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China's Clean Diesel Program: Benchmarking with international best practices and policy recommendations

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Introduction

Diesel vehicles consume large amounts of fuel and are a major source of greenhouse gas (GHG) emissions and air pollution in China. Though only 9.1% of the on-road fleet in China, diesel vehicles are estimated to be the largest on-road source of nitrogen oxides (NO_x) and particulate matter (PM) emissions: In 2020, diesel vehicles were responsible for 88.8% and 99% of on-road vehicle NO_x and PM emissions (Ministry of Ecology and Environment, 2021).

In recent years, China successively introduced a series of policies and measures to address harmful diesel emissions and they have significantly improved air quality. The national average concentration of $PM_{2.5}$ dropped from 72 μg/m³ in 2013 to 30 μg/m³ in 2021 (Ministry of Ecology and Environment, 2022). With respect to combatting climate change, China announced the goal of a peak in carbon emissions by 2030 and carbon neutrality by 2060. Reducing transportation-associated GHG emissions is critical to achieving these goals.

However, China is still facing air quality challenges. Air quality improvement in key areas is still unstable and heavy-polluted days in the autumn and winter remain frequent. In recent years, ozone pollution has also become a problem in major Chinese cities. The national average $PM_{2.5}$ concentration is especially of concern, as it is still far away from the latest World Health Organization guidelines of 5 ug/m³ (World Health Organization, 2021). In addition, carbon dioxide (CO_2) emissions from diesel vehicles are currently controlled indirectly, through an independent standard separate from the one that regulates air pollution, and thus GHG emissions from the transportation sector have not been regulated in conjunction with pollutant emissions.

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In order to help find ways to further reduce diesel pollution, ICCT planned a series of three research reports. The first paper, Yang et al. (2021), was an overview of the best practices emerging from the implementation of China's Clean Diesel Program that could be useful in other parts of the world with similar challenges; it also provided a foundation for understanding potential areas where China could further reduce diesel engine pollution. The second paper, Cackette and Shao (2021), was a historical review of policy practices in California and provided a set of policy recommendations for China to dramatically reduce air pollutants and GHG emissions from diesel mobile sources. This third and final paper aims to identify a suite of diesel emission control strategies and policies for China to consider in the next one to two decades, based on our comparison with international best practices, especially California; we quantify the emissions reduction potential of the proposed program and summarize our policy recommendations at the end.

Policy benchmarking

Table 1 compares the clean diesel policies that have been adopted or planned in China with those in California. Details of the policies can be found in the first and second reports of this series (Yang et al., 2021; Cackette & Shao, 2021). Based on these policy benchmarks and China's situation in October 2022, we then propose a policy scenario for China to further reduce air pollutants and CO_2 emissions. We quantify the emissions reduction benefits of that scenario in the subsequent sections.

Table 1. Comparison of clean diesel policies adopted or planned in China and California as of October 2022

Policy area	Policy	China	California
New vehicle and engine standards	Heavy-duty diesel engines and vehicles standard	Current: China VIa • NO_x 460 mg/kWh • PM 10 mg/kWh • Improved on-board diagnostics (OBD) • Remote OBD	Current: mandatory US 2010 • NO_x 200 mg/ bhp-hour (268 mg/kWh) • PM 10 mg/ bhp-hour (13.4 mg/kWh) Future 2024: • NO_x 50 mg/ bhp-hour (67 mg/kWh) • PM 5 mg/ bhp-hour (6.7 mg/kWh) 2027: • NO_x 20 mg/ bhp-hour (26.8 mg/kWh) • PM 5 mg/ bhp-hour (6.7 mg/kWh)
	Non-road machinery diesel engine standard	Current: China III For Power: 130 ≤ P ≤ 560 kW HC+NO_x: 4.0 g/kWh; PM: 0.20 g/kWh For Power: 75 ≤ P ≤ 130 kW HC+NO_x: 4.0 g/kWh; PM: 0.30 g/kWh Future: China IV starts from December 2022 for Power: 130 ≤ P ≤ 560 kW HC+NO_x: 2.0 g/kWh; PM: 0.025 g/kWh For Power: 56 ≤ P ≤ 130 kW HC+NO_x: 3.3 g/kWh; PM: 0.025 g/kWh	Current: U.S. Tier 4 and Not-To-Exceed (NTE) test with a standard of 1.5 times the steady-state standard Future: Tier 5 75%–90% PM and NO_x reduction based on engine size from 2028 to 2030
	Marine engine standard	Current: China phase II (equivalent to EU stage III)	Currently Tier 4 is the applicable standard for new harbor craft. Compliance with Tier 4 standards generally requires use of a particulate filter and SCR catalyst.
Vehicle emissions compliance and enforcement		• In-use portable emissions measurement system (PEMS) testing requirements starting with China V in 2017 • In-use compliance testing in China VI • Emissions warranty • Emissions recall and enforcement	• In-use PEMS testing to meet NTE requirements starting 2006 • Warranty reporting • Recall

Policy area	Policy	China	California
In-use vehicle and engine programs	In-use diesel fleet regulations	• Emissions labeling • Diesel particulate filter (DPF) retrofit program	• Replacement of older, high emitting, in-use diesel trucks • In-use diesel fleet regulations, including DPF retrofit • Truck and bus regulations, including DPF retrofit
	In-use emissions inspection	• In-use vehicle emission standards • Inspection and maintenance program • Roadside emissions inspection and remote sensing program	• Heavy-duty vehicle inspection program (HDVIP) • Smoke testing by fleets: Periodic smoke inspection program (PSIP) • Random smoke testing and tampering and OBD inspection • Remote sensing
	In-use diesel engine programs	• In-use non-road emission standard • Non-road low-emission zone • Marine Domestic Emission Control Areas (DECA)	• Replacement of older, high-emitting, off-road diesel equipment and commercial harbor craft engines. • Reducing in-use locomotive emissions
Diesel fuel programs	Diesel fuel standards	China VI: sulfur content < 10 ppm	Sulfur content < 15 ppm
	Alternative diesel fuel program	B5 Biodiesel Standard	California Low Carbon Fuel Standard
	Marine diesel	• ISO 8217 + IMO sulfur content limit	• Marine diesel fuel standard: maximum sulfur level of 0.1%
	Fuel quality compliance program	• Annual fuel quality inspection program by Administration of Market Regulation (AMR) • Random inspection by Ministry of Ecology and Environment (MEE)	Random inspection on refineries, oil tanks, truck tankers, and fuel stations.
GHG regulations and programs	New vehicle fuel consumption standards	China HDV fuel consumption standards	• Diesel engine CO_2 standards • Diesel truck CO_2 standards
	In use GHG regulation	China Green Freight Initiative	• SmartWay program
Advanced technology programs	Zero-emissions vehicles	• Zero-emission vehicle (ZEV) mandate policy • Promotion of urban electric buses and trucks	• Advanced clean truck regulation • Refueling Infrastructure for zero-emission on-road trucks
	Zero-emission non-road machinery	Current: no promotion policies electrification rate for new forklifts is about 40% in 2020, while the rate for other new non-road equipment remains about 0%.	• Goal is to achieve a full turnover of diesel off-road equipment in California to zero-emissions by 2035
Incentive programs		• Yellow label vehicle and old vehicle scrappage program • ZEV subsidy	• Carl Moyer program offers funding to adopt cleaner-than-required engines and equipment

Evaluation of emission reduction potential

Policy scenarios

We assessed the diesel emissions reductions from four transportation sectors—on-road vehicles, non-road machinery, rail engines, and marine vessels—under the following two scenarios:

» The **Adopted Policies** scenario represents policy measures and associated clean technologies in the previously defined scope adopted as of October 2022. This can be considered a business-as-usual (BAU) scenario.

» The **Proposed Policies** scenario is a set of world-class policy measures and clean technology requirements, taken from international best practices, especially California, that China could consider adopting by 2035.

To align the policy areas from our benchmarking with the modeling methodology used to estimate emissions reductions, we re-organized the policy areas in the modeling process. All of the results and discussion that follow are based on the following five categories of policies:

1. *Clean Diesel Vehicle and Engine Standards*, including new emission standards, new vehicle compliance requirements and enforcement, fuel programs, and more.
2. *In-use Diesel Vehicle and Engine Programs & Clean Fuel*, including in-use compliance regulations like labeling, a retrofit program, in-use inspection, and scrappage programs.
3. *GHG Regulations and Programs*, including energy efficiency or GHG standards, in-use vehicle GHG control, and more.
4. *ZEV Targets and Developmen*t, including advanced technology programs, incentive policies on ZEVs, and sales targets.
5. *Clean Transport*, including mode shift from road freight to rail freight.

Table 2 summarizes the key policy assumptions in the Adopted Policies and Proposed Policies scenarios. Detailed descriptions of policies and assumptions including clean grid policies for key regions are in Appendix A.

Table 2. Summary of key assumptions in the two scenarios.

Clean Diesel Actions	Scenario	Commercial vehicles	Freight rail	Marine	Non-road
Clean Diesel Vehicle and Engine Standards	**Adopted Policies**	• 2021, China VIa implemented • 2023, China VIb implemented	• No regulation	• China Phase II standard for Cat 1&2 engines • 2022, IMO Tier 3 for Cat 3 engines	• 2017, China III implemented • 2022, China IV implemented
	Proposed Policies	• 2025, China VII implemented in key regions • 2027, China VII implemented nationwide	• 2023, standard equivalent to EU Stage V	• 2025, Euro V implemented for Cat 1 & 2 engines • Expand to cover coastal and river vessels	• 2027, leapfrog to China VI from China IV
In-use Diesel Vehicle and Engine Programs & Clean Fuel	**Adopted Policies**	• Higher compliance after China VI under robust compliance measures such as OBD regulations, LEZ, and ZEZ regulations • 2020, 1 million pre-China IV were replaced with China V or NEVs	• No regulation	• DECA 2.0: covers 12 nm from Chinese coastline, plus Yangtze River, Pearl River and 12 nm around Hainan Island • 5,000 ppm fuel sulfur limit for coastal ships, 1,000 ppm for Hainan, 10 ppm for river ships	• Non-road mobile machinery exhaust smoke standard • Dynamic non-road LEZ in specific cities
	Proposed Policies	• High-emitters less than 5% of HDVs after China VII takes effect • Retire 100% pre-China V LCVs and HDVs in key regions before 2025. Retire 100% China V for LCVs and HDVs by 2030 • Require the above for the rest of China 5 years later • New vehicles have same NEV penetration of new sales	• Emissions requirement for rail engines	• IMO ECA expanded to include economic zone, 200 nm from Chinese coastline • Fuel sulfur limit: 1,000 ppm	• Enforcement for emissions limit targets for each fleet • Retrofit, or replace high emission in-use machinery
GHG Regulations and Programs	**Adopted Policies**	• 2020 average fuel consumption for new vehicles: LCV 156 g/km; Bus 480 g/km; MDT 485 g/km; HDT 960 g/km.	• No regulation	• New OGVs fuel efficiency improves about 10% every 5 years after 2020, compared to 2020 level	• 2020, voluntary engine fuel efficiency standard for non-road engines
	Proposed Policies	• LCVs fuel consumption decreases 4.5% per year from 2020 – 2030 • HDVs fuel consumption drops by 15% and 30% in 2025 and 2030, respectively, compared to 2020 • Motor vehicle air conditioning (MVAC) efficiency and emission standard	• No regulation	• New OGVs, coastal, and river vessels all need to improve 10% fuel efficiency every 5 years, compared to 2020	• Same as Adopted
ZEV Targets and Development	**Adopted Policies**	• 2025 national ZEV sales share in new fleets: Logistic, 10%; Rigid truck, 2%; City bus, 75%; Coach, 15%; Sanitation & Postal, 50%; Postal, 50%; Dump truck 1%. • Key regions are higher than national level, according to their local 14th 5-year plan	• Freight rail electrification rate is 70% in 2020 • Freight rail electrification rate reaches 80% by 2025	• OGVs, other than cruise ships (100% required) and chemical tankers (voluntary), 100% at-berth plug-in rate for shore power equipped ships • DECA regulation requires China-flagged coastal vessels built after 2020 to install shore power fitness facilities	• 2020, the electrification rate for new forklifts is about 40% • No electrification for other new non-road equipment
	Proposed Policies	• 2025 national ZEV sales share in new fleets: Logistic, 100%; Rigid truck, 15%; City bus, 100%; Coach, 55%; Sanitation & Postal, 100%; Dump truck & MDTs, 11%; Tractor-Trailer & HDTs, 7%. • 2030 & 2035 national ZEV sales share in new fleets: Logistic, 100%; Rigid truck, 30%, 55%; City bus, 100%; Coach, 55%, 80%; Sanitation & Postal, 100%; MDTs, 50%, 75%; HDTs, 30%, 40%. • Targets for key regions are 1%-5% higher than national level	• Freight rail electrification rate reaches 90% by 2025	• Progressive targets requiring China-flagged OGV fleet to install shore power fitness facility, which enables more China-flagged OGVs to use shore power at berth • Additional, similar engine electrification requirement to the one recently proposed in California's New Harbor Craft Rule.	• Electrification rate for new forklifts reaches 100% by 2030 • Electrification rate for new engineering equipment reaches 70% by 2040
Clean Transport	**Adopted Policies**	• 2020-2035, an average of 3 billion t-km from road freight to rail freight per year			
	Proposed Policies	• 2020-2035, an average of 8 billion t-km from road freight to rail freight per year • In 2035, the mode shift rate of "road to rail" is about 9.5%			

Data and methods

The baseline year for this study is 2020. Baseline data were collected from various sources, including national and industrial reports produced by governments, publicly available sources like China Association of Automobile Manufacturers (CAAM) reports and International Maritime Organization (IMO) studies, and ICCT's own databases. We analyzed four major diesel-related transportation segments: on-road commercial vehicles; non-road machinery, which includes agriculture and engineering machines; marine vessels; and freight rail. The key baseline data for each sector and the main sources of the data are listed in Table 3.

ICCT databases and publicly available data sources were used for emissions modeling of on-road commercial vehicles and the rail sector. ICCT Automatic Identification System (AIS) data and IMO data were used for emissions modeling of the marine sector. The emissions modeling of non-road machinery was conducted by Vehicle Emissions Control Center (VECC) of China and the details can be found in ICCT's previous report (Jin et al., 2021). Power grid sector data were mostly collected from China's 13th 5-year plan for the power sector (National Development and Reform Commission, 2016) and were used for calculating well-to-tank (WTT) CO_2 emissions and then estimating well-to-wheel (WTW) CO_2 emissions for each transport sector.

Table 3. Key data and sources

Sector	Key data	Sources
On-road	Sales	China Association of Automobile Manufacturers (CAAM) report, vehicle insurance data, ICCT database
	Stock	China Statistical Yearbook, supported by VECC, ICCT database
	Activity	China's National Atmospheric Emissions Inventory Guidebook, supported by VECC
	Emissions and energy intensity	China's National Emissions Inventory Guidebook, ICCT database
Rail	Sales and stock	China Statistical Yearbook
	Activity	China Statistical Yearbook
	Emissions and energy intensity	ICCT database, U.S. Environmental Protection Agency database
Marine	Activity	ICCT AIS data
	Emissions and energy intensity	IMO 4th GHG Study
	Shore power penetration	Shore power installation update released by China's Ministry of Transport in 2019, Clarksons dataset
Non road	—	Modeled by VECC
Power grid	CO_2 emissions intensity	China's 13th 5-Year Plan for Energy Development

Study scope

The scope for each sector in this study is detailed in Table 4. For the on-road sector, the policies and targets vary for different segments, fleets, and regions, and so the on-road sector is modeled by vehicle segment and region. Note that there are almost no diesel passenger cars in China, and thus the fleets in this study only cover light commercial vehicles (LCVs), buses, medium-duty trucks (MDTs), and heavy-duty trucks (HDTs). For rail and marine, we focused on the sector level and treated freight rails and vessels each as one fleet. For the non-road sector, though VECC's modeling was conducted by segment, results were shared at the sector level and that is what is presented here.

Table 4. Study scope for each sector

Sector	Region	Fleet	Segment	Power train
On-road	• Jing-Jin-Ji • Yangtze River Delta • Fen-Wei Plain • Sichuan-Chongqing • Guangdong-Hong Kong-Macao Greater Bay Area • Hainan • Rest of China	Light commercial vehicle (LCV)	• Logistic vehicle • Rigid truck • Other	Diesel, plug-in hybrid electric (PHEV) diesel, electric
		Bus	• City bus • Coach	Diesel, PHEV diesel, compressed natural gas (CNG), PHEV CNG, electric, fuel cell
		MDT	• Sanitation • Postal • Other	Diesel, CNG, electric, fuel cell
		HDT	• Tractor-trailer • Other	Diesel, electric, fuel cell
Non-road	China	All non-road machines	• Forklift • Agriculture machine • Engineering machines (these include equipment used at ports)	Diesel, electric
Rail	China	Freight rail	—	Diesel, electric
Marine	China	All vessels	—	Diesel, electric

Methodology

The study focused on tank-to-wheel (TTW) emissions for all sectors except the power grid. We estimated major diesel air pollutants and climate emissions from the four sectors from 2020 to 2035, including:

» NO_x and PM emissions, typical air pollutants from diesel fleets

» CO_2eq emissions, including tailpipe CO_2, N_2O, CH_4, and BC emissions and using 20-year global warming potential (GWP-20) values

» WTW CO_2 emissions including policies to clean up the power grid (results are in Appendix B)

On-road

ICCT's Roadmap model (ICCT, 2022) was used to estimate emissions from the on-road sector. Figure 1 shows the key data and steps in the model, which considers things such as vehicle stock, sales, and activity data by different dimensions. It also requires inputs including fuel quality, efficiency, emission controls, and emission factors. The model calculates vehicle sales, stock, activity, and CO_2 emissions, among other intermediate results. The main outputs include energy consumption and emissions of different pollutants and GHGs, including CO_2, CH_4, N_2O, NO_x, CO, HC, $PM_{2.5}$, BC, and SO_2. The model can assess WTT, TTW, and WTW emissions for GHGs and TTW emissions for pollutants.

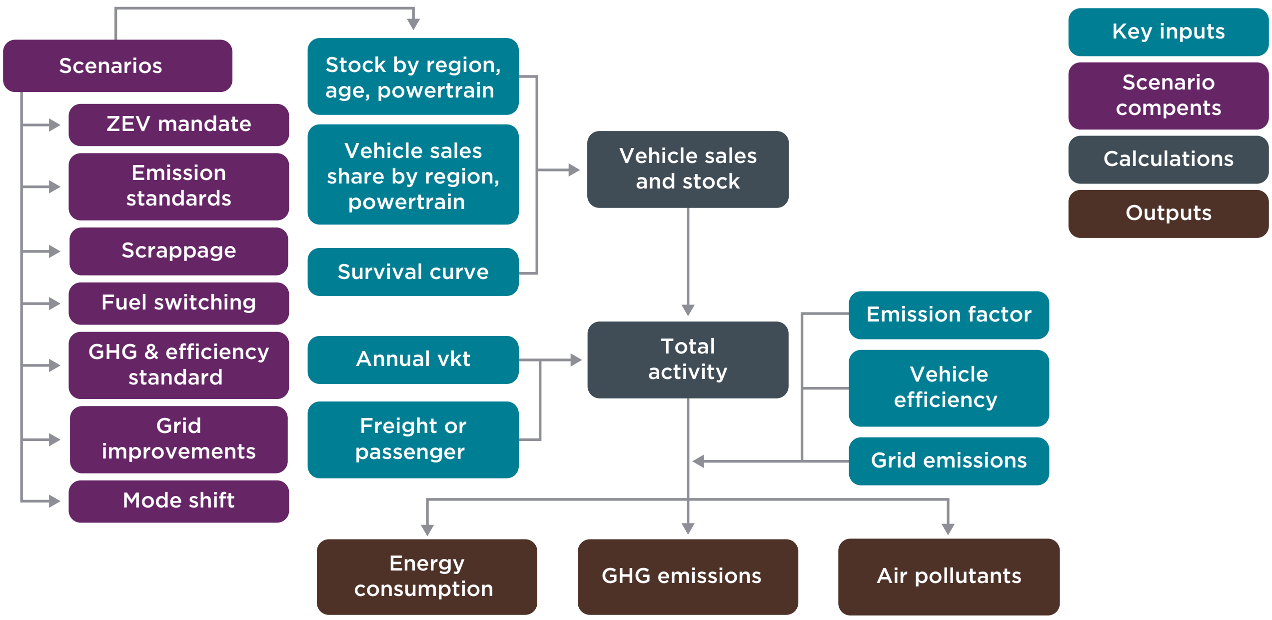

Figure 1. Schematic of ICCT's Roadmap model for the on-road sector.

Rail

An ICCT freight model for China was applied for rail and Figure 2 shows the key data and steps. The model considers things such as socioeconomic indicators, freight amount, fuels, emission controls, and emission factors. The model calculates freight rail activity and total fuel consumption, and then calculates its main outputs, including WTT, TTW, and WTW emissions for air pollutants and GHGs.

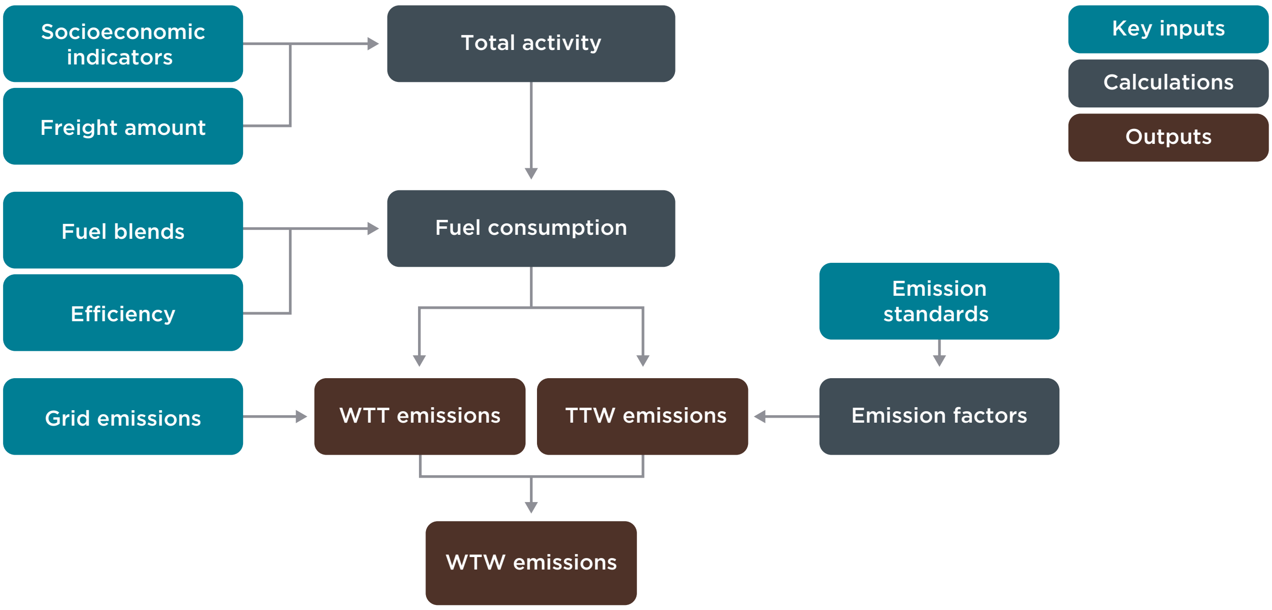

Figure 2. Schematic of ICCT's freight rail model for China.

Marine

Baseline ship emissions were estimated using ICCT's Systematic Assessment of Vessel Emissions (SAVE) model, which marries 2019 ship hourly activity data, or the Automatic Identification System (AIS) data, with 2019 ship characteristics data to produce high-resolution spatial-temporal ship emissions (Figure 3). Details of SAVE and the underlying methodology can be found in Olmer et al. (2017).

The geographical boundary of the marine emissions in this analysis extends 200 nm; it covers all from China's baseline into the Pacific Ocean and includes inland waterways.[1] As a result, marine emissions include emissions from both China-flagged and foreign-flagged ships.[2] Of the policies we modeled, some apply to all ships regardless of their flags (e.g., the emission control area policy) and others apply only to China-flagged ships (e.g., marine engine standards).

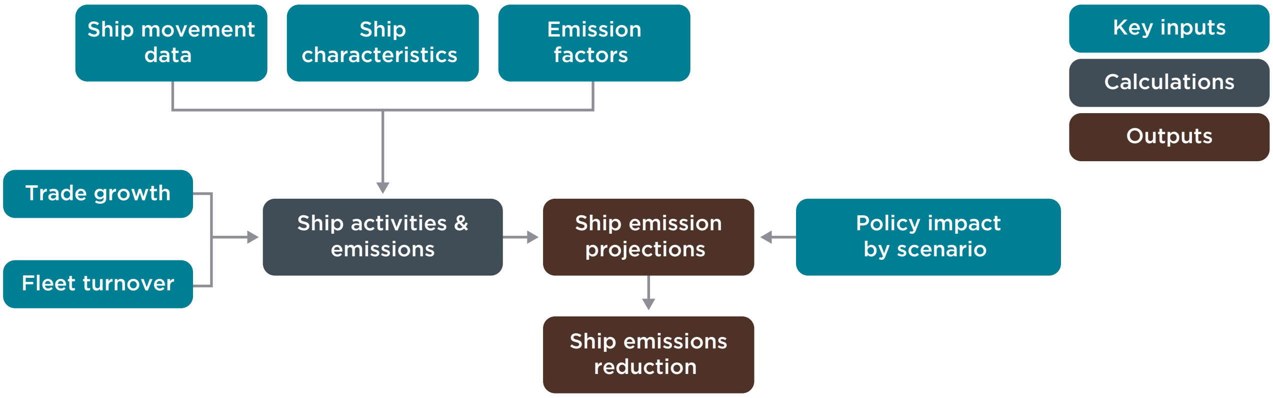

Figure 3. Schematic of ICCT's SAVE model for marine vessels.

Non-road

Non-road mobile equipment emissions were assessed by VECC-MEE with their in-house modeling. Figure 4 shows the modeling process. Baseline emission factors were generated based on engine dynamometer tests and were then adjusted using portable emissions measurement system (PEMS) real-world testing under various operation cycles. Load factors were mainly from real-world measurements. Hours of annual use were estimated based on monitoring data from major domestic companies and existing domestic and international data. N_2O and CH_4 emission factors were not available.

1 Defined by the United Nations Convention on the Law of the Sea, a country's baseline means the low-water line along the coast as marked on large-scale charts officially recognized by the coastal State. Within 12 nm from the baseline is territorial/internal sea, within 24 nm are contiguous zones, and within 200 nm are Economic Exclusive Zones. https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

2 China-flagged ships are ships flagged to the People's Republic of China.

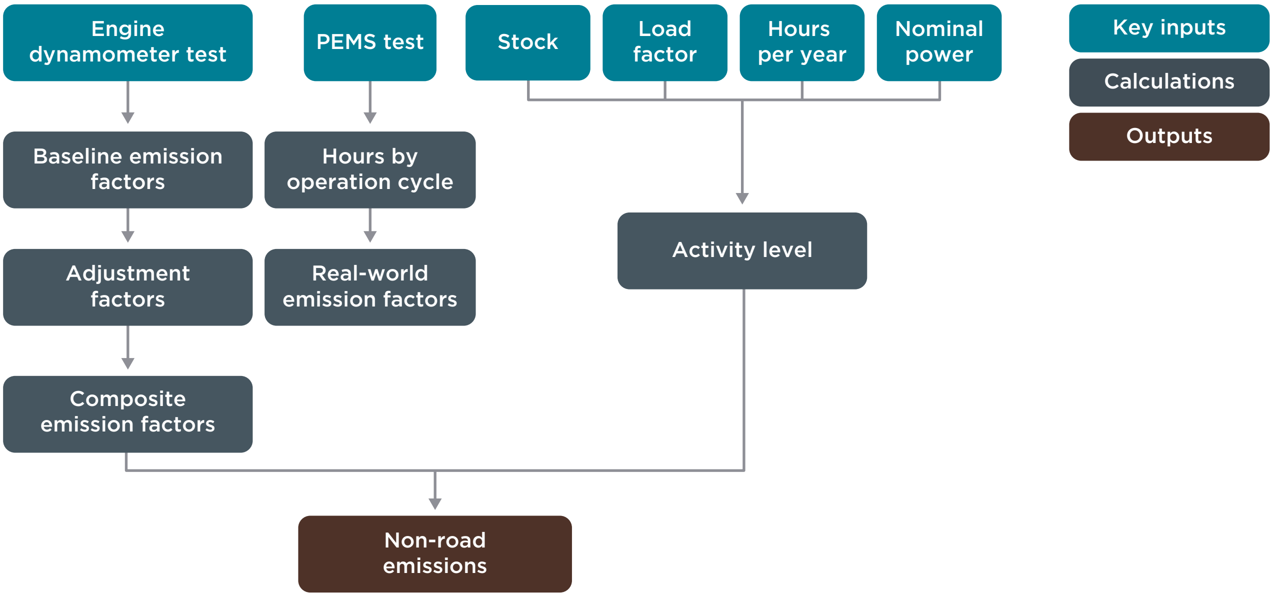

Figure 4. Schematic of VECC's methodology for modeling non-road emissions.

Results

Transport activity growth

We first project the future growth of transportation activities for the four sectors, and the on-road sector is analyzed at the fleet level. Already the world's largest vehicle market, China's considerable economic development potential and accelerating pace of urbanization are likely to further boost demand for passenger and freight transportation in the coming years.

Figure 5 shows estimated transportation activity growth for on-road fleets, rail, marine, and non-road in 2025, 2030, and 2035 compared to their respective 2020 levels. These are largely from ICCT's Roadmap model. Buses are estimated in terms of passenger activity (passenger-km). MDTs, HDTs, and rails are estimated in terms of freight activity (tonne-km). LCVs are estimated under a combination of passenger and freight activity. There is not a single measure of activity that encapsulates the marine and non-road sectors, so marine and non-road are each estimated based on their fuel consumption (MJ/year). All of these transport subsectors are expected to grow considerably. LCVs, buses, and rail are expected to have the largest activity growth. From 2020 to 2035, the level of growth ranges from about 7% (marine) and 27% (MDTs) to as large as 149% (buses) and 176% (LCVs).

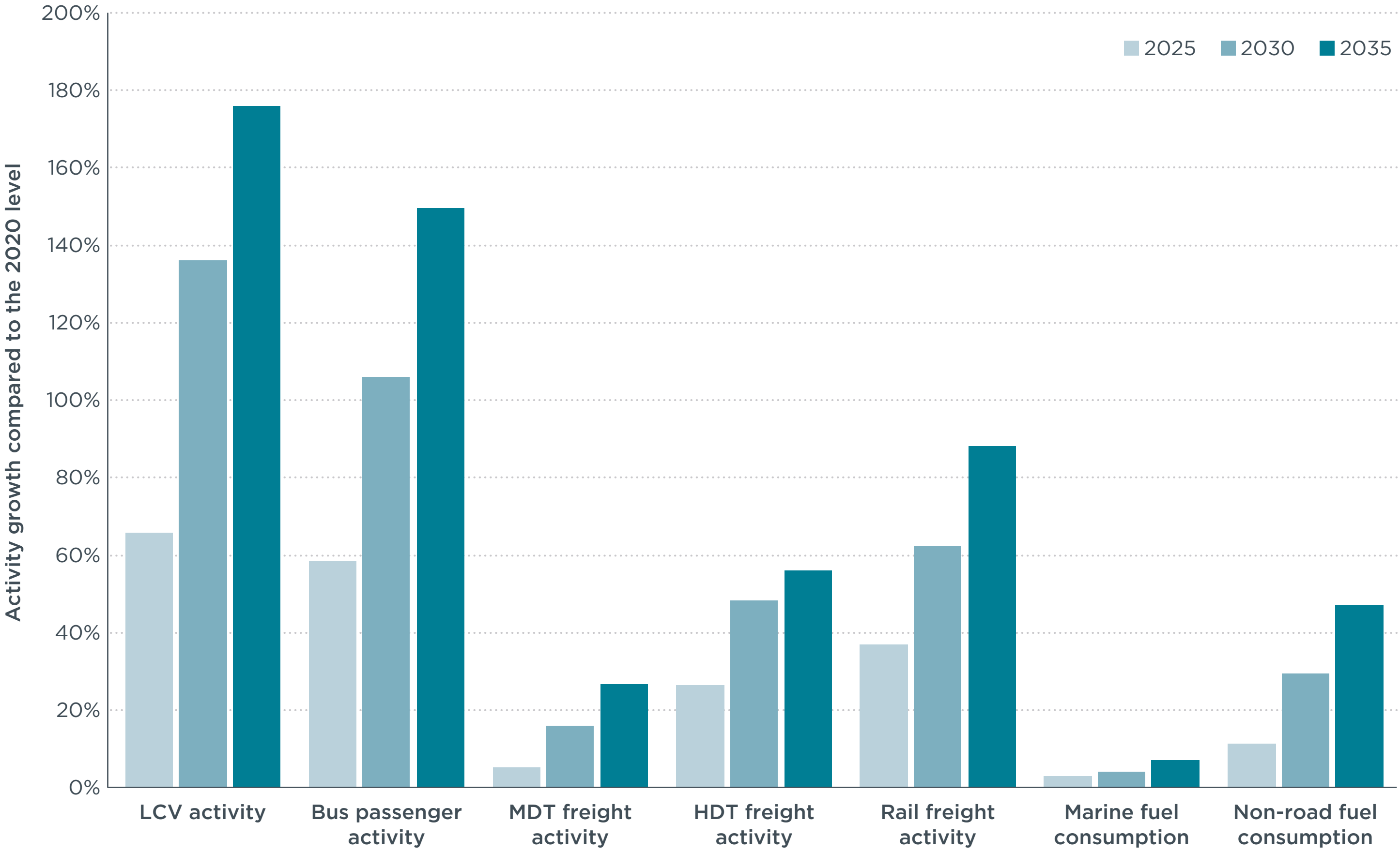

Figure 5. Projected China transport sector growth compared to the 2020 level.

Air pollutants emissions reduction potential

Figure 6 presents the benefits of NO_x and PM emissions reduction compared with the 2020 baseline by sector under the Proposed Policies scenario in 2025, 2030, and 2035, which are shown in the blue bars, and the expected emissions reductions under the Adopted Policies scenario in 2035, shown in the orange bars. **The Proposed Policies scenario shows significantly higher emissions reduction benefits than the Adopted Policies scenario.** Note that a negative value indicates the emissions are expected to *increase* compared to the baseline.

NO_x and PM from the diesel transportation sector are estimated to be reduced by 76% and 73%, respectively, in 2035 compared with the 2020 baseline in the Proposed Policies scenario. Meanwhile, the Adopted Policies scenario is estimated to only achieve 21% and 17% reductions, respectively.

The Adopted Policies scenario lacks effective controls for the rail and marine sectors. Currently, there is no emission control regulation for locomotive engines and the emission standard for marine engines is not stringent. Under the Adopted Policies scenario, NO_x emissions from rail and marine would increase by 10% and 22%, respectively, in 2035, and PM emissions would increase by 10% and 17%, respectively. However, under the Proposed Policies scenario, which includes implementing Euro V-equivalent standards for locomotive engines in 2023 and Euro V-equivalent standards for marine engines in 2025, among other electrification goals, the rail and marine sector are expected to achieve 82% and 53% NO_x emissions reduction, and achieve 83% and 55% PM emissions reduction, respectively.

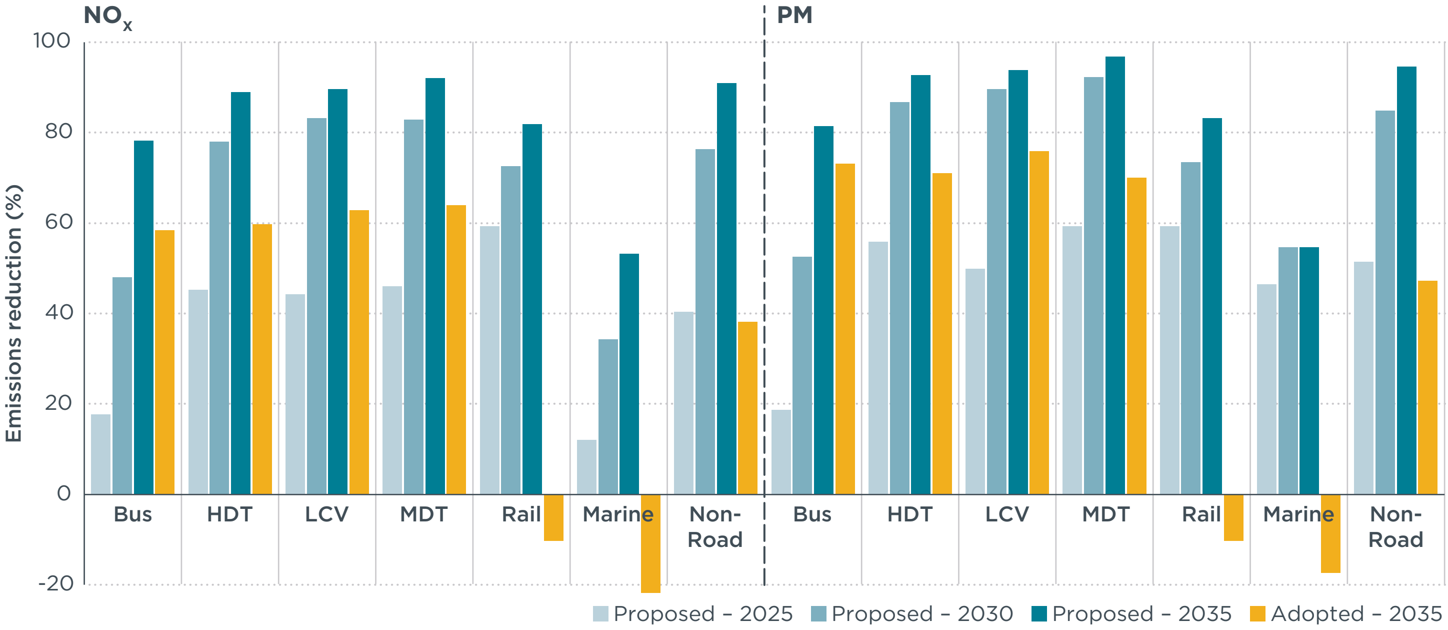

Figure 6. Projected emissions NO_x and PM reduction by sector in 2025, 2030, and 2035 under the Proposed Policies scenario and the expected emissions reduction in 2035 under the Adopted Policies scenario, all compared with the 2020 baseline.

For the non-road sector, measures in the Proposed Policies scenario, including implementation of Euro VI-equivalent standards in 2027, robust enforcement actions for in-use non-road machinery, and electrification goals, would reduce NO_x and PM emissions by 91% and 95% in 2035, compared to a 38% and 47% reduction under the Adopted Policies scenario. Under the Adopted Policies scenario, buses, HDTs, LCVs, and MDTs are expected to achieve around 60% emission reduction for NO_x and 70% reduction for PM. The Adopted Policies reductions are not enough to achieve the overall emissions and carbon peaking targets for the transportation sector, and the Proposed Policies are expected to help increase the percentage of reduction to 80% and 95% for NO_x and PM, respectively.

The left charts in Figure 7 and Figure 8 present the NO_x and PM emissions trends for all diesel transport sectors under the Adopted Policies scenario, shown with a red line, and the Proposed Policies scenario, which is bounded with black outline; they also show the emissions reduction contribution by policy category. The right pie charts of Figure 7 and Figure 8 show the share of total emissions reduction by sector in 2035 under the Proposed Policies scenario. (The emissions reduction trends for NO_x and PM for each sector under the two scenarios are presented in Appendix C.)

Diesel vehicles and engines from all sectors considered in this study are estimated to have emitted nearly 10 Mt of NO_x in 2020. The policy package in the Proposed Policies scenario is expected to bring a 77% reduction in NO_x emissions in 2035. We also find that *Clean Diesel Vehicle and Engine Standards* for new vehicles are critical to diesel emissions control, as these contribute to nearly 60% of the total NO_x reduction in 2035 under the Proposed Policies scenario. *In-use Diesel Vehicle and Engine Programs* compliance contributes 15% of NO_x emissions reduction. *Clean Transportation* policies are effective in the first 5 years with annual NO_x reductions of over 100 kt. Additionally, *ZEV Development* and *GHG Regulations* have a great co-benefit of NO_x reduction and contribute 25% of the total NO_x reduction. On the sector level, non-road, HDT, and marine are the top three critical fleets for diesel NO_x emission control and in total account for 81% of NO_x emission reduction potentials in 2035 under the Proposed Policies scenario. Note, also, that non-road is responsible for almost as much of the reduction as all of on-road.

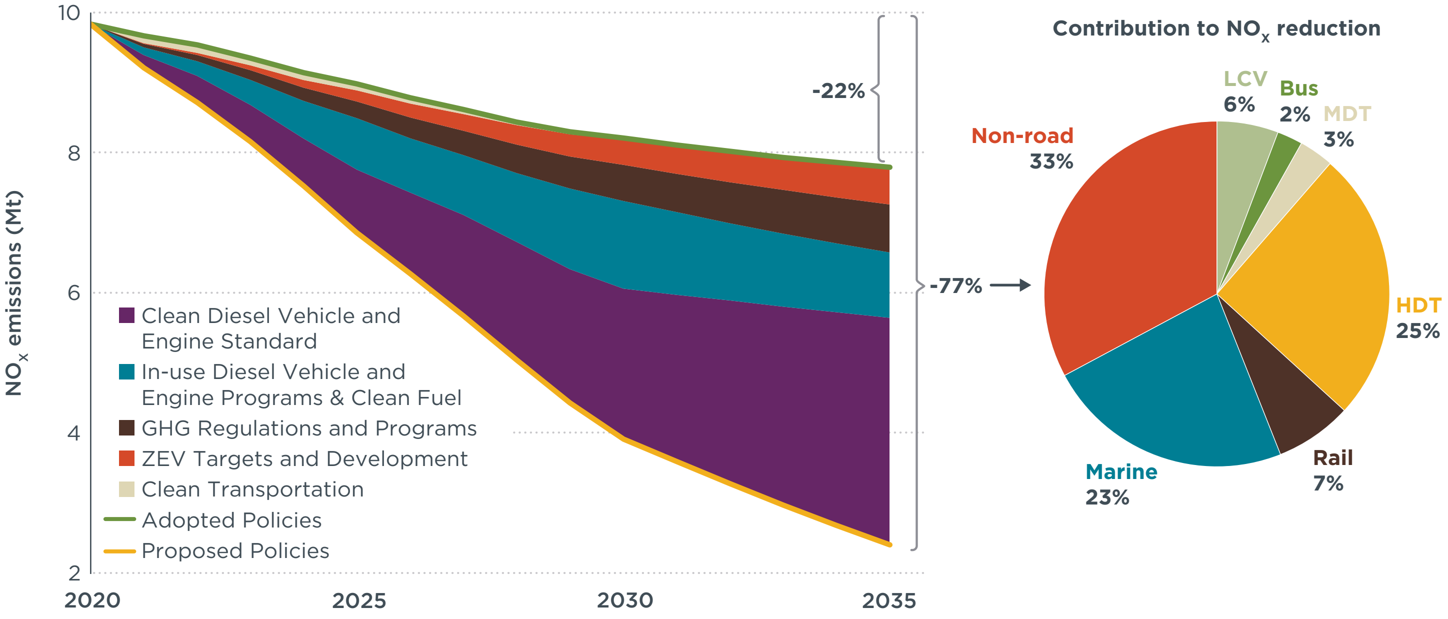

Figure 7. NO_x emissions reduction under the Adopted Policies and Proposed Policies scenarios by policy category, 2020–2035, and reduction contribution by sector in 2035 under the Proposed Policies scenario.

The strategies in the Proposed Policies scenario are expected to reduce PM emissions by 73% in 2035 (Figure 8). *In-use Diesel Vehicle and Engine Programs* are the most important category for controlling PM emissions; policies including robust compliance measures, expanding the DECA, stringent standards for marine engines, and enforcement actions for non-road machinery are expected to contribute to 50% of total PM emissions reduction in 2035. Most of those benefits come from the marine and non-road sectors, which contribute to 39% and 37% of the total PM emissions reduction in 2035, respectively. Similarly, *Clean Transportation* policies, including modal shift from truck to rail freight, contributes around 5% of total PM reduction in the first 5 years. That *ZEV Development* and *GHG Regulations* combined contribute 45% PM reductions in 2035 shows the great co-benefits they provide for PM emissions control.

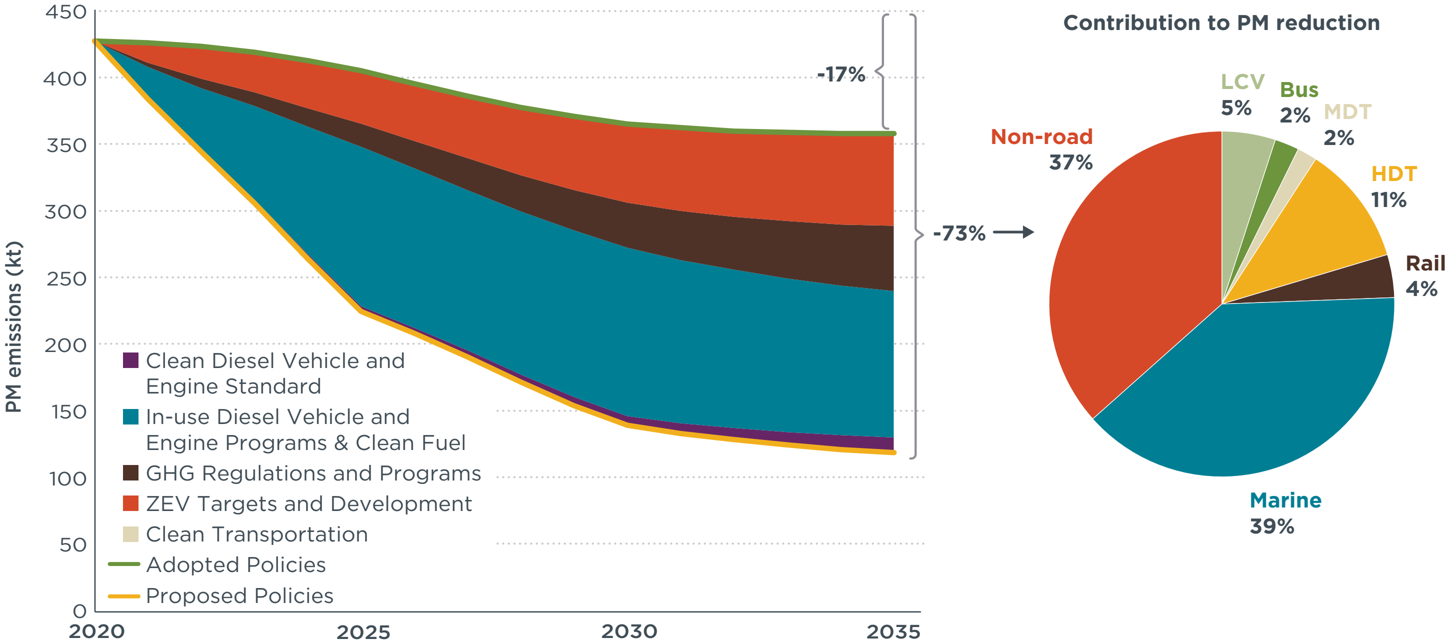

Figure 8. PM emissions reduction under the Adopted Policies and Proposed Policies scenarios by policy category, 2020–2035, and reduction contributions by sector in 2035 under the Proposed Policies scenario.

Carbon emissions reduction potential

While this study mostly focuses on criteria air pollutants, many of the policies we considered are also projected to deliver significant reductions in climate pollutants. Key policies include strengthened GHG standards for on-road vehicles, progressive vehicle and engine electrification targets, and modal shift from truck to rail. Under the Proposed Policies scenario, TTW CO_2eq emissions are estimated to be reduced by 36% in 2035 compared to the 2020 baseline, and under the Adopted Policies scenario, the TTW CO_2eq emissions are expected to be 12% *higher* in 2035.

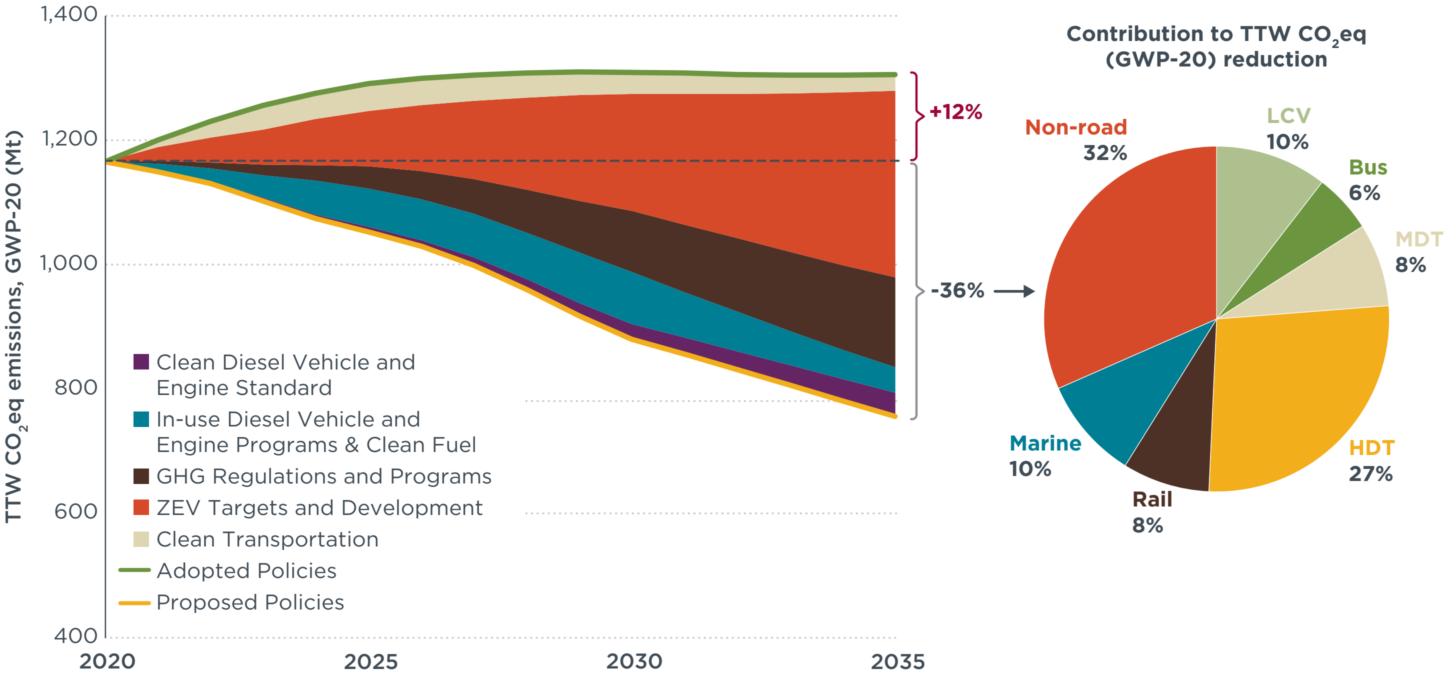

Figure 9. TTW CO_2eq emissions reduction by the policy, 2020–2035, and reduction contribution in 2035 for the Proposed Policies scenario.

Figure 9 shows the emissions reduction results for TTW CO_2eq. The diesel fleets from all sectors emitted 1,166 Mt of TTW CO_2eq in 2020. *ZEV Targets and Development* is the most effective policy category for reducing these emissions and it contributes 55% of total TTW CO_2eq reduction in 2035. Additionally, *GHG Regulations and Programs* are also critical, with a 26% contribution. *Clean Transportation* policies would be quite effective in the first 10 years, with over 40 Mt TTW CO_2eq reduction; that is 20%–45% of the total reduction. Both *Clean Diesel Vehicle and Engine Standard*s and *In-use Diesel Vehicle and Engine Programs* are expected to bring 14% TTW CO_2eq reduction in 2035, as they can push the technical improvement. These modeling results show that electrification of non-road machinery and HDTs is important for decarbonizing diesel vehicles in China.

Policy recommendations

Tighten emission standards for new diesel vehicles/engines

China's diesel vehicle emissions standard and non-road mobile machinery emission standard are still far behind the standards in California. Experience has proved that stricter emission standards can effectively promote the development of advanced emission control technologies (Yang et al., 2021). When emission control technologies are in the early stage of development, their application can increase vehicle production costs; however, once there is large-scale application and widespread commercialization, costs are significantly decreased. Currently, technologies that meet the most stringent emission standards have been widely commercialized in the United States and Europe; these can significantly reduce pollutant emissions from diesel vehicles and bring considerable benefits in improving air quality and protecting human health. We propose that the NO_x emission limit in China's next phase of the diesel vehicle emission standards be reduced by 90%, and the PM emission limit be reduced by 50%, similar to California's Omnibus regulation (Kelly & Sharpe, 2022). In addition, the implementation date of the next phase of the diesel vehicle emission standard should not be later than 2027. In key regions that are facing air quality challenges, it should be considered to implement the new standards ahead of the national schedule, as was done with the China VI standard. For non-road mobile machinery, the Euro V-equivalent emission standard should be developed and implemented as early as possible. For marine emissions, it is recommended to fully implement the Stage II emission standard and to develop the Stage III emission standard with a stringency that follows the U.S. Tier 4 standard. China has not yet promulgated emission standards for locomotive engines, and we recommend speeding up the research and implementation of these.

Strengthen compliance supervision

Although newly produced vehicles and engines must meet emission standards before they can be sold on the market, their real-world emissions often fall short of expectations. The higher real-world emissions can be related to the inherent limitations of laboratory test procedures and sometimes to manufacturer-installed devices that alter the real-world functioning of emission control technology. In addition, emissions will rise under certain operating conditions, and these driving conditions are not currently captured in new-vehicle compliance testing. High emissions during real-world driving can also be related to poor maintenance or owner tampering with emission control systems. The China VI HDV emission standard already includes a series of in-use compliance inspection requirements that are to be conducted by manufacturers and regulatory agencies. In addition, China VI adds warranty period requirements and requires that new vehicles be equipped with remote emissions management systems that upload real-driving data to the authorities. The Ministry of Ecology and Environment, together with the State Administration for Market Regulation, has established a vehicle emissions inspection and maintenance (I/M) system and a vehicle environmental recall mechanism.

The China VI emission standard and the I/M regulation have been adopted nationwide, and the key step now is to implement them effectively such that the nationwide compliance rate is high. There are two parts to this. For one, it is necessary to strictly implement the provisions of the Clean Air Law and the China VI emission standard, carry out self-inspection and random inspections of in-use compliance, and impose penalties on companies that produce and sell vehicles or engines that do not meet the standards. On the other hand, penalties should be imposed on vehicle owners who remove aftertreatment devices and/or tamper with emission control systems. In addition, a variety of new technologies, including remote sensing monitoring and remote OBD, should be fully utilized to identify tampering and improve the effectiveness of emission standard compliance supervision. In terms of marine vessel emissions, compliance supervision should be strengthened for marine fuel sulfur content, engine NO_x emissions, and the use of shore power in the marine DECA.

Accelerate the phase-out of old motor vehicles, non-road machinery, and ships

Although old diesel vehicles and engines are a small portion of the current in-use stock, the pollutants they emit are most of the diesel emissions. While yellow label vehicles have been essentially eliminated, China III and China IV diesel HDTs are the main sources of motor vehicle NO_x and PM emissions, and we recommend that China continue to accelerate the phase-out of China III and IV diesel trucks. It is recommended to completely phase out China III and earlier diesel trucks nationwide and further phase out China IV diesel trucks in key regions by 2025. At the same time, the phase-out of old non-road mobile machinery should be accelerated, and it is recommended to phase out all China I and earlier non-road machinery by 2025. Key regions can consider implementing policies such as low-emission zones for motor vehicles and non-road machinery to speed up the phase-out of old vehicles/engines. Financial subsidies can be provided to owners and companies that retire old vehicles/engines earlier than the schedule. In addition, the elimination of old ships should be accelerated. It is recommended that all ships in the DECA be required to use low-sulfur fuel and comply with the IMO Tier III NO_x standard starting in 2025, and we recommend considering expanding the area of DECA to cover as far as 200 nm off the entire Chinese coastline, where possible (this is equivalent to China's Exclusive Economic Zone).

Integrated control of GHG and pollutant emissions

Regulatory measures for controlling GHG emissions are still lacking compared with the regulations for air pollutants; this includes a lack of tailpipe emission standards that control CO_2, methane, nitrous oxide, and hydrofluorocarbons (HFCs), and a lack of inspection and management to assess compliance with fuel consumption standards. For GHG emissions from motor vehicle air conditioning systems, China lacks concrete policy solutions and fundamental data and information to effectively reduce high-GWP refrigerant consumption and reduce indirect GHG emissions. China has established fuel consumption incentive credits for high-efficiency air conditioners for passenger cars, but they have not yet been applied to commercial vehicles and electric vehicles. We recommend that China formulate vehicle GHG emission limits, incorporate those GHG emission standards into the next stage of heavy-duty vehicle emission standards, and include them in the scope of vehicle emissions compliance supervision. According to the modeling results presented above, coordinated emissions reduction of GHGs and criteria air pollutants can bring significant benefits.

Develop zero-emission targets and incentive policies to promote zero-emission vehicles/engines

ZEVs, including battery electric vehicles and hydrogen fuel cell vehicles, are the best solution to air pollution and climate problems. China has thus far set requirements for zero-emission urban buses, light-duty logistics vehicles, postal vehicles, and sanitation vehicles, but has not formulated a clear electrification roadmap for HDTs. Meanwhile, California has decided to fully electrify all medium and heavy-duty fleets by 2045 and is considering a goal of fully electrifying non-road mobile machinery by 2035. To achieve this ambitious goal, California has passed mandatory electric vehicle regulations for trucks, which require truck suppliers to gradually increase the electrification rate of new truck sales starting in 2024. In addition to this, California is developing new mandatory regulations that will require California's freight companies to purchase a certain number of zero-emission trucks. To support these rules, California provides subsidies and other financial support for the purchase of electric trucks and provides fiscal incentives for the construction of the charging infrastructure required for electric trucks.

Many other countries and regions have formulated their own heavy-duty vehicle electrification roadmaps and promotion policies. We recommend that China develop a clear electrification roadmap for heavy-duty vehicles and non-road machinery as soon as possible. For example, the electrification rate of sales of new medium-size commercial vehicles should reach at least 50% in 2030 and 75% in 2035, and the electrification rate of sales of new heavy-duty commercial vehicles should reach 30%

in 2030 and 40% in 2035. For sales of new forklifts, electrification should reach 100% in 2030, and for sales of other new construction machinery, it should reach 70% in 2040. It is also recommended that key regions research and develop innovative policy tools to help achieve the goal of electrification of heavy-duty vehicles and non-road machinery, such as pilots of zero-emission logistics parks, urban vehicle zero-emission zones, and non-road zero-emission zones. Also, key regions should consider promoting the development of hydrogen fuel cell heavy-duty vehicles. In terms of zero-emission of ships, it is recommended to formulate zero-emission targets for specific ship types, including tugboats, government law-enforcement ships, and small passenger ships, and to develop incentives for electrification of vessels.

References

Cackette, T., & Shao, Z. (2021). *California's Clean Diesel Program*. International Council on Clean Transportation. https://theicct.org/publication/californias-clean-diesel-program/

International Council on Clean Transportation. (2022). *Roadmap Model Documentation*. https://theicct.github.io/roadmap-doc/

Jin, L., Shao, Z., Mao, X., Miller, J., He, H., & Isenstadt, A. (2021). *Opportunities and pathways to decarbonize China's transportation sector during the fourteenth Five-Year Plan period and beyond*. International Council on Clean Transportation. https://theicct.org/publications/decarbonize-china-transport-14th-5-year-plan-oct21

Kelly, S., & Sharpe, B. (2022). *California's heavy-duty omnibus regulation: Updates to emission standards, testing requirements, and compliance procedures*. International Council on Clean Transportation. https://theicct.org/publication/california-us-hdv-omnibus-reg-jan22/

Ministry of Ecology and Environment. (2022, January 31). *Ministry of Ecology and Environment informs of national surface water and ambient air quality in December and January-December 2021* [Press release]. https://www.mee.gov.cn/ywdt/xwfb/202201/t20220131_968703.shtml

Ministry of Ecology and Environment. (2021). *China mobile source environmental management annual report*. http://www.gov.cn/xinwen/2021-09/11/5636764/files/3ac6b9802f8b47fc8200403308a0d25d.pdf

National Development and Reform Commission. (2016). *13th 5-Year Plan for power sector*. http://www.gov.cn/xinwen/2016-12/22/5151549/files/696e98c57ecd49c289968ae2d77ed583.pdf

Olmer, N., Comer, B., Roy, B., Mao, X., & Rutherford, D. (2017). *Greenhouse gas emissions from global shipping, 2013–2015: Detailed methodology*. International Council on Clean Transportation. https://theicct.org/publications/GHG-emissions-global-shipping-2013-2015

World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. https://apps.who.int/iris/handle/10665/345329

Yang, L., He, H., Shao, Z., Cui, H., & Mao, X. (2021). *A retrospective review of China's Clean Diesel Program*. International Council on Clean Transportation. https://theicct.org/publication/a-retrospective-review-of-chinas-clean-diesel-program/

Appendix A. Detailed policies and assumptions in the Adopted and Proposed Policy Scenarios

Table A1 gives an overview of announced zero-emission targets heavy-duty vehicles in all of China and in key provinces. With more and more policies and measures promoting zero-emission vehicles, and more focus on heavy-duty vehicles (HDVs) at the national and local levels, we believe that China's experiences as a world-leading HDV market can be useful for others who seek to develop their own markets.

Table A1. Announced zero-emission heavy-duty vehicle targets in China and key provinces (through October 2022).

Region	Document	HDV targets
China	14th 5-year Plan for Energy Saving and Emission Reduction	20% NEV sales among total vehicle sales in 2025
China	Implementation Plan of Synergic Interactions for Air Pollutants and Carbon Emission Reductions	50% NEV sales among total vehicle sales in 2030 (Key regions with air quality challenges)
Hainan	Clean Energy Vehicle Development Plan; Hainan Implementation Plan for Carbon Peaking	100% clean energy vehicles in stock for city buses in 2025 100% clean energy vehicles in sales for coaches in 2025 100% BEVs in sales for urban freight vehicles, 50% for sanitation in 2025 No diesel and gasoline vehicle sales in 2030
Beijing	14th 5-year Plan for Ecologic Environmental Protection	By 2025, 2 million NEVs, 10,000 FCEVs in stock (not mandatory) Near 100% ZEVs in stock for city buses, sanitation, postal and express vehicles, tourism coaches, and muck trucks (not mandatory)
Shanghai	14th 5-year Plan for Ecologic Environmental Protection	By 2025, increase NEVs sales in HDTs, 10,000+ FCEVs in stock 100% NEVs in stock for city buses and urban trucks; 80% NEVs for sanitation; 50% NEVs
Guangdong	14th 5-year Plan for Ecologic Environmental Protection and Comprehensive Transportation (see also here)	By 2025, 97.5% BEV in city buses Increase BEV sales for trucks, and FCEV sales for long-haul HDVs
Sichuan	14th 5-year Plan for Comprehensive Transportation	By 2025, 100% BEV in stock for city buses, sanitation and postal vehicles, urban logistic vehicles
Chongqing	14th 5-year Plan for Comprehensive Transportation	By 2025, over 80% BEV in sales for city buses
Tianjin	14th 5-year Plan for Comprehensive Transportation	Heavily promote BEVs sales in city buses, postal and logistic vehicles
Shaanxi	14th 5-year Plan for Comprehensive Transportation	By 2025, 80% BEVs in sales for city buses, postal and logistic vehicles
Shanxi	14th 5-year Plan for Comprehensive Transportation	Heavily promote BEVs sales in city buses
Henan	14th 5-year Plan for Comprehensive Transportation	By 2025, 100% BEV in stock for city buses
Hebei	14th 5-year Plan for Ecologic Environmental Protection	By 2025, over 80% BEV in sales for city buses
Jiangsu	14th 5-year Plan for Green Transportation	By 2025, 80% BEV in sales for city buses
Zhejiang	14th 5-year Plan for Ecologic Environmental Protection	By 2025, 90% BEV in sales for city buses

Table A2 presents the nationwide electrification rate of sales of new vehicles for each diesel fleet. This is the key assumption in the *ZEV Targets and Development* policy category. Table A3 shows the detailed information and assumptions for all policies across all sectors.

Table A2. Nationwide electrification rate for sales of new vehicles for each diesel fleet

Policy scenarios		Baseline (%)	Adopted (%)	World Class (%)		
Fleet	**Segment**	**2020**	**2025**	**2025**	**2030**	**2035**
LCV	**Logistic vehicle**	5	10	100	100	100
	Rigid truck	0.5	2	15	30	55
	Other	3	5	15	30	55
Bus	**City bus**	60	75	85	100	100
	Coach	8	15	25	50	80
MDT	**Sanitation**	5.5	50	80	100	100
	Postal	4.5	50	80	100	100
	Other	0.3	0.5	11	50	75
HDT	**Tractor-trailer**	0	0.2	7	30	40
	Other	0	0	7	30	40
Rail	**Freight rail**	70	80	90	90	90
Marine	**OGV (equipped with shore power)**	2	3	5	8	11
Non-road	**Forklift**	40	40	70	100	100
	Other	0	0	15	35	**70 (in 2040)**

Table A3. Detailed policies and description for the Adopted Policies and Proposed Policies scenarios

Policy Category	Policy	Adopted	Proposed
1. New vehicle and engine standards	**1.1 Heavy-duty diesel engines and vehicles standard**	• China VIa implemented in 2021 • China VIb to be implemented in 2023	• China VII to be implemented in 2027 nationally and in 2025 in key regions • NO_x limits reduced by 90% and PM limits reduced by 50%, compared to China VIb
	1.2 Non-road machinery diesel engine standard	• China III since 2017 • China IV is implemented in 2022 (Beijing implemented China IV in Dec 2021)	• China leapfrogs to Stage VI starting in 2027 (this means NO_x and PM emissions reductions are 50% and 40% compared to China IV)
	1.3 Marine engine standard	• China phase II (equivalent to EU stage III) for Category 1 and 2 engines • IMO Tier III for Category 3 engines built after 2022 entering DECA	• EU stage V limits starting 2025 for Category 1 and 2 engines • Same but in an expanded DECA
	1.4 Freight rail emission standards	• Locomotive engine emissions are currently unregulated	• EU Stage V-equivalent standards apply to new diesel locomotive engines in 2023
2. In-use Diesel Vehicle and Engine Programs	**2.1 Vehicle compliance and enforcement**	• 40% of China IV and V trucks have malfunctioning emission controls, which has led to excess BC emissions; the emission levels of these trucks are expected to be similar to China III (based on inputs from VECC) • China VI can achieve higher compliance rate due to stringent in-use regulations such as remote OBD	• Based on the Adopted Policies scenario, more robust compliance measures will be applied. The high emitter rate will decrease to 5% for China VI and VII HDVs, and there will be an extension on warranty length and useful life for China VII HDVs
	2.2 MDT and HDT scrappage program	• 1 million pre-China IV trucks were replaced with China VI or NEV by 2020	• China will retrofit, retire, and replace 100% of pre-China V trucks with China VI or NEV by 2025 in key regions, replaced by China VI and new energy trucks. The NEV ratio is aligned with the sales share • All China V trucks would be retired or replaced with China VII or NEV by 2030 in key regions • Other regions will be 5 years later
	2.3 LCV scrappage program	• No policy at the national level	• Key regions would require retirement of all pre-China V light trucks and replacement with China VI or NEV vehicles by 2025 • All China V light trucks would be retired or replaced with China VII or NEV by 2030 in key regions • Other regions will be 5 years later
	2.4 Marine Emission Control Area	• In line with DECA adopted in 2018: from 2019, OGVs enter DECA are required to use fuel with sulfur content <= 0.5% m/m. From 2022, OGVs enter DECA around Hainan Island are required to use fuel with sulfur content <= 0.1% m/m. Coverage: 12 nm off entire Chinese coastline, plus Yangtze River, Pearl River, and 12 nm around Hainan Island	• The geographical coverage of an ECA could be expanded. Coverage: 200-nm off of entire Chinese coastline where possible • Implementation date: 2025 for both SO_x and NO_x
3.GHG Regulations and Programs	**3.1 LCV fuel efficiency/ CO_2 standards**	• The current China Stage 3 LCV standards achieved an average 20% reduction in new LCV fuel consumption from 2012–2020 • The new LCV fleet average CO_2 emissions is 156 g/km on a gasoline equivalent basis for all fuel types in 2020	• Light ICE trucks fleet wide CO_2 emissions decrease 4.5% per year compared to 2020 till 2030
	3.2 HDV fuel efficiency/ CO_2 standards	• The current China Stage 3 HDV standards aims to achieve an average 15% reduction in new HDV fuel consumption from 2015–2020. • The fleet average CO_2 emissions for the new diesel bus fleet is 480g/km, new MDT fleet is 485 g/km, HDT fleet is 960 g/km in 2020. • No improvement afterward	• For new ICE HDVs, new CO_2 standard will require 15% reduction from 2020 levels by 2025 and a 30% reduction from 2020 levels by 2030. This roughly reflects the reduction required in the European Union's current HDV CO_2 emission standard in the same time span
	3.3 Marine engine efficiency/CO_2 standards	• Oceangoing vessels are subject to EEDI standards set by the IMO	• China would adopt a set of fuel efficiency standards for coastal and river vessels that are similar to the EEDI
	3.4 Non-road engine efficiency/CO_2 standards	• Voluntary engine fuel efficiency standard for non-road engines in 2020	• Same as adopted
	3.5 In-use truck fuel efficiency program	• In 2015, 1,500 trucks participated in the green freight program in Guangdong province. This level of participation is negligible from a national-level perspective.	• Higher participation in green freight programs in China, with 3% of in-use LCVs, MDTs, and HDTs affected starting in 2025, and 15% fuel savings for affected vehicles.
4. ZEV Targets and Development	**4.1 Electrification of LCVs**	• Nationwide NEVs are expected to account for about 10% of new logistics vans and 2% of new rigid light trucks by 2025. • Key regions will have slightly higher electrification rate in each segment of LCVs, according to local policies. Hainan announced to reach 100% electrification for new logistic vehicles and 50% for other LCVs in 2025. • The electrification will remain the same after 2025.	• China will reach 100% electrification for new logistic vehicles in 2025. 15% electrification for other new LCVs • New rigid truck and other LCVs can both reach 30% and 55% electrification by 2030 and 2035. • Key regions will have about 5%–10% higher electrification rate on each segment of LCVs, according to local policies. • Details for national targets are in Table A1
	4.2 Electrification of buses	• China will reach an average of 75% electrification for new city bus and 15% for new coaches in 2025. • Rest sales of city buses are all in new energy • Key Regions will have 85% - 95% electrification rate for city buses according to local 14th 5-year plans. • The electrification will remain the same after 2025.	• China will reach 100% electrification for new city bus and 55% for coaches in 2025. • New coaches can reach 68% and 80% electrification by 2030 and 2035. • Key regions will reach 100% electrification for new city buses in 2025, and about 10% higher electrification rate on each segment of city buses according to local policies. • Details for national targets are in Table A1
	4.3 Electrification of MDTs and HDTs	• For urban sanitation and postal vehicles, they will reach 50% electrification in new sales nationwide in 2025, and 60%–80% in key regions according to the local 14th 5-year plan. • For others, no significant change of market share compared with 2020 baseline levels.	• Urban sanitation and postal vehicles will reach 100% electrification of new sales nationwide in 2030, and key regions will reach 100% before 2030. • For other MDTs, BEV share in new sales would be 11%, 50% and 75% in 2025, 2030 and 2035 respectively, key regions will be 1%–5% higher. • For HDTs, BEV share in new sales would be 7%, 30%, and 40% in 2025, 2030, and 2035, respectively; key regions will be 1%–5% higher. • Details for national targets are in Table A1
	4.4 Electrification of non-road equipment	• Electrification rate for new forklifts is about 40% in 2020 • The rate for other new non-road equipment remains about 0%	• Electrification rate for new forklifts reaches 100% by 2030 • Electrification rate for new non-road engineering equipment reaches 70% by 2040
	4.5 Electrification of ship engines	• DECA regulation requires China-flagged coastal vessels built after 2020 to install shore power fitness facility. In 2020, vessels are required to use shore power if the berths have shore power available.	• Progressive targets requiring China-flagged OGV fleet to install shore power fitness facility, which enables more China-flagged OGVs to use shore power at berth • Additional, similar engine electrification requirement recently proposed in California's New Harbor Craft Rule
	4.6 Electrification of freight rail	• Current freight rail fleet electrification rate was 70% in 2020 • This rate will reach 80% in 2025 if China continues its efforts on electrifying the freight railway system	• Electrification rate of freight rail fleet will reach 90% by 2025 • It will remain 90% after 2025
	4.7 China HDV refrigerant standards	• No requirement	• A ban on the use of high-GWP refrigerants on new vehicles in 2023
5. Clean Grid	**5.1 Power sector improvement**	• The baseline grid lifecycle carbon emission factor was 635 gCO2eq/kWh in 2020	• An approximately 60% life-cycle carbon reduction from 2017 baseline in 2030, which is 307 gCO_2eq/kWh (in line with WEO's 2021 SDS data)
6. Mode Shift	**6.1 Road freight to rail freight**	• Mode shift of HDTs is an average of 4.0 billion t-km per year from 2020–2035 (these are transferred to freight rails), in line with the 2020 level	• Mode shift rate of HDTs will increase to 9.5% by 2035 • An average of 8.0 billion t-km per year

Appendix B. Results for WTW CO_2 emissions and black carbon (BC) emissions

Figure B1 shows the emissions trend potential for WTW CO_2 and Figure B2 shows the BC emissions trend, both from 2020 to 2035.

In the Proposed Policies scenario, the four sectors are expected achieve peak WTW CO_2 emissions in early 2028, ahead of China's 2030 target. Additionally, in 2035, policies under the Proposed Policies scenario are projected to reduce BC emissions by 89% compared to the 2020 baseline. That is far more than the reduction in the Adopted Policies scenario, which is only 49%. Continuous policies beyond those in the Proposed Policies scenario would be needed to keep the downward trend after 2035.

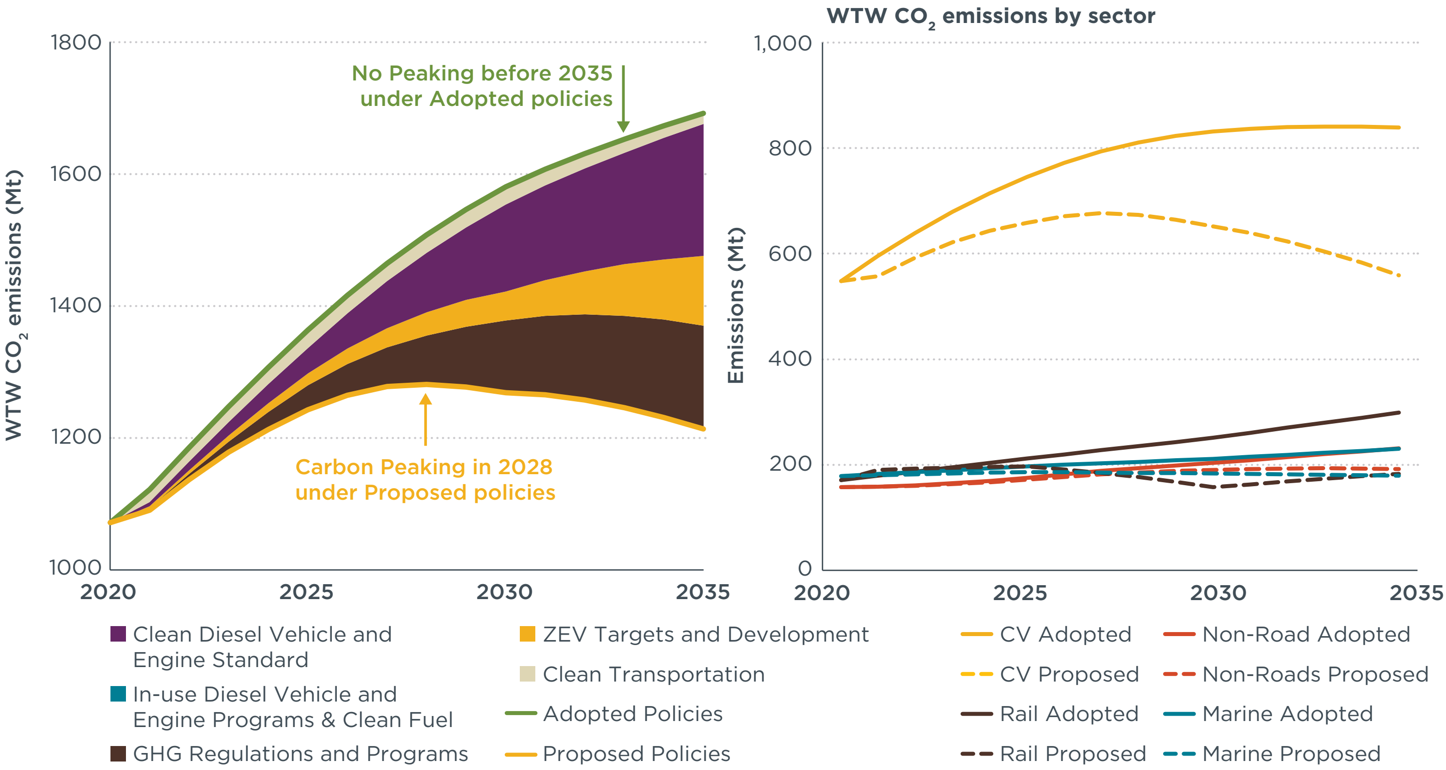

Figure B1. WTW CO_2 emissions reduction by policy category under the Proposed Policies and Adopted Policies scenarios and the emissions trendline by sector (right panel), 2020–2035.

The diesel fleets from the all sectors contributed a combined 1,055 Mt WTW CO_2 emissions in 2020; on-road vehicles were the dominant contributor with 548 Mt WTW CO_2 emissions that year, and they were followed by marine, 179 Mt, freight rail, 171 Mt, and non-road, 157 Mt. ZEV development for commercial vehicles (CVs) is one of the most important policies to reduce WTW CO_2 emissions, and reducing the carbon intensity of the electricity grid is also critical.

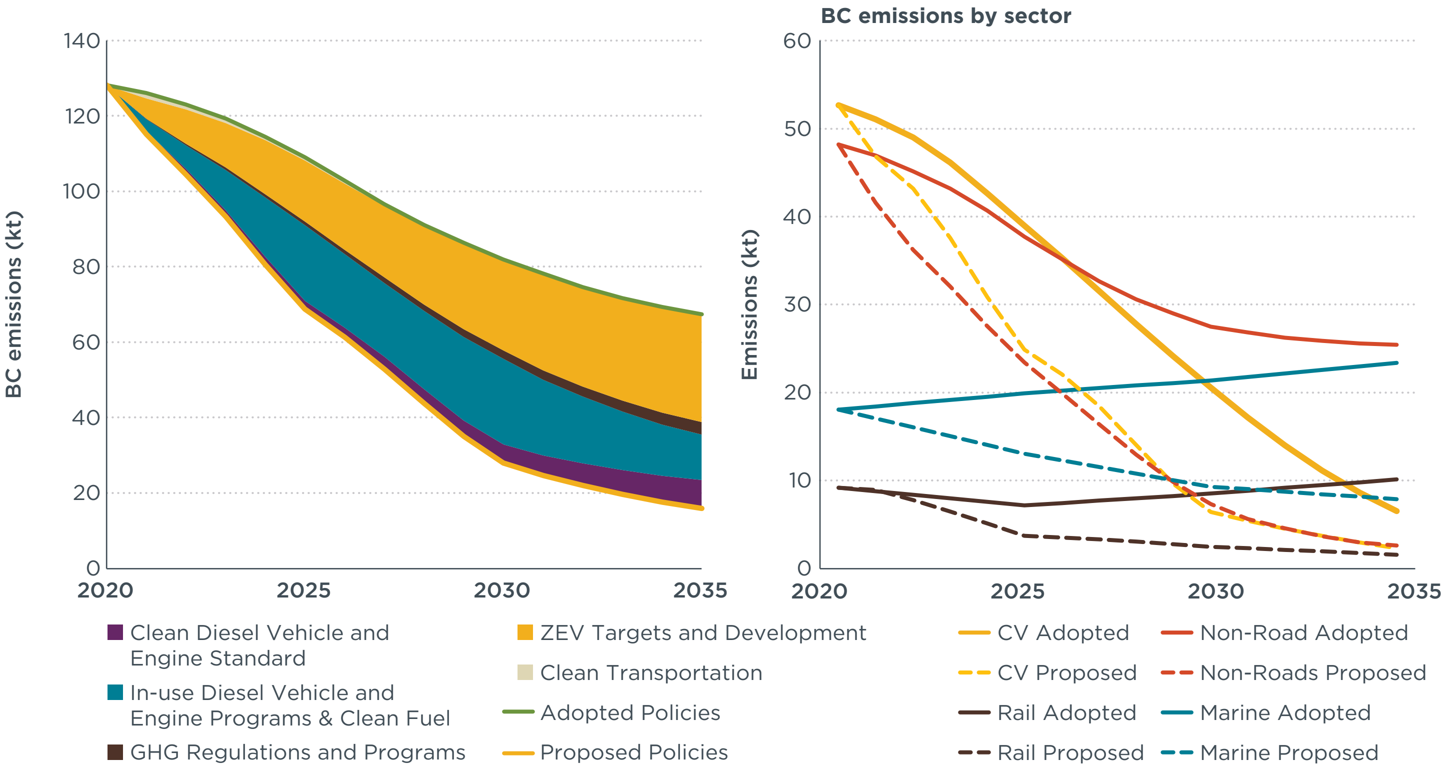

Figure B2. BC emission reduction by policy category under Proposed scenario compared with Adopted Scenario (left) and the emission trendline by sector (right) (2020-2035)

The diesel fleets we studied also contributed 128 kt BC emissions in 2020. On-road and non-road were two major contributors to BC emissions in 2020, with 53 kt and 48 kt, respectively. They were followed by marine, 18 kt, and freight rail, 9 kt. *ZEV Targets and Development* for CVs and non-road and *In-use Diesel Vehicle and Engine Programs* for rail and marine are critical policies for BC emission reduction.

Appendix C. Emissions trends by sector

Figure C1 presents the NO_x, PM, and TTW CO_2eq emission trend by sector under the Adopted Policies (solid lines) and Proposed Policies (dashed lines) scenarios.

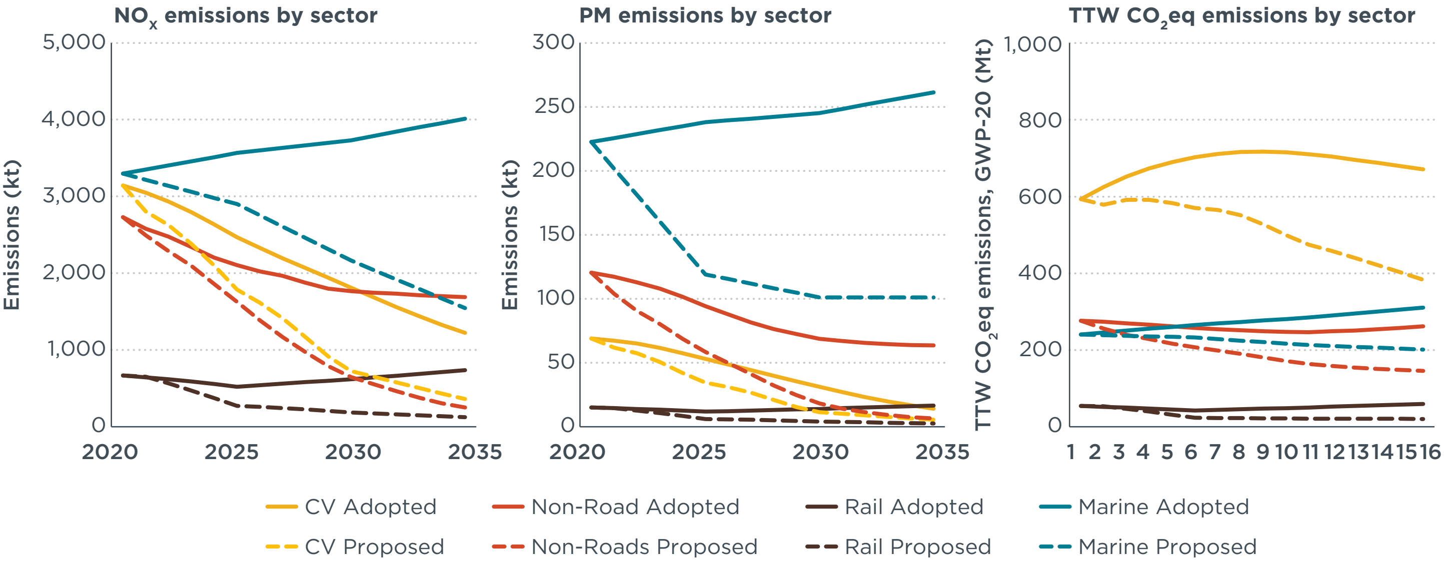

Figure C1. Emissions trend for NO_x, PM, and TTW CO_2eq by sector under Adopted Policies and Proposed Policies scenarios.