# Methods in Transportation Econometrics and Statistics (Master)

## Winter semester 2023/24, Tutorial No. 13

### Problem 13.1: Life-cycle assessment (LCA) of internal combustion and battery-electric vehicles

In order to assess and compare the global $CO_2$ "footprints" of a conventional middle-class gasoline/Diesel car (internal combustion vehicle, ICV) and a comparable battery-electric vehicle (BEV),[1] we investigate the three phases of the lifecycle of both types of car (or of any other product): production, driving/operation, and wrecking/recycling. Following materials are needed for the three phases:

#### Both gasoline/Diesel vehicles and BEVs:

1. Steel: 900 kg for the production, 100 kg during driving (spare parts). At wrecking time, 20 % of the steel can be recycled at zero additional emission,
2. Aluminum: 100 kg for the production, nothing relevant during operation, 40 % can be recycled w/o further emission.
3. Plastic: 100 kg (sum during all three phases),
4. Rubber: 30 kg for general parts plus one set of tyres (5 kg per tyre) during production, three further sets of tyres during the lifetime, no useful recycling.

#### Additionally for the gasoline/Diesel vehicles:

5. Lead starter batteries weighting 12 kg: One plus two spares during the lifetime.
6. Fuel consumption: On average 6 liters/100 km during the lifetime of 200 000 km (fuel needed during production is included in the production emission factors, see below).

#### Additionally for the BEVs:

5. Two Lithium driving batteries weighting 300 kg each (there are no starter batteries).
6. Electric energy demand by driving: On average, 20 kWh per 100 km.

[1] There is another type of vehicles with electrical engines, namely fuel cells generating electricity *in situ* out of hydrogen. Therefore we do not simply say "electrical vehicles", or similar.

## The questions

(a) Consider the ICV first and formulate the life-cycle inventory ("*Sachbilanz*") $\vec{y}^s$ for all three phases of the vehicle life.

(b) Calculate the total $CO_2$-emissions $e_1$ (1 stands for the first "pollutant": $CO_2$) using following first line of the emission-fatcor matrix,

$$\vec{C}'_{CO_2} = \vec{C}'_1 = (4, 30, 2, 2, 20, (0.4 + 2.39)\,\text{kg/liter})$$

assuming gasoline as fuel whose emission factor of $C_{16}^{\text{t2w}} = 2.39\,\text{kgCO}_2/\text{liter}$ ("tank to wheel") is derived directly from the chemistry of the oxidation (burning) process, and the contribution $C_{16}^{\text{w2t}} = 0.4\,\text{kgCO}_2/\text{liter}$ ("well to tank") is the emission in the production chain.

Compare the $CO_2$ emissions during production/recycling and during operation. Which one is higher? Also calculate the driving emissions in g $CO_2$per km and compare with the former EU fleet limit of 140 g/km, now sharpened to 95 g/km

(c) Discuss following political action solely from the point of view of $CO_2$ emissions: "Wreck middle-aged and older cars (consumption 10 l/100 km, remaining operational life phase of 100 000 km) and replace them by the same number of (subsidized) new cars (consumption 5 l/100 km)"

(d) Perform the LCA for the BEV assuming for the Li-batteries the same $CO_2$ emission factor of 20 as for the lead batteries and the specific emission factor $c_{1,el} = 480\,\text{g/kWh}$ of German energy mix ("DE mix") in 2018.

(e) Perform a sensitivity analysis by assuming (i) the "China mix" (emission factor 1 000 g/kWh), (ii) the "Norway/Sweden mix" (50 g/kWh), (iii) the DE mix but only one Lithium battery lasting the whole vehicle life.

(f) Calculate the kilometer equivalent of the $CO_2$ emission during production (how many km must be driven to emit the same amount?) for the considered ICV and BEV (DE mix). How many kilometers both the BEV (DE mix) and the ICV must be driven such that the BEV outperforms the ICV regarding total $CO_2$ emissions?