1 Combustion Cars

To calculate the total energy consumption of a combustion car requires some effort. We start out by calculating the energy needed to move a combustion car one kilometer. This can be easily done by multiplying the energy density $[\frac{kWh}{l}]$ with the typical consumption per kilometer $[\frac{l}{km}]$ of a fuel. Now, we have to consider that the fuel does not simply grow on trees or fall from the sky, but it needs to be produced. This production cost is called the *expended energy* [1] which is measured in watt hours of energy needed to produce one watt hours equivalent of fuel. Another thing to consider is the efficiency of a combustion car stuck in traffic. Start and stop driving can lead to an increase in fuel consumption up to 170%. Since we are not in a traffic jam at all times we assume consumption of 130%. The final result looks like this:

$$E_{Combustion} = \frac{E_{Diesel} + E_{Gasoline}}{2} * \frac{1}{Passengers}$$

$$E_i = 1.3 * (1 + Expended_i) * Density_i * Consumption_i * Distance$$

Substituting the respective values for $i = Diesel, Gasoline$ we get

$$E_{Combustion} = 1.148 \frac{kWh}{km * day} * \frac{Distance}{Passengers}$$

The average fuel consumption is taken from the federal statistical office of Germany(7 and 7.8 liters per 100 kilometers for diesel and gasoline, respectively). The energy densities used are $9.611 \frac{kWh}{l}$ for diesel and $9.5 \frac{kWh}{l}$ for gasoline [2].

2 Electric Cars

For electric cars the energy cost depends heavily on the model you have, in which environments you use it and at what speed you drive. Here, we use real-world data. From our own measurements, we get a real-world energy consumption of around 16 kilowatt hours per 100 kilometers with energy losses during charging of 4.5%:

$$E_{Electric} = 0.167 \frac{kWh}{km * day} * \frac{Distance}{Passengers}$$

3 Bus

The Régime Général des Transports Routiers (RGTR) claims half of the kilometers traveled by bus in Luxembourg will be realized by electric vehicles by 2025. Similarly, we will assume that one-half of the traveled distance will be made by combustion and the other by electric buses. The fuel consumption of a long-distance diesel bus is 25 liters of Diesel. With an average temperature between 5 and 10 degrees Celsius in Luxembourg we get an energy consumption between 1 and 1.5 kilowatt hours per kilometer, where we take a slightly higher than average estimation of 1.3 kilowatt hours because of a higher occupancy than in the source study.[3] Furthermore, we again assume an increase in fuel to 130% due to traffic as well as grid losses during the charging process of 4.5%. Lastly, modern busses, like the Mercedes-Benz O 530 Citaro, have a capacity of 158 people. Assuming 40% occupancy we get around 63 people per bus. putting everything together we get:

$$E_{Bus} = \frac{0.5 * E_{Combustion} + 0.5 * E_{Electric}}{Passengers} = 0.043 \frac{kWh}{km * day} * Distance$$

4 Tram

The energy consumption of the Luxembourg tram is given as 3.93 kilowatt hours per kilometer by the manufacturer. In 2023, 28.7 million passengers used the tram system[4]. If we divide this by the number of trams that run between Luxexpo and Lycée Bouneweg (according to the schedule), we get roughly 185 passengers per tram. Note that this assumes that these 185 would travel the whole way, which is of course unrealistic. Therefore:

$$E_{Tram} = \frac{3.93 \frac{kWh}{km}}{185} * \frac{Distance}{day} = 0.021 \frac{kWh}{km * day} * Distance$$

5 Train

The Luxembourg railway system is completely electrified. The trains have a relatively low average speed of slightly more than 50 kilometers per hour.

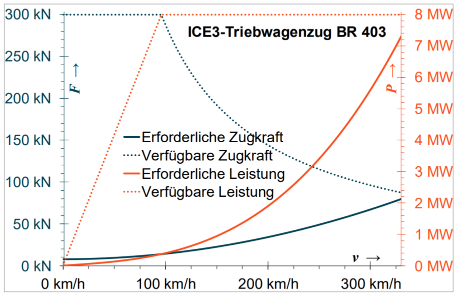

Figure 1: Traction power and drive power required to transport an ICE train consisting of 9 cars on a flat route and at a constant speed

From figure 1[5], we take that moving a train at 50 kilometers per hour requires 129 kilowatts, resulting in an energy consumption of 2.58 kilowatt hours per kilometer. For this calculation, we assume a slightly higher value of 2.7 kilowatt hours per kilometer to include acceleration costs after each stop. The CFL reported that they had 28.7 million passengers in 2023. By summing up all trains that drive on Lines 10, 30, 50 and 60 (taken from the weekly timetable), we get a total number of around 194000 train journeys. The ratio of these two results in roughly 150 passengers per train. Therefore:

$$E_{Train} = \frac{2.7\frac{kWh}{km}}{150} * \frac{Distance}{day} = 0.018\frac{kWh}{km * day} * Distance$$

6 E-Bike

The estimated energy consumption is around $0.01\frac{kWh}{km}$, which is on the upper end of what manufacturers state. Although this would currently be the cheapest form of transportation in terms of energy, using an exceptionally full bus or train would still be more efficient compared to the E-Bike.

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