

## Article

# The Potential Impacts of Electric Vehicles on Urban Air Quality in Shanghai City

Xiaojian Hu <sup>1,2,3</sup>, Nuo Chen <sup>1,2,3,\*</sup>, Nan Wu <sup>1,2,3</sup> and Bicheng Yin <sup>4</sup>

- <sup>1</sup> Jiangsu Key Laboratory of Urban ITS, Southeast University, Nanjing 211189, China; huxiaojian@seu.edu.cn (X.H.); 220193189@seu.edu.cn (N.W.)
- <sup>2</sup> Jiangsu Province Collaborative Innovation Center of Modern Urban Traffic Technologies, Southeast University, Nanjing 211189, China
- <sup>3</sup> School of Transportation, Southeast University, Nanjing 211189, China
- <sup>4</sup> School of Environment, Education and Development, The University of Manchester, Manchester M13 9PL, UK; bicheng.yin-2@postgrad.manchester.ac.uk
- \* Correspondence: 220183044@seu.edu.cn; Tel.: +86-158-5185-2958

**Abstract:** The Shanghai government has outlined plans for the new vehicles used for the public transportation, rental, sanitation, postal, and intra-city freight to be completely powered by electricity by 2020. This paper analyzed the characteristics of vehicle emissions in Shanghai in the past five years. The potential reduction in road traffic related emissions due to the promotion and application of electric vehicle in Shanghai was evaluated. The potential reduction was quantified by vehicular emissions. The vehicular emissions inventories are calculated by the COPERT IV model under the different scenarios, of which the results indicate that promoting electric vehicles is the efficient measure to control all road traffic related emissions and improve urban air quality. The results also provided basis and support for making policies to promote and manage electric vehicles.

**Keywords:** electric vehicles; vehicle emissions; urban air quality; COPERT IV



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## 1. Introduction

Industrialization and urbanization have led to a rapid increase in the number of motor vehicles in China in the past two decades. Until 2018, the total number of vehicles in China had risen to 328 million [1]. However, the rapid development of motorization was usually accompanied by an overall decline in air quality [2]. Air pollution was relatively serious in China, especially in Yangtze River delta region. The carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>) and particulate matter (PM) has already exceeded new air standards in many cities.

According to the statistics, vehicle emissions have replaced industrial waste gas as the main source of pollutants in large and medium-sized Chinese cities [3]. On-road vehicles accounted for about 20–67%, 12–36% and 12–39% of the total atmospheric CO, NO<sub>x</sub> and VOC emissions in China, respectively [4,5]. In 2017, vehicle emissions of PM exceeded 90% of the total PM [3]. As for greenhouse gases, some studies have shown that the transport sector accounted for 23% of global CO<sub>2</sub> emissions in 2010, and its share of emissions is expected to increase at a higher rate than that of other sectors towards 2050 [6].

Nowadays, urban air quality has been seriously damaged. Frequent traffic congestion and accident has become serious social problems. In order to ensure the sustainable development of city and transportation system, various urban transportation development strategies have been put forward in recent years, such as shared transportation, intelligent transportation system, low-carbon transportation and so on [7]. Based on the vehicle emissions, this paper will analyze the emission reduction potential of electric vehicles, and formulate relevant policies on vehicle emission reduction.

## 1.1. Literature Review

### 1.1.1. Study on Emission Reduction Policies

Vehicle emissions can be effectively reduced by two kinds of restrictive measures. The first category is the restriction on vehicle ownership. In the late 1960s, Singapore tried to control vehicle ownership via tax policies. Owners were also required to pay import duties, annual road taxes and additional registration fee besides the onetime registration fee [8]. In 1974, Hong Kong applied similar taxes and fees to slow down the increase of vehicle ownership [9]. In 1994, Shanghai began to issue license plates of private vehicle by auctions. It was estimated that the population of passenger vehicle in Shanghai would be 4.9 million higher in 2020 without this policy [10]. These policies led to a once-for-all reduction in vehicle ownership, but were ineffective in controlling the long-run growth.

The second category is the restriction on vehicle use intensity. In 1989, Mexico City implemented a driving restriction program that banned most drivers from driving one weekday per week [11]. In order to alleviate the congestion in the central area, London began to levy congestion charges in 2003 [12]. Rome, Stockholm and other European regions have also successively implemented the central regional traffic charging policy to release traffic pressure and improve the environment [13]. During the 2008 Olympics Games, Beijing implemented driving restrictions. Vehicles were allowed to drive every other day. After that, a series of similar restrictions was announced in many other Chinese cities. However, such restrictive measures on driving stimulated the growth of vehicle ownership. People tend to purchase another car with a different plate number so that they can drive everyday by alternate using two cars [10].

Only placing restrictions on the vehicle is not enough to reduce vehicle emissions in the long term. With the development of oil refining technology, China has ratcheted down the emission limits by implementing the Euro path guidelines since 2000 [14]. According to Annual Report on Environmental Management of Motor Vehicles in China, pre-National-II vehicles of China emitted 10.7% of NO<sub>x</sub>, 22.6% of HC, 24.7% of CO and 16.4% of PM in 2018 [15]. Guo et al. found that vehicles complying with the National-I and National-II Vehicle Emission Limits Standard were main causes to overall fleet emissions due to their deterioration. Zhang et al. found that applying National III and National IV Vehicles Emission Limits Standard can effectively reduce overall emission factors of all type vehicles with both gasoline and diesel [16]. So eliminating high-emission vehicles can also effectively abate vehicle emissions [17].

### 1.1.2. Study on Electric Vehicles

Electric vehicles are attractive and eco-efficient alternatives to conventional vehicles. There are no tailpipe emissions for electric vehicles because they are propelled by electric motors instead of internal combustion engines, even though there are many obstacles related to technology and infrastructure against the widespread adoption of electric vehicles [18]. These challenges include lack of infrastructure for charging electric vehicles [19], charging time [20], driving range [21], high price [22], and uncertainties associated with the potential benefits of these vehicles [23]. Electric vehicles have great potential to minimize the external impacts of road transportation, including air pollution [24] and associated health impacts on urban population [25], global climate change [26] and so on. Therefore, electric vehicles would be one possible solution to help reduce air pollution caused by transportation [27].

Countries such as Spain, Denmark, Ireland, Austria, Japan, and South Korea have set electric vehicle sales targets, according to the International Energy Agency (IEA) [18]. The Netherlands and Norway will prohibit the sale of gasoline and diesel vehicles in favor of electric vehicles by 2025. Germany and India will follow closely and prohibit the sale of gasoline and diesel vehicles by 2030. Various policies related to tax reductions and financial subsidies were also provided to promote electric vehicle. At the same time, the concept of shared electric vehicles is becoming more and more popular in current transport systems [28]. There is a growing movement toward electric vehicles technologies around

the world. According to the International Energy Agency (IEA), the number of electric vehicles worldwide reached 3.1 million in 2017, increased by 57% compared with 2016.

According to the 13th five year plan of Shanghai Comprehensive Transportation on the website of the Ministry of communications, by 2020, the total number of electric buses in Shanghai will exceed 8000, accounting for more than 50%, and the proportion of electric buses in the central urban area will exceed 60% [29]. According to historical statistics, the number of electric vehicles in Shanghai has increased by more than 20% since 2016. In 2018, 74 thousands electric vehicles were put into use in Shanghai. By this trend, the number of electric vehicles in Shanghai will exceed 1.1 million in 2025. Due to the current license restriction policy in Shanghai, only 100 thousands new vehicle quota will be provided each year. The number of motor vehicles in Shanghai will be about 4.55 million in 2025. Considering that the promotion policy of electric vehicles will be strengthened in the future, 30% is selected as our research index.

### 1.1.3. Study on Vehicle Emission Calculation

Vehicle emissions can be estimated by emission models, such as the MOVES Model, the IVE Model, the COPERT Model and so on [30]. Cai and Xie (2007) established vehicular emission inventories of CH<sub>4</sub>, CO, CO<sub>2</sub>, NMVOC, NO<sub>x</sub>, PM10 and SO<sub>2</sub> in China using the COPERT III model [2]. Lang et al. (2012) developed the multiyear emission inventories of CO, VOC, NO<sub>x</sub> and PM10 from road vehicles in the Beijing-Tianjin-Hebei (BTH) area [31]. Sun et al. (2016) used the vehicle age distribution to estimate the population of vehicles at different age, which contributed to a more accurate result [32].

According to the above researches, the main pollutants from vehicle emissions can be classified into two categories: Conventional pollutants and greenhouse gases. Conventional vehicular pollutants include carbon monoxide (CO), non-methane (NMVOC), nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), and particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>). As well, greenhouse gases produced by vehicle including methane (CH<sub>4</sub>), and carbon dioxide (CO<sub>2</sub>). This study will focus on these eight pollutants.

### 1.2. Motivation and Research Objectives

This study aimed to realize the following objectives:

- (1) To calculate the vehicle emission inventories from 2014 to 2018, and predict the vehicle emission inventories in 2025 in Shanghai;
- (2) To promote electric vehicle by revealing the potential benefits achieved by 30% electric vehicle market penetration goal;
- (3) To contribute to the state-of-the-art in vehicle emission model literature by presenting an application of COPERT IV model.

### 1.3. Analytical Framework

This article estimated the historical trends (from 2014 to 2018) of vehicle emissions in Shanghai. As well, the reduction effects (in 2025) of different electric vehicle proportions were evaluated. The analysis of vehicle emissions included eight pollutants: CO, NMVOC, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, CH<sub>4</sub> and CO<sub>2</sub>. Vehicle emissions were calculated by vehicle population, annual average vehicle-kilometers traveled and emission factors. As well, emission factors for different pollutants and vehicle types were simulated by the COPERT model. The reduction effects were estimated by difference of vehicle emissions under different scenarios. Two scenarios were assumed in this study: Business as usual (BAU) and 30% electric vehicles Scenario (EV-30%). The analytical framework was shown as Figure 1.

The rest of the paper is organized as follows. Section 2 introduces the study area, model, data collection and scenario design reviews the literature. Section 3 reports the results of model estimation and analysis of the results. Section 4 is the conclusion and further policy implications of this study.

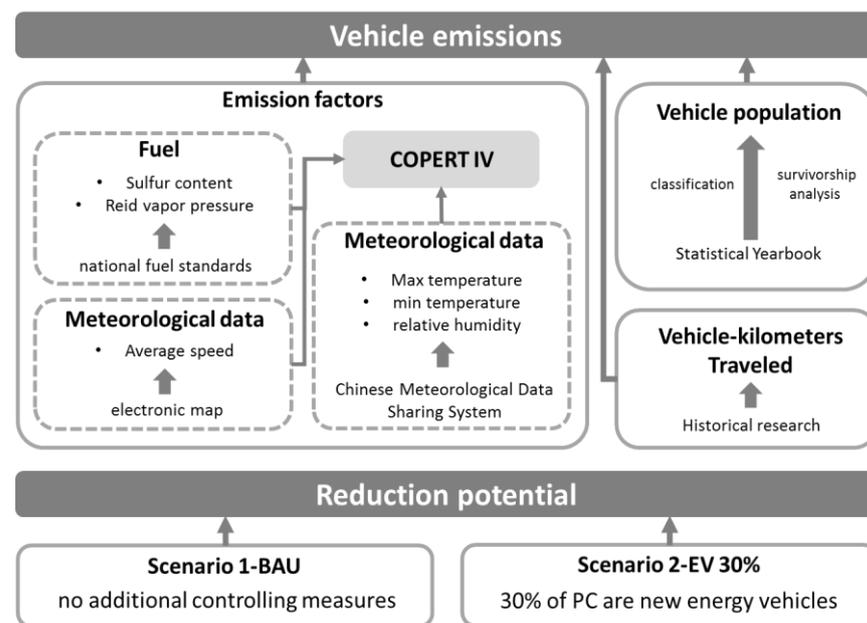


Figure 1. Analytical framework.

## 2. Methodology

### 2.1. Study Area

Shanghai is located in the eastern coastal areas of China. This city consisted 16 districts, covered a 6340.5 km<sup>2</sup> area, and had a population of 24.2 million (Figure 2). As one of the four municipalities in China, the population of vehicles in Shanghai has been more than 4 million. Traffic congestion, traffic accidents and traffic pollution caused by excessive numbers of motor vehicles have aroused great concern. Different policies to control the growth and usage of motor vehicles were carried out. As early as 1994, Shanghai implemented the auction system for the new vehicle quota. Later, traffic management measures such as driving restriction and offering public transit priority were implemented. However, special studies related to traffic pollution are still lacking. It is necessary to investigate historical trends and future changes in vehicle emissions in this area. Electric vehicles have entered Shanghai. Their potential environmental impacts are also worth evaluating.

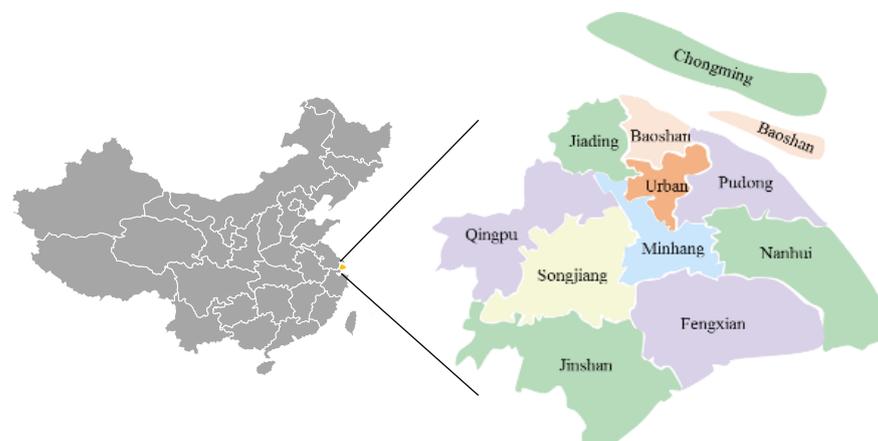


Figure 2. Location and administrative division of Shanghai, China.

## 2.2. Vehicle Emissions

Three key factors of COPERT model were considered: Vehicle population, annual average vehicle-kilometers traveled and emission factors. As well, the emissions of each particular vehicle category were calculated by Equation (1):

$$Q_{m,n} = \sum_i (P_{m,i} \times VKT_{m,i} \times EF_{m,n,i}) \times 10^{-6} \quad (1)$$

where  $m$  is the year,  $n$  represents eight pollutants,  $i$  is the type of vehicles (passenger cars (PC), light-duty vehicles (LDV), buses (BUS), heavy-duty trucks (HDT) and motorcycles (MC));  $P_{m,i}$  is the vehicle population of category  $i$  in year  $m$ ,  $VKT_{m,i}$  is the annual average vehicle kilometers travelled (km) for vehicles of category  $i$  in year  $m$ , and  $EF_{m,n,i}$  is the emission factor (g/km) for pollutant  $n$  emitted from vehicles of category  $i$  in year  $m$ .

### 2.2.1. Vehicle Population

The population of motor vehicle ownership in Shanghai from 2014 to 2018 was taken from the official Chinese Statistical Yearbooks. However, the original data from the yearbooks could not be used directly in COPERT IV. There were two major obstacles:

- (1) The vehicle types used in the COPERT IV model were divided into PC, LCV, HDT, BUS and MC, which were different from the classification in Chinese yearbooks;
- (2) The vehicle satisfied different level of fuel standards, which were updated by year.

In order to solve these problems, the data were processed as follows. First, the relationships between the Chinese vehicle types and the COPERT vehicle types were shown in Table 1 [30]. According to this table, the Chinese vehicle categories were converted to the corresponding vehicle categories in COPERT IV (Table 1).

**Table 1.** Vehicle categories conversion table.

Chinese Vehicle Category	MPC <sup>a</sup>	TW <sup>b</sup>	COPERT Vehicle Category
Big-size passenger cars	$\geq 20$		BUS
Middle-size passenger cars	$>9$ and $<20$		
Small-size passenger cars	$>5$ and $\leq 9$		PC
Mini passenger cars	$\leq 5$		
Heavy-duty vans		$\geq 12$ t	HDT
Intermediate-duty vans		$\geq 4.5$ t and $<12$ t	
Light-duty vans		$>1.8$ t and $<4.5$ t	
Mini vans		$\leq 1.8$ t	LDV
Motorcycles	-	-	MC

<sup>a</sup> Maximum passenger capacity. <sup>b</sup> Total weight.

Then, according to the vehicle age distribution and the implementation time of emission standards, the proportions of different vehicles meeting the standards in each research year could be calculated. Sun et al. suggested that the vehicle age distribution could be estimated from a survivorship curve and the population of newly registered vehicles [32]. We assumed that the survivorship of each category of vehicles registered in the same year follows a Weibull distribution [33]. The vehicle age distribution ( $X$ ) of the in-use vehicle fleet was simulated according to Equation (2):

$$\begin{cases} VP_{i,j,k} = N_{i,k-j} \times R_{i,j} \\ VP_{i,k} = \sum_j VP_{i,j,k} \\ X_{i,j,k} = \frac{VP_{i,j,k}}{VP_{i,k}} \end{cases} \quad (2)$$

where  $X$  represents the age distribution;  $i$  represents the vehicle type,  $j$  represents the vehicle age,  $k$  represents the estimated year;  $R$  represents the survival rate; and  $N$  represents new registrations in year  $k - j$ . New registrations for each vehicle type were obtained from the Chinese Statistical Yearbook. Survival-rate curve was provided by Hao et al. and Huo and Wang [33,34].

### 2.2.2. Annual Average Vehicle-kilometers Traveled (VKT)

The VKT was a necessary parameter to calculate the vehicular emissions. Song et al. collected the VKT data of various types of vehicles in Pan-Yangtze River Delta [30]. As well, the VKT that could not be directly found in the literature was estimated by the linear interpolation and regression analysis method based on the data in other years [35]. The VKT values for each vehicle type in Shanghai from 2014 to 2018 were listed in Table 2.

**Table 2.** VKT in Shanghai from 2014 to 2018 (km).

Year	2014	2015	2016	2017	2018
PC	24.1	24.4	25.0	25.2	25.9
LDV	31.4	27.8	21.0	18.9	13.6
BUS	73.1	76.8	86.0	84.6	88.8
HDT	20.2	19.9	20.0	19.1	18.7
MC	6.4	6.2	6.5	5.9	5.7

### 2.2.3. Emission Factors (EF)

As the vehicle technologies and vehicular emission regulations implemented in China are similar to those in Europe [25], the COPERT IV model is appropriate to calculate emission factors. The emission factors were related to the following parameters:

1. Fuel-related data: Sulfur content and RVP (Reid vapor pressure) values were collected from official documents of national fuel standards, as shown in Table 3;
2. Meteorological data: The monthly maximum and minimum temperatures and the relative humidity of the study areas were required to estimate emission factors. These meteorological data were obtained from the Chinese Meteorological Data Sharing System and Chinese statistic yearbook.
3. Average speed data: The average speeds for different road type were obtained from the navigation data published by Autonavi Map. Based on the huge a mounts of travel data accumulated by Autonavi and calculated through scientific methods of big data mining, it was easy to get the travel speed between any two points in Shanghai. According to the survey on the electronic map, the average speed for urban road, rural road and highway in Shanghai were 29.2 km/h, 39.96 km/h and 72.72 km/h separately.

## 2.3. Scenarios Design

On the basis of existing policies, this study discussed vehicle emissions in 2025 under the following three scenarios.

### 2.3.1. Business as Usual Scenario (BAU)

The BAU scenario was an object of reference, which made it possible to assess the reduction potential of pollutants under other reduction strategies.

The BAU scenario was supposed not to implement any additional controlling measures during study period. The natural elimination, the existing emission standards and control measures remained the same as 2018. Under the BAU Scenario, the population of PC was assumed to increase with annual average increasing rate of 13%. Considering the trend of lifting the restrictions on incremental quota of license plates, it was 2% higher than the current growth rate. As well, the population of other vehicle categories was estimated by exponential and polynomial curve fitting according to their historical trends.

### 2.3.2. 30% Electric Vehicles Scenario (EV-30%)

The EV-30% scenario was designed based on the BAU scenario. Considering the existing technology and economic level of Shanghai, this scenario assumed that the number of new energy vehicles in Shanghai would account for 30% of PC by 2025.

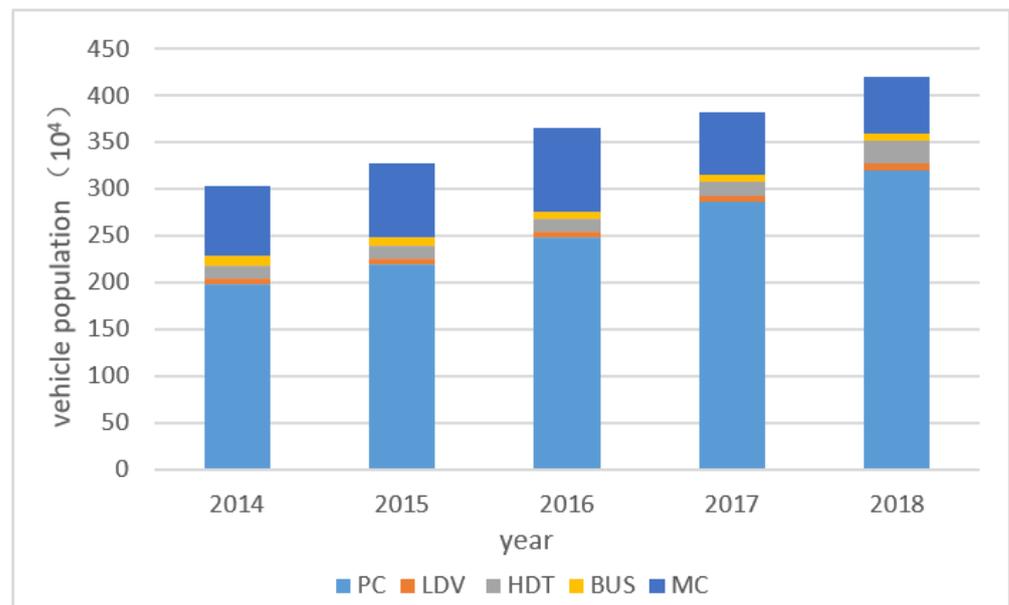
**Table 3.** Fuel-related Data in Shanghai.

Standard Code	Stage	Effective Time	Sulfur Content	RVP Values
Diesel GB19147	IV	November 2009–April 2014	<50 mg/kg	-
	V	May 2014–June 2019	<10 mg/kg	-
	VI	July 2019–now	<10 mg/kg	-
Gasoline GB17930	IV	November 2009–April 2014	<50 mg/kg	42–85 kPa (From November to April) 40–68 kPa (From May To October)
	V	May 2014–January 2019	<10 mg/kg	45–85 kPa (From November to April) 40–65 kPa (From May To October)
	VI	January 2019–now	<10 mg/kg	45–85 kPa (From November to April) 40–65 kPa (From May To October)

## 3. Results and Discussion

### 3.1. Vehicle Population Prediction

Figure 3 illustrated the number of different vehicle categories in Shanghai from 2014 to 2018. PC maintained their dominance in the market. The proportion of MC continued to decline due to the increasingly stringent restriction for MC in megacities. LDV, HDT and BUS had always been the minority, with their total number less than 10%.

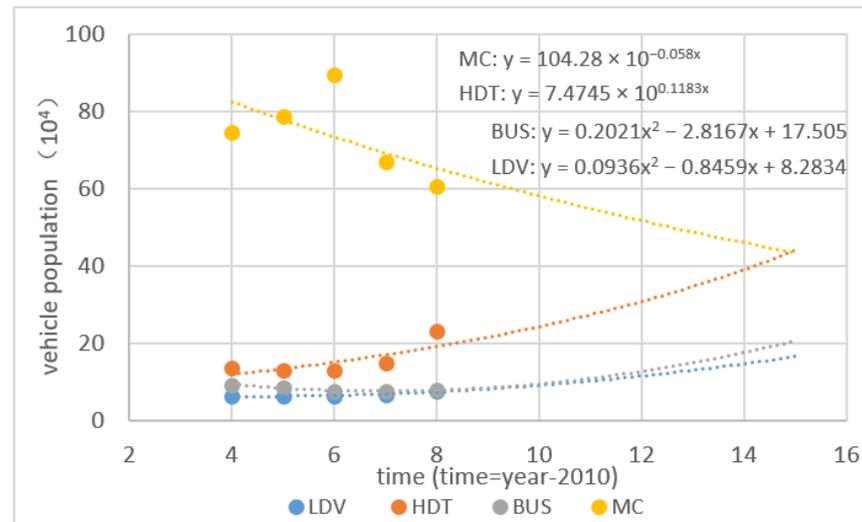


**Figure 3.** Population of Each Vehicle Categories in Shanghai.

The total number of vehicles increased steadily from 3.02 million in 2014 to 4.20 million in 2018, with an annual growth rate at 8.5%. The number of PC, LDV and HDT increased from 1986.1, 63.3 and 138.1 thousand in 2014 to 3202.7, 75.5 and 232.6 thousand in 2018. While the number of BUS and MC decreased from 93.9 and 747.3 thousand in 2014 to 79.0 and 606.0 thousand in 2018, respectively. The annual growth rate for HDT was the highest, which reached 16.2%.

Considering the new variation in vehicle population in recent years and the trend of lifting the restrictions on incremental quota of license plates, it was assumed that the vehicle population would increase at an annual rate of 13% under BAU scenario. Accordingly, the amount of PC would reach 7.28 million in 2025.

Figure 4 showed the trends of the population of LDV, HDT, BUS and MC. The amount of these vehicles in 2025 were estimated by regression analysis. From the trend curves, it could be found that the total number of LDV would increase slowly and HDT would increase significantly. The amount of LDV and HDT would reach 0.17 and 0.44 million in 2025, respectively.



**Figure 4.** Population trend for LDV, HDT, BUS, and MC.

Since 2013, Shanghai has been constructing The Transit Metropolis. The government eliminated some traditional fuel buses and replaced them by alternative energy buses gradually. So the population of BUS showed a downward trend from 2014 to 2016, followed by a steady increase. It was predicted that the population of BUS would be 0.21 million in 2025 fitting by quadratic function.

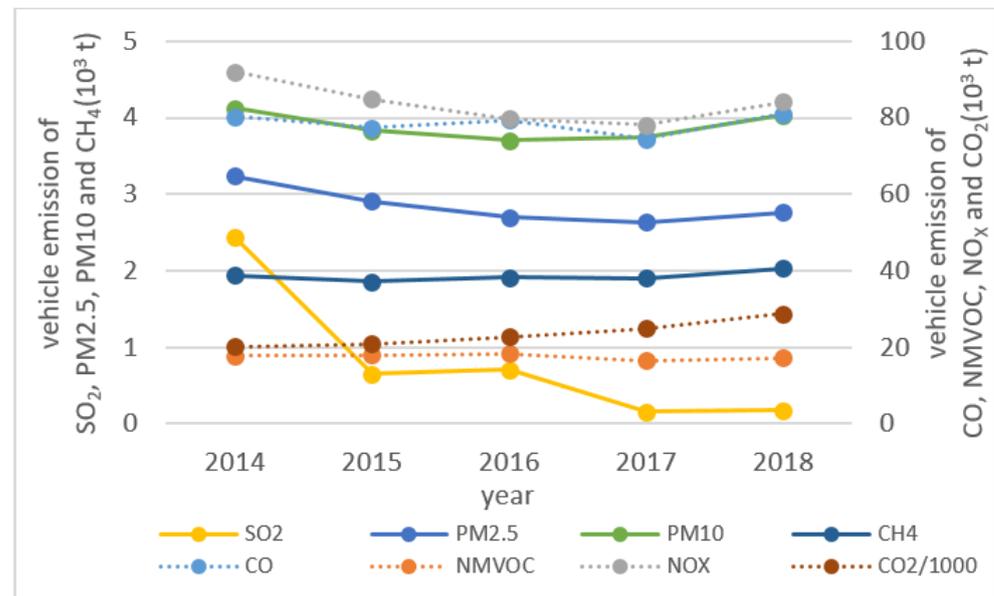
The number of MC decreased dramatically due to the implementation of the motorcycle restriction policy in 2016. The motorcycles were not allowed to run on most urban roads and the price of applying motorcycle licenses was raised by the government, which eventually resulted in the population of MC decreasing year by year. It was estimated that the MC would decreased to 0.44 million in 2025, given no added new policies.

### 3.2. Temporal Evolution of Vehicle Emissions

The vehicular emissions of CO, NMVOC, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, CH<sub>4</sub> and CO<sub>2</sub> in Shanghai from 2014 to 2018 were estimated, as shown in Figure 5. It could be seen that most pollutants declined during 2014 to 2017 and increased from 2017 to 2018, which was consistent with Song et al.'s studies [30].

From Figure 5, vehicle emission of CO fluctuated between 74.40 and 80.95 thousand tons. As well, the emission of NMVOC and CH<sub>4</sub> remained almost unchanged, stabilizing around 17.00 and 2.00 thousand tons, respectively. The trends of NO<sub>x</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> were similar. Emissions of these pollutants decreased and then increased. NO<sub>x</sub>, PM<sub>2.5</sub> attained a minimum in 2016 and PM<sub>10</sub> reached its lowest level in 2017. SO<sub>2</sub> emission decreased sharply in 2014, coinciding with the implementation time of the new fuel standards. These new standards imposed stricter requirements on the maximum sulfur content in vehicle diesel and gasoline. SO<sub>2</sub> emission declined sharply again in 2017, mainly due to the substantial reduction of higher-emission motorcycles. Due to the continuous

growth of total vehicle population and the increasing vehicle use intensity, the emission of CO<sub>2</sub> increased constantly at an average annual growth rate of 9.42%.



**Figure 5.** Vehicle emission in Shanghai from 2014 to 2018.

### 3.3. Scenario Analysis

#### 3.3.1. Emission under Specific Scenario

The pollutant emissions of CO, NMVOC, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, CH<sub>4</sub> and CO<sub>2</sub> under different scenarios were listed in Table 4.

**Table 4.** Vehicle emission inventories under different scenarios (10<sup>3</sup> t).

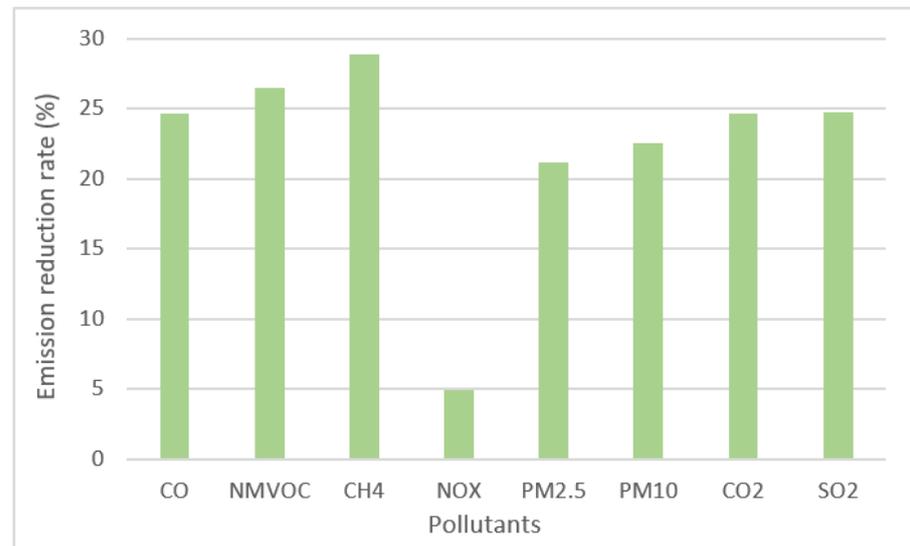
Pollutants	Scenarios		
	2018	BAU	EV-30%
CO	80951.10	144,234.88	108,737.35
NMVOC	17,249.81	25,495.76	18,751.42
CH <sub>4</sub>	2036.97	4244.83	3019.54
NO <sub>x</sub>	84,124.80	88,078.44	83,724.25
PM <sub>2.5</sub>	2762.68	4425.26	3488.84
PM <sub>10</sub>	4036.12	7460.33	5780.73
CO <sub>2</sub>	28,753,349.16	67,843,474.51	51,151,665.15
SO <sub>2</sub>	182.10	434.65	327.15

Under the BAU scenario, the vehicle emissions would increase sharply in 2025 without additional control measures. The emissions of CO, NMVOC, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, CH<sub>4</sub> and CO<sub>2</sub> would increase to 144.23, 25.50, 88.08, 0.43, 4.43, 7.46, 4.24 and 67843.47 thousand tons in 2025 with increase rate of 78.18%, 47.80%, 4.70%, 138.69%, 60.18%, 84.84%, 108.39% and 135.95%, respectively. That was because BUS and HDT were the main sources of NO<sub>x</sub>. The population of BUS and HDT increased slowly compared to other vehicle categories.

Under the EV-30% scenario, emission of CO, NMVOC, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, CH<sub>4</sub> or CO<sub>2</sub> would be 108.74, 18.75, 83.72, 0.33, 3.49, 5.78, 3.02 and 51151.67 thousand tons in 2025. Compared with 2018, the emissions would increase with rate of 34.32%, 8.71%, 48.24%, -0.48%, 26.28%, 43.22%, 77.90% and 79.66%, respectively.

### 3.3.2. Potential Reduction Analysis

The emission reduction potentials could be obtained by comparing the gap of emissions between the EV-30% scenario and BAU scenario. As well, the decreased proportions of emissions under the EV scenario compared to BAU were showed in Figure 6.



**Figure 6.** Emission reduction rate of eight pollutant under EV-30% compared with BAU.

Compared with BAU scenario, the EV-30% scenario had an overwhelming effect to reduce all the pollutants. Under EV-30% scenario, vehicle emission pollutants would be all reduced by more than 20% except for NO<sub>x</sub>. Even so, to promote the electric vehicle was still a significant way to reduce the vehicular emissions, especially in the long term.

Considering that CO<sub>2</sub> emissions from vehicles were still very high, it was far from enough to only replace the traditional vehicles with electric vehicles. Additional policies, such as improving fuel refine technology, ecological afforestation on road, and developing public traffic, should be implemented as early as possible.

## 4. Conclusions and Policy Implications

This study provided a method to estimate the potential emissions reductions achieved by promoting electric vehicles. Various data related to vehicle emissions were collected, including vehicle ownership, average driving speed, annual mileage, etc. Then the COPERT IV model was used to calculate vehicular emissions of CO, NMVOC, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, CH<sub>4</sub> and CO<sub>2</sub> between 2014 and 2018. Finally, the emission reduction potential was estimated by scenario analysis. The result provided basis and support for making policies to develop vehicle emission reduction policies.

From the case study of Shanghai, the emission inventories showed that emissions of vehicle pollutants decreased slowly between 2014 and 2016. After 2016, some pollutants showed upward trends. According to historical emission data, the emissions of CO, NMVOC, NO<sub>x</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, CH<sub>4</sub> and CO<sub>2</sub> increased by a certain extent and showed a trend of further growth. Therefore, it was necessary to formulate policies to mitigate air pollution caused by vehicles. The results of scenario analysis showed that promoting electric vehicles was the efficient measure to control vehicle emission pollutions. We estimate that CO, NMVOC, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, CH<sub>4</sub> and CO<sub>2</sub> emissions will decline by 24.61%, 26.45%, 4.94%, 24.73%, 21.16%, 22.51%, 28.87% and 24.60% respectively between 2018 and 2025, with promoting electric vehicles playing a huge role.

These results imply that, vehicular emission would increase without additional environment protection measures. In order to achieve the long-term target of vehicle emissions reductions, countermeasures, focusing on promoting electric vehicle, must be taken.

From the discussion, several policy suggestions were summarized to reduce air pollution caused by traffic.

On the one hand, promoting electric vehicles was a principle measure. Replacing traditional vehicles with new energy vehicles would have a significant potential on reducing emissions. The government could take some economic incentive policies, such as offering car purchase subsidy and reducing tax and congestion fee. These incentive policies are efficient to encourage citizens to buy electric vehicles instead of traditional fuel vehicles. As well, some traffic management measures can help to promote electric vehicles, such as giving priority to electric vehicle drivers when parking and driving and providing the right to use HOV lanes.

On the other hand, updating the emission standards and eliminating higher-emission vehicles would also help. Publishing more stringent emission standards could reduce the emission of new registered vehicle in the long term. As time goes on, vehicle performance would deteriorate and vehicle emissions would increase with age. Eliminating overage and higher-emission vehicles timely was necessary to protect the atmospheric environment, which would also play a role in the process of replacement traditional fuel vehicles with electric vehicle.

Reducing air pollution is an urgent task for governments around the world. The electric vehicle technologies are important to solve the transportation pollution problems. The enactment of supportive policies, including both regulations and subsidies, is needed to promote electric vehicles. This study provided basis and support for the promotion of electric vehicle by revealing the potential benefits can be achieved. However, enacting supportive policies was only the first step. Policies needed to be extended and expanded over time. Sustained environmental benefit assessment are necessary to continue to drive the energy transition.

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