Sonoma Technology

Air Quality Benefit from Accelerated EV Penetration in Southern California: A Case Study in the Interstate 710 Corridor

By Shih Ying "Changsy" Chang[1], Jiaoyan Huang[1], Marcus Alexander[2], Doug Eisinger[1], Nathan Pavlovic[1], and Eladio Knipping[2]

[1] Sonoma Technology | [2] Electric Power Research Institute

For the 2021 CMAS conference

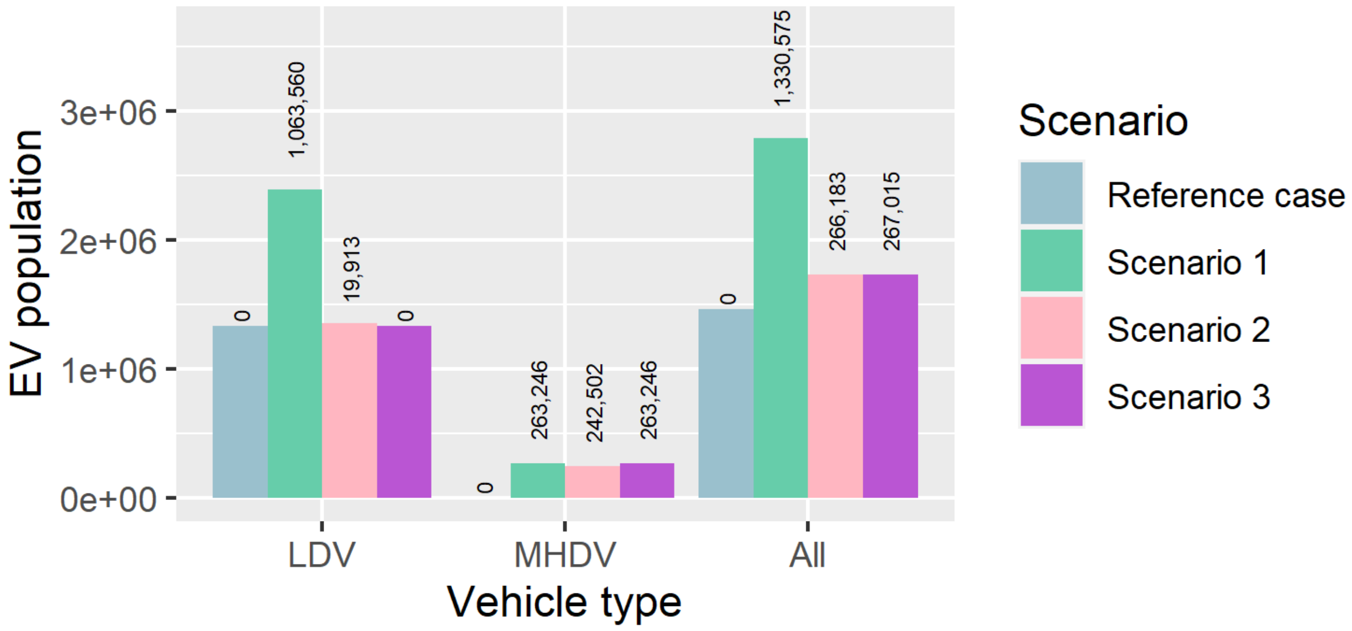
Nov. 4, 2021

600600-7613

Outline

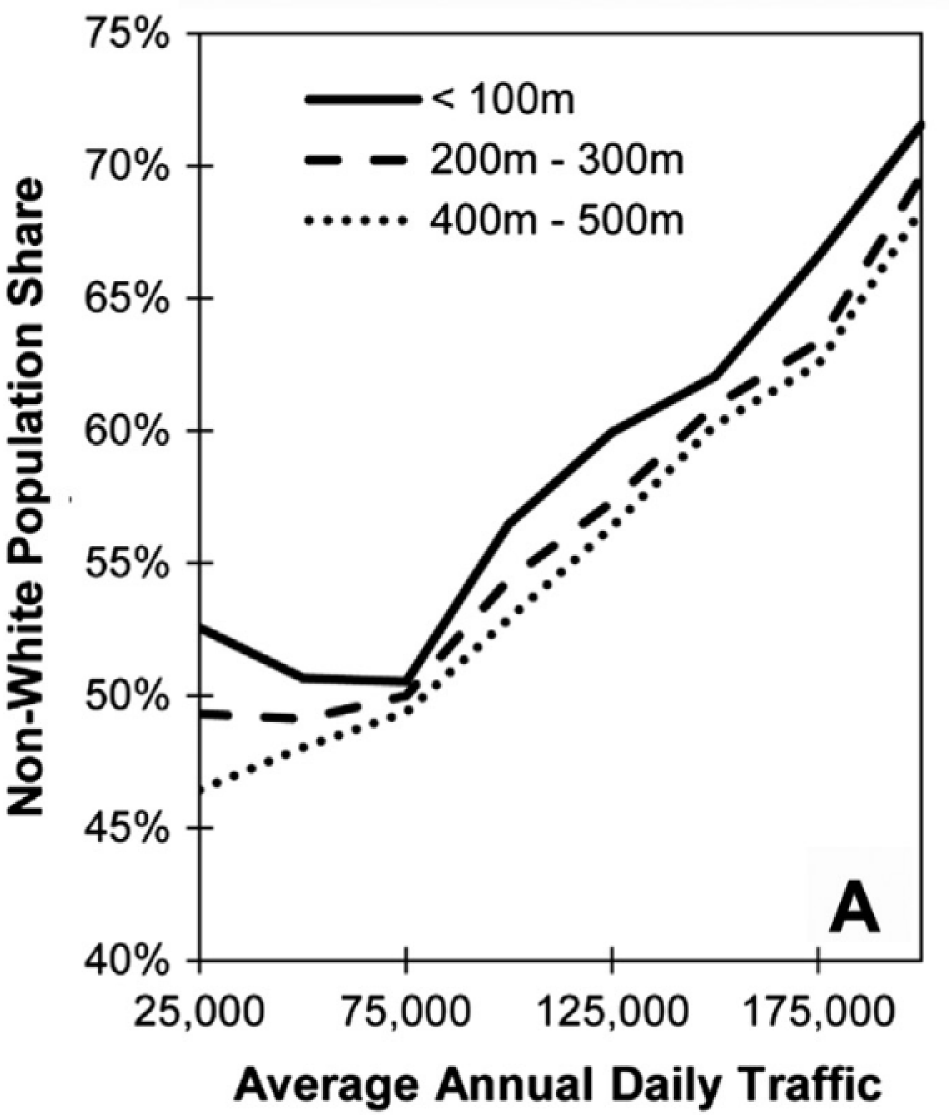
- Introduction
- Study design and domain
- Method
- Emission modeling results
- Summary

Projected electric vehicle (EV) population in the South Coast region of California in 2040



Air Quality and Environmental Justice (EJ)

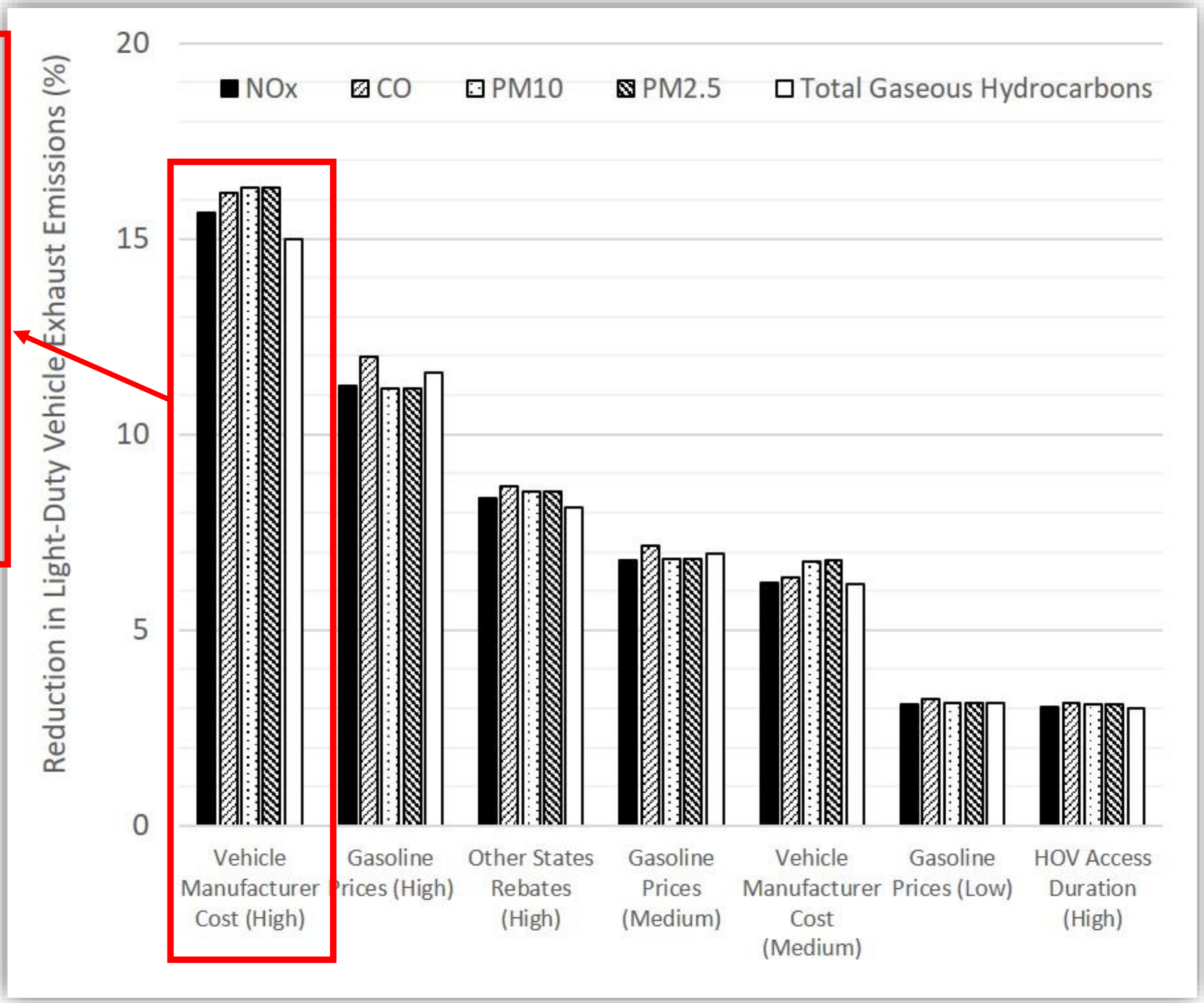
- Approximately 19% of the U.S. population lives near high-traffic volume roads
- Previous studies found that living near major roadways is associated with respiratory diseases
- Nationally, greater traffic volume and density are associated with larger numbers of non-white residents and lower median household incomes



Source: Rowangould, *Transport Research Part D*, 2013

Penetration of Electric Vehicles: Example Forecasted Impacts

- Penetration of 38% electric vehicles (EVs) in the light-duty vehicle (LDV) fleet could reduce NO_x and $PM_{2.5}$ emissions by up to 16% for the light-duty vehicle fleet by 2040 (Erdakos et al. 2019)
- California Air Resource Board (CARB) estimated 15% NOx and $PM_{2.5}$ emissions reductions for the medium- and heavy-duty vehicle fleet by 2040 under the Advance Clean Truck (ACT) regulation



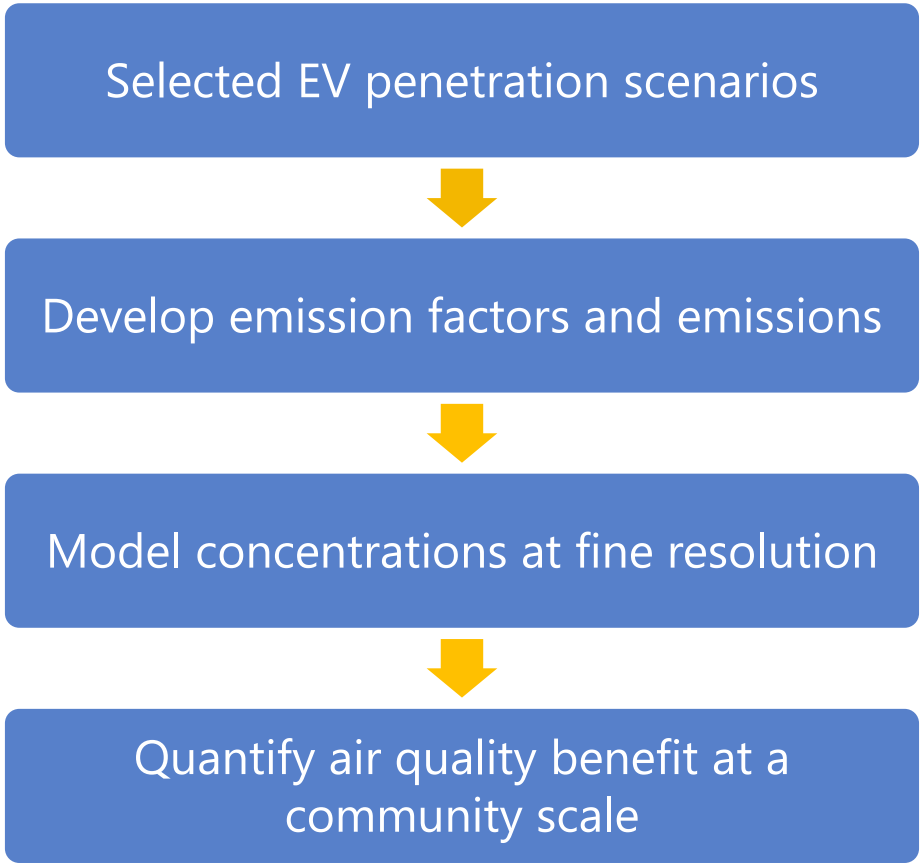
Source: http://www.trb.org/Main/Blurbs/180232.aspx

Motivation

- Substantial penetration of electric vehicles (EVs) is expected to reduce GHG emissions and yield important public health benefits
- There is, however, an ongoing need to quantify EJ community impacts from EV use
- This study evaluates EV penetration scenarios and resulting air quality benefits
- A key goal was to quantify and contrast outcomes for communities with and without EJ concerns

Study Design

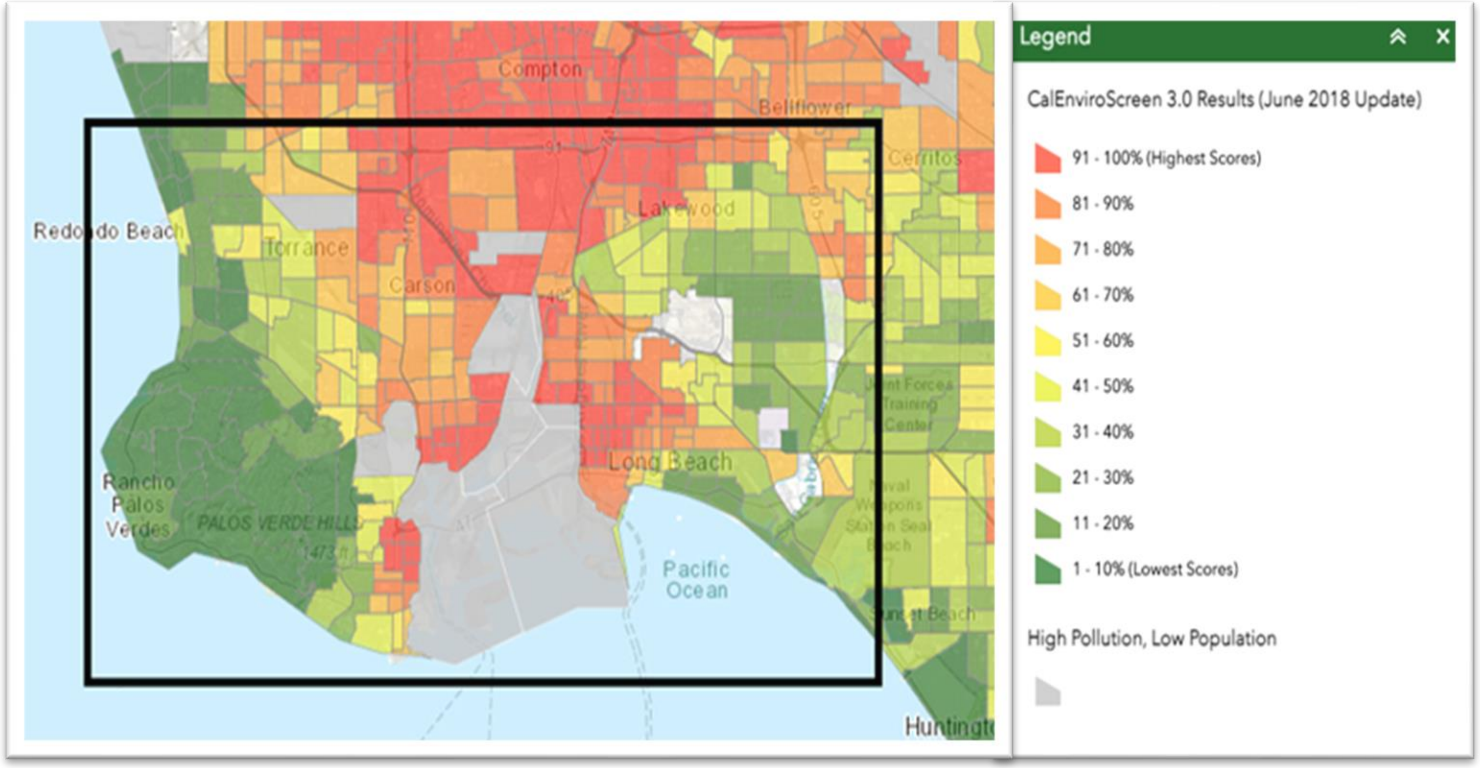
- Identify a series of EV penetration scenarios for:
  - Light-duty vehicle (LDV) fleet
  - Medium- and heavy- duty vehicle (MHDV) fleet
- Estimate on-road mobile source emission factors and emissions for each scenario
- Model NO_x and $PM_{2.5}$ concentrations from on-road vehicles at census block group* centroids
- Quantify and contrast benefits between communities with and without EJ concerns for 2040



*A Census Block Group is a geographical unit used by the United States Census Bureau which is between the Census Tract and the Census Block.

Study Domain

- Includes the area that covers the I-710 corridor and the Port of Long Beach, as well as neighboring communities.
  - High truck volume (up to 16% of annual average daily traffic in 2019)
  - Covers communities with and without EJ concerns
- In 2017, a near-road monitor within this domain had:
  - The highest $PM_{2.5}$ levels in the nation (Mukherjee et al., 2020)
  - The second highest near-road $PM_{2.5}$ increments (i.e., contributions from on-road vehicles) (Mukherjee et al., 2020)

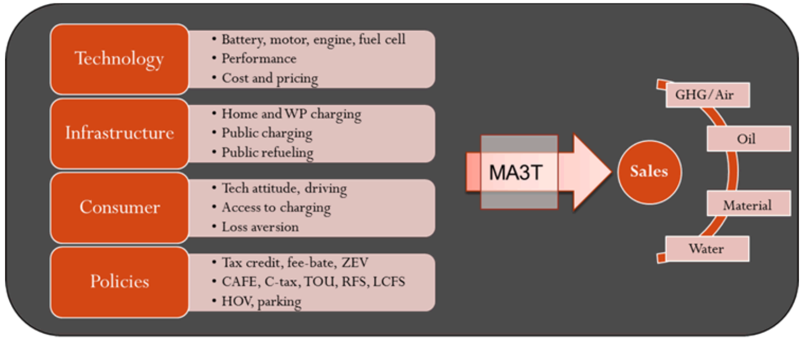


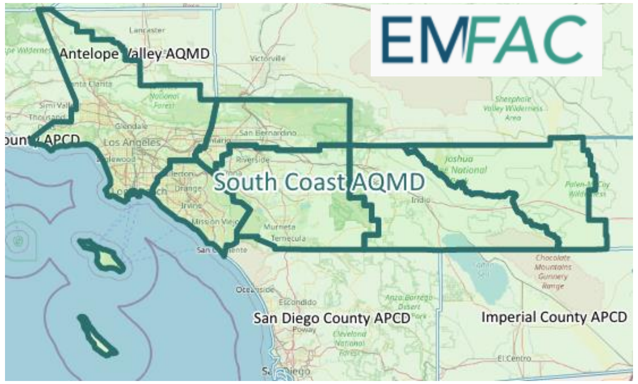
The census tracts in red represent potential communities with EJ concerns

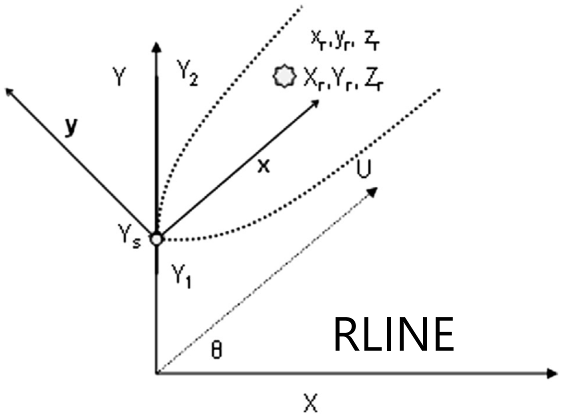
Source: https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30

Method Overview

- **EV population modeling**
  - Light duty vehicle (LDV) fleet:
    - Tool: Market Acceptance of Advanced Automotive Technologies (MA^3T)
    - Only consider battery electric vehicles (BEVs)
  - Medium- and heavy-duty vehicle (MHDV) fleet:
    - Advance Clean Truck (ACT): CARB's policy analysis spreadsheet of regulations that will accelerate EV penetration in medium and heavy-duty fleet
    - Advance Clean Fleet (ACF): CARB's presentation using South Coast as an example

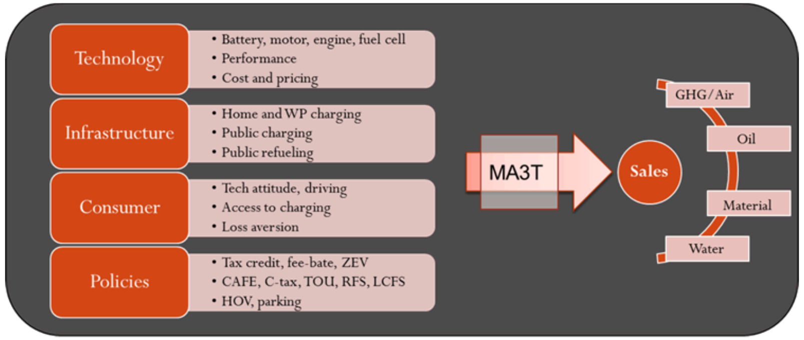


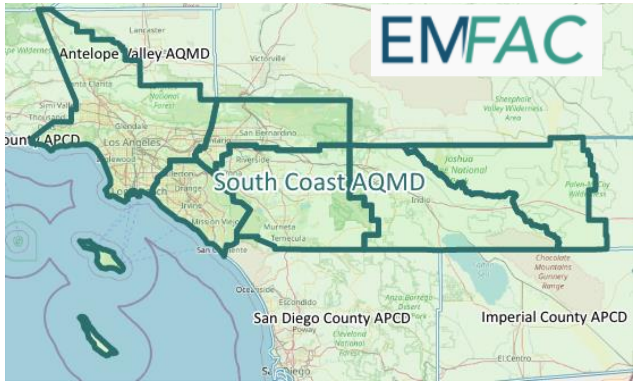


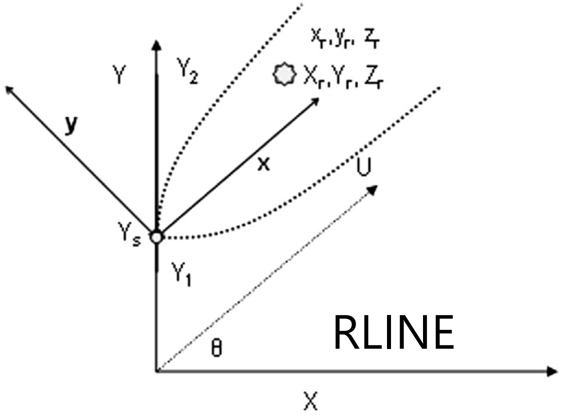


Method Overview

- **Emissions modeling**
  - CARB's EMission FACtor (EMFAC) for area under South Coast Air Quality Management District (AQMD) jurisdiction
  - EMFAC postprocessing to adopt additional EV penetration from each scenario
    - For brake wear, the emissions from EVs are half of those from ICE vehicles due to regenerative braking
- **Air Quality modeling**
  - Urban background: Inverse distance weighting (IDW) using AirNow monitoring data
  - Concentration from on-road source: Research LINE (RLINE) source model (Snyder et al., 2013)







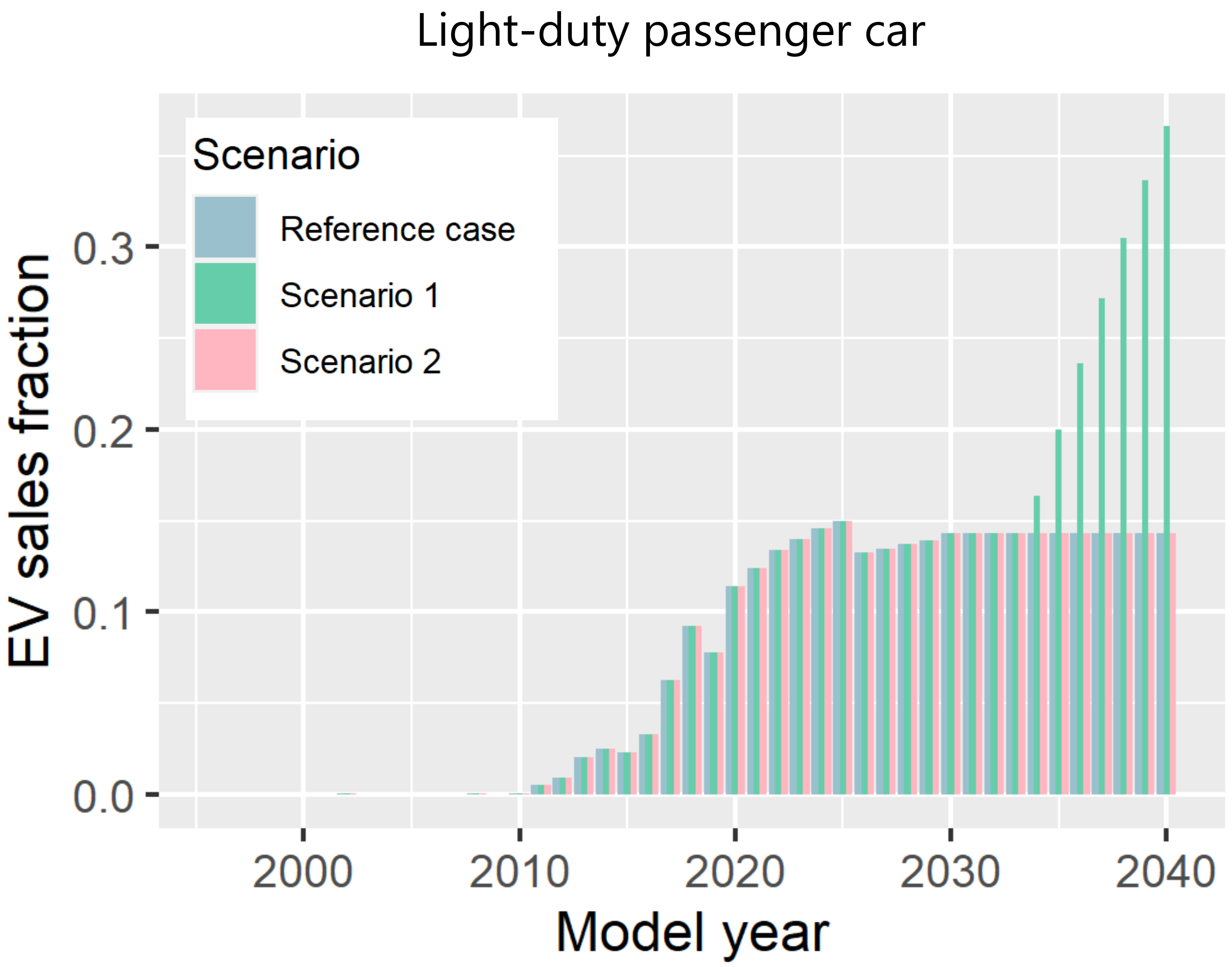
EV Penetration Scenarios

Scenario	Policies that Impact Light-Duty Fleet	Policies that Impact Medium- and Heavy-Duty Fleet
0. Reference case*	No further policies to accelerate EV penetration	No further policies to accelerate EV penetration
1. High emissions reduction	The cost to manufacture light-duty EVs is comparable to internal combustion conventional vehicles starting in 2030	Advanced Clean Truck (ACT) and Advanced Clean Fleet (ACF) regulations
2. Medium emissions reduction	Medium gasoline price increases $0.07 per gallon a year beginning in 2019	ACT regulation
3. Emission reduction for MHDVs only	No further policies to accelerate EV penetration	ACT and ACF regulations

*The reference case includes adopted policies that are embedded in EMFAC 2017 with updated light-duty EV population based on EMFAC2021 light-duty EV sales fraction.
EMFAC 2021 includes the ACT policy and therefore is not suitable for establishing the reference case.

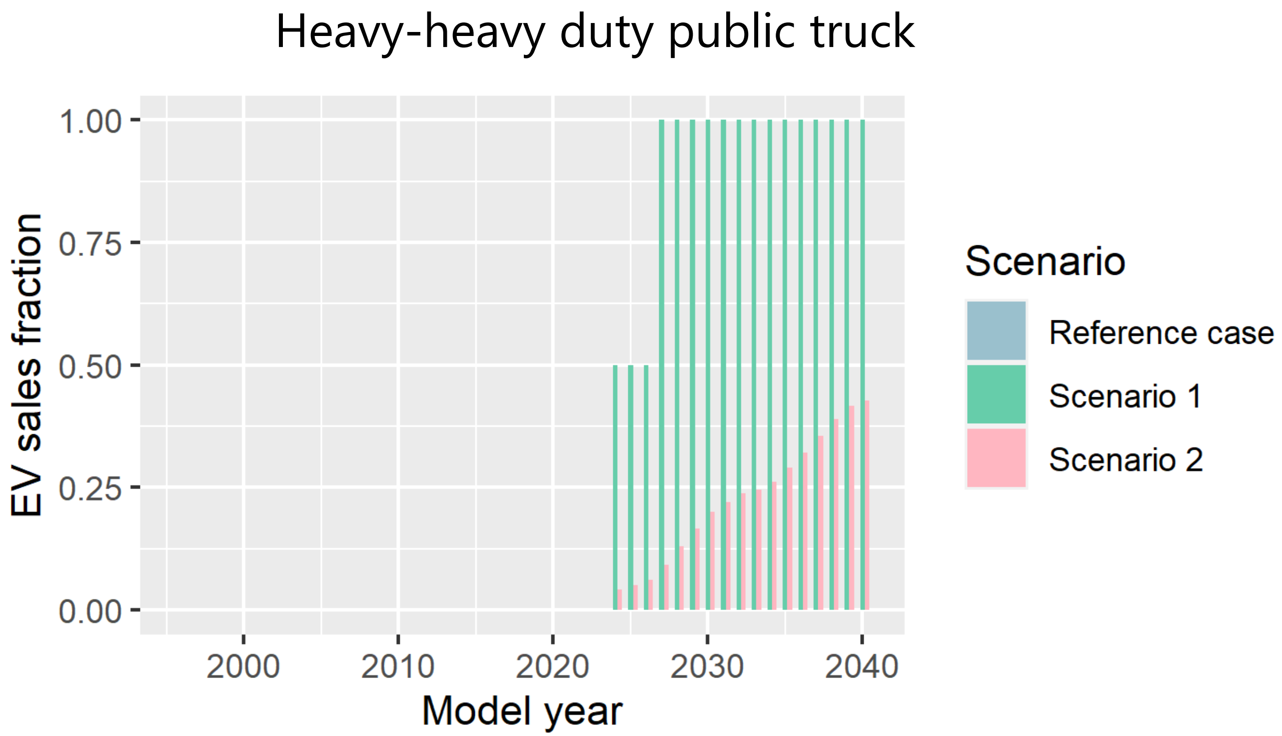
EV Penetration Modeling for Calendar Year 2040

- Scenario specific EV % by model year is calculated from:
  - MA^3T for LDV fleet
  - ACT and ACF regulations for medium- and heavy- duty fleet
- If the modeled EV % is less than EMFAC default EV %, no additional EV penetrated the fleet
- Example of EV penetration modeling: light duty passenger car



EV Penetration Modeling for Calendar Year 2040

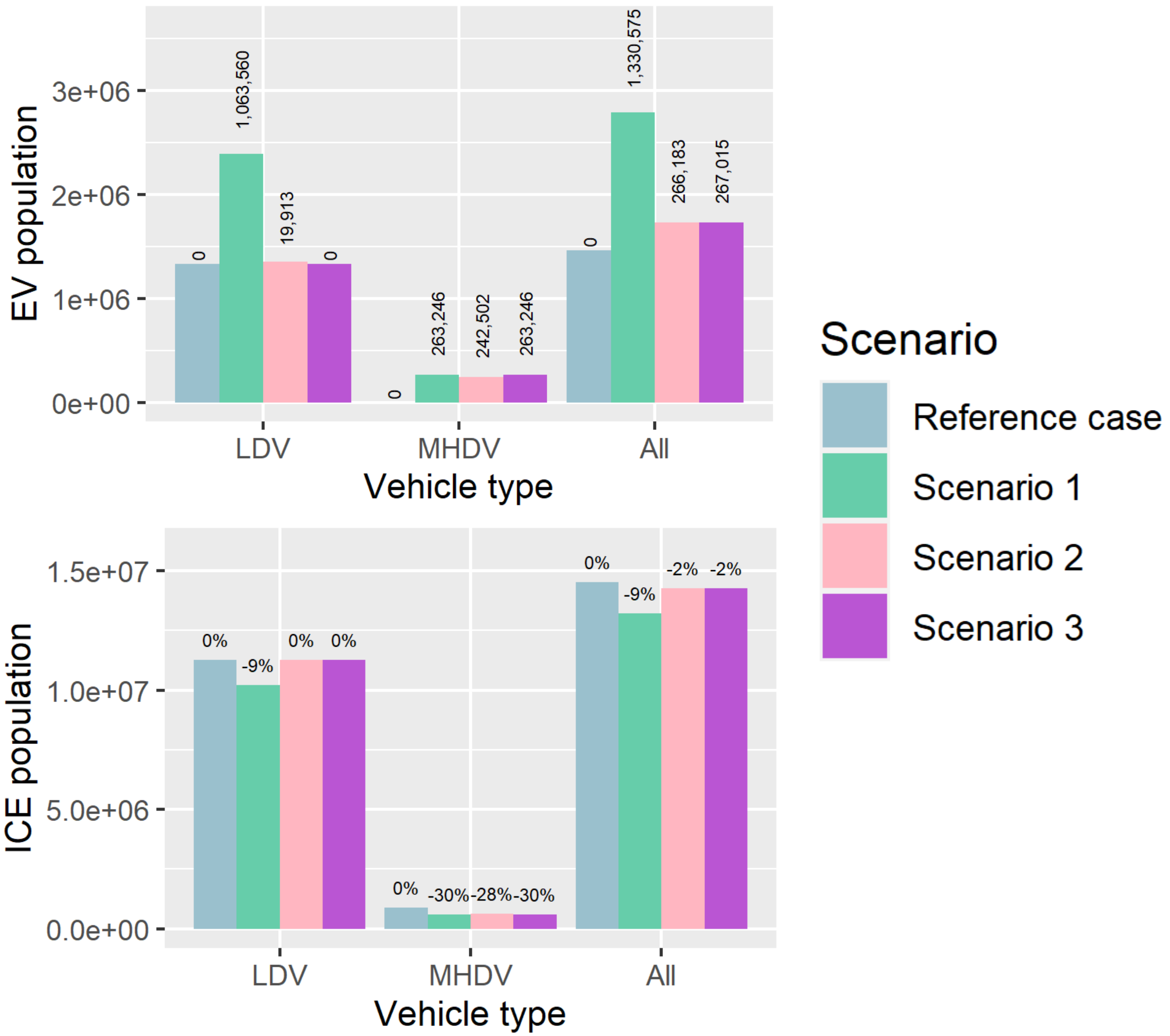
- Scenario specific EV % by model year is calculated from:
  - MA^{3}T for LDV fleet
  - ACT and ACF regulations for medium- and heavy- duty fleet
- If the modeled EV % is less than EMFAC default EV %, no additional EV penetrated the fleet
- Example of EV penetration modeling: heavy-heavy duty public truck (one out of 29 EMFAC medium- and heavy-duty trucks)
  - High EV penetration with ACT + ACF regulation



Heavy-heavy duty: gross vehicle weight rating (GVWR) > 33,000 lbs
Public truck: ARB defines "public trucks" as trucks owned by California state or local government

EV Penetration in 2040 by Scenario for South Coast Fleet

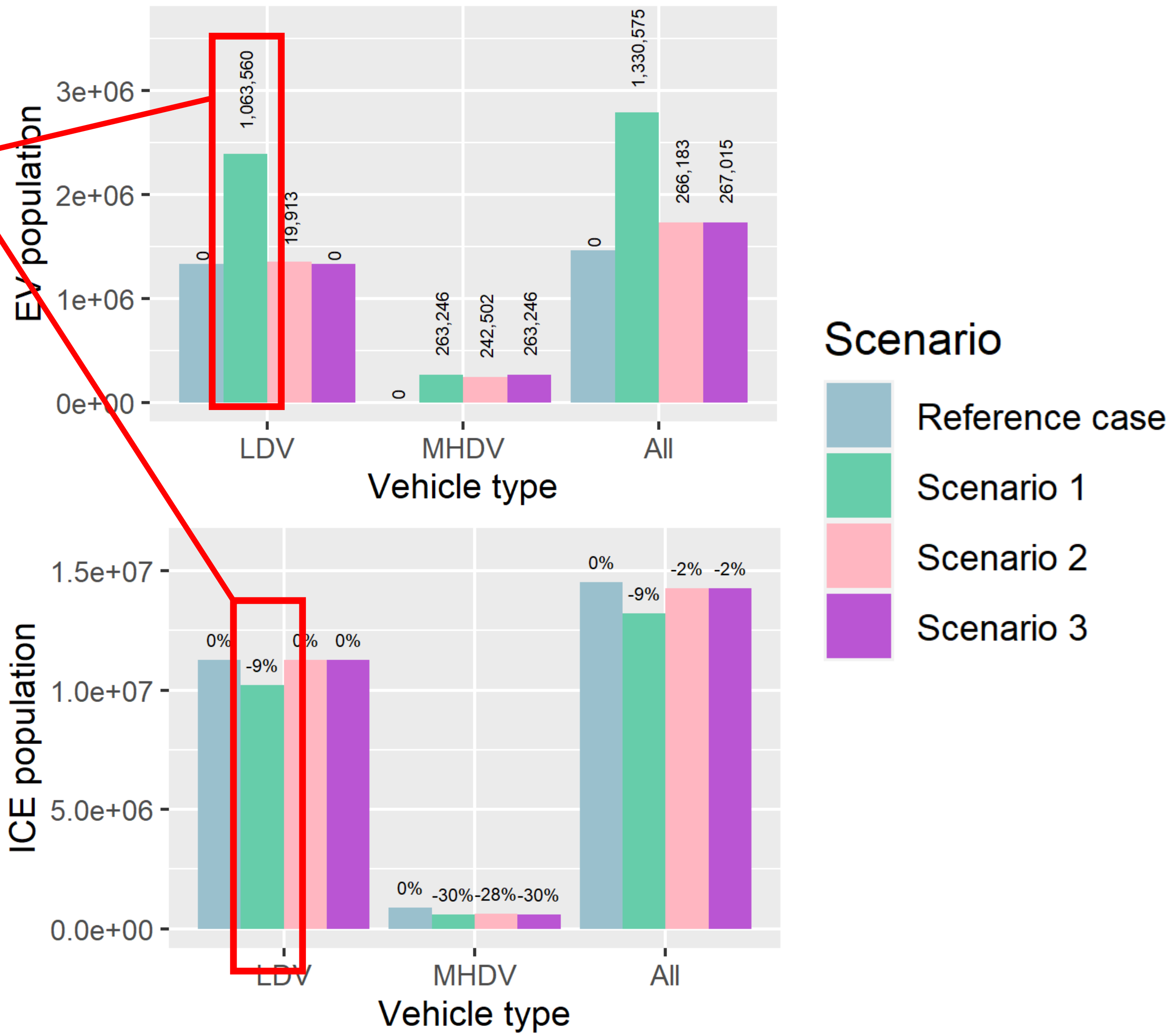
- For LDV fleet:
  - Scenario 1 replaced 9% of total on-road ICE (1 million) vehicles in the LDV fleet with EVs
  - Scenario 2 replaced 0.1% of total on-road ICE (19k) vehicles in the LDV fleet with EVs
- For MHDV fleet:
  - Scenario 1 replaced 30% of total on-road ICE (260k) vehicles in the MHDV fleet with EVs
  - Scenario 2 replaced 28% of total on-road ICE (240k) vehicles in the MHDV fleet with EVs
  - ACF replaced an additional 2% of total on-road ICE in MHDV fleet with EVs



*ICE: Internal combustion engine

EV Penetration in 2040 by Scenario for South Coast Fleet

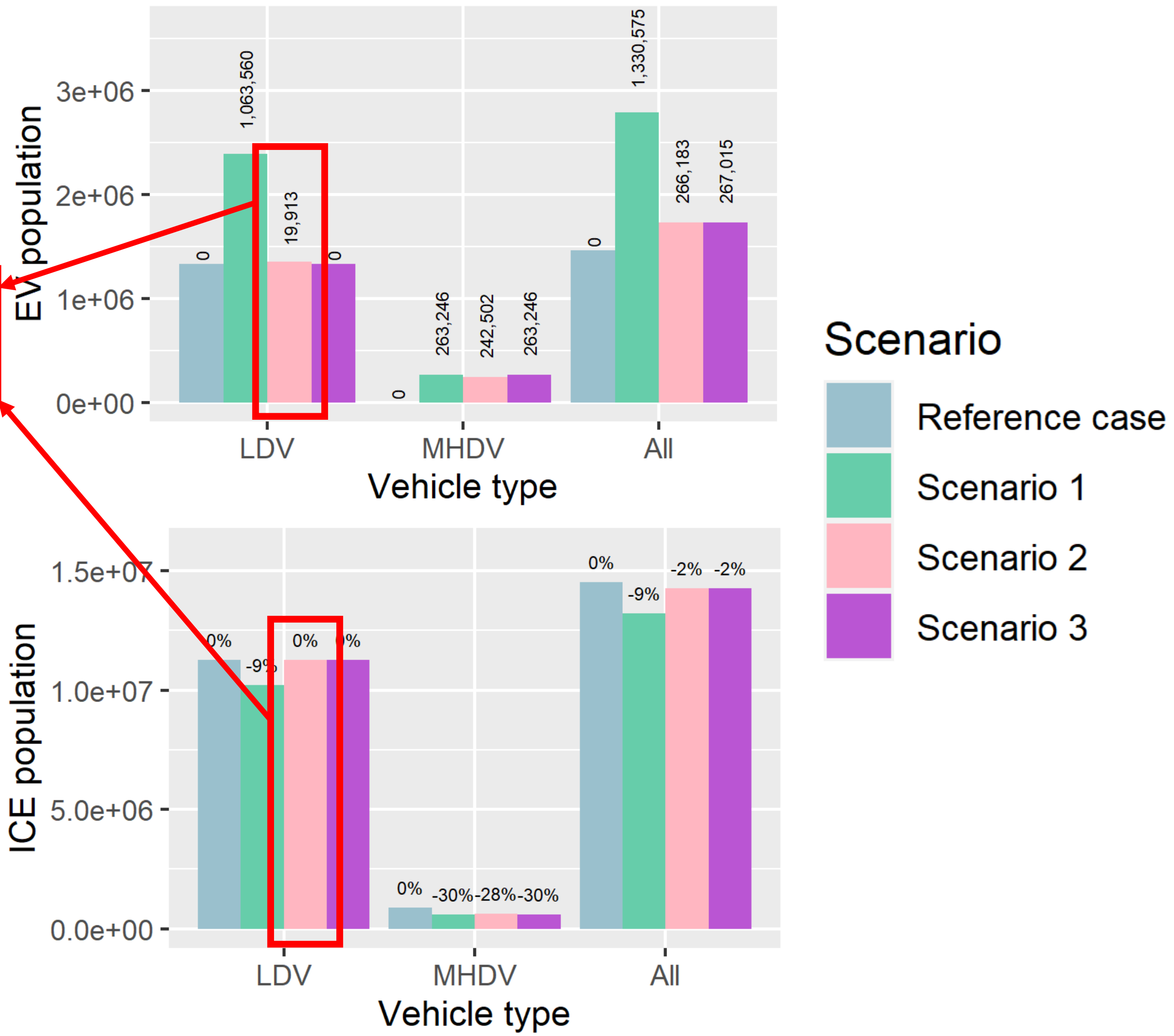
- For LDV fleet:
  - Scenario 1 replaced 9% of total on-road ICE (1 million) vehicles in the LDV fleet with EVs
  - Scenario 2 replaced 0.1% of total on-road ICE (19k) vehicles in the LDV fleet with EVs
- For MHDV fleet:
  - Scenario 1 replaced 30% of total on-road ICE (260k) vehicles in the MHDV fleet with EVs
  - Scenario 2 replaced 28% of total on-road ICE (240k) vehicles in the MHDV fleet with EVs
  - ACF replaced an additional 2% of total on-road ICE in MHDV fleet with EVs



*ICE: Internal combustion engine

EV Penetration in 2040 by Scenario for South Coast Fleet

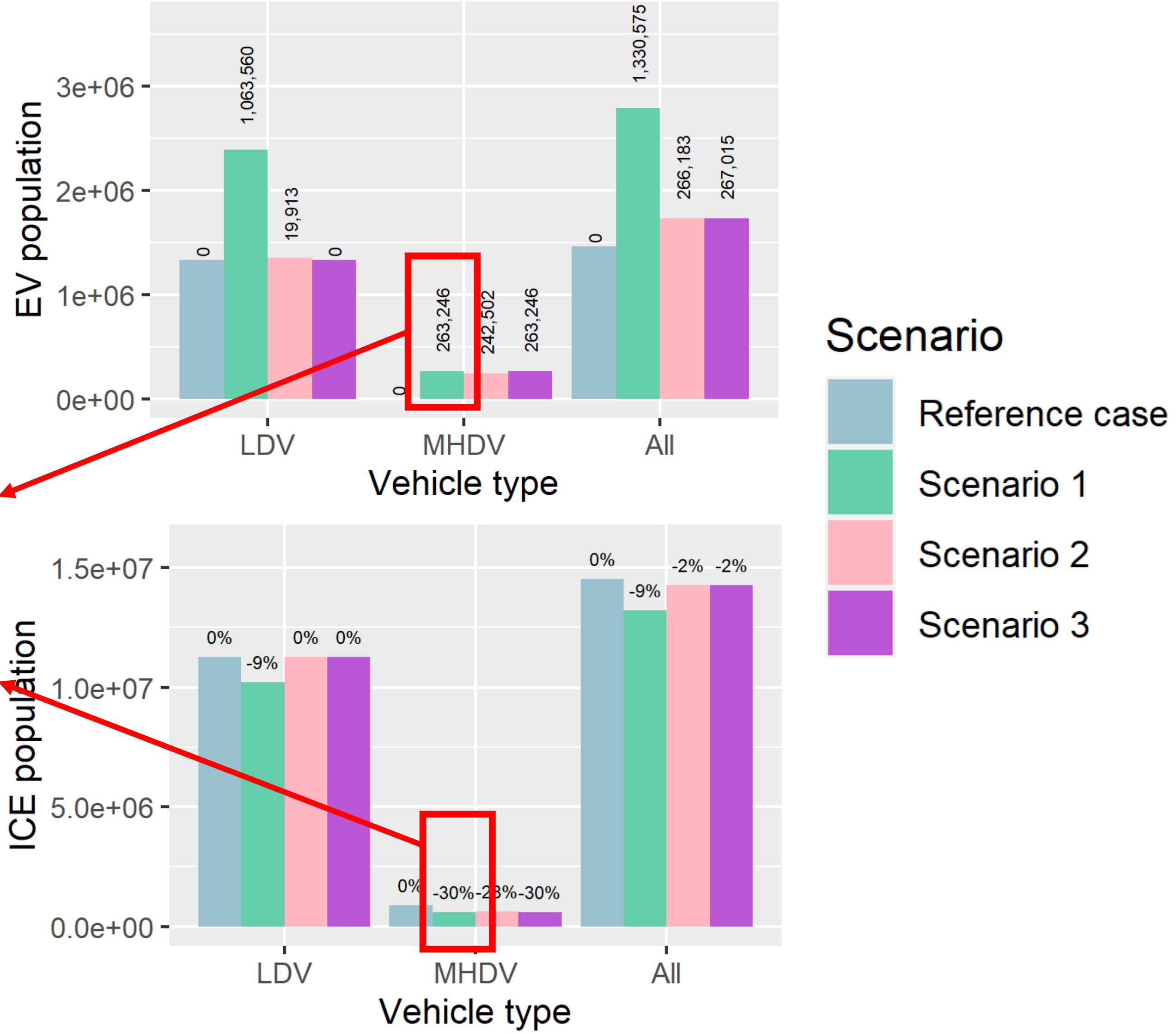
- For LDV fleet:
  - Scenario 1 replaced 9% of total on-road ICE (1 million) vehicles in the LDV fleet with EVs
  - Scenario 2 replaced 0.1% of total on-road ICE (19k) vehicles in the LDV fleet with EVs
- For MHDV fleet:
  - Scenario 1 replaced 30% of total on-road ICE (260k) vehicles in the MHDV fleet with EVs
  - Scenario 2 replaced 28% of total on-road ICE (240k) vehicles in the MHDV fleet with EVs
  - ACF replaced an additional 2% of total on-road ICE in MHDV fleet with EVs



*ICE: Internal combustion engine

EV Penetration in 2040 by Scenario for South Coast Fleet

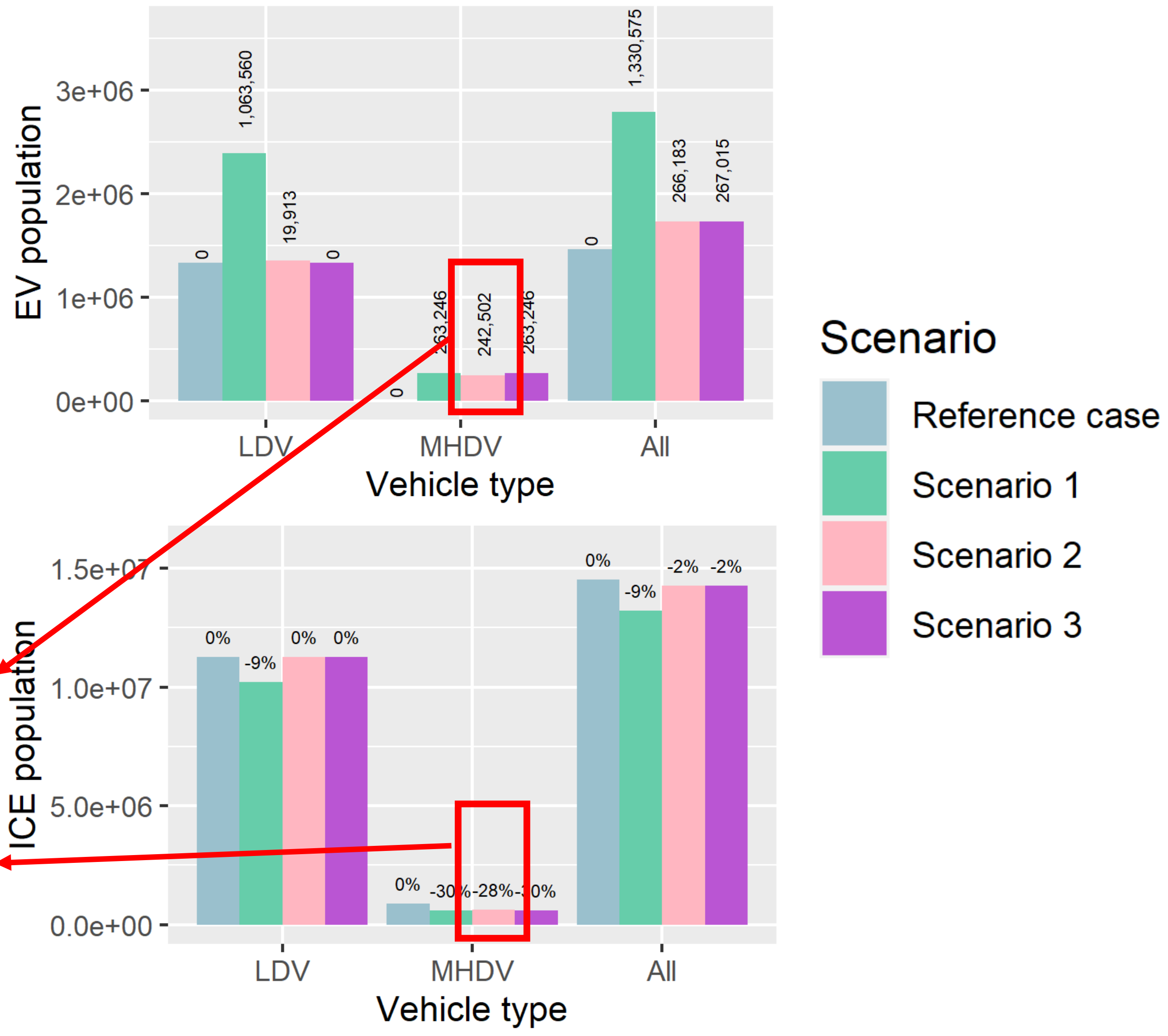
- For LDV fleet:
  - Scenario 1 replaced 9% of total on-road ICE (1 million) vehicles in the LDV fleet with EVs
  - Scenario 2 replaced 0.1% of total on-road ICE (19k) vehicles in the LDV fleet with EVs
- For MHDV fleet:
  - Scenario 1 replaced 30% of total on-road ICE (260k) vehicles in the MHDV fleet with EVs
  - Scenario 2 replaced 28% of total on-road ICE (240k) vehicles in the MHDV fleet with EVs
  - ACF replaced an additional 2% of total on-road ICE in MHDV fleet with EVs



*ICE: Internal combustion engine

EV Penetration in 2040 by Scenario for South Coast Fleet

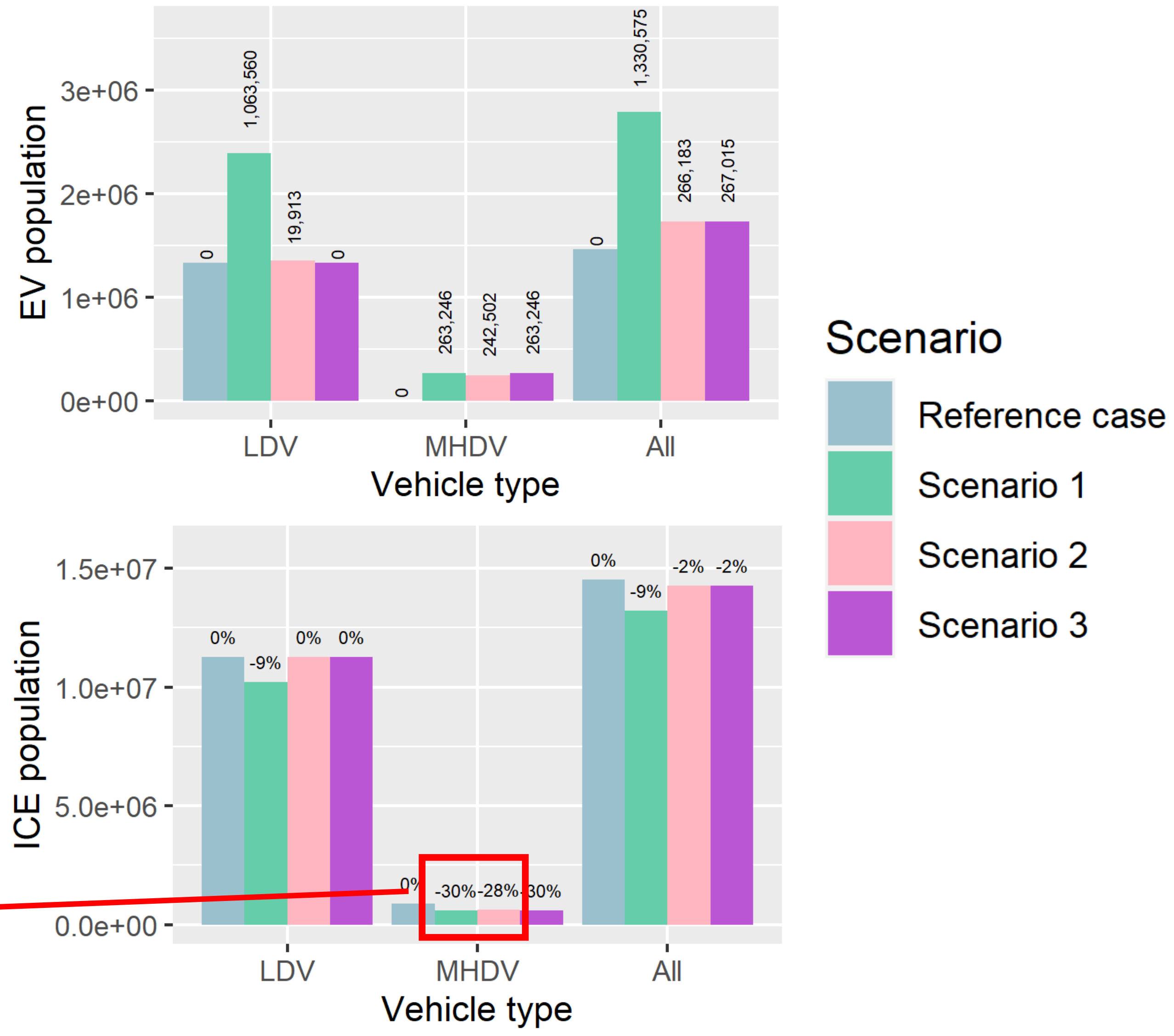
- For LDV fleet:
  - Scenario 1 replaced 9% of total on-road ICE (1 million) vehicles in the LDV fleet with EVs
  - Scenario 2 replaced 0.1% of total on-road ICE (19k) vehicles in the LDV fleet with EVs
- For MHDV fleet:
  - Scenario 1 replaced 30% of total on-road ICE (260k) vehicles in the MHDV fleet with EVs
  - Scenario 2 replaced 28% of total on-road ICE (240k) vehicles in the MHDV fleet with EVs
  - ACF replaced an additional 2% of total on-road ICE in MHDV fleet with EVs



*ICE: Internal combustion engine

EV Penetration in 2040 by Scenario for South Coast Fleet

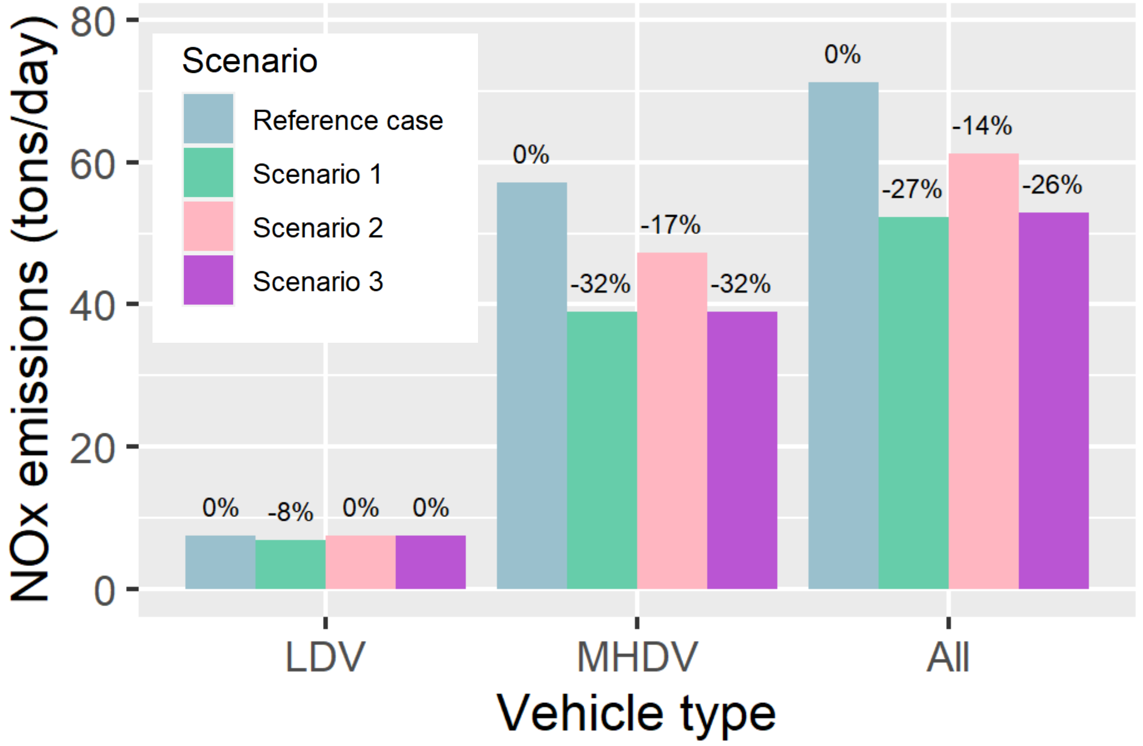
- For LDV fleet:
  - Scenario 1 replaced 9% of total on-road ICE (1 million) vehicles in the LDV fleet with EVs
  - Scenario 2 replaced 0.1% of total on-road ICE (19k) vehicles in the LDV fleet with EVs
- For MHDV fleet:
  - Scenario 1 replaced 30% of total on-road ICE (260k) vehicles in the MHDV fleet with EVs
  - Scenario 2 replaced 28% of total on-road ICE (240k) vehicles in the MHDV fleet with EVs
  - ACF replaced an additional 2% of total on-road ICE in MHDV fleet with EVs



*ICE: Internal combustion engine

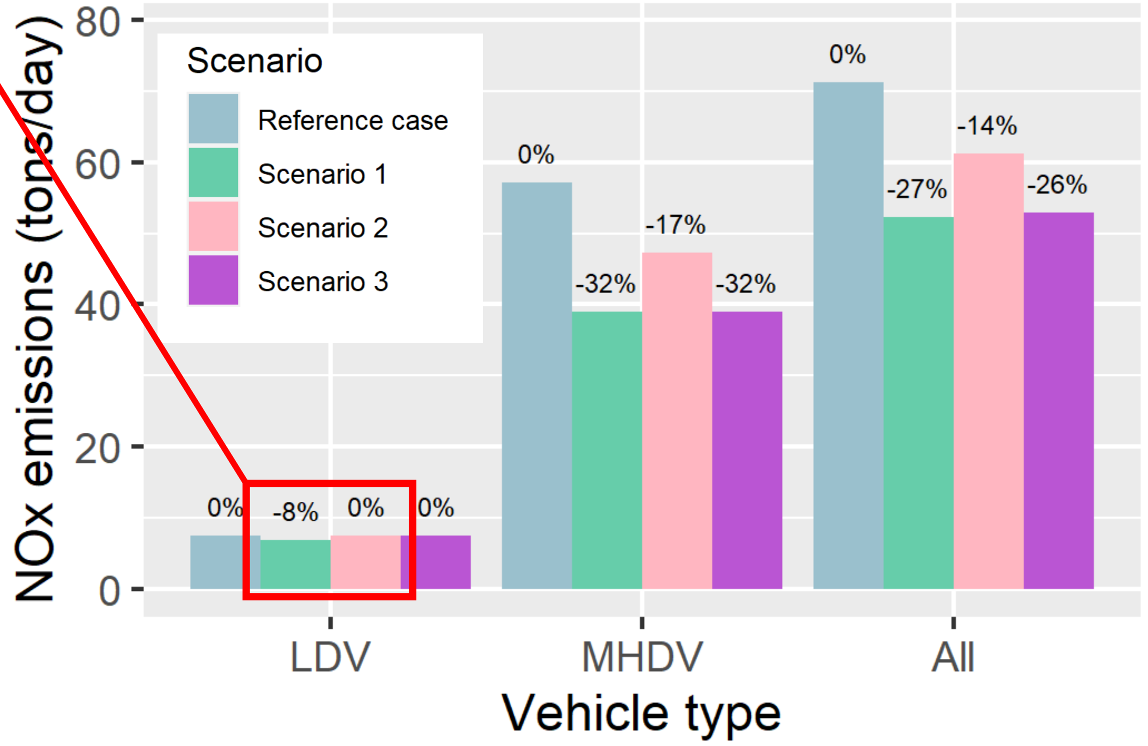
NOx Emission (Tons/Day) in 2040 by Scenario for South Coast Fleet

- For LDV fleet:
  - Scenario 1 reduced LDV NO_x emissions by 8%
  - Scenario 2 reduced LDV NO_x emissions by 0.3%
  - Policies that affect earlier model years gain more emissions benefits because earlier model-year vehicles emit more pollutants
- For MHDV fleet:
  - Scenario 1 (ACT + ACF) reduced MHDV NO_x emissions by 32%
  - Scenario 2 (ACT only) reduced MHDV NO_x emissions by 17%
  - The additional 2% of ICE replaced with ACF resulted in an additional 15% NO_x emissions reduction
- Because on-road NO_x emissions are dominated by the MHDV fleet, EV penetration into the LDV fleet has less impact on NOx emissions reduction



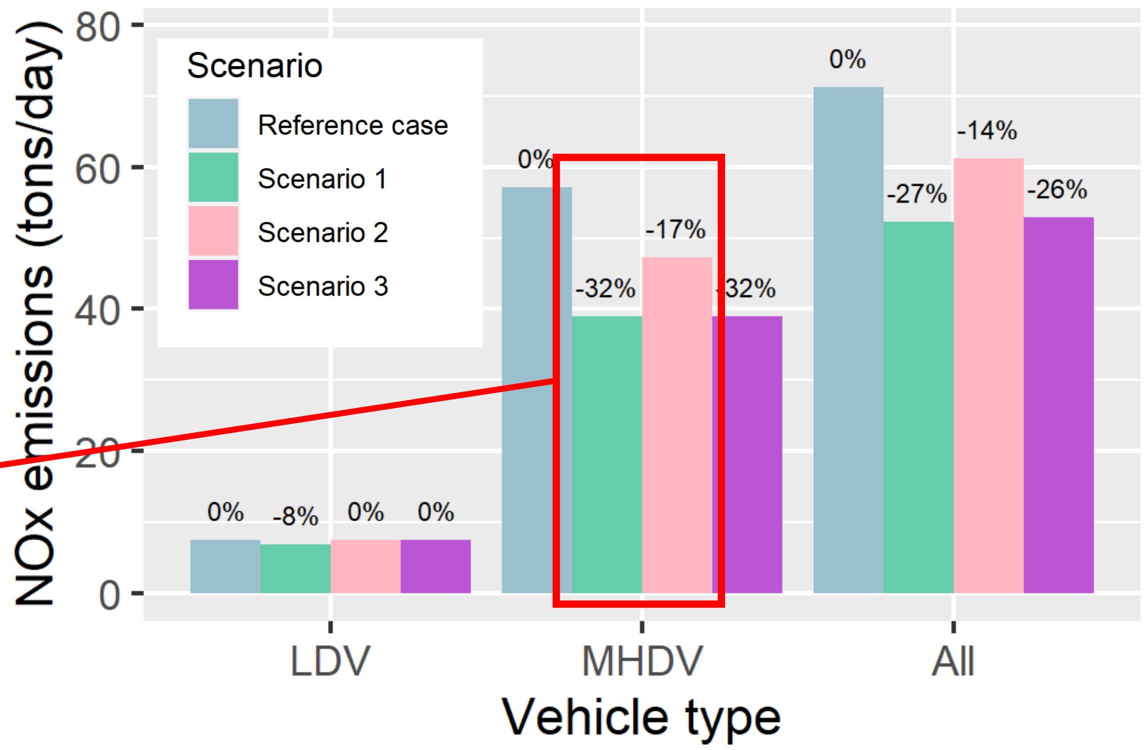
NOx Emission (Tons/Day) in 2040 by Scenario for South Coast Fleet

- For LDV fleet:
  - Scenario 1 reduced LDV NO_x emissions by 8%
  - Scenario 2 reduced LDV NO_x emissions by 0.3%
  - Policies that affect earlier model years gain more emissions benefits because earlier model-year vehicles emit more pollutants
- For MHDV fleet:
  - Scenario 1 (ACT + ACF) reduced MHDV NO_x emissions by 32%
  - Scenario 2 (ACT only) reduced MHDV NO_x emissions by 17%
  - The additional 2% of ICE replaced with ACF resulted in an additional 15% NO_x emissions reduction
- Because on-road NO_x emissions are dominated by the MHDV fleet, EV penetration into the LDV fleet has less impact on NOx emissions reduction



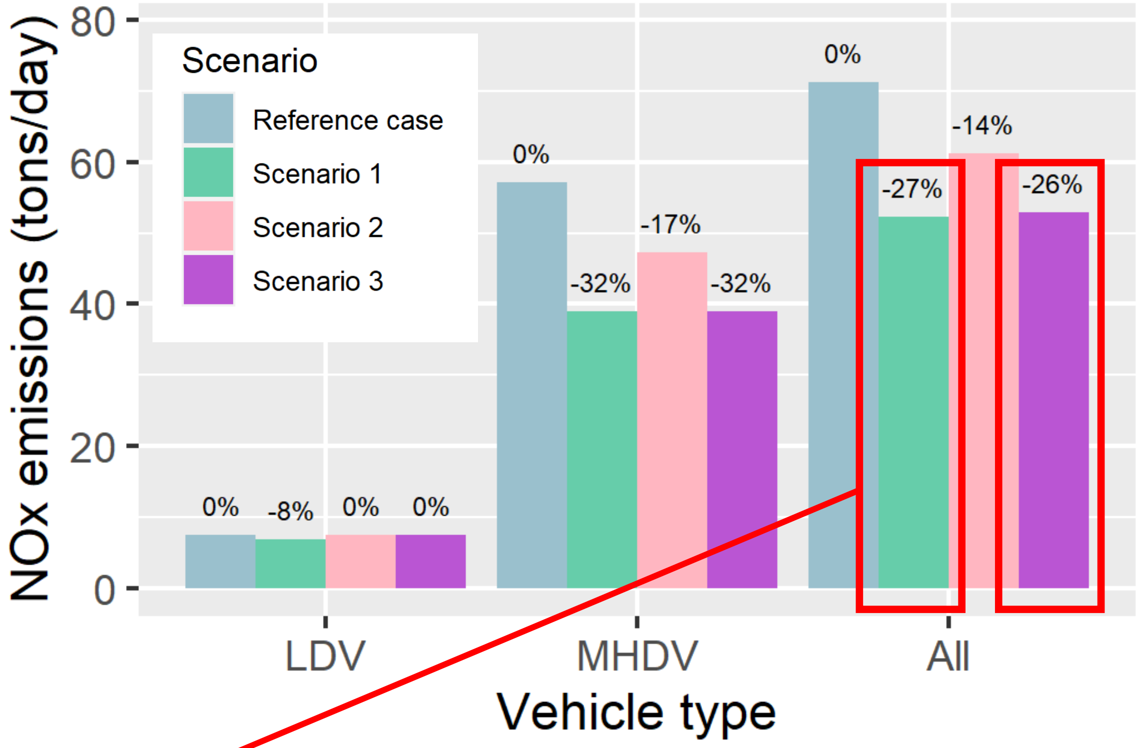
NOx Emission (Tons/Day) in 2040 by Scenario for South Coast Fleet

- For LDV fleet:
  - Scenario 1 reduced LDV NO_x emissions by 8%
  - Scenario 2 reduced LDV NO_x emissions by 0.3%
  - Policies that affect earlier model years gain more emissions benefits because earlier model-year vehicles emit more pollutants
- For MHDV fleet:
  - Scenario 1 (ACT + ACF) reduced MHDV NO_x emissions by 32%
  - Scenario 2 (ACT only) reduced MHDV NO_x emissions by 17%
  - The additional 2% of ICE replaced with ACF resulted in an additional 15% NO_x emissions reduction
- Because on-road NO_x emissions are dominated by the MHDV fleet, EV penetration into the LDV fleet has less impact on NOx emissions reduction



NOx Emission (Tons/Day) in 2040 by Scenario for South Coast Fleet

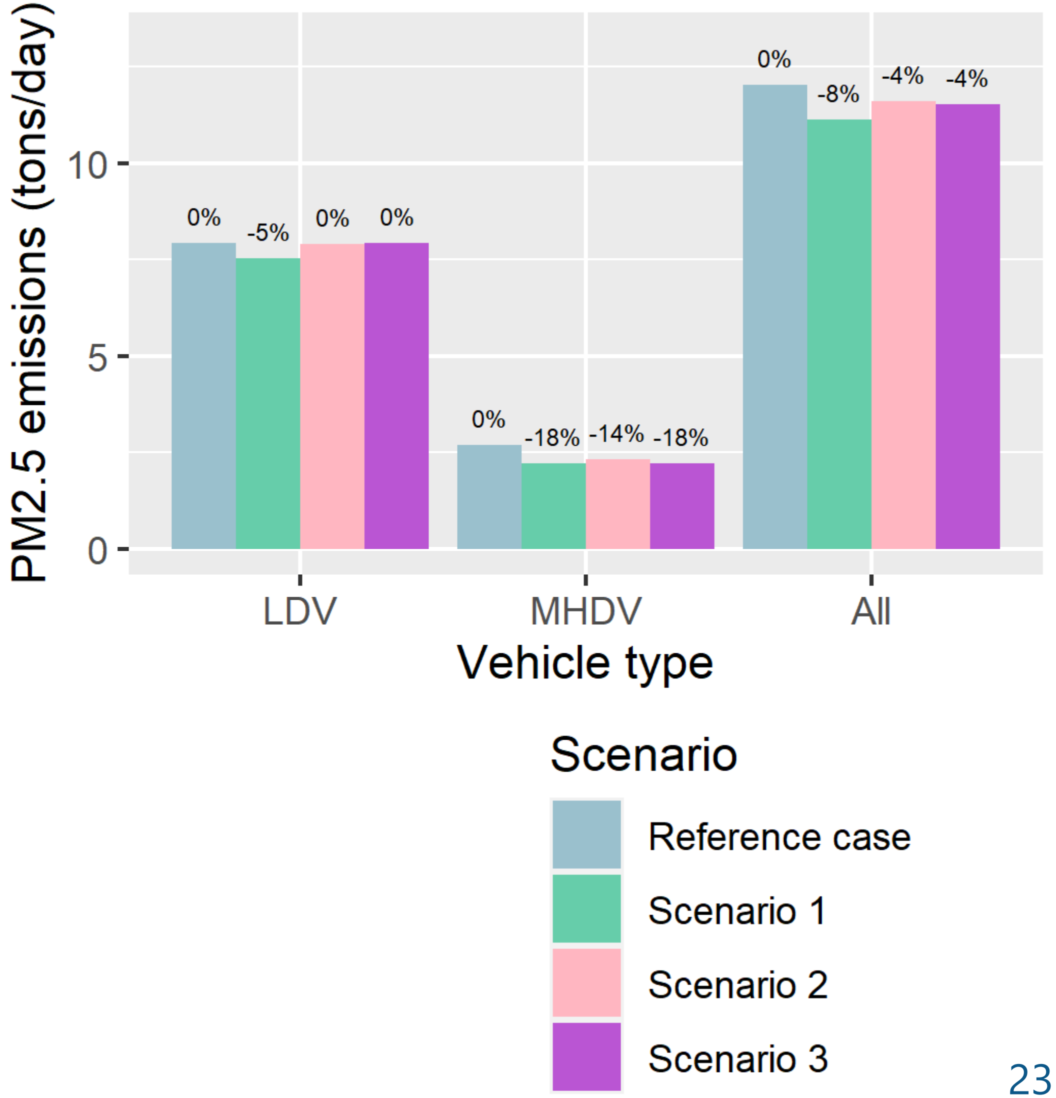
- For LDV fleet:
  - Scenario 1 reduced LDV NO_x emissions by 8%
  - Scenario 2 reduced LDV NO_x emissions by 0.3%
  - Policies that affect earlier model years gain more emissions benefits because earlier model-year vehicles emit more pollutants
- For MHDV fleet:
  - Scenario 1 (ACT + ACF) reduced MHDV NO_x emissions by 32%
  - Scenario 2 (ACT only) reduced MHDV NO_x emissions by 17%
  - The additional 2% of ICE replaced with ACF resulted in an additional 15% NO_x emissions reduction
- Because on-road NO_x emissions are dominated by the MHDV fleet, EV penetration into the LDV fleet has less impact on NOx emissions reduction



$PM_{2.5}$ Emission (Tons/Day) in 2040 by Scenario for South Coast Fleet

- In contrast to NO_x emissions, by 2040, LDVs contribute most of the on-road $PM_{2.5}$ emissions, making the benefits of electric MHDVs less impactful
- By 2040, brake wear is the major emission process contributing to on-road $PM_{2.5}$ (Reid et al. 2016)
- Embedded EMFAC assumptions key to analysis findings
  - EV penetration does not affect tire-wear emissions
  - EV brake wear emissions are half of ICE brake wear emissions
  - EV penetration significantly reduces running exhaust emissions

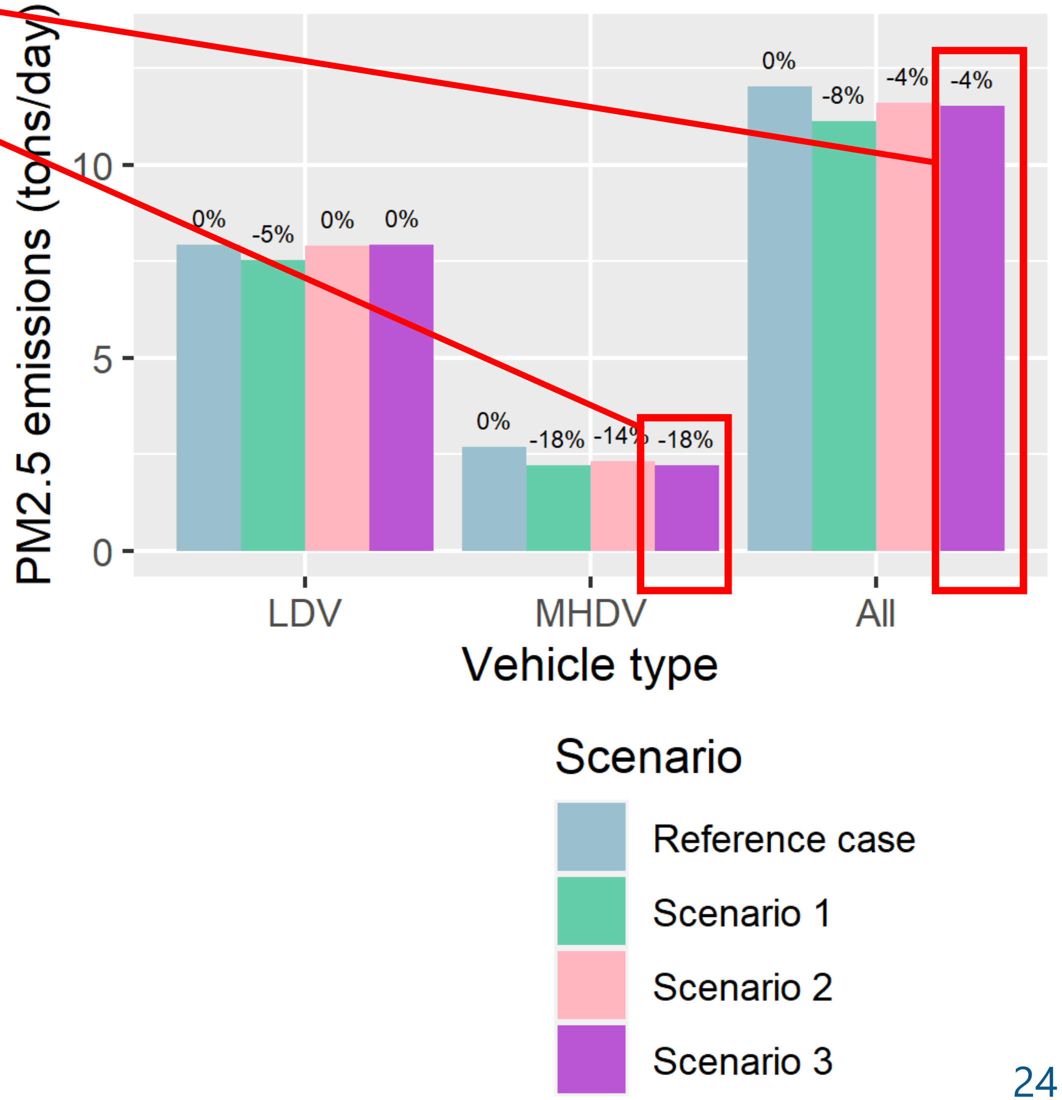
Modeled $PM_{2.5}$ emissions include running exhaust, tire wear, and brake wear



$PM_{2.5}$ Emission (Tons/Day) in 2040 by Scenario for South Coast Fleet

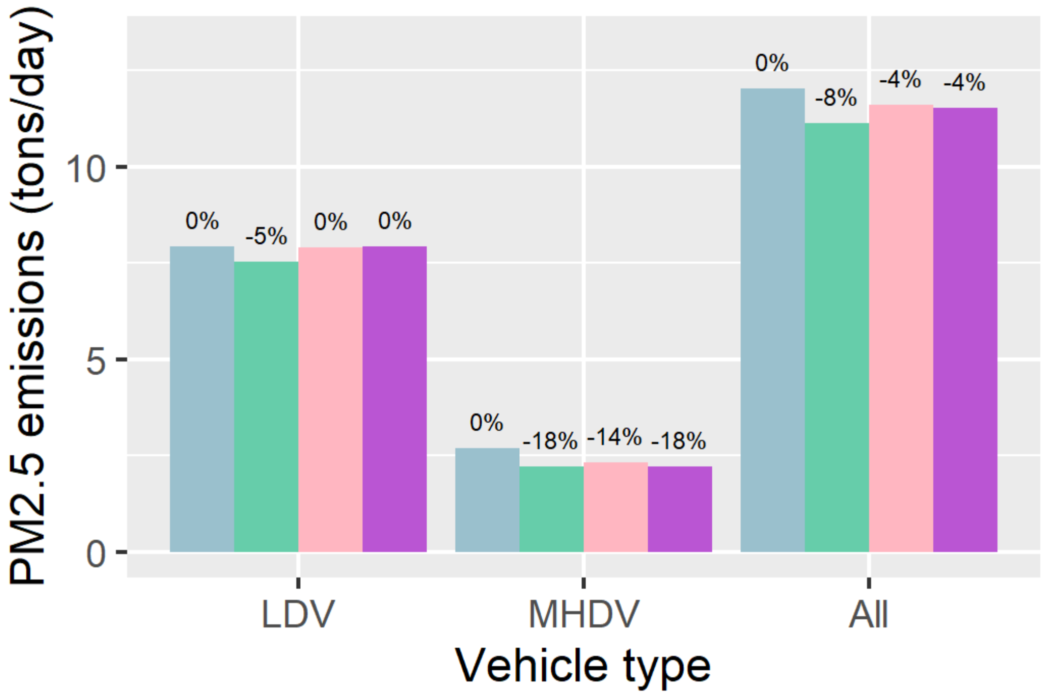
- In contrast to NO_x emissions, by 2040, LDVs contribute most of the on-road $PM_{2.5}$ emissions, making the benefits of electric MHDVs less impactful
- By 2040, brake wear is the major emission process contributing to on-road $PM_{2.5}$ (Reid et al. 2016)
- Embedded EMFAC assumptions key to analysis findings
  - EV penetration does not affect tire-wear emissions
  - EV brake wear emissions are half of ICE brake wear emissions
  - EV penetration significantly reduces running exhaust emissions

Modeled $PM_{2.5}$ emissions include running exhaust, tire wear, and brake wear

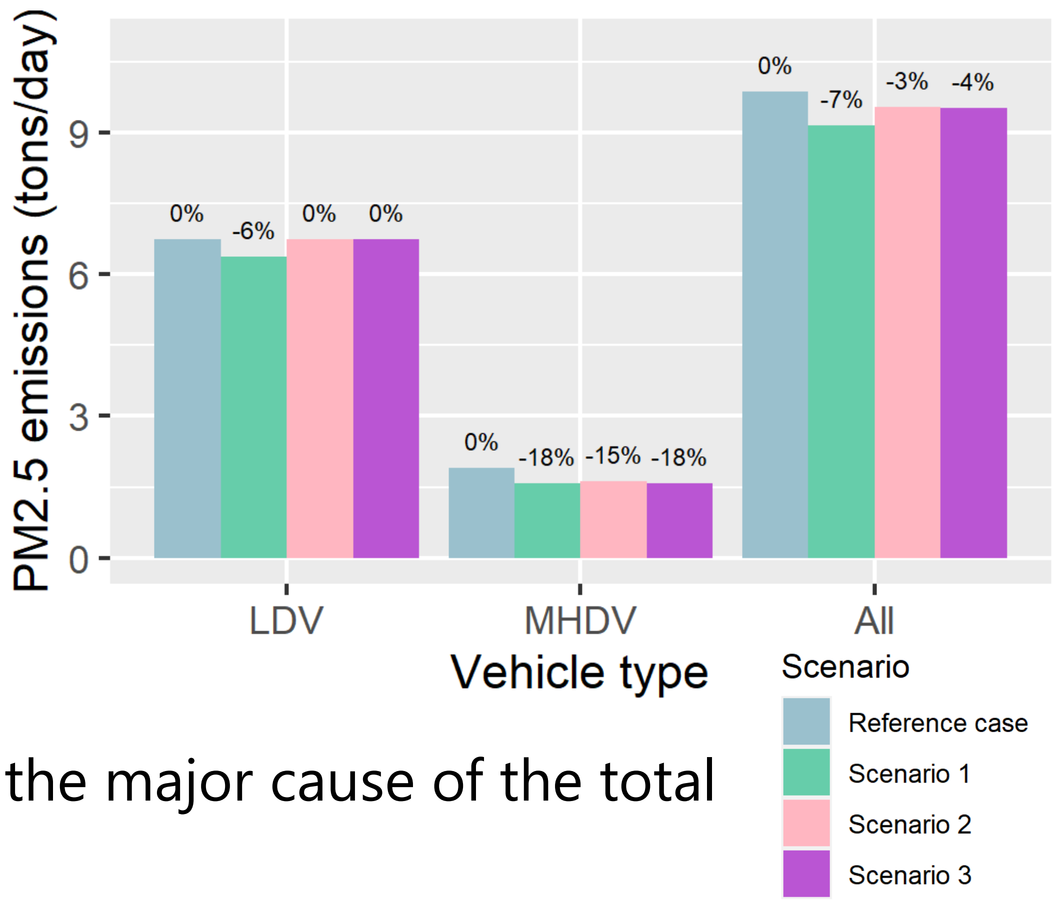


$PM_{2.5}$ Running Exhaust Emission (Tons/Day) in 2040 by Scenario for South Coast Fleet

Modeled $PM_{2.5}$ emissions include running exhaust, tire wear, and brake wear



Modeled brake wear $PM_{2.5}$ emissions

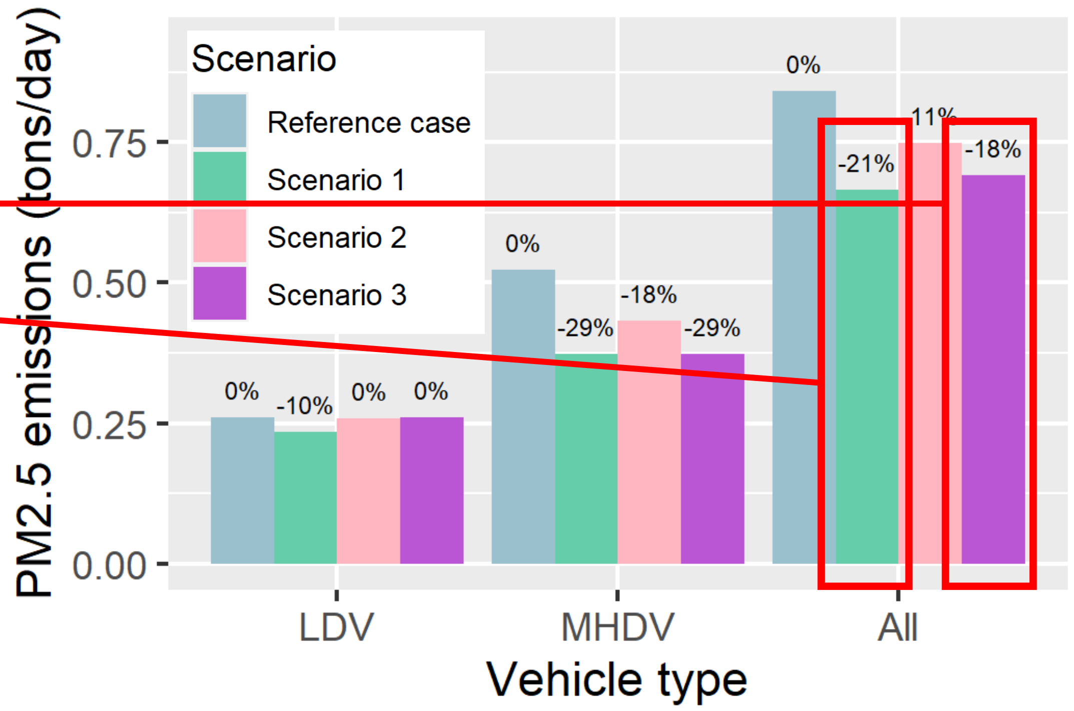


The reduction in brake wear $PM_{2.5}$ emissions is the major cause of the total $PM_{2.5}$ reduction

$PM_{2.5}$ Running Exhaust Emission (Tons/Day) in 2040 by Scenario for South Coast Fleet

- EV penetration significantly reduces running exhaust emissions
- Comparison between scenario 1 and 3 shows that LDV EV penetration contributed an additional 3% reduction of overall running exhaust $PM_{2.5}$ emissions

Modeled running exhaust $PM_{2.5}$ emissions



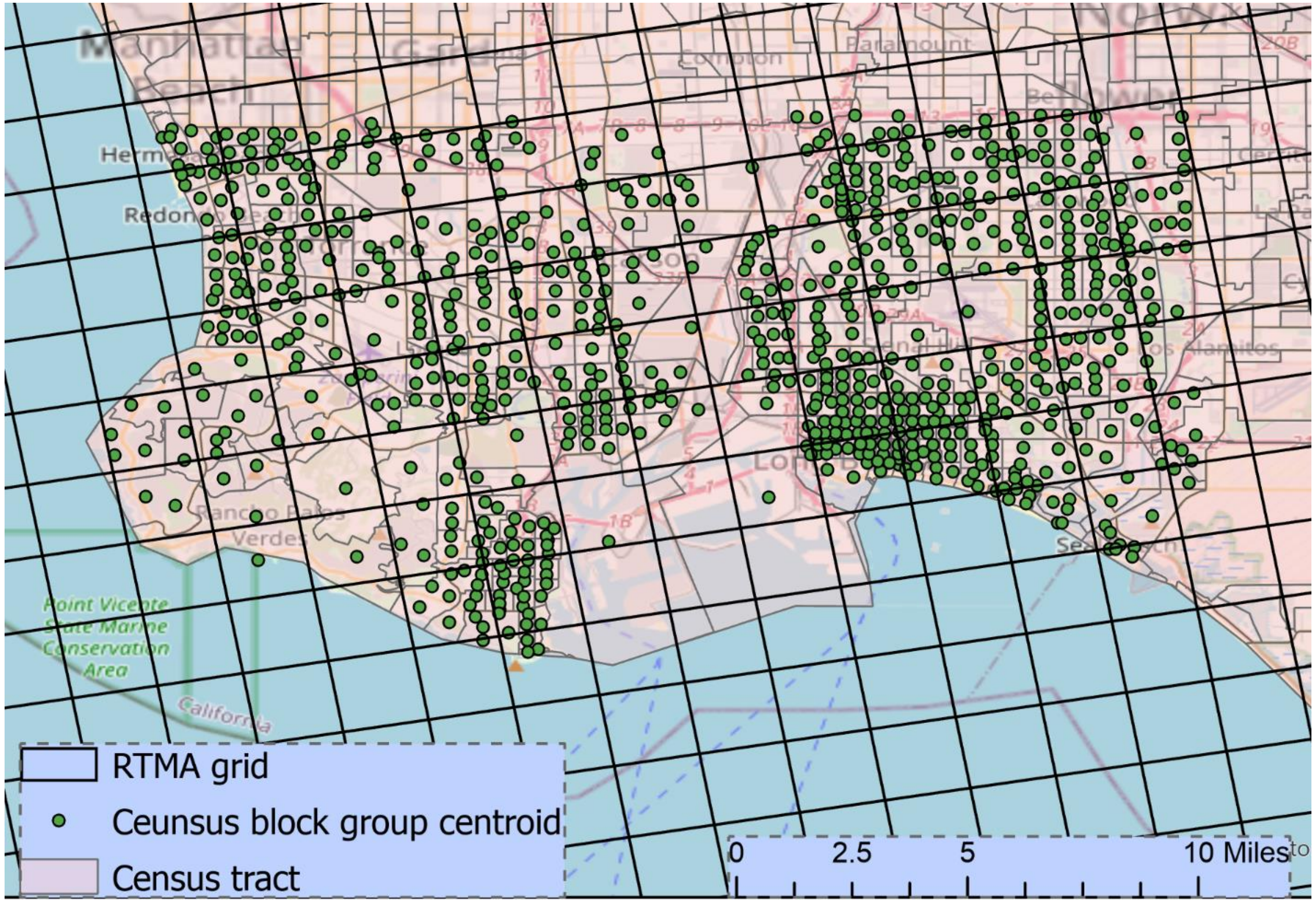
Summary of Results

Scenario	ICE reductions (%)	NO_x reductions (%)	$PM_{2.5}$ reductions (%)
Scenario 1	9	27	8
Scenario 2	2	14	4
Scenario 3	2	26	4

- NO_x emissions
  - Scenario 3 showed similar NO_x emission reduction (26%) to Scenario 1 (27%) because MHDV fleet is the major NO_x contributor
- $PM_{2.5}$ emissions
  - EV penetration does not greatly reduce $PM_{2.5}$ emissions
    - Brake wear is the biggest contributor for $PM_{2.5}$ emissions, and LDV is the biggest contributor for brake wear $PM_{2.5}$
    - Since the EV penetration in the LDV fleet is not high (0.1% and 9%) in our scenarios, the overall $PM_{2.5}$ emissions reductions is limited

Next Steps

- Develop roadway-specific emissions using traffic activity data from Streetlytics (https://www.bentley.com/en/products/brands/streetlytics)
- Fine resolution modeling using real-time mesoscale analysis (RTMA) meteorological field



References

- Rowangould, G.M., 2013. A census of the U.S. near-roadway population: Public health and environmental justice considerations. Transp. Res. Part D Transp. Environ. 25, 59–67. doi:10.1016/j.trd.2013.08.003
- Erdakos G., Chang S.Y., Eisinger D., Heller A., and Unger H. (2019) Zero emission vehicles: forecasting fleet scenarios and their emissions implications. Final report prepared for NCHRP 25-25, Task 115 by Sonoma Technology, Inc., Petaluma, CA, and Louis Berger, Denver, CO, STI-918083-7043, November. Available at http://www.trb.org/Main/Blurbs/180232.aspx.
- Mukherjee A., McCarthy M.C., Brown S.G., Huang S., Landsberg K., and Eisinger D.S. (2020) Influence of roadway emissions on near-road $PM_{2.5}$: monitoring data analysis and implications. *Transportation Research Part D: Transport and Environment*, 86(102442), (STI-7166). Available at https://www.sciencedirect.com/science/article/pii/S1361920920306295.
- Snyder, M.G., Venkatram, A., Heist, D.K., Perry, S.G., Petersen, W.B., Isakov, V., 2013. RLINE: A line source dispersion model for near-surface releases. Atmos. Environ. 77, 748–756. doi:10.1016/j.atmosenv.2013.05.074
- Reid, S., Bai, S., Du, Y., Craig, K., Erdakos, G., Baringer, L., Eisinger, D., McCarthy, M., Landsberg, K., 2016. Emissions Modeling with MOVES and EMFAC to Assess the Potential for a Transportation Project to Create Particulate Matter Hot Spots. Transp. Res. Rec. J. Transp. Res. Board 2570, 12–20. doi:10.3141/2570-02

Shih Ying Chang
Air Quality Scientist,
cchang@sonomatech.com

Supplementary slides

Comparison to previous studies

- A. EV population

Study	Heavy Duty EV population % in 2040
Raju et al., 2021	26% (CARB scoping plan in the South Coast region)
Current (this) study	30% (Scenario 1)

- C. Emissions change

Study	NO_x emission reduction (tons/day)	
	Light-duty fleet	Heavy-duty fleet
South Coast AQMP (2031)*	6	15
Current study (2040)	1	18

*Estimates with range of local, state, and federal emission reduction measures, including emission reduction programs that are still in development

- B. Emissions

Study	On-road emissions (tons/year) in 2040	
	NOx	$PM_{2.5}$
EPRI, 2020 (South Coast 1.33 km domain)*	19,000**	5,000**
Current study	26,000 (Reference case) 19,000 (Scenario 1)	4,500 (Reference case) 4,100 (Scenario 1)

* A scenario that meets California's economy-wide decarbonization targets of 40% by 2030 (relative to 1990 levels) and 80% in 2050
**Interpolated from the 2030 and 2050 estimates

ACT regulation

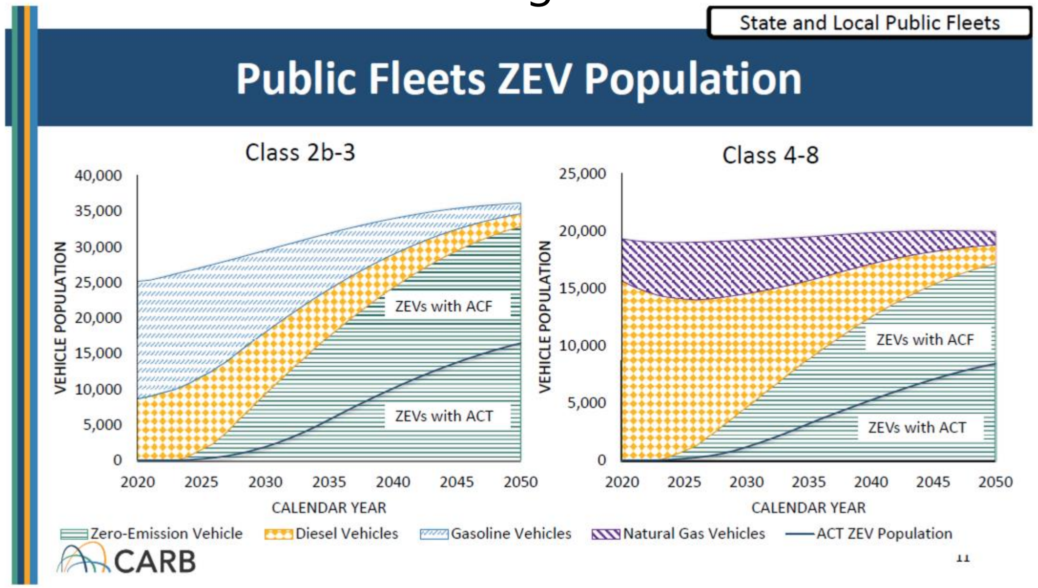
- Zero-emission truck sales: Manufacturers who certify Class 2b-8 chassis or complete vehicles with combustion engines would be required to sell zero-emission trucks as an increasing percentage of their annual California sales from 2024 to 2035. By 2035, zero-emission truck/chassis sales would need to be 55% of Class 2b – 3 truck sales, 75% of Class 4 – 8 straight truck sales, and 40% of truck tractor sales.

https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet

ACF regulation

- Phase-in zero emission trucks and buses 2023 to 2045*
  - State and local government fleets
  - High priority private fleets and federal agencies
  - Drayage trucks serving ports and railyards

Example with the state and local government fleets



Source: http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2022-air-quality-management-plan/carb-epa-presentations---hd-trucks-03-24-21.pdf?sfvrsn=8