

PHEVs LCA

In-use consumption and real-world data

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Overview

A. Introduction

Real-world data and challenges with gap calculation

B. EDS approach

Electric Driving Share and differences from Utility Factor

C. EDS in action

Considerations on real-world data and EU LCA methodology



A) Introduction

- Visualisation of real-world data
- Gap calculation
- Problems with Charge Depleting



Visualisation of real-world data

Lifetime consumption

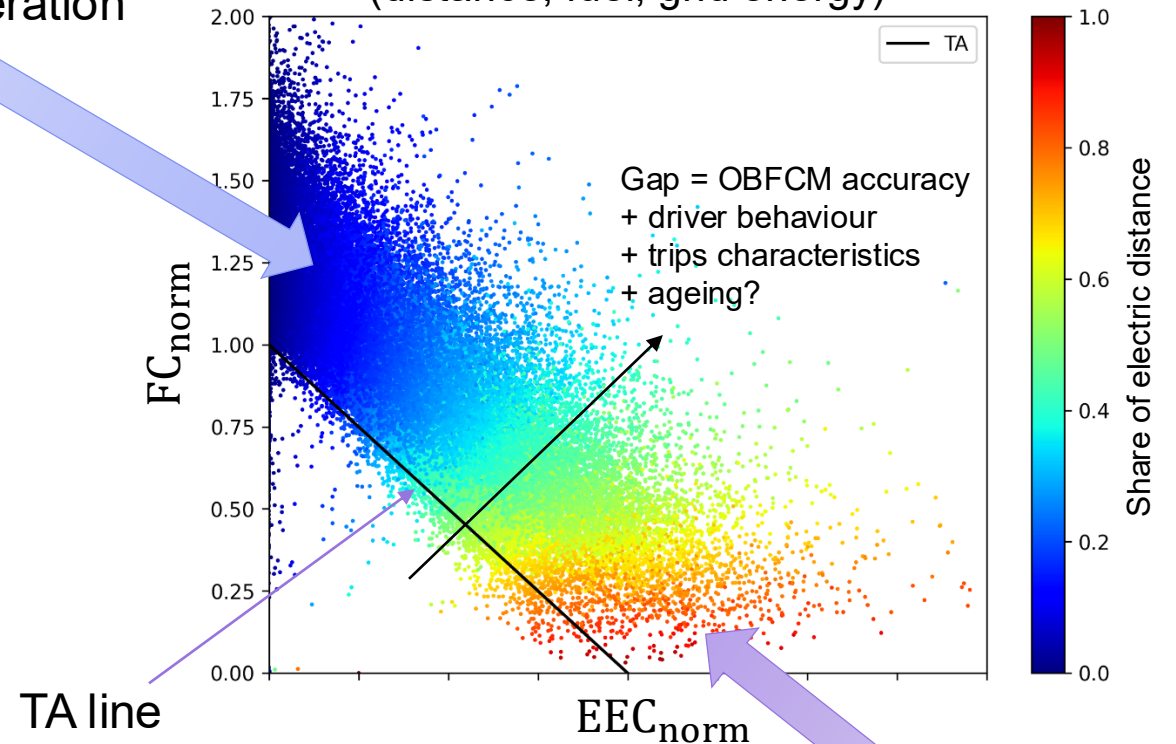
- $FC_{OBFCM}^{RW} \left[\frac{L}{100km} \right] = \frac{tot. fuel}{tot. distance} \cdot 100$
- $EEC_{OBFCM}^{RW} \left[\frac{Wh}{km} \right] = \frac{tot. grid en.}{tot. distance} \cdot 1000$

Normalisation of consumption

- x-axis: $EEC_{norm} = \frac{EEC_{OBFCM}^{RW}}{EEC_{AC,CD}^{TA}}$, 0 → pure charge sustaining
- y-axis: $FC_{norm} = \frac{FC_{OBFCM}^{RW}}{FC_{CS}^{TA}}$, 0 → pure electric driving

Mostly CS operation

OBFCM DATA (distance, fuel, grid energy)



Mostly CD operation



Gap calculation

- Not as easy as for ICE and NOVC-HEVs
- How can we calculate gap between laboratory and real-world?
- **If we calculate EEC gap on the weighted-combined values:**

$$EC_{AC,w}^{RW} \left[\frac{Wh}{km} \right] = \frac{OBFCM \text{ grid energy} \cdot 1000}{OBFCM \text{ tot. distance}}$$

$$EEC \text{ gap} [\%] = \left(\frac{EEC_{WC}^{RW}}{EEC_{WC}^{TA}} - 1 \right) \cdot 100$$

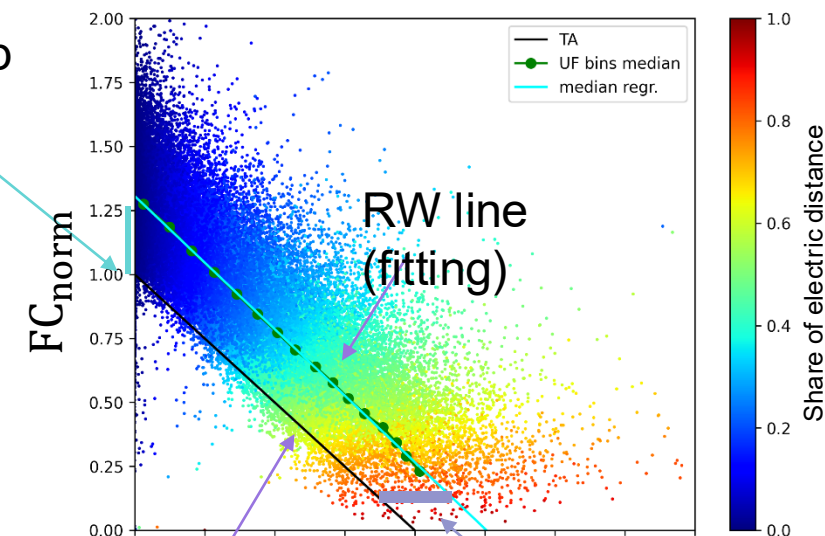
Example	TA	RW	Gap %
FC L/100km	0.9	4.3	378%
EEC kWh/100km	13.9	6	-57%

we are going to get negative gap (counter-intuitive).

$EC_{AC,w}^{RW}$ not lower because of consuming less energy per km...
...but because of less charging events per 100km!

- Better to step away from lifetime weighted-combined values for gap calculation (counter-intuitive, changes with updates to utility factor)
- Solution: refer to the two different operating modes separately, capturing the «trend» from the cloud of OBFCM points and inferring the gap
 - Gap in charge sustaining
 - Gap in **charge depleting (comes with problems)**
- Assign meaningful lifetime weights to the consumption in these modes

FC CS gap



TA line

EEC_{norm}

EEC CD gap?



Problems with Charge Depleting

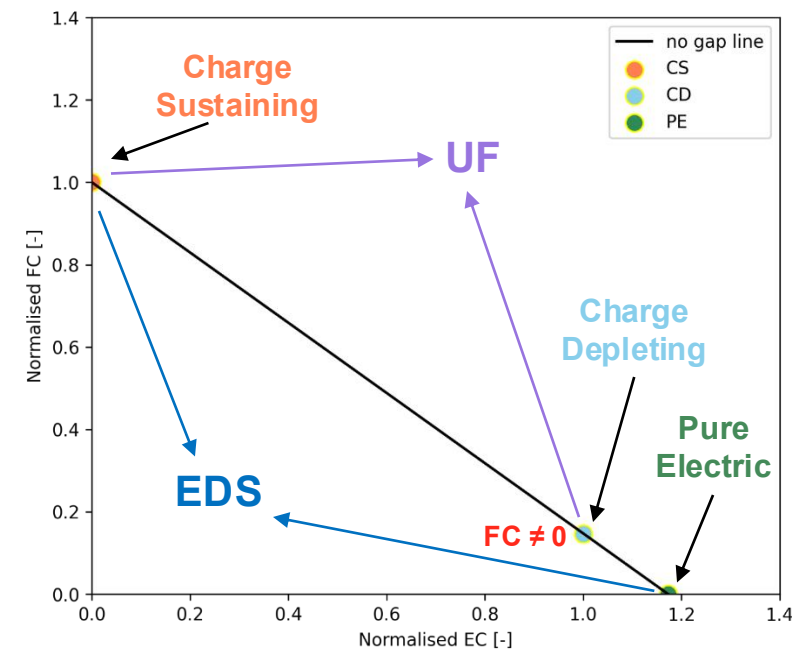
Charge depleting

- has a **clear definition in the laboratory** (driven WLTCs until transition cycle, included), **but not in the real-world**
- unclear how to get the charge depleting distance, fuel and electric energy consumption from real-world data
- **consumes both fuel and battery energy** → calculations are more complex
- **forces to stick to the Utility Factor**, while Electric Driving Share (EDS) is more straightforward

Calculation of Weighted Combined values

using UF $\Rightarrow FC \left[\frac{l}{100km} \right] = \underline{(1 - UF) * FC_{CS}} + \underline{UF * FC_{CD}}$

using EDS $\Rightarrow FC \left[\frac{l}{100km} \right] = \underline{(1 - EDS) * FC_{CS}} + \underline{EDS * 0}$



B) EDS approach

- Electric Driving Share (EDS)
- UF vs EDS
- EDS approach overview



Electric Driving Share

EDS calculated from real-world data

$$\begin{aligned}
 EDS_{vehicle}^{RW}[-] &= \frac{\text{electric energy for propulsion}}{\text{total energy for propulsion}} = \\
 &= \frac{\text{electric energy for propulsion}}{\text{electric energy for propulsion} + \text{fuel energy for propulsion}} = \\
 &= \frac{\text{grid}_{tot} \times E_{f\text{electric}}}{\text{grid}_{tot} \times E_{f\text{electric}} + \text{fuel}_{tot} \times \rho_{fuel} \times LHV_{fuel} \times E_{f\text{fuel}}}
 \end{aligned}$$

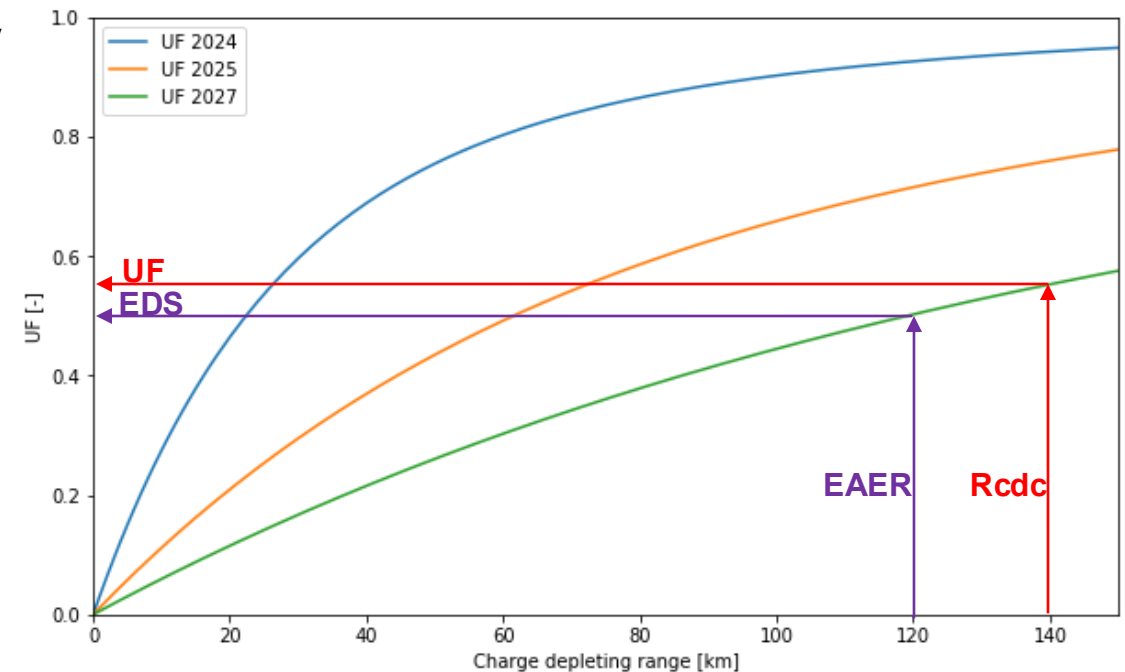
Grid energy into the battery in kWh → grid_{tot}
 powertrain efficiency in converting electric energy stored in the battery into mechanical energy for propulsion → $E_{f\text{electric}}$
 Fuel consumed in L → fuel_{tot}
 Fuel consumed in L → ρ_{fuel}
 powertrain efficiency in converting fuel energy into mechanical energy for propulsion → $E_{f\text{fuel}}$



UF vs EDS

Difference between UF and EDS

- The **Utility Factor curve** ($UF()$) represents a **cumulative probability function**
- It returns the cumulative **probability of driving less than a certain daily distance**
- **assuming CD range equal to 100km**, $UF(100\text{km})$ is the cumulative probability that I will not drive more than 100 km. Assuming that every day starts with a fully charged battery, **this probability corresponds to the ratio of distance that I can drive in charge depleting in the vehicle's lifetime.**
- $1 - UF(100\text{km})$ is the ratio of lifetime distance I will drive in charge sustaining
- $UF(\text{CD range})$ -> charge depleting distance ratio, normal **UF**
- $UF(\text{electric range})$ -> pure electric distance ratio, **EDS**



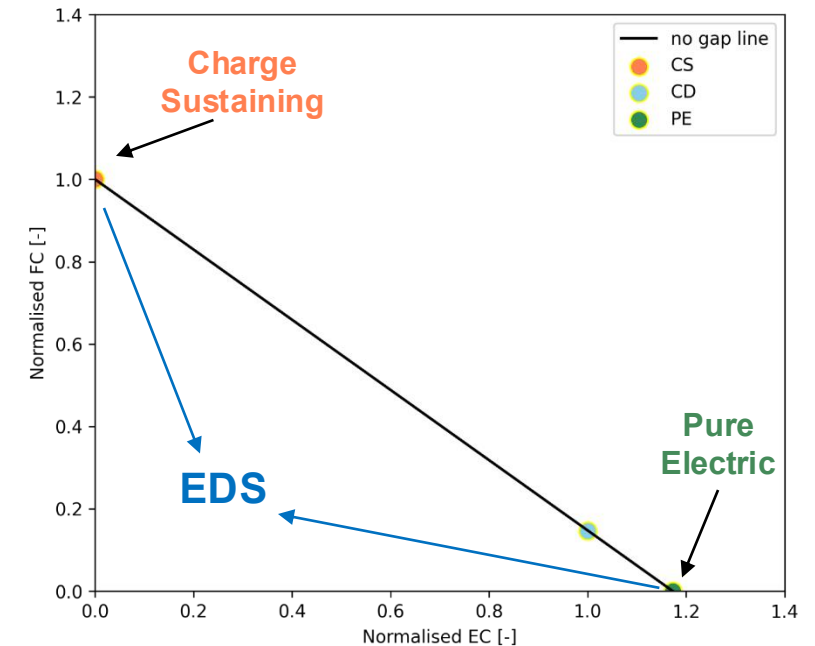
EDS approach

With the **EDS approach** we use:

- the Charge Sustaining fuel consumption
- the Pure Electric energy consumption
- the Electric Driving Share
- from real-world data we just need total distance, fuel and grid energy

We don't :

- use the Charge Depleting (confusing and complex)
- have to adjust ranges
- use the utility factor (depends on CD, curve gets updated over time)



C) EDS in action

- Calculations using real-world data
- EU methodology



Calculations using real-world data

(i)

Real-world data available in Europe (OBFCM)

- total distance travelled (km)
 - total fuel consumed (L)
 - total distance travelled in charge depleting operation with engine off (km)
 - total distance travelled in charge depleting operation with engine running (km)
 - total distance travelled in driver-selectable charge increasing operation (km)
 - total fuel consumed in charge depleting operation (L)
 - total fuel consumed in driver-selectable charge increasing operation (L)
 - total grid energy into the battery (kWh)
- No accuracy requirements
 - Parameters description in SAE J1979 leaves room for interpretation
 - Inconsistencies found in EU fleet data (see first EU Commission report on OBFCM)
- Charge Depleting (CD)
and
Charge Increasing (CI)
lifetime trackers



Calculations from real-world data

(ii)

Example using OBFCM data	OBFCM distance	OBFCM fuel	OBFCM CD distance engine-off	OBFCM CD distance engine-on	OBFCM CD fuel (engine-on)	OBFCM Grid en. into bat.
	55341.2 km	2378.75 L	17961.3 km	13341.6 km	925.01 L	2822.6 kWh

Why so high?

Why so high?

Using the Charge Depleting OBFCM parameters

Charge Depleting FC

$$FC_{CD} = \frac{925.01}{17961.3 + 13341.6} \cdot 100 = 2.96 \frac{L}{100km} \quad \text{or} \quad FC_{CD} = \frac{925.01}{13341.6} \cdot 100 = 6.93 \frac{L}{100km}$$

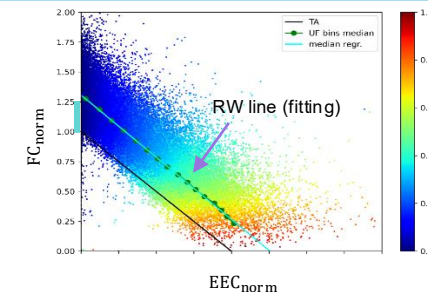
Charge Depleting EEC

$$EEC_{CD} = \frac{2822.6 \text{ kWh}}{17961.3 + 13341.6} \cdot 100 = 9.02 \frac{kWh}{100km}$$

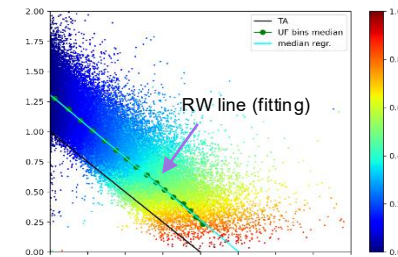
High fuel consumption in CD engine-on (6.93 L/100km)... is it actually CD? RW results are getting 'polluted'

Alternative approach (needs EDS)

Bulk analysis of OBFCM data to infer the charge sustaining fuel consumption and the pure electric energy consumption only from the triplet distance - fuel - grid energy



EU methodology - steps



• Example

From TA

	FC CS _{TA} l/100km	EEC PE _{TA} Wh/km
Model 1	7	178
Model 2	6.1	165
...

RW factors

	CS factor f_{CS}^{RW}	PE factor f_{PE}^{RW}
Model 1	1.21	1.34
Model 2	1.25	1.281
...

• Calculation steps

1. Calculate RW CS factor (f_{CS}^{RW}) and RW PE factor (f_{PE}^{RW}) using OBFCEM data, or get these factors from similar vehicles
2. Calculate an appropriate EDS RW (energy-based) from OBFCEM data (median from the specific model/category)

$$EDS_{vehicle}^{RW} [-] = \frac{\text{electric energy for propulsion}}{\text{total energy for propulsion}} = \frac{\text{grid}_{tot} \times \text{Eff}_{electric}}{\text{grid}_{tot} \times \text{Eff}_{electric} + \text{fuel}_{tot} \times \rho_{fuel} \times \text{LHV}_{fuel} \times \text{Eff}_{fuel}}$$

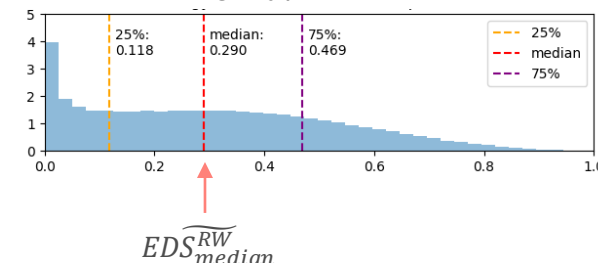
3. Calculate weighted-combined values

$$\boxed{\text{CS}} \quad FC_{WC}^{in-use} \left[\frac{l}{100km} \right] = \left(1 - EDS_{median}^{RW} \right) * FC_{CS}^{certification} * f_{CS}^{RW}$$

$$\boxed{\text{PE}} \quad EEC_{WC}^{in-use} \left[\frac{Wh}{km} \right] = EDS_{median}^{RW} * \frac{E_{AC}}{EAER} * f_{PE}^{RW}$$

'EC'
in UN R154

E_{AC} : total energy from the mains in Wh from the type 1 test full-charge
EAER: Equivalent All Electric Range



EU methodology - validation

Reference: OBFCM data

$$FC_{OBFCM}^{in-use} \left[\frac{L}{100km} \right] = \frac{tot. fuel}{tot. distance} \cdot 100$$

$$EEC_{OBFCM}^{in-use} \left[\frac{Wh}{km} \right] = \frac{tot. grid en.}{tot. distance} \cdot 1000$$

Calculated in-use values from certification data

- Inputs: for each vehicle in the EU fleet $FC_{CS}^{certification}$, $EEC_{PE}^{certification}$

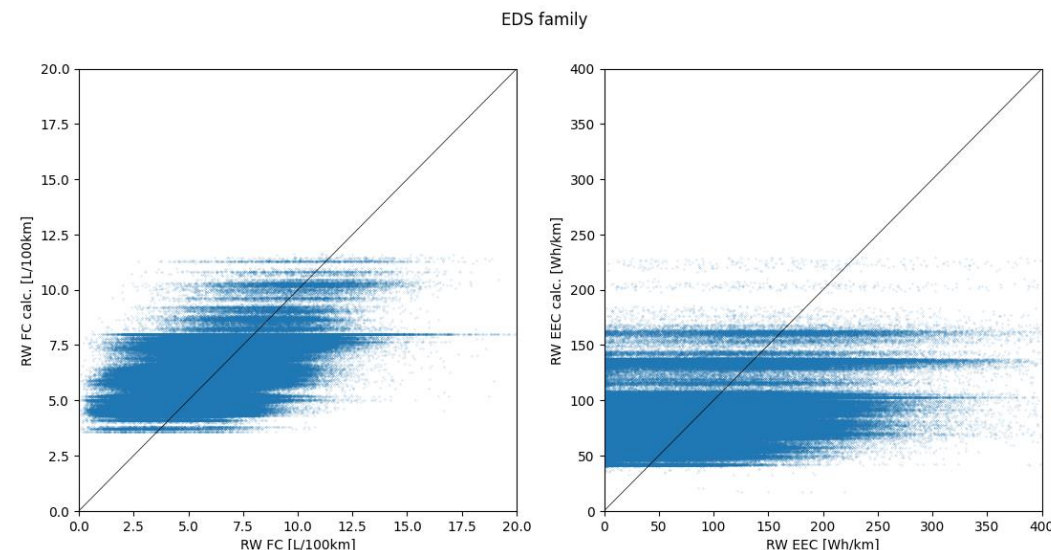
- In-use consumption

- $$FC_{CS}^{in-use} = FC_{CS}^{certification} * f_{CS}^{RW}$$
- $$EEC_{PE}^{in-use} = EEC_{PE}^{certification} * f_{PE}^{RW}$$

Avg. values in the family (IP family)

- In-use consumption weighted-combined

- $$FC_{WC,calc}^{in-use} = FC_{CS}^{in-use} \cdot (1 - EDS_{median}^{RW})$$
- $$EEC_{WC,calc}^{in-use} = EEC_{PE}^{in-use} \cdot (EDS_{median}^{RW})$$



	RW_FC	RW_FC_from_EDS_fam	RW_EEC	RW_EEC_from_EDS_fam
count	997034.000000	597871.000000	984465.000000	602983.000000
mean	5.880174	6.076773	85.407623	85.467149
std	2.416502	1.261119	67.417779	24.310803
min	0.050822	3.601043	0.000000	16.941861
25%	4.181819	5.039819	27.972871	69.574973
50%	5.750669	6.006388	76.883223	81.259047
75%	7.321952	6.785332	128.421018	95.345503
max	48.344119	11.641704	1103.755155	229.334219



Thank you

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Approach based on weighted-combined

- Need to calculate two factors
 - RW factor for weighted-combined fuel consumption
 - RW factor for weighted-combined electricity consumption

- Example

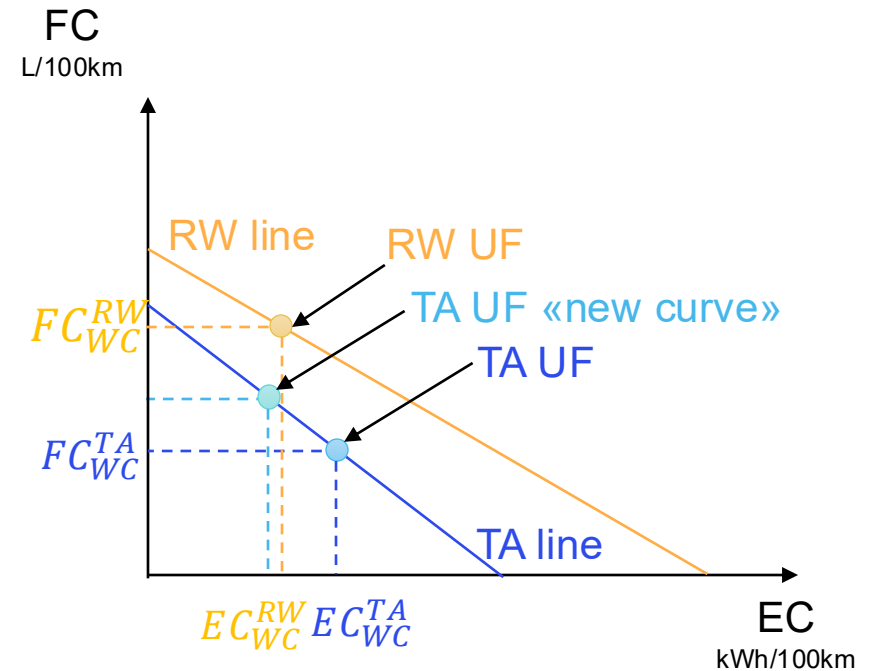
	TA	RW	RW factor / gap
FC_{WC}	1 l/100km	3 l/100km	+200%
EEC_{WC}	14 kWh/100km	7 kWh/100km	-50%

- Problem

- reference is changing (as UF 2025 and UF 2027 are phased in)
- these RW factors would not apply to PHEVs using the new UF curve

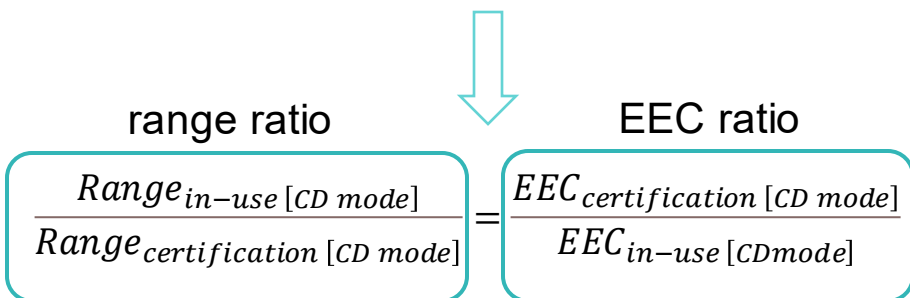
- Solution

1. Avoid using TA values and factors → use RW absolute values directly → simpler, but different approach
2. Avoid using weighted-combined → use CS and CD values (UF-independent) → complex, more in line



Approach based on in-use range and UF

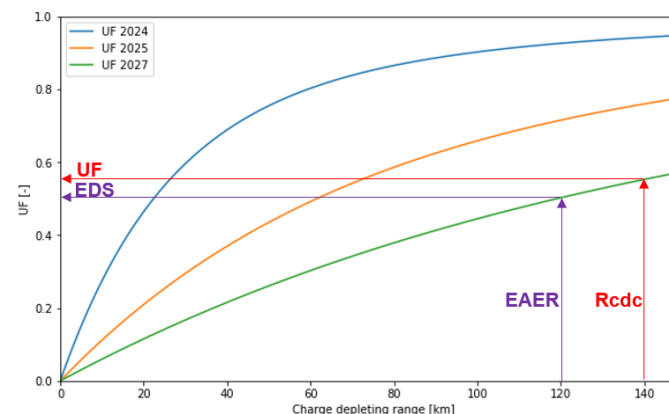
$$Range_{in-use} [CD mode] = Range_{certification} [CD mode] \times \frac{EEC_{certification} [CD mode]}{EEC_{in-use} [CD mode]}$$



	PHEV 1	PHEV 2
EC certification	200 Wh/km	200 Wh/km
EC in-use	240 Wh/km	240 Wh/km
EAER certification	25 km	40 km
EAER in-use	20 km	32 km
Rcdc certification	46.5 km	46.5 km
EEC ratio	0.8	0.8
range in-use [Rcdc]	37.2 km	37.2 km



- Two different PHEVs, with different battery capacities, end up with the same «in-use» range, a bit counter-intuitive
- Rcdc has a discrete nature: 23.25km, 46.5km, 69.75km...
- With this approach we are changing the nature of Rcdc, which acquires a more continuous nature. Consequences are unclear.



Example of Certificate of Conformity

4. Extern aufladbare Hybridelektrofahrzeuge

WLTP-Werte	Ladungserhaltung		Stromverbrauch (EC)
	CO ₂ -Emissionen	Kraftstoffverbrauch	
Niedrig	102 g/km	4.5 L/100km	111 Wh/km
Mittel	82 g/km	3.6 L/100km	121 Wh/km
Hoch	94 g/km	4.1 L/100km	143 Wh/km
Höchstwert	128 g/km	5.6 L/100km	209 Wh/km
Innerorts	NA g/km	NA L/100km	115 Wh/km
Kombiniert	105 g/km	4.6 L/100km	158 Wh/km

WLTP-Werte	CO ₂ -Emissionen	Kraftstoffverbrauch	Stromverbrauch (EC)
Kombiniert , Entladung	6 g/km	0.2 L/100km	NA Wh/km

WLTP-Werte	CO ₂ -Emissionen	Kraftstoffverbrauch	Stromverbrauch (EC)
Gewichtet, kombiniert	16 g/km	0.7 L/100km	126 Wh/km

TA CS CO₂ emissions
g/km
(needed for CS factor)

TA PE EEC
Wh/km
(needed for PE factor)



RW consumption factors and EDS

