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Energy and sustainable urban transport development in China:

Challenges and solutions

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Sammendrag:. Denne rapporten gir en oversikt over utvikling av urban veitransport og utfordringer i energiforbruket i Kina. Deretter koples en bærekraftig utvikling av urban veitransport med energiforbruk og miljøforvaltning. Den analyserer hovedutfordringene forbundet med utvikling av urban veitransport: energisikkerhet, lav effektivitet i energiutnyttelse og lite bærekraftig miljøforvaltning. Den diskuterer også nødvendige teknologiske og politiske initiativ for å håndtere disse utfordringene: for eksempel å fremme utvikling og utbredelse av renere kjøretøy, overgang fra bensin og diesel til naturgass (LPG, CNG, LNG) og biobrensel, styrke reguleringen av utslipp fra kjøretøy, fremskynde utvikling av offentlig transport og effektiv forvaltning av den økende privatbilismen.

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Abstract: This paper presents an overview of urban road transport development and challenges in energy consumption in China. It relates sustainable urban road transport development with energy consumption and environmental management. It analyzes the main challenges related to urban road transport development: energy security, low efficiency in energy utilization, and unsustainable environmental management. It also discusses necessary technological and policy initiatives to deal with these challenges: e.g., promoting the development and dissemination of cleaner vehicle technologies, substitution of LPG, CNG, LNG and biofuels for gasoline and diesel, strengthening regulations on vehicle emissions, expediting public transport development, and the effective management of the soaring private cars.

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1 Introduction

Driven by rapid economic growth and urbanization, there has been a faster-than-ever urban road transport expansion in China over the past decade. The the motor vehicle population has increased approximately 11.3% each year during the 1990s. In Beijing and Shanghai, the two largest cities in China, the growth of motor vehicle population over the past decade was 14.9% and 11.8%, respectively. In some cities, vehicle population growth has even exceeded 30% each year. As a result of this fast expansion in the road transport sector, particularly the soaring motor vehicle population, the increase in energy consumption in China's road transport sector was as high as 10% each year on average over the past decade, which is more than twice the national energy consumption growth rate during the same period.

China is currently the second largest energy consumer and CO_2 emitter in the world, after the United States. China has become a net oil importing country since 1993, with oil import recently making up approximately 40% of the total oil consumption. Further it has been recognized that emissions from motor vehicles have contributed significantly to urban air quality degradation (Li, 2002; Zhang, 2001). In this regard, there is an increasing concern over urban road transport development and the energy consumption and environmental pollution related issues in China. This study is an effort to look at sustainable urban road transport development in terms of energy consumption and environmental management in the context of China, with an emphasis on investigating the main challenges and/or consequences that China has to face if the current urban transport pattern is maintained, and to discuss policy initiatives to deal with these challenges.

This paper first provides an overview of China's urban road transport development and energy consumption over the past decade. The following section analyzes the main energy and environmental challenges that China has to face if current urban road transport patterns are maintained. Section 3 discusses technological and policy interventions. The conclusions highlight the issues for policy change and adjustment.

2 Urban road transport development and energy consumption

Since China adopted its economic reform policy in the early 1980s, cities in China have gained great development momentum while China's economy has kept an average annual growth rate of 8-9%. The number of cities in China reached 663 by 2000. Rapid urbanization has become a trend along with economic development. Cities are becoming larger, and the concentration of urban population is becoming higher. The number of residents in Beijing for example, has climbed from 5.8 million in 1985 to 11 million in 2000. The population density in Beijing currently averages to 654 people per square kilometer, and is as high as 27,300 people per square kilometer in the central area (Zhang, 2001).

Driven by increased economic activities and sustained high urban population growth, urban transport development has been pressing. The total civil motor vehicle population[1] reached 16.08 million in 2000 with an annual growth rate of 11.3% during the 1990s (Table 1; Figure 1). The total civil motor vehicle population in Beijing increased from 0.34 million in 1992 to 1.04 million in 2000 with the annual growth rate of 14.9%. In Shanghai, the biggest city in China, the civil motor vehicle population growth rate was 11.8% during the same period. In some cities, the vehicle population growth rate exceeded 30%. Figure 1 shows that the

[1] The civil vehicle population excludes military vehicles.

number of private vehicles has grown by 22.5% each year, and passenger vehicles by 18%, indicating that private and passenger vehicles have been the major driving forces to China's civil motor vehicle growth.

Table 1. Motor vehicle development in China Unit: million

	Vehicle Population	Freight Vehicles	Passenger Vehicles	Special Vehicles	Private Vehicles
1990	5.51	3.58	1.62	0.31	0.82
1991	6.06	3.87	1.85	0.34	0.96
1992	6.91	4.28	2.26	0.38	1.18
1993	8.18	4.83	2.86	0.48	1.56
1994	9.42	5.44	3.50	0.49	2.05
1995	10.4	5.69	4.18	0.54	2.50
1996	11.00	5.58	4.88	0.54	2.90
1997	12.19	5.82	5.81	0.56	3.58
1998	13.19	6.09	6.55	0.55	4.24
1999	14.53	6.66	7.40	0.57	5.34
2000	16.09	7.16	8.54		6.25

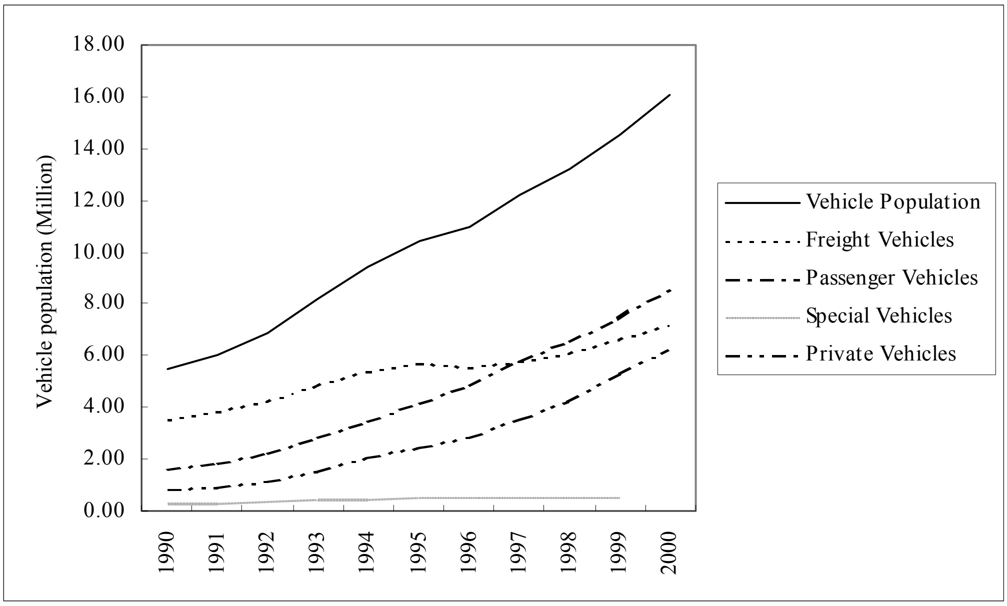

Figure 1. Motor vehicle development in China.

Urban transport infrastructure construction also showed rapid development over the past decade. For example, 13–29% of the city's investment in infrastructure was put into the transport sector over the past decades in Shanghai (Table 2). As a result, urban road transport infrastructure in Shanghai gained a sustained development momentum (Table 3). A similar trend is seen in Beijing (Table 4 and Table 5) and Shenzhen (Table 6).

Energy consumption in China's road transport sector increased from 36.4 million tce in 1990 to 93.6 tce in 2000 (Table 7; Figure 2). The average growth rate was about 10% each year during the past decade, which is very close to that of motor vehicles. Gasoline consumption increased by 8.28% on average, while diesel increased by 14.93%.[2] Approximately 85% of gasoline output and 20% of diesel output was consumed by motor vehicles in 1999 in China (SETC, 2001)

Table 2. Investment in urban infrastructure in Shanghai (in billions of yuan)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total Infrastructure Investment (A)	6.1	8.4	16.8	23.8	27.4	37.9	41.3	51.7	49.2	45.1
Transport Infrastructure Investment (B)	0.9	2.3	3.3	7	7.2	8.2	9.3	9.6	6.2	11.4
Urban Road Investment	0.2	0.4	1.1	3.4	3.3	4	3.2	5.1	2.2	2.3
Subway Investment	0.2	0.4	0.7	1.4	1.5	1.2	2.4	1.2	2.9	6.9
B/A (%)	15	27	20	29	26	22	23	19	13	25

Table 3. Road development in Shanghai

	Road length (km)	Urban road length (km)	Road area (Mm^2)	Urban road area (Mm^2)	Vehicle road area (Mm^2)	Urban vehicle road area (Mm^2)
1991	4818	1653	60	27	42	18
1992	5043	1677	64	27	45	18
1993	5105	2722	66	40	46	28
1994	5192	2799	69	43	49	30
1995	5420	3008	74	48	53	34
1996	5599	3118	81	52	59	38
1997	5713	3553	85	59	63	43
1998	6678	4712	98	73	73	54
1999	6829		107		79	
2000	9568		131		100	

Table 4. Road transport construction in Beijing

Year	Road length (km)	Road area (10^4m^2)	Underground pathways	Road transport bridges
1978	2078	1611		351
1980	2185	1664		351
1985	2979	2485	31	460
1990	3276	2905	46	562
1995	3194	3494	128	582
1996	3665	3807	161	646
1997	3637	4061	162	693
1998	3721	4214	167	715
1999	3753	4353	174	787

Source: BSB, 2000

[2] Part of the diesel consumption comes from ships and boats.

Table 5. Public transport development in Beijing

	Running vehicles in public transportation system				Running lines	Passengers carried by public transportation system (10^4person-time)	Total running taxis	Passengers carried by taxies (10^4person-time)
	Total	Buses	Rail-less trams	Subway locomotive				
1956	671	431			36	38335	569	51
1978	2743	2223	404	116	119	172559	1452	998
1980	3113	2572	429	112	123	236998	2263	945
1985	4583	3809	589	185	191	335227	11203	4496
1990	5160	4343	514	303	216	334673	11147	7157
1991	5182	4366	511	305	223	344525	14354	7786
1992	5223	4389	511	323	262	348770	28962	14371
1993	5213	4371	519	323	268	335378	46022	48770
1994	5319	4459	525	335	284	353289	56124	55525
1995	5367	4459	525	383	300	371579	56686	59600
1996	6828	5891	536	401	399	349847	59493	64895
1997	10479	9527	517	435	667	391182	59902	65386
1998	10819	9844	538	437	690	418825	61301	63817
1999	12509	11472	546	491	750	426706	61920	61817

Source: BSB,2000.

Table 6. Infrastructure of Shenzhen Economy Special Zone (1985–1998)

	1985	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Length of new road (km)	161	257	275	288	299	296	335	657	737	789	747
Area of new road (m^2)	371	613	657	635	657	651	813	869	1124	1287	1308
Per capita area of new road (m^2)							5.51	5.73	7.01	7.35	7.08
City bridges	16	30	30	37	39	41	52	102	125	145	164

Note: Does not include Bao'an and Long'gan districts

Table 7. Energy consumption in China's road transport sector

	1990	1995	2000
Energy consumption (Mtce)	36.4	59.5	93.59
Gasoline (Mt)	19.9	31	44.1
Diesel (Mt)	4.9	9.5	19.7

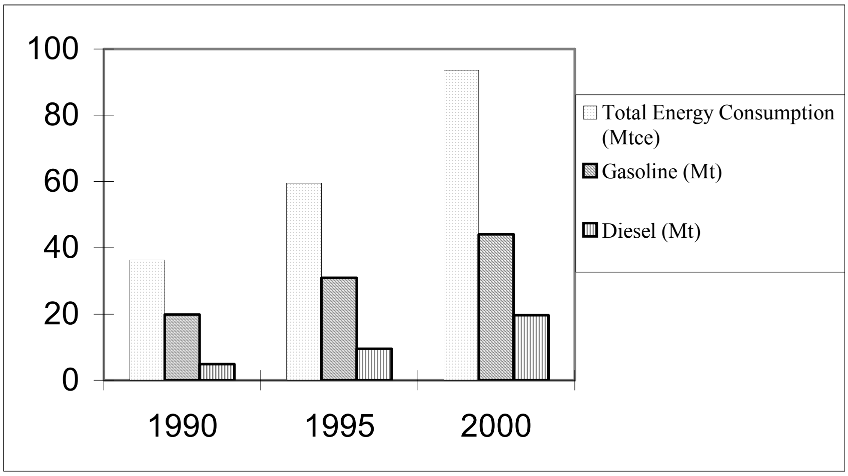

Figure 2. Energy consumption in China's road transport sector

Energy consumption pattern in the transport sector in Shanghai is similar to that of the national average (Table 8). The consumption of gasoline increased from 0.61 million tons in 1990 to 1.31 million tons in 2000 with an annual growth rate of 8.1%, while the use of diesel rose from approximately one million tons in 1990 to 2.72 million tons with an annual growth rate of 10.6%.[3] The growth of liquefied petroleum gas (LPG) consumption in road transport has been impressive in Shanghai since 1995, averaging as high as 63.7%.

Table 8. Energy consumption in Shanghai City's transport sector

	Gasoline (10^3 ton)	Diesel (10^3 ton)	LPG (10^3 m^3)	Electricity (GWh)
1990	607	996		42
1991	686	1103		42
1992	646	1189		43
1993	452	1071		54
1994	573	1184		79
1995	788	1227	9.5	89
1996	830	1874	13.2	101
1997	969	1983	21.2	140
1998	1061	2178	27.5	176
1999	1111	2522	30.9	192
2000	1323	2719	111.6	292

[3] Including that consumed by ships and boats.

3 Major energy challenges for sustainable urban transport development

3.1 Energy security

The increasing use of motor vehicles in China, particularly in cities, is a major driving force behind the increased demand for petroleum products. Energy consumption in the road transport sector increased by approximately 10% over the past decade, whereas China's total energy consumption increased by only 2.6%. Meanwhile, annual consumption of gasoline and diesel also climbed by 8.1% and 10.6%, respectively (Wu, 2002). These figures demonstrate that the growth of energy consumption in the transport sector is much higher than that of the national average.

The growth in the motor vehicle population, particularly privately owned motor vehicles in major cities, is expected to keep pace with the rapid economic growth and the improvement in people's living standards. Table 9 shows a projection of the future motor vehicle stock development in China. Table 10 gives a projection of the average annual fuel consumption per vehicle, which takes into account such factors as technology advancement and changes in the mix of motor vehicles in use. Based on Table 9 and Table 10, a projection of the future energy consumption of motor vehicles in China can be achieved (Table 11). As shown in Table 11, oil consumption of motor vehicles in 2005, 2007, and 2010 is projected to be 51.75 million tons, 59.84 million tons and 73.14 million tons, respectively.

Table 9. Projected future motor vehicle stock in China (in millions)

Year	Trucks	Passenger cars	Sedans	Total cars	Motorcycles
2005	9.05-9.56	4.50-4.90	8.43-8.69	21.98-23.15	95-105
2010	11.37-11.93	5.40-5.80	14.23-15.42	31.00-33.15	115-125
2015	15.24-15.76	6.20-6.60	22.91-24.83	44.35-47.19	

Table 10. Projected average annual fuel consumption per vehicle in China

	1990	1994	1999	2005	2010	2015
Fuel consumption (t/yr)	4.42	3.29	3.09	2.3	1.87	1.59

Table 11. Projected oil consumption of motor vehicles in China

	1999	2005	2010	2015
Vehicle population (millions)	14.52	22.45	32	46
Oil consumption by vehicles (Mt)	44.85	51.75	59.84	73.14

An alternative projection of future oil consumption from motor vehicles has been carried out that assumes that China's GDP will maintain an average annual growth increase of 7% for the next two decades, that the elasticity of petroleum product demand to GDP will be 0.8, and thus that the growth rate of petroleum product demand would be 5.6%. Also if it is assumed that the fuel consumption of the road transport sector will maintain the same growth rate as that of national petroleum consumption, then the oil consumption of motor vehicles will be 62.19 million tons in 2005, 81.67 million tons in 2010, 107.24 million tons in 2015, and 150 million tons in 2020, respectively.

The two projections are different. The first projection shows an ideal case of oil consumption development in the future. It is based on a significant improvement in road traffic condition and vehicle performance. It also depends on the improvement of the quality of petroleum products to a large extent. For energy security analysis, the second projection deserves more attention. According to the China Sustainable Energy Strategy study, China's oil consumption will be 320-360 million tons in 2020 (CERS, 2000). Based on the second projection, the contribution from China's transport sector to the country's total oil consumption will increase from 21.2% in 1990 to approximately 47% in 2020, keeping in line with the trend of China's economic growth and urbanization. This resembles the growth in the developed countries.[4]

China has become a net oil importer since 1993 (Table 12; Figure 3). In 2000 oil import was 70 million tons, which was 33% of China's total oil consumption. There will be no significant improvement in China's oil production capacity, whereas oil consumption will maintain rapid growth. It is estimated that China's oil production peak will appear during 2010-2020 with an annual oil output of 200 million tons. Then it is expected to decline to 100 million tons in 2030. Based on the projection of oil demand from the transport sector, China's oil production capacity would not be able meet the oil need from the transport sector after 2020. This has important implications for the world's oil market and China's energy security strategy.

Table 12. China's oil production and consumption in recent years

	Production (Mt)	Consumption (Mt)	Net import (Mt)
1990	138	115	-24
1991	141	124	-14
1992	142	134	-6
1993	145	147	10
1994	146	150	3
1995	150	161	10
1996	157	174	14
1997	161	197	34
1998	161	198	29
1999	160	211	44
2000	163	211	70

3.2 Low efficiency

As mentioned above, there would be a significant shortage of oil supply in the future in China. On the other hand, however, the efficiency of oil utilization has been low in China, especially in the transport sector. Table 13 shows a comparison of China's motor vehicle oil consumption efficiency with major developed countries. The United States has been the world leader in terms of single vehicle size, vehicle population and delivery capacity. Its oil consumption per vehicle (2.26 ton), however, is much lower than that of China (3.09 ton). The per-vehicle average fuel consumption in Japan and Germany in 1989 is only approximately one-third of that in China in 1999.

[4] For example, the share is 64.3% in USA, 48.4% in Germany, and 52.2 in France.

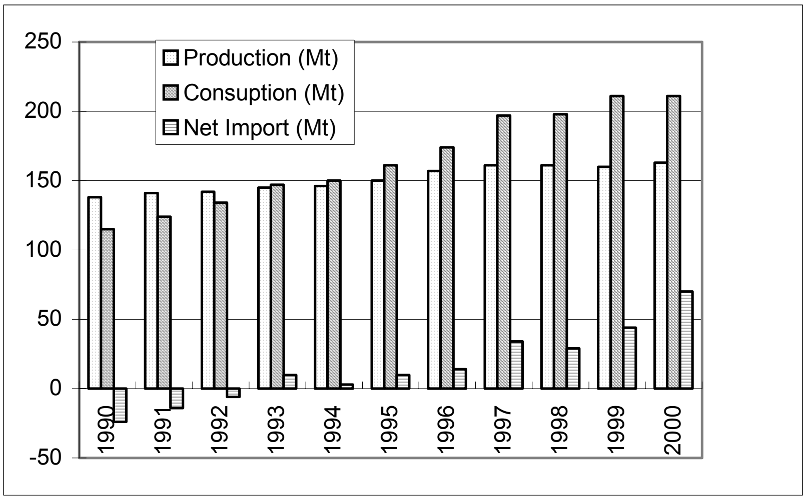

Figure 3. China's oil production and consumption in recent years

Table 13. Comparison of China's vehicle efficiency with those of developed countries

	USA	Japan	Germany	China
Vehicle population (millions)	176.19	52.45	31.28	14.53
Gasoline consumption (Mt)	347.61	32.02	25.31	31.99
Diesel consumption (Mt)	50.46	27.28	14.38	12.86
Total fuel consumption (Mt)	398.07	59.30	39.69	44.85
Average consumption per vehicle (t)	2.26	1.13	1.27	3.09
Year	1987	1989	1989	1999

Lack of efficiency in energy utilization in China's transport sector is also reflected in the relative decline of the public bus usage and the increase of taxi usage in large cities. The share of conventional buses in the total passenger vehicle usage decreased from 97% in 1996 to 55% in Shanghai, while that of taxis increased from 2.33% in 1991 to 20% in 2000 (Table 14). Further, during the ninth Five-Year-Plan period, the motor vehicles in use averaged 3.5 million per day in Shanghai, and taxi vehicles in use per day increased by as much as 88%. In Beijing, the taxi population increased from 11,147 in 1990 to 65,127 in 2000 with an annual growth rate of 19%.

Additional energy utilization deficiency lines in the explosion in the number of private vehicles, especially private cars, in some large cities. The rapid growth in the private vehicle population has been a major driving force in China's civil motor vehicle growth, and also an important contributor to urban transport congestion. In 2000, the number of private vehicles reached 6.25 million, of which 3.04 million were private cars. The average growth rate in the number of private cars was as high as 31.3% over the past decade in China. There was 0.12 million motor vehicles added in Beijing by the end of June, 2002. This was 50.6% higher compared to the same period last year, and approximately 90% of them were private vehicles. In Shanghai, 20,000 private cars were registered by the end of June, 2002, 5000 more compared with the same period of last year. The population of private motor vehicles was 65,867 in 1996 in Shenzhen, and the figure was doubled by 2000 (Li, 2001).

Table 14. Passengers using public transport in Shanghai over the past decade, in volume by millions and percent.

	Big buses		Special line buses		Subways		Taxis		Total
	(million)	(%)	(million)	(%)	(million)	(%)	(million)	(%)	(million)
1991	5694	97.17	29	0.5			137	2.33	5860
1992	5868	96.42	50	0.82			168	2.76	6086
1993	5596	93.67	109	1.82			269	4.5	5974
1994	5225	88.75	209	3.55	5	0.08	448	7.61	5887
1995	4817	84.74	301	5.24	65	1.13	511	8.89	5694
1996	1909	63.17	427	14.13	88	2.91	598	19.79	3022
1997	1878	63.45	500	16.89	111	3.75	471	15.91	2960
1998	1971	60.74	517	15.93	126	3.88	631	19.45	3245

Heavy traffic congestion in some Chinese cities is another contributor to the low efficiency in energy utilization in China. A major reason for urban heavy traffic congestion in Beijing is that population of urban motor vehicles grows much faster than urban road construction (Figure 4).

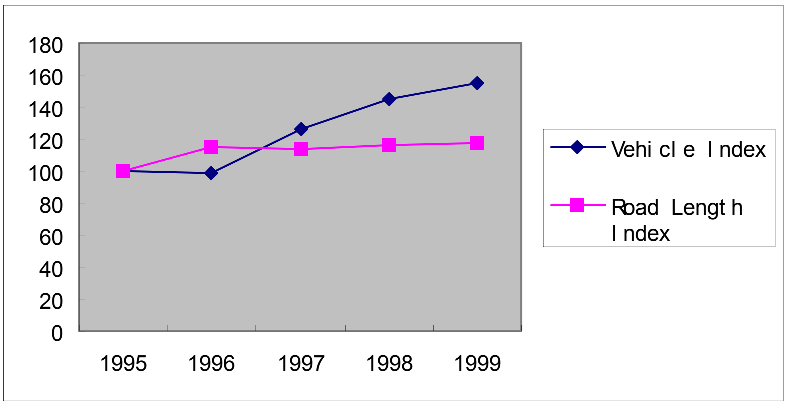

Figure 4. Vehicles and road development in Beijing (1995-1999)

3.3 Environmental challenges

As China's capital, Beijing is the city with the largest motor vehicle population. The growth of motor vehicles in Beijing has also been the fastest among Chinese cities. The major pollutants from motor vehicles are CO, HC, NO_x, and particle matter (PM) in Beijing. Table 15 shows the contribution of motor vehicles to pollutant emissions in Beijing between 1995 and 1998. Emissions of CO and NO_x from motor vehicles were higher, not only in the total volume of emissions, but also in the concentration of emissions. Further, the contribution of motor vehicle emissions in 1998 was higher than that in 1995. Figure 5 demonstrates that NO_x concentration in the busy transport areas was 35% higher than that of the city's average, indicating that exhaust emissions from urban transport sector is an important contributor to urban environmental problems. According to Beijing Environment Protect Bureau, of the 1.1 million light motor vehicles, only 0.43 million or 39% could meet the city's standard on motor vehicle emissions in 2001. For heavy motor vehicles, the percentage was only 8% (Li, 2002).

Table 15. Comparison of the emission contribution from motor vehicles and fixed sources between 1995 and 1998

	Motor vehicles		Fixed sources	
	CO	NOx	CO	NOx
1995				
Emission (10^3t/yr)	1,075.1	93.4	325	140
Emission contribution (%)	76.8	40.2		
Concentration contribution (%)	76	68		
1998				
Emission (10^3t/yr)	1,290	115	270	150
Emission contribution (%)	82.7	42.9		
Concentration contribution (%)	84.1	72.8		

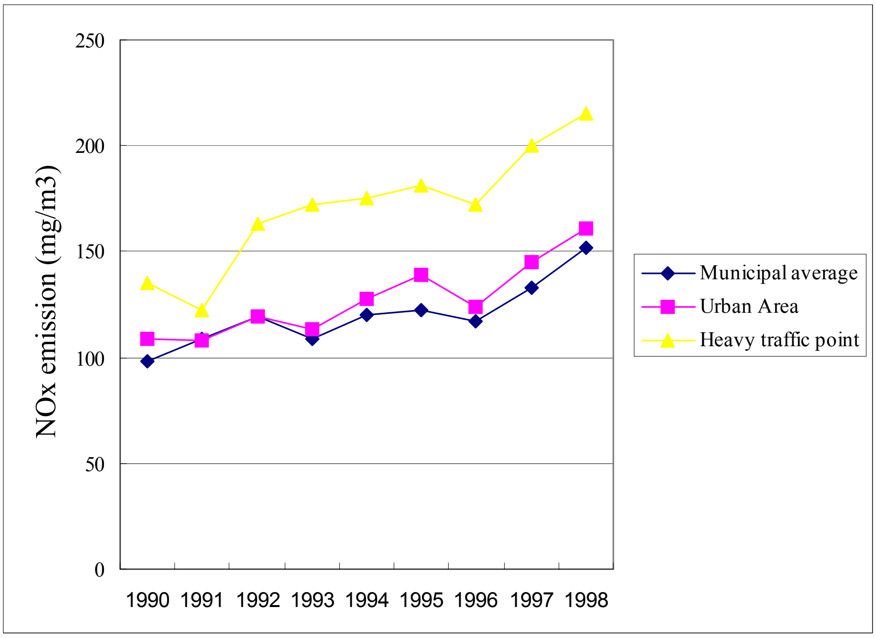

Figure 5. NOx emissions concentrations in different areas of Beijing

A survey conducted in Shanghai in 1998 demonstrates that each index of air pollutants from motor vehicles exceeded the standards at more than 20 major measured intersections. Among the measured locations, 30% were heavily polluted, 65% polluted to a great extent, and 5% lightly polluted.

In addition to local environmental pollution, transportation sector is also a major CO_2 emitter as most fuels consumed in the sector are fossil fuels. In 1990, the transport sector contributed 5.66% of China's total CO_2 emission (RTCCCCS, 1999). If China's oil consumption in the transport sector reaches 150 million tons[5] in 2020, it would produce 0.45 million tons of carbon emissions.[6]

4 Policy initiatives

4.1 Promoting development and dissemination of clean vehicles

In China there has been a general consensus on the role of the development and dissemination of cleaner motor vehicles in promoting energy for sustainable urban transport development. Both the central and municipal governments have taken substantial efforts to promote the development and/or dissemination of such cleaner motor vehicles as LPG vehicles, compressed natural gas (CNG) vehicles, liquefied natural gas (LNG) vehicles, electric vehicles, hybrid electric vehicles, and fuel cell electric vehicles.

During the Eighth Five-Year-Plan period (1991–1995), the central government supported research and development of methanol vehicles, CNG vehicles, and LPG vehicles, and substantial progress was made. During the Ninth Five-Year-Plan Period, the central government listed the research and development of electric vehicles in key national science and technology research projects.

In 1999, the central government started a National Clean Vehicles Action in twelve large and medium-sized cities, including the four cities directly under the jurisdiction of the central government: Beijing, Tianjin, Shanghai, and Chongqing. The on-going program is organized and managed jointly by more than ten government agencies, such as the Ministry of Science and Technology (MOST), the State Economic and Trade Commission (SETC), and the State Environment Protection Administration (SEPA). The main focus areas of the program are: 1) to promote the diffusion of alternative fuel (LPG and CNG) motor vehicles; 2) to speed up the process of the cleaning of oil-consuming motor vehicles; 3) to support the research and development of electric vehicles; and 4) to conduct demonstration projects. In addition to government funded R&D and demonstration, the activities of the program include improvement in planning, policy adjustment, standards and regulation development, training, and exhibitions. Marked progress has been made since the initiation of the program. Under the program, now more than 110 thousands of buses and taxes have switched from burning gasoline and diesel to using LPG and CNG, and more than 100 gas supply stations have been built.

The municipal governments of the three major cities Beijing, Shanghai and Shenzhen have also taken their own efforts to facilitate the development and dissemination of clean vehicles:

Beijing
From 1999, the Beijing municipal government began to replace conventional diesel buses with LPG buses within the Ring 3. Some of the taxis were remolded to utilize clean fuel. The public traffic department invested 1.2 billion yuan to import CNG engines from the U.S. in 2000. Since October of 1999, 500 CNG buses were put into service in succession. The old-type diesel buses were retired completely within the Ring 3. Further, a new regulation was promulgated requesting new licensed cars for taxi service must be equipped with dual-fuel engines. Currently the problem is that there is a shortage of gas filling stations and the filling process takes more than 40 minutes. To solve this problem, the municipal government has permitted private companies to invest and operate gas filling stations to make them more effective in operation.

[5] 150 million tons of oil is approximately 6280.2 PJ in energy.

[6] For the transportation sector, CO_2 emission factor was 70.5 t/PJ, see RTCCCS (1999).

Shanghai
Shanghai is actively promoting the deployment of cleaner vehicle technologies by popularizing three unique catalytic converters, speeding-up the process of remolding LPG taxis, LPG light trucks and CNG buses, and constructing LPG and CNG gas filling stations. In 1999, 9,000 taxis were switched from running on gasoline to running on a combination of gasoline and LPG. 35 LPG filling stations were also built that year. By 2002, 40,000 taxis will become LPG-fueled and all public buses running in the Pudong District should be replaced by CNG buses. According to the planning of the municipal government, more motor vehicles will be switched from gasoline and diesel to cleaner fuels (Table 16).

Shenzhen
A fuel-switching program has been started in Shenzhen since 1996. Under the program, taxis and buses are encouraged to switch from gasoline to a combination of LPG and gasoline. By the end of 1999, 3,200 taxis had become dual-fuel fueled. According the municipal government's planning, all the new taxis must be equipped with dual-fuel engines from 2000. The price of LPG is 2.0 yuan per liter and the price of gasoline is 2.75 yuan per liter. LPG taxi drivers can enjoy 6.0 yuan reduction in fuel cost per hundred kilometers. If it is assumed that a taxi can run 500 km a day on average (in Beijing the average is 300 km per day), a LPG taxi driver can save 30 yuan in fuel costs. A major barrier to the diffusion of LPG taxis is that there are currently only two gas filling stations in Shenzhen and they are located outside of the Special Zone.[7] As a result, most of the dual-fuel vehicles still use gasoline.

Table 16. Future energy consumption structure of vehicles in Shanghai

Year	Vehicle population (10^3)	Gasoline powered (%)	Diesel powered (%)	Dual-fuelled (%)	LPG powered (%)	CNC powered (%)	Methanol powered (%)	EV (%)
2000	500	51	45	3.5	0.3	0.1		0.1
2005	550	48	45.5	5.5	0.5	0.3		0.2
2010	700	46	42	7.7	2.5	1.5		0.3
2015	850	43	38	10.5	3.5	3.5	1.0	0.5
2020	1000	38	33	15.5	5.5	5.5	1.5	1.0
2025	1200	30	28	17	10	10	2	3.0
2030	1400	25	20	20	12	15	3	5.0

Now the municipal government is planning to build 40 new LPG filling stations before 2005, and it is expected that 15,000 motor vehicles will become dual-fuel fueled (Li, 2001).

4.2 Substituting gasoline and diesel with LPG, CNG, LNG and biofuels

The identified natural gas reserve is currently at 1,120 billion cubic meters in China, and production is at 27 billion cubic meters. It is expected that annual natural gas production will reach 150 billion cubic meters by 2015, and thereafter maintain 100-150 billion cubic meters. Furthermore, it is likely that natural gas will be imported from Russia. It is estimated that the volume of imported natural gas from Russia can be as high as 100 billion cubic meters per year. There is also a possibility of importing LPG from Southeast Asian countries. In this regard, annual national gas consumption could reach 200 billion cubic meters, which is

[7] Shenzhen covers an area of 2020 square kilometers, of which 327.5 square kilometers are of Special Zone.

approximately 10% of the country's total energy consumption. If 5–10% of natural gas available in 2020, roughly 10-20 billion cubic meters in volume, could be used to fuel vehicles in the form of LNG and CNG and to make fuel cells to power electric vehicles, this would provide a substitute for 10-20 million tons of gasoline and diesel.

Another alterative to gasoline and diesel in the transport sector is biofuel, including ethanol and vegetable seed oil. Tests have shown that mixing gasoline with 10% ethanol could increase combustion efficiency of the engine without significantly changing the engine's configuration. During the Ninth Five-Year-Plan period (1995–2000), MOST supported the research and development of the technologies with which ethanol could be made from agricultural residues. During the Tenth Five-Year-Plan period (2001–2005), the Ministry currently funds the research of producing ethanol from sorghum. Now other government agencies such as the State Development Planning commission (SDPC) are also attaching a great importance to the production of ethanol from agricultural products. It is estimated that the technologies for producing alternative liquid fuels will be commercialized by 2020. The production capacity could reach more than one millions tons in 2020, and several ten million tons in 2030 (Gu, 2002).

4.3 Strengthening vehicle emissions control

Recently the control of exhaust emissions from motor vehicles has become stricter in large- and medium-size cities in China. Leaded gasoline has been banned in Shanghai since December 1, 1997. From July 1, 1999, a new and stricter standard on exhaust emissions from motor vehicles has been adopted. Substantial efforts have been made to implement the new standards. In 1999, about 6,000 motor vehicles were chosen randomly to conduct an emissions test, and 95% of the motor vehicles tested met the new emission standard. A public health survey showed that lead content in children's blood decreased from 83 mg per liter in 1997 to 73 mg per liter.

Since 1994, Beijing has promulgated 11 local standards on vehicle emissions. The new motor vehicle emission standard, equivalent to the Euro I emissions standard for light vehicles was implemented in 1999, and for heavy vehicles in 2000. Both are the earliest in China. With the approval of the State Council, the Beijing municipal government has recently announced that it will put its newly upgraded vehicle emission standards, which are equivalent to the Euro II emission standard, into effect on January 1, 2003.

4.4 Expediting urban public transport development

Some governments of Chinese cities have recognized the importance of public transport development in the sustainability of a city development. Priority has been given to public transport development in integrated urban planning. Urban subway construction has become a priority in urban infrastructure planning and development, and more bus lines have appeared in large- and medium-sized cities.

During the Ninth Five-Year-Plan period, investment in subway construction increased by 41% on average in Shanghai. According to Shanghai Municipal Government planning, urban railways will become a major passenger carrier by 2005, transporting 2.5–3.0 million passengers per day, accounting for 20–30% of the total public transport capacity. By 2020, the urban railway system is expected to transport 12 million passengers per day, accounting for half of the public transport capacity. According to the recently completed Beijing railway development planning, the urban railway length will ultimately reach 1,000 kilometers, and 300 kilometers will be constructed by 2008 (BYD, 2002).

5 Conclusions

China has experienced a faster-than-ever expansion in road transportation in its mega-cities over the past decade. If the current urban road transport pattern continues to follow this trend, China will have to face significant challenges, including short energy supply, security threats, low efficiency in vehicle energy use, and environmental pollution. In order to avoid such an unsustainable development trend, substantial technological and policy initiatives should be taken, including prompting the development and dissemination of cleaner vehicle technologies, substitution of gasoline and diesel with LPG, CNG, LNG and biofuels, strengthening vehicle emission control, and expediting public transport development.

Further, special attention should be paid to the management of the soaring of the private car population. In this regard, substantial lessons could be learned from foreign countries such as the United States, Singapore, and Europe.

These policy changes and adjustments will have a profound impact on reshaping China's urban road development pattern, and contribute to sustainable urban road development and well-being of its population.

References

Beijing Statistic Bureau (BSB), 2000, Beijing over the Past 50 Years.

Beijing Youth Daily (BYD), 2002. *Beijing Youth Daily*, July 27, 2002.

China Energy Research Society (CERS), 2000. Report on China Sustainable Energy Development Strategy, Beijing, December, 2000.

Gu, S.H., 2002. Energy issues in urban transport development. Presentation on the *WWF/Tsinghua Workshop on Sustainable Urban Road Transport and Greening of Auto Industry in China.* June 20-21, 2002, Tsinghua University, Beijing, China.

Li, T. J., 2002. Control of pollutant emissions from vehicles in Beijing: practice and lessons. Presentation on the *WWF/Tsinghua Workshop on Sustainable Urban Road Transport and Greening of Auto Industry in China.* June 20-21, 2002, Tsinghua University, Beijing, China.

Li, X.G., 2001. A case study of urban transport in Shenzhen. *Urban Road Transport Research Report No.5, 2002.* Institute for Techno-Economics and Energy Systems Analysis, Tsinghua University, Beijing, China.

Research Team of China Climate Change Country Study (RTCCCCS), 1999. China Climate Change Country Study, Tsinghua University Press, Beijing, China.

State Economic and Trade Commission (SETC), 2001. Motor Vehicle Development Planning for the Tenth Five-Year-Plan Period.

Wu, W.H., 2002. Impact of China's entry to WTO on China's auto industry and oil consuption. Presentation on the *WWF/Tsinghua Workshop on Sustainable Urban Road Transport and Greening of Auto Industry in China.* June 20-21, 2002, Tsinghua University, Beijing, China.

Zhang A.L., 2001. A case study of urban transport in Beijing. *Urban Road Transport Research Report No.3, 2002.* Institute for Techno-Economics and Energy Systems Analysis, Tsinghua University, Beijing, China.

Zhang S.R., 2001. A case study of urban transport in Shanghai. *Urban Road Transport Research Report No.4, 2002.* Institute for Techno-Economics and Energy Systems Analysis, Tsinghua University, Beijing, China.