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Climate and air quality benefits from accelerating electrification of Guangdong's on-road transportation

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INTRODUCTION

Guangdong has been one of China's leading markets for new energy vehicles (NEVs), particularly zero-emission vehicles (ZEVs) (Niu, Ma, & Zhang, 2023).[1] Recognizing the crucial role of on-road vehicle electrification in supporting decarbonization and air quality improvement targets, the province set an NEV sales target of 20% of all vehicles for 2025 in its 14th Five-Year Plan (People's Government of Guangdong Province, 2022a). Cities in Guangdong have also set more stringent targets: Shenzhen announced a 60% NEV sales share target during the 14th Five-Year Plan period; Guangzhou announced a 50% NEV sales share and specified a 30% fuel-cell electric vehicle (FCEV) sales share for public buses and sanitation trucks; and Foshan set a target of 18,000 total FCEVs in use by 2030, covering passenger cars, public buses, logistics vehicles, and dump trucks (Jin, Chu, &Wang, 2023; Jin & Chu, 2023; Niu, Ma, & Zhang, 2023).

A faster transition to vehicle electrification is necessary to support Guangdong in achieving its environmental targets. A study from the World Resources Institute found that further electrification targets are needed to achieve the provincial carbon peak target before 2030 and carbon neutrality target by 2060 (Liu et al., 2023; People's Government of Guandong Province, 2022b). Guangdong's Air Quality Improvement Action Plan also highlights electrification as one of the key measures against air pollution, especially ozone (Guangdong Provincial Department of Environmental Protection, 2021). In 2022, ozone was the primary air pollutant in Guangdong for almost 84% of days, and the annual average ozone concentration was 157 micrograms per cubic meter of air (μg/m^3), 9% higher than 2021. Nitrogen dioxide (NO_2), fine particulate matter ($PM_{2.5}$), and particulate matter (PM_{10}) were the primary pollutants for the remaining days, with annual average ambient concentrations of 19 μg/m^3, 20 μg/m^3 and 34 μg/m^3, respectively (Guangdong Provincial Department of Environmental Protection, 2023). An accelerated transition to NEVs will help Guangdong reduce the greenhouse gas (GHG) and air pollutant emissions, as well as improve air quality.

Previous ICCT work with Hainan found that successful widespread adoption of NEVs is important for achieving the province's environmental goals. These studies quantified the emissions reduction and air quality improvement benefits from setting 100% NEV sales targets for most vehicle segments in their Mid- to Long-Term Action Plan on New Energy Vehicle Deployment (2023–2030), and evaluated potential benefits from including ambitious electrification targets for coaches and trucks (Cui & He, 2019; Cui et al., 2022; Shao, 2023; Niu & Xie, 2024). The studies found that an accelerated electrification pathway in Hainan including coaches and trucks would cut CO_2 emissions from the on-road transportation sector by 53% in 2035 and achieve peak CO_2 emissions no later than 2030. Faster adoption of battery-electric coaches and trucks could also contribute to significant air quality improvement by reducing road-transport-related NO_2 emissions 67%, $PM_{2.5}$ emissions 42%, and ozone 44% in 2035.

In this context, this report proposes an accelerated electrification pathway for on-road vehicles in Guangdong from 2021 to 2035. We perform detailed GHG and pollutant emissions modeling, as well as air quality modeling, to evaluate the climate and air quality benefits. We also consider the feasibility of electrifying different vehicle categories in different cities or zones when developing policy scenarios. Based on the modeling results, we conclude with policy suggestions for Guangdong's NEV transition.

1 NEVs include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel-cell electric vehicles (FCEVs), while ZEVs only refer to BEVs and FCEVs.

STUDY METHODOLOGY

STUDY SCOPE

This analysis is conducted at a city level due to the heterogeneity of regional economic development, and the results are aggregated into the four zones illustrated in Figure 1. Zone 1 encompasses the city of Shenzhen, which has advanced economic and ZEV market development. Zone 2 includes only the city of Guangzhou, which has relatively high ZEV sales. Zone 3 consists of the other cities (excluding Shenzhen and Guangzhou) in the Pearl River Delta region, an important economic zone, and Zone 4 includes the remaining Guangdong cities.

Figure 1
Overview of Guangdong and study zones

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The vehicle categories and assumptions on annual vehicle-kilometers traveled (VKT) for each category, sourced from previous ICCT studies, are shown in Table 1 (Jin, Shao et al., 2021; Niu, Yang, et al., 2023). For light-duty vehicles, this analysis includes only passenger cars (including taxis, ride-hailing cars) and light-duty commercial vehicles. For heavy-duty vehicles, we follow the classification in ICCT's Guangdong HDV market and TCO study (Niu, Ma, & Zhang, 2023), and further specified medium-duty and heavy-duty trucks based on their gross vehicle weight (GVW). We also analyze concrete mixer trucks, as the ultra-low emission standard for the cement industry requires adoption of NEVs; battery electric concrete mixer trucks have been used successfully in Hainan province (Niu, Cui, & Xie, 2024).

Table 1

Vehicles categories, descriptions, and annual vehicle-kilometers traveled estimates

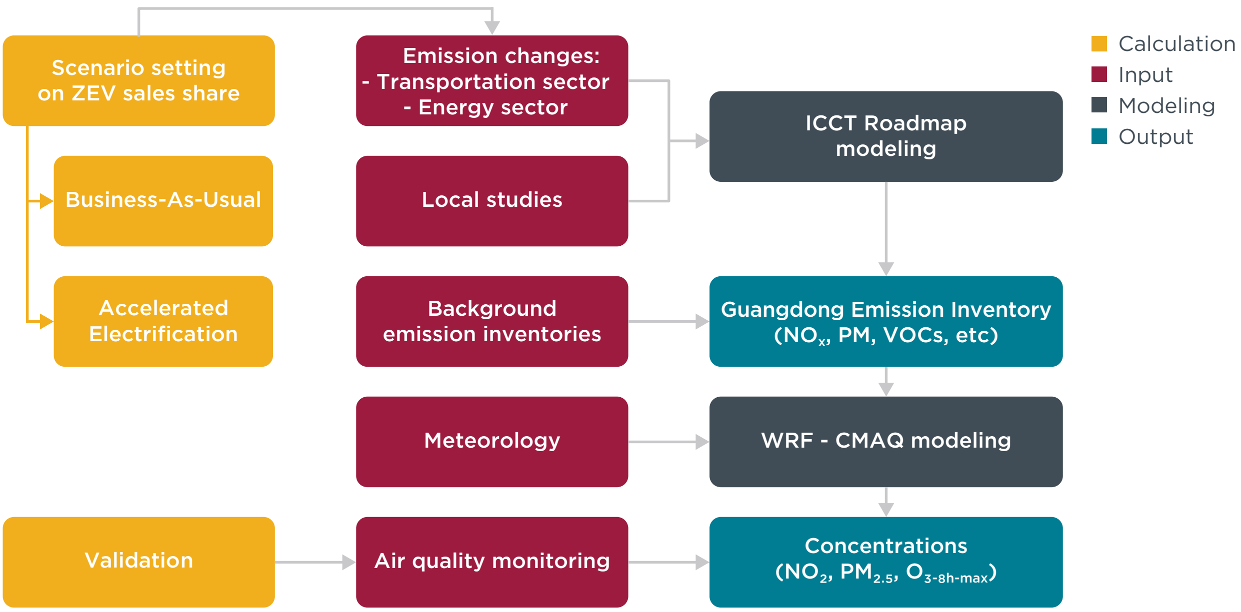
Vehicle category	Subcategory	Description	Annual VKT
Passenger cars		Private cars, taxis, ride-hailing cars, etc.	12,000
Light commercial vehicles		Vans, pickup trucks, etc., with GVW lower than 3.5t	21,000
Buses	City bus	Inner-city public bus	45,000
	Coach	Intercity coach	85,000
Medium-duty trucks (GVW 3.5-12 tonnes)	Logistics truck	Mostly used for urban logistics, GVW is 3.5t–4.5t	80,000
	Dump truck		50,000
	Straight truck	Other mid-duty excluded above	90,000
Heavy-duty trucks (GVW > 12 tonnes)	Dump truck		60,000
	Tractor-trailer	Mostly for long-haul delivery	120,000
	Utility truck	Special-purpose trucks excluding concrete trucks	20,000
	Concrete mixer	Concrete mixer trucks	50,000
	Straight truck	Heavy-duty trucks not included in other categories	100,000

OVERALL METHODOLOGY

The overall methodology, illustrated in Figure 2, is the same as used in the ICCT's Hainan air quality study (Niu & Xie, 2024). Note that interprovincial transport is not included in the emission inventory because the data was not available.

Figure 2

Overall study methodology



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EMISSION INVENTORY

ICCT's Roadmap model is used to project greenhouse gas (GHG) and air pollutant emissions from Guangdong's on-road transportation sector. (International Council on Clean Transportation, 2023) This analysis covers the time frame from 2021 (baseline year) to 2035. Both well-to-tank (WTT) and tank-to-wheel (TTW) GHG emissions are considered. These include carbon dioxide (CO_2), nitrous dioxide (N_2O), and methane (CH_4) emissions, in addition to nitrogen oxides (NO_x), particulate matter (PM), volatile organic compounds (VOCs), sulfur oxides (SO_x), and ammonia (NH_3). The WTT emissions denotes emissions from the processes of producing, storing, and distributing fuels used in the vehicles, while TTW emissions refers to the emissions directly from the tailpipe.

The GHG emissions and air pollutants from Guangdong's on-road transportation from 2021 to 2035 were projected under two scenarios: a Business-As-Usual (BAU) scenario and an Accelerated Electrification (AE) scenario. Both scenarios reflect the actual zero-emission sales shares in 2021, sourced from various ICCT studies (C. Shen & Mao, 2023; Chu et al., 2024; Chu, 2021; Chu & Cui, 2023).

- The BAU scenario includes growth under policy plans that have been published or proposed, including the target announced by the Chinese government of 45% of all vehicle sales to be NEVs by the end of 2027.
- The AE scenario reflects a faster transition to ZEVs for all vehicle fleets. The AE scenario refers to the ambitious ZEV targets in ICCT's suggested roadmap for implementing China's 14th Five-Year Plan and China's clean diesel program (Jin et al., 2021; Niu, Yang, et al., 2023). These targets are primiarly based on national- and local-level NEV targets and on the advanced targets in California and the European Union. Considering the differences in economic development, the scenario assumes Zone 2 (Guangzhou) will meet the ambitious targets in the ICCT studies, while the same targets will be implemented 2–3 years earlier in Zone 1 (Shenzhen), 2–3 years later in Zone 3, and 5 years later in Zone 4.

The baseline ZEV sales shares and ZEV sales targets for both scenarios are illustrated in Figure 3. Overall, the BAU scenario meets the 45% NEV sales share target in 2027, and the Accelerated Electrification scenario meets the 55% NEV sales share target in 2027 and the 90% target in 2035.

The vehicle stock in Guangdong in 2021 was collected from the China Statistical Yearbook and the World Resources Institute report (Liu et al., 2023; National Bureau of Statistics of China, 2023.) The future stock was projected using the ICCT Roadmap model based on vehicle survival curves by vehicle category and on key socioeconomic indicators influencing vehicle sales growth, such as population, vehicle stock per capita, and the growth rate in gross domestic product. Assumptions on energy efficiency and emission intensity (TTW emission factors) by vehicle category were made by combining the best available data, vehicle fuel efficiency simulation, and various ICCT studies on vehicle real-world efficiency and emissions (Mao & Rodríguez, 2022; Y. Zhang et al., 2023; Mao, Zhang, et al., 2023; Niu & Rodríguez, 2022; Niu, Yang, et al., 2023).

Figure 3
ZEV share of fleet-level sales in the 2021 baseline year and the projected ZEV sales share under the Business-As-Usual and Accelerated Electrification scenarios

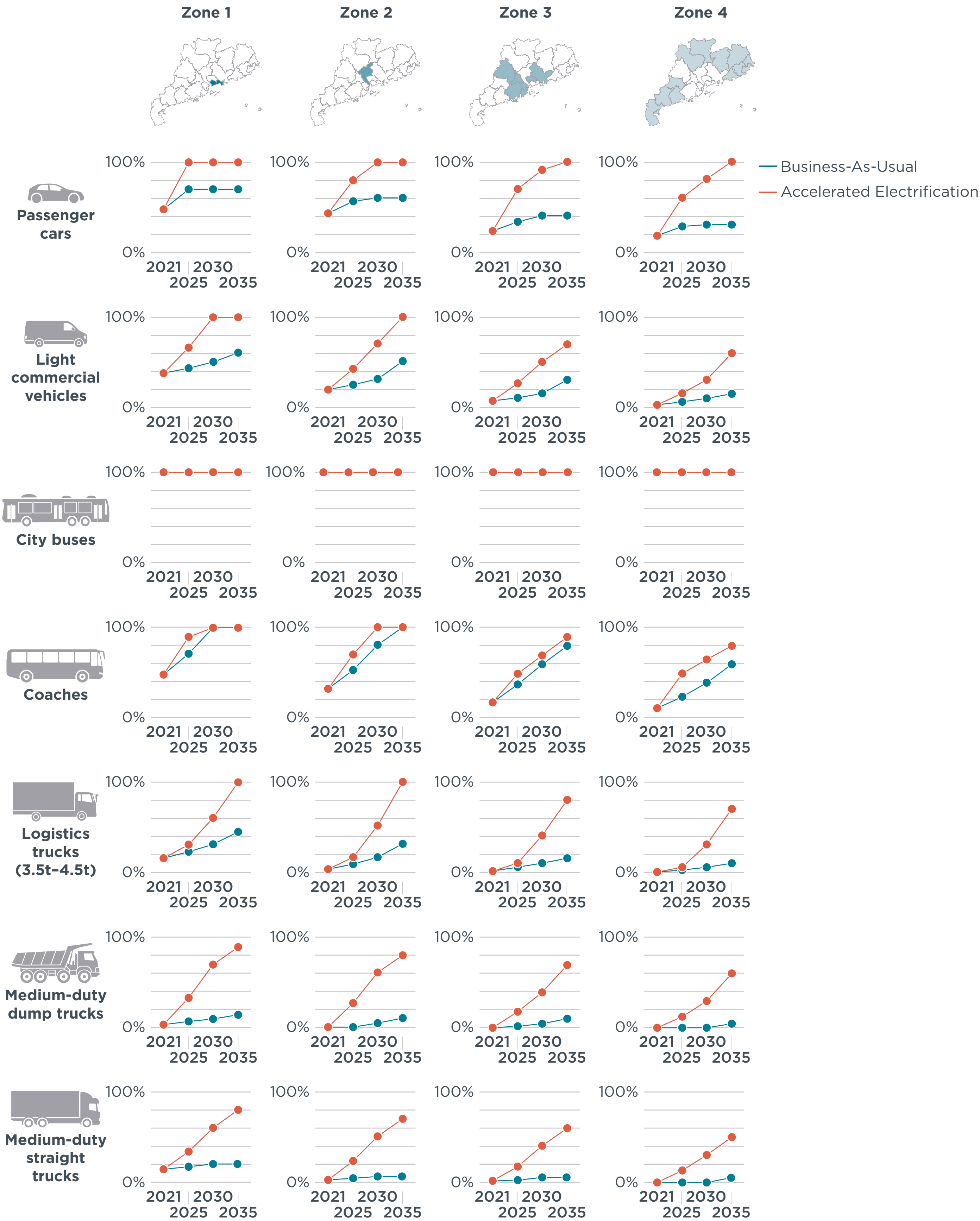
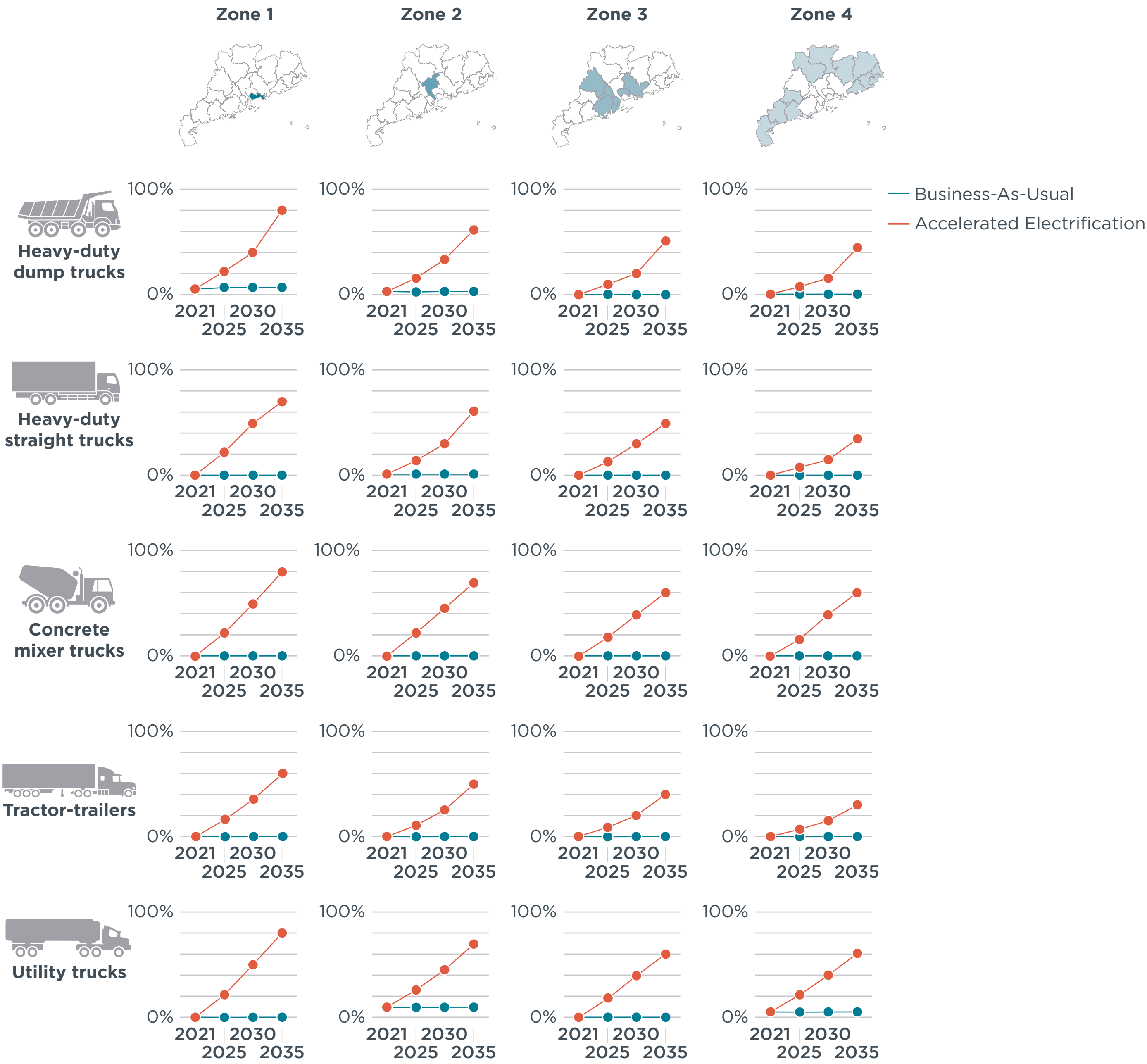


Figure 3
(continued)



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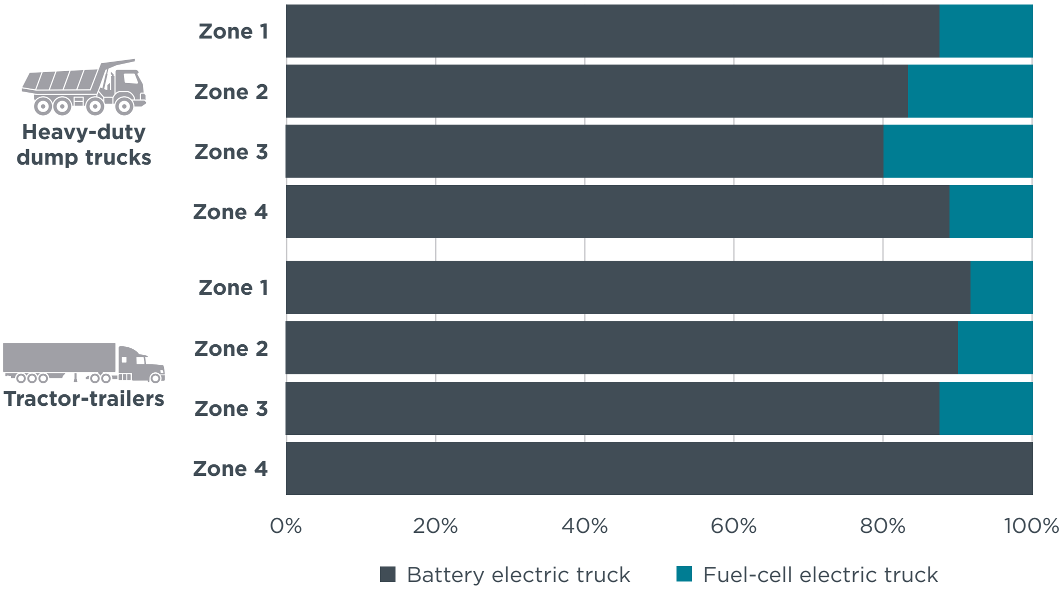
This study also considers future adoption of fuel-cell electric trucks, as Guangdong is a pioneer in promoting hydrogen application in the transportation sector in China. Projections of FCEVs' deployment are based on local policy targets, development plans, and suggestions from local consultants and stakeholders (People's Government of Guangdong Province, 2022; Guangdong Provincial Development and Reform Commission, 2022; Guangzhou Municipal Development and Reform Commission, 2020; Foshan Municipal People's Government, 2018). This study considers FCEV shares ranging from 10% to 30% of new ZEVs by 2035 in Guangzhou and Foshan for public buses, logistics trucks, and sanitation trucks (utility vehicles). As our studies indicate fuel-cell heavy-duty dump trucks and tractor-trailers are able to achieve total cost of ownership (TCO) parity with their diesel counterparts before 2035 in Guangdong province, we also include the sales share of FCEVs for heavy-duty dump trucks and tractor-trailers, shown in Figure 4 (Niu, Ma, & Zhang, 2023; Mao, Basma, et al., 2021).

Foshan, in Zone 3, leads in the FCEV sales share due to the region's large hydrogen industry and ambitious plans to deploy these vehicles.

Figure 4

Sales of new ZEVs by technology under the Accelerated Electrification scenario in 2035



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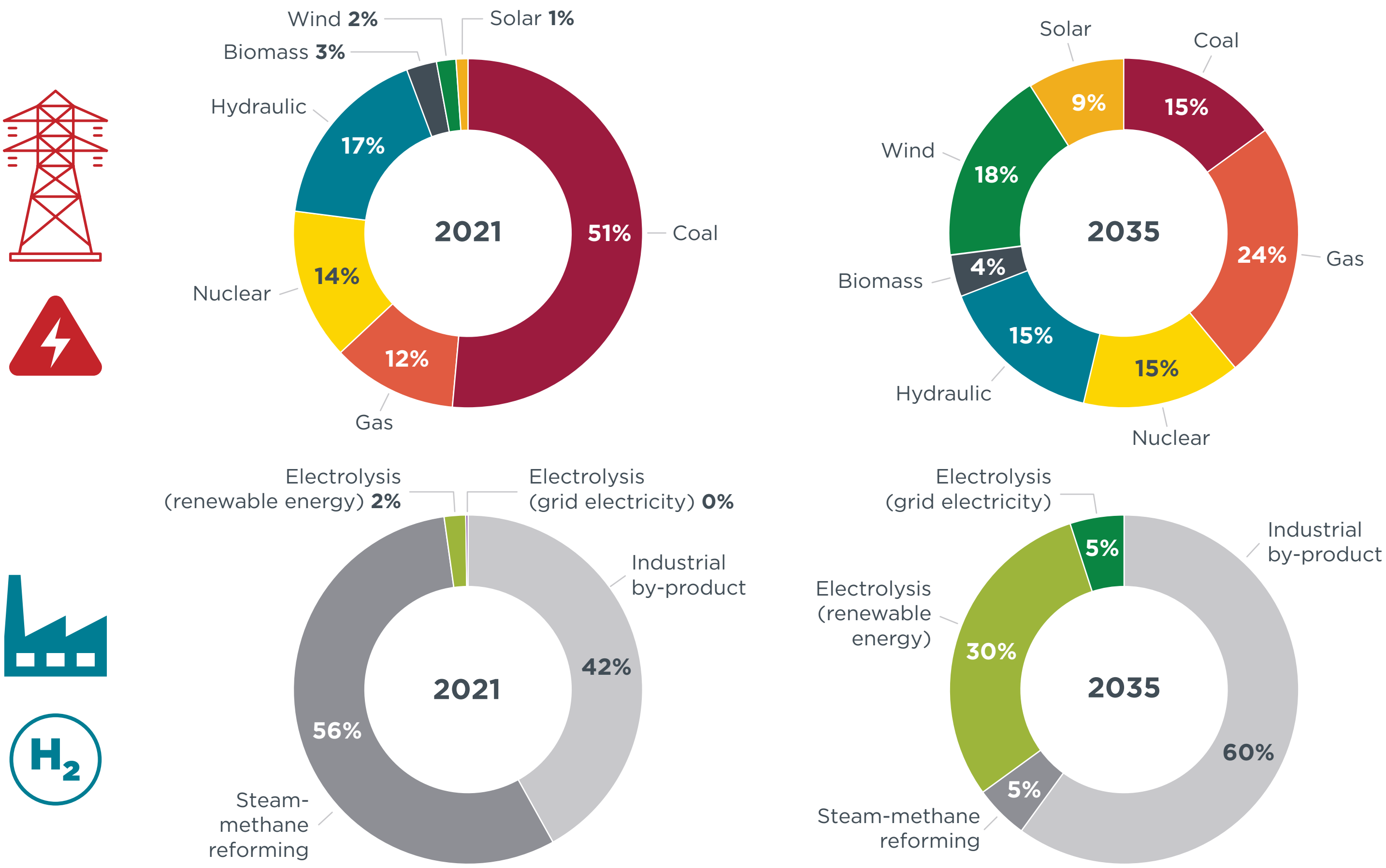
To calculate the WTT emissions, we apply the results of grid mix and hydrogen production pathways summarized in the previous Guangdong market and TCO study to the BAU and Accelerated Electrification scenarios (Figure 5) (Niu, Ma, & Zhang, 2023). The emission factors are sourced from the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model and other studies (Wang et al., 2022; Cai et al., 2023; O'Connell et al., 2023; Zhou et al., 2022; Zhang, Xiong, et al., 2023).

Figure 5

Current and projected grid mix and hydrogen production pathways in Guangdong province



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AIR QUALITY MODELING

This analysis combines three different background emission inventories to model the baseline NO_2, $PM_{2.5}$ and ozone concentrations from all emission sources inside and outside Guangdong province. The background emission inventories used are: 1) the Multi-resolution Emission Inventory model for Climate and air pollution research (MEIC) at a resolution of 0.25° × 0.25° (of longitude and latitude) (Department of Earth System Science Tsinghua University, 2024.; Li, Liu, et al., 2017; Zheng et al., 2018); 2) MIXv2 Asian emission inventory at a resolution of 0.1° × 0.1° (Li, Kurokawa, et al., 2024); and 3) internal emission inventory studies from Guangdong Academy of Environmental Science at 3km × 3km.

As this study is intended to identify air quality benefits from on-road electrification, we assume the emissions from all other nontransportation-related sources stay the same in 2035 under the BAU scenario. Under the AE scenario, the changes in TTW emissions—or the reductions in tailpipe emissions compared with the BAU scenario—in 2035 are assigned into the Guangdong's transportation sector under a 3 × 3 km grid according to road network, population, and land uses. The WTT emission changes—or the increase or decrease in energy production emissions compared with the BAU scenario—are estimated based on the energy consumption of different powertrains. These WTT emission changes are assigned into Guangdong's energy sector under

3 × 3 km grid according to locations of energy production plants and the historic emission inventory in MEIC.[2]

The Weather Research and Forecasting (WRF) model and the Community Multiscale Air Quality (CMAQ) model were employed to simulate the chemical reactions and diffusions of the pollutant emissions, and to project the pollution concentrations. Both models are well documented and widely used in air quality studies (Skamarock et al., 2019; U.S. Environmental Protection Agency, 2018). The meteorology data are collected from the U.S. National Weather Service geographic information system portal, an open database.

CLIMATE AND AIR QUALITY BENEFITS

GREENHOUSE GAS EMISSIONS REDUCTION

Figure 6 illustrates the TTW and WTW GHG emission reduction benefits by vehicle type and zone. In 2035, the WTW GHG emissions in the Accelerated Electrification scenario will decrease by 31% compared to the BAU scenario, a combination of a 45% decrease of TTW GHG emissions and a roughly 3% increase of WTT GHG emissions. The accelerated transition of mid- and heavy-duty vehicle fleets is particularly important for decarbonizing on-road transportation in Guangdong province, because this would contribute over 60% of the total WTW GHG emissions reduction from electrification. Passenger cars can provide 32% of the total decarbonization benefits.

The faster electrification path in Shenzhen (zone 1) and Guangzhou (zone 2) contributes 30% and 22%, respectively, of the total reduction for the entire province, reflecting their crucial role in Guangdong province. Other cities in the Pearl River Delta region (zone 3) can also bring 34% of the decarbonization benefits, while zone 4 cities contribute 14%.

2 The emission assignments are supported by our local consultants. For example, the emissions from power generation were assigned to power plants according to the information on power plants and power sector emission distribution in the MEIC.

Figure 6

Reductions in 2035 GHG emissions by vehicle type and zone in Guangdong province under the Accelerated Electrification scenario

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AIR POLLUTANT EMISSION REDUCTIONS

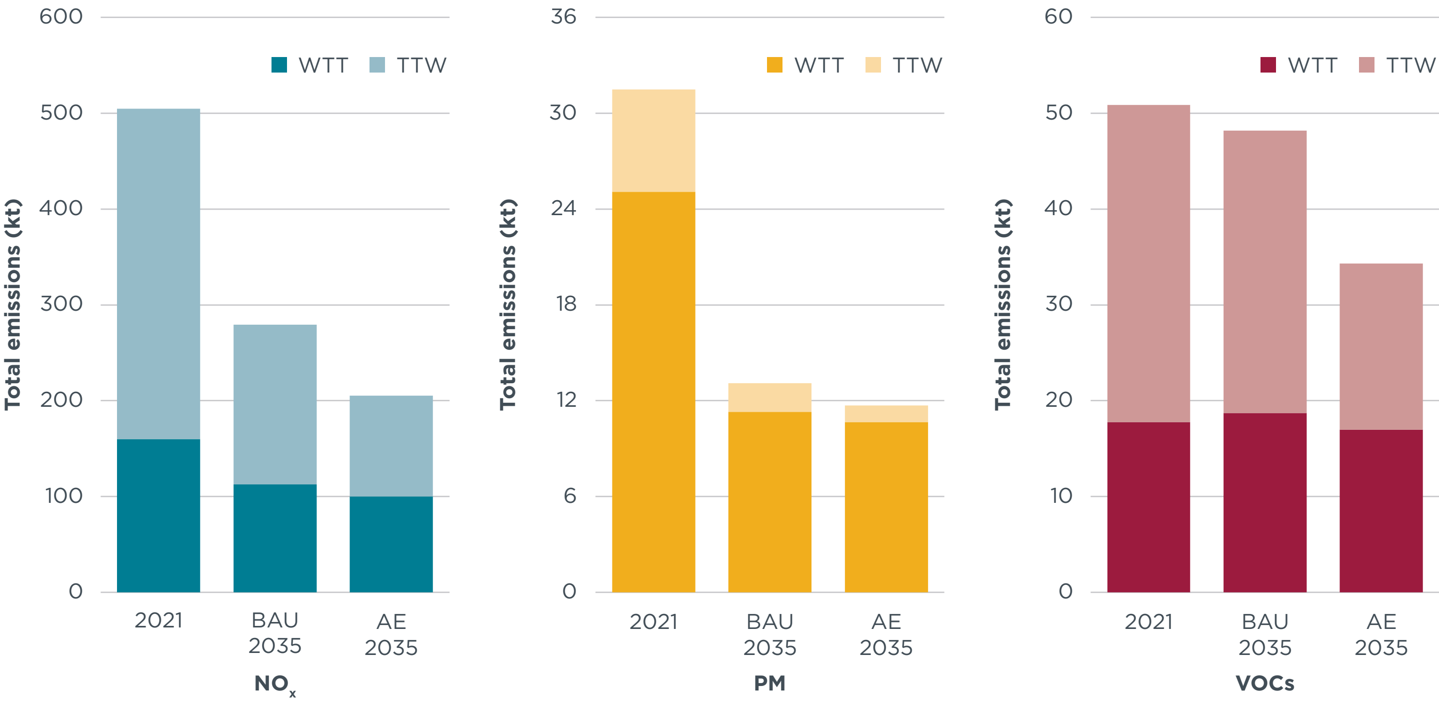
Emissions of NO_x, PM, and VOCs in 2021 and in 2035 under the two scenarios are shown in Figure 7. For TTW emissions, NO_x emissions are projected to be reduced 69% in the Accelerated Electrification scenario and 52% in the BAU scenario. PM emissions are reduced 84% in the Accelerated Electrification scenario and 73% in the BAU scenario by 2035, as compared with 2021 levels. VOC emissions are also reduced 48% under the Accelerated Electrification scenario and 11% in the BAU scenario in the same timeframe.

For WTT emissions, which include emissions from energy production, NO_x emissions are reduced by 38% in the Accelerated Electrification scenario and 30% in the BAU scenario. PM emissions are reduced by 57% under the Accelerated Electrification scenario and 55% in the BAU scenario. Emissions of VOCs are reduced by 32% in the

Accelerated Electrification scenario but increase by 6% in the BAU scenario. A grid mix of almost 60% renewable electricity contributed greatly to reductions in WTT emissions in the Accelerated Electrification scenario due to the rapid growth in ZEVs.

Figure 7

Well-to-tank (WTT) and tank-to-wheel (TTW) pollutant emissions in the 2021 baseline year and in 2035 under two scenarios



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AIR QUALITY IMPROVEMENTS

Figure 8 shows the geospatial distributions of the modeled 2021 baseline pollutant concentrations and the benefits—in terms of lower pollutant concentrations—in 2035 under the Accelerated Electrification scenario compared with the BAU scenario. The modeling results of annual average NO_2, $PM_{2.5}$, and ozone concentrations in the 2021 baseline year in Guangdong are 19 μg/m^3, 20.4 μg/m^3 and 112.7 μg/m^3, respectively. The model was validated with daily air quality monitoring data from 2021, shown in Appendix: Modeling validation.

As shown in the figure, NO_2 reductions of up to 10 μg/m^3 in 2035 mainly occur in Guangzhou and Foshan. Ozone reduction appeared to cover a wider range in the Pearl River Delta region; the reduction can be as high as 5 μg/m^3 as ozone is generally well controlled and improved across the whole province from on-road electrification. Lastly, the $PM_{2.5}$ improvement spread across the whole Guangdong area is, at most, 3 μg/m^3.

Figure 8

Geospatial distributions of modeled 2021 baseline pollutant concentrations and reductions in 2035

Baseline 2021	Additional reductions in pollutant concentrations from Accelerated Electrification compared with Business-As-Usual in 2035

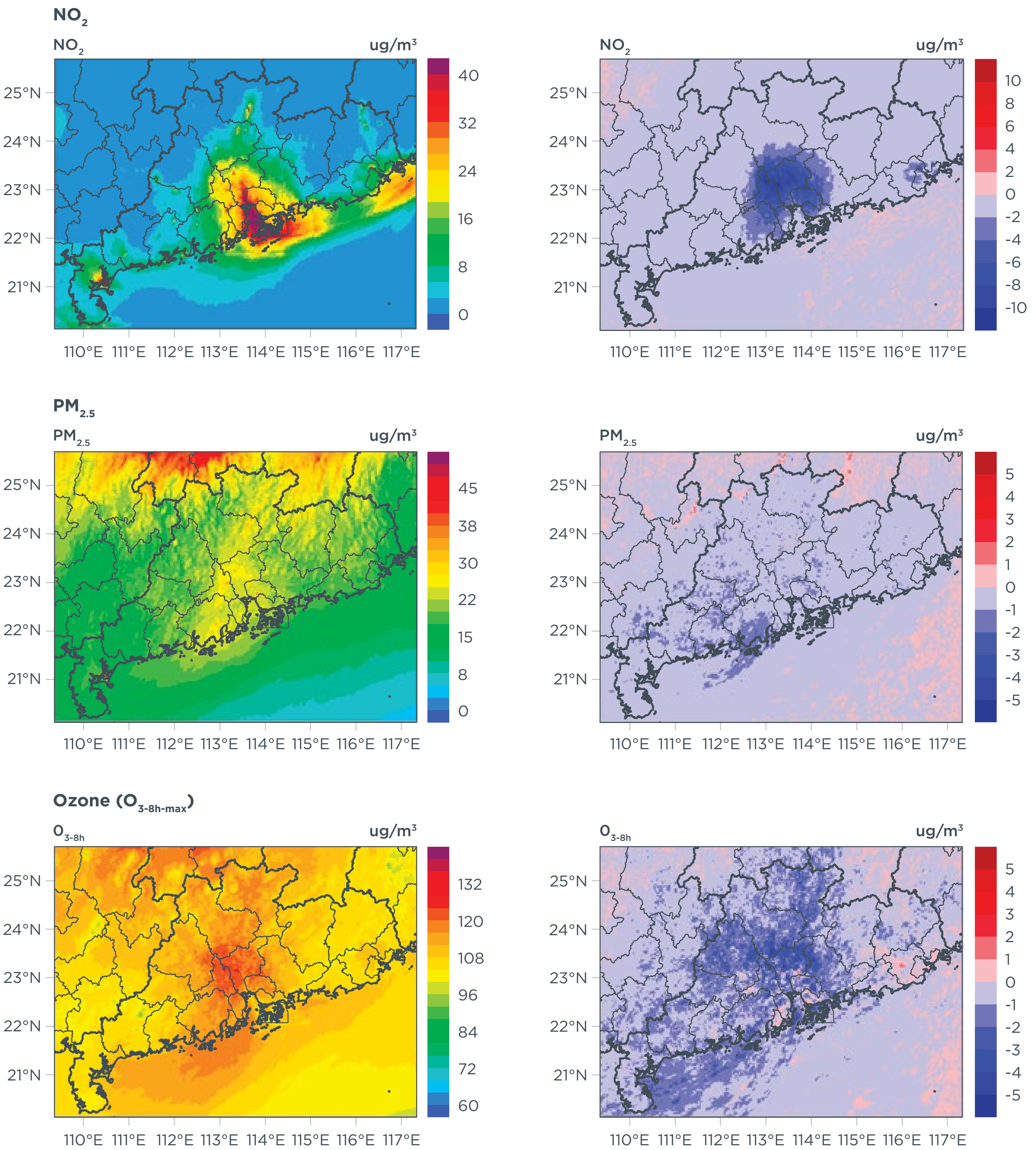

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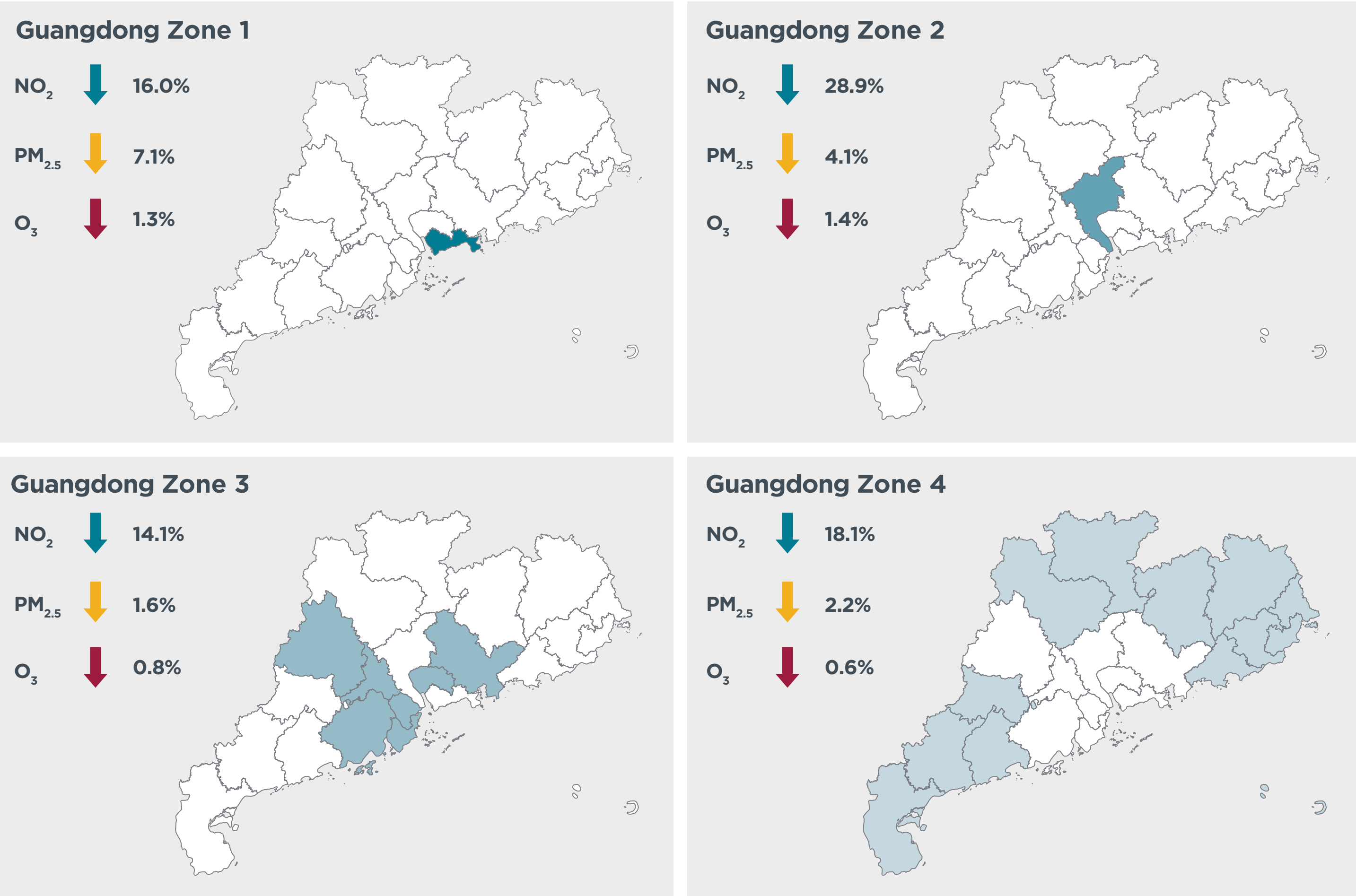
Figure 9 shows the estimated air quality improvements by zone. Overall, the Accelerated Electrification scenario could reduce NO_2, $PM_{2.5}$ and ozone concentrations by 18%, 4%, and 1%, respectively, for the whole province in 2035 compared with the BAU scenario. Guangzhou is projected to have the most air quality improvement from accelerated on-road electrification for all pollutants. For ozone, although the percentage reduction is not as high as NO_2, it is a reversal of the 9% increase from 2021 to 2022.

Figure 9

Air quality improvement by zone area in 2035 under the Accelerated Electrification scenario, as compared with the BAU 2035 scenario



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FINDINGS AND RECOMMENDATIONS

The emissions and air quality modeling performed for this study shows that faster adoption of zero-emission vehicles in Guangdong province would have great potential benefits for climate and air quality. An Accelerated Electrification scenario with ambitious targets for new ZEV sales could, by 2035, reduce 31% of WTW GHG emissions from the on-road transportation sector in Guangdong, compared with the BAU scenario. The Accelerated Electrification scenario would result in a reduction of 18% of NO_2 emissions and 3% of $PM_{2.5}$ emissions while also reducing the ozone concentration by 1% in 2035. The accelerated target can effectively support and ensure Guangdong is able to achieve climate and air quality improvement goals. Based on these findings, Guangdong province could consider the following policy recommendations:

Consider ZEV sales share targets of up to 90% in 2035 in the 15th Five-Year Plan or other provincial policy plans. In the 14th Five-Year Plan, Guangdong set a 20% NEV sales targets for all vehicles, acknowledging the need to accelerate the electrification of on-road vehicles, but the target only applied to passenger cars, public buses, taxis, logistics trucks, and sanitation trucks, and exempted heavy-duty trucks. Guangdong could explore a feasible electrification roadmap and set the ZEV targets for specific vehicle types and zones. The Hainan NEV Development Plan could provide a reference for such a plan.

Ambitious electrification targets could be set for heavy-duty trucks for specific use cases. Based on current policies and market developments, public buses and logistics trucks can achieve a 90%–100% target in 2035 for Shenzhen or Guangzhou, while other cities can set a relative high target for logistics trucks to promote the ZEV transition. Further, successful use cases of battery electric and fuel-cell electric trucks should also convince the government to set a ZEV sales share target of over 50% for dump trucks and over 60% for concrete mixers.

Support sales of NEVs or ZEVs as the preferred technology pathway to decarbonization and consider disincentivizing sales of natural gas-powered vehicles. Considering the limited reduction potential of CO_2, NO_X, and PM emissions, along with the methane leakage of natural gas, continuing to favor natural gas-powered vehicles risks putting Guangdong on a pathway that is not compatible with the province's carbon emissions reduction goals.

Consider leveraging the resources of multiple government agencies in Guangdong to explore the most effective policy packages for decarbonizing transport in the province. These agencies include the Department of Ecology and Environment, Department of Transportation, Department of Industry and Information Technology, and the Development and Reform Commission. There are several policy instruments that could potentially be used:

» Sales requirements that would compel manufacturers to sell an increasing share of ZEVs in Guangdong.

» Zero-emission zones or corridors giving unrestricted access only to zero-emission vehicles, thereby encouraging early scrappage of conventional fuel-powered vehicles and stimulating the deployment of ZEVs.

» Smartly designed purchase and in-use incentives to close the cost gap between ZEVs and their conventional fuel-powered counterparts.

» Purchase requirements that apply to specific fleets and a mandate requiring that a certain percentage of vehicle procurements be ZEVs, such as drayage trucks at ports and public buses.

» Action plans for charging or refueling infrastructure buildout, in partnership with stakeholders, to encourage accelerated BEV and FCEV adoption.

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APPENDIX: MODELING VALIDATION

Table A1
Calculations of validation criteria

R	RSME	NMAE
$FMF = \frac{\Sigma(O_i - \bar{O})(M_i - \bar{M})}{\left(\Sigma (M_i - \bar{M})^2 \Sigma(O_i - \bar{O})^2\right)^{1/2}}$	$RMSE = \left(\frac{1}{N}\Sigma (M_i - O_i)^2\right)^{1/2}$	$NMAE = \frac{\Sigma\lvert M_i - O_i\rvert}{\Sigma O_i}$

Where:	
O_i	represents the i^{th} monitored value
$\bar{O}$	represents the average monitored value
M_i	represents the i^{th} modeled value
$\bar{M}$	represents the average modeled value
N	represents the total pairs of monitored and modeled values

The validation results are shown in Table A2. These results are similar to those found in several other local air quality modeling studies (Chen et al., 2022; Shen et al., 2017; Wang et al., 2022; Xu et al., 2023; Yang et al., 2019).

Table A2
Validation results

Zone	NO_2			O_3-8h			$PM_{2.5}$		
	R	RMSE (μg/m³)	NMAE	R	RMSE (μg/m³)	NMAE	R	RMSE (μg/m³)	NMAE
Zone 1	0.26	7.35	0.27	0.52	31.56	0.28	0.56	6.72	0.35
Zone 2	0.26	12.74	0.34	0.18	42.75	0.33	0.45	8.98	0.36
Zone 3	0.51	10.75	0.36	0.35	40.59	0.31	0.52	8.05	0.36
Zone 4	0.40	8.58	0.47	0.34	33.42	0.28	0.46	9.27	0.41

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