Assessing the GHG mitigation effect of the *National VI Emissions Standard* for light duty vehicles in China

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**Abstract**

Assessing the mitigation effect on greenhouse gas (GHG) reduction of the *National VI Emissions Standard* bears great significance in enhanced actions on climate change in China. This research established a reference scenario and *National VI* scenario to evaluate whether the *National VI Emissions Standard* could make a contribution to synergistic emission reduction. Here are the main conclusions: carbon dioxide (CO\(_2\)) was the majority GHG emissions type, accounting for around 99% of GHG emissions between 2019 and 2025 for these two scenarios; implementing the *National VI Emissions Standard* will not mitigate total GHG emissions from 2019 to 2025, but the *National VI Emissions Standard* could help mitigate methane (CH\(_4\)) and nitrous oxide (N\(_2\)O), not CO\(_2\) if considering the mitigation effect from the perspective of GHG type. Based on the results and discussion, this research suggests to consider the economic and technical feasibility of incorporating carbon emissions limits into the *National VII Emissions Standard* while continuing the evaluation of the *National VI Emissions Standard*.

**Keywords** *National VI Emissions Standard* · Carbon emission reduction · Policy recommendation · China

**Introduction**

The Paris Agreement reiterates the political consensus on the long-term goal of keeping the increase in global average temperature to well below 2 °C above preindustrial levels and urges all the parties to make efforts together toward the hope of a temperature increase no more than 1.5 °C (UNFCCC, 2015; Liu et al., 2017). This agreement requires all the nations to make a contribution to decarbonization and leave no one behind (Höhne et al., 2020); the Chinese government fulfills the Paris Agreement and pledges to achieve a carbon peak before 2030 and achieve carbon neutrality before 2060. The Chinese government’s commitment requires deep, rapid transformations and slashing emissions domestically; meanwhile, the industry sector, building sector, and transportation sector will play important role in deep decarbonization, due to the fact that these three sectors are the first three emitters in China (Liu et al., 2016; Chai et al., 2017; Tian et al., 2019). Many researches showed that the transportation sector of China will not peak before 2030 due to huge increasing transport demand (Yuan et al., 2021; Xie et al., 2020; Zhu, et al., 2017; Liu et al., 2018; Yin et al., 2015). Furthermore, the road-based transport is the largest emission source in the transportation sector (Xue et al., 2019), accounting for 82.7% of total CO\(_2\) emission in the entire transportation sector in 2015 (Zhang et al., 2019); thus, road-based transport has a much larger CO\(_2\) emission reduction potential compared to other transport modes (Yi et al., 2017; Wang et al., 2017; China Academy of Transportation Science, 2019).

Many researches applied models and scenarios to find pathways to control the energy use of the transportation sector. The models include Leap (Yi et al., 2017), Vensim (Tian et al., 2019), CGE (Du et al., 2020), PECE (Liu et al., 2018), IPAC (Jiang et al., 2021), and TIMES (Zhang et al., 2016). The pathway includes lowering down transport demand, improving the fuel economy of traffic transportation or promoting electrification of the transportation sector (Wang and He, 2018; Pan et al., 2018; Zheng et al., 2015; Cai et al.,...
The energy use of on-road vehicles is the focus of energy saving and emission reduction in the transportation sector. For example, in order to reduce carbon emissions in the transportation sector, EU has set the CO₂ emission reduction targets for passenger vehicles and light commercial vehicles respectively (ICCT, 2019). China has established a relatively complete policy system for the passenger cars, and its criteria for corporate average fuel consumption are in line with the international standards; unfortunately, the CO₂ emission limit for vehicles has not yet been released in China. It is necessary to achieve emission reduction by developing the energy saving technology and new energy vehicles (NEVs) (Wang et al., 2017). For example, the electric vehicles are the key measures to slow down the energy use of the transport sector (Qi et al., 2017; Zhuang and Jiang, 2012); however, the electric vehicles could not stop the increase of energy use of the transportation sector because of low share of electric vehicles in total vehicles fleet for the short-term, although electric vehicles have already gradually permeated into automobiles fleet quickly. The energy use of the transportation sector would still increase driven by fuel-based automobiles, the policymakers need to push forward policies or measures to slow down the trend.

However, the problem of conventional air pollutants such as carbon monoxide (CO), hydrocarbons (HC), N₂O, and particulate matter (PM) emitted from fuel-based automobiles might be more urgent than the problem of CO₂ emission, because fuel-based automobiles are one of the major sources of air pollution in regions undergoing urbanization (Ma and Zhang, 2000). The four conventional air pollutants from fuel-based automobiles in 2019 were primarily estimated at 160 million tons in total (MEE, 2019). In order to control the conventional air pollutants, series of motor vehicle emissions standards have been launched by following the practices of Europe. The Stage I standard for motor vehicle emissions (also called the National I Emissions Standard) was promulgated in 2000, and then the National II Emissions Standard in 2005, the National III Emissions Standard in 2008, the National IV Emissions Standard in 2011, and the National V Emissions Standard in 2017 respectively, while the latest National VI Emissions Standard was put into effects since 2019. The increasingly strict standards greatly facilitate the emission reduction of pollutants from motor vehicles (Liang et al., 2011), for example, the total fleet of motor vehicles in 2019 was 1.8 times larger than that in 2010; however, the total conventional air pollutants from motor vehicles in 2019 was only 30.8% of that in 2009 (MEE, 2011; MEE, 2019). Whether the emission standards could help mitigate the GHG emission is unclear, few research was carried out to assess the mitigation effect of motor vehicle emission standards. The government would still insist in implementing the motor vehicle emission standards and even carry out much stricter standards due to the fuel-based automobiles would still be the mainstream vehicle type for some time. Thus, it has great importance to make it clear whether motor vehicle emissions standards could make a contribution to GHG emission mitigation.

Based on a literature review on emission standards for motor vehicles and regulating the energy consumption of the transportation sector, this research applied scenario analysis to assess the mitigation effect on GHG emissions before and after the implementation of the National VI Emissions Standard, in order to provide evidence to make it clear whether emission standards could help mitigate GHG emissions and provide support for policymakers to decide how to improve the emission standards.

Methodologies and scenario setting

Methodologies

Limits and measurement methods for emissions from light-duty vehicles (short for National VI) (GB 18,352.6–2016) is taken into full effect by two stages: the National VI Stage I (National VIa) which came into effect on July 1, 2020, at the national level and the National VI Stage II (National VIb) which is due to take effect on July 1, 2023, at the national level. The National VIb adopts stricter requirements for CO, CH, and PM than the National VIa. The National VI Emissions Standard is much stricter than the European phase VI emission standard limit level, indicating Chinese emission standards for vehicles have the ability to surpass the Europe, not just following the step of Europe. In fact, several provinces and cities have implemented the National Via since 2019 before the National Via took effect at the national level; furthermore, Guangdong, Shenzhen, Shanghai, and Beijing directly entered the National VIb. Therefore, this research mainly fixed the time span between 2019 and 2025. The National VI Emission Standard is designed for newly sold light-duty vehicles and has no bind on light-duty vehicles having been sold before 2019; thus, this research assessed the GHG mitigation effect of the National VI Emissions Standard only target at the newly sold light-duty vehicles registered after 2019 abiding by the National VI Emissions Standard.

It is necessary to define the concept of a light-duty vehicle. Automobiles could be divided into two categories in China, namely passenger vehicles and commercial vehicles; the private cars are counted into the category of passenger vehicles, while the commercial vehicles could be further divided into two sub-categories, namely light commercial vehicles and heavy commercial vehicles. The passenger vehicles and light commercial vehicles could be merged into one group called light-duty vehicles, which the National VI Emissions Standard applies to. Then, it is also necessary to
make it clear what kinds of GHG are emitted from light-duty vehicles. Light-duty vehicles may emit multiple types of gasses into the air, such as CO$_2$, CO, HC, N$_2$O, CH$_4$, and PM. Among them, CO$_2$, CH$_4$, and N$_2$O have the greenhouse effects; thus, these three gasses were selected to assess the GHG mitigation effect. Aggregated GHG emissions in this research are stated in CO$_2$-equivalent (CO$_2$-eq) using the Global Warming Potential with a time horizon of 100 years (GWP100) with values based on the contribution of Working Group I to the AR6. The GWP100 of CH$_4$ is 29.8, while the GWP100 of N$_2$O is 273 (IPCC, 2020). The GHG emissions of light-duty vehicles are calculated by Eq. (1) as shown below. In Eq. (1), $TG$ refers to the aggregated GHG emissions; $SN_i$ refers to the sales of vehicle type $i$; $DD_i$ refers to the driving distance per year for vehicle type $i$; and $EI_{ij}$ refers to the emission factor per mileage of greenhouse gas type $j$ for the vehicle type $i$.

$$TG = \sum SN_i \times DD_i \times EI_{ij}$$  

(1)

The sales of automobiles for past years were obtained from the China Statistical Yearbooks (NBSC, 2020), while the sales of automobiles for future years were from the author’s estimation or transport experts’ consultation. Because the time span for this research is just 7 years, this research assumed all the new sales would not be retired before 2025. The parameter driving distances per year of specific vehicles were provided by the China Association of Automobile Manufacturers (CAAM), while the parameter emission factors per mileage were from emission standards, CAAM, and literatures.

**Scenarios setting**

This research designs two scenarios, namely the reference scenario and the National VI scenario. The reference scenario assumes that the National V Emissions Standard is still in effect and the National VI Emissions Standard has not taken effect, indicating that all the new sales of light-duty vehicles will still follow the National V in this scenario; in fact, the reference scenario does not reflect the real situation, and this research proposed this scenario to compare the change in GHG emission when carrying out the National VI Emission Standard. The National VI scenario is the scenario that the National VI Emissions Standard has been practically put into effect just like the real situation; in this scenario, all the parameters are the same with the reference scenario except the fuel economy and emission intensity of CH$_4$ and N$_2$O. Implementing the National VI Emissions Standard would slightly undermine the fuel economy of new light-duty vehicles by increasing around 2.0% of energy use per kilometer for an individual vehicle (Yang et al., 2018), because the vehicles manufacturers produce the light-duty vehicles abiding by the National VI Emissions Standard through installed additional exhaust gas treatment equipment, leading to the decreasing of fuel economy. The emission reduction effect of the National VI Emissions Standard defined in this research means the difference between GHG emissions of all new light-duty vehicles between the reference scenario and National VI scenario.

The total sales of automobiles in 2020 was 25.31 million, which dropped by 1.7% compared to that in 2019 due to COVID-19 (NBSC, 2021). However, China has already recovered from the pandemic at some extent with the growth rate of GDP positive (Li et al., 2020; Lu, 2019), the new sales of an automobile would stop falling and enter the increasing track with high possibility (CAAM, 2021). The CAAM also predicted that the growth rate of new sales of an automobile will keep at 4% during the 14th five-year plan period (XHN, 2021), and this research followed this prediction in both of these two scenarios. In 2020, the share of new sales of NEVs in total new sales of automobiles was 5.45%, while the Chinese government expected the new sales of NEVs will account for 20% of total new sales of automobiles in 2025; however, the penetration rate of NEVs in 2021 has been 14.3% (CAAM, 2022), and experts optimistically estimated that the penetration rate of NEVs would reach to 30% in 2025. This research believed 30% in 2025 for passenger vehicles could be easily achieved, but would be not easily achieved for light commercial vehicles because the electricity-based light commercial vehicles are not acceptable by consumers. This research assumed different development targets for passenger vehicles and light commercial vehicles (Table 1). The share of new sales of passenger vehicles and light commercial vehicles in total new sales in 2020 was 79.6% and 6.64%, and this research assumed these two shares would not be changed before 2025. There is no emission limit for CH$_4$ and N$_2$O in the National VI Emissions Standard, and this research cited the emission factors for CH$_4$ and N$_2$O for on-road vehicles by the US Environmental Protection Agency (EPA). The emission factors for CH$_4$ and N$_2$O in EPA Tier 2 represent the National V Emissions Standard, while the EPA Tier 3 represents the National VI Emissions Standard (EPA, 2022).

Furthermore, evidence shows the difference between the real fuel economy and the certified fuel economy of the light-duty vehicles in China is as high as 29% on average (Li, 2018). For example, the certified fuel use for the passenger vehicle and light commercial vehicles in 2025 will be 4.5 L per 100 km and 5.5 L per 100 km, while the real fuel use for a passenger vehicle would be 5.8 L per 100 km, 7.1 L per 100 km for a light commercial vehicle. Correspondingly, the carbon emission intensity for a passenger vehicle in 2025 would be 131 g CO$_2$ per kilometer and 161 g CO$_2$ per kilometer for a light commercial vehicle (Table 1). It should be noted that implementing the National VI Emissions Standard
might change consumers’ preferences; however, it is unclear how many consumers will change their minds to choose NEVs because of National VI Emissions Standard; thus, this research assumed the consumers’ preferences could not change.

Results analysis and discussion  The effects of GHG emissions reduction

If comparing the aggregated GHG emissions of every single year from 2019 to 2025 (Table 2), it could find that the aggregated GHG emissions under the National VI scenario would always be larger than that in the reference scenario. The aggregated GHG emissions of the National VI scenario in 2025 would be 242.0 million-ton CO₂e, while the reference scenario would just be 237.4 million-ton CO₂e. Furthermore, if comparing the cumulative aggregated GHG emissions from 2019 to 2025 between National VI scenario and the reference scenario, the National VI scenario has emitted more GHG emissions by 18.42 million tons of CO₂e than the reference scenario, accounting for about 2.1% of the cumulative aggregated GHG emissions in the reference scenario from 2019 to 2025. It means that implementing the National VI Emissions Standard will not reduce the GHG emissions.

However, if considering the mitigation effect from the perspective of GHG types (Table 2), it could find that the CH₄ emissions and N₂O emissions in the National VI scenario were smaller than that in the reference scenario from 2019 to 2025 due to the stricter emission standard, since the

| Variables | Unit | 2019  | 2020  | 2021  | 2022  | 2023  | 2024  | 2025  | 2019–2025 |
|-----------|------|-------|-------|-------|-------|-------|-------|-------|-----------|
| Sales of automobiles | Million | 25.76 | 25.31 | 26.32 | 27.38 | 28.47 | 29.61 | 30.79 |
| The share of NEVs in new sale passenger vehicles | % | 5.0 | 5.45 | 13.4 | 18 | 22 | 26 | 30 |
| The share of NEVs in new sale light commercial vehicles | % | 5.0 | 5.45 | 7 | 9 | 12 | 16 | 20 |
| New Sales of passenger vehicles abiding by National VI | Million | 7.07 | 13.33 | 18.14 | 17.87 | 17.68 | 17.44 | 17.16 |
| Sales of light commercial vehicles abiding by National VI | Million | 0.34 | 0.99 | 1.63 | 1.65 | 1.66 | 1.65 | 1.64 |
| Annual mileage | km | 13,000 | (passenger vehicles) | 28,000 | (light commercial vehicles) |
| Fuel economy of passenger vehicles | L/100 km | 5 | 5 | 4.9 | 4.8 | 4.7 | 4.6 | 4.5 |
| Fuel economy of light commercial vehicles | L/100 km | 5.7 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 |
| Actual carbon emission intensity of passenger vehicles | gCO₂/km | 146 | 146 | 143 | 140 | 137 | 134 | 131 |
| Actual carbon emission intensity of light commercial vehicles | gCO₂/km | 167 | 161 | 161 | 161 | 161 | 161 | 161 |
| CH₄ emissions level | mg/km | 4.85 | (V) | 1.37 | (VI a) | 1.37 | (VI b) |
| N₂O emissions level | mg/km | 5.10 | (V) | 4.16 | (VI a) | 4.16 | (VI b) |

Table 2 GHG emissions in reference scenario and National VI scenarios (million-ton CO₂e)
reference scenario still implemented the National V standard which had a higher emission intensity than that in National VI scenario (Table 1); on the contrary, the CO₂ emissions in the National VI scenario were larger than that in the reference scenario, and the CO₂ was the majority greenhouse gas type, accounting for around 99% of GHG emissions in each year in the reference scenario and National VI scenario. The cumulative CO₂ emissions in the National VI scenario have been larger by 2.4% than that in the reference scenario from 2019 to 2025, while the cumulative emissions of CH₄ and N₂O in the National VI scenario have been smaller by 71.7% and 18.2% than that in reference scenario (Fig. 1).

The reasons why the National VI Emissions Standard can not synergistically mitigate GHG emission mainly lie in two aspects. First, whether the National VI Emissions Standard could cut emissions mainly hinges on the actual pathways of emissions reduction. Currently, the fuel-based vehicles mainly mitigate conventional air pollutant emissions through a series of exhaust gas treatment technologies, such as turbocharger, hybrid-power, lean combustion, variable valve timing, exhaust gas recirculation, and three-way catalyst (Xu and Shi, 2017; Wu and Yang, 2013; Si, 2010), while developing an advanced engine product also help to mitigate conventional air pollutions, and an advanced engine product is the feasible pathway to adopt to a stricter emissions standard for the long-term scale not just in China, but also at broad. However, developing an advanced engine product would take 4 to 5 years to be put into operation (Pan, 2018). As a result, the automobile manufacturers tend to upgrade the exhaust gas treatment technologies before the National VI Emissions Standard was expired which may lead to a slight increase in fuel consumption for an individual vehicle (Yang et al., 2018). That is why the National VI Emissions Standard has increased CO₂ emissions slightly. Second, regarding emissions of non-CO₂ GHG, although the National VI Emissions Standard could significantly reduce N₂O and CH₄ emissions, the share of non-CO₂ GHG in the aggregated GHG emissions is relatively low, because the major of aggregated GHG emissions is still CO₂ emission.

It is clear that one NEV could emit no air pollutants compared with the fuel-based light-duty vehicles, indicating that the increase in the shares of NEVs in light-duty vehicles would significantly reduce GHG emission. This research wants to focus on the GHG mitigation effect of the National VI Emissions Standard for light-duty vehicle in China. Furthermore, consumers’ preferences would be changed because of implementing the National VI Emissions Standard, and the consumers show more propensity to buy the NEVs due to the predictable stricter emissions standards; however, it is quite difficult to measure how many consumers would change their willingness to buy NEVs. Thus, the share of NEVs in new light-duty vehicles is the same in the reference scenario and National VI scenario, leading to the increase of NEVs have no influence on the GHG mitigation between the reference scenario and National VI scenario.

Comparison of carbon emission intensity of automobile

By 2019, 348 million automobiles were registered in China, of which 230 million were private vehicles. The annual increment still stays around 20 million though the growth rate of the automobile fleet has slowed down in recent years (NBSC, 2020). NEVs could not replace the fuel-based vehicles in the short term, fuel-based vehicles will remain dominant in the road traffic field, and GHG emissions from automobiles will still increase with a relatively fast growth rate; thus, it has great importance of updating the emission standard. According to the analysis results above, the National VI Emissions Standard could exert some active role in the synergistic mitigation of GHG emissions; however, in a limited manner, as a result of the failure to constrain the carbon emissions from automobiles, the emission standard could not rule carbon intensity of fuel-based vehicles.

The fuel economy and carbon intensity of light-duty vehicles in China still have great potential for improvement. In the Energy-saving and New Energy Vehicle Industry Development Plan (2012–2020), it is pointed out that by 2020, the average fuel use of passenger vehicles manufactured in the year is expected to be reduced to 5.0 L per hundred kilometers, and for energy-saving passenger vehicles, it would be reduced to 4.5 L per hundred kilometers. In recent years, despite the remarkable decline in average fuel use among passenger vehicle makers as published by the Ministry of Industry and Information Technology (MIIT), many research institutes have discovered the great difference between the real fuel consumption and comprehensive operation-mode fuel consumption (Pan, 2018; iCET, 2015; iCET, 2016). At the current stage, although the transportation sector has

![Fig. 1 The emission changes in different GHG types](image-url)
made great achievement especially in the field of transportation infrastructure and transportation technologies in China, however, the fuel economy and the carbon intensity of automobiles have always fallen behind the developed countries like the EU and South Korea (ICCT, 2019), as shown in Fig. 2.

Incorporating GHG emission limits into the emissions standards for motor vehicles became the global trend, and countries like the EU, Canada, the US, and South Korea have already started adopting GHG emission limits as an important indicator of the fuel economy in a bid to signal their initiative in tackling the climate change. However, GHG emission limits have yet to be incorporated into the fuel economy-related or emission control standards in China. Thus, it is difficult for the policymakers in China to control the growing GHG emissions from road traffic. Therefore, it is necessary to directly include the carbon emission limits into subsequent emissions standards for automobile and gradually implement a standard that enables synergistic mitigation of conventional air pollutant emissions and GHG emissions.

Limitations.
There were several uncertainties in this research. First is the uncertainty associated with data sources; there are several empirical assumptions to support this research, like annual mileage and the difference between the real fuel consumption and the certified fuel consumption of the light-duty vehicles. The second is the uncertainty about the future; COVID-19 is still spreading around the world, and the future global economy is still unclear. However, this research assumed that the new sales of light-duty vehicles will increase based on an implicit hypothesis that China would battle with the epidemic successfully and the domestic economy will recover successfully. The third is that this research only considered three common greenhouse gas type, CO₂, CH₄, and N₂O; the other greenhouse gas type like chlorofluorocarbon (CFCs) were not considered due to lacking data.

Conclusions and policy suggestions  Main conclusions

Improving the emission standard for automobiles is the fundamental requirement and inevitable choice for the automobile industry in the medium and long term. Evaluating the mitigation effect of the National VI Emissions Standard on GHG emissions is of great significance for implementing the national climate strategy and facilitating the nationally determined contributions to peaking carbon emissions. This research compared the differences of GHG emissions in the reference scenario and the National VI scenario to assess synergistic GHG mitigation effect-oriented to the National VI Emissions Standard. The main analysis results are as follows: The CO₂ was the majority greenhouse gas type accounting for around 99% of GHG emissions between 2019 and 2025 for the reference scenario and National VI scenario; the cumulative CO₂ emissions between 2019 and 2025 in National VI scenario would be larger than that in reference scenario by 2.4%, while the cumulative CH₄ and N₂O were smaller by 71.7% and 18.2% respectively; furthermore, if considered the mitigation effect from the perspective of aggregated GHG emissions, the cumulative aggregated GHG emission in National VI scenario from 2019 to 2025 would be larger than that in reference scenario by 2.1%.

Policy suggestions

Given the conclusions and discussions above, the following suggestions are proposed:

Consider the economic and technical feasibility of incorporating carbon emissions limits into the future National VII Emissions Standard while continuing the evaluation of the National VI Emissions Standard.

Besides, it is also suggested to organize relevant institutes and researchers to assess the standards that enable synergistic mitigation of conventional air pollutants and GHG emissions during the 14th Five-year Plan period and also make efforts to verify the carbon emission intensity limit correspondence to National VI Emissions Standard; explore the feasibility of incorporating the carbon emissions limits into the future National VII Emissions Standard, put them into trial, and make a transition during the 15th Five-year Plan period, thus leading the use and production of automobiles towards a green low-carbon direction by strictly enforcing the carbon emissions limits, and encouraging the penetration rate of NEVs in total vehicle fleet.

Give full play to the role of carbon emissions standards in driving technical breakthroughs in the automobile sector.

Fig. 2 The comparison of fuel economy of automobiles in different countries
Taking the 14th Five-year Plan period as an important window period of opportunity, efforts should be continued to improve relevant national standards for energy efficiency, pollutants, and GHG emissions limits, so as to clarify the national expectations for enhancing control over carbon emissions from the automobile sector, encourage automobile makers to increase their innovative inputs into advanced green technologies, and facilitate the R&D of diversified technologies that make vehicles lighter, smarter, electronic and hydrogen-powered, thereby securing competitive edge in the new wave of global transformation of vehicle technologies.

Play the role of carbon emission standards in supporting carbon emission peaking in the transportation sector.

It is advised to implement strict national emissions standards for pollutants and GHG emissions from automobiles and incorporate relevant policies and actions into the action plan for delivering the nationally determined contributions by 2030 and peaking carbon emissions as early as possible. Besides, efforts should be made to help the transportation sector achieve carbon emissions peaking, make breakthroughs in optimizing the transportation structures, and gradually eliminate the conventional fuel-based vehicles.

Author contribution Xiaoqi Zheng: conceptualization, methodology, data curation, and writing—original draft. Qimin Chai: conceptualization, methodology, and writing—original draft. Yi Chen: data curation and writing—original draft. Xiaomei Li: conceptualization and methodology.

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