Revisiting Tire Wear Emissions from On-road Vehicles in MOVES4 in a Vehicle Electrification Era

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Exhaust emission reductions highlight TWP as a source of major concern

Non-exhaust particulate matter (PM) emissions are gaining focus as stricter exhaust regulations and vehicle electrification reduce exhaust PM as well as brake wear through regenerative braking in electric vehicles (EVs). Consequently, tire wear particles (TWP) have become a significant component of traffic PM emissions, particularly from EVs as EVs are heavier than gasoline vehicles due to battery weight.

Exhaust emissions are declining, while TWP emissions are gradually increasing.

- Stricter exhaust regulations and the growth of EVs are significantly reducing exhaust emissions.
- Regenerative braking in EVs significantly reduces brake wear PM.

There is an urgent need to accurately quantify tire wear emissions from on-road vehicles.

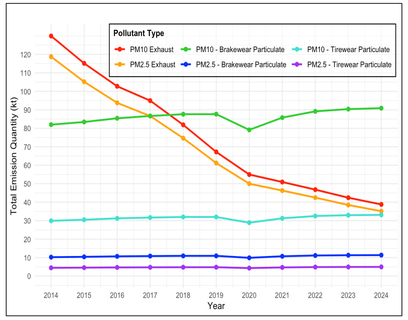


Fig.1 Total emission quantity of different pollutants based on MOVES4

Two areas where MOVES requires updates

Recent studies found a linear relation of TWP PM emissions with vehicle weight.

- EVs are heavier than gasoline vehicles due to large battery packs.
- On average, EVs weigh 43% more than gasoline cars.
- The 43% weight increase suggests a proportional rise in tire wear PM emissions.

Based on that, we suggest two areas where MOVES need an update

- **The assumption of fixed TWP PM_{10} to $PM_{2.5}$ ratio.**
- **More tire wear PM due to extra weight of EVs.**

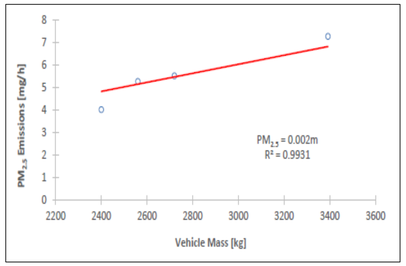
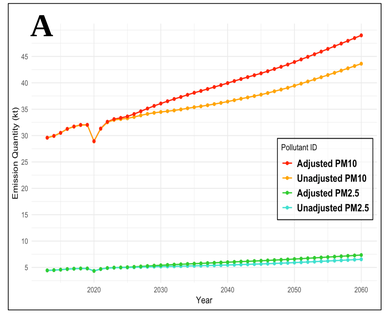


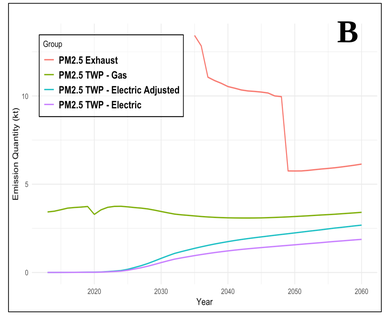
Fig. 2 $PM_{2.5}$ emissions as a function of vehicle mass for all-season tires (**Zhang et al., 2024**).

In this work, we revisited several key assumptions of MOVES:

- Incorporated adjusted EV weights into MOVES4 simulations.
- Projected TWP emissions for the next 40 years using updated parameters.
- Reassessed the PM_{10} to $PM_{2.5}$ ratio of TWPs from our on-road sampling.
- Revisited the correlation of TWP PM emissions with vehicle speed.

Projected increase in TWP emissions from EVs for the next 40 years





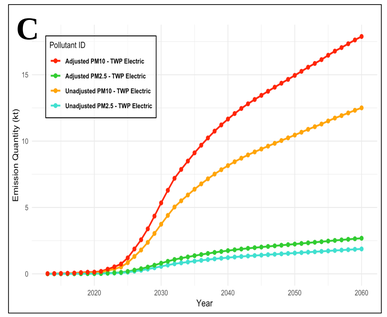


Fig. 3-A Comparison of TWP $PM_{2.5}$ and PM_{10} emissions for all vehicles.

Fig. 3-B $PM_{2.5}$ emissions from different sources for the next 40 years.

Fig. 3-C TWP emissions from electric vehicles for the next 40 years.

The adjusted weight of electric vehicles was used as an input parameter of MOVES4 for projecting TWP emissions for the next 40 years.

On-road TWP sampling at different speed

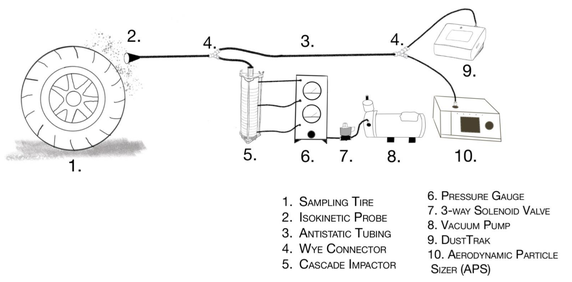


Fig. 4 Schematic of instrumental setup for on-road sampling

We equipped a vehicle with all the instruments shown in the schematic and conducted TWP measurements.

- Sampling location: Kentland Farm, Blacksburg, VA
- Tire details: Hankook H436 255/65R18
- Vehicle used: Ford Explorer
- Instrument used: Aerodynamic Particle Sizer (APS), DustTrak, Cascade impactor, and GPS data logger
- Sampling details: Sampling at 10, 20, 30 and 40mph speed

Update TWP PM_{10} to $PM_{2.5}$ ratio from on-road sampling

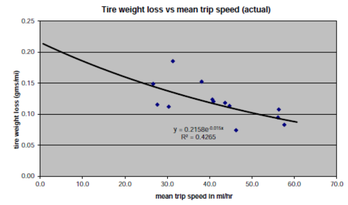


Fig. 5 Relationship between light-duty tire weight loss (per vehicle) and mean trip speed from MOVES3 and MOVES4

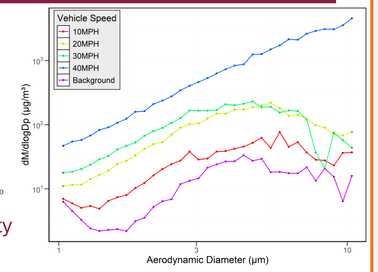


Fig. 6 TWPs size distribution at different speed from on-road sampling

The MOVES model assumes higher TWP emissions at lower speeds. However, our on-road sampling yielded the opposite trend.

- We identified an average PM_{10} to $PM_{2.5}$ ratio of 10.7, in contrast to the value of 6.67 used by the MOVES4 model
- PM ratio decreases at lower speeds and increases at higher speeds.

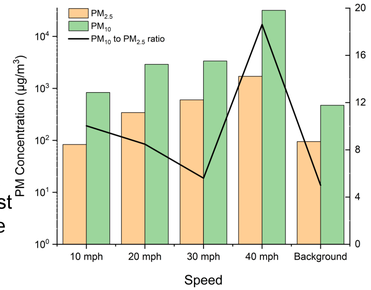


Fig. 7 PM_{10} to $PM_{2.5}$ ratio at different constant speed

Conclusions

- The increased weight of electric vehicles should be accounted for, and the corresponding TWP emissions from EVs should be revised in the updated MOVES model.
- The TWP PM_{10} to $PM_{2.5}$ ratio in the MOVES model should be updated based on the on-road TWP measurements.
- Relationship between PM TWP emissions and mean trip speed should be revisited in MOVES.

References

1. Zhang, Q. et al., 2024. Direct measurement of brake and tire wear particles based on real-world driving conditions. Science of the Total Environment, Volume 906.
2. USEPA (2023) Motor Vehicle Emission Simulator: MOVES4. Office of Transportation and Air Quality. US Environmental Protection Agency. Ann Arbor, MI. August 2023.

Acknowledgments

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