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Research Article

The Analysis of CO_2 Emissions and Reduction Potential in China's Transport Sector

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China's transport sector is responsible for approximately 10% of national CO_2 emissions. In the process of industrialization and urbanization of China, emissions from transport sector would continuously increase. In order to investigate the emissions and reduction potential and provide the policy guidance for policymakers in China's transport sector, this study decomposed the CO_2 emissions using the Kaya identity, calculated the contribution based on the Logarithmic Mean Divisia Index (LMDI) method to explore the underlying determinants of emissions change, and then constructed different scenarios to predict the emissions and estimate the potential of emission reduction in the future. Results indicated that carbon emissions in China's transport sector have increased from 123.14 Mt in 1995 to 670.76 Mt in 2012. Income effect is the dominant factor that results in the increase of emissions while energy intensity effect is the main driving force to lower carbon emissions. The transportation modal shifting, transportation intensity change, and population growth have the positive but relatively minor impact on emissions. The accumulated emission reduction is expected to be 1825.97 Mt, which is 3 times more than the emissions in 2010. Policy recommendations are thus put forward for future emission reduction.

1. Introduction

Climate change and emissions mitigation have already attracted extensive attention in recent years. As the main carbon emissions emitter in the world, China has responsibility and obligation to reduce carbon emissions. Chinese government has announced that by 2020 the CO_2 emissions per unit of gross domestic product (GDP) would be reduced by 40–45% compared to 2005 levels [1]. The transport sector is one of the major contributors to the rapid growth of total CO_2 emission. The CO_2 emissions from China's transport sector account for approximately 10% of China's total emissions in 2008 [2]. The increase of passenger and freight traffic will inevitably lead to a significant increase in energy consumption and CO_2 emissions in China's transport sector. The total emissions from China's transport sector are predicted to double by 2020 [3]. Therefore, the transport sector plays an important role in energy conservation and emissions mitigation in China.

It is the basis for policy making to find out the main factors affecting the energy consumption and emissions in China's transport sector. Taking automotive engine technology improvement, rapid transit system, and fuel conversion, [4] designed different scenarios and forecasted the carbon emissions in China's road transport during 2000–2020. The study above indicated that vehicle technology improvement, especially engine technology, was likely to be the most effective means to meet emissions reduction targets. Reference [5] conducted the input-output analysis on carbon emission structure of EU land transportation. The results have shown output level per capita, population growth, and energy intensity were the primary influencing factors on carbon emissions in land transport sector. Reference [6] verified that road transport-related energy consumption, transport value added, transport CO_2 emissions, and road infrastructure are mutually causal in the long-run. Reference [7] explored the effect of road transportation services on energy consumption and carbon emissions in Finland. It

concluded that the major cause of the decline of carbon intensity was the shift of balance from transporting bulk goods to transporting parcelled goods. Reference [8] held that the mitigation policies played important role in improving energy efficiency and promoting the development of new energy, which would reduce carbon emissions in transport sector effectively. Reference [9] analyzed the effect of energy subsidy reforms on transport sector in Malaysia using the computable general equilibrium (CGE) model. Meanwhile, carbon trading is proved to be another significant policy instrument to reduce emissions in Malaysia's transport sector. Reference [10] assessed what extent the emissions in German transport sector was effected when transport sector would have been covered by the emissions trading scheme the EU launched in 2005. Reference [3] analyzed the regional differences of carbon emissions of urban passenger transportation in China. There have been significant regional disparities on urban passenger transport. In addition, motorization rate and transport structure were the substantial factors determining urban passenger transport associated GHG emissions.

The Logarithmic Mean Weight Divisia Index (LMDI) method is a popular index decomposition analysis (IDA) approach because of the advantages of path independence, residual-free ability to handle zero values and consistency in aggregation [11]. It is widely used to investigate the influencing factors of the change of energy consumption and CO_2 emissions [12–14]. However, it is relatively deficient of the study about driving factors to CO_2 increase in transport sector through LMDI method. Reference [15] explored the factors affecting the emissions in transport industry in selected Asian countries during the 1980–2005 period using the LMDI method. The study indicated that per capita gross domestic product (GDP), population growth, and energy intensity are the main factors driving transport sector CO_2 emission growth in the countries considered. Reference [16] presented a LMDI decomposition analysis of the changes in CO_2 emissions from passenger cars in Denmark and Greece during the period 1990–2005. They found that the decreasing share of diesel cars contributes to reducing CO_2 emissions. Reference [17] used the LMDI decomposition analysis method to identify and analyze the driving forces of CO_2 emissions in eleven final energy consuming sectors. Results shown increases in energy intensity contributed to a significant increase in emissions in transport sector. Reference [18] performed a time serial LMDI decomposition analysis that the change of CO_2 emissions in transport sector was decomposed to six effects including emission coefficient effect services share effect, modal shifting effect, transportation intensity effect, per capita economic activity effect, and population effect. The research indicated that the per capita economic activity effect and transportation modal shifting effect are primarily responsible for the increase of transport sector CO_2 emissions growth while transportation intensity effect and transportation structure effect are significant factors in the reduction of CO_2 emissions in transport sector. Reference [19] uncovered China's transport CO_2 emission patterns at the regional and provincial level. The study presented the CO_2 emission features, including per capita emissions, emission intensities, and historical evolution and quantified the driving forces by adopting both period-wise and time-series LMDI analyses. Accelerating industrialization and urbanization are also underlying driving forces of change in transport sector [20].

Accordingly, this paper intends to address four important questions including analyzing the CO_2 emission trajectory, exploring the major driving forces of CO_2 emissions change, estimating the emission reduction potential from China's transport sector by 2020 and making policy recommendations for future emission reduction.

2. Methodology and Data Sources

2.1. Sources of Data. The data from 1995–2012 used in this paper mainly include annual GDP, the industrial output, population collected from the China Statistical Yearbook [21], the transportation services by transportation mode and by passenger and freight transport, and energy consumption per transportation services, coming from Yearbook of China Transportation & Communications [22]. The transportation services by passenger and freight transport are shown in Tables 1 and 2.

In this study, the year of 1995 is taken as a base year. The GDP is in the unit of billion yuan and is measured using the base year prices. The population data are the mean value of the beginning and end of the year. The CO_2 emissions factors and fractions of carbon oxidized of different energy types come from [23, 24]; see Table 3.

The transportation services can be classified into passenger person-kilometers and freight tonne-kilometers. However, they are commonly incomparable, which makes it difficult to measure the total transportation services. In this study, the comprehensive transportation services, including both passenger person-kilometers and freight tonne-kilometers, are used to evaluate the total output in China's transport sector. In order to unify the measurement unit, the passenger person-kilometers will be converted to freight tonne-kilometers through division by a conversion coefficient. The volume of comprehensive transportation services is measured by tonne-km in this paper. The conversion coefficients of each transportation mode refer to [25], presented in Table 4. The conversion coefficient is determined by the comparison of revenues and expenditures per person-kilometer with those of moving one tonne of goods 1 km. In other words, transporting one tonne of goods 1 km is equivalent to transporting one passenger 1 km for railway in terms of expenditures. In addition, the conversion coefficient of civil aviation has been modified based on the comparison of total transportation services, the volume of passenger person-kilometers, and freight tonne-kilometers given by [22] and the historical and present expenses.

2.2. Estimation of CO_2 Emissions. The annual CO_2 emissions in China's transport sector can be assessed, respectively, based on the transportation services, energy consumption per transportation services, and CO_2 emissions factor and the fractions of carbon oxidized by energy types. The transportation mode denotes railway, road, waterway, and civil aviation.

Table 1: The transportation service by mode for passenger transport, unit: billion passenger-km.

Year	Railway	Road	Waterway	Civil aviation
1995	354.57	460.31	17.18	68.13
1996	334.76	490.88	16.06	74.78
1997	358.49	554.14	15.57	77.35
1998	377.34	594.28	12.03	80.02
1999	413.59	619.92	10.73	85.73
2000	453.26	665.74	10.05	97.05
2001	476.68	720.71	8.99	109.14
2002	496.94	780.58	8.18	126.87
2003	478.86	769.56	6.31	126.32
2004	571.22	874.84	6.63	178.23
2005	606.20	929.21	6.78	204.49
2006	662.21	1013.08	7.36	237.07
2007	721.63	1150.68	7.78	279.17
2008	777.86	1247.61	5.92	288.28
2009	787.89	1351.14	6.94	337.52
2010	876.22	1502.08	7.23	403.90
2011	961.23	1676.02	7.45	453.70
2012	981.23	1846.75	7.75	502.57

Table 2: The transportation service by mode for freight transport, unit: billion tonne-km.

Year	Railway	Road	Waterway	Civil aviation
1995	1304.95	469.49	1755.22	2.23
1996	1310.62	501.12	1786.25	2.49
1997	1326.99	527.15	1923.50	2.91
1998	1256.01	548.34	1940.58	3.35
1999	1291.03	572.43	2126.30	4.23
2000	1377.05	612.94	2373.42	5.03
2001	1469.41	633.04	2598.89	4.37
2002	1565.84	678.25	2751.06	5.16
2003	1724.67	709.95	2871.58	5.79
2004	1928.88	784.09	4142.87	7.18
2005	2072.60	869.32	4967.23	7.89
2006	2195.44	975.42	5548.57	9.43
2007	2379.70	1135.47	6428.48	11.64
2008	2510.63	3286.82	5026.27	11.96
2009	2523.92	3718.88	5755.67	12.62
2010	2764.41	4338.97	6842.75	17.89
2011	2946.58	5137.47	7542.38	17.39
2012	2918.71	5953.49	8170.76	16.39

The energy, used by transport sector, is disaggregated into nine kinds, including coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel, natural gas, and electricity. The calculation method is presented as follows:

$$C^t = \sum_{i=1}^{4} C_i^t = \sum_{i=1}^{4} \sum_{j=1}^{9} A_{ij}^t R_{ij}^t F_j^t O_j, \tag{1}$$

Table 3: The CO_2 emission coefficients and fractions of carbon oxidized of different energy types.

Fuel	F = CO_2 emission factors, Kg CO_2/Kg	O = fractions of carbon oxidized, %
Coal	2.53	90
Coke	3.14	93
Crude oil	2.76	98
Fuel oil	2.98	98
Gasoline	2.20	98
Kerosene	2.56	98
Diesel oil	2.73	98
Natural gas	2.09	99
Electricity	0.90	—

Note: this study follows the assumption that the generation of electricity comes from the coal-fired entirely. The CO_2 emission factor of electricity is calculated by utilizing life-cycle assessment in coal-to-energy chains.

Table 4: The conversion coefficient between passenger and freight tonnes, unit: freight tonne/passenger.

Transportation	Railway	Road	Waterway	Civil aviation
Coefficient	1	0.2	0.3	0.083

where C^t is the total CO_2 emissions in year t; C_i^t is the CO_2 emissions of the ith transportation mode in year t; A_{ij}^t is the transportation services of the ith transportation mode based on jth energy in year t; R_{ij}^t is the energy consumption per transportation service of the ith transportation mode based on jth energy in year t; F_j is the CO_2 emission factor of jth energy in year t.

2.3. Decomposition Analysis

2.3.1. Model Construction. The CO_2 emissions in Chinese transport sector can be broken into six driving factors in this study. The extended Kaya identity is used to describe the relationship between CO_2 emissions and influencing factors, as follows:

$$\begin{aligned} C^t &= \sum_{i=1}^{4} C_i^t = \sum_i \frac{C_i^t}{E_i^t} \frac{E_i^t}{A_i^t} \frac{A_i^t}{A^t} \frac{A^t}{\mathrm{GDP}^t} \frac{\mathrm{GDP}^t}{P^t} P^t, \\ C^t &= \sum_{i=1}^{4} F_i^t EI_i^t AS_i^t AI^t AG^t P^t. \end{aligned} \tag{2}$$

The following symbols are applied to present the methodology:

i: the ith transportation mode.

E_i^t: the energy consumption of the ith transportation mode in year t,

A_i^t: transportation services of the ith transportation mode in year t.

A^t: the total transportation services in year t.

GDP^t: the gross domestic product.

P^t: the total population in year t;

$F_i = C_i/E_i$: the emissions coefficient of the ith transportation mode in year t, indicating that the energy substitution results in energy structure change of the ith transportation mode.

$EI_i = E_i/A_i$: the energy intensity of the ith transportation mode in year t.

$AS = A_i/A$: the output share of the ith transportation mode in year t.

$AI = A^t/\mathrm{GDP}^t$: the transportation intensity in year t.

$AG^t = \mathrm{GDP}^t/P^t$: the GDP per capita in year t.

2.3.2. Decomposition Analysis. In this paper, LMDI method is employed to estimate the impacts from each driving factor and probe into the major influencing factors on total emissions in China's transport sector. The change of CO_2 emissions between a base year 0 and a target year t will be decomposed as follows:

$$\begin{aligned}\Delta C_{\text{total}} &= C^t - C^0 \\ &= \Delta C_{ES} + \Delta C_{EI} + \Delta C_{AS} + \Delta C_{AI} + \Delta C_{AG} \\ &\quad + \Delta C_{TP}.\end{aligned} \tag{3}$$

These factors are referred to as the energy structure effect (ΔC_{ES}), energy intensity effect (ΔC_{EI}), transportation structure effect (ΔC_{AS}), transportation intensity effect (ΔC_{AI}), income effect (ΔC_{AG}), and population scale effect (ΔC_{TP}).

The above effects on CO_2 emissions will be calculated based on the following equations [26]:

$$\begin{aligned}\Delta C_{ES} &= \sum_{i=1}^{4} \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln\left(\frac{F_i^t}{F_i^0}\right), \\ \Delta C_{EI} &= \sum_{i=1}^{4} \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln\left(\frac{EI_i^t}{EI_i^0}\right), \\ \Delta C_{AS} &= \sum_{i=1}^{4} \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln\left(\frac{AS_i^t}{AS_i^0}\right), \\ \Delta C_{AI} &= \sum_{i=1}^{4} \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln\left(\frac{AI^t}{AI^0}\right), \\ \Delta C_{AG} &= \sum_{i=1}^{4} \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln\left(\frac{AG^t}{AG^0}\right), \\ \Delta C_{TP} &= \sum_{i=1}^{4} \frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0} \ln\left(\frac{P^t}{P^0}\right).\end{aligned} \tag{4}$$

3. Simulations and Analysis

3.1. Analysis CO_2 Emissions in China's Transport Sector

3.1.1. The Total CO_2 Emissions. There has been a significant increase in CO_2 emissions in China's transport sector over the period of 1995–2012. The CO_2 emissions and growth rate in China's transport sector are illustrated in Figure 1. The CO_2 emissions have increased from 123.14 million tonnes (Mt) in 1995 to 660.76 Mt in 2012, at an annual growth rate of 11.17%. The CO_2 emissions increased continually while its growth rate was fluctuant substantially during the study period. In particular, from 1995 to 2005, the fluctuation range exceeded 10%. Since the beginning of the Twelfth Five-Year Plan, affected by national steady economic growth, energy-saving, and emission reduction policies, the average annual growth rate of CO_2 emissions during 2010–2012 remains approximately 10%.

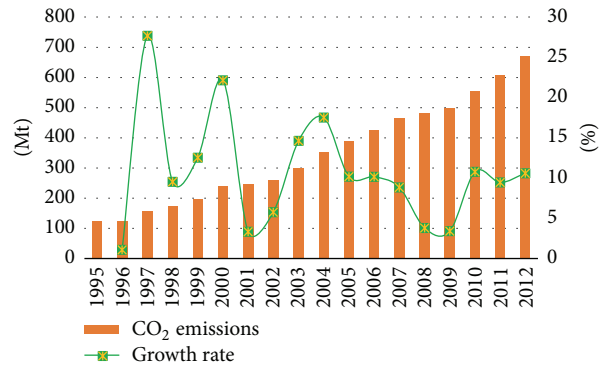

Figure 1: Trends in CO_2 emissions and growth rate in China's transport sector.

3.1.2. CO_2 Emissions by Energy Type. Figure 2 shows the annual CO_2 emissions by energy type in China's transport sector. Obviously, the emissions by energy type mainly come from diesel and gasoline, accounting for 49.51% and 16.36% of the total in 2012, respectively. From 1995 to 2012, CO_2 emissions from diesel fuel and gasoline have increased by 760.59% and 282.11%, respectively. The share of CO_2 emissions from diesel in the total has increased from 31.33% to 49.51% while the share of CO_2 emissions from gasoline has decreased from 23.33% to 16.37%. Apparently, the growth of diesel is the main contributor to the growth of energy consumption and CO_2 emissions. Furthermore, CO_2 emissions from fuel oil, kerosene, electricity, and natural gas increased rapidly, but the share remained roughly unchanged. With the elimination of the steam locomotive and improvement of railway electrification, the energy consumption, such as the coal and coke, experienced a significant decline.

3.1.3. CO_2 Emissions by Transportation Mode. The change of annual CO_2 emissions from different transportation modes during 1995–2012 is shown in Figure 3. The road transportation is responsible for the great majority of middle-short distance transportation which results in a large amount of energy consumption and CO_2 emissions. In terms of both absolute amount and relative proportion, road transportation is the fastest-growing CO_2 emitter. The mounting passenger person-kilometers and freight tonne-kilometers are the immediate cause of CO_2 emissions increase in road transport sector. During the study period, passenger person-kilometers

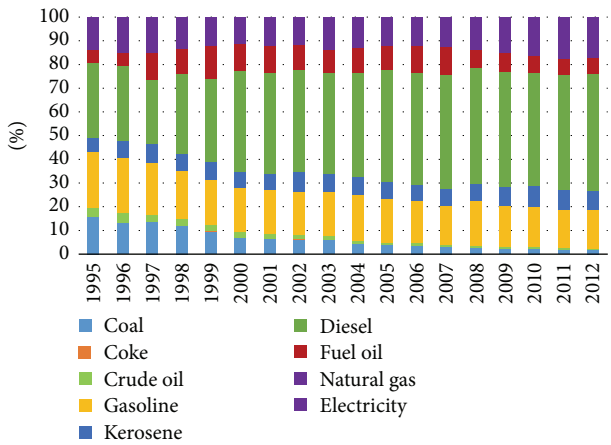

Figure 2: The CO_2 emissions by fuel type in China's transport sector from 1995–2012.

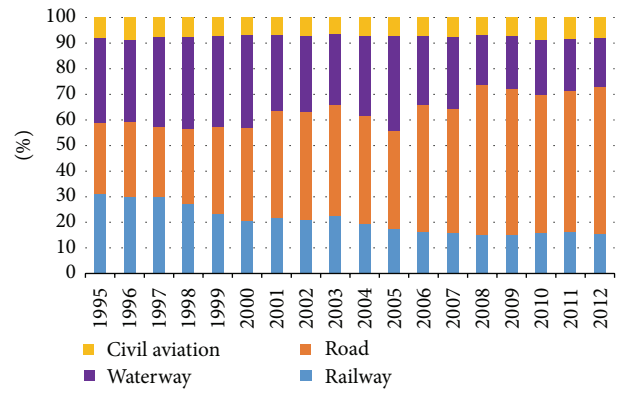

Figure 3: The CO_2 emissions by transportation mode in China's transport sector from 1995 to 2012.

and freight tonne-kilometers in road transport sector have increased by 5.43 times and 16.01 times, respectively. Along with the growth of transportation services, the energy consumption and CO_2 emissions also went up drastically. The CO_2 emissions grew from 30.96 Mt in 1995 to 387.57 Mt in 2012, with an increase of 11.52 times and the corresponding share grew from 25.14% to 55.03%.

The railway transportation plays an important role in long distance transportation. During 1995–2012, the CO_2 emissions by railway transport sector rose constantly with an average annual growth rate of 5.04%. The main reason is that the rising electricity use in railway transport sector indirectly brought about increasing CO_2 emissions in line with the railway electrification. In 2012, the CO_2 emissions by railway transport sector reached to 137.33 Mt. On the contrary, the share of CO_2 emissions by railway transport sector displayed a decreasing trend, which shows the growth rate of emissions in railway transport sector is lower than that of the total. That is beneficial on the energy-saving and emission reduction policies implemented by China's Railway Ministry to enhance the supervision of energy saving and promote the technology progress [27].

Over the past decades, the transportation services in civil aviation are estimated to increase by more than 15 times while the CO_2 emissions increased by approximately 4 times, which results from technological progress and energy utilization efficiency improvement. The share of CO_2 emissions by civil aviation remained relatively steady during 1995–2012.

From 1995–2012, CO_2 emissions by waterway transportation grew steadily with an average annual growth rate of 4.5%. Nevertheless, there has been a sharp fluctuation in emissions growth rate. From 2004 to 2005, the growth rate of CO_2 emissions in waterway transport sector is more than 30% annually while in 2001, 2006, and 2008, the decline rate reaches 19%.

3.2. LMDI Decomposition of CO_2 Emissions. In consideration of the impact of national economic planning and comparability of each time interval, the study period is split into four time intervals. This study employed LMDI method to estimate the impacts of six influencing factors on the CO_2 emissions in China's transport sector. The decomposition results by time intervals are presented in Figure 4 and the accumulated effects and corresponding contribution are available in Figure 5. The accumulated effects indicate that income effect is the dominant driving force to the CO_2 emissions increase while the energy intensity effect has the most significant negative impact on emissions, followed by energy structure effect. Transportation structure effect, transportation intensity, and population scale effect have the positive but relatively minor effect on emissions. Overall, the accumulated positive effects extremely outweigh the accumulated negative effects, which lead to significant emissions increase in China's transport sector. The accumulated contribution is the ratio of accumulated effects (accumulated emission increase or reduction) caused by a particular variable and total emissions change during the study period. The accumulated contribution is −2.67% (ΔES), −15.12% (ΔEI), 7.92% (ΔAS), 7.85% (ΔAI), 95.55 (ΔAG), and 6.48% (ΔTP), respectively. Generally, the energy intensity change (ΔEI) led to a 78.58 Mt reduction in emissions, which accounted for 15.12% of the total emissions change in China's transport sector during 1995–2012. In contrast, income effect (ΔAG) increased emissions by 496.51 Mt and accounted for 95.55% of the total.

3.2.1. Energy Structure Effect. The carbon content varies widely from energy to energy, which results in different emission factors. The use of low carbon energy sources, such as natural gas, will reduce the emissions with fixed energy consumption. Accordingly, energy structure adjustment affects the emissions as well. In this study, the comprehensive CO_2 emission factor by transportation mode, calculated by (5), is defined to show the application amount of low carbon energy sources. Figure 6 depicts the trajectory of the emission factor by transportation mode. To some degree, the emission factor is heavily reliant on energy structure. It can be calculated that the CO_2 emissions per standard coal equivalent rank from big to small are coke > coal > electricity > fuel oil > diesel > crude oil > kerosene > gasoline > natural gas. The railway transportation adopts coal and electricity as the

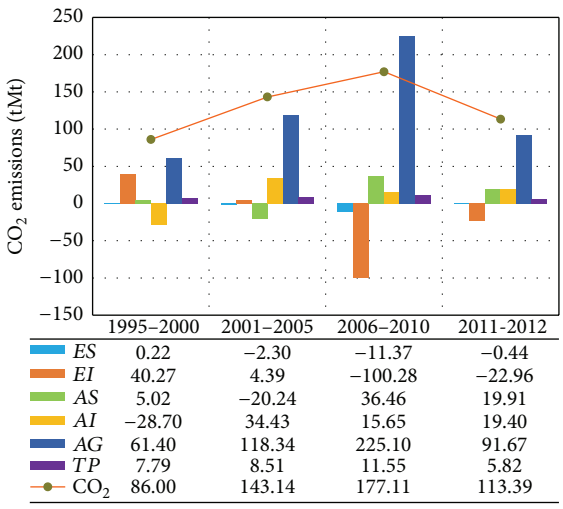

FIGURE 4: Decomposition of CO_2 emissions from energy consumption in China's transport sector.

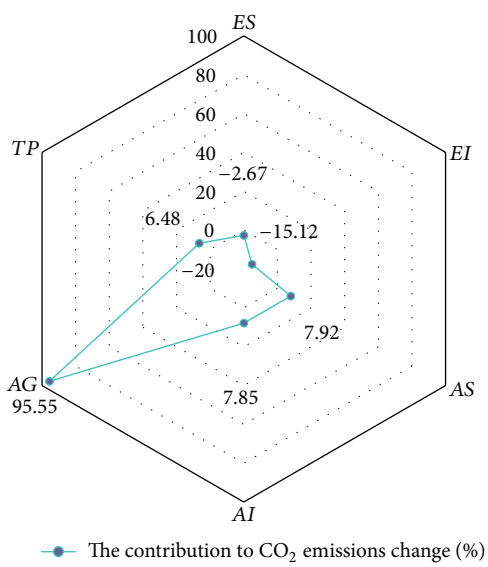

FIGURE 5: Contribution to CO_2 emissions change in China's transport sector during 1995–2012.

main fuels and, therefore, has the highest emission factor. The elimination of steam locomotive and electrification improvement gives rise to the decreasing coal use and increasing power use, thus decreasing emissions coefficient in railway transport sector. It can be seen from Figure 6 that the emission factor in road transport sector is lowest but rises slowly from 1995 to 2012. The main reason is that natural gas, gasoline, and diesel contain lower carbon content. However, the energy consumption per unit of transportation service of a diesel-based vehicle is only equivalent to about 60% of a gasoline-based vehicle. Accordingly, with the growth of diesel-based vehicle, the proportion of diesel consumption improves rapidly, which leads to the increase of emission factor. Additionally, there is a less obvious variation tendency of the emissions coefficient in waterway. This paper works on

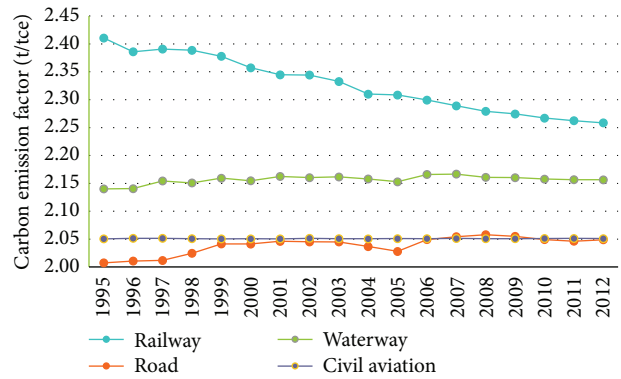

FIGURE 6: The CO_2 emission factor by transportation mode.

the assumption that only kerosene is used by civil aviation; therefore, the emission factor remains unchanged.

The accumulated effect of energy structure (C_{ES}) is −13.89 Mt, which accounts for 2.67% of the total emissions change. Figure 4 demonstrates that energy structure effect is negative except for 1995–2000, which indicates the energy structure optimization inhibited the growth of CO_2 emissions from the transport sector. From 1995 to 2000, the emissions increase driven by energy structure change is 0.22 Mt. However, during 2001–2012, the energy structure effect results in a decline of 14.11 Mt in emissions, which accounts for 0.26%, −1.61%, −6.42%, and −0.39% of the emission change during corresponding research period, respectively. During the study period, CO_2 emission factor in railway transport mode declined while it remained stable in other transportation mode. Therefore, the effect of energy structure derives from the change of energy structure in railway transport sector. However, during 1995–2000, energy structure effect is positive, meaning that energy structure adjustment promotes the growth of emissions. The emission factor in road and water transportation modes increases slightly which concur with the energy structure effect. Therefore, energy structure changes in road and water transportation modes increase emissions. In this study, the effect of energy structure on emissions was limited to a certain transportation mode and the impact of energy structure optimization from the whole transport system was not evaluated. Comparatively speaking, the energy structure effect was underestimated.

3.2.2. Energy Intensity Effect. Energy intensity of the transport sector is defined as the energy consumption per unit energy consumption service. The energy intensity reflects the energy utilization efficiency. In this study, the energy intensity by transport mode is estimated based on transportation services and relevant energy consumption. Generally speaking, the energy intensity will decline with technical progress. However, energy intensity change in China's transport sector does not fully comply with this rule. Figure 7 shows the trend of energy intensity of different transportation modes during 1995–2012. The energy intensity in transport sector rose significantly during 1995–2003, reached a maximum 213 kg standard coal/1000 tonne-kilometer in 2003, and then

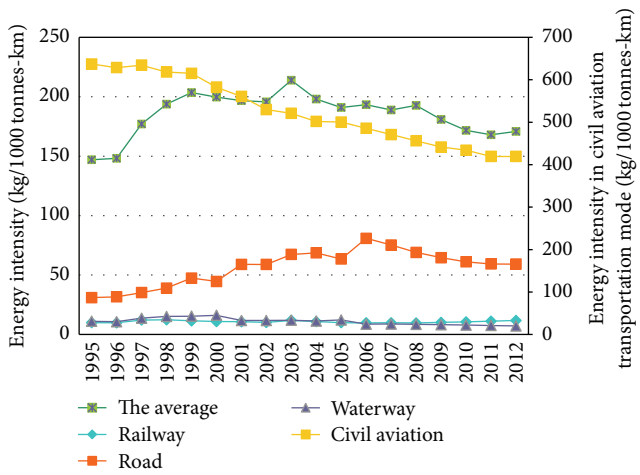

Figure 7: The energy intensity by transportation mode.

declined. Specific to transportation mode, it is shown that energy intensity in railway and waterway transportation modes had not changed much during 1995–2012, while energy intensity in road transportation mode experienced a substantial increase from 1995 to 2006 and then declined from 2006 to 2012. That is attributed to the increasing private vehicles. The energy efficiency of private vehicles is already lower than public transit. The demand for performance and traveling comfort require more sophisticated equipment and machinery, which results in more energy consumption. In addition, more vehicles exacerbated traffic jam, leading to a waste of energy. As a result of the development of engine energy saving technologies, the implementation of fuel consumption rate standard for private vehicles in 2004, the public transportation system construction, and the promotion of new energy vehicles, the energy intensity in road transportation started to decrease from 2006 [3, 28]. Civil aviation transportation had highest energy intensity, remaining above 420 kg standard coal/1000 tonne-kilometers, because of the exceptional mode of transport with powerful motive force. Besides, the low development level of science and technology, irrational transport structure, and poor attendance lead to more energy consumption per unit of transportation service in China's civil aviation sector than developed countries'. Since 1995, the energy intensity had displayed a downward trend. The key reason for the decline is the engine technical progress that improves the efficiency of energy utilization. Meanwhile, the optimizing channels and ticket mechanism also contribute to cut down the energy intensity. During 1995–2000, waterway transport had experienced a substantial increase in energy intensity and then declined after 2000. Overall, the energy intensity of the other three transportation modes changed in the same direction but with different turning points.

The energy intensity is the significant factor in restraining the emissions growth. From 1995 to 2012, the accumulated effect of energy intensity is a decrease of 78.58 Mt, which accounts for 15.12% of the total emissions change in absolute value. During 1995–2000 and 2001–2005, the energy intensity effect increased by emissions by 40.27 Mt and 4.39 Mt, which accounted for 46.83% and 3.07% of the emissions change, respectively. Obviously, the total effect of energy intensity during 1995–2005 is positive as a result of the increasing energy intensity or decreasing energy efficiency in road transport sector. The positive effect of energy intensity in road transport sector significantly exceeded the negative effect in civil aviation sector, which ultimately increased the emissions. During 2005–2010 and 2011–2012, the energy intensity effect is negative. The energy efficiency improvement both in road and in civil aviation of transport sector contribute to the decrease of emissions in transport sector.

3.2.3. Transportation Structure Effect. Each transportation mode also varies significantly in energy structure and energy efficiency. Thus, transportation structure change is bound to affect the energy consumption and CO_2 emissions. It can be seen in Figure 5 that transportation structure shifting increases the CO_2 emissions by 41.15 Mt, accounting for 7.92% of the total emissions change. Obviously, the transportation structure effect is positive but the effect is limited and minor. Transport structure effect except for the time interval 2001–2005 has contributed to emissions increase mainly because the demand for transportation services turns from low energy consumption transportation mode to high. With the rapid development and diversification of income groups, some comfortable and convenient transportation modes, such as road and civil aviation transportation, provide increasing transportation services. The percentage of passenger and freight transport for railways decreased substantially, from 45.77% and 29.39% in 1995 to 40.07% and 17.10% in 2012, respectively. However, the percentage of passenger transport for road increased from 46.48% in 1995 to 55.32% in 2012 and the freight transport remained stable for the period 1995–2008 and skyrocketed after 2008. Both passenger and freight transportation service in civil aviation accounted for a relatively small part but have started to climb sharply in recent years. From 1995 to 2012, the proportion of passenger transport for civil aviation increased from 5.84% to 15.05%, an increase of 208.68%. After 1999, the freight transportation service of civil aviation accounted between 10–12%, with a slight fluctuation. Compared with the energy consumption per unit transportation service of different transportation modes, the order is civil aviation > road > waterway > railway. Therefore, transportation structure adjustment means the change of energy intensity in transport sector, which ultimately affects CO_2 emissions.

3.2.4. Transportation Intensity Effect. Transportation intensity is defined as the transportation services per unit of GDP, reflecting the GDP value produced by per unit of transportation service. As shown in Figure 4, the transportation intensity effect plays a minor role in promoting the CO_2 emissions increase in China's transport sector. The accumulated effect of transportation intensity is an increase of 40.78 Mt over the period 1995–2012. The transportation intensity has greatly depressed from 0.60 tonne-kilometer/yuan in 1995 to 0.46 tonne-kilometer/yuan in 2003, which means unit

transportation service is more effective and is able to create more GDP. Therefore, the transportation efficiency improvement has an adverse influence on energy consumption and CO_2 emissions. That is mainly attributed to the scale of transportation, transportation system improvement, and advanced management mechanism. A great leap forward had been made in transportation infrastructure construction. The excellent transport system improves the transportation efficiency and the energy efficiency, contributing to the decrease of emissions. Besides, the operation of high-speed electric locomotive is also responsible for the emission mitigation because of high transport capacity and low energy consumption.

However, during 2003–2012, the transportation intensity showed an upward trend, indicating the decrease of transportation efficiency. The current transportation infrastructure cannot meet the reality demand for transportation because of the sharp increase in China's vehicle population. The imperfect transportation system leads to less efficient transportation service. The passenger travel time is more concentrated than that in former years due to the fast-paced life and busy work, which will exacerbate the inefficiency further.

3.2.5. Income Effect. At the macroscopic level, the total income is equal to the total output. Therefore, the GDP per capita reflects the income level of residents. Results show that the income effect is the dominant force leading to the increase in CO_2 emissions. During the period 1995–2012, the accumulated effect is an increase of 496.51 Mt, which has exceeded the total CO_2 emissions change, unpredictably. During four time slots, the emissions increased by 61.40 Mt, 118.34 Mt, 225.10 Mt, and 91.67 Mt, which accounted for 71.40%, 82.68%, 127.09%, and 80.84%, respectively. It can be seen that the emissions increase affected by income improvement exceeded the total emission change during 2006–2010. The income of both urban and rural residents is continuously growing over the past 17 years. The growing income improves the dweller standard of living, which results in the increase of automobile amount. The mobile population means the number of vehicles. With the rapid increase of vehicles, the energy consumption and CO_2 emissions in transport sector must be increased. Another important factor contributed to CO_2 emissions change is the surging transportation demand for tourism. In addition, the commodities consumption rising as the living standard improvement and the logistics system is heavily reliant on the transportation system, which drives the CO_2 emissions growth consequently. Engel's law reveals that the proportion of nonfood expenditures, such as the expenditure for transportation services, is increasing. As a result, the effect of the income rise is growing during the four time intervals.

3.2.6. Population Scale Effect. Population scale effect is another important contributor to the emissions increase in China's transport sector. The cumulative effect of population growth is 33.67 Mt, with a contribution rate 6.47%. Meanwhile, it can also be seen that the population scale effects during four time intervals are all positive but comparatively minor. China's population has continued to increase from 1.20 billion in 1995 to 1.35 billion in 2012. Even keeping the transportation services per capita unchanged, growing population will result in growing demand for transportation services, which thus increases the energy consumption and CO_2 emissions. Urbanization is also increasingly important in pace with population growth in China [29]. The demand for raw materials transportation promotes the development of transport sector, which leads to the emissions increase [30]. As might be expected, population growth is a continuous driving force to emissions change over the next few decades.

3.3. Emission Reduction Potential

3.3.1. Estimation of CO_2 Emissions. According to (3), we obtain the following equation, employed to forecast the CO_2 emissions in China's transport sector:

$$C^t = C^0 + \Delta C_{ES} + \Delta C_{EI} + \Delta C_{AS} + \Delta C_{AI} + \Delta C_{AG} + \Delta C_{TP} = \sum_i C_i^t = \sum_{i=1}^{4}\left(C_i^0 + \sum_{j=1}^{6}\Delta C_{ij}\right). \tag{5}$$

The CO_2 emissions at the target year can be calculated when emissions at baseline year and the contribution from various factors affecting emissions change have been given. In this section, various effects can be calculated according to the following equation [31]:

$$\Delta C_{ij} = W \ln\left(1 + \alpha_{ij}\right), \quad W = \frac{C_i^0\left(\prod_{i=1}^{6}\left(1+\alpha_{ij}\right) - 1\right)}{\ln\left(\prod_{i=1}^{6}\left(1+\alpha_{ij}\right)\right)}, \tag{6}$$

where α_{ij} denote the growth rate of the ith transportation mode jth variable. Further, three scenarios are set to evaluate the possible emissions from 2011 to 2020 and give a comprehensive comparison of results in China's transport sector.

3.3.2. Set of Scenarios. The target for emission reduction is determined based on the real development status and mitigation potential of sectors and enterprises. According to different growth rates of independent variables, three CO_2 emissions scenarios and two emissions reduction scenarios are established to evaluate the emissions reduction potential in China's transport sector. The CO_2 emission scenarios, including business as usual (BAU) scenario, the higher growth rate scenario, and the lower growth rate scenario, are designed to evaluate the CO_2 emissions from 2010 to 2020 based on different growth rates of independent variables. The growth rates of various variables are set based on the historical trends and development planning, technical indicators in China's transport sector. Therefore, the scenario design is reasonable and realizable. In this study, we assume

that the year of 2010 is the baseline year. The CO_2 emission scenarios are described as followed.

(1) BAU Scenario. BAU scenario is designed in accordance with historical trends or the relatively reliable prediction by government and any new mitigation policies or measures would not be introduced during 2010–2020. We take the CO_2 emissions in BAU scenario as the benchmark to assess the emission reduction potential in the future. Considering the difference of energy intensity and transportation structure in different transportation modes, changes of the variables are set separately. According to China's Transportation five-year plan, energy consumption per unit transportation service in road and waterway transportation modes in 2015 decreased by 10% and 15%, respectively, compared with that in 2005, and the civil aviation decreased by 3% compared with that in 2010 [32]. In addition, we assume that energy consumption per unit transportation service of road and waterways in 2020 decreased by 15% and 20% compared with the 2005's level, respectively, and civil aviation by 5% compared with the 2010's level. Finally, energy consumption per unit transportation service of railway transportation in 2015 and 2020 decreased by 3% and 5% compared with the 2010's level. Then, the growth rate of energy intensity of various transportation modes can be calculated based on the above assumptions. According to the research report of "National Population Development Strategy Research Report" published by the Central People's Government, the growth rate of China's population will be negative over the next decades. China's population growth rate would reduce to 0% in 2033 [33]. Accordingly, the average change rate of population is calculated to be 0.32% every year. The change of energy structure, transportation structure, and GDP per capita follow the historical trends and the corresponding growth rate is the average growth rate during 1995–2012.

(2) Scenario 1 (The Higher Growth Rate Scenario). The growth rates of variables including *ES*, *EI*, *AS*, *AI*, *AG*, and *TP* are all 0.2% higher than that in the BAU scenario.

(3) Scenario 2 (The Lower Growth Rate Scenario). The growth rate of variables including *ES*, *EI*, *AS*, *AI*, *AG*, and *TP* are all 0.2% lower than that in the BAU scenario.

The higher and lower growth rate scenarios are designed to estimate the possible emission reduction in China's transport sector. More importantly, the effect of each variable change is quantifiable, which would make policymakers acquaintance with emissions mitigation and conduce to policy making. Specific hypothesis of various scenarios is displayed in Table 5.

The emission reduction potential scenarios including moderate emission reduction scenario and aggressive emission reduction scenario are set to evaluate the emission reduction in China's transport sector from 2010 to 2020 based on emission scenarios. The emission reduction potential scenarios measure the possible emission reduction when economic development goals change, new mitigation policies put into effect, or more stringent energy saving index is set.

Table 5: Hypothesis of variables, unit: %.

		BAU	Scenario 1	Scenario 2
ES	Railway	−0.40	−0.20	−0.60
	Road	0.13	0.33	−0.07
	Waterway	0.05	0.25	−0.15
	Civil aviation	0	0	0
EI	Railway	0.42	0.62	0.22
	Road	4.62	4.82	4.42
	Waterway	−2.26	−2.06	−2.46
	Civil aviation	−2.53	−2.33	−2.73
AS	Railway	−3.60	−3.40	−3.80
	Road	5.30	5.50	5.10
	Waterway	0.15	0.35	−0.05
	Civil aviation	3.96	4.16	3.76
AI		−0.49	−0.29	−0.69
AG		9.54	9.74	9.34
TP		0.32	0.52	0.12

Two emission scenarios are presented as follows: (1) moderate emission reduction scenario: the CO_2 emissions will transform from BAU scenario to scenario 2; (2) aggressive emission reduction scenario: CO_2 emissions will transform from scenario 1 to scenario 2.

3.3.3. CO_2 Emissions under Different Scenarios. Based on the hypothesis and (5)–(6), the CO_2 emissions in China's transport sector under different scenarios are shown in Figures 8–10. In BAU scenario, the CO_2 emissions are predicted to be 1012.94 Mt in 2015 and 2184.73 Mt in 2020, of which emissions from road transportation will be 654.21 Mt in 2015 and 1670.67 Mt in 2020, accounting for 64.59% and 76.47% of the total. Results show that CO_2 emissions from transport sector increase significantly, with the growth rate of 84.84% in 2015 and 298.67% in 2020, respectively, compared with that in 2010. The road transportation is the fastest-growing in CO_2 emissions with an annual growth rate of 20.16% while the railway transportation is the lowest-growing in CO_2 emissions with an annual growth rate of 5.43%. The living standard of the peasants would rise considerably over the next few decades due to increasing receipts, which led to rapid increase in traffic needs. During the urbanization process, constantly improved and perfect infrastructures for traffic also drive more traffic needs. However, the road transportation is the preferred one because of the convenience and efficiency. The rapid development of road transportation will lead to a large increase in emissions. Compared with the other transportations, railway traffic system is fairly complete and additional railway line is limited. With the increase in speed and the introduction of high speed railway, the energy efficiency of the railway will improve significantly. Therefore, the railway transportation will undergo a smaller increase in emissions.

The CO_2 emissions will be 1073.16 Mt in 2015 and 2452.41 Mt in 2020 under scenario 1 and 955.99 Mt in 2015 and 1945.76 Mt in 2020 under scenario 2. It can be seen that

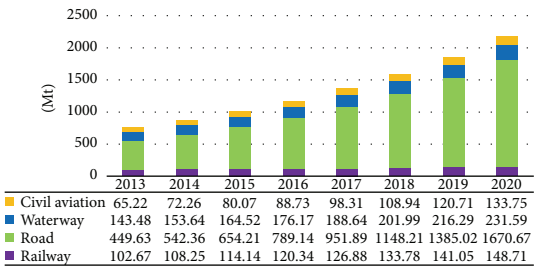

Figure 8: The CO_2 emissions in China's transport sector in BAU scenario.

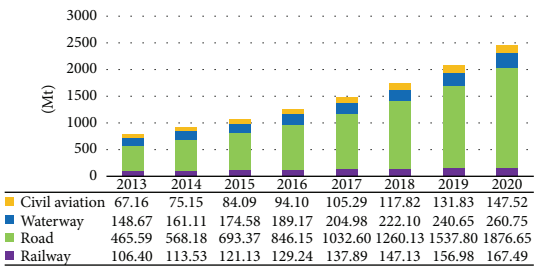

Figure 9: The CO_2 emissions in China's transport sector in scenario 1 (high growth rate).

the CO_2 emissions in scenario 1 are higher than those in BAU scenario and scenario 1.

3.3.4. Emission Reduction Potential. According to the results in Figures 8–10, emissions reduction in different scenarios is calculated. Results show there is the huge emission reduction potential in China's transport sector. Under the scenario of moderate emission reduction, CO_2 emissions would reduce by 56.96 Mt in 2015 and 238.97 Mt in 2020, accounting for 5.62% and 10.94% of the total, respectively. The accumulated emission reduction during 2013–2020 reaches 872.00 Mt, which is approximately equal to the total emissions in 2014. While the emission reduction will be 117.18 Mt in 2015 and 506.66 Mt in 2020 under the scenario of aggressive emission reduction and the corresponding proportion is 11.56% and 23.19%, respectively. The accumulated emission reduction reaches 1825.97 Mt, which is approximately equal to the total emissions in 2018 and 3 times more than the emissions in 2010. Therefore, the more ambitious measures implemented by government will drive more emissions reductions.

Furthermore, road transportation has the greatest potential for emission reduction. The emission reduction from road transportation accounted for 87.52% of the total under aggressive emission reduction scenario and 93.89% under moderate emission reduction scenario.

4. Conclusions and Policy Implication

In the past decades, China's transport sector developed rapidly in line with the rapid development of economy. It has led to a substantial increase in transportation services demand. Thus, energy consumption and CO_2 emissions have

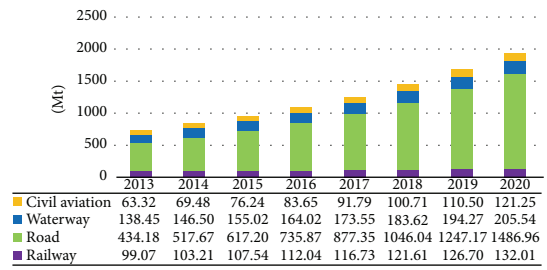

Figure 10: The CO_2 emissions in China's transport sector in scenario 2 (low growth rate).

also increased significantly. In this paper, the LMDI method is used to explore the major driving factors to emissions change in China's transport sector. Moreover, the emissions and reduction potential are evaluated based on scenario analysis.

4.1. Conclusions. Main conclusions of this paper are drawn as follows:

(1) There has been a significant increase in CO_2 emissions in China's transport sector. The emissions have increased from 123.14 Mt in 1995 to 660.76 Mt in 2012, with an annual growth rate of 11.17%. The CO_2 emissions from road transportation increased significantly. The emissions from civil aviation increased more than 4 times; meanwhile, the energy utilization efficiency went up significantly. Diesel fuel consumption increased sharply, which was responsible for most emissions increase by energy types. The share of CO_2 emissions by gasoline consumption continued to decline slowly.

(2) Income effect plays a dominant role on increasing emissions in China's transport sector. Emissions due to the improvement of income increased 496.51 Mt, which accounted for 95.55% of the total during 1995–2012. The income effect is all positive during four time intervals. In particular, income effect during 2006–2010 resulted in an increase of 225.10 Mt in emissions, which exceeded the total emissions change of 177.11 Mt, while energy intensity effect is the main force to the decline, which leads to a decrease of 15.12% in emissions during 1995–2012. However, energy intensity effect during 1995–2005 is positive. Energy intensity effect increased emissions by 40.27 Mt during 1995–2000 and by 4.39 Mt during 2001–2005, accounting for 46.83% and 3.07% of the total emission change. The transportation modal shifting, transportation intensity change, and population growth have a positive but relatively minor effect on emissions increase, leading to emissions increase by 7.92%, 7.85%, and 6.48% during the study period, respectively. In addition, results have shown that the transportation demand transfers from the high energy efficiency transportation to the lower during 1995–2012.

(3) The CO_2 emissions in China's transport sector in 2020 are predicted to be 2184.73 Mt in BAU scenario, 2452.42 Mt in high growth rate scenario, and 1945.76 Mt in low growth rate scenario. The emission reduction in China's transport sector is considerable. Accumulated emissions reduction is expected to be 1825.97 Mt under the scenario of aggressive emission reduction and 872.00 Mt moderate emission reduction scenario. The emission reduction by road transportation accounts for a large part in the total.

4.2. Policy Implication

(1) The government should control the private vehicle ownership properly to reduce the total CO_2 emissions. On one hand, the absolute amount of vehicle stock is restricted by paying higher tax when purchasing the second vehicle. On the other hand, raising automobile quality and increasing the life of the vehicles contribute to the vehicles reduction.

(2) An extra effort should be made to improve public transport. Meanwhile, by strengthening publicity, government should guide the transportation demands from private transport to public transport. Perfect planning on transport system contributes to depressing the energy consumption and emissions. In addition, walk and bicycle riding are encouraged in short distance travel.

(3) The new energy vehicles are further heavy promotion in public transit, environmental sanitation and government agency. The proportion of new energy vehicles owned by these sectors should be set by central government and local government to ensure the policy effectiveness.

(4) More stricter energy consumption standard is also expected to help improve the energy efficiency in China's transport sector. Cleaner and higher performance oil productions are supposed to be developed and used by transport sector.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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