OCTOBER 2021

# Policy recommendations to reduce pollution from Hainan's on-road vehicle fleet

## BENCHMARKING WITH INTERNATIONAL BEST PRACTICES

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## ACKNOWLEDGMENTS

Funding for this work was generously provided by Rockefeller Brothers Fund and Energy Foundation China. The authors thank the Hainan Department of Ecology and Environment for their support and Michael Walsh, Felipe Rodríguez, Chunxiao Hao, Jianhua Chen, and Wenshuai Xu for their constructive reviews of an earlier version of this paper. Their support and reviews do not imply any endorsement, and any errors are the authors' own.


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The International Council on Clean Transportation (ICCT) is an independent nonprofit organization founded to provide first-rate, unbiased technical research and scientific analysis to environmental regulators. Its mission is to improve the environmental performance and energy efficiency of road, marine, and air transportation to benefit public health and to mitigate climate change.

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The Vehicle Emission Control Center (VECC) of the Chinese Research Academy of Environmental Sciences (CRAES) is the only provider of technical support for the management of vehicle-related environmental protection in China. It supports China's Ministry of Ecology and Environment on policy development regarding emissions monitoring and emissions control of mobile sources, and is responsible for information disclosure and compliance management of mobile source emissions.


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# EXECUTIVE SUMMARY

China's southernmost province, Hainan, is in the process of becoming the largest Free Trade Port (FTP) in the world. This tropical island province has made environmental improvement its highest priority as it pursues development of the FTP. It envisions building a world-class environmentally friendly economy by 2035 to attract investment, business, talent, and tourists from around the world.

Although already boasting the cleanest air in China, Hainan's pollution levels are still some distance from the new WHO air quality guidelines. In 2019, Hainan's annual average $PM_{2.5}$ concentration was 16 μg/m$^3$, 220% higher than the WHO-recommended level of 5 μg/m$^3$. The 90th percentile of daily maximum 8-hour ozone concentrations in Hainan was 118 μg/m$^3$ in 2019, 10% higher than the previous year and 18% above the WHO-recommended daily level of 100 μg/m$^3$.

On-road vehicles are recognized as the primary source of Hainan's $PM_{2.5}$ pollution, with a contribution of 30%, and an important contributor to Hainan's ozone pollution. Local environmental policymakers are clear that on-road vehicles are the key obstacle to achieving Hainan's air quality targets. This report provides policy recommendations for reducing pollution from Hainan's on-road vehicle fleet during the 2021–2035 period, through policy benchmarking with international best practices. Our key finding and policy recommendations are summarized in Table ES-1.

**Table ES-1.** A summary of policy recommendations for Hainan

| Policy category | Area | Evaluation of current program | Policy recommendations |
|---|---|---|---|
| Vehicle electrification | LDV | Yellow | • Leverage more comprehensive, powerful, and innovative policy measures to achieve the full electrification ambition |
| | HDV | Yellow | • Develop a clear electrification roadmap for heavy-duty trucks<br>• Leverage comprehensive demand- and supply-side policy measures to stimulate electric truck deployment |
| | Grid mix | Yellow | • Keep greening grid mix by increasing the share of electricity generated from renewable energy sources |
| New vehicle emission standards and compliance | LDV | Yellow | • Effectively enforce the China 6 standards<br>• Closely track the development of China 7 and Euro 7 standards<br>• Adopt as soon as practicable the China 7 standards to stimulate the full transition to electric vehicles |
| | HDV | Yellow | • Effectively enforce the China VI standards<br>• Closely track the China VII and Euro VII standards<br>• Adopt as soon as practicable the China VII standards to stimulate the transition to low-NOx and zero-emission vehicles |
| | Compliance | Yellow | • Leverage various new technologies, including remote sensing and remote OBD, to improve the robustness of vehicle emission compliance programs |
| In-use vehicle emission control programs | In-use inspection | Yellow | • Enhance the use of OBD data in I/M programs<br>• Use multiple data sources, including remote sensing, to inform and cross-validate I/M |
| | In-use fleet regulations | Brown | • Leverage both incentives and regulations to encourage legacy in-use fleets to be replaced by zero-emission vehicles, when feasible, or meet new vehicle emission standards through retrofiting, repowering, or vehicle replacement |
| | Idling rules | Brown | • Introduce idling rules to reduce idling emissions |
| Fuel quality standards and compliance | Gasoline | Yellow | • Effectively enforce the China VI gasoline fuel quality standards<br>• Tighten gasoline RVP requirements |
| | Diesel | Blue | • Effectively enforce the China VI diesel fuel quality standards |
| | Compliance | Yellow | • Introduce certification, data reporting, and liability tracking mechanism to ensure comprehensive supervision throughout the entire fuel supply chain<br>• Increase frequency of fuel quality inspections and sample size<br>• Introduce robust penalties on non-compliant stakeholders<br>• Pursue authority for environmental agencies to conduct separate fuel quality inspections focusing on emission-related specifications |
| Low/Zero emission zone | | Brown | • Develop LEZ/ZEZ schemes based on feasibility analysis<br>• Implement LEZ/ZEZ schemes in a phased manner, with pilot programs initiated first |

**Blue** strong compared with reviewed best practices
**Yellow** weak, incomplete, or less comprehensive than reviewed best practices
**Brown** absent/lacking critical components compared with reviewed best practices

We also evaluate the emission reduction potential of effectuating these policy recommendations in Hainan. As shown in Figure ES-1, three scenarios are analyzed. Scenario Business-as-Usual (BAU) reflects policy measures implemented in Hainan as of the baseline year (i.e., 2018). Scenario ADOPTED reflects policy measures adopted to date and to be implemented in Hainan no later than 2035. Scenario POTENTIAL reflects the international best practices we recommend Hainan adopt and implement during 2021–2035.

With no new policy measures implemented after 2018, the emissions of NOx, PM, VOCs, and CO from Hainan's on-road vehicle fleet will experience a continuous increase and double the 2018 values by 2035. This is mainly because demand for passenger and freight transportation in Hainan will grow significantly in the years ahead with the development of the Hainan FTP.

If Hainan were to enforce strictly all currently adopted policies and realize their announced vehicle electrification ambition, the NOx, PM, VOCs, and CO emissions from Hainan's on-road vehicle fleet would decrease by 74%, 74%, 75%, and 73%, respectively, in 2035, compared to the BAU scenario. Potential policies based on the international best practices are expected to further reduce the NOx, PM, VOCs and CO emissions by 57%, 29%, 14%, and 14% in 2035. Part of the identified policy opportunities are not reflected in the emission modeling due to data deficiencies or uncertainties in scheme design; therefore, the estimated emission reduction benefits are conservative.

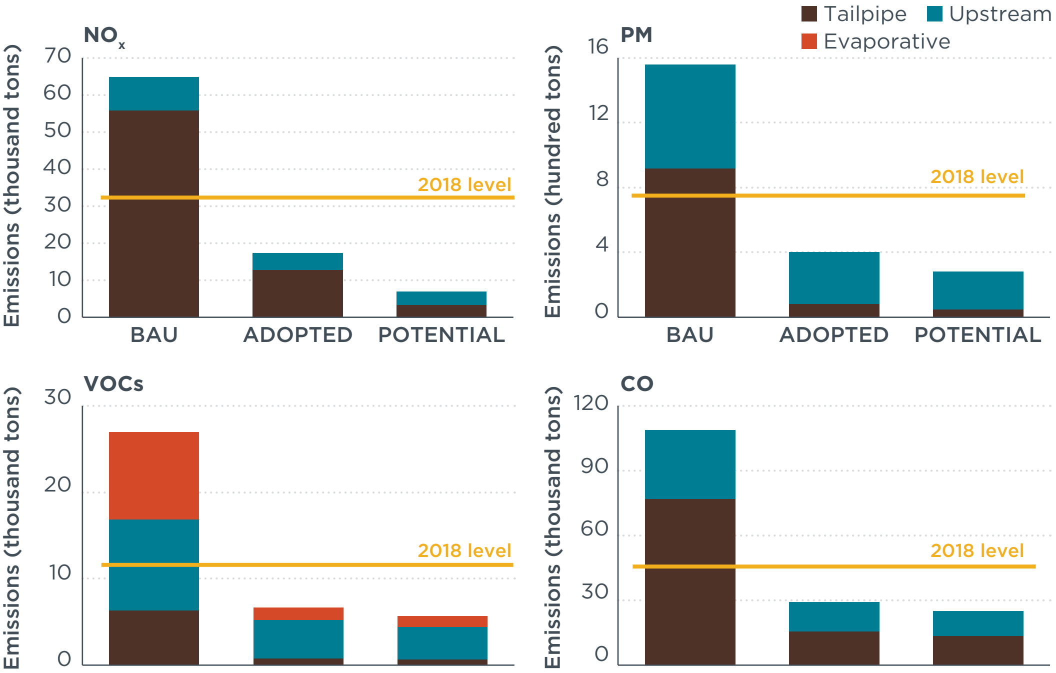


**Figure ES-1.** Fuel cycle emissions from Hainan's on-road vehicle fleet in 2035 under different scenarios

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# ABBREVIATIONS

| | |
|---|---|
| APS | auxiliary power systems |
| ASEAN | Association of Southeast Asian Nations |
| BEV | battery electric vehicle |
| CARB | California Air Resources Board |
| CCCPC | Central Committee of Communist Party of China |
| CO | carbon monoxide |
| CRAES | Chinese Research Academy of Environmental Sciences |
| DPF | diesel particulate filter |
| EPA | Environmental Protection Agency |
| FCEV | fuel cell electric vehicle |
| FTP | free trade port |
| GPF | gasoline particle filter |
| GVWR | gross vehicle weight rating |
| HDV | heavy-duty vehicle |
| ICCT | International Council on Clean Transportation |
| LDV | light-duty vehicle |
| MEE | Ministry of Ecology and Environment |
| MIIT | Ministry of Industry and Information Technology |
| MIL | malfunction indicator lamp |
| $NH_3$ | ammonia |
| NMHC | non-methane hydrocarbon |
| NMOG | non-methane organic gases |
| NOx | nitrogen oxides |
| $N_2O$ | nitrous oxide |
| OBD | on-board diagnostics |
| ORVR | onboard refueling vapor recovery |
| PEMS | portable emission measurement system |
| PHEV | plug-in hybrid electric vehicle |
| PM | particulate matter |
| PN | particulate number |
| THC | total hydrocarbon |
| U.S. | United States |
| VECC | Vehicle Emission Control Center |
| VOCs | volatile organic compounds |
| WHO | World Health Organization |

# INTRODUCTION

Hainan is China's southernmost tropical island province, covering an area similar to the Netherlands and home to more than 9 million people. It is traditionally known as the nation's most popular beach resort destination. More recently it has been strategically positioned as China's gateway to the Pacific and Indian Oceans and as the nation's new icon for economic openness and green development (CCCPC and China State Council, 2018). Due to its proximity to member states of the Association of Southeast Asian Nations (ASEAN), Hainan serves as China's southern frontier for integrating with the Southeast Asian economic block and is an important node on China's Maritime Silk Road (Figure 1).

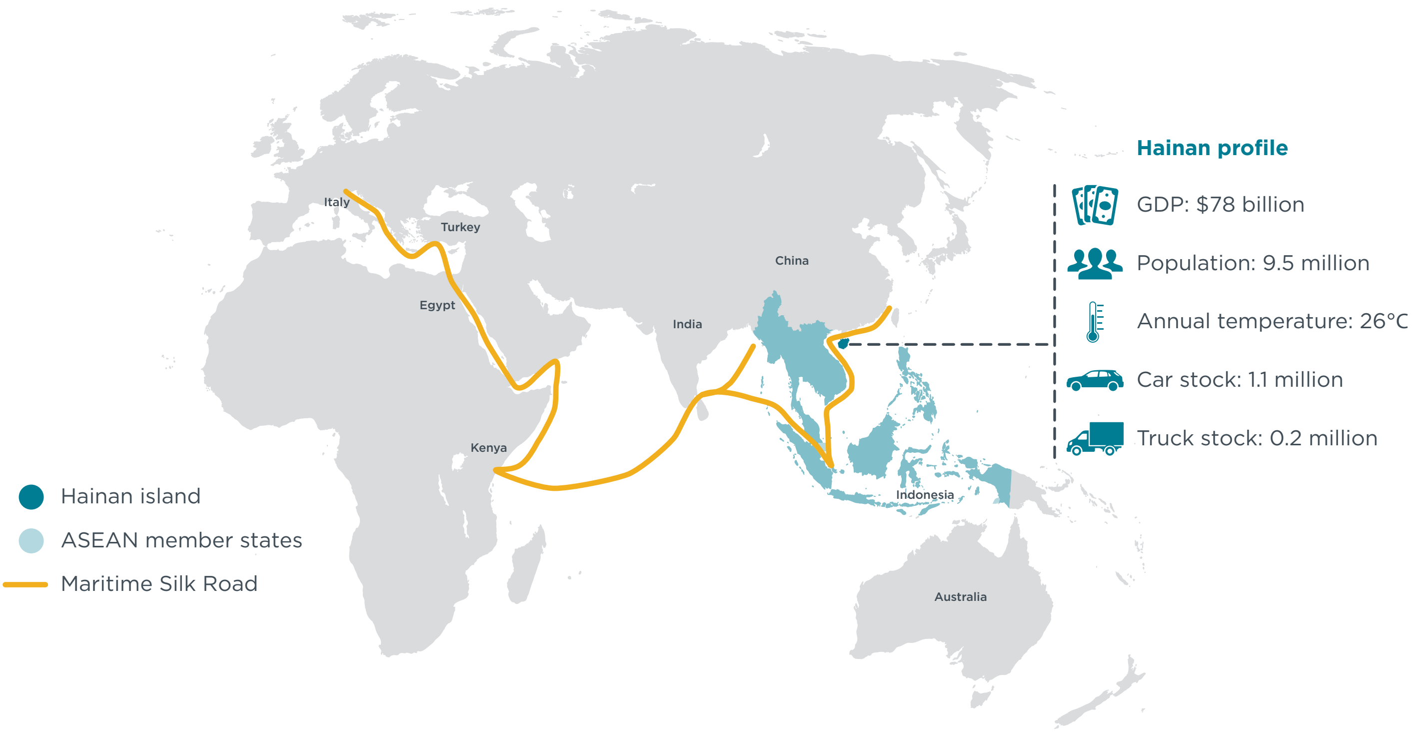


**Figure 1.** Profile and strategic location of Hainan.

In June 2020, the Chinese central government rolled out a master plan to make the whole of Hainan island the largest free trade port (FTP) globally—dozens of times larger than the existing Hong Kong FTP and Singapore FTP (CCCPC and China State Council, 2020). Moreover, Hainan prioritizes ecological wellbeing in the FTP development process; the island envisions building a world-class environmentally friendly economy that will attract investments, business, talent, and tourists from around the world (Zhou & Yang, 2021).

Even though the island province has the cleanest air in China, its pollution levels are still some distance from the new World Health Organization (WHO) air quality guidelines. In 2019, Hainan's annual average $PM_{2.5}$ concentration was 16 µg/m³, 220% higher than the WHO-recommended level of 5 µg/m³. As a tropical island, Hainan is also facing emerging challenges regarding ozone pollution due to its high year-round ambient temperatures. Hainan's 90th percentile of daily maximum 8-hour ozone concentration was 118 µg/m³ in 2019, 10% higher than the previous year and 18% above the WHO-recommended daily level of 100 µg/m³ (Hainan Department of Ecology and Environment, 2020; WHO, 2021).

Based on the latest official pollution source data, on-road vehicles are the primary source of Hainan's $PM_{2.5}$ pollution, with a contribution of 30% (Sun et al., 2020). On-road vehicles are also a major contributor to the gaseous precursors of ozone—

nitrogen oxides (NOx) and volatile organic compounds (VOCs)—and thus play a critical role in ozone emission control. Environmental policy makers in Hainan are clear that on-road vehicle emissions are the key obstacle to achieving Hainan's ambitious air quality targets (Kang, 2019).

This white paper provides policy recommendations to reduce pollution from Hainan's on-road vehicle fleet during 2021–2035 through policy benchmarking with international best practices. We also evaluate the emission reduction potential of effectuating these policy recommendations in Hainan. This study is a joint effort of the International Council on Clean Transportation (ICCT) and the Vehicle Emission Control Center (VECC) of the Chinese Research Academy of Environmental Sciences (CRAES).

## POLICY BENCHMARKING

This section compares on-road vehicle emission control policies adopted in Hainan by the end of 2020 with international best practices. Five policy categories are considered, including vehicle electrification, new vehicle emission standards and compliance, in-use vehicle programs, fuel quality standards and compliance, and low- and zero- emission zones. For each policy category, we investigate the gaps between Hainan's policy and international best practices, and we provide policy recommendations correspondingly.

### VEHICLE ELECTRIFICATION

Accelerating the transition to electric vehicles, in combination with a clean grid mix, is the single most important strategy for reducing pollution from Hainan's on-road vehicle fleet in the coming fifteen years. Electric vehicles here include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and fuel cell electric vehicles (FCEVs). The following three sections focus on light-duty vehicle electrification, heavy-duty vehicle electrification, and achieving a clean grid mix, respectively.

#### Light-duty vehicle electrification

In 2019, Hainan announced the goal of phasing out new sales of gasoline and diesel light-duty vehicles no later than 2030. Still, Hainan's progress through 2020 on light-duty vehicle electrification was limited and stronger policy efforts will be needed to realize this ambitious target.

As shown in Figure 2, Hainan's strategy aimed to achieve a 100% electric share of new light-duty truck sales in 2020 and gradually to increase the electric share of new private car sales to 40% in 2020, 80% in 2025, and 100% in 2030 (Hainan Provincial People's Government, 2019). These full electrification targets are world-leading and will deliver substantial emission reduction benefits if fulfilled. However, only 4.2% of new light-duty truck sales and 12.7% of new private car sales in Hainan were electric vehicles in 2020—both are far from Hainan's announced targets.

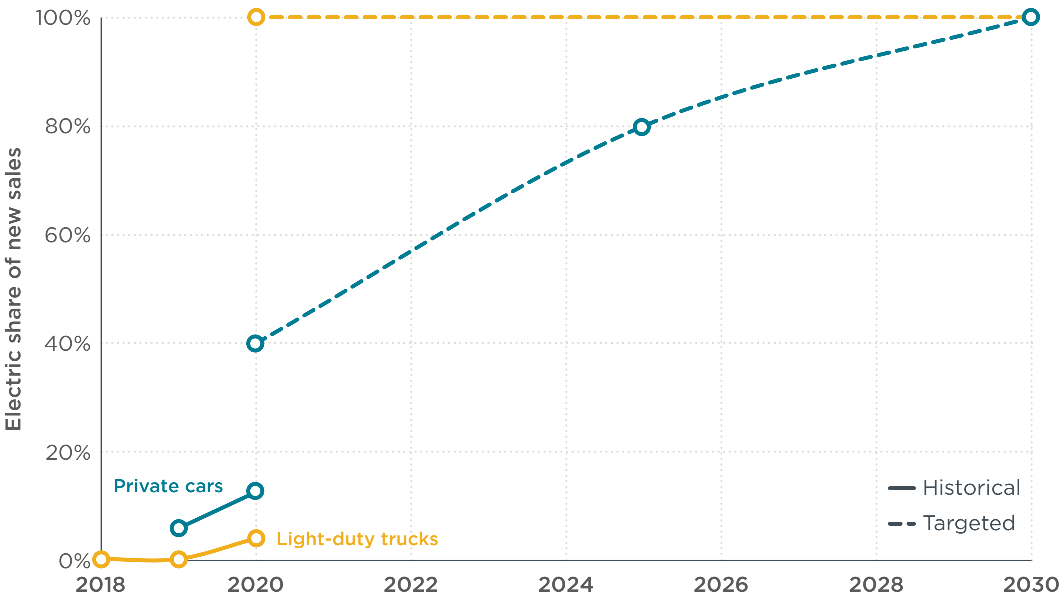


**Figure 2.** Historical and targeted electric shares of new light-duty vehicle sales in Hainan

This limited progress in vehicle electrification indicated the need for Hainan to introduce more comprehensive, powerful, and innovative policy tools to further stimulate electric vehicle deployment. Generally, these will include vehicle regulations, financial incentives, charging infrastructure development, and consumer awareness campaigns, each aiming to increase the availability, affordability, convenience, and acceptance of electric vehicles. Still, there is no "one-size-fits-all" solution. Hainan will need to investigate the policy packages that fit best through continuous evaluation and adjustment.

Nonetheless, the experience of European markets and California have proven the effectiveness of stringent vehicle emission standards and electric vehicle sales requirements in driving electric vehicle uptake (Cui, Hall, Li & Lutsey, 2021). The current vehicle emission standards (i.e., China 6 standards) and electric vehicle sales requirements in China are not stringent enough to help Hainan realize its full electrification ambition. In addition, leading cities globally have started to leverage innovative city-level policy tools, such as zero-emission zones, to support the shift from traditional fuel vehicles to electric vehicles (Cui, Pramoda, & Wappelhorst, 2021).

***Policy recommendations***. We recommend that Hainan leverage more comprehensive, powerful, and innovative policy measures to support the achievement of its full electrification ambition, including adopting next-generation vehicle emission standards and more stringent electric vehicle sales requirements, and establishing zero-emission zones.

### Heavy-duty vehicle electrification

Heavy-duty vehicles accounted for 79% of NOx emissions from Hainan's on-road vehicle fleet, based on VECC's previous estimation. As of 2020, Hainan has already achieved a 100% electric share of new buses. However, for heavy-duty trucks, Hainan lacks a clear electrification roadmap.

Considering the uncertainties surrounding the availability and affordability of electric models of heavy-duty vehicles, Hainan does not propose any electrification goals for heavy-duty trucks. Instead, Hainan is considering promoting gas-powered technologies as alternative solutions, at least in the near- to medium term (Hainan Provincial People's Government, 2019). However, recent studies have shown that in the current technology landscape, the conventional wisdom that gas-powered vehicles are cleaner than diesel is no longer valid (Rodríguez, 2020). From the perspective of vehicle emission control, it is not a cost-effective choice to continue providing policy advantages to gas-powered vehicles. Electric vehicles are the real clean technologies that are worth investing in in Hainan for heavy-duty trucks.

Internationally, California is at the frontier of heavy-duty truck electrification. California has set a target to achieve a zero-emission drayage truck fleet by 2035 and a zero-emission medium- and heavy-duty vehicle fleet by 2045. To achieve this target, California has already adopted supply-side regulations requiring an increasing annual sales percentage of zero-emission trucks from 2024, as shown in Figure 3 (Buysse & Sharpe, 2020). California is also developing demand-side regulations requiring medium and large size fleets in California to purchase specified numbers of zero-emission trucks. In addition, California is providing electric truck purchase incentives, financing support, and charging infrastructure installation subsidies to bridge the cost gap between owning an electric truck and a diesel one.

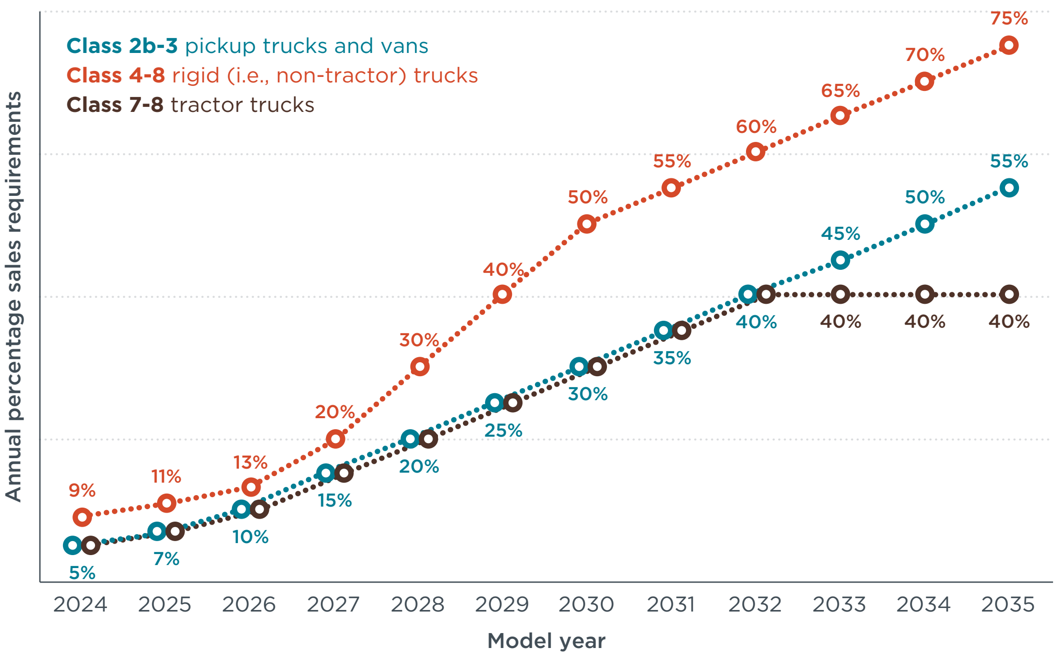


**Figure 3.** Zero-emission vehicle sales share requirements in California for trucks.
Source: Buysse & Sharpe, 2020

***Policy recommendations***. We recommend that Hainan develop a clear electrification roadmap for heavy-duty trucks and leverage comprehensive demand- and supply-side policy measures to stimulate electric heavy-duty truck deployment.

### Clean grid mix

A clean grid mix is critical for maximizing the emission reduction benefits of vehicle electrification. Hainan's current grid mix is still dominated by coal; the province will need to increase significantly the share of renewable energy sources in the grid mix.

In 2018, 56% of Hainan's electricity supply originated from coal, 4% from gas, 26% from nuclear, and 14% from renewables. Coal's share declined to 50% in 2020 and will fall further to 30% by 2025 (Sun & Zhu, 2021). As for installed capacity, the share of coal power will decrease from 33% in 2020 to 17% in 2025, 15% in 2030, and 11% in 2035. Nuclear power is expected to play a primary role while gas will be used to provide peaking power (Sun & Zhu, 2021; Ni, 2021; Fan, 2021).

California has one of the cleanest grid mixes in the world. Almost none of California's electricity supply originates from coal or oil. The majority was generated from natural gas (43%) and renewables (32%) in 2019. California's goal is to achieve a 60% renewables share by 2030.

***Policy recommendations***. We recommend that Hainan continue to green its grid mix by increasing the share of electricity generated from renewable energy sources.

## NEW VEHICLE EMISSION STANDARDS AND COMPLIANCE

Stringent new vehicle emission standards accelerate the application of the most advanced clean technologies, including electrification technologies, while comprehensive compliance programs ensure that the intended outcomes from stringent new vehicle emission standards materialize throughout the vehicle lifecycle. The following three subsections focus on emission standards for new light-duty vehicles (LDVs), emission standards for new heavy-duty vehicles (HDVs), and vehicle emission compliance programs, respectively.

### Light-duty vehicle emission standards

The effective LDV emission standards in Hainan are the China 6 standards, which were implemented on July 1, 2019, one year earlier than the national timeline (General Office of Hainan Provincial People's Government, 2019). The China 6 standards are among the world's most advanced LDV emission standards, but are not as stringent as the United States (U.S.) Tier 3 standards, which took effect in 2017 and will be fully implemented in 2025.

As shown in Figure 2, the tailpipe emission limits of the China 6 standard are stricter than the Euro 6 standards but are more lenient than the U.S. Tier 3 standards, regardless of test procedure differences. In particular, the U.S. Tier 3 standards regulate NOx emissions in combination with non-methane organic gases (NMOG), which covers a wider range of pollutants than non-methane hydrocarbon (NMHC). Still, the NMOG+NOx limit set in the U.S. Tier 3 standards for 2025 is 73% lower than the China 6 limit of NMHC+NOx. As for particulate emissions, the China 6 standards are at the vanguard by introducing a fuel-neutral PN limit of $6 \times 10^{11}$#/km which requires the adoption of diesel particulate filters (DPFs) and gasoline particle filters (GPFs) (He, 2020).

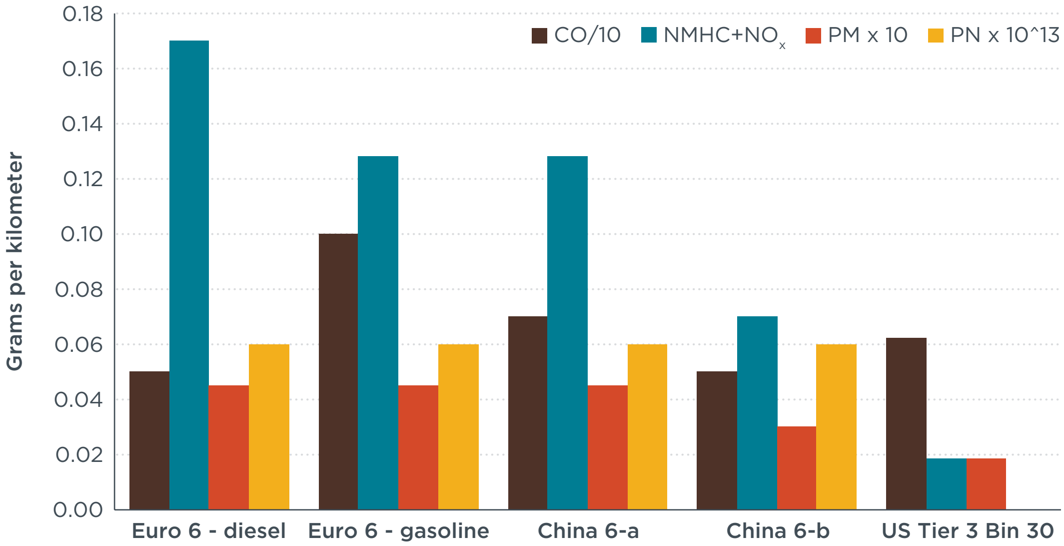


**Figure 4.** Emission limits under the Euro 6, China 6, and U.S. Tier 3 standards

*Notes:*

[a] Emission limits are those for Type I test (regular temperature, cold start emission test) for passenger cars on a per-vehicle maximum limit basis. The U.S. Tier 3 standards are fleet averaged. The fleet average standards are equivalent to the Tier 3 Bin 30 level.

[b] For diesel vehicles, the Euro 6 standards regulate total hydrocarbon (THC) in combination with nitrogen oxides (NOx) . THC covers not only non-methane hydrocarbon (NMHC) but also methane; however, diesel engines have negligible methane emissions. For gasoline vehicles, the particulate number (PN) limits under the Euro 6 standards only apply to direct injection vehicles.

[c] The U.S. Tier 3 standards regulate non-methane organic gases (NMOG) in combination with NOx. NMOG covers a wider range of species than NMHC.

[d] This figure does not take into consideration the difference in test cycles and procedures among China, EU, and U.S. standards.

Evaporative emission limits are another critical element of LDV emission standards, given that evaporative volatile organic compounds (VOCs) are a key gaseous precursor to both $PM_{2.5}$ and ozone. This is particularly important in Hainan considering its high year-round ambient temperature.

As shown in Table 1, the evaporative emission requirements under the China 6 standards are superior to the Euro 6 standards, with a tighter emission limit over the 48-hour diurnal emission test and a higher conditioning temperature of (38±2°C) prior to the test. In addition, the China 6 standards, reflecting the U.S. Tier 3 standards, introduced a refueling emission limit of 0.05 g/L, which forces the introduction of onboard refueling vapor recovery (ORVR) systems. The U.S. Tier 3 standards feature the most stringent evaporative emission requirements, with limits aiming to achieve essentially zero fuel vapor emissions (Rodríguez et al., 2019).

**Table 1.** Evaporative emission limits under the Euro 6, China 6, and U.S. Tier 3 standards

| Test procedure | Evaporative emission limits | | |
|---|---|---|---|
| | Euro 6 | China 6 | U.S. Tier 3 |
| **Hot-soak + 48-hour diurnal test** | 2.0 g/test | 0.7 g/test | 0.3 g / test |
| **Hot soak + 72-hour diurnal test** | / | / | 0.3 g / test |
| **Refueling test** | / | 0.05 g/L | 0.053 g/L |

Regarding test cycles, real-world emission requirements, and on-board diagnostics (OBD) provisions, the China 6 standards are roughly equivalent to international best practice. As for useful life requirements, the China 6-b standards require 200,000-kilometer durability of emission control devices, which is stricter than the Euro 6 standards but lags behind the U.S. Tier 3 requirements of 240,000 kilometers.

The European Commission is currently developing the Euro 7 standards, the proposal for which is expected to be released by the end of 2021 (European Commission, 2020). Potential improvements under discussion over the Euro 6 standards include tightening of limits of all currently regulated pollutants, introduction of limits for pollutants currently unregulated such as ammonia ($NH_3$), nitrous oxide ($N_2O$), and brake particles, introduction of tighter evaporative and refueling emission tests and limits, extension of the boundary conditions for on-road testing, elimination of conformity factors for on-road in-service conformity evaluations, extension of durability provisions, and introduction of on-road monitoring. The China 7 standards are also under development.

***Policy recommendations***. We recommend that Hainan effectively enforce the China 6 standards, closely track the development of China 7 and Euro 7 standards, and adopt as early as practicable China 7 standards to stimulate the full transition to electric vehicles.

### Heavy-duty vehicle emission standards

The adopted HDV emission standards in Hainan are the China VI standards. Hainan followed China's national timeline and fully implemented the China VI standards on July 1, 2021. The China VI standards are one of the most advanced in the world, but are not as stringent as the newly adopted California low-NOx standards, which will come into force in 2024 and be tightened in 2027 (CARB, 2020).

As shown in Figure 5, the NOx limits of the China VI standards are comparable to Euro VI and U.S. 2010 standards, but are considerably behind the California low-NOx standards, regardless of test procedure differences. The California low-NOx standards tighten the NOx limits under the U.S. 2010 standards by 75% and 90% in 2024 and 2027, respectively. In addition, new requirements under low-load cycle and idling are introduced, during which a disproportionate amount of NOx emissions is found to be emitted but not effectively regulated under existing standards (Badshah et al., 2019).

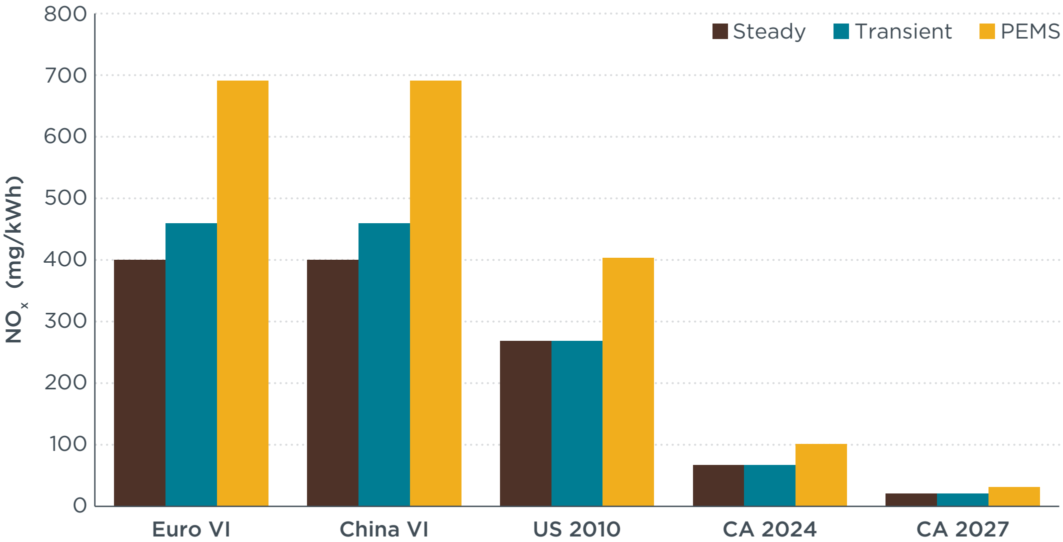


**Figure 5.** Emission limits under the Euro VI, China VI, U.S. 2010 and California low-NOx standards

*Notes:*

[a] This figure does not take into consideration the difference in test cycles and procedures among China, EU, U.S., and California standards.

Regarding real-world emission requirements and OBD provisions, the China VI standards are roughly equivalent to international best practices. The China VI-b standards require vehicles to be equipped with a remote OBD system, which is a first in vehicle regulations across the globe. As for useful life requirements, the distance definition of useful life for HDVs is the same in the China VI, Euro VI and U.S. 2010 standards at 700,000 km. However, the United States defines the useful-life age limit at 10 years while China VI and Euro VI standards do so at 7 years. Under the California low-NOx standards, the definition of useful life will be lengthened to 600,000 miles (~965,000 km) or 11 years, whichever comes first, from 2027, and 800,000 miles (~ 1.3 million km) or 12 years from 2031 onwards.

The European Commission is currently developing the Euro VII standards, the proposal of which is expected to be released by the end of 2021 (European Commission, 2020). Based on the latest discussions, the Euro VII standards are likely to bring about similar stringency with the California low-NOx standards by introducing tightened NOx limits and durability provisions and new requirements on low-speed and low-power conditions, as those in urban operation (Rodríguez and Badshah, 2021). The China VII standards are also under development.

***Policy recommendations***. We recommend that Hainan effectively enforce the China VI standards, closely track the development of China VII and Euro VII standards, and adopt as early as practicable the China VII standards to stimulate the transition to low-NOx and zero-emission vehicles.

### Vehicle emission compliance programs

Hainan follows China's national vehicle emission compliance program, the current version of which—the China VI compliance program—largely mirrors the world-leading U.S./California program but lacks robust enforcement due to limited staff and technical resources.

Both the China/Hainan program and the U.S./California program cover the full vehicle useful life, feature a shared burden between regulatory agency and industry, and are given strong and clear legal authority. The major gap between China/Hainan's compliance program and its U.S./California counterpart is lack of robust enforcement due to staff and technical resource shortages for in-use testing.

Government-run in-use testing is very resource-intensive. The regulatory agency needs to requisition vehicles from private owners or fleet owners for testing and to compensate them for the vehicles' use. Technicians must thoroughly check the status of the vehicle and the maintenance records, and calibrate the vehicle if needed before conducting tests. At least two weeks are needed to complete the testing and additional time might be needed to verify the test results. With approximately 1,500 staff and an advanced vehicle emission testing lab in place, California's government-run Heavy-Duty In-Use Compliance (HDIUC) program led to the identification and recall of over 500,000 noncompliant vehicles in California in 2018 (CARB, 2018a). By comparison, Hainan, with insufficient staff and technical resources, is not capable of launching such in-use testing programs to enforce vehicle emission standards.

In this case, a practical approach for Hainan to effectively enforce vehicle emission standards is to rely on new technologies. California has been leveraging multiple new technologies, such as remote sensing devices, to help identify noncompliant vehicles and high emitters. Remote sensing technology enables cheap, quick and unobtrusive screening of vehicles on a mass scale. Hainan has been developing its remote sensing network since 2019, with a goal of installing a total of 50 sets of remote sensing devices covering all 19 city-level jurisdictions of the province. By the end of 2020, Hainan had installed 37 sets of remote sensing devices but had not yet started to utilize remote sensing data in vehicle emission compliance.

Another new technology that Hainan could leverage to improve in-use compliance is remote OBD. The China VI-b standards innovatively require all new HDVs to be equipped with a remote OBD system, enabling regulatory agencies to receive real-time emission-related data remotely, such as NOx sensor output. China's Ministry of Ecology and Environment (MEE) is currently developing a technical specification for the remote OBD system, which is expected to be published in 2021. Local governments such as Beijing and Nanjing have already been conducting remote OBD pilot programs on heavy-duty buses (Yang et al., 2021). Hainan has not started to explore this area yet.

***Policy recommendations***. We recommend that Hainan leverage various new technologies, including remote sensing and remote OBD, to improve the robustness of vehicle emission compliance programs.

## IN-USE VEHICLE PROGRAMS

Mitigating emissions from legacy and in-use vehicles is equally important as, and possibly more important than, the advancement of emission control technologies driven by new vehicle standards. There are various programs worldwide to control and reduce emissions from the in-use fleet. The following three sections focus on in-use vehicle emission inspection programs, in-use fleet regulations, and idling rules, respectively.

### In-use vehicle emission inspection programs

In-use vehicle emission inspection programs address in-use excess emissions resulting from deterioration of emission control devices and improper maintenance and repair. Hainan follows China's national in-use vehicle inspection program, which is similar to the world-leading California program in its design principles but is less robust in a few respects.

Both China/Hainan and California leverage Inspection and Maintenance (I/M) programs to identify in-use vehicles with excess emissions. However, China/Hainan mainly relies on tailpipe testing while California's I/M programs rely increasingly heavily on checking OBD systems. Tailpipe testing is no longer required in most cases in California. China/Hainan has already attempted to adopt California's best practices: China's newly-adopted I/M program includes Malfunction Indicator Lamp (MIL) check, scanning for fault codes, and readiness. However, since China's new vehicle OBD program was not as comprehensive as that in California, some of the codes are not available on pre-China 6 vehicles, thus impairing the effectiveness of OBD I/M checks.

In addition, Hainan mainly relies on roadside inspections to supplement the I/M program. Hainan had installed 37 sets of remote sensing devices by the end of 2020, but remote sensing data has not yet been utilized in in-use vehicle emission inspections. By comparison, California uses a wide range of data sources, including spot checks and remote sensing data, to help identify high emitters and non-compliance vehicles.

***Policy recommendations***. We recommend that Hainan enhance the use of OBD data in I/M programs, and use multiple data sources, including remote sensing, to inform and cross-validate I/M data.

### In-use fleet regulations

Another common in-use program is to require modern emission controls on in-use fleets, aiming at expanding to older vehicles the deployment of newer emission control technologies that are usually equipped on new vehicles. This can take the form of in-use fleet regulations, which are usually fulfilled by retrofitting, repowering or replacing vehicles.

Hainan leverages incentives and road access restrictions to encourage early retirement of gross emitters, but lacks regulations requiring modern emission controls in the in-use fleet. By contrast, California introduced a series of regulations in the 2000s to reduce emissions from in-use diesel fleets.

Various in-use diesel fleets in California are required to meet equivalent emissions requirements for new vehicles to accelerate the emission reduction technology upgrades in applicable in-use vehicles, but with an extended timeline. To take the *Truck and Bus Regulation* as an example, heavy-duty diesel trucks and buses are required to become DPF-equipped and to upgrade to newer engines that are compliant with U.S. 2010 standards following the timeline shown in Table 2. Noncompliant vehicles will be stripped of their registrations and the owners will be fined.

**Table 2.** Requirements of California Truck and Bus Regulation

| Engine model year | DPF required | Compliance with U.S. 2010 standard required |
|---|---|---|
| **Pre 1994** | Not required | January 1, 2015 |
| **1994-1995** | Not required | January 1, 2016 |
| **1996-1999** | January 1, 2012 | January 1, 2020 |
| **2000-2004** | January 1, 2013 | January 1, 2021 |
| **2005-2006** | January 1, 2014 | January 1, 2022 |
| **2007-2009** | If already equipped | January 1, 2023 |

***Policy recommendations***. We recommend that Hainan leverage both incentives and regulations to encourage replacement of legacy in-use fleets with zero-emission vehicles, when feasible, or meet new vehicle emission standards through retrofitting, repowering, or replacement of vehicles.

### Idling rules

There are also programs that target in-use emissions that cannot be easily captured by new vehicle emission testing, such as emissions that occur during extra idling time. Hainan does not have idling rules and California is leading the world in this area.

California's idling rule started with school buses in 2003 and was expanded to cover all diesel HDVs with a gross vehicle weight rating (GVWR) over 10,000 pounds in 2004. Under the idling rule, vehicles are not allowed to be idled for more than five minutes. The rule also requires heavy-duty engines of model year 2008 or newer to be equipped with a non-adjustable and tamper-resistant automatic engine shutdown system, which shuts down an engine after five minutes of idling.

Trucks with sleeper cabs often utilize idle reduction technologies, such as diesel-fueled auxiliary power systems (APS) and fuel-fired heaters, to guarantee cab comfort (e.g., heating and cooling) without idling the engine during rest periods. The idling rule requires these cab comfort devices to meet specific emission standards or be equipped with specific emission control technologies. For example, fuel-fired heaters must meet California's ultra-low emission vehicle (ULEV) certification limits, while diesel-fueled APS must have a verified level 3 PM trap or have exhaust routed to the vehicle's PM control system. Hainan does not have any idling rules.

***Policy recommendations***. We recommend that Hainan introduce idling rules to reduce idling emissions.

## FUEL QUALITY STANDARDS AND COMPLIANCE

Stringent fuel quality standards are of great importance to vehicle emission control. Better fuel quality not only reduces air pollutants from fuel combustion directly, but also enables the use of advanced exhaust aftertreatment technologies such as DPF. The following three subsections focus on gasoline fuel quality standards, diesel fuel quality standards, and fuel quality compliance compliance programs, respectively.

### Gasoline fuel quality standards

The effective gasoline fuel quality standards in Hainan are the China VI standards plus a tougher Reid Vapor Pressure (RVP) requirement, which is roughly equivalent to the most stringent standards in the world, with a few exceptions.

The gasoline fuel quality specifications that affect vehicle emissions most include sulfur, olefins, benzene, and aromatics contentst, and RVP. Table 3 compares the requirements on these five specifications under the China VI, Beijing VI, Euro V, and California Reformulated Gasoline Phase 3 (CaRFG3) standards. The China VI standards are comparable to their Beijing and European counterparts in general, but are behind the California standards in olefins, aromatics, and RVP requirements.

A higher RVP will enhance fuel vapor generating and result in higher evaporative VOCs emissions (U.S. EPA, 2012). Though Hainan has already adopted a localized RVP limit stricter than the national requirement, there is still a gap from the California standards. Based on the Wade-Reddy equation for vapor generation, the tank vapor generated per liter gasoline in Hainan could decrease approximately tenfold if the gasoline RVP declines from the currently required 60 kPa to the California requirement of around 50 kPa. This would lead to a significant reduction in evaporative VOCs emissions in Hainan.

**Table 3.** Gasoline fuel quality standards in China, Europe, and California

| Technical specifications | China VI | | Beijing VI | Euro V | CaRFG3[d] | | |
|---|---|---|---|---|---|---|---|
| | Hainan version | National version | | | Flat limits | Averaging limits | Cap limits |
| **Sulfur (ppm, max.)** | 10 | 10 | 10 | 10 | 20 | 15 | 30 |
| **Olefins (vol%, max.)** | 18/15[a] | 18/15[a] | 15 | 18 | 6 | 4 | 10 |
| **Benzene (vol%, max.)** | 0.8 | 0.8 | 0.8 | 1.0 | 0.8 | 0.7 | 1.1 |
| **Aromatics (vol%, max.)** | 35 | 35 | 35 | 35 | 25 | 22 | 35 |
| **RVP (kPa)** | 60 max | Summer: 40-65<br>Winter: 45-85 | Spring: 45-70<br>Summer: 42-62<br>Autumn: 45-70<br>Winter: 47-80 | Summer: 60/70[b] max | Warm season: 48.2/47.6[c] max | – | Warm season: 44.1-49.6 |

*Notes*:
[a] The 18% and 15% limit apply to phase VI-a (effective on January 1, 2019) and phase VI-b (effecitve on January 1, 2023), respectively.
[b] The 70 kPa limit applies to specific European countries with relatively low ambient temperature in summer.
[c] The 47.6 kPa limit applies to gasoline fuels NOT containing ethanol. Otherwise, the 48.2 kPa limit applies.
[d] All gasoline batches must not exceed cap limits. In addition, gasoline producers could choose from two compliance options. The first is that all gasoline batches comply with flat limits. The second is that gasoline batches above averaging limits be offset by batches below averaging limits.

***Policy recommendations***. We recommend that Hainan effectively enforce the China VI gasoline fuel quality standards and further tighten the gasoline RVP requirements.

### Diesel fuel quality standards

The effective diesel fuel quality standards in Hainan are the China VI standards, which are already among the most stringent in the world.

Sulfur content is the diesel fuel quality specification that affects vehicle emissions most.  In addition, polyaromatic content, cetane number, density, ash content, and viscosity also impact vehicle emissions. Table 4 compares the requirements on these six specifications under the China VI, Beijing VI, Euro V, U.S., and California standards. In general, the China VI standards are comparable to the other world-leading diesel fuel quality standards. Particularly, the sulfur content requirement under the China VI standard—10 ppm—is already the toughest in the world.

**Table 4.** Diesel fuel quality standards in China, Europe, the United States, and California

| Technical specifications | China VI | Beijing VI | Euro V | U.S. standard | California standard |
|---|---|---|---|---|---|
| **Sulfur (ppm, max.)** | 10 | 10 | 10 | 15 | 15 |
| **Polyaromatics (vol%, max.)** | 7 | 7 | 8 | – | – |
| **Cetane number (min.)** | 51 | 51 | 51 | A minimum cetane index of 40 or a maximum aromatic content of 35% | A minimum cetane index of 40 or a maximum aromatic content of 35% |
| **Density (kg/m3)** | 820-845 (20°C) | 820-845 (20°C) | ≤ 845 (20°C) | – | – |
| **Ash content (% m/m, max.)** | 0.01 | 0.01 | 0.01 | – | – |
| **Viscosity (mm2/s)** | 3.0-3.8 | 2.5-7.5 | 2.0-4.5 | – | – |

***Policy recommendations***. We recommend that Hainan effectively enforce the China VI diesel fuel quality standards.

### Fuel quality compliance programs

Hainan's fuel quality compliance programs are not as comprehensive as the California programs, which represent international best practices in this field.

There are several gaps between Hainan's fuel quality compliance programs and the best practices from California. First, Hainan's programs focus on end-of-pipe control. Key measures include fuel quality inspections at gas stations and special campaigns against cheap and dirty fuels sold in the black market. By comparison, the California programs emphasize source control and feature comprehensive supervision throughout the entire fuel supply chain.

As is shown in Figure 6, the California Air Resources Board (CARB) requires all stakeholders involved in the fuel supply chain, including refiners, oxygenate blenders, distributors, and retailers, to become certified and to report data for compliance purposes. CARB staff verify the reported data based on sales records and invoices, and they collect fuel samples from refineries, tankers, bulk plants, gas stations, and commercial users for testing. If noncompliant fuel is identified, CARB can track the invoices to determine the fuel's origin and penalize the entire supply chain rather than just the retailers. Under this liability tracing mechanism, upstream suppliers sometimes collect fuel samples from their downstream clients to test on their own.

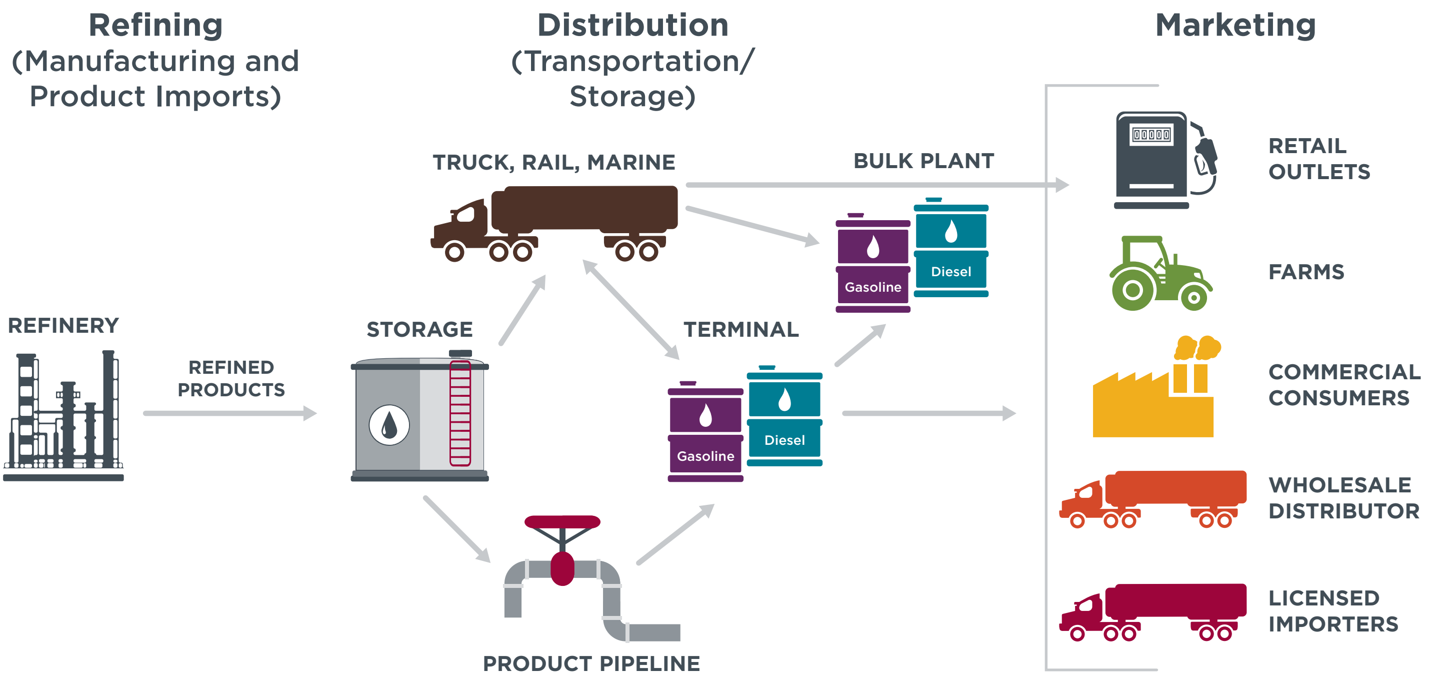


**Figure 6.** California's fuel quality compliance program. Source: California Air Resources Board

Second, Hainan's fuel quality inspection scale is not large enough. During 2017-2019, the Hainan Market Supervision Administration conducted four rounds of fuel quality inspections. Only 49 samples from 5 refineries and 22 retail stations were collected and tested. By comparison, CARB conducted 481 inspections and analyzed 1,650 samples in 2017. CARB takes two different approaches for sampling. The first is to send staff to sample at the refinery for analysis at the lab. The other is to use a mobile lab to do onsite screening. Since 2020, China's MEE has also been using a mobile lab to conduct onsite fuel quality screening in key areas with severe air pollution (Sinochem, 2021). Hainan has not yet introduced this new technology to improve the efficiency of their fuel quality inspections.

Third, Hainan's program lacks deterrent penalties for noncompliance. Hainan's major enforcement measure is an administrative penalty such as suspension of business for a specific period. By contrast, California imposes severe penalties on noncompliant stakeholders. For example, CARB charged British Petroleum a $2.5 million fine for non-compliance of fuel quality standards (CARB, 2018b).

Last but not least, Hainan's environmental agencies are not sufficiently engaged in fuel quality compliance programs. In China, the national market supervision administration and its local equivalent is the single agency for sampling and testing fuel quality. By comparison, California's programs feature collaboration between environmental and quality assurance agencies. Both agencies have distinct and clear responsibilites and operate without conflict. They conduct separate investigations, with CARB focusing on emission-related specifications and the quality assurance agency focusing on performance-related specifications.

***Policy recommendations***. We recommend that Hainan improve its fuel quality compliance programs in four ways. The first is to introduce certification, data reporting, and liability tracking mechanisms to ensure comprehensive supervision throughout the entire fuel supply chain. The second is to increase the frequency of fuel quality inspections and sample size. The third is to introduce robust penalties on noncompliant stakeholders. The last is to grant authority to environmental agencies to conduct separate fuel quality inspections focusing on emission-related specifications and to enforce directly Hainan's fuel quality standards.

## LOW- AND ZERO-EMISSION ZONES

A low-emission zone (LEZ) is an area where only vehicles that meet specific emission criteria are granted unrestricted access, along with pedestrians and cyclists. Other vehicles are either prohibited from entering or must pay a fee to enter. A zero-emission zone (ZEZ) is an extreme version of a LEZ, with emission criteria set at zero emissions. LEZ/ZEZ is a powerful policy tool to encourage early scrappage of legacy in-use fleets and stimulate the deployment of low- and zero-emission vehicles.

Hainan has no LEZs or ZEZs implemented as of August 2021. European cities are the pioneers in LEZ/ZEZ policies. To date, European cities have established hundreds of LEZs, several dozen of which have been moving towards ZEZs (Cui, Gode & Wappelhorst, 2021).

Amsterdam is a prominent example. It has a LEZ in place and plans to progressively upgrade it to a ZEZ covering the entire city area by 2030.The current LEZ in Amsterdam covers the entire built-up area for mopeds and scooters and the central urban area within the A10 ring road (around 70 $km^2$) for all the other vehicle categories. It operates 24 hours a day, 7 days a week. Only vehicles that meet specific emission criteria are allowed to enter the zone. Non-compliant vehicles are fined €70 ($86) in the case of mopeds and scooters, €100 ($122) for passenger cars, taxis, light commercial vehicles, and buses/coaches, and €250 ($306) for trucks.

The planned ZEZ in Amsterdam will cover the city center (around 6.5 $km^2$) by 2022 and expand to the A10 ring road by 2025. It will be further expanded to the entire built-up area by 2030. As currently planned, the 2022 ZEZ covering the city center will apply to buses and coaches only. The 2025 ZEZ overlapping with the current LEZ will apply to all vehicles except passenger cars. By 2030, all modes of transport will be covered by the city-wide ZEZ. Table 5 shows the progressively tightened emission criteria for the Amsterdam LEZ towards ZEZ in the coming decade.

**Table 5.** Gradually tightened emission criteria as the Amsterdam LEZ moves toward becoming a ZEZ

<table>
<tr><th colspan="2" rowspan="3">Vehicle category</th><th colspan="11">Vehicles allowed to enter</th></tr>
<tr><th colspan="4">City center</th><th colspan="4">Outside city center but within A10 ring road</th><th colspan="3">Outside A10 ring road but within the built-up area</th></tr>
<tr><th>2021</th><th>2022</th><th>2025</th><th>2030</th><th>2021</th><th>2022</th><th>2025</th><th>2030</th><th>2021</th><th>2025</th><th>2030</th></tr>
<tr><td rowspan="2">Passenger cars</td><td>Diesel</td><td colspan="3">Euro 4/5/6 vehicles, ZEVs</td><td>ZEVs</td><td colspan="3">Euro 4/5/6 vehicles, ZEVs</td><td>ZEVs</td><td colspan="2">All</td><td>ZEVs</td></tr>
<tr><td>Non-diesel</td><td colspan="3">All</td><td>ZEVs</td><td colspan="3">All</td><td>ZEVs</td><td colspan="2">All</td><td>ZEVs</td></tr>
<tr><td rowspan="2">Taxis</td><td>Diesel</td><td colspan="2">Euro 5/6 vehicles, ZEVs</td><td colspan="2">ZEVs</td><td colspan="2">Euro 5/6 vehicles, ZEVs</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td>ZEVs</td></tr>
<tr><td>Non-diesel</td><td colspan="2">All</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td>ZEVs</td></tr>
<tr><td rowspan="2">Vans</td><td>Diesel</td><td colspan="2">Euro 4/5/6 vehicles, ZEVs</td><td colspan="2">ZEVs</td><td colspan="2">Euro 4/5/6 vehicles, ZEVs</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td>ZEVs</td></tr>
<tr><td>Non-diesel</td><td colspan="2">All</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td>ZEVs</td></tr>
<tr><td rowspan="2">Trucks</td><td>Diesel</td><td>Euro 4/5/6 vehicles, ZEVs</td><td>Euro 6 vehicles, ZEVs</td><td colspan="2">ZEVs</td><td>Euro 4/5/6 vehicles, ZEVs</td><td>Euro 6 vehicles, ZEVs</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td>ZEVs</td></tr>
<tr><td>Non-diesel</td><td colspan="2">All</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td>ZEVs</td></tr>
<tr><td colspan="2">Buses and coaches</td><td>Euro 4/5/6 vehicles, ZEVs</td><td colspan="3">ZEVs</td><td colspan="2">Euro 4/5/6 vehicles, ZEVs</td><td colspan="2">ZEVs</td><td colspan="2">All</td><td>ZEVs</td></tr>
<tr><td colspan="2">Mopeds and scooters</td><td colspan="2">Vehicles with first registration of January 1 2011 or later; ZEVs</td><td colspan="2">ZEVs</td><td colspan="2">Vehicles with first registration of January 1 2011 or later; ZEVs</td><td colspan="2">ZEVs</td><td>Vehicles with first registration of January 1 2011 or later; ZEVs</td><td colspan="2">ZEVs</td></tr>
</table>

When developing such environmental zones, the common practices are to take a phased approach to launch a pilot program first, either small-scale or affecting specific vehicle categories only, and then upgrade it to a larger scope, in stages. A pilot program will provide policy makers an opportunity to gain useful experience to inform the implementation of enhanced versions. Since the feasibility of electrifying different vehicle categories (e.g., passenger cars, light-duty trucks, heavy-duty trucks) varies, it is reasonable for LEZs and ZEZs to coexist in the same city but affect different vehicle segments or different areas.

A feasibility analysis is critical to help Hainan determine the best way to design its own LEZs/ZEZs based on key local conditions such as geographical features, vehicle market characteristics, and the spatial distribution of population, traffic volumes, and vehicle emissions. Based on this, a clear roadmap needs to be developed and released to clarify how the Hainan LEZ/ZEZ will be phased in with specific milestones. This will help industry and the public to understand what is coming well in advance and to prepare fully for it.

***Policy recommendations***. We recommend that Hainan develop LEZ/ZEZ schemes based on feasibility analysis and implement LEZ/ZEZ schemes in a phased manner, with pilot programs initiated first.

## SUMMARY OF POLICY RECOMMENDATIONS

Based on a comprehensive policy benchmarking, we evaluated Hainan's current on-road vehicle emission control programs, investigated the gaps from international best practices, and provided corresponding policy recommendations, as summarized in Table 6.

**Table 6.** A summary of policy recommendations

| Policy category | Area | Evaluation of current program | Policy recommendations |
|---|---|---|---|
| **Vehicle electrification** | **LDV** | Yellow | • Leverage more comprehensive, powerful, and innovative policy measures to achieve the full electrification ambition |
| | **HDV** | Yellow | • Develop a clear electrification roadmap for heavy-duty trucks<br>• Leverage comprehensive demand- and supply-side policy measures to stimulate electric truck deployment |
| | **Grid mix** | Yellow | • Keep greening grid mix by increasing the share of electricity generated from renewable energy sources |
| **New vehicle emission standards and compliance** | **LDV** | Yellow | • Effectively enforce the China 6 standards<br>• Closely track the development of China 7 and Euro 7 standards<br>• Adopt as soon as practicable the China 7 standards to stimulate the full transition to electric vehicles |
| | **HDV** | Yellow | • Effectively enforce the China VI standards<br>• Closely track the China VII and Euro VII standards<br>• Adopt as soon as practicable the China VII standards to stimulate the transition to low-NOx and zero-emission vehicles |
| | **Compliance** | Yellow | • Leverage various new technologies, including remote sensing and remote OBD, to improve the robustness of vehicle emission compliance programs |
| **In-use vehicle emission control programs** | **In-use inspection** | Yellow | • Enhance the use of OBD data in I/M programs<br>• Use multiple data sources, including remote sensing, to inform and cross-validate I/M |
| | **In-use fleet regulations** | Brown | • Leverage both incentives and regulations to encourage legacy in-use fleets to be replaced by zero-emission vehicles, when feasible, or meet new vehicle emission standards through retrofitting, repowering, or vehicle replacement |
| | **Idling rules** | Brown | • Introduce idling rules to reduce idling emissions |
| **Fuel quality standards and compliance** | **Gasoline** | Yellow | • Effectively enforce the China VI gasoline fuel quality standards<br>• Tighten gasoline RVP requirements |
| | **Diesel** | Blue | • Effectively enforce the China VI diesel fuel quality standards |
| | **Compliance** | Yellow | • Introduce certification, data reporting, and liability tracking mechanism to ensure comprehensive supervision throughout the entire fuel supply chain<br>• Increase frequency of fuel quality inspections and sample size<br>• Introduce robust penalties on non-compliant stakeholders<br>• Pursue authority for environmental agencies to conduct separate fuel quality inspections focusing on emission-related specifications |
| **Low/Zero emission zone** | | Brown | • Develop LEZ/ZEZ schemes based on feasibility analysis<br>• Implement LEZ/ZEZ schemes in a phased manner, with pilot programs initiated first |

**Blue** strong compared with reviewed best practices
**Yellow** weak, incomplete, or less comprehensive than reviewed best practices
**Brown** absent/lacking critical components compared with reviewed best practices

# EVALUATION OF EMISSION REDUCTION POTENTIAL

This section evaluates the emission reduction potential of effectuating the above policy recommendations in Hainan. The baseline year and target year of this emission modeling exercise are 2018 and 2035, respectively. Due to data deficiencies or uncertainties regarding the potential scheme design, some of the identified policy opportunities are not reflected in the emission modeling, including more robust vehicle emission compliance programs, fuel quality compliance programs, and I/M programs, introducing idling rules, tightened gasoline RVP requirements and launching low/zero emission zones. Therefore, the estimated emission reduction benefits are conservative.

## SCENARIOS

Three scenarios are analyzed. Scenario business-as-usual (BAU) reflects policy measures implemented in Hainan as of the baseline year (i.e., 2018). Scenario ADOPTED reflects policy measures adopted as of 2020 and to be implemented in Hainan no later than 2035, as detailed in the previous section. Scenario POTENTIAL reflects the international best practices that we recommend Hainan adopt and implement during 2021-2035. Table 7 summarizes the key policy assumptions by policy category for the three scenarios.

**Table 7.** Key policy assumptions for the three scenarios

| Policy Category | BASELINE | ADOPTED | POTENTIAL |
|---|---|---|---|
| **LDV emission standards** | • No new standards after China 5 | • China 6 effective on July 1, 2019 | • Same as adopted |
| **HDV emission standards** | • No new standards after China VI | • China VI effective on July 1, 2021 | • China VI effective on July 1, 2021<br>• Next-generation standards effective on January 1, 2027, reducing NOx and PM emissions by 90% and 40%, respectively, compared with China VI |
| **In-use vehicle emission control programs** | • No new in-use requirements | • Same as baseline | • Replace all pre-China IV medium to heavy-duty trucks by 2025<br>• Replace all China IV medium to heavy-duty trucks by 2030<br>• Replace all China V medium to heavy-duty trucks by 2035 |
| **Gasoline fuel quality standards** | • No new standards after China V | • China VI effective on January 1, 2019 with a RVP requirement of 60 kPa max. | • Same as adopted |
| **Diesel fuel quality standards** | • No new standards after China V | • China VI effective on January 1, 2019 | • Same as adopted |
| **Taxi electrification** | • EV share unchanged in 2018-2035 | • 2021: 80% EV | • 2021: 100% EV |
| **Private car electrification** | • EV share unchanged in 2018-2035 | • 2020: 13% EV<br>• 2025: 80% EV<br>• 2030: 100% EV | • Same as adopted |
| **Bus electrification** | • EV share unchanged in 2018-2035 | • 2021: 100% EV | • Same as adopted |
| **Light-duty truck electrification** | • EV share unchanged in 2018-2035 | • 2020: 4% EV<br>• 2021: 100% EV | • Same as adopted |
| **Medium-duty truck electrification** | • EV share unchanged in 2018-2035 | • Same as baseline | • 2025: 11% EV<br>• 2030: 50% EV<br>• 2035: 75% EV |
| **Heavy-duty truck electrification** | • EV share unchanged in 2018-2035 | • Same as baseline | • 2025: 5% EV<br>• 2030: 30% EV<br>• 2035: 40% EV |
| **Grid mix** | • Grid mix unchanged in 2018-2035 | • 2035: 15% coal, 15% natural gas, 50% nuclear, and 20% renewables | • 2035: 14% natural gas, 26% nuclear, and 60% renewables |

## METHODS

We assessed emissions from Hainan's on-road vehicle fleet (i.e., LDVs and HDVs) from 2018 to 2035 using VECC's in-house on-road vehicle emission inventory model. We take emissions produced in the full fuel life cycle into consideration, including tailpipe emissions, evaporative emissions, and upstream emissions (i.e., emissions from the production, storage, and distribution of fuels).

The model projects the 2019-2035 vehicle sales and stock in Hainan based on the 2018 Hainan vehicle stock data, key socioeconomic indicators (e.g., GDP growth) and vehicle survival curves for different vehicle segments. Tailpipe and evaporative emission factors are generated based on real-world emission testing conducted by VECC. Upstream emission factors for gasoline, diesel, natural gas and electricity are estimated combining the best available data from public sources and Hainan's grid mix characteristics. Based on Hainan's announced targets for a cleaner grid mix, we assume that 15% of Hainan's electricity supply will come from coal, 15% from natural gas, 50% from nuclear, and 20% from renewable sources in 2035 under the ADOPTED scenario. For the POTENTIAL scenario, we assume a 2035 grid mix of 14% natural gas, 26% nuclear, and 60% renewables, taking Hainan's current grid mix and California's clean grid targets into consideration.

Test-cycle efficiency values of fossil fuel vehicles, BEVs, and PHEVs are derived from public data released by China's Ministry of Industry and Information Technology (MIIT) and adjusted to real-world values by applying a multiplier of 34% (Yang & Yang, 2018). Fuel efficiency is assumed to improve at 3% annually for LDVs and 1% for HDVs (Yang & Cui, 2020). Electric efficiency is assumed to improve at 1% for both LDVs and HDVs (Lutsey, Cui & Yu, 2021). The PHEV electric kilometer fraction is determined by the real-time data of China's National Big Data Alliance of New Energy Vehicles.

## DISCUSSION OF RESULTS

Figure 7 shows the lifecycle emissions from on-road vehicles in Hainan in 2035 under three scenarios (bars), and the 2018 level for comparison (yellow line). We use different bar colors to distinguish tailpipe emissions (brown), evaporative emissions (red), and upstream emissions (blue).

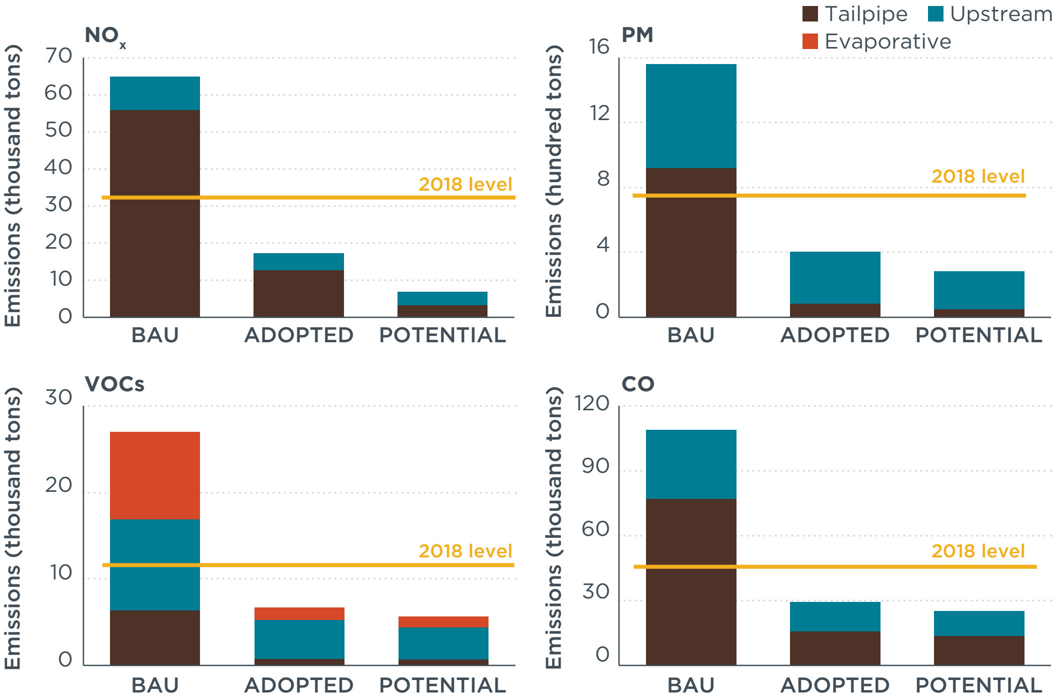


**Figure 7.** Fuel-cycle emissions from on-road vehicles in Hainan in 2035

With no new policy measures implemented after 2018 (i.e., BAU scenario), the emissions of NOx, PM, VOCs, and CO from Hainan's on-road vehicle fleet are projected to experience a continuous increase in the coming years and to double the 2018 values by 2035. This is mainly because demand for passenger and freight transportation in Hainan will grow significantly with the development of Hainan FTP.

As of 2020, Hainan has adopted a series of effective policy measures such as the China 6/VI vehicle emission standards and the China VI fuel quality standards. In addition, Hainan has rolled out an ambitious roadmap to achieve a 100% electric share of new LDV sales. Under this ADOPTED scenario, we project the NOx, PM, VOCs, and CO emissions from Hainan's on-road vehicle fleet to decrease by 74%, 74%, 75%, and 73%, respectively, in 2035, compared with the BAU scenario. These emission reduction benefits are built upon an effective implementation of adopted policies, especially fully electrifying new light-duty vehicles, in combination with a cleaner grid mix.

Compared to the currently adopted policies, potential policies based on international best practices are expected to deliver larger emission reduction benefits, especially for NOx and PM. As is shown in Figure 7, the projected NOx, PM, VOCs, and CO emissions under the POTENTIAL scenario are 57%, 29%, 14%, and 14% lower than the ADOPTED scenario in 2035. In particular, the tailpipe NOx and PM emissions are projected to see a 74% and 44% decline. These are attributable to the adoption of next-generation HDV emission standards, early scrappage and replacement of legacy fleets, an accelerated transition to electric heavy-duty trucks, and an increasing share of electricity generated from renewables. The reason VOCs and CO emissions are not substantially reduced is that the primary contributor to emissions of these two air pollutants—LDVs—are assumed to be fully electrified under the ADOPTED scenario. Thus there is limited room for further emission reduction.

# FINAL REMARKS

Hainan is determined to achieve world-class air quality in the 2030-2035 timeframe and has identified on-road vehicle emissions as the key barrier to this goal. The development of the Hainan FTP provides the island province a golden opportunity to adopt world-class policies to clean its on-road vehicle fleet. With this report, the ICCT and VECC seek to help Hainan identify the international best practices on vehicle emission control and understand the potential emission reduction benefits of introducing these best practices.

Adopting current best practices is only the first step. In the coming fifteen years, it is important for Hainan to regularly evaluate its emission reduction progress, continue tracking newly emerged international best practices, and adjust and improve their policy packages in a timely way. The ICCT and VECC will continue to contribute to this dynamic process. Constrained by data availability, this report does not include air quality modeling. Future research would ideally evaluate the impacts of effectuating these policy recommendations on Hainan's air quality.

Finally, institutional development and improvement of the legal framework will be essential to ensure smooth adoption and successful implementation of these world-class policies. Hainan will need to increase staff and technical resources significantly and modify their local vehicle emission control rules as needed to establish the legal basis for innovative policy measures like zero-emission zones.

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