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*Article*

# Energy Consumption and Energy Efficiency of the Transportation Sector in Shanghai

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**Abstract:** This article investigates changes in the transportation sector in Shanghai between 2000 and 2010 and the implications of this on transportation energy consumption and energy efficiency. The results show that from 2000 to 2010: (1) the traffic energy consumption increased from 597.96 million tons of carbon to 2070.22 million tons of carbon, with an average annual growth rate of 13.49%, and oil met 94.49% of this energy demand by 2010; (2) among present transportation modes, waterway transportation accounts for over 50% of the energy consumption within the transportation sector (on the dominant transportation modes for Shanghai residents, private car use accounted for the largest proportion of energy consumption, whereas rail transportation accounted for the smallest proportion of energy consumption); (3) the energy consumption per unit conversion traffic volume had an upward trend, whereas the energy consumption per unit output value showed a declining trend. Across the study period, the energy consumption elasticity coefficient is 0.94 on average, indicating that the change rate of energy consumption has lagged behind that of economic growth. Correspondingly, some recommendations for energy policy were presented.

**Key words:** transportation industry; energy consumption; elasticity coefficient

## 1. Introduction

To date, the Chinese government and scholars have been facing the challenges of curtailing carbon emissions and mitigating the foreseeable adverse effects of anthropogenic climate change. Within China, cities have the highest density of human populations and are hubs of social and economic development [1]. These metropolitan areas have very high demands for energy and, correspondingly, are responsible for emitting large amounts of man-made carbon emissions. Therefore, in recent years, the city-region has become a key spatial unit to measure, analyze and control greenhouse gas (GHG) emissions [2]. Within the city-region analysis of specific sectors (such as industry, transport, commerce and residential sectors) is a major path and framework for analyzing energy consumption and carbon emissions. Cross-sector analysis reveals that the rate of transportation energy consumption increased year by year, and its growth rate has been higher than many other sectors. Indeed, the transportation sector is one of the fastest-growing energy use industries [3]. Since the 1990s, Shanghai has been China's largest metropolitan region and, eventually, the economic capital, as witnessed by both explosive growth in the population and local economy. At the end of 2010, according to State Statistics Bureau of China 2011 and Shanghai Municipal Statistics Bureau 2011, the local population in Shanghai accounted for approximately 1.38% of the total population in China, but local GDP accounted for 4.29% of the national GDP. However, the rapid development of the city has resulted in increasing levels of energy demand and consumption [4]. Yet, Shanghai does not possess significant energy resources, and the city heavily relies on importing energy (often in the form of goods and services) from domestic provinces with fossil energy and oil-producing countries. Despite this, Shanghai suffers from an energy shortage that is impeding the city's socio-economic development. A key component of this increasing level of energy demand is the rapidly expanding transportation sector. This sector has significantly contributed to the rapid growth of GHG emissions, caused serious environmental pollution and has consequently generated significant concerns about energy security [5]. Thus, to address the specific characteristics of Shanghai's socio-economic development whilst delivering an increasingly sustainable urban transportation system is a major issue and a key priority for the city government.

This article presents the analysis estimates of the 2000–2010 Shanghai transportation sector energy consumption and energy utilization efficiency in order to help inform the development of a sustainable, low-carbon transportation sector within Shanghai. The second part of this paper is a review of the literature, and the third part analyses Shanghai's transportation energy consumption. The fourth part presents an analysis of Shanghai's transportation energy use efficiency, including energy intensity and energy elasticity. The fifth part concludes with specific policy recommendations.

## 2. Literature Review

The growing energy consumption and carbon emissions of the transportation sector have recently attracted the growing concern of international scholars. In terms of transportation energy consumption, some scholars launched analyses ranging from policy-making, land use, population density, preferred transportation and technology [2,6–7]. From the perspective of settlement morphology, Zhou *et al*. argued that reducing transportation energy consumption and $CO_2$ emission levels can be achieved

through appropriate public policies, using Xiamen city as a case study [5]. Rentziou *et al*. analyzed the issues of passenger transportation vehicle mileage, energy consumption and GHG emissions. They also analyzed the influence of the fuel tax on environmental protection [8]. From the perspective of optimizing land use, Su *et al*. considered public transportation priority development as an effective approach for reducing urban passenger transportation carbon emissions. Akisawa and Kaya explored how to reduce the energy consumption of transportation and minimize the total stroke length under the conditions of continuous congestion; they further set the congestion factor as the endogenous variable and discussed its influence on minimizing fuel consumption [6]. Su *et al*. researched the urban population size and number of vehicles impacting the traffic carbon emissions mainly via the turnover of both passenger and freight. Shim *et al*. analyzed the relationship between the energy consumption characteristics, which considered the environmental protection and sustainable development of transport and urban form elements. They asserted that the transportation energy efficiency of high-density, multi-core cities is higher than that of single-core or mononuclear cities [9]. Tanczos and Torok analyzed the energy consumption and carbon dioxide emissions of the transportation sector in Hungary and proposed that standards should be developed to improve energy efficiency and reduce harm to the environment [10]. Saidur *et al*. analyzed the energy efficiency of the transportation sector in Malaysia; they concluded that road transportation is more efficient than air and ocean transportation [11]. Based on a comparative study on Canada's 12 major cities with various policies in place to curb private vehicle use, Poudenx argued that competitively designed transportation modes is a major way to reduce energy consumption and GHG emissions [12]. Using lifecycle analysis, Vanek and Sun concluded that rail relative to other means of transportation can better reduce carbon dioxide [13]. This conclusion is similar to the findings of Song *et al*. [14]. It has become a concern to investigate changes in the transportation sector in Shanghai between 2000 and 2010 and the implications of this on transportation energy consumption and energy efficiency. We focus on this. Lund and Munster thought that the development of renewable energy and cogeneration technology, e.g., wind energy and biomass, *etc*., could contribute to the development of the transportation sector by reducing carbon dioxide emissions [15]. Soimakallio *et al*. studied transportation energy production research in Finland, and their results showed that the competitiveness of the ethanol and biomass fuels used in the production of energy is slightly higher than fossil fuels. Therefore, they asserted that one method of reducing GHG emissions is to use bio-fuel in the transportation sector [16]. Sanchez *et al*. [7] compared differently powered vehicle using natural gas, biodiesel and diesel buses in Madrid. Meanwhile, they performed an analysis of the selective catalytic reduction system when using biodiesel. Cristea *et al*. [17] also conducted an empirical analysis using trade and transportation data. They found that the GHG emissions generated by international transportation accounts for 33% of global trade-related emissions. From the previous research, we find that suitable policies can control the structure of transport, popular density and usage of urban land for reducing energy consumption. Rational vehicle use also decreases consumption.

The scholars also used different calculation methods to analyze energy consumption in the transportation sector and the consequent environmental problems. For example, Hankey and Marshall used the Monte Carlo method to study GHG emissions in the process of urban sprawl and development. One-hundred forty-two cities were included in the study (accounting for 56% of the total population of the United States), which explored the impact of six different scenarios. They concluded

that in general, vehicle GHG mitigation may involve three types of approaches: more-efficient vehicles, lower-GHG fuels and reduced VKT (vehicle kilometers traveled) [18]. Our analyses suggest that all three categories must be evaluated; otherwise, improvements in one or two areas (e.g., vehicle fuel economy, fuel carbon content) can be offset by backsliding in a third area (e.g., VKT growth). Nealer *et al*. used the survey data of the U.S. Department of Transportation Bureau of Statistics and the Bureau of Economic Analysis. They analyzed energy consumption and GHG emissions in the trucking sector and proposed an improvement program identified through scenario analysis [19]. Li *et al*. [3] estimated Shanghai's $CO_2$ emissions from 1995 to 2006 according to the Intergovernmental Panel on Climate Change IPCC guidelines. The energy demand and $CO_2$ emissions were also projected until 2020, as well as the $CO_2$ mitigation potential of the officially planned policies and countermeasures that are not yet implemented, but will be enacted or adopted by the end of 2020 in Shanghai. Therefore, the $CO_2$ emissions from the transportation sector increased from 7% in 1995 to 18% in 2006. In 2006, the $CO_2$ emissions from energy conversion, industry and transportation accounted for 43%, 29% and 18% of the total emissions, respectively.

## 3. Energy Consumption of Shanghai's Transportation Sector

The rapid development of the transportation sector will inevitably lead to the increase of transportation energy consumption, resulting in a rigid growth on transportation energy demand. Waterway transport, air lift and road transportation are the typical transportation modes with high energy demands. The input and use of these high-energy consumption transportation modes make energy consumption increase substantially. These high energy consumption modes of transportation are responsible for high emissions. It goes without saying that environmental pollution, especially large amounts of greenhouse gas emissions, are a serious threat to the life and health of people. These high levels of emissions and threats to health require the transportation sector to accelerate the transition to new, less-polluting energy sources and to seek alternative sources of energy, reducing the use of fossil fuels. Thus, environmental pollution will be reduced.

### *3.1. Overview of Transportation Development Status of Shanghai*

Over the past three decades, Shanghai has achieved remarkable achievements during the process of industrialization and urbanization. Nowadays, Shanghai is the largest urban agglomeration, with 23 million inhabitants, in China. With the robust economic development and rapid increase in the level of urbanization, demand for diverse transportation modes has increased, especially among urban residents. The growth in private cars has witnessed sustained year-on-year increases. Transportation in Shanghai has entered a rapid development stage since 1990.

According to the census data in the 2000–2011 Shanghai Statistical Yearbook, passenger traffic, passenger rotation volume, freight transport and cargo rotation volume increased rapidly (see Table 1). By the end of 2010, the passenger traffic reached 134.32 million persons, with an average annual growth rate of 6.59% between 1990 and 2010. The passenger turnover reached 12.14 million·km, with an average annual growth rate of 14.59% between 1990 and 2010. Simultaneously, cargo reached 810.24 million tons, with an average annual growth rate of 9.55%. The corresponding freight turnover is 16,173 billion tons-km in 2010, and the average annual growth rate is 9.55%. The stable and healthy

development of Shanghai transportation provides a strong guarantee for economic and social development. The GDP of Shanghai increased from 7,816.6 million RMB Yuan in 1990 to 1,716,598 million RMB Yuan in 2010, with an average annual growth rate of 15.65% across this period.

**Table 1.** The basic situation of transportation in Shanghai from 1990 to 2010.

| Year | Passenger traffic (10,000 person) | Passenger rotation volume (100 million person·km) | Freight transport (10,000 tons) | Cargo rotation volume (100 million tons·km) |
|---|---|---|---|---|
| 1990 | 3,835 | 113.94 | 22,848 | 3,359 |
| 1995 | 5,265 | 170.98 | 22,531 | 4,187 |
| 1996 | 5,822 | 171.81 | 40,928 | 3,814 |
| 1997 | 6,057 | 181.99 | 41,373 | 4,016 |
| 1998 | 6,139 | 199.15 | 42,090 | 4,838 |
| 1999 | 6,406 | 217.95 | 44,485 | 5,606 |
| 2000 | 6,893 | 234.72 | 47,954 | 6,620 |
| 2001 | 6,324 | 286.93 | 49,545 | 6,992 |
| 2002 | 7,326 | 332.12 | 54,196 | 7,472 |
| 2003 | 7,212 | 353.62 | 58,669 | 8,587 |
| 2004 | 8,968 | 599.62 | 63,180 | 10,036 |
| 2005 | 9,487 | 663.93 | 68,741 | 12,132 |
| 2006 | 9,619 | 742.87 | 72,617 | 13,837 |
| 2007 | 10,371 | 883.25 | 78,108 | 15,949 |
| 2008 | 10,927 | 869.07 | 84,347 | 16,031 |
| 2009 | 11,136 | 1,002.59 | 76,967 | 14,436 |
| 2010 | 13,432 | 1,214.25 | 81,024 | 16,173 |

Data source: extracted from the 2000–2011 Shanghai Statistical Yearbook. Note: person·km, one person moved one kilometer in transportation; tons·km: one ton of goods moved one kilometer by transportation means.

### *3.2. Characteristics Analysis of Transportation Energy Consumption and Structural Evolution*

The China Statistical Yearbook, China Energy Statistical Yearbook and other authoritative statistics only contain the energy consumption of the transportation, storage and postal service in the various sub-sectors. In other words, transportation (different transportation modes, including road transport, rail transportation and air transport), material handling industry, warehousing, postal industry and other sub-sectors are not broken down. However, the energy consumption of the material handling industry, warehousing, postal services and other subsections are small (according to the relevant data of the national Bureau of Statistics of China, in 2007, about 7.6%). Accordingly, the article uses the data for transportation, storage and postal services as an approximation of the energy consumption of transportation. According to the Shanghai Municipal Statistics Bureau, the city's total energy consumption in 2010 was 111,610,000 tons of standard coal; the energy consumption in the transportation, storage and postal services was 20,702,200 tons of standard coal, accounting for 18.55 percent of the city's total energy consumption. Various energy consumption standard amounts of Shanghai transportation are shown in Table 2.

**Table 2.** Various energy consumption standard amounts of transportation (10,000 tons of standard coal).

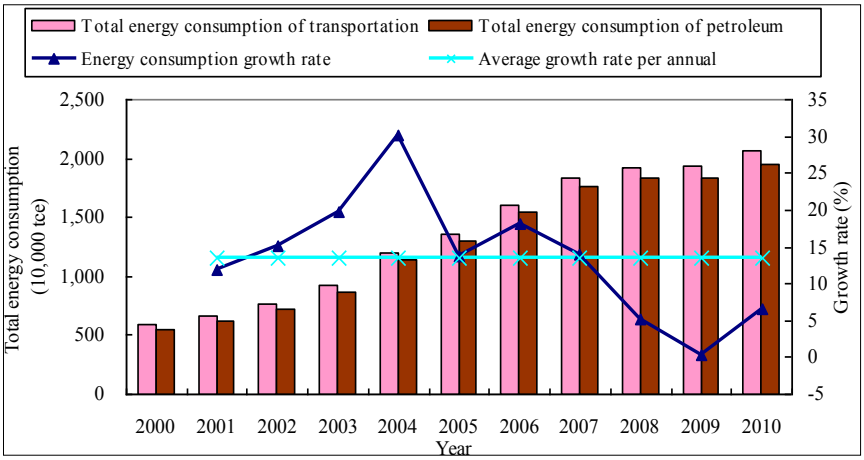
| Year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw total | 6.99 | 12.57 | 11.39 | 11.12 | 7.58 | 6.32 | 4.42 | 4.41 | 5.15 | 4.84 | 4.09 |
| Fuel oil | 359.31 | 397.78 | 443.82 | 523.20 | 647.93 | 771.79 | 871.06 | 984.22 | 957.53 | 907.20 | 919.12 |
| Gasoline | 19.92 | 21.85 | 26.18 | 54.85 | 63.36 | 90.27 | 99.30 | 111.83 | 132.28 | 138.03 | 144.36 |
| Kerosene | 79.50 | 84.95 | 150.11 | 147.92 | 242.84 | 272.52 | 382.71 | 432.36 | 481.21 | 517.50 | 580.84 |
| Diesel oil | 82.88 | 110.60 | 92.88 | 125.40 | 154.50 | 138.60 | 160.95 | 190.88 | 211.67 | 228.58 | 245.94 |
| Liquefied petroleum gas (LPG) | 0.34 | 0.36 | 0.26 | 3.61 | 12.51 | 12.70 | 11.81 | 11.45 | 12.70 | 11.22 | 11.21 |
| Other petroleum products | 8.40 | 9.31 | 11.52 | 13.85 | 18.98 | 18.66 | 18.63 | 31.51 | 46.21 | 39.56 | 54.84 |
| Natural gas | 0.13 | 0.78 | 0.91 | 1.82 | 2.34 | 2.60 | 2.23 | 2.52 | 3.30 | 3.87 | 3.76 |
| Heat | 0.60 | 0.20 | 0.21 | 0.46 | 0.59 | 0.69 | 0.86 | 0.96 | 0.89 | 2.71 | 2.95 |
| Electricity | 40.24 | 11.00 | 11.79 | 37.93 | 45.24 | 46.28 | 55.44 | 62.42 | 74.65 | 31.81 | 41.92 |

Data source: collected according to the 2001–2011 Shanghai Industrial Traffic Energy Statistical Yearbook.

In recent years, Shanghai's transportation energy consumption has increased rapidly. With an evolving consumption structure, its basic characteristics are shown as follows:

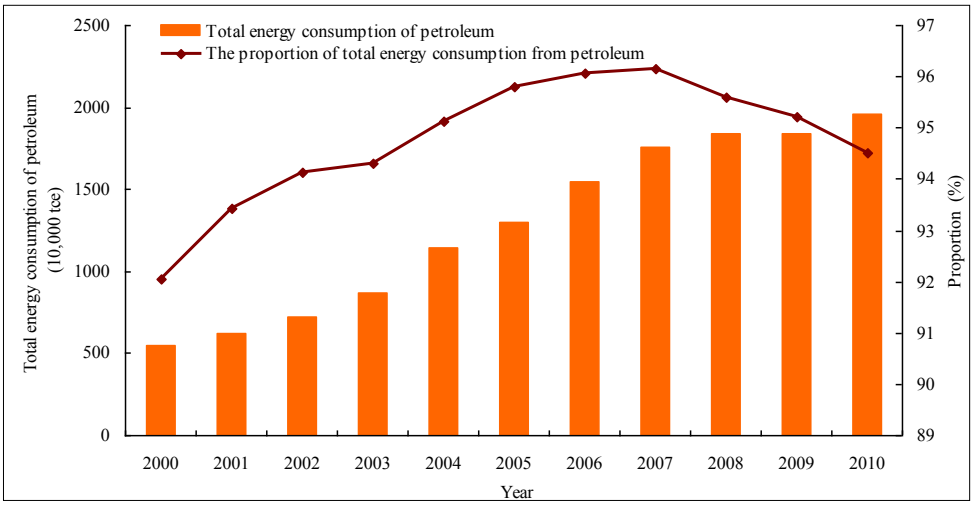
(1) Transportation energy consumer products include oil, electricity, heat, gas and coal. From the change trends of total energy consumption, the transportation energy consumption continues to grow. Transportation energy consumption increased by 2.46 times from 5.9796 million tons of standard coal to 20.7022 million tons of standard coal during 2000–2010. The average annual growth rate is 13.49 percent, which is higher than the annual average growth rate (7.36%) of the energy consumption of the whole city over the same period. Figure 1 shows Shanghai's total energy consumption and the change in the trend of the energy consumption growth rate. Shanghai's transportation energy consumption grows rapidly from 2000 to 2004. The average annual growth rate is 19.18 percent. After 2004, the growth of transportation energy consumption slows.

**Figure 1.** The total energy consumption and energy consumption growth rate of the transportation section and petroleum.



(2) Transportation is one of the national key energy-using industries and is the top consumer of oil. The transportation energy consumption of Shanghai increases year by year from 2000 to 2010, and the growth of oil consumption is particularly rapid, increasing by 2.55 times from 5.5035 million tons of standard coal to 19.5631 million tons of standard coal. The average annual growth rate is 13.83 percent. Its transportation energy consumption accounted for 94.49% of the total transportation energy consumption in 2010. As shown in Figure 2, the transportation industry becomes the main momentum to drive oil consumption growth. At the same time, the oil consumption of transportation accounts for a gradual increase in the proportion of the city's oil consumption, reaching 40.95% by 2010, becoming the second largest oil consumer industry, second only to industry.

**Figure 2.** The tendency of transportation petroleum energy consumption.

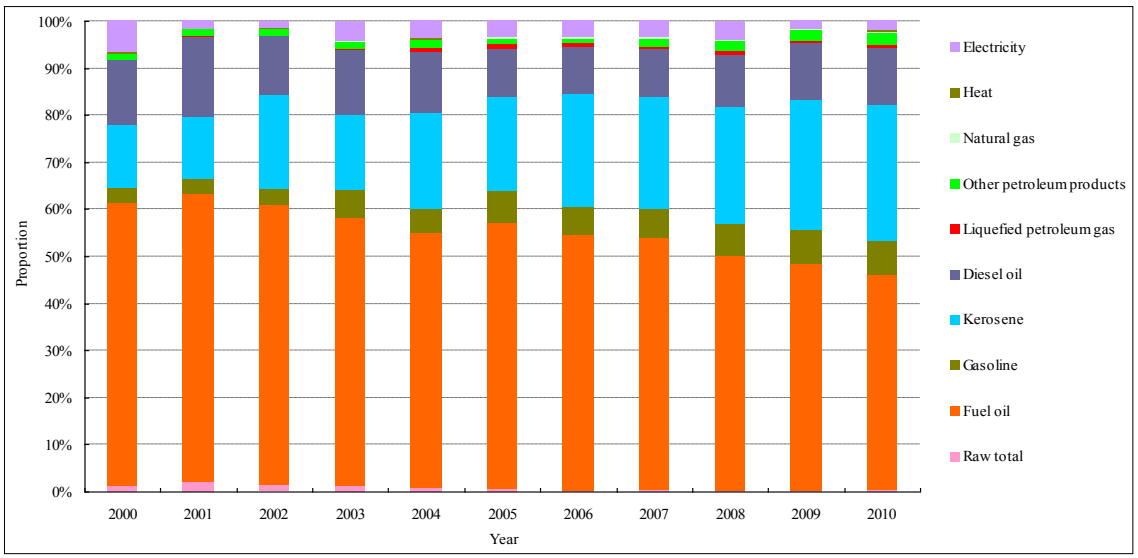



(3) Since the 1980s, the specific energy mix of transportation energy consumption has changed significantly from mainly coal and oil products, to petroleum-based products, which account for the absolute proportion today. The transportation sector is a major consumer of fuel oil, kerosene and gasoline. As shown in Figure 3, fuel oil, gasoline, kerosene, diesel, liquefied petroleum gas (LPG) and other petroleum products, natural gas, heat and electricity consumption increased gradually. Conversely, the consumption of raw coal decreased gradually. This is due to the rapid development of urban transportation and some emerging, high-speed modes of transport, such as the rapid development of aviation, high-speed rail and high-speed bus. The development of these high-speed modes of transportation changes the position of the original coal and petroleum products and petroleum products in absolute terms.

In the study period, changes in coal consumption showed a decline in volatility, with an average annual decline rate of 11.58 percent. The proportion of energy consumption of petroleum was large and grew rapidly. Fuel oil, gasoline, kerosene and diesel fuel have an important role in the field of transport. Consequently, energy consumption continued to grow, with an average annual growth rate of 10%, 25%, 24% and 12%, respectively. LPG showed fluctuating growth generally, peaking in 2004 at 96,800 tons, then declined gradually. With the continuous advancement of science and technology, more and more types of petroleum products have been used to supply the transportation sector. As a result, the consumption of other petroleum products increased from 62,700 tons in 2010 to 387,900

tons in 2010, with an average annual growth rate of 22 percent. Natural gas consumption increased gradually from one million cubic meters to 30 million cubic meters over the same time period, with an average annual growth rate of 70 percent. The heat consumer consumption presented a volatile increase, increasing from 86,300 GJ to 865,600 GJ, an average annual growth of 42 percent. Changes in electricity consumption presented two stages: electricity consumption reduced from 1.266 billion kWh to 895 million kWh in the year of 2000 to 2001, gradually increased after 2001 and increased from 895 million kWh to 3.411 billion kWh, with an average annual growth rate of 16 percent.

**Figure 3.** The transportation energy consumption proportion of Shanghai.




### *3.3. Transportation Energy Consumption Analysis of Different Modes*

The production activities of transportation are the displacement of people and things, belonging to the tertiary industry in the national economy, including railways, highways, waterways and civil aviation, which undertake the transportation of passengers or cargo. With the rapid economic development and diversification of the residents' income class, the demand for transportation is increasing. The demand stops not just at the travel layer, but develops into the efficient, fast, comfortable and other, different layers. The energy consumption of each transportation mode in the Shanghai transportation industry in 2001–2009 is shown in Table 3.

From the energy consumption proportion of different transportation modes, waterway transportation energy consumption accounts for the largest proportion of the total energy consumption, reaching 54% by 2009; the ratios of energy consumption by other transportation modes from high to low are as follows: 30%, 14% and 2%, respectively. From the development trend of various modes of transportation in 2001 to 2010, rail transportation energy consumption gradually increased from 2001 to 2005 and then showed increased variability, although on a downward trend, to 297,700 tons of standard coal from 340,000 tons of standard coal. The energy consumption of highway transportation increased from 1.56 million tons of standard coal to 5.34 million tons of standard coal. Waterway transportation increased from 4.533 million tons of standard coal to 9.7429 million tons of standard coal, and aviation transportation increased from 911,000 tons of standard coal to 2.4699 million tons of standard coal. Thus, the average annual growth levels of highway transport, waterway transport and

aviation transportation were 17.18%, 10.51% and 20.81%, respectively. Obviously, the growth rate of air transportation energy consumption was the fastest.

**Table 3.** The energy consumption of different transportation modes in the Shanghai transportation industry (10,000 tons of standard coal).

| Year | Railways | Highways | Waterways | Civil aviation |
|---|---|---|---|---|
| 2001 | 29.00 | 156.00 | 453.30 | 91.10 |
| 2002 | 29.00 | 175.00 | 505.10 | 153.80 |
| 2003 | 31.00 | 193.00 | 528.20 | 159.10 |
| 2004 | 34.00 | 217.00 | 602.80 | 221.50 |
| 2005 | 34.00 | 324.02 | 804.03 | 98.76 |
| 2006 | 33.08 | 382.71 | 871.06 | 157.67 |
| 2007 | 33.46 | 432.36 | 984.22 | 203.83 |
| 2008 | 34.25 | 484.92 | 1026.21 | 201.48 |
| 2009 | 29.77 | 534.00 | 974.29 | 246.99 |

Note: standard coal means standard coal equivalent; datum collected according to the 2002–2010 Shanghai Comprehensive Transportation Annual Report; the provision of the heat value of 1 kg of standard coal is 7,000 kcal.

### *3.4. Energy Consumption of Residents' Different Transportation*

The dominant transportation modes for Shanghai residents mainly are public buses, rail transit, taxis, ferries and private cars (including small cars, mini trucks and cars); the first three belong to public transportation. The proportion of ferries in all transportation is very small. Less relevant statistics can be found in the Shanghai Statistical Yearbook, so only the energy consumption of public buses, rail transit, taxis and private cars are analyzed. The annual mileage of different transportation and patronage, as well as private car ownership in 2002–2010 is shown in Table 4.

**Table 4.** Annual mileage and patronage of different transportation, as well as private car ownership.

| | Year | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| Bus and trolley Bus | Mileage travelled (100 million km) | 10.43 | 10.8 | 11.41 | 11.3 | 11.28 | 11.4 | 11.18 | 11.17 | 11.72 |
| | Total traffic (100 million persons/time) | 27.75 | 27.31 | 28.38 | 27.81 | 27.4 | 26.5 | 26.6 | 27.06 | 28.08 |
| Taxi | Mileage travelled (100 million km) | 51.37 | 56.45 | 56.43 | 58.12 | 61.05 | 60.66 | 63.18 | 61.99 | 64.85 |
| | Total traffic (100 million persons/time) | 4.41 | 4.97 | 5.46 | 5.64 | 5.89 | 5.78 | 6.16 | 6.09 | 6.33 |
| Rail transit | Mileage travelled (10,000 km·train) | 633.29 | 813.18 | 957.04 | 1,142 | 1,457.32 | 1,696.8 | 2,516 | 2,871 | 4,778 |
| | Total traffic (100 million persons/time) | 3.57 | 4.06 | 4.8 | 5.94 | 6.56 | 8.14 | 11.28 | 13.18 | 18.84 |
| Private motor vehicles owned (10,000 cars) | | 23.84 | 36.82 | 53.25 | 70.37 | 89.07 | 61.29 | 72.04 | 85.19 | 103.85 |

Data source: collected according to the 2003–2011 Shanghai Industrial and Transportation Statistics Yearbook.

3.4.1. The Calculation of the Energy Consumption of Residents' Different Transportation

Annual energy consumption of the various transportation modes can be obtained by using the annual mileage of different transportation modes to multiply the per kilometer fuel consumption. The energy consumption for various modes of transportation is calculated as:

$$C_i = D_i \cdot A_i \cdot F$$

where $C_i$ is the fuel consumption of number $i$ transportation, and its unit is kg; $D_i$ is the annual mileage of number $i$ transportation, and its unit is km; $A_i$ is fuel consumption for an average of one hundred kilometers, and its unit is L/100 km; and $F$ is the fuel density, and its unit is kg/L.

The buses of different cities or different lines in the same city are effected by climate, road conditions, traffic flow, the flow of people, the driver operating habits, the distance between two sites and the number of traffic lights, so their 100-km fuel consumption are not the same. Few lines of the central area of Shanghai and peri-urban areas are investigated. The analysis showed the one-hundred-kilometer consumption of buses to be 35–47 L, with an average of 40 L and the one-hundred-kilometer consumption of taxis, 9–11 L, with an average of 10 L. In the analysis of Shanghai family car running costs, Li *et al* [4] used 8.8 L as the one-hundred-kilometer average fuel consumption of home cars. Thus, the one-hundred-kilometer average fuel consumption of private cars is supposed to be 8.8 L in the article.

The buses in Shanghai use $0^{\#}$ diesel fuel as the main fuel, the diesel density being 0.835 kg/L. Taxis and private cars use $93^{\#}$ gasoline as the fuel, the gasoline density being 0.725 kg/L.

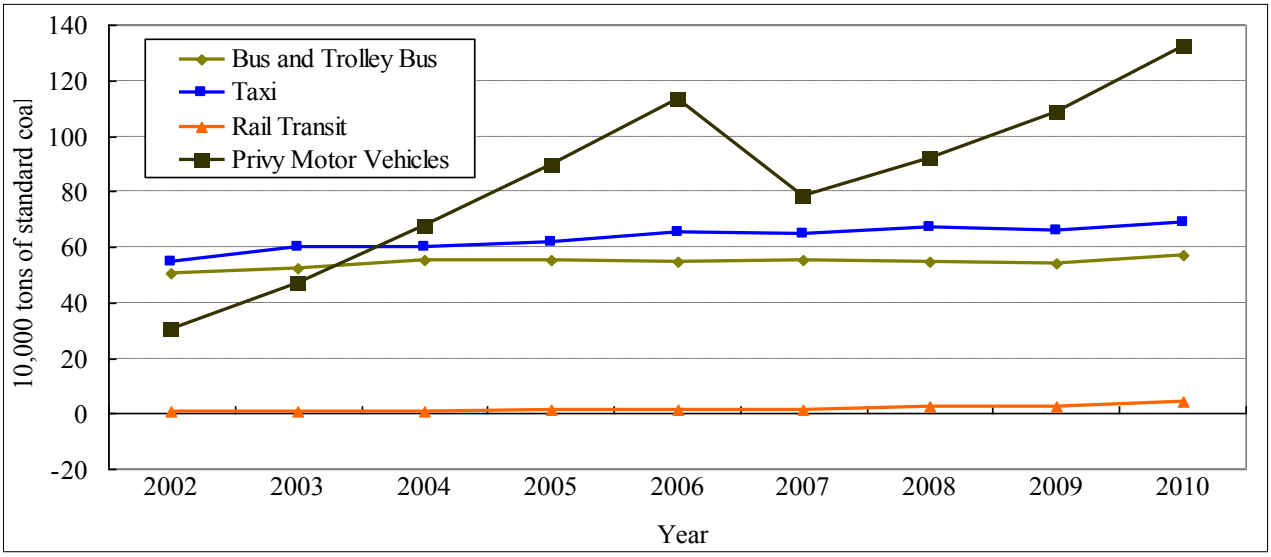
In the study of Li *et al*. [4], the average annual mileage of a Shanghai private car is 13,575 km; the article uses the data. Rail transit uses electric traction; according to the 2003 annual report Shanghai Shentong Metro Co., Ltd., the one-hundred-kilometer power consumption of rail transit is 263.8 kWh. Assume that all the electricity of rail transportation comes from coal-fired power, according to the data in the Chinese national energy statistical reporting system, which per kWh needs about 345 g of standard coal. Therefore, the energy consumption of one hundred kilometers of rail transit is 91.01 kg of standard coal.

3.4.2. Results

The energy consumption of various travel modes is shown in Figure 4. It can be seen that the energy consumption structure of various travel modes in Shanghai transportation has undergone great changes, mainly from public buses and taxis to public buses and trams and taxis. The overall energy consumption of private cars shows rapid growth overall, with three distinct phases: energy consumption increased year by year in 2002–2006, reached an extreme value of 1.1351 million tons of standard coal in 2006, with an average annual growth rate of 39.45%; in 2006–2007, it fell, the annual decline rate being 31.19%; from 2007–2010, the energy consumption of private cars grew year-on-year, with an average annual growth rate of 19.23%. Public buses and trams and taxi energy consumption show only a slight increase, with an average annual growth rate of 1.50% and 3.01%, respectively. The energy consumption of rail transportation has increased year by year, increasing from 5,800 tons of standard coal to 43,500 tons of standard coal; the average annual growth rate is 29.78 percent. The proportion of the total energy consumption from private cars is the largest of the

various travel modes; the proportion of public buses, trams and taxis decreased. The proportion of private cars, public buses and trams and taxis are 50.33%, 26.31% and 21.69%, respectively. Due to the smaller base, the energy consumption of rail transportation accounts for the smallest percentage.

**Figure 4.** The energy consumption of various transportation modes.




## 4. The Energy Efficiency of Shanghai's Transportation

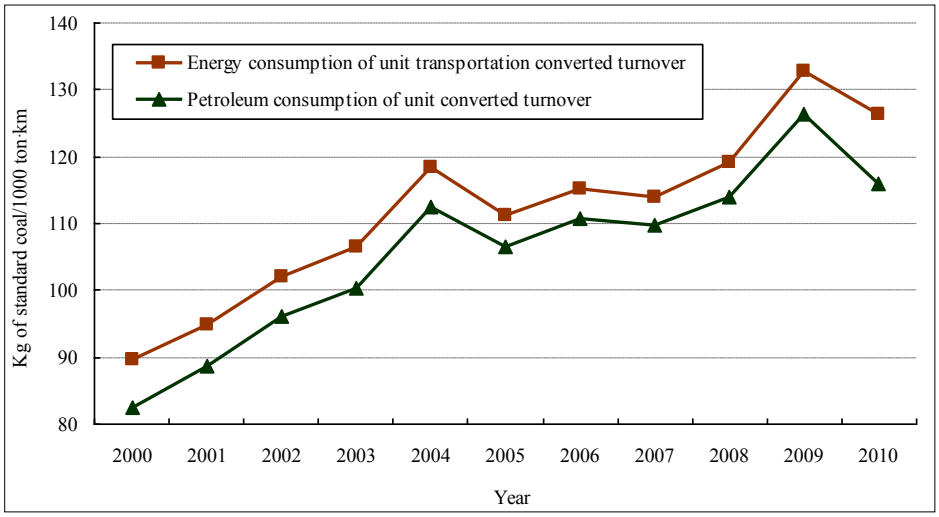
### *4.1. Transportation Energy Intensity Analysis*

Energy intensity indicators contain two major categories: one is the energy consumption per unit of product (such as per ton of steel, railway comprehensive converted turnover, *etc*.); the other is the energy consumption per unit of output (such as GDP, industrial added value, the main income, *etc*.). For the ease of corresponding national binding targets (energy consumption per unit of GDP), at the same time, according to the characteristics of the transportation industry, because it is a service industry, the main products are the displacement service of passenger and cargo and taking into account the continuity of industry statistics. This study uses unit energy consumption of transportation turnover and energy consumption per unit of output for considerations. The data is based on the National Bureau of Statistics of China.

When we calculate the unit energy consumption of transportation turnover, the turnover is unified as a billion ton·km. For the amount of passenger services, according to the energy consumption situation, billion person·kilometer is converted to billion ton·km. The passenger and freight conversion factor prescribed by the Chinese statistical system, the press shop rate, and the rail, ocean, coastal and inland water transportation coefficients are one; by seat rate, for river, it is 0.33; for highway, it is 0.1; for domestic aviation, it is 0.072; and for international aviation, it is 0.075. The determination of these coefficients depends on how much human and material resources consumed by the transportation of ton·km and 1 km. On this basis, the sum of passenger and cargo traffic volume is the traffic converted turnover.

From the unit energy consumption of converted turnover, the unit energy consumption of transportation converted turnover in 2000–2010 shows some variability and an overall upward trend. The main reasons are as follows: in recent years, the rapid development of the transportation business, the accelerating construction of the highway infrastructure, the rapid increase of highway mileage, the subsequent growth of the number of motor vehicles and the high energy consumption of civil aviation and road transportation have increased in popularity. After 2009, comprehensive energy consumption per ton converted turnover of transportation rose to 132.83 kg of standard coal, an increase of 48.31% compared to 2000. After 2009, as technology advances, in particular, the acceleration of the process of electrification of the railway unit energy consumption of transportation turnover has dropped slightly, reducing to 126.38 kg of standard coal/ton·km. During the same period, unit petroleum energy consumption of converted turnover and unit comprehension energy consumption of converted turnover showed similar changes in energy consumption trends, as shown in Figure 5. This reflects that unit petroleum energy consumption of converted turnover played a decisive influence on the change trend of the unit comprehensive energy consumption of converted turnover.

**Figure 5.** The energy consumption of transportation converted turnover.




The energy consumption per unit of output from 2000 to 2010 is shown in Table 5. Compared to the unit energy consumption of transportation converted turnover, the overall transportation sector energy consumption per unit of output shows a downward trend: energy consumption per unit of output is 2.47 tons per million in 2010. Compared to 3.47 tons of standard coal per million in 2000, it shows a decrease of 28.82%. The main reasons are the optimal adjustment of the industrial infrastructure, the continuous development of science and technology, the continuous progress of energy-saving technology, the development and use of clean energy and fuel-efficient cars, as well as the transportation sector transportation of high value-added products. The decline of energy consumption per unit of output is a performance of energy-saving. Although unit energy consumption of transportation converted turnover is rising, it does not mean that the transportation sector is not energy efficient. Energy consumption per unit of output has been in a slight decline. However, Shanghai is populous and lacks resources, and the slight decline could not resolutely deny that there are many problems of the transportation sector in Shanghai. Therefore, we should continue to increase

the implementation of energy savings and environmental protection and strive to build a low-carbon, environmentally friendly transportation system.

**Table 5.** Transportation energy consumption per unit of output in major years.

| year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Energy intensity by GDP (tce/$10^4$ Yuan) | 3.47 | 2.75 | 2.98 | 3.38 | 3.69 | 2.64 | 2.7 | 2.88 | 2.7 | 3.05 | 2.47 |

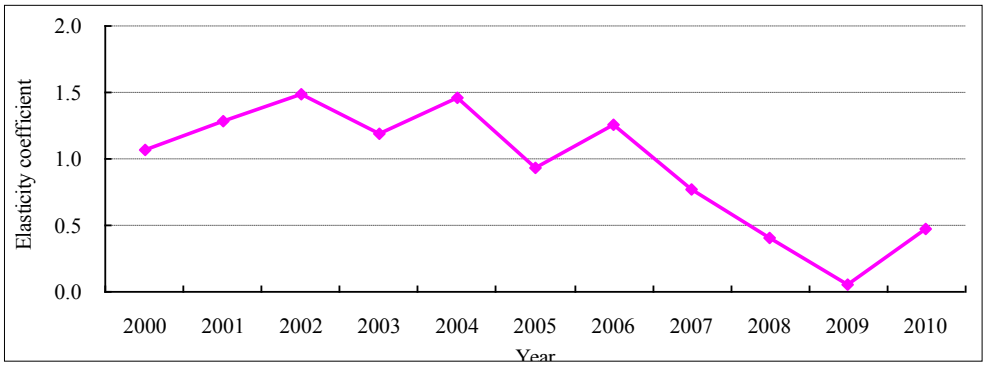
Data source: gross domestic products of transportation collected according to 2001–2011 Shanghai Industrial Traffic Energy Statistical Yearbook; Energy consumption of transportation collected according to the 2001–2011 Shanghai Industrial Traffic Energy Statistical Yearbook; the unit energy consumption is the ratio of energy consumption to gross domestic product.

### *4.2. Transportation Energy Elasticity Analysis*

The elasticity coefficient of energy consumption means that, when the total economy increase by one percent, the relative change degree of the energy consumption can be used to reflect the relationship of the growth of energy consumption. Figure 6 shows the elasticity coefficient of energy consumption in Shanghai in 2000 and 2010. The average is 0.94, indicating that the overall level of energy consumption is lower than the total economic growth. The case in each year is not the same; some years are more volatile. In 2000 and 2007, the growth of energy consumption and economic development are consistent, meaning that economic growth will cause the same degree changes of energy consumption. After 2007, the growth in energy consumption is significantly lower than that of regional GDP.

It is generally believed that the changes of the elasticity coefficient of energy consumption and the industrial infrastructure in the process of economic development are closely linked. Firstly, industrialization processes generally convert light steering to heavy industry at the center; the energy demand of economic growth depends mainly on the energy source inputs. At the same time, the growth rate of energy consumption is generally ahead of that of the economy. Secondly, this turned to the processing and assembly industry as the center, and energy consumption reaches a certain level and remains stable. Thirdly, this turns to the technology and knowledge-intensive industries as the center; with the changes in the industrial infrastructure, technological progress and the improvement in the management, energy consumption decreased. Corresponding to this, changes in the elasticity coefficient of energy consumption also reflect a change that starts low, to high, after descending [5,14]. This means that, with the continuous deepening adjustment of the industrial infrastructure to the technology and knowledge-intensive industries, the Shanghai elasticity coefficient of energy consumption already has the external conditions to pull back from high consumption. Additionally, it maintains a relatively low level for a long period of time. For energy savings and reduction, the implementation of a low-carbon development strategy has a positive meaning.

**Figure 6.** Elasticity coefficient of traffic energy.




## 5. The Measures and Recommendations for Shanghai's Urban Transportation Energy Efficiency

The results showed that, in the period from 2000 to 2010, the total energy consumption of transportation increased from 5.9796 million tons of standard coal to 20.7022 million tons of standard coal, with the average annual growth rate of 13.49%; and oil consumption is a major part. The proportion of total transportation energy consumption was up to 94.49% in 2010. Among different travel modes of the residents, the usage of the private car has the largest proportion in the total energy consumption, while rail transportation is the smallest. Between the years of 2000 and 2010, the per unit of output of transportation energy consumption showed a downward fluctuating trend, and the overall level of energy consumption growth in the same period in Shanghai is less than the total economic growth. In order to facilitate the energy conservation of Shanghai transportation, measures need to be adopted that address the following three issues.

Firstly, optimize the structure of transportation and improve transportation energy utilization efficiency. An integrated transportation infrastructure is an important factor for the energy consumption of transportation. For a long time, highways, waterways, railways, civil aviation and other transportation modes belonged to different departments; they have poor convergence and coordination, impacting the full play of comparative advantage and the combination of the efficiency of various modes of transportation. The overall efficiency of energy use is low. At present, with the super-ministry reform in China and the construction of the Ministry of Transport, an integrated transportation system has ushered in a good opportunity for development, and an integrated transportation structure is becoming more rational, building energy savings continuously, which will have important and positive impacts on transportation energy savings.

Secondly, there are issues concerning the improvement of the efficiency of the transportation capacity of public transportation. We should consider the characteristics of urban transportation energy consumption, with the background of the 12th five-year transportation plan, and strive to improve the efficiency of the transportation capacity of public transport. Furthermore, we should improve the public transportation infrastructure and operations to reduce operating power consumption by reducing the unloaded ratio. The rail and bus steam trams are a high-capacity public transportation system. Through rational distribution, we can achieve transportation route coordination optimization, seamless and zero distance transfer and enhance the overall efficiency of public transportation and comprehensive benefits.

Thirdly, the resources of coal-bed methane, oil sand, geothermal energy, fuel ethanol and bio-diesel have been developed in China. The mass production of new energy can meet the need of the economic development of Shanghai for a period of time.

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