ZEV Routing and Fleet Size Minimization for Drayage Operations

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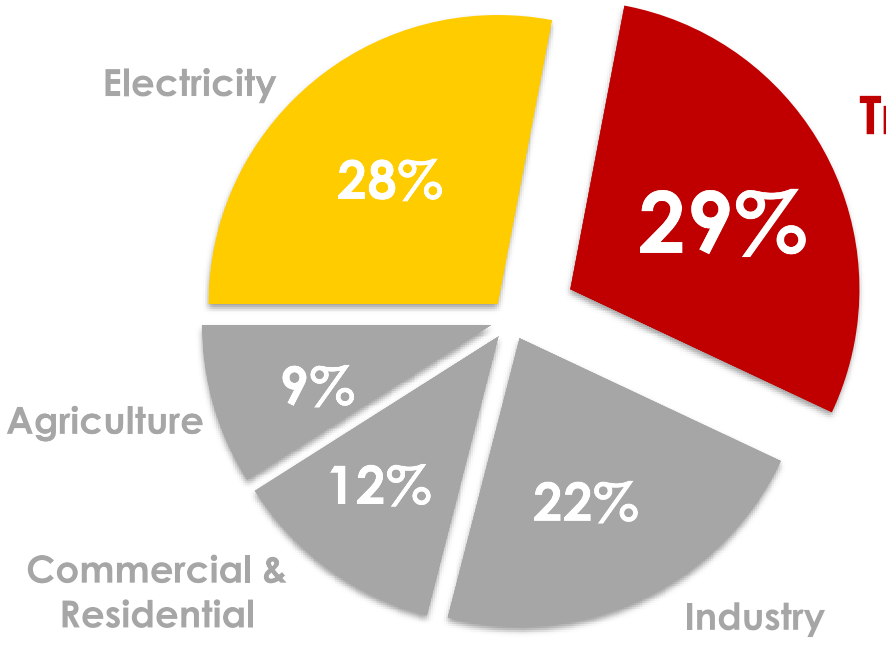
OUTLINE

- Background & Motivation
- Problem Description
- Models & Algorithms
- Data Description
- Numerical Results
- Conclusions

BACKGROUND & MOTIVATION

Total U.S. Greenhouse Gas Emissions by Economic Sector in 2017



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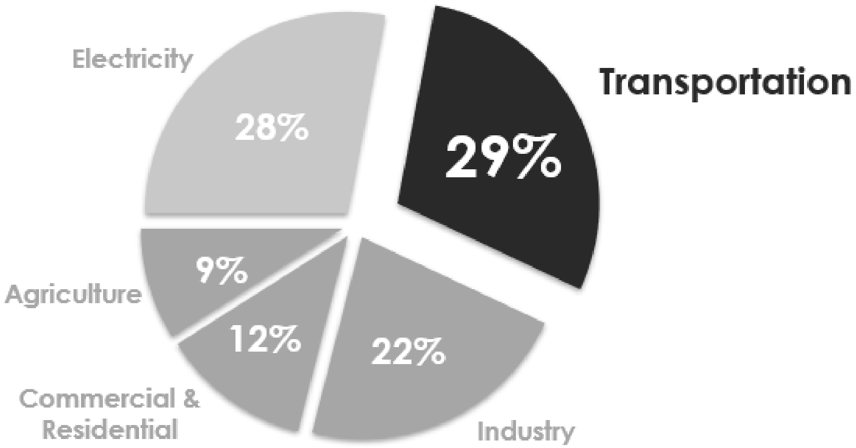
Data from *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017*

BACKGROUND & MOTIVATION

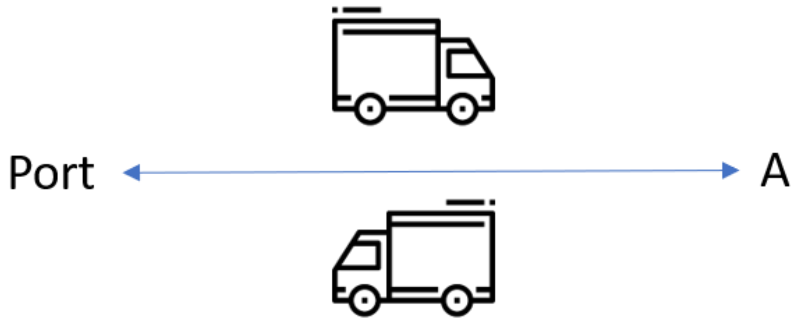
Total U.S. Greenhouse Gas Emissions by Economic Sector in 2017

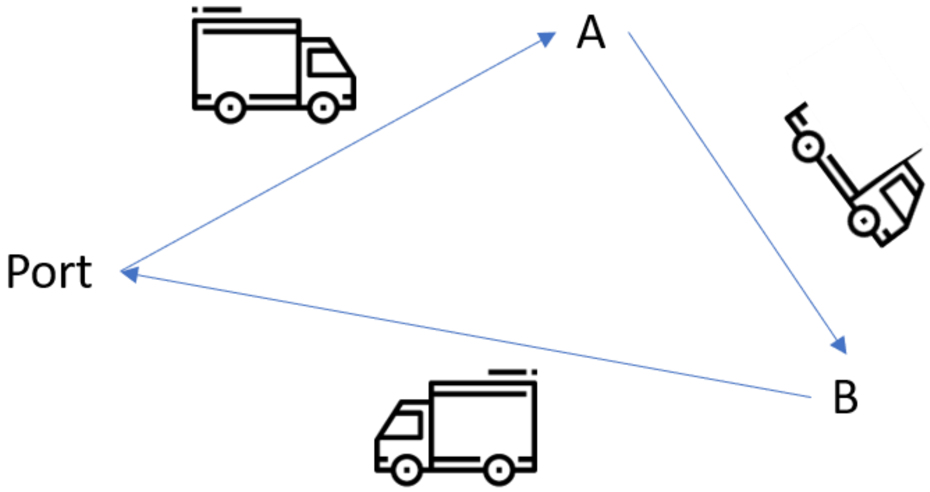


Zero Emission Vehicles In Drayage Operations

APPLICABLE?

PROBLEM DESCRIPTION





Types of Trips Allowed in Our Drayage Operations

PROBLEM DESCRIPTION

- For each trip, all trucks must start from the port and then return to the port.
- Demands are in the form of the number of containers and they only exist between the port and the other locations. The containers are either fully loaded or empty.
- All trucks operate under three different states: carrying no container, carrying an empty container or carrying a fully loaded container.
- Trucks have different power consumption rates for each different operating states. Diesel - miles per gallon (mpg) values | ZEV - battery consumption rates
- All ZEVs are battery powered and the charging stations are installed within the port.
- There are no refueling detours for any truck because fueling stations are pervasive for diesel trucks and ZEVs charge at the port.

MODELS & ALGORITHMS

Minimize Total Miles Travelled
Minimize Fleet Size to Satisfy the Demand

Minimum cost circulation problem

- Input – container demand and supply at each location
- Output – vehicle trips that start and end at the port

→

Bin-packing problem

- Input – vehicle trips
- Output – number of vehicles needed
- Heuristic, not optimal solution

MODELS & ALGORITHMS

- **Minimum Cost Circulation Problem**
  - Formulate into a linear programming problem
  - Feed into standard LP solver to solve it optimally
- **Bin-packing Problem**
  - Adapt a subset sum algorithm
  - A heuristic algorithm with fast speed and good solution quality

Algorithm 1 Subset sum algorithm

$U \leftarrow N$
$k \leftarrow 1$
while $U \neq \emptyset$ **do**
  $T_k \leftarrow \arg\max_{P \subseteq U} \{\sum_{i \in P} d_i : \sum_{i \in P} d_j \leq k_F\}$
  $U \leftarrow U \setminus T_k$
  $k \leftarrow k + 1$
end while
return $T_1, T_2, \ldots, T_{k-1}$

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Subset sum algorithm from: *David Pisinger and Paolo Toth. Knapsack problems. In Ding-Zhu Du and Panos M. Pardalos, editors, Handbook of Combinatorial Optimization, pages 299–428. Kluwer Academic, 1998.*

DATA DESCRIPTION

- POLA & POLB Survey Data 2010-2012
- Contains origin and destination pairs for container demands
- 10 representative days are selected to generate average daily demand
- 135 empty containers | 176 loaded containers | 94 locations

NUMERICAL RESULTS

Diesel Truck

- Estimated refueling time – 0.25 h
- Tank capacity – 226 gallons
- MPG under different states – 8 | 7 | 5 mpg

Speed

- Short distance average speed –20 miles/h
- Long distance average speed – 45 miles/h
- Long distance criteria – > 5 miles of radius

ZEV Truck

- Charging time – 3 hrs for 0-80% and 2 hrs for 80-100%
- Charging pattern – 0-20% is left unused
- Battery capacity, Battery consumption rate and Vehicle range under the different states – next slide

Others

- Truck daily operation time limit – 8 hrs
- Truck refueling detours – None
- Distance increase factor – 1.25

NUMERICAL RESULTS

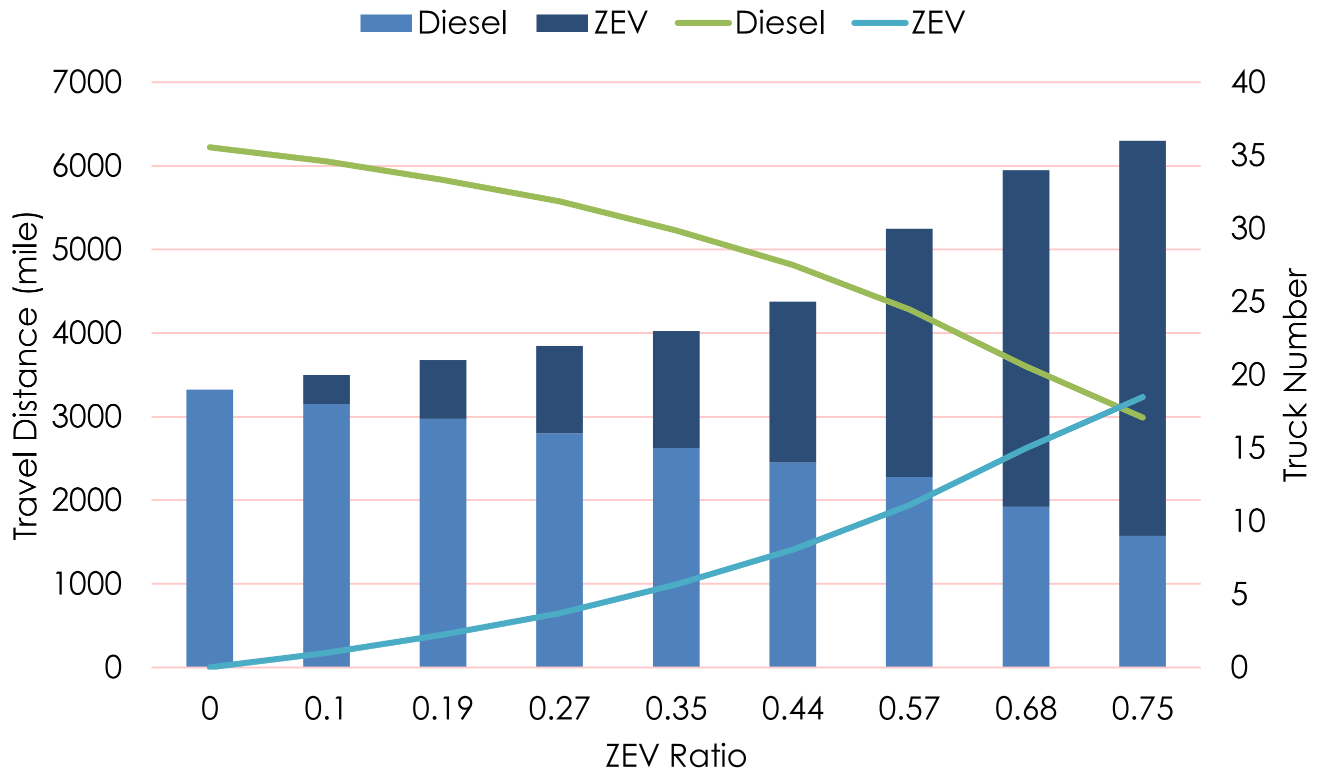
Battery Information for different years

Year	Consumption Rate with Fully Loaded Container (kwh/mile)	Consumption Rate with Empty Container (kwh/mile)	Consumption Rate with No Container (kwh/mile)	Battery Capacity (kwh)
Present	4	2.82	2.4	240
2025	3.37	2.1	1.6	525
2030	3.18	2.01	1.5	650

Year	Fully Loaded Container (mile)	Empty Container (mile)	No Container (mile)
Present	60	85	100
2025	156	250	328
2030	204	323	433

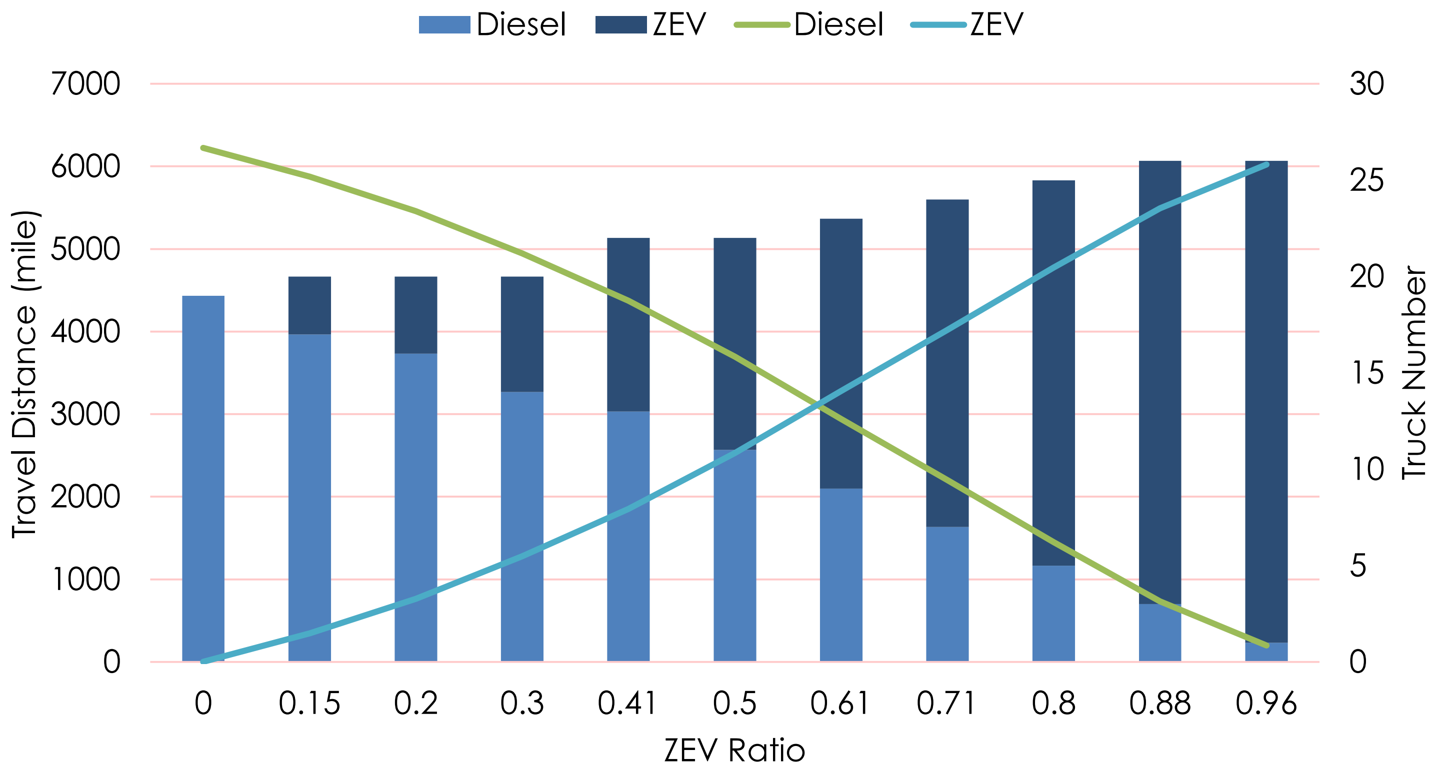
ZEV ranges for different years

NUMERICAL RESULTS



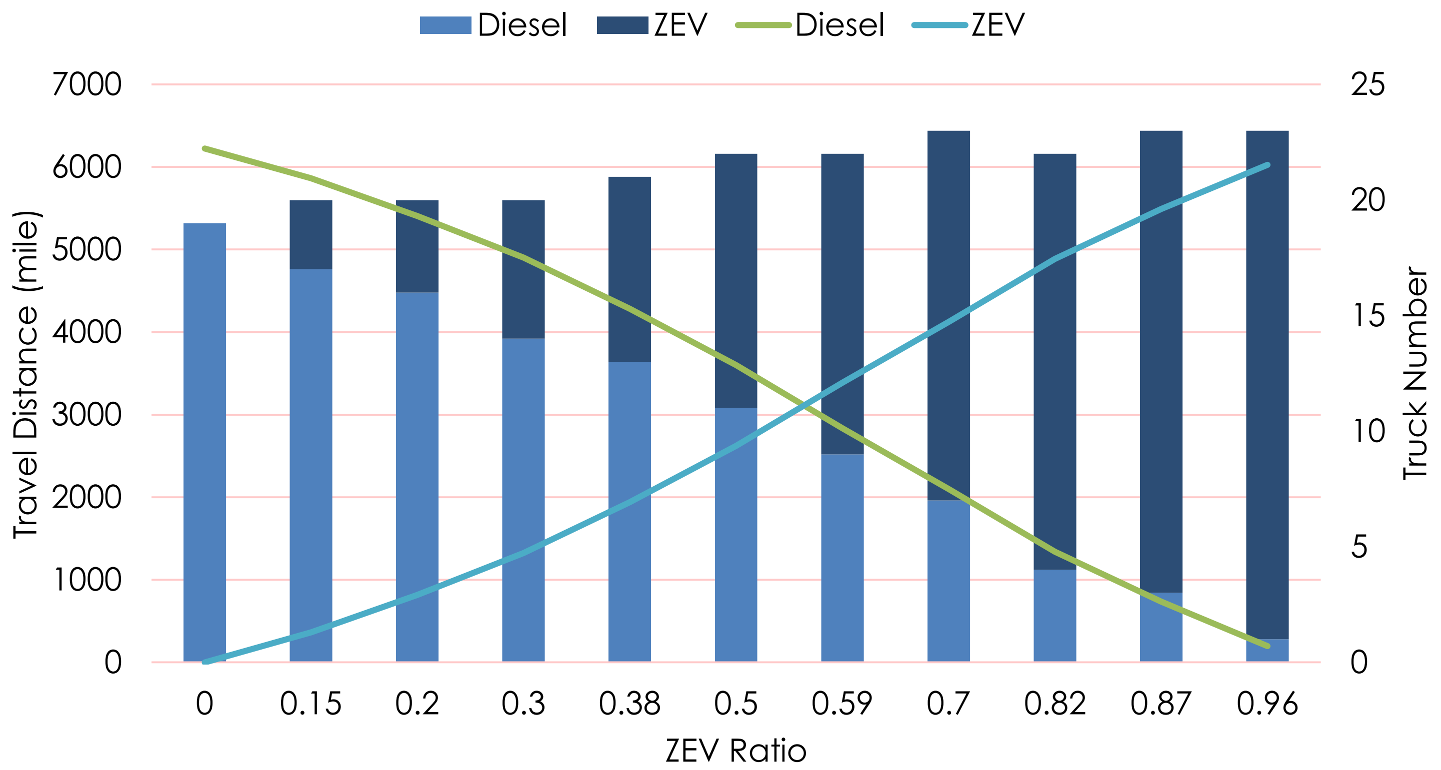
Distances and Fleet Size under Different ZEV Ratios – Present Year

NUMERICAL RESULTS



Distances and Fleet Size under Different ZEV Ratios – Year 2025

NUMERICAL RESULTS



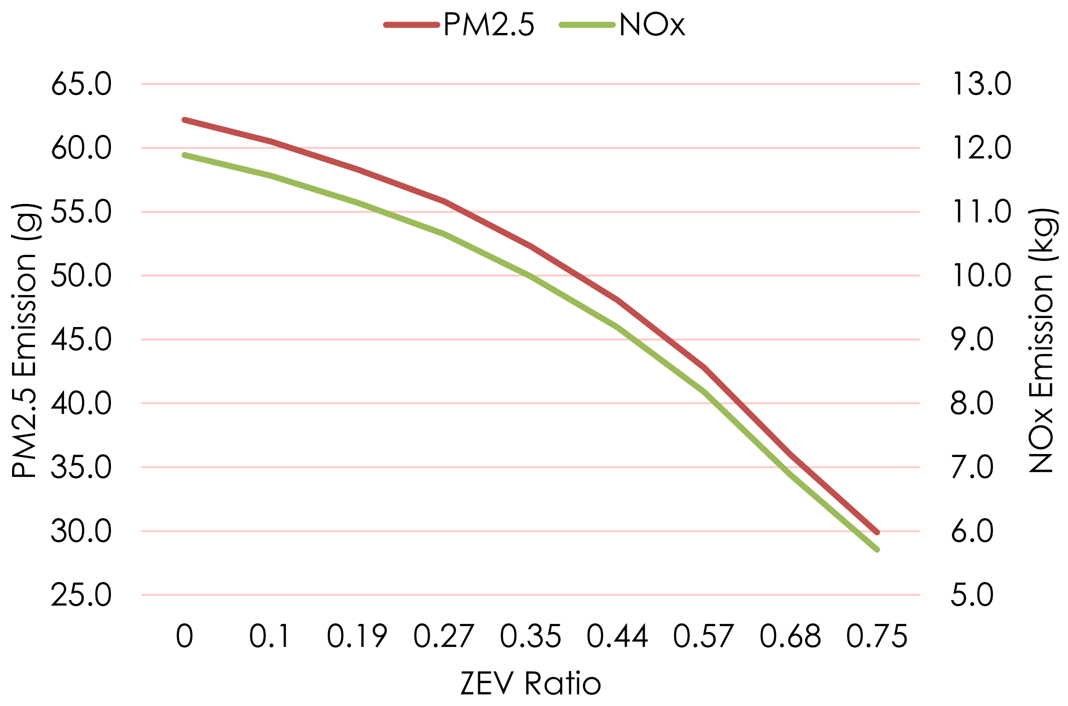
Distances and Fleet Size under Different ZEV Ratios – Year 2030

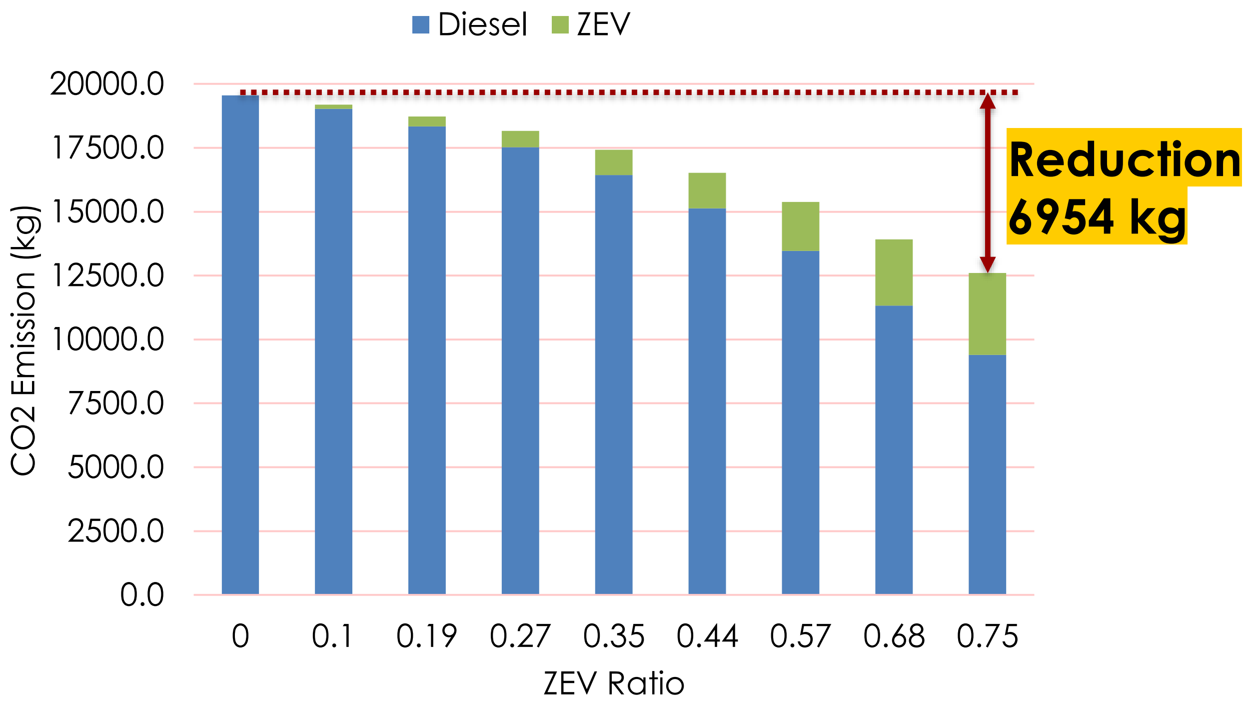
NUMERICAL RESULTS – Emissions

Vehicle Technology	Criteria Pollutant Emissions $PM_{2.5}$ (g/mile)	NO_x (g/mile)	CO2 Emissions CO2 (g/mile)	CO2-TOU (g/mile)
Diesel Present	0.01	1.91	3143.2	N/A
Diesel 2025	0.005	0.96	2781.6	N/A
Diesel 2030	0.005	0.96	2494.6	N/A
ZEV Present	0	0	992.0	966.0
ZEV 2025	0	0	932.0	907.0
ZEV 2030	0	0	871.0	848.0

Emission Rates for Diesel Trucks and ZEVs

NUMERICAL RESULTS – Emissions





Estimated Emissions for Diesel Trucks and ZEVs – Present Year

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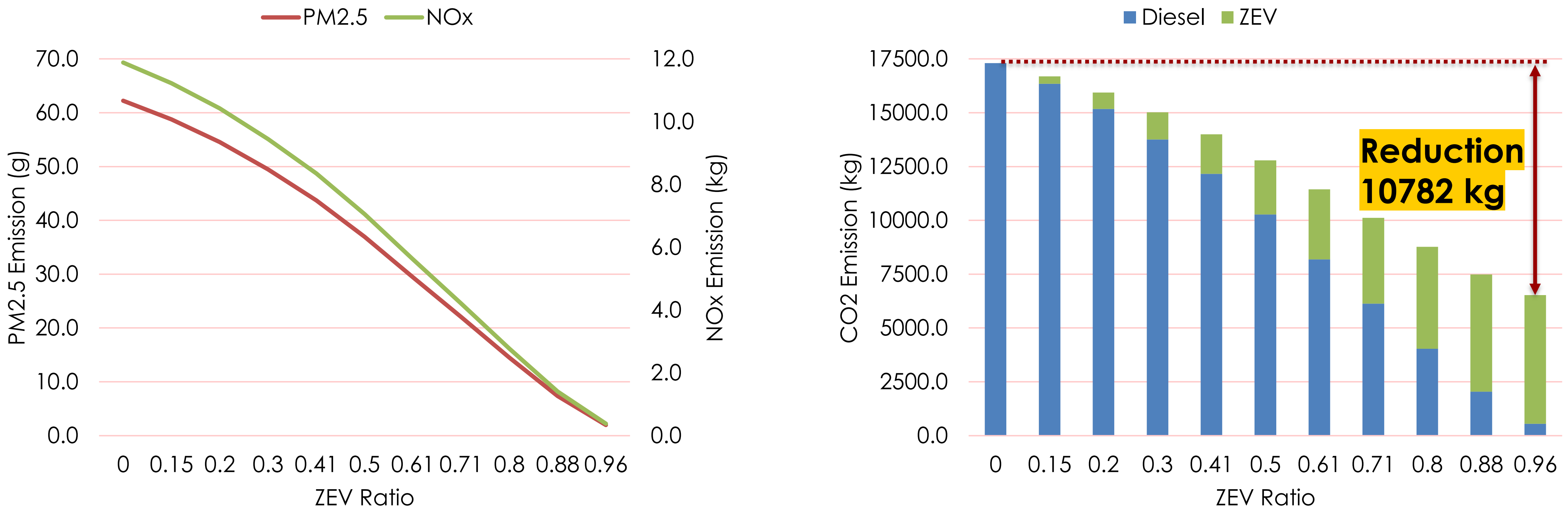
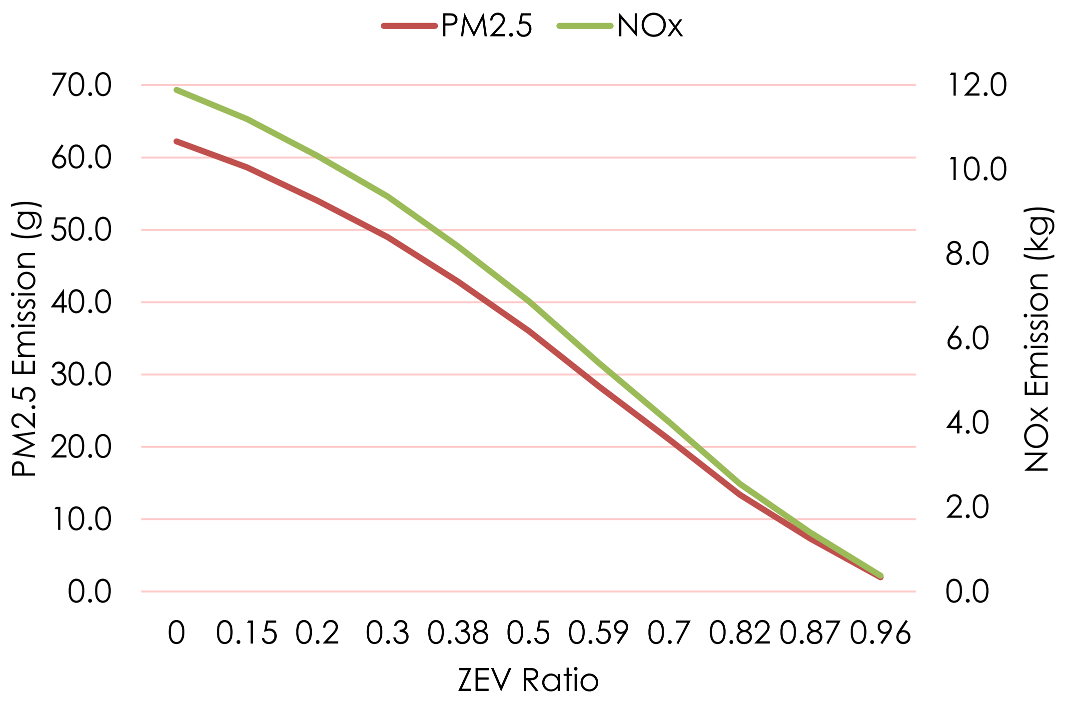
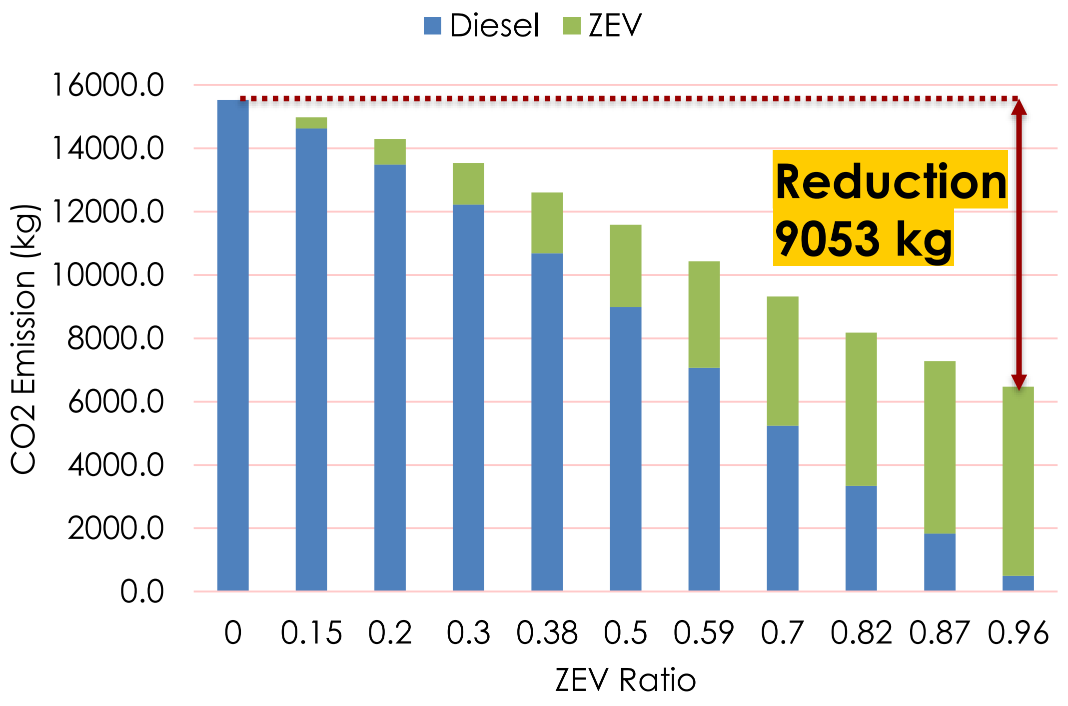
NUMERICAL RESULTS – Emissions



Estimated Emissions for Diesel Trucks and ZEVs – Year 2025

NUMERICAL RESULTS – Emissions





Estimated Emissions for Diesel Trucks and ZEVs – Year 2030

CONCLUSIONS

- With today's battery technology and assuming charging only occurs at the depot, the driving range is not sufficient to cover all the demand and there is still a need to maintain a diesel fleet.
- With more efficient battery technology projected for Years 2025 and 2030, the performance of the ZEVs significantly improves: average number of trips for the ZEVs increases, the charging time reduces significantly.
- Replacing diesel trucks with ZEVs in drayage operations can eliminate PM2.5 and NOx emissions by diesel trucks. The reduction in CO2 is quite significant.

THANKS

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