The Way to CO2 Emission Reduction and the Co-Benefits of Local Air Pollution Control in China's Transportation Sector : A Policy and Economic Analysis

Mao Xianqiang, Yang Shuqian and Liu Qin

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Yang Shuqian
Liu Qin

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Comments should be sent to:
Dr. Mao Xianqiang, School of Environment, Beijing Normal University,
19#, Xinjiekouwai Street, Haidian District, Beijing 100875 China.
Tel: +81-010-58807812.
Fax: +81-010-58807812.
Email: maox@bnu.edu.cn

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

THE WAY TO CO_2 EMISSION REDUCTION AND THE CO-BENEFITS OF LOCAL AIR POLLUTION CONTROL IN CHINA'S TRANSPORTATION SECTOR: A POLICY AND ECONOMIC ANALYSIS

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EXECUTIVE SUMMARY

The transportation sector in China has joined the power generation and the steel and iron industries as a major CO_2 emission contributor. To determine which policy instrument(s) would be effective in reducing CO_2 emissions, various policy instruments which have been or are likely to be implemented in the near future in China are examined and compared in this study. These instruments include carbon tax, energy tax, fuel tax, clean energy vehicle subsidy, and a reduction on ticket prices. The CIMS model system is employed as the simulation vehicle to predict the emission dynamics of CO_2 and local air pollutants under business-as-usual and policy scenarios for the transportation sector of China from 2008 to 2050. The 2020 CO_2 reduction target is also set according to the national carbon intensity reduction pledge of China.

The policy instruments proposed in this research study can all help mitigate the CO_2 emission intensity of the Chinese transportation industry to different extents and bring about the co-benefits of local air pollutant reduction. Among these policy instruments, energy and fuel taxes, with the tax rates set, are the two most promising instruments for CO_2 emission intensity reduction to reach the 2020 carbon intensity reduction targets while subsidies are the least promising options. CO_2 tax could be an effective policy tool, but with the low tax rate considered in China, there is no way that the transportation sector would significantly contribute to achieving a desirable carbon intensity reduction.

The CIMS model is applied to simulate and determine how CO_2, energy, and fuel taxation can stimulate technology competition and substitution in the transportation sector of China and to ascertain how these taxes will influence energy consumption and pollutant emissions reduction.

1.0 RESEARCH BACKGROUND

China has today become the largest CO_2 emitter in the world. Greenhouse gas (GHG) emissions in China are especially difficult to cope with because of China's heavy reliance on carbon-intensive sources of energy supplies and the situation will last for decades.

Among the high carbon intensive industries, China's transportation sector keeps up with rapid development. Since the 1980s, the automobile market has increased rapidly with an annual average growth rate of 12%~14%, far exceeding that of the country's GDP (9.6%), from 1.80 million vehicles in 1980 to 50.9 million in 2008[1]. In 2009, China produced 13 million automobiles and became the world's largest producer for the first time. Then in 2010, China produced 18.26 million and sold 18.06 million automobiles and continued to be the largest producer as well as consumer of automobiles. Passenger transportation in China increased from 11.73 billion person-times in 1995 to 29.77 billion person-times in 2009 with an average annual growth rate of 7.1%[1]. For freight transportation, the average growth rates of total freight volume during the years from 2002 to 2008 was 12.95%, and the annual average rates of increase of rail, road, water, air and pipeline transportation freight turnover were 5.93%, 12.21%, 11.70%, 19.49% and 42.57%, respectively[1].

In 1995, total energy consumption in the transportation sector was 58.63 million tons of coal equivalent (Mtce) and in 2007, the number increased to 206.43 Mtce. In 2003, the share of energy use of transportation was around 16%[2]. In 2006 China's fuel consumption in the transportation sector accounted for 47.63% of the national total [3].

In 1994, China's transportation sector emitted 1.66E+08 tons CO_2 and the proportion of total CO_2 emissions was 5.4%[4]. In 2007, CO_2 emissions in the transportation sector increased to 4.36E+08 tons, and the proportion of total CO_2 emissions increased to 7.0%[5], showing that transportation had the joined power generation, steel and iron industries in becoming a major CO_2 emissions sector. Our simulation found that CO_2 emissions in the transportation sector in 2008 amounted to 6.37E+08 tons and its contribution to total emissions had increased to 10%.

Hence, reducing GHG emissions in the transport sector has become increasingly necessary, and what can be done in this sector to mitigate GHG emissions has become an important issue. For CO_2 reduction, China has announced a national goal of a 40% – 45% cut in carbon intensity (tons/GDP) below 2005 levels by 2020. China's nationwide development plan: The Eleventh Five-Year Plan (2006-2010) for National Economic and Social Development[6] also put forward objectives of lowering national energy consumption per unit Gross Domestic Product (GDP) by 20%. China's Twelfth Five-Year Plan (2011-2015) for National Economic and Social Development[7] says that CO_2 emissions and energy consumption per unit of GDP in 2015 should be 17% and 16% lower than that in 2010, respectively.

At the same time, transportation vehicles have caused local air pollution emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NO_x), and particulate matter (PM), among others, which has become a serious environmental concern. According to Zhou Wei[8], more than 50% of CO, NO_x and HC are from motor vehicle emissions, and in some large cities, the proportion is as high as 80% With CO_2 reduction in the transportation sector, the co-benefits of local air pollutants reduction will be obtained.

2.0. OBJECTIVES

2.1 General Objectives

The general objective of this project was to examine the effectiveness of economic policy instruments and regulations on carbon dioxide (CO_2) emission reduction in the Chinese transportation sector in order to draw up a proper policy framework to achieve CO_2 emissions reduction for the sector and to disclose what co-benefits of local pollutants emission reduction could be gained in the process.

2.2 Specific Objectives

The specific objectives of the study were:

- To simulate CO_2 reduction target scenarios for China's transportation industry, according to China's national CO_2 emission reduction targets and find out what policies or regulations applied to the transportation sector could help achieve such targets.
- To disclose what co-benefits could be gained after applying specific policies or regulations to the transportation sector, such as CO, HC, NO_x, and PM emission reduction.

This project is expected to contribute to the solution of the problems identified in Section 1 in several respects as follows:

- Depicting energy and environmental trajectories of the transportation sector, under different policy scenarios, such as different fuel tax, carbon tax and energy tax rates and tax bases; clean energy vehicle subsidies (CEVS); reduction on ticket prices (RTP); and quantitatively analyzing various policy impacts including changes in energy consumption and corresponding emissions.
- Comparing different policy scenarios, taking into account CO_2 emission reduction targets and the co-benefits of local air pollutant emission reduction in the years to come.
- Helping China's decision-makers to better understand the strengths and weaknesses of proposed policy instruments and optimizing the design and implementation of key policy instruments.

3.0 LITERATURE REVIEW

Economic policy instruments on energy use and carbon emissions have been discussed and put into practice in many developed countries. As a main contributor to rising energy consumption and air pollution, the transportation sector has attracted a lot of concern.

Focusing on the economic aspect, fuel tax has been put into practice since the early 20th century to raise government revenue. Currently, energy and carbon taxes are widely used in European Union (EU) countries. Baranzini[9] reviewed the energy tax and carbon tax implementation in several European countries and pointed out that only the policies of Norway and Sweden offered enough incentive for energy saving. Ghalwash[10] did an empirical analysis of energy tax impact on consumer preferences and concluded that the impact was actually uncertain in different fields. For example, energy tax elasticity was larger than price elasticity in the heating industry while it was the opposite in the transportation sector. Bjertnas et al.[11] applied the Computable General Equilibrium (CGE) model to analyze welfare changes caused by energy taxation.

Gielen and Moriguchi's research[12] showed that in the case of global taxation, trade effects are negligible; in the case where only Japan and Europe introduce a tax, Japanese production will be reduced significantly with a carbon leakage exceeding 50%. However, a CO_2 tax of 2,500 yen[1] per ton of CO_2 in

[1] 1 US$ = 125 yen

combination with an import tariff of 2,500–5,000 yen per ton of steel can prevent carbon leakage. Florosa and Vlachou[13] looked at the demand for energy in the manufacturing sector of Greece and evaluated the impact of a carbon tax on energy-related CO_2 emissions, showing that a carbon tax of US$ 50 per ton of carbon can result in a considerable reduction in direct and indirect CO_2 emissions from the 1998 level; this implies that a carbon tax on Greek manufacturing is an environmentally effective policy for mitigating global warming, albeit a costly one.

Mao and Yang[14] reviewed the effects of the energy tax policy in Sweden, and made proposals on how to apply international practices in China. Zhang and Li[15] found that the impact of carbon tax on economic growth in China varied considerably between different regions in the country; it stimulated economic growth in most eastern regions while it hindered it in some middle and western provinces. Meanwhile, Lin and Li[16] sought to contribute to the debate on carbon-motivated border tax adjustments (CBTAs) by focusing on the potential impacts of CBTAs on different regions in China from the perspective of competitiveness. The results showed that CBTAs would affect the competitiveness of different producers, their comparative advantages, relative trade shares, outputs and emissions. CBTAs would also induce structural changes in the economy and result in a shift of industrial output toward non-industrial output.

Liu, Jiang, and Hu[17] analyzed the different effects of energy tax and carbon tax on the choice of clean technologies in the electric power sector while Zhang Weifu et al.[18] explored the impacts of energy taxation on international trade and environmental pollution.

Existing studies have widely addressed the issue of policy analysis in China and other parts of the world. However, most are concerned about one single instrument and there are very few studies about China's transportation sector. In this report, we compare the various instruments, namely CO_2 tax, energy tax, fuel tax, clean energy vehicle subsidy (CEVS), and a reduction on ticket prices (RTP) to find out which policy instruments are effective in achieving the CO_2 intensity reduction targets and what co-benefits would transpire when applying these policy instruments.

The energy-economy-environment model is an important tool in complex analyses involving many factors. Generally, there are three versions of the model: top-down, bottom-up, and hybrid. In recent years, the most popular are CGE (top-down), MARKLE (bottom-up), LEAP (bottom-up), AIM (bottom-up), NEMS (hybrid), and IIASA-WECE3 (hybrid).

The CGE model was first developed by Johansen from Norway in 1960 and has been widely applied by the modeling community to explore the relationship between energy, environment and the economy. For example, Jorgenson and his colleagues[19,20,21,22] , Boyd and Uri[23], and Boyd and Roya et al.[24] assessed the net benefits of CO_2 emission reduction through energy taxation. Some of the important contributions to this field include the GREEN model developed by OECD[25], the LINKAGE model developed by the World Bank[26], and the work of Norland et al. and Jorgenson[27,28] making predictions based on CGE models of the effect of an energy tax reform implemented in the U.S. Nowadays, CGE models have expanded on the SGM model from the U.S. Department of Energy, the MINICAN model from the Pacific Northwest National Laboratory (PNNL), the World Scan model from Netherlands, the IMAGE model from the National Institute of Environment and Health, and the HASA model from the International Institute for Applied Systems Analysis[29]. Two impressive studies on China's GHGs emission reduction were carried out by Zhang[30,31] from the University of Groningen, and Garbaccio, Ho and Jorgenson [32] from Harvard University.

The MARKAL model, the AIM model and the LEAP model are categorized as typical bottom-up models. Representative studies by MARKAL (developed by IEA)[33] include those made by Sato et al.[34], Naughten[35], Larson et al. [36], and Chen et al.[37]. Studies based on AIM and LEAP are reported by Zhu and Jiang[38] and Zhang et al.[39] to simulate urban energy consumption and emissions in China's transportation sector.

The Canadian Integrated Modeling System (CIMS) developed by the Energy and Materials Research Group (EMRG), led by Prof. Mark Jaccard at Simon Fraser University (SFU), is a relatively new model for China, but has been widely used in Canada, the USA and Australia. With CIMS, Bataille, Tu, and Jaccard studied the roles of China and Canada in a global low-carbon society[40] while Murphy, Rivers, and Jaccard[41] simulated industrial energy consumption and GHG emissions in Canada. Jaccard, Tu, and

Nyboer et al.[42] made a comparison of sustainable energy development of China and Canada and Rivers and Jaccard[43][44] discussed how subsidies work on GHG emission reduction based on a case study from Canada. Tu [45,46] analyzed China's energy future and CDM potential and made an assessment of emerging industrial technologies worldwide and the implications for the CIMS model. Finally, Murphy and Abate[47][48] simulated the impact of some GHG emission reduction policies in the transportation and electricity sectors.

4.0 RESEARCH METHODS

This study applied the CIMS model to analyze how economic policy instruments such as fuel tax, energy tax, carbon tax and subsidies would affect CO_2 and local air pollutant emissions in the transportation sector. The CIMS model is a hybrid technology simulation model, designed to help policy-makers to better understand the effects of policy alternatives aimed at changing energy demands and emissions[49]. Although the CIMS model was developed in Canada, its basic modelling of real-life factors allows it to capture the energy-economy-environment system in other countries as well. If country-specific parameters are substituted according to the country facts of, in this case, China, it could easily be amended to become a 'China Integrated Modeling System'.

Tu et al.[50][51] discussed the practicability of using CIMS in Chinese circumstances. Our research group used it for sectoral analysis of the power generation and steel and iron industries to analyze how the implementation of carbon taxation on the two sectors could affect industrial technical substitution and subsequently, energy use and CO_2 emission reduction. It was found that taxation instruments could promote enormous technology substitutes and reduce energy use and CO_2 emissions for the power industry, but they were much less effective for the steel and iron industry[52] [53].

The strength of the CIMS lies in the fact that its modelling principle is to simulate technological competition and the substitution process of an industry. With the logical assumption that as old technologies die out of the market and/or with market expansion, new technologies emerge, the CIMS simulates the dynamics of the allocation of emerging market share to all available technologies, decided by the ratio of Life-Cycle Costs (LCCs) of a specific technology over the total LCCs of all the available technologies in the market. The allocation of additional market share to a certain technology is determined by the following equation (1).

$$MS_j = \frac{[CC_j * \frac{r}{1-(1+r)^{-n_j}} + MC_j + EC_j + i_j]^{-v}}{\sum_{k=1}^{K}\left\{[CC_k * \frac{r}{1-(1+r)^{-n_k}} + MC_k + EC_k + i_k]^{-v}\right\}} \quad \text{(Equation 1)}$$

Where: MS_j—Proportion of technology j accounting for additional market share;
CC_j — Capital cost of technology j;
MC_j — Maintenance cost of technology j;
EC_j — Energy cost of technology j;
n_j — Average life span of technology j;
r — Social discount rate;
i_j —Intangible cost;
v —Variable (describing heterogeneity in the market); and
k — Number of technologies.

MS_j is the market share of technology j; CC_j is its capital cost; n is the technology lifespan; MC_j is its maintenance and operation cost; and EC_j is its energy cost, which depends on energy prices and energy consumption per unit of energy service output to produce a tonne of steel, heating a squared meter (m^2) of a residence, and transporting a person one kilometre.

The n_j parameter represents the weighted average time preference of decision makers for a given energy service demand; it is the same for all technologies at a given energy service node, but can differ between nodes according to empirical evidence.

The discount rate (r) determines the relative importance of capital costs versus operating costs in the total life-cycle cost of a technology. In this report, "r" is 8%.

The i_j parameter represents all intangible costs and benefits that consumers and businesses perceive in addition to financial cost values used in most bottom-up analyses for technology j as compared to all other technologies at a given energy service node. Intangible costs represent costs in terms of time, congestion and comfort loss, etc. It allows consumer behavior to be simulated more accurately because it represents attributes that do not affect technical-economic costs, but result in differences in consumers' choices. Intangible cost parameters associated with undesirable attributes are added to the capital costs while those associated with desirable aspects (benefits) are subtracted.

In this research, we were able to infer the intangible costs of all technologies through a try-and-adjust method. We collected the market shares of all technologies in years 2005 and 2008. Taking 2005 as the base year, the different costs (capital costs, operation and maintenance costs, and energy costs) of all technologies were supposed to drive the emerging new market share allocated to each technology in 2008. By comparing the simulated and actual market shares of the technologies in 2008, we could deduce whether the costs of the technologies were under-estimated or over-estimated. The under-estimated part of the costs represents the intangible costs of the technology in question (over-estimated costs means the technology had a positive effect on consumers).

The 'v' parameter represents heterogeneity in the market. It determines the shape of the inverse power function that allocates market share to technology j. A high value of 'v' means that the technology with the lowest LCC captured almost the entire new market in terms of share, and a low value for 'v' means that the market shares of new equipment are distributed fairly evenly, even if their LCCs differ significantly. A conventional bottom-up optimization model might have 'v' = ∞, equivalent to saying that the cheapest technology on a financial cost basis captured 100% of the market. In this study, 'v' was 10, based on the research by Jaccard[54].

Total emissions in the transportation sector were calculated according to equation (2).

$$SUM_i = \sum_{k=1}^{K} S_j * \varepsilon_j \qquad \text{(Equation 2)}$$

Where: SUM_i —Total emissions of pollutant i;

S_j — Stock of technology j;

ε_j — Emission factors per stock of technology j; and

K — Number of technologies.

Total energy consumption in the transportation sector was calculated using equation (3).

$$SUN_i = \sum_{k=1}^{K} S_j * \varphi_j \qquad \text{(Equation 3)}$$

Where: SUN_i —Total consumption of energy i;

S_j — Stock of technology j;

φ_j — Energy consumption per stock of technology j; and

K — Number of technologies.

The CIMS simulates the competition of technologies at each energy service node in the economy based on a comparison of their LCCs and some technology-specific controls, such as a maximum market share limit in the cases where a technology is constrained by physical, technical or regulatory means from capturing all of a market. Total emissions and energy consumption of the sector are decided by emission factor ε_j, energy consumption factor φ_j and technology stock S_j. The CO_2 emissions from electricity power were not considered in this research or were assumed to be zero for vehicles that consumed electricity. In this study, energy price, technology cost and transportation demand were assumed to be exogenous and to remain the same from 2005 to 2050.

5.0 CIMS-CHINA-TRANSPORTATION MODELING

The most crucial step of this study was to create a Chinese-characterized transportation module based on the CIMS model, namely, to construct a dendritical structure of transportation technologies and employ proper parameters for every competing technology to reflect a real picture of the transportation industry in China.

5.1 CIMS-China-Transportation Model Structure

5.1.1 Dendritical structure of transportation technologies

Figure 1 shows the constructed dendritical structure of the sub-sectors within the transportation sector of China. The meanings of the abbreviations of the transportation technology codes are listed in Appendix 1.

In this research, 95 technologies in transportation sector were considered covering PDL_W(Passenger domestic longdistance_Waterway), PDL_A(Passenger domestic longdistance_Air transportation), PDL_R(Passenger domestic longdistance_Rail transportaion), PDS_B(Passenger domestic shortdistance_Bus transportaion), PDS_T(Passenger domestic shortdistance_Taxi transportation), PDS_PC(Passenger domestic shortdistance_Personnal car transportation), PDS_O(Passenger domestic shortdistance_Others transportation), PDS_MRT(Passenger domestic shortdistance_MRT transportation), FD_Road(Freight domestic_Road transportaton), FD_Rail(Freight domestic Rail transportaton), FD_W(Freight domestic Water way), FD_A(Freight domestic Air transportation), FD_P(Freight domestic Pipeline transportation), FI_M(Freight International Marine transportation), FI_Rail(Freight International Rail transportation), FI_Road(Freight International Road transportation) and FI_A(Freight International Air transportation).

The energy forms considered for the transportation sector were gasoline, diesel, CNG, LPG, electricity, gasoline_HEV (gasoline used in hybrid electric vehicles), biodiesel and kerosene. Types of energy forms and their abbreviations as used in this study are shown in Table 1. CO_2 and local air pollutants such as CO, HC, NO_x, and PM were considered as emission factors.

Table 1. Types of energy forms and their abbreviations as used in this study

Energy form	Abbreviations
Gasoline	G
Diesel	D
Compressed Natural Gas	CNG
Liquefied Petroleum Gas	LPG
Gasoline for Hybrid Electric Vehicle	G_HEV
Electricity	E
Biodiesel	BD

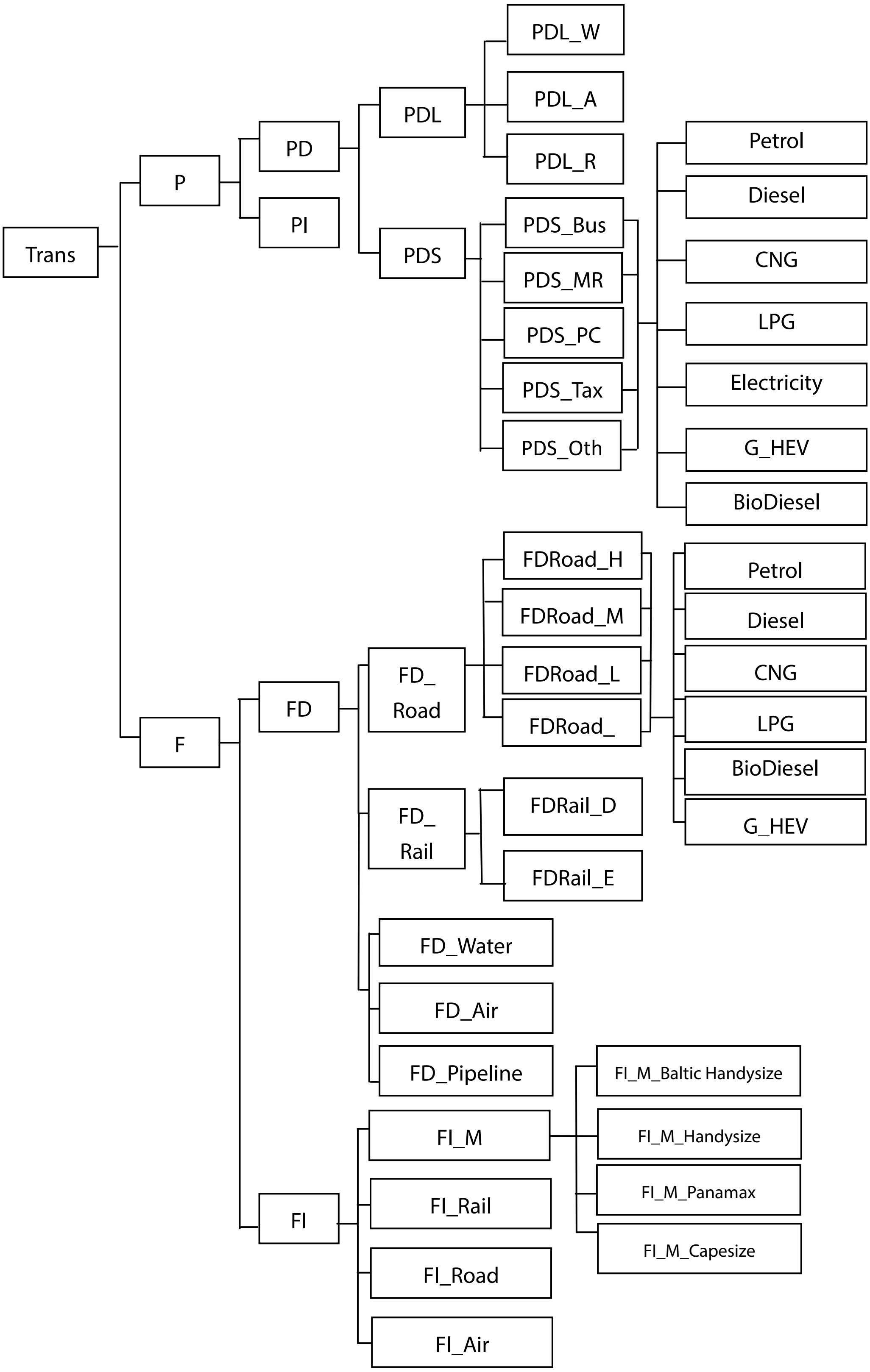

Figure 1. Constructed dendritical technical structure of China's transportation sector in the model

5.1.2 Data source and database

This study covered the main components of China's transportation industry including air, water, road, railway and pipeline transportation, and the data involves passenger transportation and freight transportation as well as energy consumption and pollutant emissions. The main data needed were as follows:

1) Market shares of the 95 technologies in base year (2008) in China
2) China's transportation demand forecast during 2008-2050
3) Energy efficiency parameters of the 95 technologies
4) CO_2 emission factors of the 95 technologies
5) CO, HC, NO_x and PM emission factors of the 95 technologies;

Besides these, the capital costs, maintenance and operation costs, and intangible costs of the 95 technologies were also needed to support technology competition simulation. The main data sources were as listed below.

- Energy-Economy-Environmental model databases, e.g., IPAC, LEAP, MARKAL model et al.[55] [56] [57] .
- National Bureau of Statistics of China. China Statistical Yearbook (2006-2009). Beijing: China Statistical Publishing House.
- Yearbook of China Transportation & Communications of year 2006-2009. Beijing: China Statistical Publishing House.
- Extensive literature review[58] [59] [60].
- Online databases which included the following:
  - http://www.gov.cn/jrzg/2007-06/03/content_634545.htm (accessed 3 June, 2007)
  - http://www.mof.gov.cn/zhengwuxinxi/caizhengxinwen/201006/t20100601_320713.html.
  - http://www.mof.gov.cn/xinwenlianbo/quanguocaizhengxinxilianbo/200805/t20080519_27660.html
  - CIMS-Canada database [61] [62] [63];
- Experts and transportation government departments' interviews.
- Energy efficiency and emission factors of the 95 technologies of CIMS_China_Transportation model are shown in Appendices 2 and 3.

The emission factors were calculated through dividing the emission of technology 'i' in 2009 by its transport turnover in that year. The emissions data was drawn from the '2010 China Vehicle Emission Control Annual Report'[64] and the transportation turnover data was drawn from the 'China Statistical Yearbook'[65].

5.1.3 Model calibration and parameter sensitivity analysis

To ensure data and simulation accuracy, the CIMS has a calibration function such that only when the percentage differences between the simulated base year values of energy and emissions, and the observed values of energy and emissions are less than 5%, respectively, can the accuracy of the constructed model be accepted.

Sensitivity analysis was conducted to check how variations in the exogenous variables (parameters) in the model could affect the output of the simulation and to determine whether the values of the parameters employed in the model were suitable or needed to be extracted through a specific regression process.

In equation (1) of the CIMS China_Transportation model, parameters 'v', (heterogeneity coefficient), 'r' (discount rate), and 'i' (intangible cost) were the three parameters exogenously entered which needed to be re-checked by sensitivity analysis. The analysis showed that the tested parameters were generally suitable for the simulation. The sensivity analysis results are presented in Appendix 4.

5.2 Design of Policy Instrument Scenarios

5.2.1 Business as usual (BAU) scenario

In the BAU scenario, the transportation industry is assumed to keep developing along the current trajectory, there are no emission reduction targets, and no new policies or regulations will be implemented for the transportation industry. Table 2 shows the freight and passenger transportation figures for the period 2005-2050, which were set exogenously with reference to the research of the Energy Research Institute, National Development and Reform Commission (NDRC) of China[66].

Table 2. Predicted market stocks of freight and passenger transportation (2005-2050)

Items	2005	2008	2014	2020	2026	2032	2038	2044	2050
Passenger (pkt)*	1.75 E+12	2.32 E+12	4.3 5E+12	7.91 E+12	1.32 E+13	2.09 E+13	3.00 E+13	4.04 E+13	5.26 E+13
Freight (tkt)*	8.03 E+12	1.10 E+13	1.68 E+13	2.51 E+13	3.54 E+13	4.82 E+13	6.14 E+13	7.49 E+13	8.94 E+13

Note: * pkt means ‘passenger kilometer travel’, and tkt means ‘ton kilometer travel’, measuring the quantity of passenger and freight transportation, respectively.

In this research, we set 2008-2050 as the simulation period and 2008 as the base year while CO_2 emissions and CO_2 intensity in 2005 were also cited, considering China’s commitment to carbon intensity being reduced by 40-45% by 2020 compared with the year 2005. All monetary prices in this study were in 2008 price terms.

5.2.2 CO_2 tax scenario

In this research, CO_2 taxation was assumed to be levied on CO_2 emissions. CO_2 tax rates, from 10 CNY /ton to 300 CNY /ton were tested. 10 CNY /ton is the CO_2 tax rate suggested by a study hosted by the Ministry of Finance[67]. Considering both the current CO_2 tax rate of England, Sweden, Finland, Denmark, Norway, and Canada, and China’s current low income level, the highest CO_2 rate in this study was set at 300 CNY /ton[68].

5.2.3 Fuel tax scenario

Referring to the ‘fuel pricing and taxation reform’ in force since 2009 in China’s transportation sector, the fuel tax base in this research was assumed to cover only gasoline, diesel and kerosene consumption, and the tax rates were in percentages of the energy price, and the various provisions of tax rates were tested in the model simulation (Table 3).

Table 3. Energy prices in baseline and fuel tax scenarios (CNY /GJ)

Scenarios	Diesel	Gasoline	Kerosene
Baseline	119.68	145.62	112.45
Fuel tax (10% rate)	131.65	160.18	123.69
Fuel tax (30% rate)	155.59	189.3	146.18
Fuel tax (50% rate)	179.52	218.43	168.675
Fuel tax (100% rate)	239.36	291.23	224.9

5.2.4 Energy tax scenario

The energy tax bases included not only gasoline, diesel and kerosene, but also biodiesel, CNG, LPG, gasoline-HEV (gasoline consumption by HEV vehicles) and electricity.

Table 4. Energy prices in baseline and energy tax scenarios (CNY /GJ)

Scenarios	Diesel	Biodiesel	Gasoline	LPG	CNG	E	G_HEV	Kerosene
Baseline	119.68	120.58	145.62	186.1	138.76	94.44	145.62	112.45
Energy tax (10% rate)	131.65	132.64	160.18	204.71	152.63	103.89	160.18	123.69
Energy tax (30% rate)	155.59	156.75	189.302	241.9	180.38	122.8	189.30	146.18
Energy tax (50% rate)	179.52	180.87	218.43	279.1	208.13	141.7	218.43	168.67
Energy tax (100% rate)	239.36	241.1574	291.2338	372.2	277.51	188.9	291.23	224.90

5.2.5 Clean energy vehicle subsidy (CEVS) scenario

In this scenario, subsidies are assumed to be given to those vehicles using clean energy such as HEV (Hybrid Electric Vehicle), CNG_V (Compressed Natural Gas Vehicle), LPG_V (Liquid Petroleum Vehicle), and BDV (Bio-Diesel Vehicle) with reference to China's current CEVS policy[69]. The subsidy rate varies with different energies and technologies (Table 5).

Table 5. Subsidies for different technologies in the CEVS scenario (CNY /Vehicle)

Technologies	Subsidy amount	Technologies	Subsidy amount	Technologies	Subsidy amount
FD_Road_H_BD	100000	PDS_Bus_L_CNG	60000	PDS_PC_M_LPG	20000
FD_Road_M_BD	80000	PDS_Bus_L_LPG	60000	PDS_PC_M_BD	20000
FD_Road_L_BD	60000	PDS_Bus_L_BD	60000	PDS_PC_M_HEV	40000
FD_Road_Mini_BD	40000	PDS_Bus_L_HEV	250000	PDS_PC_L_CNG	10000
FI_Road_H_BD	100000	PDS_Bus_Mini_CNG	40000	PDS_PC_L_LPG	10000
PDS_Bus_H_CNG	100000	PDS_Bus_Mini_LPG	40000	PDS_PC_L_BD	10000
PDS_Bus_H_LPG	100000	PDS_Bus_Mini_BD	40000	PDS_PC_L_HEV	30000
PDS_Bus_H_BD	100000	PDS_Bus_Mini_HEV	150000	PDS_TA_CNG	20000
PDS_Bus_H_HEV	420000	PDS_PC_H_CNG	30000	PDS_TA_LPG	20000
PDS_Bus_M_CNG	80000	PDS_PC_H_LPG	30000	PDS_TA_BD	20000
PDS_Bus_M_LPG	80000	PDS_PC_H_BD	30000	PDS_TA_HEV	40000
PDS_Bus_M_BD	80000	PDS_PC_H_HEV	50000		
PDS_Bus_M_HEV	350000	PDS_PC_M_CNG	20000		

5.2.6 Reduction on Ticket Price (RTP) Scenario

In this scenario, the ticket price of public transportation is assumed to be 60% reduced in relation to Beijing's public transportation (including public bus and subway) subsidy[70].

6.0 RESULTS

6.1 BAU Scenario

Total CO_2 Emissions

In the BAU scenario, total CO_2 emissions keep increasing from 2008 to 2050 (Figure 2), but the growth rate of CO_2 will first increase and then decrease from 2020 to 2050. In 2008 (base year), China's transportation sector emitted 6.37E+08 tons of CO_2 and in 2050, this will increase to 5.84E+09 tons, about 11 times larger the 2005 figure. The level will peak in 2020 to 13.7% after which it will decrease. In 2050, the CO_2 rate of increase will decrease to 5.7% (Figure 2).

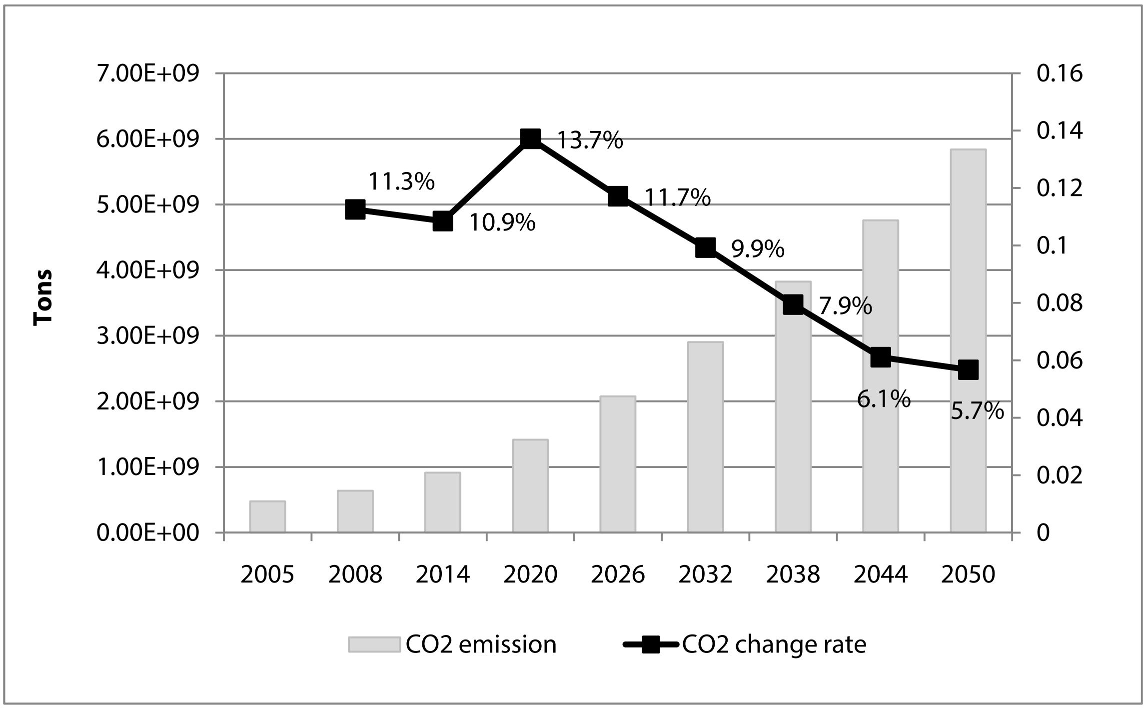

Figure 2. CO_2 emissions and annual rates of increase in the BAU scenario (2008-2050)

Freight transportation emits much more CO_2 than passenger transportation (Figure 3). From 2008 to 2050, CO_2 emissions from passenger transportation will increase at a higher rate than from freight.

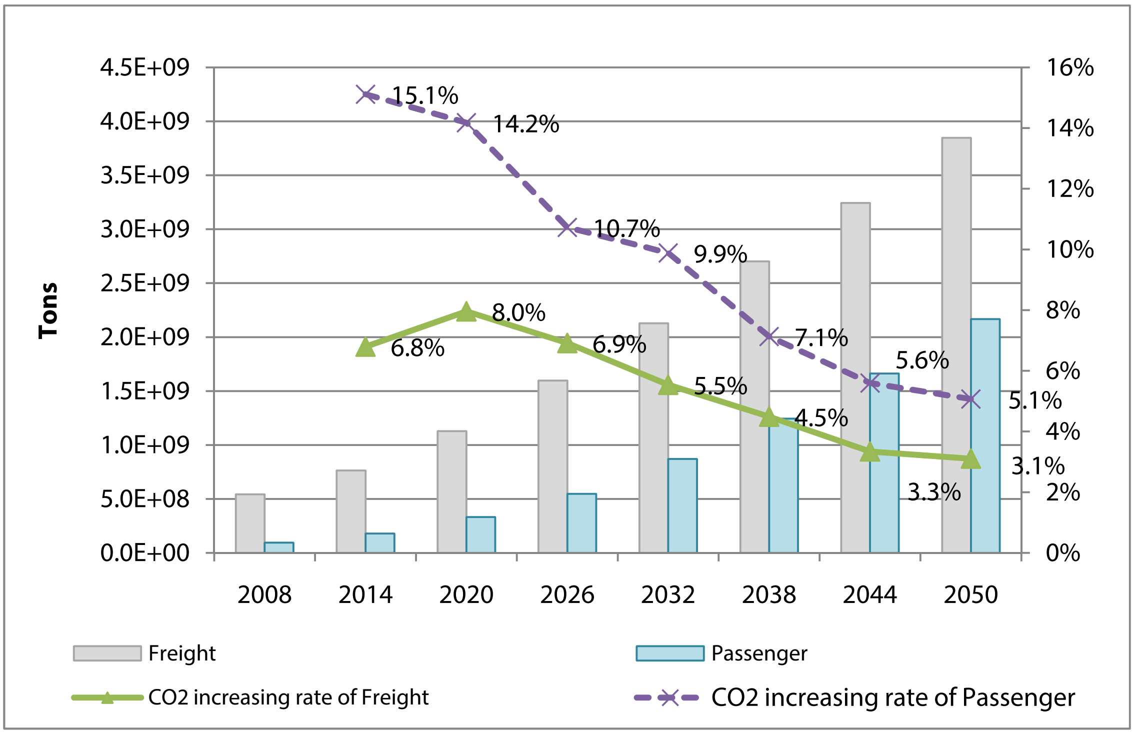

Figure 3. Total CO_2 emissions and annual CO_2 increase rates in the BAU scenario for freight and passenger transportation

CO_2 Intensity

The CO_2 intensity of freight transportation will keep decreasing from 2008 to 2050. In 2005, the CO_2 intensity of freight transportation was 5.13E-05 tons/tkt while in 2050, the CO_2 intensity decreases to 4.3E-05 (Figure 4). This is because the share of FD_Water (lower CO_2 emission factor technology) will increase and for domestic road transportation, a lower CO_2 intensity technology will get more market share (Figure 5).

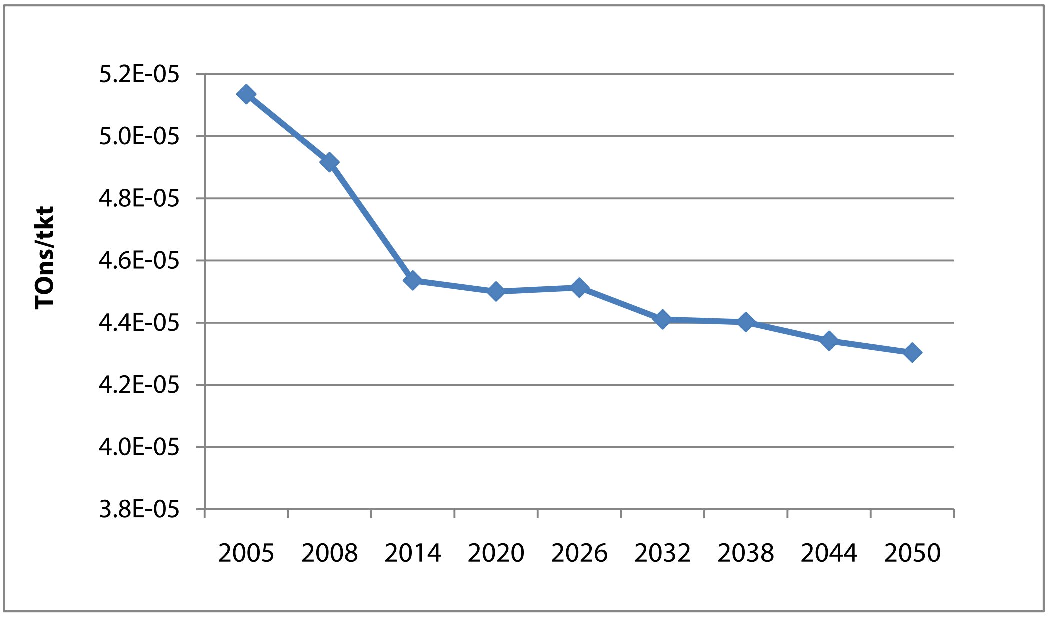

Figure 4. CO_2 intensity of freight transportation in the BAU scenario

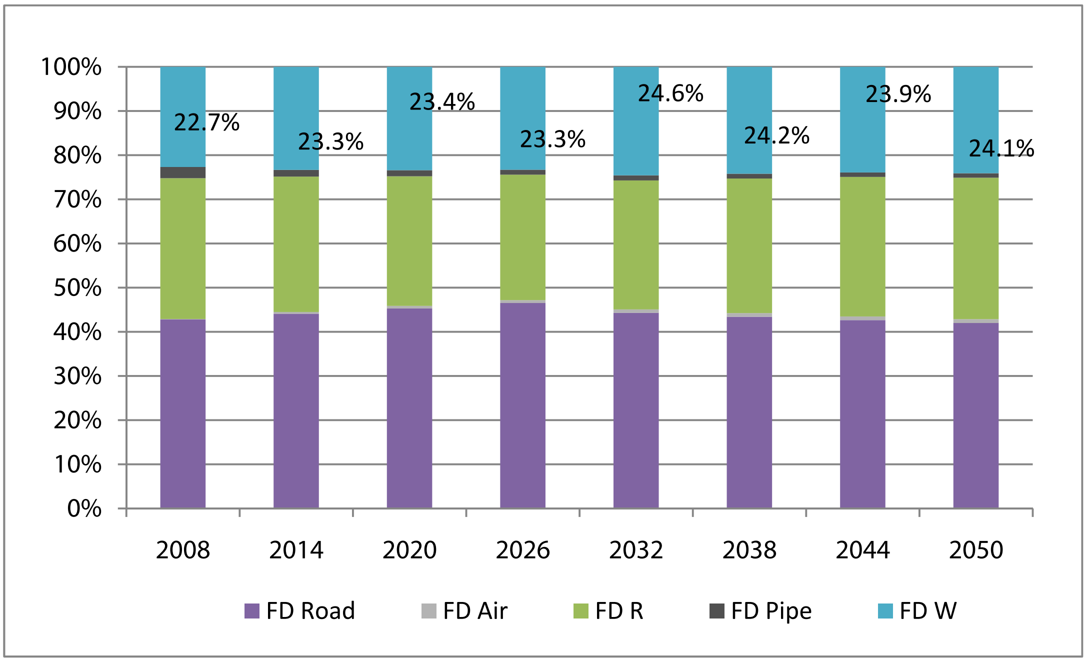

Figure 5. Shares of sub-sectors of freight domestic transportation in the BAU scenario

For passenger transportation, the CO_2 intensity in 2005 was 4.11E-05 tons/pkt, and it will not change much in 2050 (Figure 6). From 2005 to 2050, the CO_2 intensity of passenger transportation first increases and then deceases. This is due to technology competition illustrated in Figure 7, showing that from 2008–2020, China's personal car stock increases speedily, and its share in the total passenger domestic market also increases. The CO_2 emission factor of personal cars is much higher than that of public transportation. After 2020, with the improvement in public transportation market share, the CO_2 intensity decreases in subsequent years.

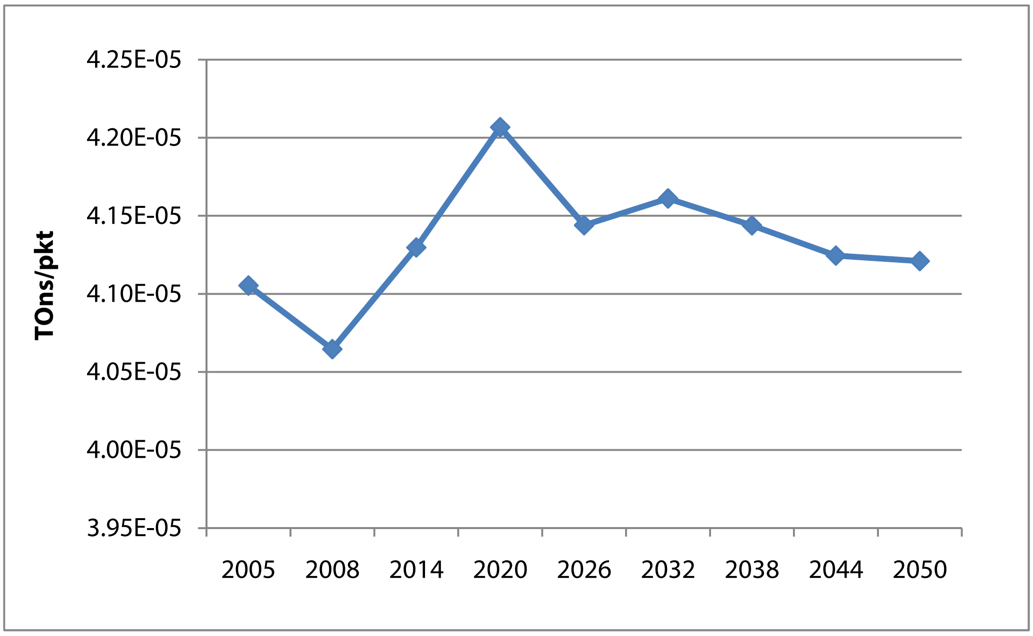

Figure 6. CO_2 intensity of passenger transportation in the BAU scenario

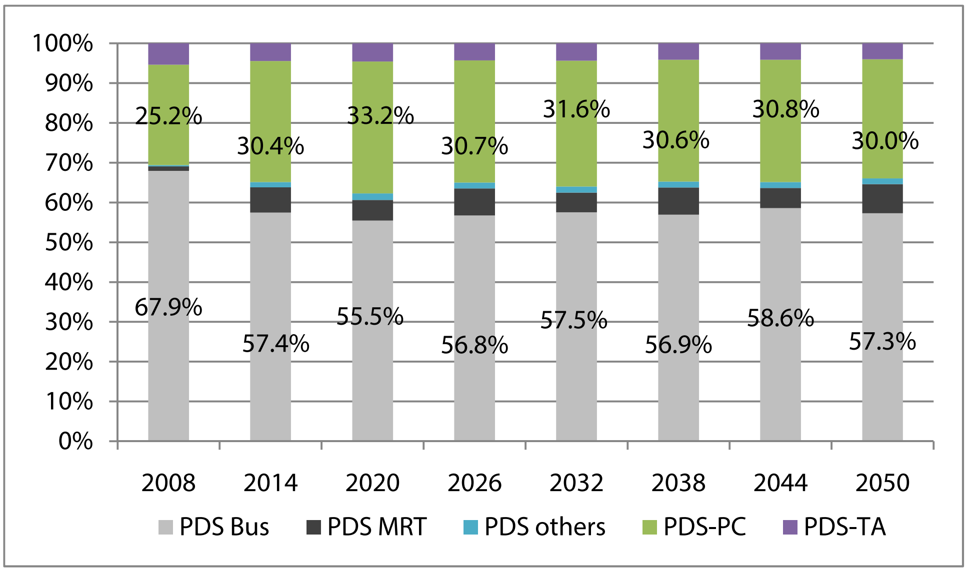

Figure 7. Shares of the domestic passenger transportation market in the BAU scenario (2008-2050)

Local Air Pollutant Emissions

According to the model simulation, China's transportation sector emitted 7.32E+07 tons CO, 9.35E+06 tons HC, 1.50E+07 tons NO_x and 1.77E+06 tons PM in 2008 (base year). In the following decades, local air emissions will keep increasing year by year for all the pollutants, as indicated in Figure 8. We can see that CO, HC and NO_x are the three most important local air pollutants.

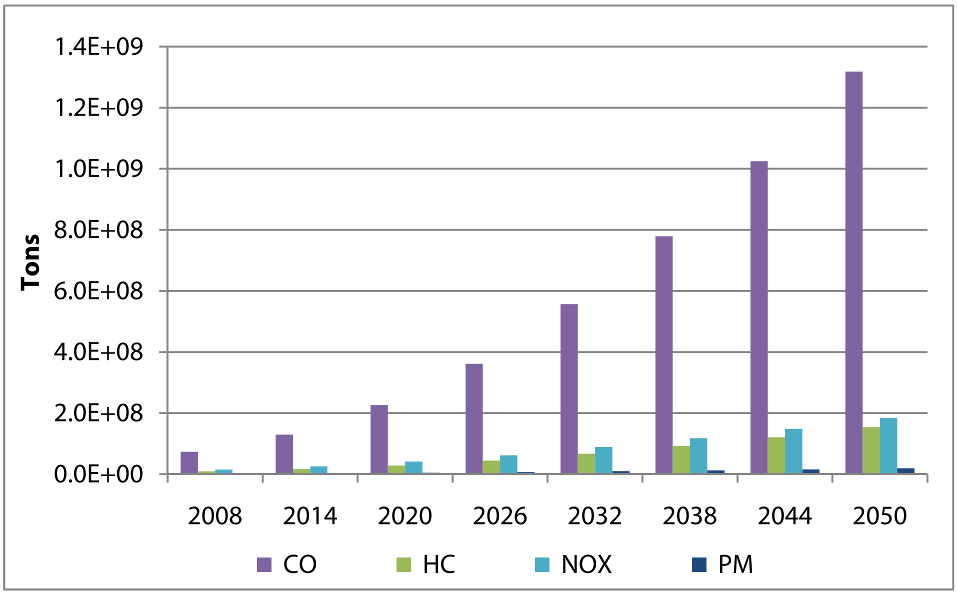

Figure 8. Local pollutants in the BAU scenario (2008-2050)

6.2 Policy to Achieve the CO_2 Emission Reduction Target

6.2.1 China's CO_2 emission reduction target

China has announced the national goal of a 40-45% cut in carbon intensity (tons/GDP) below 2005 levels by 2020. In this research, the CO_2 emission reduction goal in the transportation sector is set according to the national target.

Table 6 shows the projected total CO_2 emission and CO_2 intensity in 2020 in China. In 2005, the GDP of China was 18.31 trillion CNY and the total CO_2 emission level was 4.55 billion tons, so the CO_2 intensity of year 2005 was 0.00025 ton/CNY. In order to achieve the CO_2 intensity reduction target, the CO_2 intensity in 2020 should be lower than 0.000136 ton/CNY. Since the GDP in China will be 64.80 trillion CNY in 2020 with an average annual rate of increase of 8.8%[71], achieving the CO_2 intensity reduction target in 2020 means that the total amount of emissions must be less than 8.9 billion tons then, which is 1.95 times the level in 2005.

Table 6. GDP and total CO_2 emissions and CO_2 intensity in China in 2005 and 2020 (in 2005 prices)

Year	GDP (Trillion CNY)	CO_2（billion tons）	Intensity ton/CNY）
2005	18.31	4.55	0.000248416
Projected quantity for 2020	64,80	8.90**	0.000136629*

Source: CASS (Chinese Academy of Social Sciences) [72].
Notes: * 45% reduction in CO_2 intensity compared 2005.
** Total CO_2 emissions with 45% reduction in CO_2 intensity.

We assume that all the sectors should contribute at the same CO_2 reduction rate. For China's transportation sector, CO_2 emission in 2020 should be no more than 1.95 times of that in 2005, or, in other words, the ratio of '$Carbon_{2020/2005}$'※ should be lower than 1.95.

6.2.2 Policy instruments to achieve the target and their co-benefits

In this research, we simulated five policy scenarios to achieve set CO_2 emission reduction targets: CO_2 tax, fuel tax, energy tax, CEVS and RTP.

CO_2 Tax

CO_2 emissions in 2005 and 2020 and the ratio of $Carbon_{2020/2005}$ under the BAU and CO_2 tax scenarios are shown in Table 7.

Table 7. CO_2 emissions in BAU and CO_2 tax scenarios

CO_2 tax scenarios	Base-line in 2005	BAU 2020	10 CNY/ ton in 2020	50 CNY/ ton in 2020	100 CNY/ ton in 2020	150 CNY/ ton in 2020	200 CNY/ ton in 2020	300 NY/ ton in 2020
CO_2	4.76E+08	1.41 E+09	1.40 E+09	1.36 E+09	1.31 E+09	1.27 E+09	1.23 E+09	1.16 E+09
$Carbon_{2020/200}$	-	2.97	2.95	2.86	2.76	2.67	2.59	2.44

As Table 7 shows, even when the CO_2 tax is as high as 300 CNY/ton, $Carbon_{2020/2005}$ is still much higher than 1.95, meaning it cannot help achieve the CO_2 emission reduction goal. For China, since the

※Carbon $_{2020/2005}$ means the ratio of CO_2 emission in year 2020 divided by CO_2 emission in 2005.

CO_2 tax policy is still under debate and a tax rate of 10-20CNY/ton is proposed, a CO_2 tax rate of 300 CNY/ton or higher seems far from a realistic choice in the near future. If the tax on CO_2 is just 10-20 CNY/ton, there is absolutely no way that the transportation sector would contribute anything significant to achieving the reduction target.

As for local air pollutants reduction, according to Table 8, for the year 2020, 10 CNY/ton CO_2 tax will reduce annual CO emissions by 1.28E+06 tons, HC emission by 1.44E+05 tons, NO_x emission by 1.56E+05 tons and PM by 1.47E+04 tons[1], with reduction rates of 0.56%, 0.51%, 0.38% and 0.32%, respectively. At the tax rate of 300 CNY/ton CO_2, annual reduction will be raised to 2.68E+07 tons CO, 2.94E+06 tons HC, 2.68E+06 tons NO_x and 2.36E+05 tons PM reduction[2], or with reduction rates of 11.83% 10.45%, 6.52% and 5.06%, respectively.

Table 8. Emission reduction co-benefits of CO_2 tax in 2020

CO_2 tax scenarios	BAU	10 CNY/ ton	50 CNY/ ton	100 CNY/ ton	150 CNY/ ton	200 CNY/ ton	300 CNY/ ton
CO emissions in 2020 (ton)	2.27 E+08	2.25 E+08	2.21 E+08	2.17 E+08	2.12 E+08	2.08 E+08	2.00 E+08
HC emissions in 2020 (ton)	2.81 E+07	2.80 E+07	2.76 E+07	2.70 E+07	2.65 E+07	2.61 E+07	2.52 E+07
NO_x emissions in 2020 (ton)	4.12 E+07	4.10 E+07	4.06 E+07	4.01 E+07	3.96 E+07	3.92 E+07	3.85 E+07
PM emissions in 2020 (ton)	4.67 E+06	4.65 E+06	4.61 E+06	4.56 E+06	4.52 E+06	4.49 E+06	4.43 E+06
CO reduction rate compared with baseline	-	0.56%	2.28%	4.34%	6.33%	8.24%	11.83%
HC reduction rate compared with baseline	-	0.51%	2.07%	3.93%	5.69%	7.35%	10.45%
NO_x reduction rate compared with baseline	-	0.38%	1.51%	2.76%	3.86%	4.84%	6.52%
PM reduction rate compared with baseline	-	0.32%	1.29%	2.32%	3.18%	3.91%	5.06%

Fuel Tax

The CO_2 emissions in 2005 and 2020 and the ratio of $Carbon_{2020/2005}$ under fuel tax scenarios are shown in Table 9.

Table 9. CO_2 emissions and the ratio of $Carbon_{2020/2005}$ in baseline and fuel tax scenarios

Fuel tax Scenarios	Baseline in 2005	BAU in 2020	10% Fuel tax in 2020	30% Fuel tax in 2020	50% Fuel tax 2020	100% Fuel tax in 2020
CO_2 emissions (ton)	4.76E+08	1.41E+09	1.29E+09	1.09E+09	9.38E+08	7.04E+08
$Carbon_{2020/2005}$	-	2.97	2.71	2.29	1.97	**1.48**

In the 10% fuel tax scenario, in 2020, the rate of $Carbon_{2020/2005}$ is 2.71, a little less than in BAU. When the fuel tax rate increases to 50% and 100%, the rate decreases to 1.97 and 1.48, respectively. When the fuel tax rate is higher than 53%, China's transportation sector will achieve the CO_2 reduction target set.

The 10% fuel tax will lead to 5.50%, 4.67%, 2.81% and 2.01% reductions in CO, HC, NO_x and PM emissions, respectively. With a higher fuel tax rate, there will be much more co-benefits from local air

[1] This is the difference between BAU and 10 CNY/ton scenarios.
[2] This is the difference between BAU and 300 CNY/ton scenarios.

pollutants reduction. With a 100% fuel tax, 7.96E+07 tons CO, 8.13E+06 tons HC, 6.16E+06 tons NO_x and 4.25E+05 tons PM emissions will be abated, with reduction rates of 35.15%, 28.89%, 14.94% and 9.11%, respectively (Table 10).

Table 10. Emission reduction co-benefits of fuel tax in 2020

Fuel tax scenarios	BAU	10% Fuel tax	30% Fuel tax	50% Fuel tax	100% Fuel tax
CO emissions in 2020 (ton)	2.27E+08	2.14E+08	1.93E+08	1.75E+08	1.47E+08
HC emissions in 2020 (ton)	2.81E+07	2.68E+07	2.46E+07	2.29E+07	2.00E+07
NO_x emissions in 2020 (ton)	4.12E+07	4.00E+07	3.84E+07	3.72E+07	3.50E+07
PM emissions in 2020 (ton)	4.67E+06	4.58E+06	4.46E+06	4.39E+06	4.24E+06
CO reduction rate compared with baseline	-	5.50%	14.97%	22.60%	35.15%
HC reduction rate compared with baseline	-	4.67%	12.53%	18.75%	28.89%
NO_x reduction rate compared with baseline	-	2.81%	6.84%	9.80%	14.94%
PM reduction rate compared with baseline	-	2.01%	4.45%	6.06%	9.11%

Energy Tax

The CO_2 emissions in 2005 and 2020 and the ratio of $Carbon_{2020/2005}$ under energy tax scenarios are shown in Table 11. In the 100% energy tax scenario, the rate of $CO2_{2020/2005}$ will be 1.56 and an energy tax rate higher than 60% can gain enough CO_2 emission reduction.

Table 11. CO_2 emissions and the ratio of $Carbon_{2020/2005}$ in BAU and energy tax scenarios

Energy tax scenarios	Baseline in 2005	BAU in 2020	10% Energy tax in 2020	30% Energy tax in 2020	50% Energy tax in 2020	100% Energy tax in 2020
CO_2 emissions (ton)	4.76E+08	1.41E+09	1.30E+09	1.11E+09	9.69E+08	7.41E+08
$Carbon_{2020/2005}$	-	2.97	2.73	2.34	2.04	**1.56**

Energy tax can also bring about tremendous emission reductions. In the 10% energy tax scenario, there will be 4.73%, 4.07%, 2.24% and 0.16% reduction for CO, HC, NO_x and PM emissions (Table 12). When the energy tax rate rises up to 100%, the CO, HC and NOx reduction rates will be as high as 31.31%, 26.53% , 12.28% and 0.71% respectively.

Why does CO_2 tax seems far from effective compared with fuel and energy taxes? Table 13 more or less gives the answer. As the table shows, a 10 CNY/ton CO_2 tax is just roughly equal to 0.5% of the energy tax, and a CO_2 tax of 600 CNY/ton CO_2 is equal to 30% energy tax. Psychologically, an energy tax rate of 30% would be much acceptable than a 600 CNY/ton CO_2 of carbon tax. So the seemingly ineffectiveness of CO_2 tax is explained by the low level of the tax rates that we tested in the study.

Table 12. Emission reduction co-benefits of energy tax in 2020

Energy tax scenarios	BAU	10% energy tax	30% energy tax	50% energy tax	100% energy tax
CO emissions in 2020 (ton)	2.27E+08	2.16E+08	1.97E+08	1.82E+08	1.56E+08
HC emissions in 2020 (ton)	2.81E+07	2.70E+07	2.50E+07	2.34E+07	2.07E+07
NO_x emissions in 2020 (ton)	4.12E+07	4.03E+07	3.89E+07	3.79E+07	3.61E+07
PM emissions in 2020 (ton)	4.67E+06	4.60E+06	4.52E+06	4.47E+06	4.38E+06
CO reduction rate compared with baseline	-	4.73%	12.94%	19.69%	31.31%
HC reduction rate compared with baseline	-	4.07%	11.03%	16.71%	26.53%
NO_x reduction rate compared with baseline	-	2.24%	5.48%	7.90%	12.28%
PM reduction rate compared with baseline	-	0.16%	0.35%	0.47%	0.71%

Table 13. Equivalent of CO_2 tax and energy tax (in 2005 prices)

CO_2 tax (CNY/ton)	Energy tax (CNY/L Gasoline)	Gasoline price (CNY/L Gasoline)	Energy tax rate
10	0.022	4.39	0.5%
50	0.11	4.39	2.5%
100	0.219	4.39	5.0%
150	0.329	4.39	7.5%
200	0.438	4.39	10.0%
250	0.548	4.39	12.5%
300	0.657	4.39	15.0%
600	1.314	4.39	30.0%

Source: Research Institute for Fiscal Science [73].

CEVS and RTP

According to Tables 14 and 15, CEVS and RTP scenarios assumed in this report are not likely to effectively help the transportation sector to achieve the CO_2 reduction rate. In CEVS and 60% and 100% RTP scenarios, CO emissions will be reduced by 0.41%, 0.35% and 0.40% respectively; HC emissions will be reduced by 0.26%, 0.34% and 0.42% respectively; NO_x will be reduced by 0.41%, 0.20% and 0.24% respectivly; PM will be reduced by merely 0.04%, 0.02% and 0.02% , respectively (Table 16).

To sum up, even at the high tax rate scenario of 300 CNY/ton, a CO_2 tax cannot help meet the CO_2 intensity reduction target. Fuel tax and energy tax , on the other hand, would be more effective in meeting the CO_2 reduction target while the CEVS and RTP would help very little in total CO_2 reduction. CO_2 tax, energy tax and fuel tax have notable co-benefits of local air pollutants reduction of CO, HC and $NO_{x,}$ but CEVS and RTP have very weak effects on total local pollutants reduction.

Table 14. CO_2 emissions in baseline and CEVS scenarios

CEVS Scenarios	Baseline in 2005	CEVS in 2020
CO_2 emissions (ton)	4.76E+08	1.40E+09
$Carbon_{2020/2005}$	-	2.94

Table 15. CO_2 emissions in baseline and RTP scenarios

RTP Scenarios	Baseline in 2005	RTP of 60% in 2020	RTP of 100% in 2020
CO_2 emissions (ton)	4.76E+08	1.41E+09	1.40E+09
$Carbon_{2020/2005}$	-	2.96	2.95

Table 16. Emission reduction co-benefits of CEVS and RTP in 2020

CEVS and RTP scenarios	Baseline	CEVS in 2020	RTP of 60% in 2020	RTP of 100% in 2020
CO emissions in 2020 (ton)	2.27E+08	2.26E+08	2.26E+08	2.26E+08
HC emissions in 2020 (ton)	2.81E+07	2.81E+07	2.80E+07	2.80E+07
NO_x emissions in 2020 (ton)	4.12E+07	4.10E+07	4.11E+07	4.11E+07
PM emissions in 2020 (ton)	4.67E+06	4.65E+06	4.66E+06	4.66E+06
CO reduction rate compared with baseline	-	0.41%	0.35%	0.40%
HC reduction rate compared with baseline	-	0.26%	0.34%	0.42%
NO_x reduction rate compared with baseline	-	0.41%	0.20%	0.24%
PM reduction rate compared with baseline	-	0.04%	0.02%	0.02%

7.0 CONCLUSIONS

We simulated CO_2 emissions and local air pollutants under the current trajectory (baseline scenario) and various policy scenarios for China's transportation sector for the period 2008-2050, with the intention of comparing the effectiveness of the policy instruments of CO_2 tax, fuel tax, energy tax, CEVS and RTP.

The policy instruments proposed in this research can all help mitigate CO_2 intensity to different extents and bring about the co-benefits of local air pollutants reduction. Among these instruments, energy tax and fuel tax were found to be the two most promising instruments for CO_2 intensity reduction while subsidies were the least promising options. A CO_2 tax should have been an effective policy tool, but with the low tax rate proposed, there is no way that it would enable the transportation sector to contribute significantly to achieving carbon intensity reduction.

Although this study has produced important results including the impacts the different policy instruments would have on pollution emission reduction, there are some limitations which should be addressed in future studies on this subject:

1) The total transportation demand in this study was exogenously set and price-demand elasticity was not considered. The omission of demand elasticity is a limiting feature of almost all bottom-up models. Future research should link the CIMS model and top-down models such as CGE to fill this gap.

2) The energy prices during the period 2008-2050 in this research were assumed to be constant at the level of year 2005, but the actual situation is that fuel prices in China have been subject to a large increase since China set up a new fuel pricing mechanism on 1 January 2009, allowing fuel prices to be adjusted to keep pace with fluctuations in the international market. The impact of price fluctuations could be simulated in the same way as allowing LCCs to change.

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APPENDICES

Appendix 1. Transportation technology codes

Code	Full Name
FD_Air_N	Freight_Domestic_Air_Normal
FD_Air_ENGSV	Freight_Domestic_Air_EnergySaving
FD_W	Freight_Domestic_Water
FD_Rail_D	Freight_Domestic_Railway_Electricity
FD_Rail_E	Freight_Domestic_Pipeline
FD_Pipeline	Freight_Domestic_Railway_Diesel
FD_Road_Mini_G	Freight_Domestic_Road_Mini_Gasoline
FD_Road_Mini_D	Freight_Domestic_Road_Mini_Diesel
FD_Road_Mini_BD	Freight_Domestic_Road_Mini_Biodiesel
FD_Road_L_G	Freight_Domestic_Road_Light_Gasoline
FD_Road_L_D	Freight_Domestic_Road_Light_Diesel
FD_Road_L_BD	Freight_Domestic_Road_Light_Biodiesel
FD_Road_M_G	Freight_Domestic_Road_Medium_Gasoline
FD_Road_M_D	Freight_Domestic_Road_Medium_Diesel
FD_Road_M_BD	Freight_Domestic_Road_Medium_Biodiesel
FD_Road_H_G	Freight_Domestic_Road_Heavy_Gasoline
FD_Road_H_D	Freight_Domestic_Road_Heavy_Diesel
FD_Road_H_BD	Freight_Domestic_Road_Heavy_Biodiesel
FI_Air_N	Freight_International_Air_Normal
FI_Air_ENGSV	Freight_International_Air_EnergySaving
FI_Rail_D	Freight_International_Railway_Diesel
FI_Rail_E	Freight_International_Railway_Electricity
FI_M_handy	Freight_International_Marine_Handy
FI_M_handymax	Freight_International_Marine_Handymax
FI_M_banamax	Freight_International_Marine_Banamax
FI_M_capesize	Freight_International_Marine_Capesize
FI_Road_G	Freight_International_Road_Gasoline
FI_Road_D	Freight_International_Road_Diesel
FI_Road_BD	Freight_International_Road_Biodiesel
PI_Air_N	Passenger_International_Air_Normal
PI_Air_ENGSV	Passenger_International_Air_EnergySaving
PI_Road_G	Passenger_International_Road_Gasoline
PI_Road_D	Passenger_International_Road_Diesel
PI_Road_CNG	Passenger_International_Road_Compressed Natural Gas
PI_Road_LPG	Passenger_International_Road_Liquid Petrol Gasoline
PI_Road_BD	Passenger_International_Road_Biodiesel
PI_Road_HEV	Passenger_International_Road_Hybrid Electric Vehicle
PDL_Air_Normal	Passenger_Domestic_LongDistance_Air_Normal
PDL_Air_ENGSV	Passenger_Domestic_LongDistance_Air_EnergySaving
PDL_W	Passenger_Domestic_LongDistance_Water
PDL_Rail_D	Passenger_Domestic_LongDistance_Rail_Diesel
PDL_Rail_E	Passenger_Domestic_LongDistance_Rail_Electricity
PDL_Rail_SF	Passenger_Domestic_LongDistance_Rail_Superfast
PDS_PC_L_G	Passenger_Domestic_ShortDistance_Personal Cars_Light_Gasoline
PDS_PC_L_D	Passenger_Domestic_ShortDistance_Personal Cars_Light_Diesel
PDS_PC_L_CNG	Passenger_Domestic_ShortDistance_Personal Cars_Light_

Appendix 1 continued

Code	Full Name
PDS_PC_L_LPG	Passenger_Domestic_ShortDistance_Personal Cars_Light_Liquid Petrol Gasoline
PDS_PC_L_BD	Passenger_Domestic_ShortDistance_Personal Cars_Light_Biodiesel
PDS_PC_L_HEV	Passenger_Domestic_ShortDistance_Personal Cars_Light_Hybrid Electric Vehicle
PDS_PC_M_G	Passenger_Domestic_ShortDistance_Personal Cars_Medium_Gasoline
PDS_PC_M_D	Passenger_Domestic_ShortDistance_Personal Cars_Medium_Diesel
PDS_PC_M_CNG	Passenger_Domestic_ShortDistance_Personal Cars_Medium_Compressed Natural Gas
PDS_PC_M_LPG	Passenger_Domestic_ShortDistance_Personal Cars_Medium_Liquid Petrol Gasoline
PDS_PC_M_BD	Passenger_Domestic_ShortDistance_Personal Cars_Medium_Biodiesel
PDS_PC_M_HEV	Passenger_Domestic_ShortDistance_Personal Cars_Medium_Hybrid Electric Vehicle
PDS_PC_H_G	Passenger_Domestic_ShortDistance_Personal Cars_Heavy_Gasoline
PDS_PC_H_D	Passenger_Domestic_ShortDistance_Personal Cars_Heavy_Diesel
PDS_PC_H_CNG	Passenger_Domestic_ShortDistance_Personal Cars_Heavy_Compressed Natural Gas
PDS_PC_H_LPG	Passenger_Domestic_ShortDistance_Personal Cars_Heavy_Liquid Petrol Gasoline
PDS_PC_H_BD	Passenger_Domestic_ShortDistance_Personal Cars_Heavy_Biodiesel
PDS_PC_H_HEV	Passenger_Domestic_ShortDistance_Personal Cars_Heavy_Hybrid Electric Vehicle
PDS_Bus_H_G	Passenger_Domestic_ShortDistance_Bus_Heavy_Gasoline
PDS_Bus_H_D	Passenger_Domestic_ShortDistance_Bus_Heavy_Diesel
PDS_Bus_H_CNG	Passenger_Domestic_ShortDistance_Bus_Heavy_Compressed Natural Gas
PDS_Bus_H_LPG	Passenger_Domestic_ShortDistance_Bus_Heavy_Liquid Petrol Gasoline
PDS_Bus_H_BD	Passenger_Domestic_ShortDistance_Bus_Heavy_Biodiesel
PDS_Bus_H_E	Passenger_Domestic_ShortDistance_Bus_Heavy_Electricity
PDS_Bus_H_HEV	Passenger_Domestic_ShortDistance_Bus_Heavy_Hybrid Electric Vehicle
PDS_Bus_M_G	Passenger_Domestic_ShortDistance_Bus_Medium_Gasoline
PDS_Bus_M_D	Passenger_Domestic_ShortDistance_Bus_Medium_Diesel
PDS_Bus_M_CNG	Passenger_Domestic_ShortDistance_Bus_Medium_Compressed Natural Gas
PDS_Bus_M_LPG	Passenger_Domestic_ShortDistance_Bus_Medium_Liquid Petrol Gasoline
PDS_Bus_M_BD	Passenger_Domestic_ShortDistance_Bus_Medium_Biodiesel
PDS_Bus_M_E	Passenger_Domestic_ShortDistance_Bus_Medium_Electricity
PDS_Bus_M_HEV	Passenger_Domestic_ShortDistance_Bus_Medium_Hybrid Electric Vehicle
PDS_Bus_L_G	Passenger_Domestic_ShortDistance_Bus_Light_Gasoline
PDS_Bus_L_D	Passenger_Domestic_ShortDistance_Bus_Light_Diesel
PDS_Bus_L_CNG	Passenger_Domestic_ShortDistance_Bus_Light_Compressed Natural Gas
PDS_Bus_L_LPG	Passenger_Domestic_ShortDistance_Bus_Light_Liquid Petrol Gasoline
PDS_Bus_L_HEV	Passenger_Domestic_ShortDistance_Bus_Light_Hybrid Electric Vehicle
PDS_Bus_Mini_G	Passenger_Domestic_ShortDistance_Bus_Mini_Gasoline
PDS_Bus_Mini_D	Passenger_Domestic_ShortDistance_Bus_Mini_Diesel
PDS_Bus_Mini_CNG	Passenger_Domestic_ShortDistance_Bus_Mini_Compressed Natural Gas
PDS_Bus_Mini_LPG	Passenger_Domestic_ShortDistance_Bus_Mini_Liquid Petrol Gasoline
PDS_Bus_Mini_HEV	Passenger_Domestic_ShortDistance_Bus_Mini_Hybrid Electric Vehicle
PDS_MRT	Passenger_Domestic_ShortDistance_ Mass Rapid Transit
PDS_Others_G	Passenger_Domestic_ShortDistance_Others_Gasoline
PDS_Others_D	Passenger_Domestic_ShortDistance_Others_Diesel
PDS_Others_E	Passenger_Domestic_ShortDistance_Others_Electricity
PDS_TA_G	Passenger_Domestic_ShortDistance_Taxi_Gaosline
PDS_TA_D	Passenger_Domestic_ShortDistance_Taxi_Diesel
PDS_TA_CNG	Passenger_Domestic_ShortDistance_Taxi_Compressed Natural Gas
PDS_TA_LPG	Passenger_Domestic_ShortDistance_Taxi_Liquid Petrol Gasoline
PDS_TA_BD	Passenger_Domestic_ShortDistance_Taxi_Biodiesel
PDS_TA_HEV	Passenger_Domestic_ShortDistance_Taxi_Hybrid Electric Vehicle

Appendix 2. Energy efficiency and emission factors of freight transportation technologies

Technologies	Energy Efficiency (GJ/tkt)	Emission Factors (tons/tkt)				
		CO_2	CO	CH	NO_x	PM
FD_Road_H_G	1.29E-03	9.53E-05	2.28E-06	5.55E-07	2.02E-06	2.20E-07
FD_Road_H_D	1.13E-03	6.19E-05	2.72E-06	5.76E-07	1.79E-06	2.40E-07
FD_Road_H_BD	9.43E-04	7.83E-06	2.83E-06	5.99E-07	6.70E-07	2.10E-07
FD_Road_L_G	3.80E-03	2.80E-04	3.68E-06	4.40E-07	3.40E-07	6.70E-08
FD_Road_L_D	4.23E-03	1.82E-04	3.75E-06	4.51E-07	4.01E-07	6.89E-09
FD_Road_L_BD	3.17E-03	2.63E-05	3.93E-06	4.80E-07	2.73E-07	6.50E-08
FD_Road_M_G	2.37E-03	1.74E-04	2.89E-06	4.78E-07	1.03E-06	7.53E-08
FD_Road_M_D	2.11E-03	1.13E-04	3.20E-06	4.92E-07	1.01E-06	7.98E-08
FD_Road_M_BD	1.64E-03	1.36E-05	3.76E-06	5.02E-07	5.60E-07	7.40E-08
FD_Road_Mini_G	6.41E-03	4.72E-04	4.43E-06	1.80E-07	9.20E-08	2.65E-09
FD_Road_Mini_D	7.09E-03	3.07E-04	4.88E-06	2.23E-07	5.04E-08	2.55E-09
FD_Road_Mini_BD	5.58E-03	4.63E-05	4.62E-06	1.99E-07	8.14E-08	3.03E-09
FD_Air_Normal	1.33E-02	1.20E-03	3.06E-05	6.48E-06	2.01E-05	2.70E-06
FD_Air_ENGSV	9.95E-03	9.02E-04	4.08E-05	8.64E-06	2.69E-05	3.60E-06
FD_Pipeline	1.32E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FD_Rail_D	3.02E-04	1.62E-05	1.80E-06	3.80E-07	1.18E-06	1.58E-07
FD_Rail_E	2.52E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FD_Water_	4.23E-05	2.27E-06	2.09E-06	4.44E-07	1.38E-06	1.85E-07
FI_Air_Normal	1.33E-02	1.20E-03	2.45E-05	5.18E-06	1.61E-05	2.16E-06
FI_Air_ENGSV	9.95E-03	9.02E-04	3.26E-05	6.91E-06	2.15E-05	2.88E-06
FI_Rail_D	3.02E-04	1.62E-05	1.80E-06	3.80E-07	1.18E-06	1.58E-07
FI_Rail_E	2.52E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FI_Road_H_BD	9.43E-04	7.83E-06	2.28E-06	5.55E-07	2.02E-06	2.20E-07
FI_Road_H_D	1.13E-03	6.19E-05	2.72E-06	5.76E-07	1.79E-06	2.40E-07
FI_Road_H_G	1.29E-03	9.53E-05	2.83E-06	5.99E-07	6.70E-07	2.10E-07
FI_M_banamax	8.01E-06	3.88E-08	1.88E-06	4.02E-07	1.12E-06	1.67E-07
FI_M_capesize	4.07E-06	1.97E-08	1.94E-06	4.11E-07	1.23E-06	1.77E-07
FI_M_handy	1.57E-05	7.60E-08	2.09E-06	4.32E-07	1.38E-06	1.91E-07
FI_M_handymax	1.12E-05	5.43E-08	2.20E-06	4.45E-07	1.51E-06	2.10E-07

Appendix 3. Energy efficiency and emission factors of passenger transportation technologies

Technologies	Energy Efficiency (GJ/pkt)	Emission Factors (tons/pkt)				
		CO_2	CO	CH	NO_x	PM
PI_Air_ENGSV	9.95E-04	9.02E-05	7.65E-05	7.99E-06	3.87E-06	1.80E-07
PI_Air_Normal	1.33E-03	1.20E-04	1.02E-04	1.07E-05	5.16E-06	2.40E-07
PDL_Rail_D	2.65E-04	1.28E-05	4.49E-06	4.69E-07	2.27E-07	1.06E-08
PDL_Rail_E	2.21E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PDL_Rail_SF	1.77E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PDL_Water	2.99E-05	1.44E-06	5.24E-06	5.47E-07	2.65E-07	1.23E-08
PDS_Bus_H_BD	2.59E-04	1.53E-06	6.70E-06	6.90E-07	3.60E-07	1.40E-08
PDS_Bus_H_CNG	3.25E-04	1.83E-05	1.35E-06	7.30E-07	2.43E-07	8.30E-09
PDS_Bus_H_D	2.81E-04	1.39E-05	6.80E-06	7.10E-07	3.44E-07	1.60E-08
PDS_Bus_H_E	7.54E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PDS_Bus_H_G	2.91E-04	2.14E-05	7.70E-06	8.10E-07	2.50E-07	7.10E-09
PDS_Bus_H_HEV	1.42E-04	5.13E-06	1.50E-06	2.00E-07	8.00E-08	8.00E-10
PDS_Bus_H_LPG	3.06E-04	1.83E-05	1.10E-06	7.00E-07	2.29E-07	8.40E-09
PDS_Bus_L_CNG	3.71E-04	2.09E-05	1.33E-06	2.57E-06	2.15E-06	2.14E-07
PDS_Bus_L_D	3.74E-04	1.70E-05	2.30E-05	1.88E-06	2.80E-06	2.90E-07
PDS_Bus_L_G	3.56E-04	2.62E-05	3.10E-05	2.04E-06	2.30E-06	2.10E-07
PDS_Bus_L_HEV	1.71E-04	6.30E-06	1.40E-06	5.60E-07	5.00E-07	3.00E-08
PDS_Bus_L_LPG	3.86E-04	2.31E-05	1.28E-06	2.46E-06	2.04E-06	2.20E-07
PDS_Bus_M_BD	2.90E-04	1.58E-06	9.70E-06	1.03E-06	9.40E-07	9.60E-09
PDS_Bus_M_CNG	3.38E-04	1.90E-05	5.78E-06	1.70E-06	8.45E-07	9.90E-09
PDS_Bus_M_D	3.15E-04	1.44E-05	1.12E-05	1.12E-06	9.22E-07	1.20E-07
PDS_Bus_M_E	7.81E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PDS_Bus_M_G	3.00E-04	2.21E-05	1.24E-05	1.66E-06	8.77E-07	9.70E-09
PDS_Bus_M_HEV	1.44E-04	5.31E-06	7.90E-06	3.00E-07	1.12E-07	7.00E-10
PDS_Bus_M_LPG	3.52E-04	2.10E-05	6.71E-06	1.50E-06	8.35E-07	1.04E-08
PDS_Bus_Mini_CNG	6.27E-04	3.52E-05	1.45E-06	2.88E-06	2.32E-06	2.20E-07
PDS_Bus_Mini_D	6.31E-04	2.88E-05	2.16E-05	1.95E-06	3.05E-06	3.05E-07
PDS_Bus_Mini_G	6.01E-04	4.43E-05	2.32E-05	2.08E-06	2.50E-06	2.16E-07
PDS_Bus_Mini_HEV	2.89E-04	1.06E-05	1.66E-06	7.80E-07	7.65E-07	4.45E-08
PDS_Bus_Mini_LPG	6.52E-04	3.90E-05	1.42E-06	2.67E-06	2.14E-06	2.41E-07
PDS_MRT	5.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PDS_Others_D	9.00E-05	1.91E-05	1.18E-07	1.10E-08	9.20E-08	9.20E-09
PDS_Others_E	1.58E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PDS_Others_G	7.18E-04	4.84E-05	2.20E-05	2.77E-06	2.50E-06	2.16E-07
PDS_PC_H_BD	1.70E-03	9.10E-06	9.95E-05	2.01E-06	3.50E-06	2.85E-07
PDS_PC_H_CNG	2.60E-03	1.22E-04	1.49E-05	2.99E-06	2.50E-07	2.13E-07
PDS_PC_H_D	1.84E-03	8.89E-05	2.14E-05	2.13E-06	3.25E-06	2.99E-07
PDS_PC_H_G	2.24E-03	1.65E-04	2.40E-05	2.94E-06	2.67E-06	2.06E-07
PDS_PC_H_HEV	1.20E-03	4.42E-05	1.60E-05	9.40E-07	8.00E-07	4.30E-08
PDS_PC_H_LPG	1.85E-03	9.37E-05	1.41E-06	2.82E-06	2.25E-06	2.25E-07
PDS_PC_L_BD	7.38E-04	3.96E-06	1.70E-05	1.85E-06	3.40E-06	2.90E-07
PDS_PC_L_CNG	1.59E-03	5.33E-05	3.10E-06	2.10E-06	2.30E-06	2.10E-07
PDS_PC_L_D	8.01E-04	3.87E-05	1.90E-05	2.01E-06	3.20E-06	3.10E-07
PDS_PC_L_G	1.41E-03	7.92E-05	2.70E-05	2.26E-06	2.44E-06	2.00E-07
PDS_PC_L_HEV	5.23E-04	1.92E-05	3.60E-06	3.00E-07	3.00E-07	6.00E-08
PDS_PC_L_LPG	8.07E-04	4.08E-05	1.57E-06	1.94E-06	2.22E-06	2.05E-07

Appendix 3 continued

Technologies	Energy Efficiency (GJ/pkt)	Emission Factors (tons/pkt)				
		CO_2	CO	CH	NO_x	PM
PDS_PC_M_BD	1.09E-03	9.03E-06	9.80E-06	1.88E-06	3.24E-06	2.99E-07
PDS_PC_M_CNG	2.36E-03	7.89E-05	1.40E-06	2.88E-06	2.32E-06	2.20E-07
PDS_PC_M_D	1.19E-03	5.74E-05	2.05E-05	2.05E-06	3.05E-06	3.05E-07
PDS_PC_M_G	1.97E-03	1.27E-04	2.20E-05	2.47E-06	2.50E-06	2.16E-07
PDS_PC_M_HEV	7.74E-04	2.85E-05	1.50E-06	8.00E-07	7.65E-07	4.45E-08
PDS_PC_M_LPG	1.19E-03	6.04E-05	1.35E-06	2.67E-06	2.14E-06	2.41E-07
PDS_TA_BD	1.09E-03	9.03E-06	9.80E-06	1.88E-06	3.24E-06	2.99E-07
PDS_TA_CNG	2.36E-03	7.89E-05	1.40E-06	2.88E-06	2.32E-06	2.20E-07
PDS_TA_D	1.19E-03	5.74E-05	2.05E-05	2.05E-06	3.05E-06	3.05E-07
PDS_TA_G	1.97E-03	1.27E-04	2.20E-05	2.77E-06	2.50E-06	2.16E-07
PDS_TA_HEV	7.74E-04	2.85E-05	1.50E-06	8.00E-07	7.65E-07	4.45E-08
PDS_TA_LPG	1.19E-03	6.04E-05	1.35E-06	2.67E-06	2.14E-06	2.41E-07
PDL_Air_ENGSV	9.95E-04	9.02E-05	6.12E-05	6.39E-06	3.10E-06	1.44E-07
PDL_Air_Normal	1.33E-03	1.20E-04	8.16E-05	8.52E-06	4.13E-06	1.92E-07
PI_Road_BD	2.59E-04	1.53E-06	6.70E-06	6.90E-07	3.60E-07	1.40E-08
PI_Road_CNG	4.42E-04	1.83E-05	1.35E-06	7.30E-07	2.43E-07	8.30E-09
PI_Road_D	2.69E-04	1.39E-05	6.80E-06	7.10E-07	3.44E-07	1.60E-08
PI_Road_G	2.98E-04	2.14E-05	7.70E-06	8.10E-07	2.50E-07	7.10E-09
PI_Road_HEV	1.36E-04	5.13E-06	1.50E-06	2.00E-07	8.00E-08	8.00E-10
PI_Road_LPG	2.28E-04	1.83E-05	1.10E-06	7.00E-07	2.29E-07	8.40E-09

Appendix 4. Sensitivity analysis of the model parameters in the simulation

A sensitivity analysis was carried out to see how variations in the exogenous variables (parameters) in the model could affect the output of the simulation and to determine whether the values of the respective parameters employed in the model were suitable or needed to be extracted through a specific regression process.

In equation (1) of the CIMS China_Transportation model, parameters 'v', (heterogeneity coefficient), 'r' (discount rate), and 'i' (intangible cost) were the three parameters exogenously entered which needed to be re-checked by the sensitivity analysis.

The sensitivity factor (S) was calculated using equation (A-1).

$$S = \frac{\Delta x / x}{\Delta y / y} \qquad \text{(A-1)}$$

Where: S — Sensitivity factor of parameter x;
X — dependent or output variable; and
Y — independent or input variable;

Parameter 'v'

The 'v' parameter represents heterogeneity in the market. A high value of 'v' means that the technology with the lowest LCC captured almost the entire new market in terms of share and a low value for 'v' means that the market shares of new equipment are distributed fairly evenly, even if their LCCs differ significantly. If 'v' = 10, then when the LCC of technology A is 15% more expensive than B, B captures 85% of the emergying market share. If 'v' = 1, then when the technology LCC of A is 15% more expensive than technology B, B only captures 55% of the emergying market share. We consider the first case a more homogeneous market situation and the second case, a more heterogeneous market situation. Parameter 'v' is a key factor that can influence technology competition and the rate of technology substitution in a simulation, and finally affect the credibility of the final output.

In the transportation sector, there are 5 sub-sectors： FI (Freight_International transportation), FD (Freight_Domestic transportation), PI (Passenger_Internarional transportation), PDL (Passenger_Domestic_Long distance transportation) and PDS (Passenger_Domestic_short distance transportation). We did sensitivity analyses of all these sub-sectors by calculating the total CO_2 emissions in the transportation sector with different values of 'v'.

Theoretically, parameter 'v' in equation (1) varies from 0-∞ and its default value in CIMS_China_Transportation is 10. For the sensitivity analysis, 'v' values of 20, 5, 11 and 9 were tested to show how changes in it might affect the final outputs of CO_2 emissions. The results are shown in Tables A-1 to A-5. Here, all the CO_2 emission values are the simulated values of the year 2020 in the baseline scenario.

Table A-1. Sensitivity factors of 'v' in FI

Values of 'v'	5	9	10 (baseline)	11	20
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.427 E+09	1.416E+09	1.41E+09	1.414E+09	1.412E+09
Sensitivity Factors	-1.77E-02	-5.72E-03	-	-4.26E-03	-1.80E-03

Table A-2. Sensitivity factors of 'v' in FD

Values of 'v'	5	9	10 (baseline)	11	20
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	2.162 E+09	1.512E+09	1.41E+09	1.335E+09	1.008E+09
Sensitivity Factors	-1.06E+00	-6.87E-01	-	-5.61E-01	-2.88E-01

Table A-3. Sensitivity factors of 'v' in PI

Values of 'v'	5	9	10 (baseline)	11	20
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.416E+09	1.417E+09	1.41E+09	1.417E+09	1.42E+09
Sensitivity Factors	-2.09E-03	-1.51E-02	-	-1.84E-03	2.00E-03

Table A-4. Sensitivity factors of 'v' in PDL

Values of 'v'	5	9	10 (baseline)	11	20
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.41E+09	1.41E+09	1.41E+09	1.42E+09	1.42E+09
Sensitivity Factors	1.17E-02	1.42E-02	-	5.34E-03	6.89E-03

Table A-5. Sensitivity factors of 'v' in PDS

Values of 'v'	5	9	10 (baseline)	11	20
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.4E+09	1.41E+09	1.41E+09	1.42E+09	1.43E+09
Sensitivity Factors	1.53E-02	6.45E-03	-	1.59E-02	9.69E-03

From Tables A-1 to A-5, we see that in most cases the sensitivity factors of 'v' are much lower than 1. The only case showing sensitivity of 'v' is for Freight_Domestic transportation when v = 5; the sensitive factor is observed to be -1.06. This means that in future studies, we should pay more attention to the 'v' parameter for Freight_Domestic transportation.

Parameter 'r'

The other important parameter in equation (1) that needed to be checked was 'r', the discount rate. In the CIMS_China_Transportation model, 'r' was set in all the 95 technologies with a value of 8%. We chose 5 technologies with the largest market shares in the 5 sub-sectors (FI, FD, PI, PDL and PDS) to test the sensitivity factors of 'r'. The chosen technologies were: FD_W (Freight_Domestic_Waterway) in FD transportation, FI_W_Capesize (Freight_Internationl_Waterway_Capesize) in FI transportation, PI_A_N (Personal_Internationsl_Air_Normal) in PI transportation, PDL_R_E (Personal_Domestic_Long distance_Rail_Electricity) in PDL transportation, and PDS_Road_Bus_H_D (Personal_Domestic_Short diatance_Road_Bus_Heavy_Diesel) in PDS transportation. All the CO_2 emission values were simulated values for the year 2020 in the baseline scenario.

Table A-6. Sensitivity factors of 'r' in FD_W

Values of 'r'	0.06	0.08 (baseline)	0.1
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	9.74E+08	1.41E+09	1.62E+09
Sensitivity Factors	1.246473	-	0.720134

Table A-7. Sensitivity factors of 'r' in FI_W_Capesize

Values of 'r'	0.06	0.08 (baseline)	0.1
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.41E+09	1.41E+09	1.42E+09
Sensitivity Factors	0.005408	-	0.004267

Table A-8. Sensitivity factors of 'r' in PI_A_N

Values of 'r'	0.06	0.08 (baseline)	0.1
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.45E+09	1.41E+09	1.45E+09
Sensitivity Factors	-0.09356	-	0.09136

Table A-9. Sensitivity factors of 'r' in PDL_R

Values of 'r'	0.06	0.08 (baseline)	0.1
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.38E+09	1.41E+09	1.45E+09
Sensitivity Factors	0.106928	-	0.092692

Table A-10. Sensitivity factors of 'r' in PDS_R_Bus_H_D

Values of 'r'	0.1	0.08 (baseline)	0.06
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.45E+09	1.41E+09	1.45E+09
Sensitivity Factors	0.092692	-	-0.09269

From Table A-6 to A-10, we see that in most cases, 'r' was not a sensitive parameter in the CIMS_China_Transportation model. The only exception is in FD_W transportation, when r = 0.06 and the sensitivity factor is 1.25. Empirical studies have shown that the Chinese social discount rate is usually 0.12 and the 'r' value of the transportation industry should be no less than 0.08[i]. The major model output, CO_2 emissions, are generally not sensitive to the discount rate 'r' in the CIMS_China_Transportation model.

Parameter 'i'

Similar to what we did with parameter 'r', we chose 5 technologies with the largest market share in the 5 sub-sectors (FI, FD, PI, PDL and PDS). We simulated 4 scenarios: with a 5% and 10% increase on 'i', and a 5% and 10% decrease on it. All the CO_2 emissions values were the simulated values for the year 2020 in the baseline scenario. Tables A-11 to A-15 show the results of sensitivity analysis of parameter 'i'.

Table A-11. Sensitivity factors of 'i' in FD_W transportation

Change of 'i'	Baseline	10%	5%	-5%	-10%
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.41E+09	1.573E+09	1.508E+09	1.287E+09	1.129E+09
Sensitivity Factors	-	1.12	1.32	1.80	2.02

Table A-12. Sensitivity factors of 'i' in FI_W transportation

Change of 'i'	Baseline	10%	5%	-5%	-10%
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.41E+09	1.416E+09	1.415E+09	1.414E+09	1.413E+09
Sensitivity Factors	-	0.0078	0.0086	0.0096	0.0097

Table A-13. Sensitivity factors of 'i' in PI_A_N transportation

Change of 'i'	Baseline	10%	5%	-5%	-10%
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.415E+09	1.414E+09	1.415E+09	1.415E+09	1.415E+09
Sensitivity Factors	-	-0.0016	-0.0015	-0.0014	-0.0013

Table A-14. Sensitivity factors of 'i' in PDL_R transportation

Change of 'i'	Base-line	10%	5%	-5%	-10%
Simulated CO_2 emissions for 2020 in the baseline scenario (ton)	1.415E+09	1.433E+09	1.424E+09	1.404E+09	1.393E+09
Sensitivity Factors	-	0.13	0.027	0.15	0.16

Table A-15. Sensitivity factors of 'i' in PDS_R_Bus_H_D transportation

Change of 'i'	Baseline	10%	5%	-5%	-10%
Simulated CO_2 emissions of year 2020 in baseline scenario (ton)	1.415 E+09	1.436 E+09	1.427 E+09	1.398 E+09	1.376 E+09
Sensitivity Factors	-	0.15	0.18	0.24	0.27

According to Table A-11, parameter 'i' of FD_W transportation is a sensitve parameter to total CO_2 emissions in the transportation sector. In future research on this topic, we should investigate the intangible costs of all 95 technologies to improve the accuracy of the CIMS_China_Transportation model.

The sensitivity analysis in this study showed that the tested parameters in the model were generally suitable/qualified for the simulation.

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