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Evaluation of Low Emission Zone Policy on Vehicle Emission Reduction in Beijing, China

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Abstract. This study evaluates the effect of the LEZ in Beijing from the perspective of vehicle emission reduction based on developing an urban street-scale vehicle emission inventory on the basis of the local emission factors and the dynamic or static traffic data via a bottom-up approach. In 2016, before the implementation of the LEZ, the vehicle emission of CO, HC, NO_x, and PM were 49.01×10^4 , 6.31×10^4 , 5.96×10^4 , and 0.12×10^4 t, respectively. According to the simulation results, the LEZ policy would have an obviously positive effect on emission reduction, especially for CO and HC. In order to realize the long-term mitigation target, it is necessary to update and amend the detailed terms of the LEZ policy regularly according to the traffic development and vehicle emission.

1. Introduction

In recent years, due to the rapid development of social economic and urbanization process, Beijing has been frequently plagued by serious atmospheric pollution, and made great efforts to save energy and reduce emission. With the gradually effective management of coal combustion, fugitive dust and industrial point source and dust, but the increase of vehicle ownership and travelled kilometers, and the aggravated congestion, vehicle emission has contributed more and more to the deterioration of air quality especially in urban area [1].

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Vehicles consume gasoline or diesel, and release air pollutants such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NO_x), and particulate matter (PM). The emission level of an individual vehicle (also called emission factor) will increase dramatically with the vehicular ages and mileages because of the deterioration of catalyst converter and the aging of vehicle itself (usually called the old car when the vehicle is ageing). The old car is a relative term, referring the vehicles with older ages, accumulating mileages, poor conditions and low emission standards, which accounts for a very low proportion of the total vehicle amount but a very high percentage of the total emission.

Therefore the elimination and restriction of the old car, such as the establishment of low emission zone (LEZ) policy have become a common and effective measure to improve the air quality in many megacities, e.g., London, Milan, Singapore, and Stockholm [2]. In broad terms, LEZs are areas where access is restricted for certain vehicles, generally based on the emission standard the vehicle was constructed to meet, and may include a complete ban or impose a charge to enter the LEZ [3]. An LEZ essentially introduces a considerable change in the normal traffic fleet turnover, resulting in lower emission than would be experienced without the LEZ. An LEZ may cover a few roads or a large inner city area. At the beginning of the year 2017, Beijing also established an LEZ policy that the ageing light-gasoline vehicles with the control standard of CHN I and CHN II would be prohibited to drive within the 5th ring area (the urban area of Beijing in general) on weekdays [3].

In view of the above background, for decision support, this study is to evaluate the effect of the LEZ in Beijing from the perspective of vehicle emission reduction, with a method of developing an urban street-scale vehicle emission inventory on the basis of the local emission factors and the dynamic or static traffic data via a bottom-up approach.

2. Data and methodology

Figure 1 shows the technical map of emission reduction evaluation of the LEZ policy. At first, the vehicle emission inventory with high spatiotemporal resolution was built with a bottom-up method. Then the change of vehicle activity level was simulated according to the LEZ policy scenarios in order to calculate the new inventory. At last the emission reduction of LEZ was derived quantificationally by comparing these two inventories.

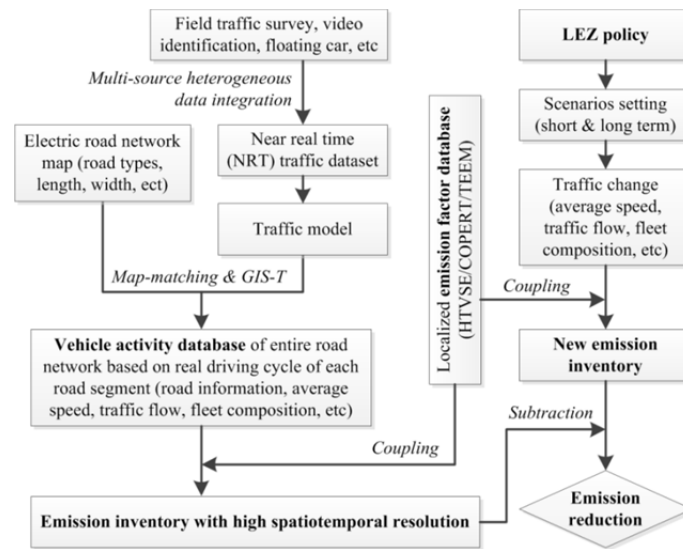


Figure 1. The technical map of emission reduction evaluation of the LEZ policy.

2.1 Vehicle emission inventory

Vehicle emission inventory refers to the total emission loads within a certain time and space, which is calculated depending on emission factors (EF) and vehicle activity.

2.1.1. Emission factors. Emission factors describe the emission characteristics of individual vehicles by computing their emission levels per mileage, time, or fuel consumption. The emission factor database of regulation pollutants (including CO, HC, NO_x, and PM) of Beijing were derived from the HTVSE system (NKU) [4], TEEM model (Transport Research Laboratory, UK), and COPERT model (European Union) [5], which had been amended and updated by adequate local measurements to improve the representativeness and authenticity of reflecting actual localized emission rates of vehicle with diversified types, fuels, I/M statuses, driving behaviours, and road attributes.

2.1.2. Vehicle activity. Vehicle activity contained traffic volume, speed, and fleet composition, which were able to reflect the real-road driving cycle and obtained by the means of field traffic survey, video identification, and floating cars [6]. All these multi-source heterogeneous data were integrated into a near-real-time traffic dataset, depending on which a traffic model could deduce the vehicle activity level of the entire road network (clustering into urban freeways, artery roads, and local roads). Then with the technology of GIS for transportation (GIS-T) including road segments cutting and map-matching, a real-driving-cycle-based vehicle activity database of the whole city was built as the inputs for the emission inventory model.

2.1.3. Emission inventory. Emission inventory was calculated and simulated with the Urban High Temporal-Spatial Resolution Vehicle Emission Inventory Model and Decision Support System (HTSVE) [4]. This system is developed by Nankai University and has been applied successfully for vehicle emission control decision support in Beijing [6], Tianjin [7], Nanjing [8], and Langfang [9]. It is able to calculate the vehicle emission inventory with high spatiotemporal resolution, and would be helpful for accurately modelling a numerical simulation of air quality in the city, which has been proposed by Jing et al. in their position papers[6].

In the HTSVE system, the hourly vehicle emission load per road segment was calculated according to the traffic volume and emission factors using a bottom-up method, as:

$$W_{i,j}^p = \sum_c EF_{c,v}^p \times Q_{c,i,j} \times L_i \quad (1)$$

where i is the road segment; j is the hour (h); c is the vehicle category; v is the travelling speed (km/h); p is the pollutant sort; $W_{i,j}^p$ is the emission of pollutant p on road segment i at time j (g); $EF_{c,v}^p$ is the emission factor of pollutant p for vehicle category c at speed v (g/km); $Q_{c,i,j}$ is the traffic volume of vehicle category c on road segment i at time j (veh/h); and L_i is the length of road segment i (km). The total urban emission of pollutant p is the summation of $W_{i,j}^p$.

2.2 Evaluation approach

According to the LEZ policy announcement of Beijing's authority, the geographical scope of the LEZ is within the 5th ring area and the restricted vehicle is the CHN-I and CHN-II light-duty-gasoline vehicle (LDGV)[4]. Besides, two scenarios of the LEZ were considered in this research, i.e., the short

term (traffic volume would be reduced as the result of restricted vehicles not travelling on the road) and long term (restricted vehicles would be replaced by compliant vehicles, and the traffic volume and speed would be restored to the pre-LEZ levels), as listed in Table 1. The base year of calculation was 2016. The evaluation indexes were the emission reduction and the traffic flow change under different LEZ scenarios, which were simulated by the HTVSE system.

Table 1. The scenarios of the LEZ policy in Beijing.

Scenarios	Implementation period
Current situation (2016)	Pre-LEZ
Scenario I	Short term
Scenario II	Long term

3. Results and discussion

3.1 Current emission

3.1.1. Vehicle amount and activity level. Beijing's vehicle amount had reached 5.7×10^6 by the end of 2016, while the total length of the road network was 2.2×10^4 km. vehicles in Beijing were classified into: (a) 8 categories according to the usage: LDV: light-duty vehicle; MDV: middle-duty vehicle; HDV: heavy-duty vehicle; LDT: light-duty truck; MDT: middle-duty truck; HDT: heavy-duty truck; Taxi; Bus. (b) 5 categories according to the control standard: CHN I, CHN II, CHN III, CHN IV, CHN V. Figure 2 shows the vehicle fleet composition and its geographical distribution. The LDV and the CHN-IV vehicles were the dominant vehicles within the 5 ring area of Beijing.

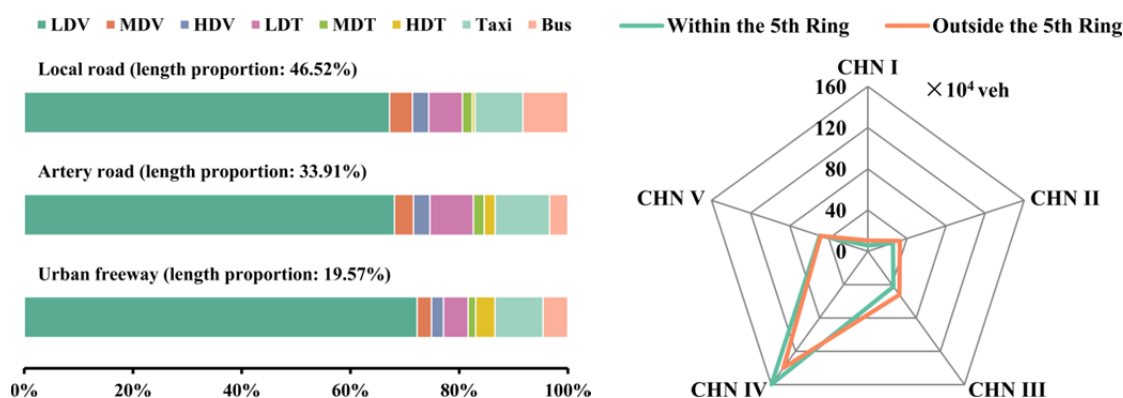


Figure 2. The vehicle fleet composition and its geographical distribution.

Figure 3 shows the daily variation tendency of vehicle traffic volume and average speed of typical roads in Beijing. The daily traffic volume featured an approximate M-shaped distribution, while the speed variation displayed a W curve, suggesting that the traffic had two peaks—early (7:00–9:00) and late (17:00–19:00)—in which the travelling speed were the slowest due to traffic congestion.

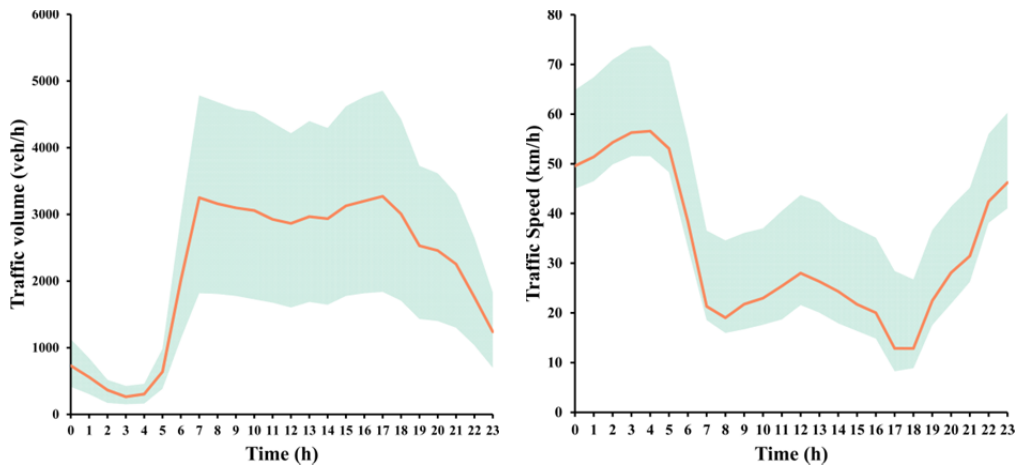


Figure 3. The daily variation tendency of vehicle traffic volume and average speed in typical roads.

3.1.2. Vehicle emission inventory. By coupling the vehicle emission factors and activity level in the HTVSE system, the emission inventory was calculated. In 2016, the vehicle emission of CO, HC, NO_x, and PM were 49.01×10^4 , 6.31×10^4 , 5.96×10^4 , and 0.12×10^4 t, respectively. Figure 4 shows the emission proportion of different vehicles. Although the amount of the CHN-I and CHN-II light-duty-gasoline vehicles was very few, they contributed significantly to the pollutants emission. Therefore, it was very necessary to restrict the driving of these vehicles.

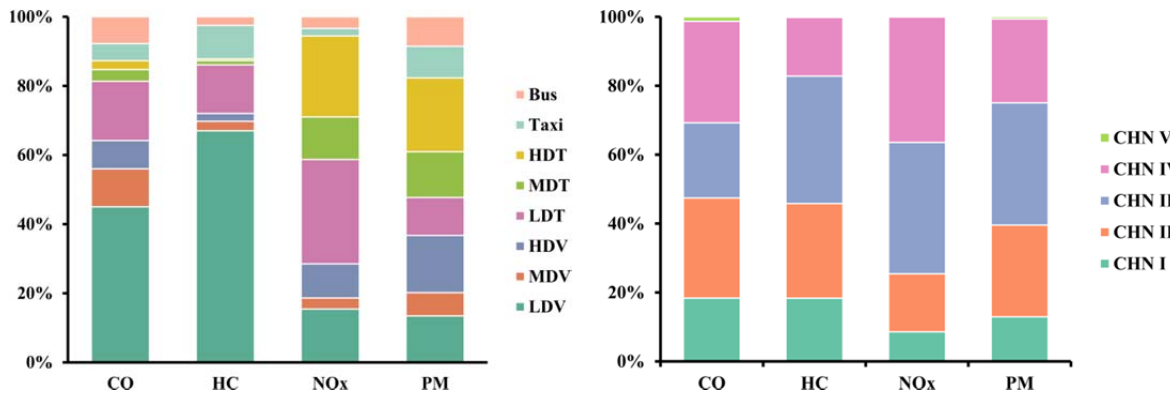


Figure 4. The emission proportion of different vehicles.

3.2 Evaluation of LEZ

3.2.1. Traffic flow effect. The LEZ policy would change the traffic flow of the road network. According to simulation results by the traffic model embedded in the HTVSE system, in Scenario I (short term LEZ), the traffic volume was reduced as the result of restricted vehicles not travelling on the road, and the daily average speed of the road network would be increased from 30.1 km/h (current situation) to 34.3 km/h, and the speed of peak hours would be increased from 22.9 km/h (current situation) to 25.7 km/h, suggesting that the LEZ policy was very helpful for easing urban traffic jams. However in Scenario II (long term), the restricted vehicles would be replaced by compliant vehicles, and the traffic volume and speed would be restored to the pre-LEZ levels.

3.2.2. *Emission reduction of LEZ.* Figure 5 shows the emission reduction of the 2 LEZ policy scenarios. Additionally, the gridding emission display of these scenarios simulated by the GIS tool of the HTVSE system is shown as Figure 6.

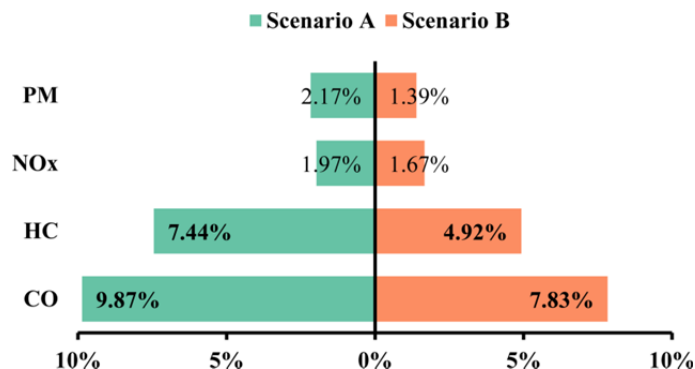


Figure 5. The emission reduction of the 2 LEZ policy scenarios.

From the simulation results, the LEZ policy had an obviously positive effect on emission reduction no matter the period was short term or long term, especially for CO and HC because of the restricted of the light-gasoline vehicles which were the biggest emitters of these two pollutions and accounting for a large proportion of the total vehicle population, in contrast the reductions of NO_x and PM were comparatively lower.

On account of the distinct decreasing of the on-road vehicles and improving of traffic congestion, the emission reduction of Scenario I was relatively higher than that of Scenario II. Nevertheless, from the experiences of LEZ in Europe, that vehicle emission would gradually return to the level of pre-LEZ years later since the vehicles are aging and the catalytic converter is deteriorating [10]. As a result, in order to realize the long-term mitigation target, it is necessary to update and amend the detailed terms of the LEZ policy regularly according to the traffic development and vehicle emission.

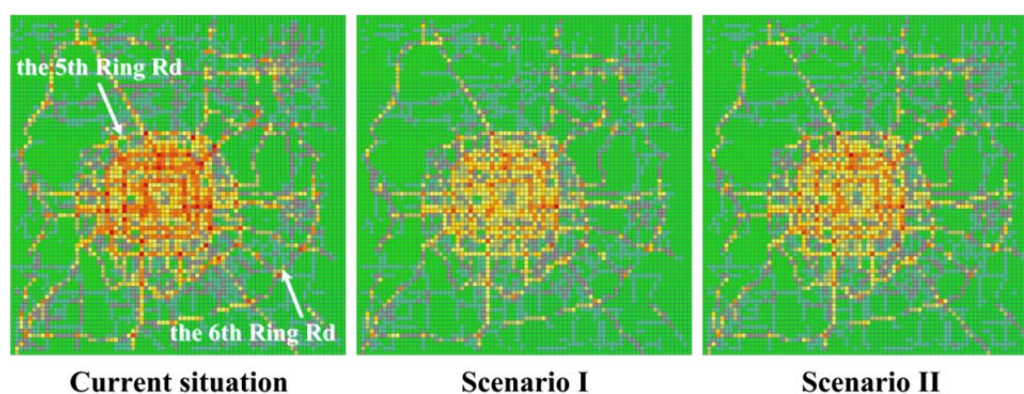


Figure 6. The gridding emission display of the 2 LEZ policy scenarios (1 km × 1 km) (CO is taken for example here).

4. Conclusions

Based on developing an urban street-scale vehicle emission inventory with high spatiotemporal resolution on the basis of the local emission factors and the dynamic or static traffic data via a bottom-up approach, this study evaluates the effect of the LEZ in Beijing from the perspective of vehicle emission reduction.

In 2016, before the implementation of the LEZ, the vehicle emission of CO, HC, NO_x, and PM were 49.01×10^4 , 6.31×10^4 , 5.96×10^4 , and 0.12×10^4 t, respectively. According to the simulation of the HTVSE system, the LEZ policy would have an obviously positive effect on emission reduction no matter the period was short term or long term, especially for CO and HC. And the emission reduction of the short-term LEZ would be relatively higher than the long-term. In order to realize the long-term mitigation target, it is necessary to update and amend the detailed terms of the LEZ policy regularly according to the traffic development and vehicle emission.

Acknowledgements

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