HW 2: Energy Demand and CO2 Emissions

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1

Creating a new category combining all buses, single-unit trucks, and combination trucks gives the following:

1.1

The average fuel economy is

Table 1: Average Fuel Economy of HDVs

Year	Fuel economy (mpg)
2020	21.2
2019	20.8

1.2

The CO_2 emissions per mile is given by $\frac{1}{miles/gal} \times \frac{CO_2}{gal} = \frac{CO_2}{mile}$. This gives

Table 2: HDV Fuel Consumption

Year	Fuel economy (mpg)	Fuel consumption (gpm)	Emissions (g CO_2/gal)	Emissions (g CO_2/mile)
2020	21.2	0.0471698	10180	480.1887
2019	20.8	0.0480769	10180	489.4231

1.3

The total CO_2 emissions for all LDVs and HDVs is

Table 3: Emissions of LDVs and HDVs

Vehicle category	Year	Fuel consumed (thousand gallons)	Emissions (g CO_2/gal)	Emissions (g CO_2)	Emissions (M tons CO_2)
ALL LDV	2020	111930145	8887	994723198615000	994723199
	2019	131455731	8887	1168247081397000	1168247081
ALL HDV	2020	46853407	10180	476967683260000	476967683
	2019	48094540	10180	489602417200000	489602417

Calculating the percentage of emissions from HDVs per year:

Table 4: HDV Emissions Proportion

Year	LDV Emissions	HDV Emissions	HDV Proportion
2020	994723199	476967683	0.324
2019	1168247081	489602417	0.295

From this we can see that HDVs made up a greater percentage of CO_2 emissions in 2020 than in 2019.

1.4

Comparing the values I got to the values from the EPS's Greenhouse Gas Emissions Inventory:

Table 5: Comparison to EPA Reported Emissions Values

Year	LDV Emissions	HDV Emissions	Total Emissions (MMT CO_2)	EPA Values (MMT CO_2)
2020	994723199	476967683	1471.691	1627.619
2019	1168247081	489602417	1657.849	1874.291

Though the values from my calculations differ from the EPA reported values, they are not wildly different from each other. They are close enough in my judgement that the difference could largely be explained by things like different measuring procedures.

2

The drive cycle I'm analyzing is the "Fleet DNA drayage Representative" cycle from NREL. The cycle is shown in Figure 1.

I am also using the assumed values in Table 6 for my calculations.

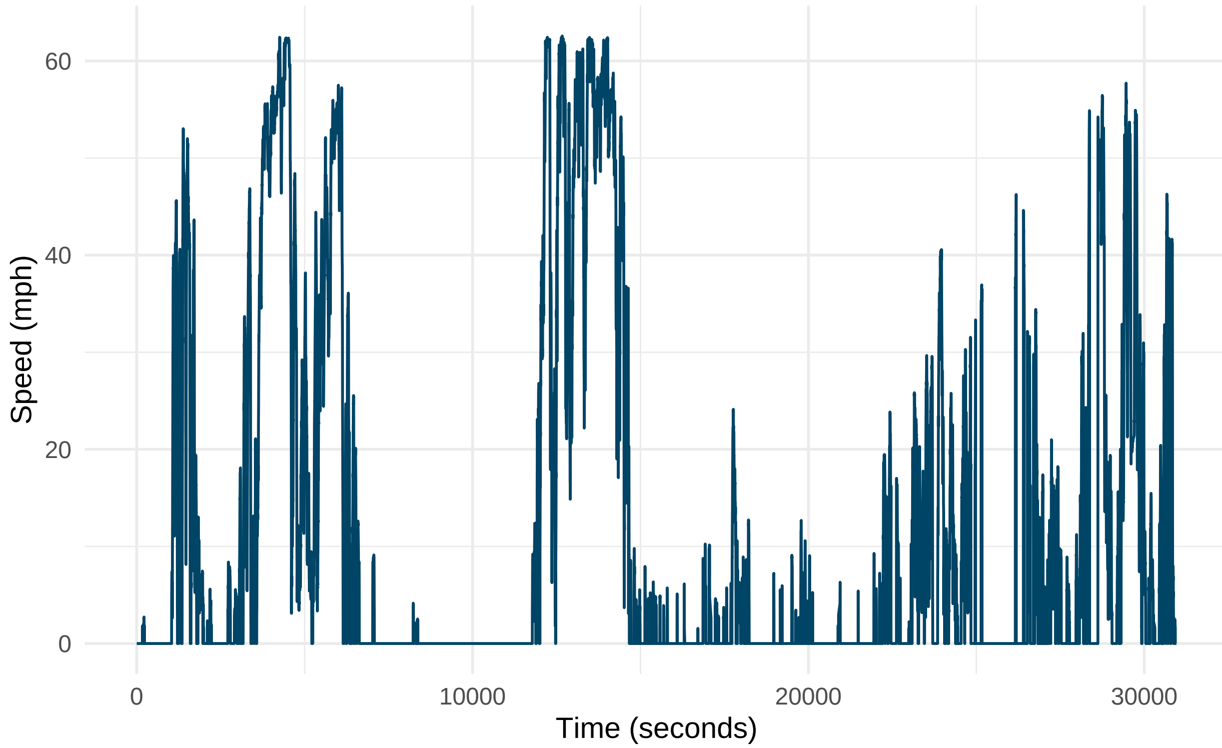

Figure 1: Fleet DNA drayage Representative drive cycle.

Table 6: Assumed Values for Calculations

Coefficient	Symbol	Value
Drag coefficient	C_D	0.6
Frontal area	A_v	8.5 m^2
Empty vehicle weight	m_E	11,000 kg
Cargo weight	m_C	9,000 kg
Rolling resistance coefficient	C_R	0.006
Density of air	ρ_a	1.17 kg/m^3
Acceleration of gravity	g	9.81 m/s^2

2.1

The road-load equation for power is given by

$$P_V = \frac{1}{2}\rho_a C_D A_v v^3 + v\left(C_R m_v g + m_v g \sin\alpha + m_v a_v\right),$$

where $m_v = m_E + m_C$, and $\sin\alpha \approx$ grade (rise/run).

Using this equation, we can calculate the tractive power for each second in the drive cycle. Note that since this is not a hybrid electric vehicle, there is no regenerative braking, and so all negative values of power are set to 0. We also set a limit on acceleration due to speed gaps causing unrealistic values. The limits are $-3.5 < a < 2.5$.

The plot of the tractive power is given in Figure 2.

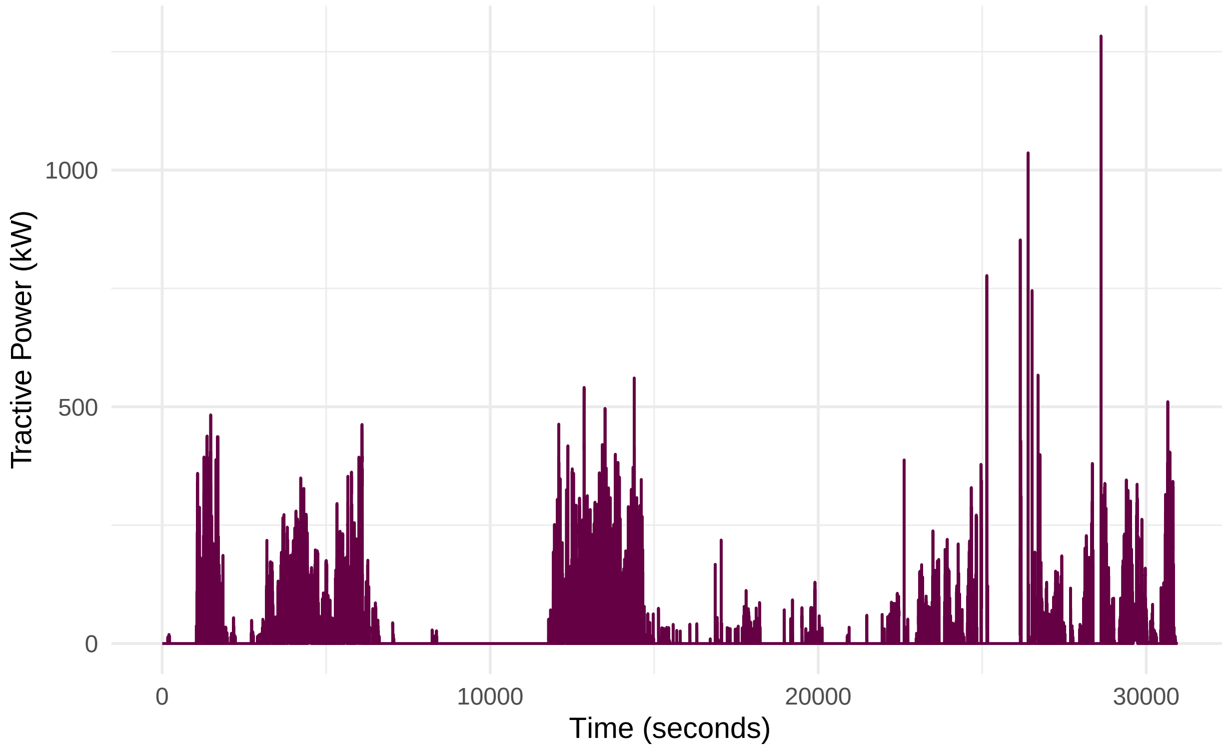

Figure 2: Plot of tractive power for drayage drive cycle.

2.2

A graph of engine power along with tractive power is given in Figure 3. I am using only from 13900 to 14000 seconds for clarity of the graph.

The data generally seem to make sense, as the engine power is often more than the tractive power, which is expected due to losses. Though I am not sure why tractive power sometimes exceeds engine power; it appears to have something to do with the spikes in tractive power, which might be due to some time gaps in the data, or possibly a small temporal offset between the engine and tractive power.

2.3

The total energy required to move the vehicle for this drive cycle is 193 kWh.

2.4

Table 7: Components of Total Tractive Power

	Drag	Rolling	Acceleration	Gravity	Total
Energy (kWh)	52.8	51.7	117.9	29.7	252
%	21.0	20.5	46.8	11.8	100

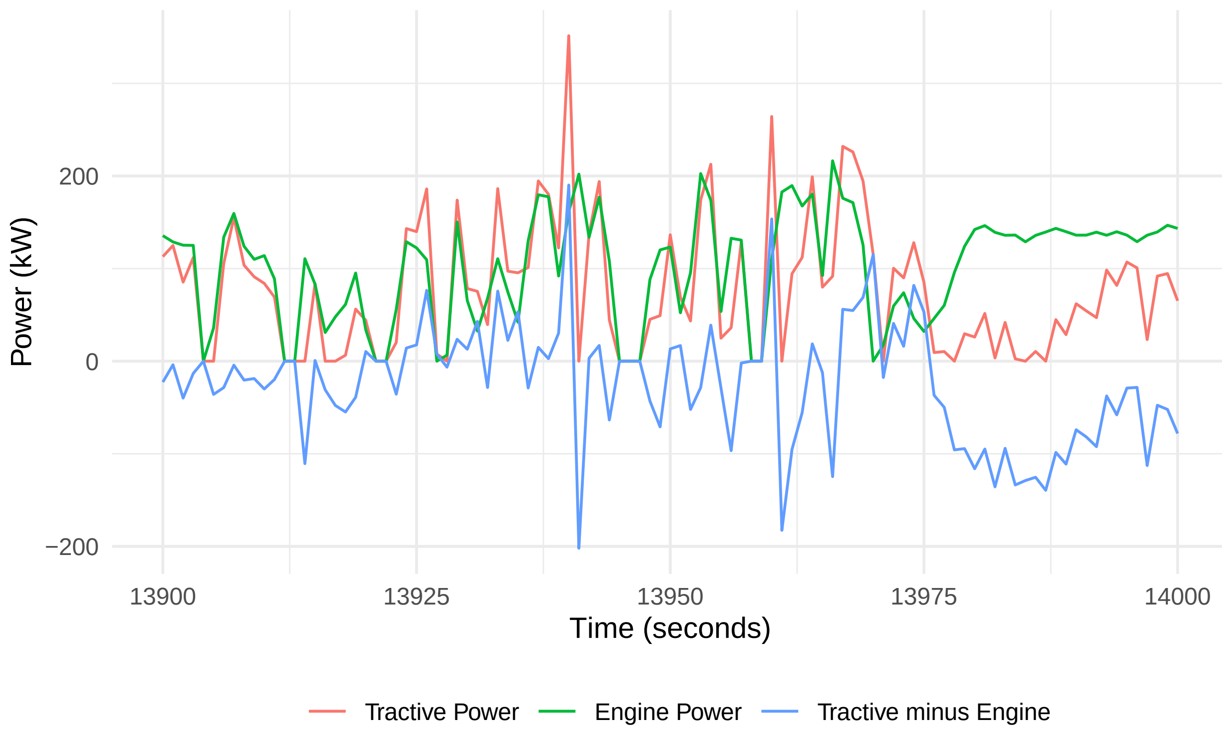

Figure 3: Comparison of engine and tractive power.

2.5

Assuming the "negative" tractive power would be used for regenerative braking, an additional 78 kWh would be available. If 50% of that power was recaptured, then the additional tractive power needed would be reduced to 154 kWh, a reduction of 20.25%.

2.6

Assuming an auxiliary power load of 7 kW, the engine power used to move the vehicle is $P_{Engine} - 7$ kW, but not less than 0 kW. Finding the total energy expended by the engine attempting to move the vehicle gives 218 kWh. The total energy actually required to move the vehicle is 193 kWh, so the efficiency of the drivetrain is 88.5%.

2.7

Low-sulfur diesel has an energy content of 128,488 Btu/gal according to the AFDC. This is equivalent to 37.656 kWh/gal. Assuming an engine efficiency of 0.3, the total fuel needed for this drive cycle is $F = \frac{193[\text{kWh}]/0.3}{37.7[\text{kWh/gal}]} = 17$ gal. The total distance in this drive cycle is 157965 meters or 98.2 miles, giving an overall fuel economy of 5.74 mpg, and a fuel consumption of 174 gallons per 1000 miles.

2.8

The energy required in the regenerative-braking scenario (2.5) is 154 kWh. The fuel needed is now $F = \frac{154[\text{kWh}]/0.3}{37.7[\text{kWh/gal}]} = 14$ gal, with a fuel economy and consumption of 7.19 mpg and 139 gallons per 1000 miles. If this drive cycle (98.2 miles) is representative of a typical day, then at 5 days per week and 52 weeks per year, the fuel saved is 5[days/wk] $\times$ 52[wk/yr] $\times$ $(17 - 14)$[gal] $=$ 901[gal/yr] for each truck. Given a current (26 Sept. 2022) diesel price of $4.889/gal, this amounts to a savings of $4405 per year per truck.

3

From Annual Energy Outlook 2022 Table 40, we get that the 2021 fuel economies of certain vehicle technologies are as follows:

- ICE vehicles: 42.94 mpg
- Hybrid vehicles: 62.51 mpge
- 200 mile range EVs: 101.9 mpge

From the EIA we obtain the emission rate of coal and natural gas energy production:

Table 8: CO_2 Emissions per Kilowatt-hour Produced

Energy Source	Electricity (M kWh)	CO_2 Emissions (M MT)	CO_2 per kWh (kg)
Coal	757763	767	1.012
Natural Gas	1402438	576	0.411
Petroleum	13665	13	0.951

Assuming the electricity used in the EVs is produced from coal and natural gas, we can calculate an average of the two emission rates. By summing the total emissions and total energy generated, we find that the overall emission rate is $\frac{767+576}{757763+1402438} \times 1000 = 0.62$ kg CO_2 per kWh.

3.1

The following table shows information on CO_2 emissions by vehicle type. I am assuming that the emission rate from petroleum electricity generation is similar enough to the rate when using an ICE vehicle to use in these calculations. I am also using a conversion factor of 1 kWh to 0.03 gallons of gasoline.

Table 9: CO_2 Emissions per Mile by Vehicle Type

Vehicle Type	MPG (equiv)	Miles per kWh	CO_2 per kWh (kg)	CO_2 per Mile (g)
ICE	42.9	1.29	0.951	738
Hybrid	62.5	1.88	0.951	507
EV	101.9	3.06	0.622	203

The EV has the lowest emission rate per mile, while the ICE vehicle has the highest. This follows my intuition, as even with the inefficiencies in electricity production EVs are much more efficient per kWh than gas-powered vehicles. The emission rate of the EVs could theoretically fall even further if cleaner electricity sources are used.

3.2

Using the EPA 2020 average of 25.5 mpg and 350 g CO_2/mile for the ICE vehicle, the hybrid vehicle now has the worst emission rate. Though in reality this probably would not be the case; a lower emission rate per gallon of gasoline used would benefit both ICE and hybrid vehicles. It's possible my previous assumption that emissions would be similar between an ICE and petroleum electricity generation is misguided, in which case the numbers I calculated may change significantly.

3.3

Some notable sources of related emissions not included in the previous calculations are: vehicle production, transporting vehicles to dealerships or similar, refining of crude oil into gasoline, and mining operations needed for coal/natural gas.