission of logistics sector in China. However, the energy intensity and the factors that influenced CO₂ emission contributed to the reduction of CO₂ emission in overall research period, which factors had multiplicative indexes less than one and additive indexes below zero, as shown in Figure 6.

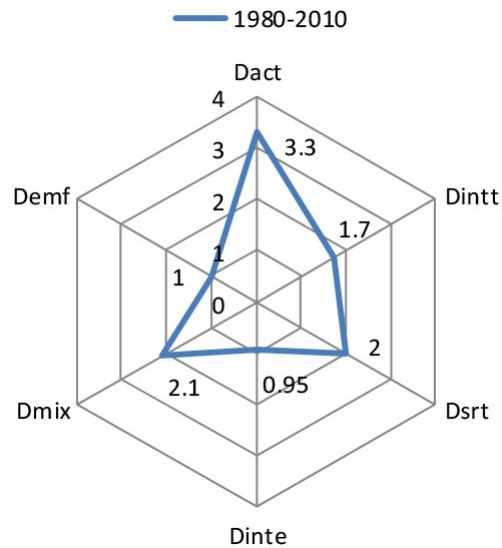


Figure 6. Radar chart for CO₂ emission decomposition in 1980-2010

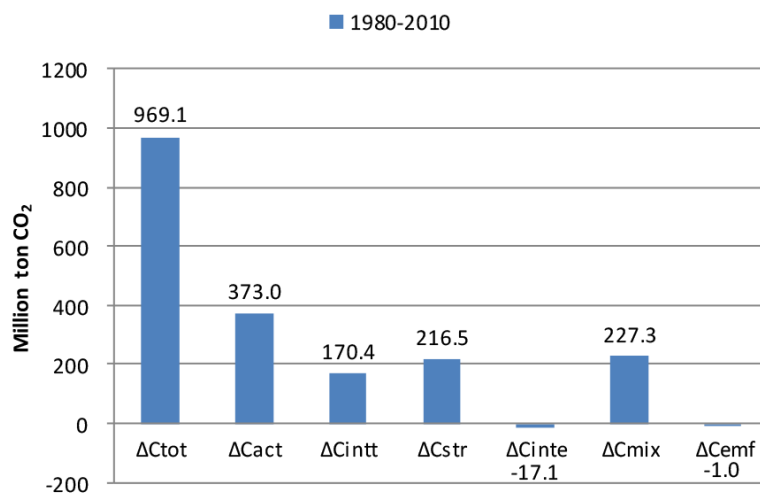


Figure 7. Bar chart for CO₂ emission decomposition in 1980-2010

Logistics activity is the most important factor contributing to the increase of CO₂ emission in logistics industry, which increased 373 million tons CO₂ emission, with 38.5% share of total CO₂ emission change. The main reason was that the rapid economic growth boosted the demand for logistics service, with the increasing of freight turnover volume from 1202.7 billion kilometer-tons in 1980 to 14183.7 billion kilometer-tons in 2010, thus indirectly resulting in the increase of energy consumption and CO₂ emission. China's economy has continuously developed in recent thirty years since reform and opening-up. However, China is still at the primary stage of motorization and the economic growth is at the cost of consuming a great deal of natural resource. In addition, the integrated logistics system cannot operate efficiently because of the outdated logistics technology and management method, which resulted in low energy efficiency and high carbon emission intensity.

Next, fuel mix is another important factor to the increase of CO₂ emission in logistics sector, which caused the accumulated increasing of 227.3 million tons carbon emission, with 23.5% share of total CO₂ emission change. Transport mode shift ranked the third, with the increasing of 216.5 million tons carbon emission and 22.3% share. In fact, there was a tight relationship between fuel mix and transport mode shift, transport mode determined the fuel type. The decomposition results have shown that the transport modes and energy structure are unreasonable in China, and the petroleum is still the primary energy source in logistics activities at present. Transport intensity ranked the fourth, with the increase of 170.4 million tons carbon emission and 17.6% share. Because of the development of global economy, change of production and management mode, the transport distance increased and the transport intensity increased from 56.4 km-tons per Yuan in 1980 to 122.2 km-tons per Yuan in 2010, which caused the increase of energy consumption and emission.

The decomposition result showed that energy intensity caused the CO₂ emission to reduce by 17.1 million tons between 1980 and 2010, and it accounted for 1.8% share of total change in absolute value. It may attribute to the effective strategies which aimed at improving energy efficiency, such as introducing advanced logistics technologies, updating logistics facilities and equipment, improving fuel quality, and so on. In recent years, Chinese government is making efforts to save energy and reduce emission in logistics sector. The CO₂ emission factor has small effect on the change in CO₂ emission in logistics industry, with the reduction of only 1 million tons carbon emission. It was because that we assumed the carbon emission coefficients of coal, diesel, gasoline and kerosene were constant. The carbon emission coefficient of electricity was calculated on basis of the individual fossil fuels used in power generation.

3.3.2. Change of Carbon Dioxide Emission in Different Periods

We divided the study period into multi-stages in order to examine the factors that caused the change in CO₂ emission of logistics well. Chinese administration departments take five years as a plan cycle when they make macro policies. We suppose that there are no obvious differences in two continuous five-year plans. So we divide the research period into three sub-stages, i.e. 1980-1990, 1990-2000 and 2000-2010. Additionally, taking account of rapid economic growth and policy adjustment in recent ten years, we further divided the period 2000-2010 into 2000-2005 and 2005-2010. Figures 8 - 9 showed the radar charts for multiplicative decomposition and the bar charts for additive decomposition of CO₂emission in logistics industry in different sub-stages, respectively.

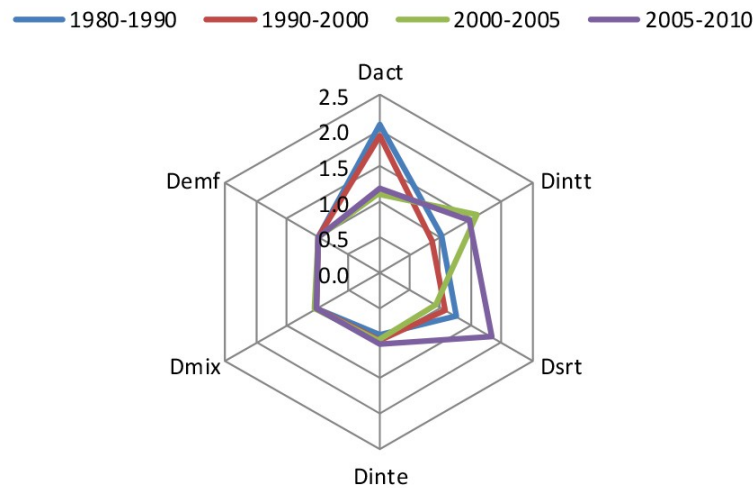


Figure 8. Radar chart for CO₂ emission decomposition in multi-stages

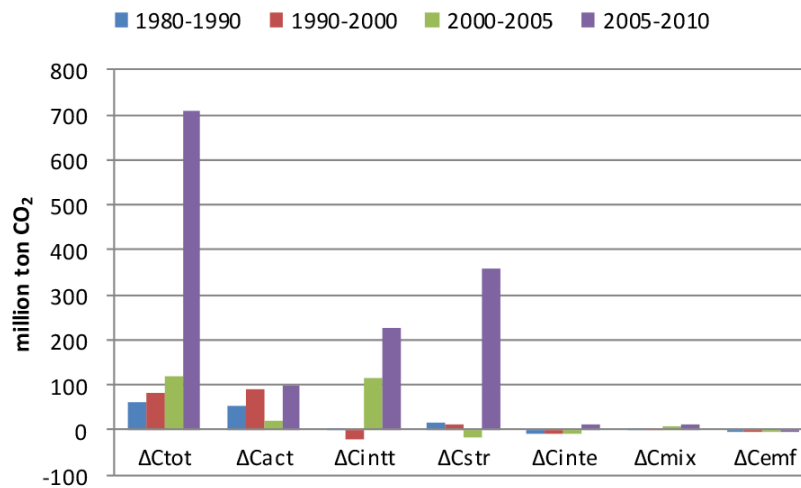


Figure 9. Bar chart for CO₂ emission decomposition in multi-stages

The change in CO₂ emission in different sub-stages (in turn, 1980-1990, 1990-2000, 2000-2010, accounted for 6.3%, 8.3%, 85.4% share of the total CO₂ emission change, respectively, with the increasing of 61.27, 80.35, 827.43 million tons carbon emission in the study period. The CO₂emission of China’s logistic industry had greatly increased in the period of 2000-2010. Especially, in the stage of 2005-2010, it accounted for 73% share of total CO₂ emission in research period, with the increasing of 707.6 million tons carbon emission. Global economy was in recession in that time, Chinese government endeavored to pull domestic demand by investing plenty of money in public service and infrastructure to deal with world financial crisis in 2008. China’s GDP ranked the second place, which is next to America and exceeded Japan in the world in 2010. As previously mentioned, economic growth would make the demand for logistics service increase, and it enhanced the energy consumption and CO₂ emission.

From Figures 8-9, we can conclude that the changes in CO₂ emission and the influence factors have extreme similarities between the stages of 1980-1990 and 1990-2000. For example, logistics activity was the leading factor that caused the increase of CO₂ emission, with 85.5% and 114.4% share of the total change in the two periods, respectively; the energy intensity and the emission factor had positive roles in reducing the CO₂ emission due to the updating and innovation of logistics technologies and logistics equipment. However, the critical factors to changing in carbon emission were transformed in recent ten years. For example, logistics activity, transport intensity and fuel mix had adverse effect on the change in carbon emission from 2000 to 2005; herein, transport intensity was the first primary contributor to the increase of carbon emission. Transport structure, energy intensity and emission factor had positive role in decreasing carbon emission. From 2005 to 2010, all decomposition factors led to the increase of CO₂ emission, except for emission factor. Transport structure played the most important role in increasing CO₂ emission with 358 million tons CO₂ emission, which accounted for 50.6% share of total CO₂ emission. The effect resulted from the change of transport model from lower energy consumption model such as railway transport to higher energy consumption model such as highway and aviation transport. Transport mode shift mainly depended on customer's demand for transportation service, such as cost, security, convenience, promptness, flexibility, and so on.

4. Conclusions and Policy Implications

4.1. Conclusions

Carbon dioxide emission has a tight link with economic growth and energy consumption. As an emerging and important industry in China, the logistics industry is promoting economic growth; on the other hand, it consumed a great deal of energy and emitted plenty of CO₂, and it was the main reason for global warming. In order to examine the change in CO₂ emission of China's logistics industry, we firstly calculated the carbon dioxide emission of logistics industry in the period of 1980-2010; and further analyzed the factors that influenced the changes in CO₂ emission of logistics industry by using logarithmic mean Divisia index (LMDI) method. We can draw some conclusions from the present study as follows:

1. Carbon dioxide emission in China's logistics industry has a continually rising trend in the study period. It has increased by 21.5 times, from 45.1 million tons CO₂ in 1980 to 1014.1 million tons CO₂ in 2010, with the average annual growth rate of 11.7%, which accounted for 12.2% share of total CO₂ emission of China.
2. The highway transport is the main contributor to carbon dioxide emission in logistics activities, which accounted for 76.8% (or 778.47 million tons CO₂) share of total carbon dioxide emission in 2010. The waterway transport ranked the second, which accounted

for 18.1% (or 183.37 million tons CO₂) of total carbon emission; railway, aviation and pipeline accounted for 2.5%, 1.7% and 0.9%, respectively.

3. According to the results of decomposition, logistics activity, transport mode shift, transport intensity and fuel mix are critical effect factors to the increase of change in CO₂ emission, however, the energy intensity and CO₂ emission factors were contributing to the reduction of carbon dioxide emission in China's logistics industry in overall study period. Therein, logistics activity is the most important factor contributing to the increase of CO₂ emission in logistics during the period of 1980-2010, which increased 373 million tons carbon emission, with 38.5% share of total CO₂ emission change.
4. The critical effect factor caused the change in CO₂ emission in logistics sector would vary with the change of external environment factors, such as economy level, logistics technology and equipment, energy price, labor cost, production and management mode, and so on.

4.2. Policy Implications

Facing the rapid growth in demand for logistics services due to economic growth, it's difficult to decrease total CO₂ emission in logistics industry, because there are tight relations between economic growth, logistics demand, energy growth and carbon emission. However, we can take some strategies to improve energy efficiency and reduce CO₂ emission per unit of energy consumption, which can offset the increase of total CO₂ emission, such as: (1) Optimize social logistics system and update logistics facility and equipment. Logistics is an extremely complex economy activity. It is significant to optimize the social logistics system for energy conservation and emission reduction. Nevertheless, logistics has been paid attention in recent years, and the current logistics system is unreasonable in China, such as unscientific layout of logistics network, underdeveloped traffic condition, outdated warehouse, and so on. The administration departments should further to optimize social logistics system by relocating and constructing gather and distribution centers, junction stations, and building modern warehouse for improving logistics operation efficiency, reducing energy consumption and emission. (2) Encourage transport mode to shift from high emission to low carbon mode. The research result showed that the transport mode has critical effect on the change of CO₂ emission. Railway transport and waterway transport have low energy intensity and strong transport capacity; however, due to the flexibility and convenience of highway transport and aviation transport's promptness, the share of freight turnover volumes present an increasing trend in recent years in China. Policy makers can encourage people to choose lower energy consumption transport by making transport pricing policy. (3) Introduce advanced information communication technology. Information communication technology (ICT) helps operators to make efficient route plan and schedule, vehicle loading, driving time and travel distance, and it can avoid

traffic congestion and reduce energy consumption and emission (Liao et al., 2011). ICT was generally utilized in truck transport in developed countries; however, few operators use it in China. So it is necessary to introduce advanced information communication technology. (4) Increase investment on designing high fuel efficiency and low emission engine. Efficient engine design and fuel economy standard play a great role in cutting fuel demand, which can improve trucks fuel economy (Schipper, 2009). However, because of the limited technology resource, China's transport carrier emission standard is still lower than international emission standard. Scientific and technological administrations should increase investment and organize R&D team to design high fuel efficiency and low emission engine. (5) Improve electricity generation and fuel refining technology. The development of energy technology has a little positive effect in decreasing the energy consumption and carbon emission in recent years in China, but it's very limited. Energy and environment administration division should make effort to improve the electricity generation and fuel refining technology for reducing the carbon coefficients. For example, the power stations can adopt new energy technologies, such as nuclear power, wind power, solar power and biomass power to generate electricity. In addition, high quality fuel can release more energy and less emission, and the petroleum companies should explore and introduce new fuel refining technology to improve the purity of fuel oil.

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Appendix A

The LMDI formula for each factor in the decomposition analysis (see Table A1)

| Effect factors | Multiplicative decomposition | Additive decomposition |
|---------------------------|--|--|
| Logistics output(act) | $D_{act} = \exp\left(\sum_i \frac{(E_i^t - E_i^0)/(\ln E_i^t - \ln E_i^0)}{(E^t - E^0)/(\ln E^t - \ln E^0)} \times \ln\left(\frac{Y^t}{Y^0}\right)\right)$ | $\Delta E_{act} = \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0} \times \ln\left(\frac{Y^t}{Y^0}\right)$ |
| Transport mode(str) | $D_{str} = \exp\left(\sum_i \frac{(E_i^t - E_i^0)/(\ln E_i^t - \ln E_i^0)}{(E^t - E^0)/(\ln E^t - \ln E^0)} \times \ln\left(\frac{S_i^t}{S_i^0}\right)\right)$ | $\Delta E_{str} = \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0} \times \ln\left(\frac{S_i^t}{S_i^0}\right)$ |
| Transport intensity(intt) | $D_{act} = \exp\left(\sum_i \frac{(E_i^t - E_i^0)/(\ln E_i^t - \ln E_i^0)}{(E^t - E^0)/(\ln E^t - \ln E^0)} \times \ln\left(\frac{T^t}{T^0}\right)\right)$ | $\Delta E_{intt} = \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0} \times \ln\left(\frac{T^t}{T^0}\right)$ |
| Energy intensity(inte) | $D_{inte} = \exp\left(\sum_i \frac{(E_i^t - E_i^0)/(\ln E_i^t - \ln E_i^0)}{(E^t - E^0)/(\ln E^t - \ln E^0)} \times \ln\left(\frac{I_i^t}{I_i^0}\right)\right)$ | $\Delta E_{inte} = \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0} \times \ln\left(\frac{I_i^t}{I_i^0}\right)$ |
| Fuel mix(mix) | $D_{mix} = \exp\left(\sum_i \frac{(E_i^t - E_i^0)/(\ln E_i^t - \ln E_i^0)}{(E^t - E^0)/(\ln E^t - \ln E^0)} \times \ln\left(\frac{M_{ij}^t}{M_{ij}^0}\right)\right)$ | $\Delta E_{mix} = \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0} \times \ln\left(\frac{M_{ij}^t}{M_{ij}^0}\right)$ |
| Emission factor(emf) | $D_{emf} = \exp\left(\sum_i \frac{(E_i^t - E_i^0)/(\ln E_i^t - \ln E_i^0)}{(E^t - E^0)/(\ln E^t - \ln E^0)} \times \ln\left(\frac{U_{ij}^t}{U_{ij}^0}\right)\right)$ | $\Delta E_{emf} = \sum_i \frac{E_i^t - E_i^0}{\ln E_i^t - \ln E_i^0} \times \ln\left(\frac{U_{ij}^t}{U_{ij}^0}\right)$ |

Table A1. Calculation formula of decomposition

