

A Study of Emissions of Electric Vehicles, Preliminary Results

Rahim Khoie*, Divyanshu Trivedi, and Grace Hamada
School of Engineering and Computer Science
University of the Pacific
Stockton California, U.S.A.
*rkhoie@pacific.edu

Abstract: This study develops an energy consumption model for driving an electric vehicle (EV) by integrating speed-dependent forces acting on the moving car including inertia, rolling resistance, and drag components. This model enhances the physical realism of the simulation, especially at both lower and higher speeds. The model is then used to estimate the CO₂ emissions for Tesla Model 3 and Ford Mustang Mach-E in two contrasting U.S. states: California (with significant renewable components in its electricity energy portfolio) and North Dakota (with significant coal used in its electricity generation).

Our results show that at 80 km/h, the Tesla Model 3 produces 41 g-CO₂/km in California, 88 g-CO₂/km under the U.S. average grid, and 185 g-CO₂/km in North Dakota. The Ford Mach-E, due to greater mass and consumption, produces 47–215 g-CO₂/km over the same regions. For comparison, gasoline vehicles are modelled using the EPA average factor of 139.2 g-CO₂/km, based on typical fuel economy of 6.0 L/100 km given by U.S. Environmental Protection Agency ([EPA 2018](#)).

Keywords: Emissions, Electric Vehicles, Speed Modeling

1. Introduction

With the global push for decarbonization, quantifying the carbon emissions of electric vehicles (EVs) under realistic operating and grid conditions has become an increasingly urgent concern. Several notable studies have sought to evaluate and compare the emissions of EVs with internal combustion engine vehicles (ICEVs), particularly under varying regional electricity generation fuel mixes. While these studies have offered valuable insights, their findings often diverge significantly sometimes by over 100% largely due to differences in assumptions, modeling scope, and input data. Here we present a realistic physical model for studying the emissions of electric vehicles for different driving conditions in locations with different electricity energy portfolios.

0. Modeling Speed-Dependent Energy Consumption and Emissions

In our model we consider three main forces acting on the vehicle, namely inertia, road friction, and air resistance, all three of which having velocity dependence as given by:

$$F_{total}(v) = F_{inertia} + F_{rolling} + F_{drag} \quad Eq. (1)$$

Where $F_{inertia}$ is the force required to overcome the vehicle's inertia. In our model we use a velocity-dependent coefficient, $C(v)$, which takes into account the fading of this force as the vehicle goes from rest to steady-state speed as given by:

$$C(v) = \left(0, 1 - \left(\frac{v}{100}\right)^2\right) \quad Eq. (2)$$

Where v is velocity, and $C(0)$ is 1 (maximum inertia force at the start of acceleration from rest state) and $C(100)$ is 0 (no inertia force at speeds higher than 100 km/h). With that, the $F_{inertia}$ is given by:

$$F_{inertia} = m a C(v) \quad Eq. (3)$$

Where m is mass of the vehicle and a is its acceleration.

$F_{rolling}$ is the force required to overcome the friction between the road and the tires. Using $C_r(v)$, a velocity-dependent coefficient, this force will have a mild dependence on the speed, and is given by:

$$F_{rolling}(v) = mg C_r(v) = mg (C_{r0} + \alpha v) \quad Eq. (4)$$

Where g is the gravitational acceleration (9.81 m/s^2), C_{r0} is the base rolling resistance coefficient (set to 0.012 in this study), and α is a small coefficient, typically 10^{-5} to 10^{-4} per km/h.

F_{drag} is the force required to overcome the air resistance, which increases with the square of velocity as given by (Anderson 2016):

$$F_{drag}(v) = \frac{1}{2} A \rho C_d v^2 \quad Eq. (5)$$

Where A is the frontal area (m^2) of the vehicle, ρ is the air density (1.225 kg/m^3), C_d is Drag coefficient and v is the speed (m/s) of the vehicle.

With all forces acting on the vehicle, the energy consumption, E , can now be determined simply by:

$$E = E(v) = \frac{F_{total}(v) d}{\eta(v) 3600} \quad Eq. (6)$$

Where d is the distance travelled by the vehicle in meters and $\eta(v)$ is the drivetrain efficiency which is speed dependent (0.85-0.91)

Note: the coefficient 3600 converts Joules to Wh and m to km so energy E is in Wh/km.

Emissions are then calculated by scaling energy use with grid-specific emission factors and is given by:

$$Emissions \left[\frac{gCO_2}{km} \right] = E \left[\frac{Wh}{km} \right] \frac{EF_{grid} \left[\frac{gCO_2}{kWh} \right]}{1000} \quad Eq. (7)$$

Where $E[\frac{Wh}{km}]$ is the energy given by Eq. 6 and EF_{grid} is the grid average emissions factor in units of $[\frac{gCO_2}{kWh}]$. The EF values for California is $210[\frac{gCO_2}{kWh}]$ and for North Dakota is $950[\frac{gCO_2}{kWh}]$ (EPA 2022). For comparison, the emissions of gasoline cars are estimated from:

$$CO2\ Emissions = Fuel \left(\frac{L}{100km} \right) * 23.2 \quad Eq. (8)$$

Where L is litres of gasoline consumed and 23.2 is number of gCO_2 per litre of gasoline per km.

1. Results

To verify the validity of our model, we first produced results for energy consumption as a function of speed as shown in Fig. 1. The input data including various parameters of the cars as well as constants used in our model are reported elsewhere. (Khoie, 2026). These results have similar trends with actual data reported by (Galvin 2017).

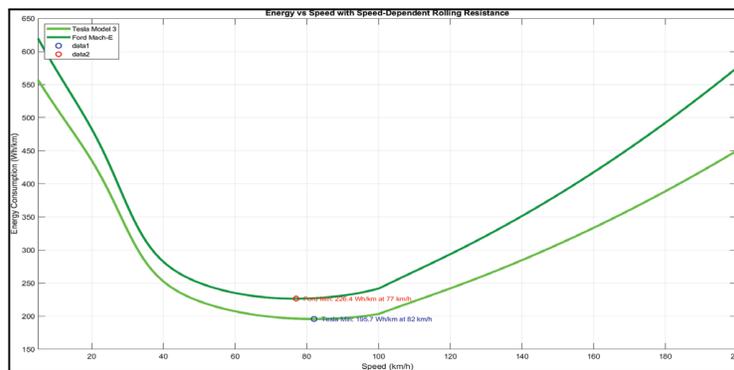


Figure 1: Energy consumption versus speed for Tesla Model-3 and Ford Mach-E.

Fig. 2 shows emissions results for Tesla Model 3 and Ford Mach-E for three different driving conditions using electricity generated in California. Also shown in Fig. 2 are the emissions of a similar ICE vehicle. In all three driving conditions (city at 30 km/h, highway at 120 km/h, and mixed at 60 km/h) the EVs in California have significantly less emissions than gasoline cars. This is due to significant renewable electricity generated in California (with emission factor of 210 g-CO₂/kWh).

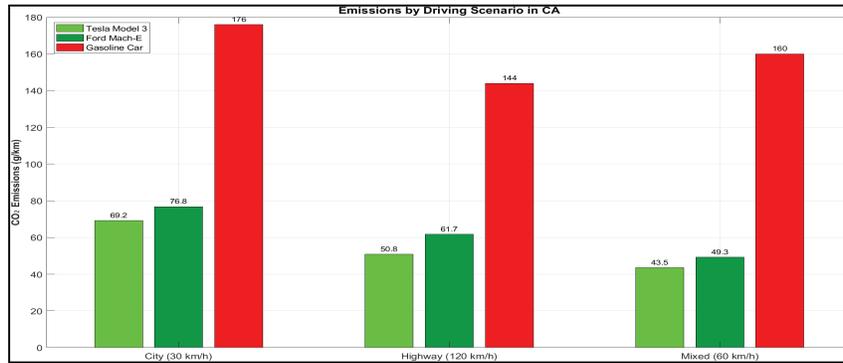


Figure 2: Emissions of EV and Gasoline cars for city, highway, and mixed driving conditions in California.

Fig. 3 shows emissions results for Tesla Model 3 and Ford Mach-E for three different electricity fuel mixes of California, North Dakota, and the average U.S. (under driving condition of 80 km/h in all three). While with California and average U.S. electricity fuel mixes, EVs produce less emissions, their emissions in North Dakota (with emission factor of 950 g-CO₂/kWh) are significantly higher than gasoline ICE vehicle.

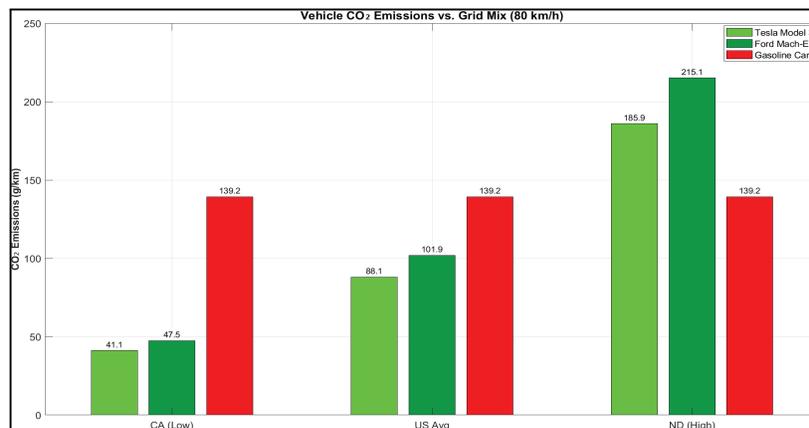


Figure 3: Emissions of EV and ICE for electricity fuel mix in California, Average U.S., and North Dakota driving at 80 km/h.

2. Conclusion

The biggest take away from our study is that while EV emissions vary depending on driving conditions, they have a much more significant dependence on the fuel mix used to produce the electricity. In the states such as North Dakota, Ford Mach-E at nominal speed of 80 km/h produces 215 g-CO₂/km which is 55% more emissions than gasoline cars. However, if and when electric vehicles are mandated to be charged ONLY by solar panels, the emissions of EVs will then be reduced to single-digit numbers shown in Fig. 4, depending on where the panels are manufactured (Khoie 2024).

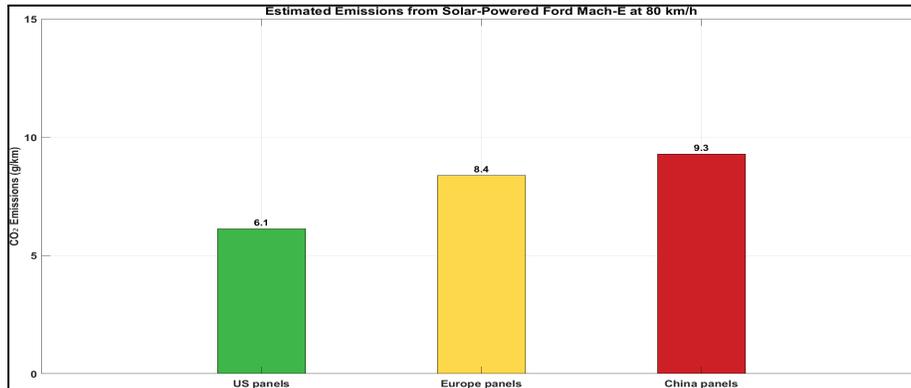


Figure 4: Emissions of Ford Mach-E at 80 km/h with electricity produced from solar panels made in the U.S., Europe, and China

5. Acknowledgments

This work was supported by grants from University of the Pacific’s School of Engineering and Computer Science for creation of Carbon Capture Center for Mitigating Climate Change Crisis C³FMC³.

6. References

Anderson J.D, (2016) *Fundamentals of Aerodynamics*, 6th Edition, McGraw-Hill, New York.

Galvin R, (2017) *Energy Consumption Effects of Speed and Acceleration in Electric Vehicles: Laboratory Case Studies and Implications for Drivers and Policymakers*, Transportation Research Part D: Transport and Environment, vol. 53, pp. 234–248, <https://doi.org/10.1016/j.trd.2017.04.021>

Khoie R and Mueller D (2024) “A Comprehensive Study of Carbon Footprint of Solar Power Generation from Raw Materials to Operation and Maintenance in Various Locations in the United States,” SOLAR 2024, *American Solar Energy Society 53rd National Solar Conference and Summit*, Washington, DC, May 20-23, 2024.

Khoie R (2026) “A Physics-based Model for studying the emissions of Electric Vehicles,” *Clean Technology and Environmental Policy* (2026).

U.S. Environmental Protection Agency (EPA 2018), Greenhouse Gas Emissions from a Typical Passenger Vehicle. <https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle>

U.S. Environmental Protection Agency (EPA 2022). *EPA eGRID Summary Tables 2022 PDF*. https://www.epa.gov/system/files/documents/2024-01/egrid2022_summary_tables.pdf?utm_source=chatgpt.com