Method for adjusting the utility factor (UF**) and fuel consumption estimates for plug-in hybrid vehicles (PHEVs)**

Plug-in hybrid vehicles (PHEVs) generally operate either in charge-depleting mode or in charge-sustaining mode. In charge-depleting mode, they mostly or exclusively use electricity from the battery to power their wheels (thus depleting the battery over time). In charge-sustaining mode, they use mostly liquid fuel (gasoline or diesel), supplemented by no more electricity than they can recuperate from decelerating (thus maintaining a given battery charging level over time). The fraction of distance that a PHEV operates in charge-depleting mode (using predominantly electricity) is called utility factor (UF).

For the WLTP-based fuel consumption estimates used in the European Union and other locations, the utility factor is estimated as follows (EC 2017; ISI 2021):

$$UF(AER, d_n) = 1 - \exp\left[-\sum_{i=1}^{10} c_i \left(\frac{AER}{d_n}\right)^i\right] \quad (1)$$

where AER is the all-electric range WLTP range, and:

- $d_n = 800\ km$ (for Europe)
- $c_{1..10} = [26.25, -38.94, -631.05, 5964.83, -25095, 60380.2, -87517, 75513.8, -35749, 7154.95]$.

However, research by the Fraunhofer Institute for Systems and Innovation Research (ISI) has shown that the UF estimated using above equation is overly optimistic; i.e., that the real-world UF tends to be lower than the officially estimated UF (ISI 2021). This bias affects the emission estimates of PHEVs. We therefore employ an approach based on the research by ISI to use a more realistic estimate for the UF.

First, we back-calculate the UF for each PHEV vehicle model using equation 1 (since the actual UF is not supplied in the fuel economy certification data).

Second, we calculate electricity consumption in charge-depleting mode ($fc_{\text{el,cd}}$) and fuel consumption in charge-sustaining mode ($fc_{\text{fuel,cs}}$) based on the utility factor from the first step and on the combined electricity and fuel consumption per 100 km that is supplied in the fuel consumption data:

$$fc_{\text{el,cd}} = \frac{fc_{\text{el,combined}}}{uf}$$
$$fc_{\text{fuel,cs}} = \frac{fc_{\text{fuel,combined}}}{1 - uf}$$

Third, we adjust the UF using estimates by ISI by altering coefficient d_n using equation 1:

- Private car: $d_n = 1544\ km$
- Company car: $d_n = 4200\ km$
- Mixed use car: $d_n = 2460\ km$

Fourth and finally, we recalculate the combined (fuel + electricity) consumption for each vehicle using the corresponding adjusted UF.

$$fc_{\text{el,combined,adjusted}} = fc_{\text{el,cd}} \times uf(d_n)$$
$$fc_{\text{fuel,combined,adjusted}} = fc_{\text{fuel,cs}} \times (1 - uf(d_n))$$

References

EC (European Commission); 2017. Commission Regulation (EU) 2017/1151 supplementing Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to

emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information, amending Directive 2007/46/EC of the European Parliament and of the Council, Commission Regulation (EC) No 692/2008 and Commission Regulation (EU) No 1230/2012 and repealing Commission Regulation (EC) No 692/2008. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02017R1151-20200125

ISI (Fraunhofer Institute for Systems and Innovation Research ISI); 2021. Realistic Test Cycle Utility Factors for Plug-in Hybrid Electric Vehicles in Europe. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cce/2021/BMU_Kurzpapier_UF_final.pdf