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RESEARCH ARTICLE

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Analysis on the Energy Demand, CO_2 and Pollutant Emissions, and Health Benefits from Urban Road Transport Sector: A Case Study of Shenyang

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Abstract: As society develops and urbanization accelerates, energy requirement and environmental emissions in the road transport field have expanded in Shenyang, China. It is necessary to look at its future energy needs and environmental emission trends. In this work, we have used the LEAP model to account for the energy requirement and environmental emissions from 2017 to 2030 under five scenarios for the road transport sector in Shenyang. Additionally, the intake fraction approach was applied to estimate the health effects and financial damages of NO_X, SO_2, PM_{10}, and $PM_{2.5}$ emissions. The results indicate that the energy required in 2030 will reach 8.18–10.65 Mtce in various scenarios. By 2030, under the business as usual (BAU) scenario, the emissions of CO_2, CO, SO_2, NO_X, PM_{10}, and $PM_{2.5}$ will be 31089.51, 1794.4, 20.59, 205.88, 6.6, and 6.5 kt, respectively. Regarding health benefits, financial damage caused by NO_X, SO_2, PM_{10}, and $PM_{2.5}$ emissions will reach RMB 8.594, 0.117, 1.013, and 1.566 billion in 2030 under the BAU scenario. Moreover, the development of energy-efficient and new energy automobiles is the best means of reducing energy demand and environmental emissions; thus, this approach should be paid special attention when developing future energy efficiency and emission abatement policies for road transport.

Keywords: LEAP model, Shenyang, road traffic, energy demand, environmental emissions

1. Introduction

The issues of energy security and environmental pollution facing human society are becoming more and more dangerous. Globally, the transport sector consumes just less energy than the industrial sector and is the second highest energy consumer, accounting for approximately 60% of the global crude oil consumption [1] and about 24% of the worldwide total CO_2 emitted from fossil fuel burning [2]. Energy consumption and emissions from road vehicles occupy a dominant position, with crude oil consumption contributing to approximately 80% of total crude oil consumed in the transport sector [1]. Moreover, motor vehicle emissions, as a cause of air pollutants, are emitted in densely populated areas of cities, and it is easy to cause photochemical smog that is harmful to human health [3].

As a means of energy policy assessment and climate change mitigation diagnosis, LEAP models are widely employed to forecast energy usage and environmental contaminant emissions in the traffic department in different countries around the world [4, 5]. For example, Azam et al. [6] assessed the energy usage and pollutant releases from traffic transport sector during 2012–2040 in the Malaysian, and the findings indicated that the energy demand and pollutant emissions are minimal under the natural gas alternative. Sritong et al. [7] employed the LEAP model to evaluate energy requirements and CO_2 emissions under realistic and idealistic scenarios in the Thailand road transport sector during 2010–2030. Prasad and Raturi [8] studied the fuel demand for land transport during 2016–2040 in Fiji based on the LEAP model and concluded that Greenhouse gases (GHG) emissions were approximately 864 Gg of CO_2-eq in 2016, which will increase to 1158.4 Gg under business as usual (BAU) case in 2040.

The research on energy efficiency and emission abatement based on the LEAP model in China's transportation field has also been significantly developed [9–11]. For instance, Lei et al. [12] employed the LEAP model to evaluate the energy depletion, CO_2, and pollutant emissions of the Chinese road traffic department in 2050 and calculated the health gains from pollutant emission mitigation based on the inhalation factor method. Yan et al. [13] and Ma et al. [14] studied the energy depletion and carbon emissions of the transportation departments of Jiangxi and Jilin Province, respectively. Scenario analysis was employed by Ye et al. [15] to anticipate carbon emissions of Shanghai's road traffic sector and suggested that carbon emissions are expected to peak in 2030. Peng et al. [9] evaluated the energy efficiency, greenhouse

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gases, and pollutant emissions of passenger transport in Tianjin from 2010 to 2040 and concluded that the energy depletion and greenhouse gas emissions could be minimized under the integrated scenario. These studies have focused on energy demand and environmental emissions in the transport sector, and less on the health impacts of pollutant emissions. To our knowledge, one study has been carried out to examine the health impacts of pollutant emissions in the transport sector at a national level [12]. However, there is still a lack of research on energy demand, environmental emissions, and related health impacts in the transport sector at the city level.

Shenyang is the central city in Northeast China, whose civilian vehicle fleet has expanded dramatically from 211,000 in 2000 to 2,097,000 in 2017, an increase of nearly 10 times in 17 years [16]. Shenyang City has a prominent air pollution problem, especially in winter. To promote urban air ambient conditions, Shenyang has also introduced a few policies to reduce energy depletion and pollution in the field of road traffic. Shenyang's 13th Five-Year Plan for Controlling Greenhouse Gas Emissions states that it should actively promote low-carbon transportation, accelerate the establishment of urban public transportation infrastructure, and vigorously promote the application for clean energy and new energy automobiles. In 2014, Shenyang was selected as the second batch of new energy vehicle extension and utilization cities jointly issued by the Ministry of Finance, Ministry of Science and Technology, Ministry of Industry and Information Technology and Development and Reform Commission, and in 2015, the Shenyang Municipal Government issued the Implementation Plan for the Promotion and Application of New Energy Vehicles in Shenyang (2015–2020). However, previous studies have failed to consider the energy demand and environmental impact for road traffic in Northeast China, and the relevant research on Shenyang is still in a bare stage. This article takes the road traffic of Shenyang as an example to evaluate the energy demand, pollutant emissions (CO_2, CO, SO_2, NO_X, PM_{10}, and $PM_{2.5}$), and health benefits between 2017 and 2030 under five alternative scenarios, at the urban level.

2. Methodology and Data

2.1. The LEAP model

The LEAP model is a computer software system designed for energy policy analysis and reduction of greenhouse gas emissions created by the Stockholm Environment Institute in Sweden and Boston University in the United States [12]. In this paper, the traffic analysis function in the LEAP model is utilized to build a series of scenarios to investigate the impact of various policies on energy efficiency and emission reduction in road transportation. Shenyang's road traffic department is classified into two sub-departments: passenger traffic sector and freight traffic sector. Besides, buses, taxis, and private passenger cars are divided among the passenger traffic sector; heavy freight vehicles, medium freight vehicles, and light freight vehicles are classified in the freight traffic sector. Based on "The Outline of the 13th Five-Year Plan for National Economic and Social Development of Shenyang City," this study sets the average annual GDP per capita growth rates and disposable income of urban residents to 6.5% and 7.5% from 2017 to 2030, respectively.

2.2. Calculation of energy consumption and environmental emissions

1) Energy consumption

This study calculates the energy consumption of "Tank-to-wheel" (TTW) for motor vehicles. Energy consumption of upstream fuel processes (mining, production, distribution, and transportation processes, etc.) is not calculated:

$$EC_t = SK_{t,i} \times MIL_{t,i} \times FE_{t,i} \tag{1}$$

where *i* represents vehicle types, *i* represents the year, EC_t represents the sum of energy consumption of all vehicles in year *t*, $SK_{t,\ i}$ represents the number of vehicles of the *i*-th type in year t, $MIL_{t,\ i}$ represents the average distance traveled (km) by vehicle of the *i*-th type in year *t*, and $FE_{t,i}$ represents the fuel economy of the *i*-th type in the *t*-th year, that is, the fuel demand of the car per 100 km.

2) Environmental emissions

$$GE_t = \sum_{J=1}^{l} EC_{t,j} \times MIL_{t,j} \times EF_{t,j} \tag{2}$$

where *j* represents fuel types, GE_t is the emission of CO_2 and atmospheric pollutants (CO, NO_X, SO_2, PM_{10}, and $PM_{2.5}$) in year *t*, $EC_{t,\ j}$ is the consumption of *j*-th fuel in year *t*, and $EF_{t,\ j}$ is the carbon dioxide and atmospheric pollutant emission factor of the *j*-th fuel in year *t*.

2.3. Health benefits estimation

Previous studies [12, 17, 18] used the intake fraction method to evaluate the health effects resulting from air pollutants. Therefore, the intake fraction approach is also used to estimate the health gains from decreasing air pollutant emissions in this paper. The calculation formula and parameters of the intake fraction approach are as follows [19]:

$$Dose_x = POP \times BR \times \Delta C_x = IF_x \times RA_x \tag{3}$$

where $Dose_x$ is the total amount of pollutant *x* entering the human body, *POP* is the total exposed population, *BR* is the breathing rate, here takes 20 m^3/day [18], ΔC_x is the concentration change of pollutant *x* in the atmosphere, IF_x is the inhalation factor of pollutant *x*, and RA_x is the total amount of pollutant *x* discharged by the pollution source.

Air pollution can cause some health damage. We examined four health consequences for each of SO_2 and NO_X and six health consequences associated with PM_{10} and $PM_{2.5}$. Equation (4) shows the relationship between human health outcomes and dose–response coefficients:

$$Case_{hx} = Dose_{hx} \times DR_{hx} \tag{4}$$

where $Case_{hx}$ is the amount of health consequence *h* due to air pollution *x*, and DR_{hx} is the dose–response relationship between health outcomes *h* and air pollution *x* (case/t). Besides, the dose–response coefficient (DR_{hx}) and the concentration–response coefficient (CR_{hx}) can be expressed by the Equation (5):

$$DR_{hx} = \frac{CR_{hx} \times f_{hx} \times 10^{12}}{365 \times BR} \tag{5}$$

where CR_{hx} is the concentration–response coefficient (case * $m^3/\mu g$) and f_{hx} is the baseline of mortality or morbidity incidence rates. The values of CR_{hx} and f_{hx}.

Equation (6) is the economic loss caused by health outcomes:

$$HB_{hx} = \sum Dose_{hx} \times DR_{hx} \times UE_{hx} \tag{6}$$

where HB_{hx} is the health benefits (yuan) and UE_{hx} is the unit value for the health outcome h (yuan/case).

According to Equations (3), (4), (5), and (6), the economic loss caused by air pollutant x can be expressed by Equation (7):

$$HB_{hx} = \sum \frac{IF_x \times RA_x \times CR_{hx} \times f_{hx} \times UE_h \times 10^{12}}{365 \times BR} \tag{7}$$

2.4. Scenarios design

This study uses scenario analysis to set up five scenarios for analysis and discussion. They are the baseline scenario (BAU), the promotion of public transportation scenarios (PTP), the improvement of vehicle fuel economy scenarios (FEI), the promotion of energy-saving and new energy vehicle scenarios (END), and the comprehensive scenario (CP).

1) Basic data

The base year for the calculation model is 2017, and the model parameters of the base year are set concerning the data for 2016 and 2018, as shown in Table 1. The number of motor vehicles comes from the "Shenyang Statistical Yearbook." Average annual travel distance and fuel economy come from prior research [20, 21]. The emission factors during the TTW phase of CO and NO_X are derived from the Technical Environment Database (TED) in the LEAP model, and emission factors of $PM_{2.5}$, PM_{10}, and SO_2 are derived from the literature [12]. The details of the values are given in Table 2.

Table 2
Emission factors for CO_2 and air pollutant

Energy type	CO (kg/TJ)	NO_X (kg/TJ)	SO_2 (kg/tce)	PM_{10} (kg/tce)	$PM_{2.5}$ (kg/tce)
Gasoline	8000.00	600.00	0.60	0.57	0.441
Diesel	1000.00	800.00	5.40	1.35	1.061
CNG	400.00	600.00	0.00	0.04	0.031

2) Business as usual

The BAU scenario refers to the continued present trend in the absence of policy factors interfering. The purpose of setting it is to make a comparative analysis with policy scenarios. In the baseline scenario, it is assumed that the social and economic sectors of Shenyang City will continue their current state of development between 2017 and 2030. The vehicle fuel economy and average annual driving distance remain unchanged and are still the same as the parameters of the base year (2017).

3) Public transport promotion

Buses and taxis are an essential part of urban public transportation. Considering the significant role of public transportation in energy efficiency and emission mitigation, China has introduced a variety of policies and measures to boost the advancement of public transportation. Similar to the methods in the related literature [22–25], this paper promotes the development of public transportation in the model by increasing the average annual driving distance of buses and taxis and reducing the

Table 1
Basic data of the Shenyang road traffic sector in the base year (2017)

Sector	Vehicle type	Energy type	Vehicle stock	Annual vehicle travel (km)	Fuel economy per 100 km
Passenger traffic	BUS	Diesel	3812	70,000	28.0 L
		CNG	1868	70,000	24.6 kg
		Electricity	1795	70,000	88.1 kWh
	TAXI	Gasoline	16,662	120,000	8.5 L
		Diesel	537	120,000	6.3 L
		CNG	358	120,000	5.5 kg
		Electricity	90	120,000	23.5 kWh
	PV	Gasoline	1,583,937	18,000	8.5 L
		Diesel	50,551	18,000	6.3 L
		CNG	25,275	18,000	6.3 L
		Electricity	8425	18,000	23.5 kWh
Freight traffic	HFV	Diesel	40,674	33,039	28 L
		CNG	411	33,039	24.6 kg
	MFV	Diesel	37,137	29,889	17 L
		CNG	375	29,889	14.9 kg
	LFV	Gasoline	50,016	27,127	18.8 L
		Diesel	48,016	27,137	13.9 L
		CNG	1000	27,137	12.2 kg
		Electricity	1000	27,137	44.1 kWh

Note: PV: private vehicle; FV: freight vehicle; HFV: heavy freight vehicle; MFV: medium freight vehicle; LFV: light freight vehicle.

average yearly driving mileage of private cars. The detailed values are presented in Table 3.

Table 3
Average annual travel distance of vehicles under the PTP scenario

Vehicle type	2017	2020	2030	References
BUS	70,000 km	73,000 km	86,000 km	[20]
TAXI	120,000 km	120,600 km	124,900 km	[21]
PV	18,000 km	17,160 km	13,800 km	[21]
HFV	62,000 km	62,600 km	63,900 km	[21]
MFV	29,000 km	29,000 km	31,700 km	[21]
LFV	25,000 km	25,000 km	25,300 km	[21]

4) Fuel economy improvement

The fuel economy of motor vehicles is enhanced as an important way of reducing energy depletion and emissions [23]. The fuel economy of motor cars is expected to be further improved, along with advances in internal combustion engine technology and the trend toward lighter vehicles [21]. The “Energy Conservation and New Energy Vehicle Technology Roadmap” formulated by the Chinese Society of Automotive Engineers states that the average fuel economy of new passenger vehicles will fall to 4 L/100 km by 2025 and to 3.24 L/100 km by 2030. Regarding the literature [21], the fuel economy of taxis, buses, private vehicles, and trucks are set, as presented in Table 4.

Table 4
Fuel economy of cars under FEI scenario

Year	BUS	TAXI	PV	HFV	MFV	LFV
2017	28.0 L	8.5 L	8.5 L	28.0 L	17.0 L	14.0 L
2020	27.4 L	8.2 L	8.2 L	27.2 L	16.5 L	13.4 L
2030	26.1 L	7.7 L	7.7 L	25.8 L	16.0 L	12.8 L

5) Energy-saving and new energy vehicle development

“Shenyang New Energy Vehicle Promotion and Application Implementation Plan (2015-2020)” states that Shenyang will complete the promotion goal of 10,000 new energy vehicles and build 120 charging stations and 7,200 charging piles by 2020. Specific quantitative measures for this study: diesel buses will be phased out, and the percentages of CNG and pure electric buses are to be increased to 25% and 75% by 2020, respectively; the ratio of gasoline, diesel, CNG, and pure electric vehicles in the new taxis will reach 30%, 5%, 5%, and 60%, respectively, by 2030; the proportion of petrol, diesel, CNG, and pure electric vehicles in newly added PV is 51%, 5%, 9%, and 35%, respectively. For FV, the proportion of CNG-fueled vehicles in heavy freight vehicle and medium freight vehicle will gradually increase to 5% by 2030; among the newly added light freight vehicle, the percentages of gasoline, diesel, CNG, and electric vehicles is to be 10%, 5%, 25%, and 60%, respectively, by 2030.

6) Comprehensive scenario

The CP scenario that is a combination of PTP, FEI, and END scenarios, not only promotes public transportation, improves vehicle fuel economy, but also promotes energy-saving and new energy vehicles. The average yearly driving distance of the vehicle is the same as in Table 3, and the fuel economy of the vehicle is the same as in Table 4. The percentage of energy-saving and new energy vehicles is the same as that of the END scenario.

3. Results and Discussion

3.1. Energy demand

1) Total energy demand

The total energy requirement forecast of Shenyang’s road transportation segment from 2017 to 2030 under five scenarios is illustrated in Figure 1. In the BAU scenario, the total energy demand of Shenyang’s road traffic sector in 2030 is 10.7 Mtce, which is 1.5 times the 7.3 Mtce in 2017. Fan et al.’s [26] research shows that the energy needs and emissions of urban passenger transport in Beijing in 2030 would be approximately 1.8 times higher than in 2015 under the BAU scenario. Their study has similar growth multiples to the present study, which to some extent can justify the present study.

The total energy demand under the PTP, FEI, END, and CP scenarios will reach 9.7 Mtce, 10.1 Mtce, 9.2 Mtce, and 8.2 Mtce by 2030, respectively. Overall, the total energy demand from 2017 to 2030 under the BAU, PTP, FEI, and END scenarios has continued to increase. However, the total energy demand from 2017 to 2030 showed an upward and then downward trend, reaching a peak in energy demand of around 8.24 Mtce in around 2028 under the CP scenario. Besides, the four energy-saving (PTP, FEI, END, and CP) scenarios set out in this paper have visible energy-saving effects. Among them, the energy demand reduction under the CP scenario is the largest, which is mainly because the CP scenario is a combination of the other three scenarios.

Figure 2 shows the energy-saving effect of other scenarios against the BAU scenario. In 2017–2030, the energy-saving effects of the four energy-saving scenarios gradually increase with

Figure 1
Total energy demand of the road traffic sector under five scenarios

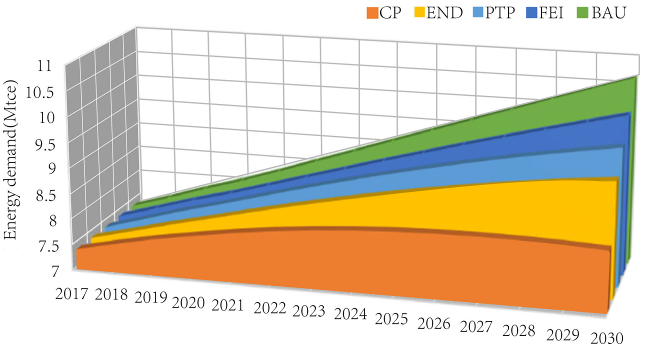

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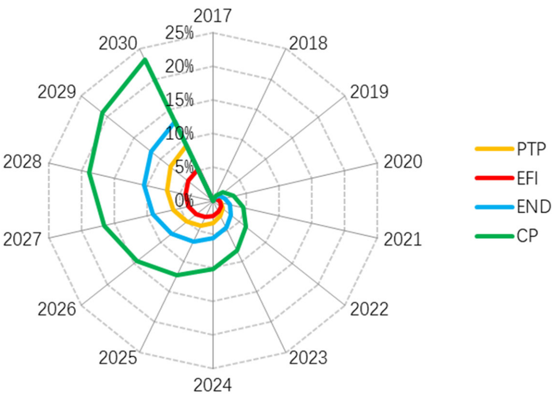
Figure 2
Energy-saving effect of alternative scenarios compared to the BAU scenario



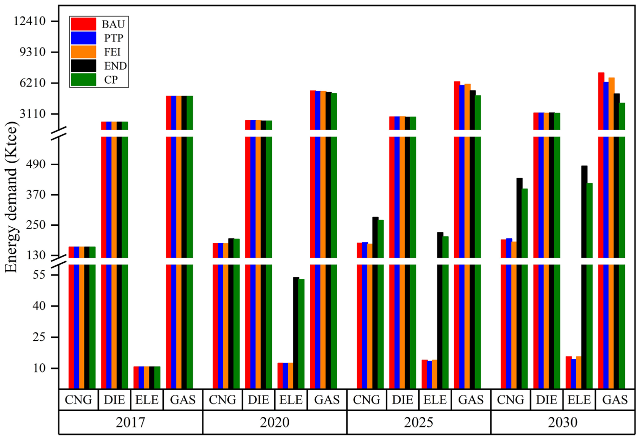
time, and the order of energy-saving effects in the same year is the CP scenario, the END scenario, the PTP scenario, and the FEI scenario. The CP scenario has the best energy-saving effect, with 3.08%, 12.27%, and 23.23% in 2020, 2025, and 2030, respectively. Furthermore, it can be seen that the way of END has the largest contribution to the decrease of energy needs in the CP scenario, the gift of PTP is centered, and the donation of FEI is the smallest. If energy use in the road transport sector is to be curtailed further, it would be an excellent idea to boost promotions for energy-saving and energy vehicles in the future.

2) Energy demand for energy type

Figure 3 shows the predicted values for the energy demand of energy types (DIE, GAS, and ELE stands for diesel, gasoline, and electricity, respectively). The consumption of gasoline, diesel, CNG, and electricity is 4882.2, 2292.2, 163.1, and 10.7 ktce, accounting for 66.4%, 31.2%, 2.2%, and 0.2% of the total energy requirement in 2017, respectively. Besides, it can be seen that the requirement for gasoline, diesel, CNG, and electricity has shown an upward trend from 2017 to 2030.

In the future, gasoline and diesel will still dominate the energy consumption structure. By 2030, the demand for gasoline under the BAU, PTP, FEI, END, and CP scenarios will reach 7243.2, 6273.8, 6722.8, 5125.53, and 4191.2 ktce, respectively. Also, the share of gasoline use in total energy demand gradually increases with time

Figure 3
Demand for energy type under five scenarios



under the BAU scenario, but it gradually decreases with time under other scenarios. Under the CP scenario, the proportion of gasoline demand will reach 65.9%, 60.2%, and 51.2% in 2020, 2025, and 2030, respectively.

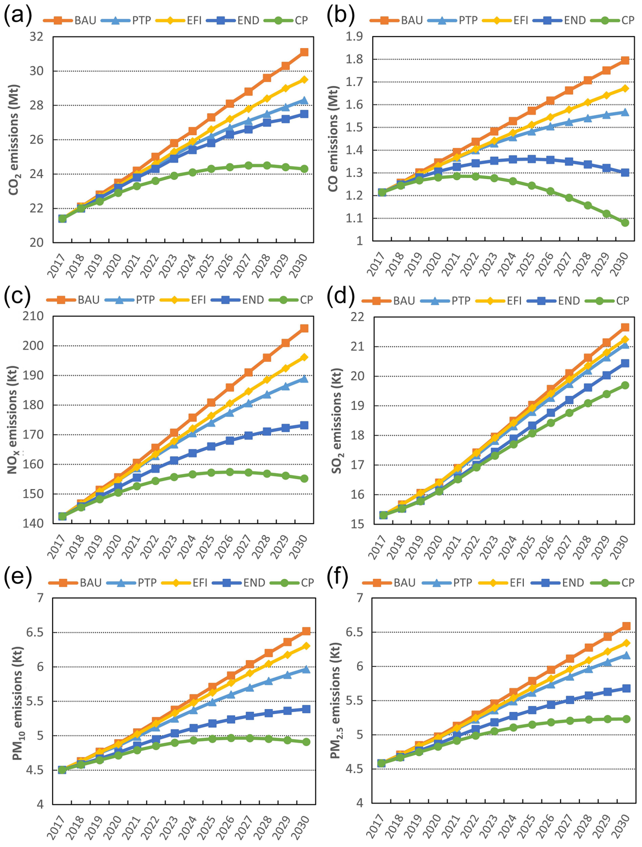
Unlike the situation with gasoline, the demand for diesel under different scenarios in the same year is the same. Under the BAU, PTP, FEI, END, and CP scenarios, the demand for diesel is 3205.0, 3204.3, 3186.9, 3215.7, and 3181.3 ktce by 2030, respectively. The ratio of the energy demand for diesel to total energy use is gradually decreasing from 2017 to 2030 under the BAU scenario, but the change is small. However, under the PTP, FEI, END, and CP scenarios, its proportion will gradually increase over time. The growth rate under the CP scenario is the largest, and the proportion values in 2020, 2025, and 2030 are 30.9%, 34.1%, and 38.9%, respectively; the growth rate under the FEI scenario is the slowest, and the proportion values in 2020, 2025, and 2030 are 30.6 %, 31.1%, and 31.5%, respectively. The difference between gasoline and diesel is mainly since that the energy-saving measures implemented in the traffic sector are aimed at passenger traffic where the primary energy demand is gasoline and less involving freight traffic where the main energy demand is diesel.

3.2. Environmental emissions

1) CO_2 emissions

Figure 4 (a), (b), (c), (d), (e), and (f) show the CO_2, CO, NO_X, SO_2, PM_{10}, and $PM_{2.5}$ emissions under various scenarios, respectively. Since 2017, carbon dioxide emissions have been increasing under the BAU, PTP, FEI, and END scenarios,

Figure 4
Emissions of atmospheric pollutants under five scenarios



reaching 31.1 Mt, 28.3 Mt, 29.5 Mt, and 27.5 Mt by 2030, respectively. Only under the comprehensive scenario, the carbon dioxide emissions showed an increasing trend followed by a decreasing trend and reached a peak of 24.5 Mt around 2028 and then fell to 24.3 Mt in 2030. Using a bottom-up modeling approach, Hao et al. [27] evaluated the GHG emissions of passenger cars in China, showing that GHG emissions peak in 2027, similar to the findings of this research.

2) Pollutant emissions

The total emissions of CO are 1.21 Mt in 2017. In the "business-as-usual" scenario, CO_2 emissions would have increased at an average yearly rate of 3.2 % to 1.79 million tons in 2030, 1.49 times more than in 2017. The emissions of CO under the PTP and FEI scenarios are 1.57 Mt and 1.67 Mt in 2030, which are 12.66% and 6.84% lower than the BAU scenario, respectively. Under the END scenario, carbon oxide emissions first increase and then decrease, reaching a peak of 1.36 Mt in 2025 and then reducing to 1.30 Mt which is 27.50% less than the BAU scenario by 2030. Therefore, facilitating the development of energy-saving and new energy automobiles has the greatest effect on the carbon monoxide reduction effect. Ye et al. [15] predicted that under the combined mitigation scenarios and the new energy automobile package scenarios, the peak time of CO emissions of urban transportation will be 2018 and 2025 in Shanghai, respectively.

The emissions of NO_X in 2017 were 142.46 kt. The annual growth rate of NO_X emissions is 2.9% and will reach 205.87 kt in 2030 under the baseline scenario. Under the PTP, FEI, and END scenarios, the NOx emissions in 2030 are 188.89 kt, 196.15 kt, and 173.18 kt, respectively, which are 8.25%, 4.73%, and 15.88% less than the BAU scenario. Under the CP scenario, NOX emission reduction is the largest, reaching a peak of 157.40 kt by 2026 and decreasing to 155.21 kt by 2030.

The emissions of SO_2 under all five scenarios are overgrowing, and even under the CP scenario, there is no peak in emissions. Under the BAU, PTP, FEI, END, and CP scenarios emissions of SO_2 in 2030 are 21.65, 21.07, 21.24 20.44, and 19.69 kt, respectively. In contrast to the BAU program, SO_2 emissions in 2030 will be decreased by 2.70%, 1.89%, 5.60%, and 9.05% in PTP, FEI, END, and CP scenarios, respectively.

Emissions of PM_{10} were 4.50 kilotons in 2017, while in the BAU scenario, its emissions will grow to 6.52 kt by 2030, with an average yearly growth rate of 2.89%. Under the PTP, FEI, END, and CP scenarios, emissions of PM10 in 2030 are 5.97 kt, 6.30 kt, 5.39 kt, and 4.91 kt, respectively. Among them, PM_{10} emissions under the CP scenario will reach a peak of 4.97 kt in 2026.

In all five scenarios, there is little change in PM2.5 and PM10 emissions in 2030, with both ranging from 4.50 to 6.60 kt. The difference is that under the CP scenario, $PM_{2.5}$ emissions have been increasing without a peak, while PM_{10} emissions peak in 2026 and then slowly decline. Under the BAU, PTP, FEI, END, and CP scenarios, $PM_{2.5}$ emissions in 2030 are 6.59 kt, 6.16 kt, 6.34 kt, 5.68 kt, and 5.23 kt, respectively.

3.3. Health impact assessment

With the growth of motor vehicle ownership, exhaust emissions from motor cars have turned out to be one of the leading sources of pollution affecting the urban air environment. Compared with industrial sources, motor vehicle emissions are closer to densely populated urban areas and lower in emission locations, so they are more likely to affect human health [28]. Epidemiology has confirmed that there is a clear correlation between the increase in atmospheric pollutants including PM_{10}, $PM_{2.5}$ NO_X, and SO_2 emissions and the increase in resident mortality and morbidity [29, 30]. Therefore, this study assessed four health outcomes related to SO_2 and NO_x by referring to previous studies and also evaluated six health outcomes associated with PM_{10} and $PM_{2.5}$.

In the health effects evaluation, the economic outcomes related to NO_X emissions is the largest, and the economic outcomes related to SO_2 is the smallest in 2030. The total financial damage associated with NO_X emissions are RMB 8,593,608,300, 7,884, 590,900, 8,187,472,500, 7,176,553,900, and 6,478,561,400 under the BAU, PTP, FEI, END, and CP scenarios. Among the economic losses caused by NO_X emissions, the proportion of mortality outcomes is 99.28%, and the other three health outcomes total 0.72%. The economic loss caused by SO_2 emissions is much smaller than NO_X in 2030, which is mainly because the SO_2 emissions are relatively less than the NO_X emissions. The economic loss of SO_2 emissions under the CP scenario is RMB 153,665,000, which is RMB 16,266,500 million less than the RMB 168,618,300 in the BAU scenario in 2030. The emissions of PM_{10} and $PM_{2.5}$ are basically the same in the BAU scenario, but the economic loss of PM_{10} emissions is RMB 1,012,807,200, and the financial loss of $PM_{2.5}$ emissions is RMB 1,566,141,300. The economic loss of $PM_{2.5}$ is 1.54 times that of PM_{10}. The main reason is that compared with PM_{10}, $PM_{2.5}$ has a small particle size, large area, and intense activity and can be suspended in the air for a long time to adsorb toxic and harmful substances, so it has a greater impact on physical health.

In general, the financial damage associated with NO_X, SO_2, PM_{10}, and $PM_{2.5}$ emissions are the largest in the BAU scenario in 2030. All other scenarios show varying degrees of reduction in economic losses compared to the BAU scenario, but the CP scenario shows the largest reduction.

4. Conclusion and Recommendation

The study found that the total energy requirement for the road traffic department in Shenyang was 7.3 Mtce in 2017. If no energy-saving measures are applied, that is, in the BAU scenario, the total energy needs will reach 10.7 Mtce by 2030. The total energy requirement of the CP scenario is minimal, peaking at 8.24 Mtce around 2028, and decreasing to 8.18 Mtce by 2030. Gasoline and diesel have always dominated the energy consumption structure from 2017 to 2030. The share of gasoline and diesel demand in total energy requirement is 50%–70% and 30%–40% in each base year under different scenarios. The extensive use of energy-efficient and new energy automobiles is of major implications for adjusting the energy need structure for the road traffic department. The proportion of CNG and electricity energy need in total energy need will increase from 1.8% and 0.1% in 2017 to 4.7% and 5.3% in 2030 under the END scenario, respectively.

The emissions of CO_2, CO, NO_X, SO_2, PM_{10}, and $PM_{2.5}$ have continued to increase under the BAU scenario. By 2030, their emissions will be 31.09 Mt, 1.79 Mt, 205.88 kt, 21.65 kt, 6.52 kt, and 6.59 kt, respectively. Under the CP scenario, the emissions of SO_2 and $PM_{2.5}$ will be 19,69 kt and 5.23 kt by 2030. However, the emissions of CO_2, CO, NO_X, and PM_{10} in the CP scenario first increase and then decrease. The emissions of CO_2, CO, NO_X, and PM_{10} reached peak emissions of 24.50 Mt, 1.29 Mt, 157.40 kt, and 4.96 kt in 2027, 2021, 2026, and 2026, respectively. By 2030, the emissions of CO_2, CO, NO_X, and PM_{10} will be reduced to 24.30 Mt, 1.08 Mt, 155.21 kt, and 4.91 kt.

Based on the above findings, this paper makes the below energy conservation and emission abatement policy recommendations for road transport in Shenyang.

1) Boost the intensity of public transport development. The travel needs of residents are rigid, but the way they travel is flexible and optional. Improving the structure of travel, increasing the share of public transport trips, guiding and controlling the utilization of personal motor vehicles, can effectively reduce the energy usage, CO_2 emissions, and air pollutant emissions from road traffic departments. Therefore, Shenyang should thoroughly implement the strategy of prioritizing the development of public transportation, further improve the urban public transportation service system, explore new bus service modes such as custom buses, night buses, and community buses, and boost the development of low-carbon, efficient, and high-capacity Bus Rapid Transit System an, so on.

2) Encourage the deployment of energy-efficient and new energy vehicles. The demand for vehicles in Shenyang will continue to grow for an extended period, and the energy shortage and environmental pollution problems caused by it will become more prominent. The utilization of new energy cars can improve the energy demand structure of the road traffic department and reduce its reliance on oil resources. Shenyang's road traffic sector should take public transportation as a breakthrough point, take the car rental, postal services, sanitation, and private cars as critical areas and further introduce policies and measures to boost the promotion of new energy automobiles.

3) Improve the construction of transportation infrastructure. A sound foundation implementation is a prerequisite and foundation for the healthy development of urban transportation, and it serves an essential function in the green development of the transport department. In the future, Shenyang City should plan scientifically and build a comprehensive three-dimensional, modern integrated transportation system to enable road resources to be used more effectively. Moreover, in the field of electric vehicle infrastructure construction, it is necessary to improve the supporting infrastructure construction, actively invest in the construction of charging piles and charging stations, and at the same time carry out the construction, upgrade, and transformation of the supporting power grid.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

Qiang Yue is an Editorial Board Member for *Green and Low-Carbon Economy*, and was not involved in the editorial review or the decision to publish this article. The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

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