10.04.2015

SIMULATIVE VALIDATION OF COMBINED APPROACH FOR OVC-HEV.

WLTP-SG-EV-08-05-rev1

BMW GROUP

WLTP – COMBINED APPROACH FOR OVC-HEV.

FURTHER VALIDATION ISSUES OF THE COMBINED APPROACH.

► **Validation of the calculation method for the CD-phase specific values R_{CDa}, EAER and EC calculated from the charge-depleting test.**

► Validation of the combined approach for the phase specific values R_{CDa}, EAER and EC calculated from the charge-depleting test.

► Validation of a adjusted method that allows the OVC-HEV interpolation family building with different R_{CDC} between vehicle low and high.

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CALCULATIONS FOR PHASE SPECIFIC CD VALUES.

Required phase specific CD values and calculation method according to the proposal from Japan:

- Equivalent all electric range EAER: $$EAER_p = \frac{\left(M_{CO2,CS,p} - M_{CO2,CDavg,p}\right)}{M_{CO2,CS,p}} \cdot d_p \cdot n_p \Rightarrow n_p = \text{int}\left(\frac{R_{CDa,p}}{d_p}\right) + 1$$

- Electric energy consumption EC: $$EC_p = \frac{E_{AC}}{EAER_p}$$

- Actual charge depleting range R_{CDa}: $$R_{CDa,p} = \frac{E_{AC}}{EC_{AC,p}} \Rightarrow EC_{AC,p} = \frac{\sum_{j=1}^{n-1} EC_{AC,p,j} \times d_{p,j}}{\sum_{j=1}^{n-1} d_{p,j}}$$

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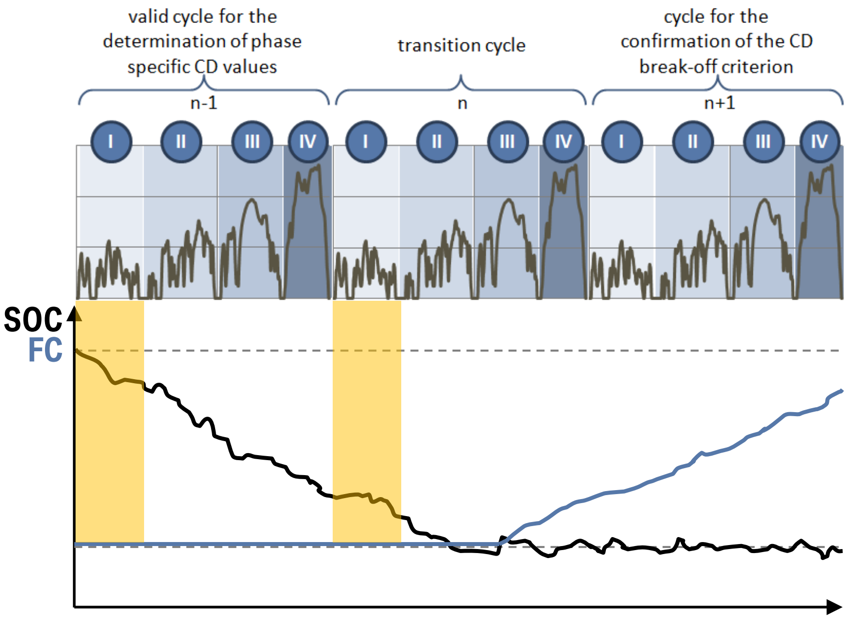
PHASE SPECIFIC EQUIVALENT ALL ELECTRIC RANGE.



$$EAER_p = \frac{\left(M_{CO2,CS,p} - M_{CO2,CDavg,p}\right)}{M_{CO2,CS,p}} \cdot d_p \cdot n_p$$

$M_{CO2,CDavg,p}$ shall be calculated by using M_{CO2} of the considered phase of all cycles up to the transition cycle (including transition cycle).

n_p is the estimated number of charge-depleting phases p.

$$n_p = \mathrm{int}\left(\frac{R_{CDa,p}}{d_p}\right) + 1$$

is always a upwards adjusted whole number (integer).

▶ The upwards adjusted whole number of estimated charge-depleting phases and the inappropriate average $M_{CO2,CDavg,p}$ leads to an inaccuracy that could be improved as it can be seen on the next slide.

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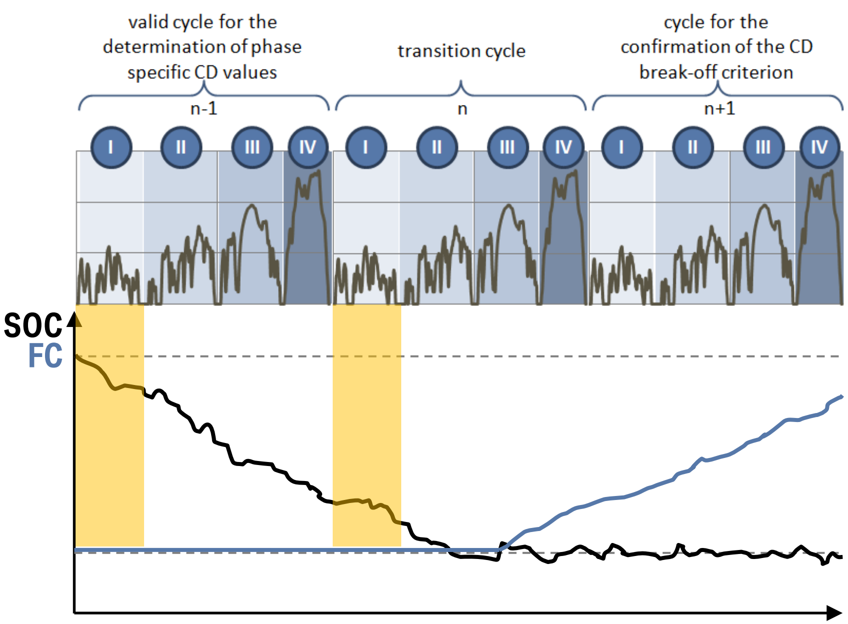
PHASE SPECIFIC EQUIVALENT ALL ELECTRIC RANGE.



$$EAER_p = \frac{(M_{CO2,CS,p} - M_{CO2,CDavg,p})}{M_{CO2,CS,p}} \cdot d_p \cdot n_p$$

$M_{CO2,CDavg,p}$ shall be calculated by using M_{CO2} of the considered phase of all cycles **excluding** the transition cycle.

$n_p \Rightarrow \frac{R_{CDa,p}}{d_p}$ **replace** the upwards adjusted estimated number of charge-depleting with a floating-point number.

$$EAER_p = \frac{(M_{CO2,CS,p} - M_{CO2,CDavg,p})}{M_{CO2,CS,p}} \cdot R_{CDa,p}$$

▶ Advantage: Continuous linear line describing the phase specific $EAER_p$ within a family and it is therefore possible to be interpolated for a individual vehicle

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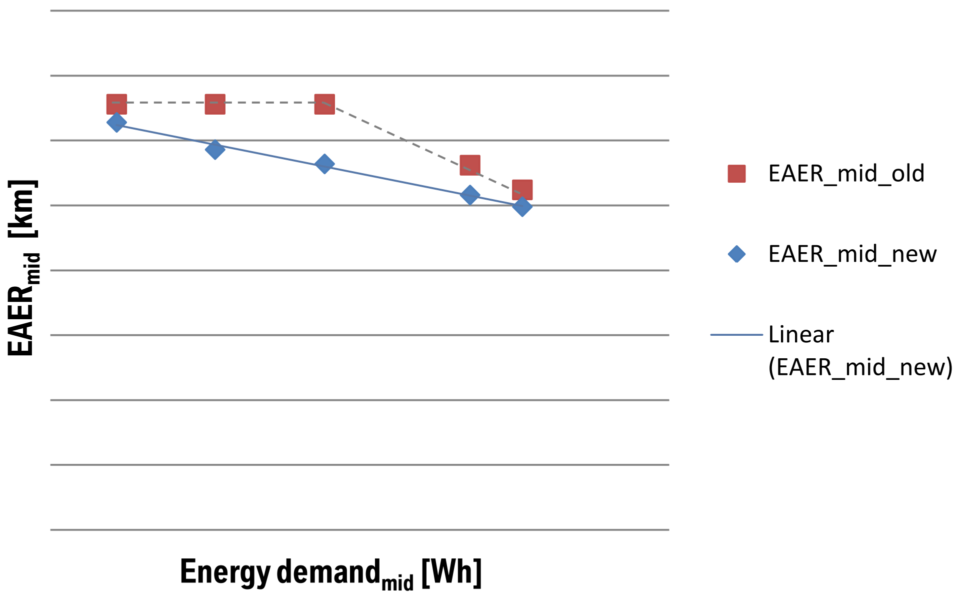
PHASE SPECIFIC EQUIVALENT ALL ELECTRIC RANGE.



$$EAER_p = \frac{\left(M_{CO2,CS,p} - M_{CO2,CDavg,p}\right)}{M_{CO2,CS,p}} \cdot d_p \cdot n_p$$

$$EAER_p = \frac{\left(M_{CO2,CS,p} - M_{CO2,CDavg,p}\right)}{M_{CO2,CS,p}} \cdot R_{CDa,p}$$

- Recommendation:
  Adopt the adjusted EAER calculation equation.
  Exclude the transition cycle for $M_{CO2,CDavg,p}$

$$EAER_p = \frac{\left(M_{CO2,CS,p} - M_{CO2,CDavg,p}\right)}{M_{CO2,CS,p}} \cdot R_{CDa,p}$$

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FURTHER VALIDATION ISSUES OF THE COMBINED APPROACH.

► Validation of the calculation method for the CD-phase specific values R_{CDa}, EAER and EC calculated from the charge-depleting test.

► **Validation of the combined approach for the phase specific values R_{CDa}, EC and the ("new") EAER calculated from the charge-depleting test.**

► Validation of a adjusted method that allows the OVC-HEV interpolation family building with different R_{CDC} between vehicle low and high.

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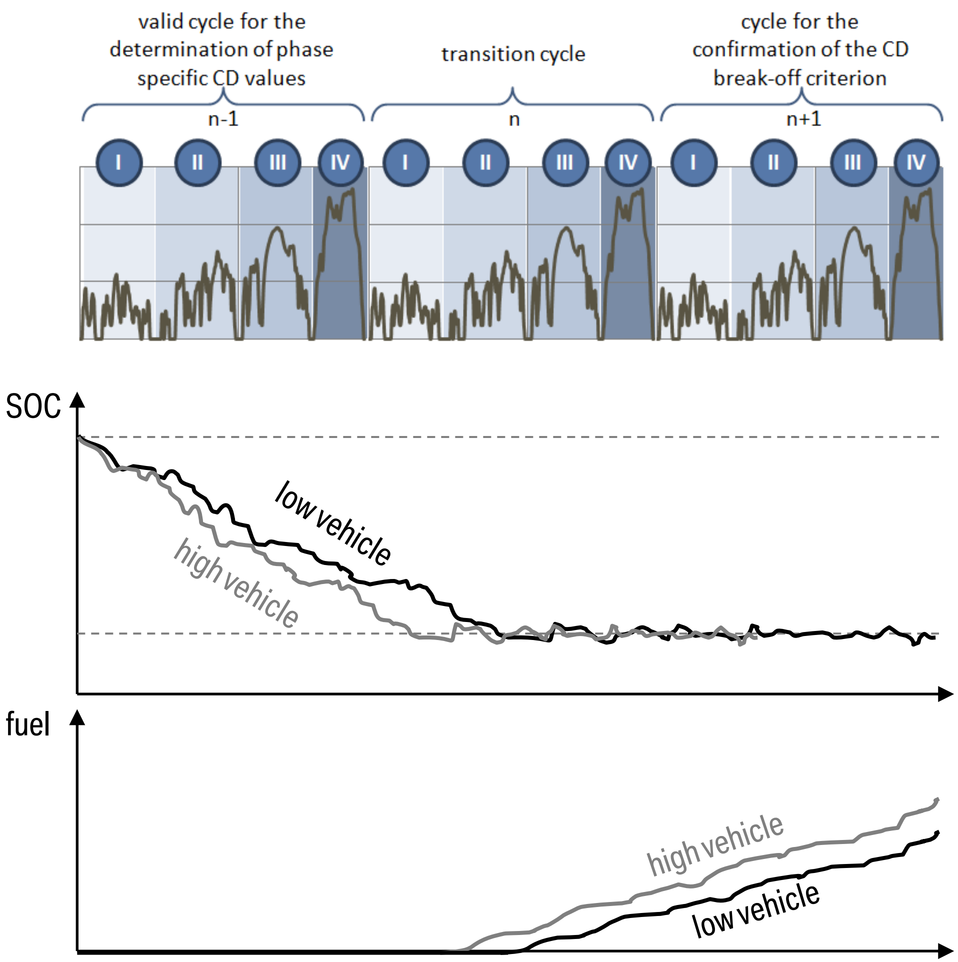
DIFFERENT CASES WITHIN ONE INTERPOLATION FAMILY.



1st case within a vehicle family

- No ICE-start until SOC_{min} is reached.
- Performance of the electric power train is higher than the power demand of the high vehicle.

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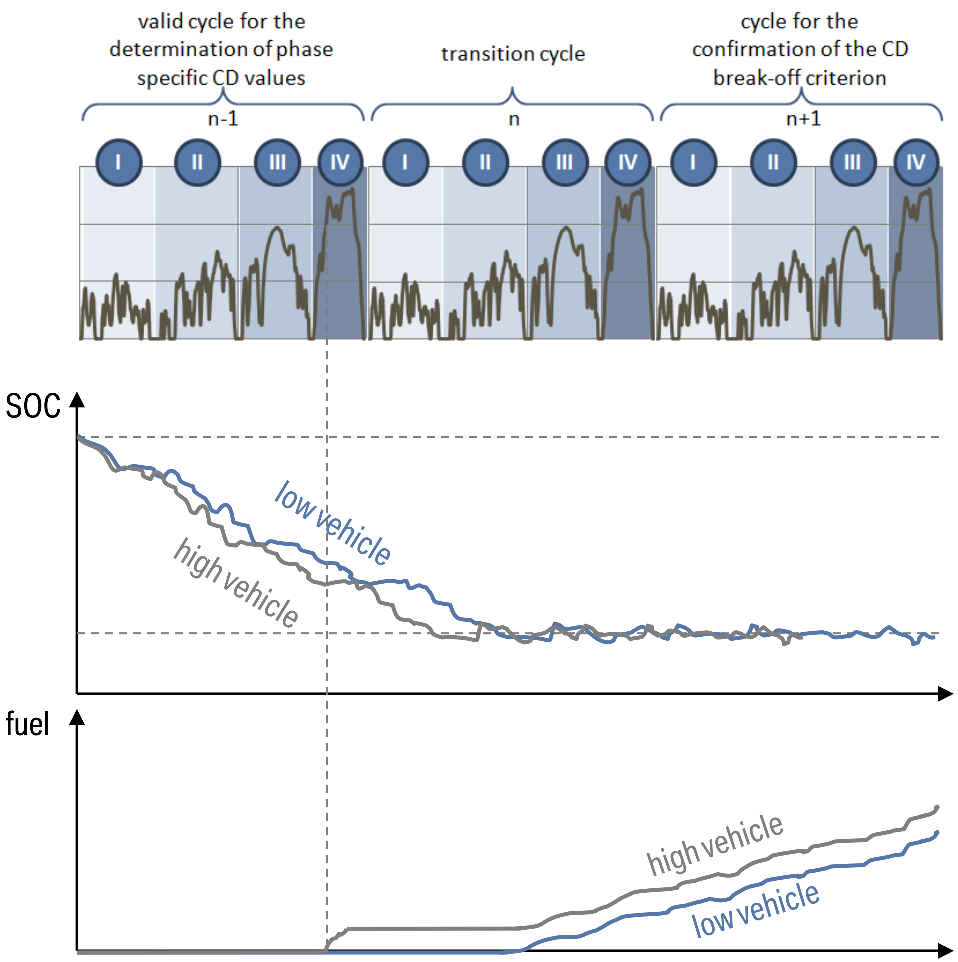
DIFFERENT CASES WITHIN ONE INTERPOLATION FAMILY.



2nd case within a vehicle family

low vehicle

- No ICE-start until SOC_{min} is reached.
- Performance of the electric power train is higher than the power demand of the low vehicle.

high vehicle

- ICE-start before SOC_{min} is reached.
- The limited power of the electric power train causes ICE start of the high vehicle.

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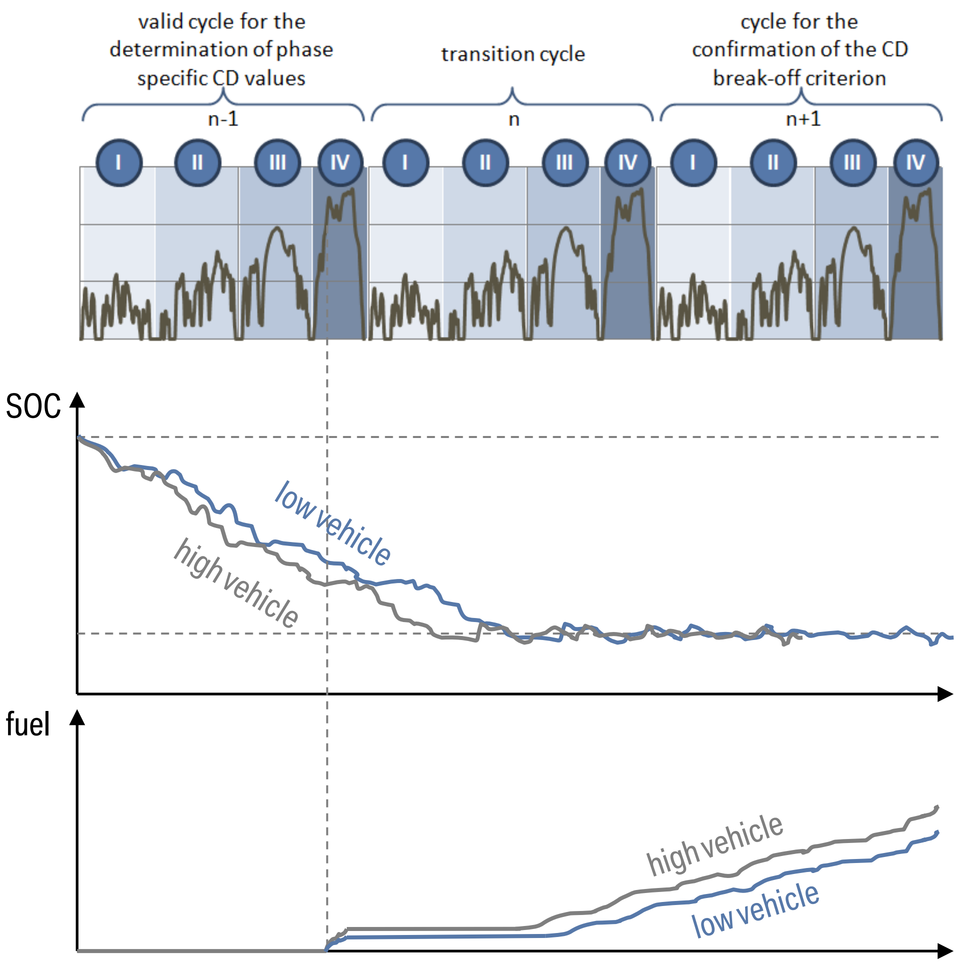
DIFFERENT CASES WITHIN ONE INTERPOLATION FAMILY.



3rd case within a vehicle family

low vehicle

- ICE-start before SOC_{min} is reached.
- The limited power of the electric power train causes ICE start of the low vehicle.

high vehicle

- ICE-start before SOC_{min} is reached.
- The limited power of the electric power train causes ICE start of the high vehicle.

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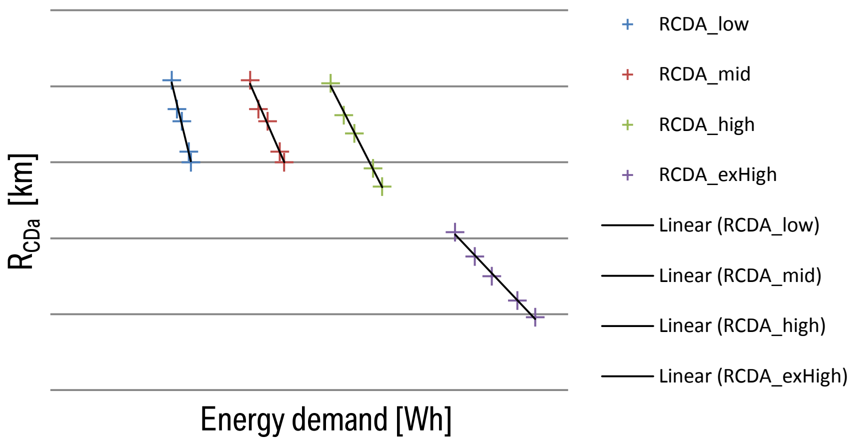
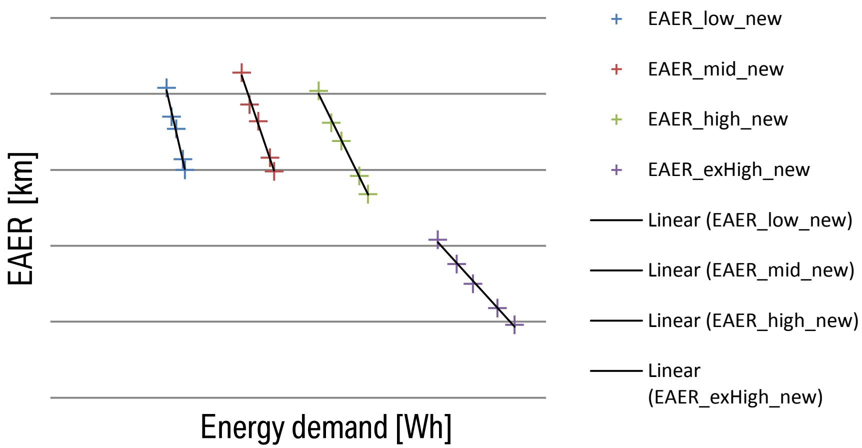
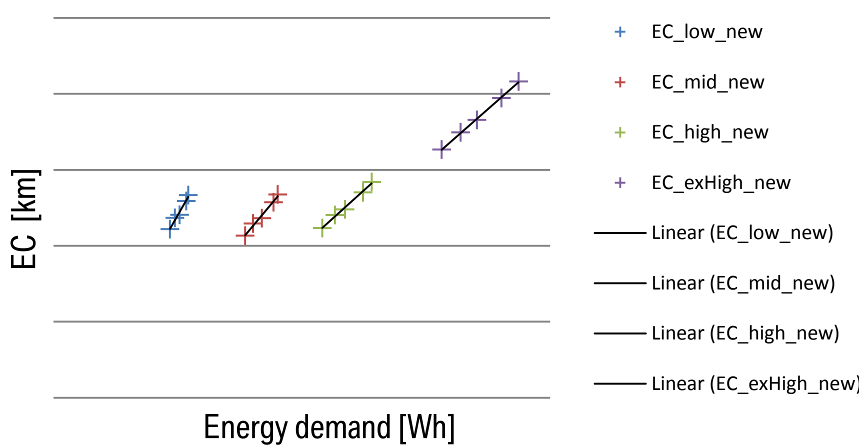
1^ST CASE RESULTS.



1st case within a vehicle family

- No ICE-start until SOC_{min} is reached.
- Performance of the electric power train is higher than the power demand of the high vehicle.





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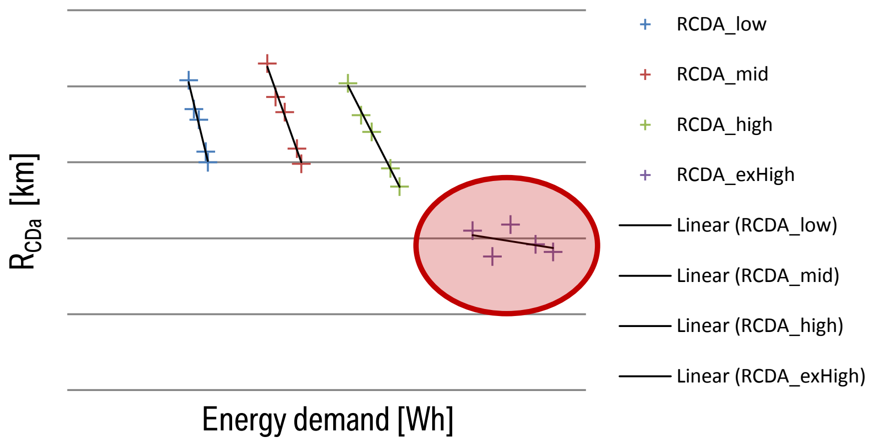
2ND CASE RESULTS.



2nd case within a vehicle family

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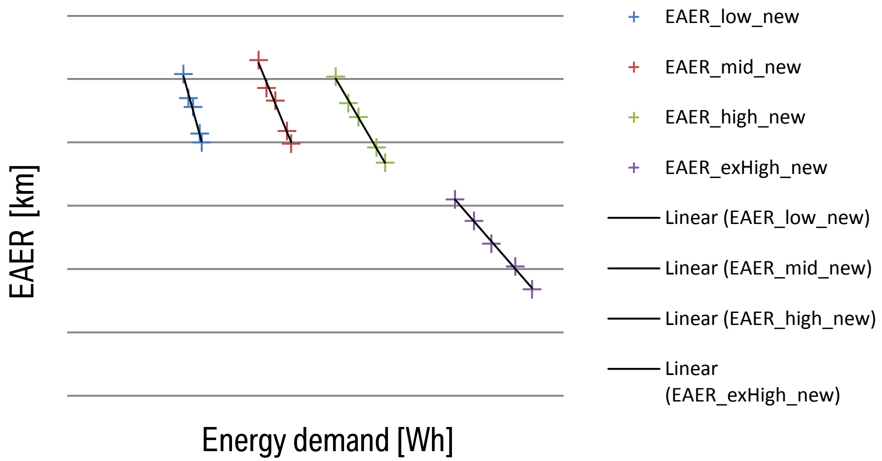
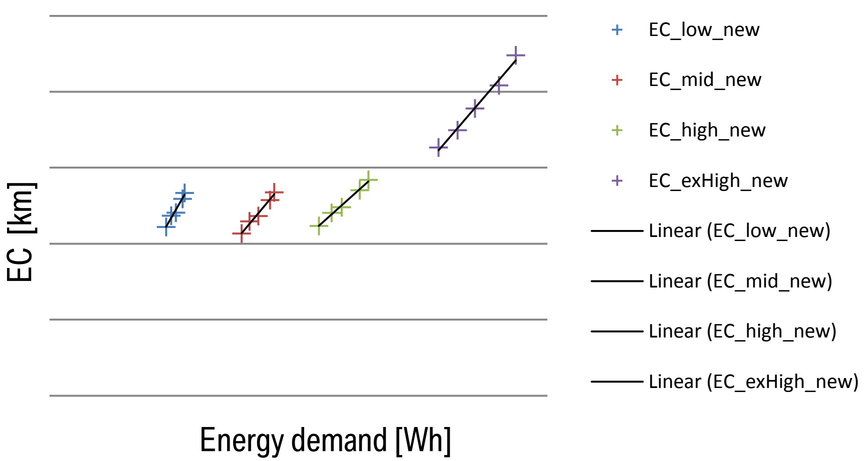
- The limited power of the electric power train causes ICE start of the high vehicle.





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WHY DOES THE INTERPOLATION WORK FOR EAER BUT NOT FOR R_{CDA}?

EAER

The calculation of EAER takes care about CO_2 mass emission of the charge-depleting test **and** electric energy consumptions. Due to the consideration of both energy sources, potential non-linearity is compensated.

$$EAER_p = \frac{\left(M_{CO2,CS,p} - M_{CO2,CDavg,p}\right)}{M_{CO2,CS,p}} \cdot R_{CDa,p} \Rightarrow R_{CDa,p} = \frac{E_{AC}}{EC_{AC,p}}$$

R_{CDa}

The calculation of R_{CDa} **ignores** the CO_2 mass emission between the 1st cycle and cycle (n-1), what is correct the purpose of the R_{CDa}. But that leads the an higher inaccuracy because the non-linearity is not compensated.

$$R_{CDa,p} = \frac{E_{AC}}{EC_{AC,p}}$$

This problem is **not caused** by the interpolation because R_{CDa} would show the same non-linearity in such special cases if a vehicle family would be measured.

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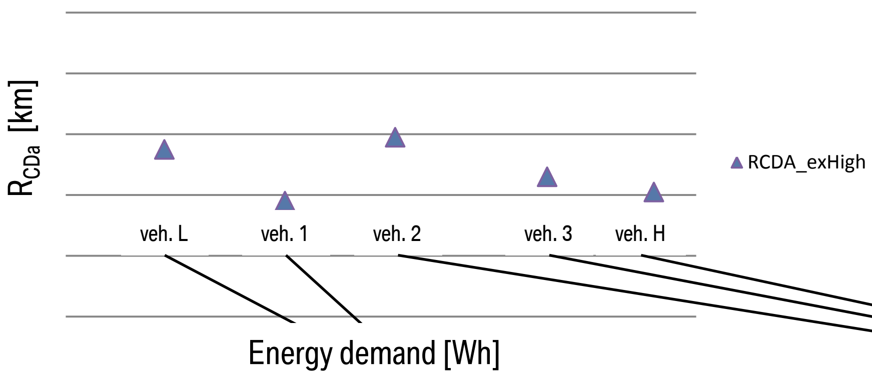
2ND CASE PROBLEM.



2nd case within a vehicle family

low vehicle

- No ICE-start until SOC_{min} is reached.
- Performance of the electric power train is higher than the power demand of the low vehicle.

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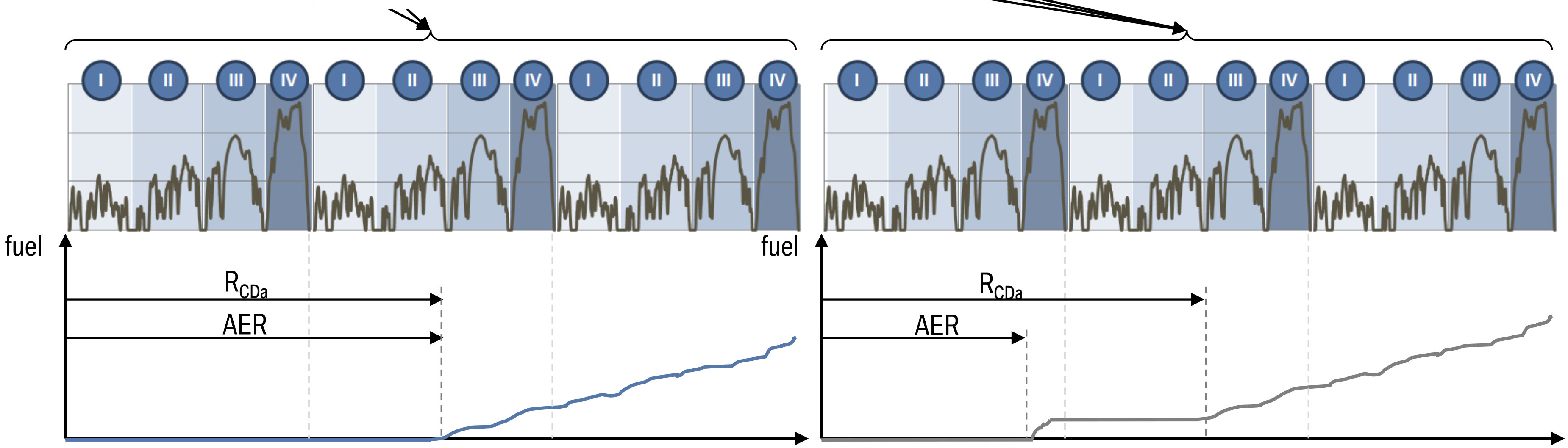

▶ How to detect such cases? ➔ $\left| \frac{AER_{TML}}{R_{CDa,TML}} - \frac{AER_{TMH}}{R_{CDa,TMH}} \right| \leq 10\%$

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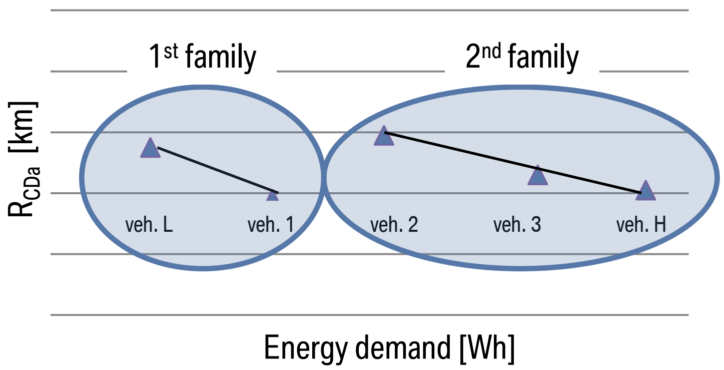
POTENTIAL 2ND CASE SOLUTIONS.

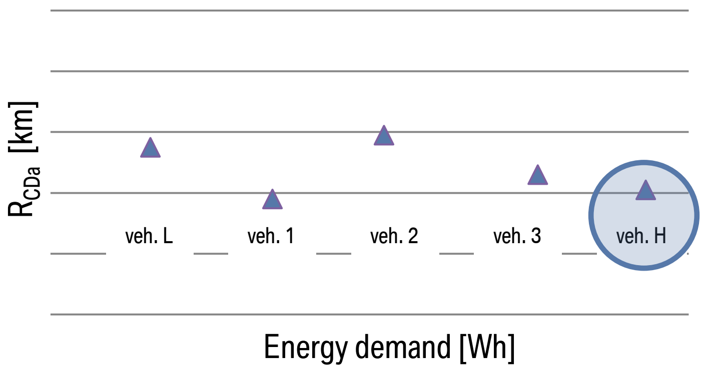
1st solution:

- Use $\left|\frac{AER_{TML}}{R_{CDa,TML}}-\frac{AER_{TMH}}{R_{CDa,TMH}}\right|\leq 10\%$ as family criteria.



2nd solution:

- If $\left|\frac{AER_{TML}}{R_{CDa,TML}}-\frac{AER_{TMH}}{R_{CDa,TMH}}\right|>10\%$ use the lowest R_{CDa}.



3rd solution:

- Remove the requirement to have phase specific R_{CDa}, because phase specific EAER is enough.

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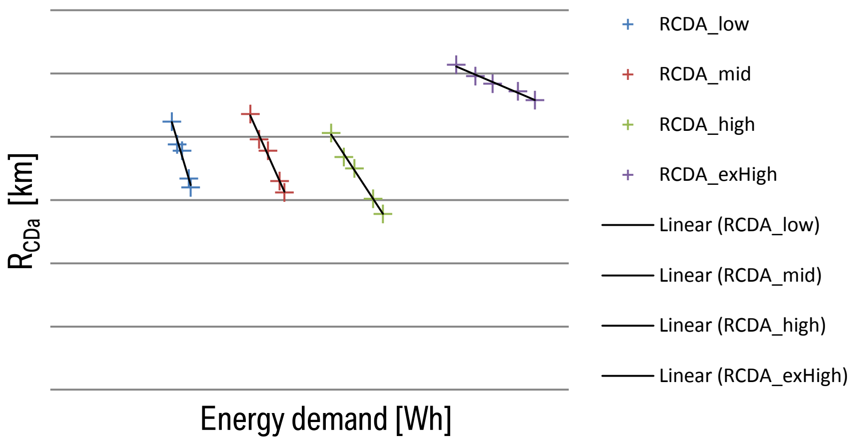
3RD CASE RESULTS.



3rd case within a vehicle family

low vehicle

- ICE-start before SOC_{min} is reached.
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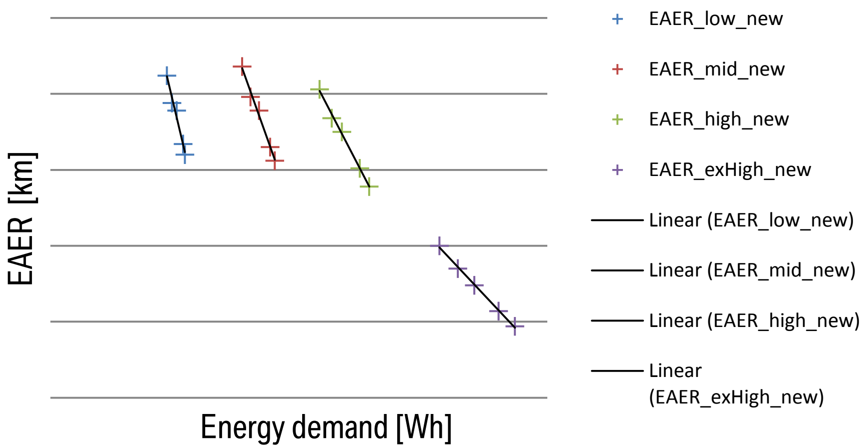

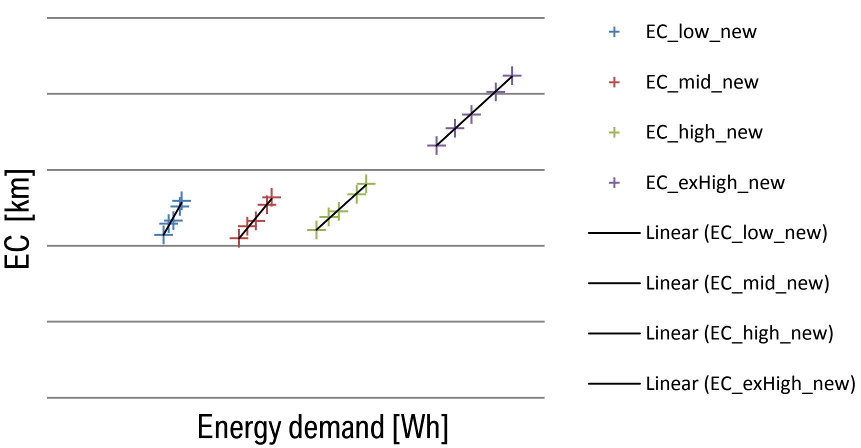

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FINAL RECOMMENDATION.

Validation of the calculation method for the CD-phase specific values R_{CDa}, EAER and EC calculated from the charge-depleting test.

- Recommendation:
  Adopt the adjusted EAER calculation equation.
  Exclude the transition cycle for $M_{CO2,CDavg,p}$

$$EAER_p = \frac{\left(M_{CO2,CS,p} - M_{CO2,CDavg,p}\right)}{M_{CO2,CS,p}} \cdot R_{CDa,p}$$

Validation of the combined approach for the phase specific values R_{CDa}, EC and the ("new") EAER calculated from the charge-depleting test.

1st solution:

- Use $\left|\frac{AER_{TML}}{R_{CDa,TML}} - \frac{AER_{TMH}}{R_{CDa,TMH}}\right| \leq 10\%$ as family criteria.

2nd solution:

- If $\left|\frac{AER_{TML}}{R_{CDa,TML}} - \frac{AER_{TMH}}{R_{CDa,TMH}}\right| > 10\%$ use the lowest R_{CDa}.

3rd solution:

- Remove the requirement to have phase specific R_{CDa}, because phase specific EAER is enough.

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FURTHER VALIDATION ISSUES OF THE COMBINED APPROACH.

► Validation of the calculation method for the CD-phase specific values R_{CDa}, EAER and EC calculated from the charge-depleting test.

► Validation of the combined approach for the phase specific values R_{CDa}, EC and the ("new") EAER calculated from the charge-depleting test.

► **Validation of a adjusted method that allows the OVC-HEV interpolation family building with different R_{CDC} between vehicle low and high.**

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IDEA: ADJUSTMENT OF "SAME RCDC" AS INTERPOLATION FAMILY CRITERION.

value	interpolation **with RCDC** family criterion using old calculation	interpolation **without RCDC** family criterion using the old calculation	interpolation **with adjusted RCDC** family criterion using a **new methodology**
$M_{CO2,CD}$	OK	NOK	
$M_{CO2,CS}$	OK	OK	
$M_{CO2,weighted}$	OK	OK	
FC_{CD}	OK	NOK	
FC_{CS}	OK	OK	
$FC_{weighted}$	OK	OK	
$EC_{AC,CD}$	OK	NOK	
$EC_{AC, weighted}$	OK	OK	
EC	OK	NOK	
E_{AC}	interpolation is not necessary because other family criteria ensure a similar recharged energy (e.g. same storage, converter,...)	interpolation is not necessary because other family criteria ensure a similar recharged energy (e.g. same storage, converter,...)	
R_{CDC}	OK	NOK	
AER	NOK, but can be handled with AER-RCDa-ratio criterion	NOK (but can be handled with AER-RCDa-ratio criterion)	
EAER	OK	OK	
R_{CDa}	OK	OK	

Disadvantage: Manufacturer has to build two OVC-HEV families instead of one family in case of a R_{CDC} switch (e.g. 2 CD cycles for TML and only 1 CD cycle for TMH).
Advantage: Better linearity.

Advantage: Manufacturer is allowed to build one OVC-HEV family even if there is a R_{CDC} switch.

Disadvantage: Bad linearity for some values (see "NOK").

Advantage: This approach tries to:
-**combine both advantages** and to
-**avoid both disadvantages**.

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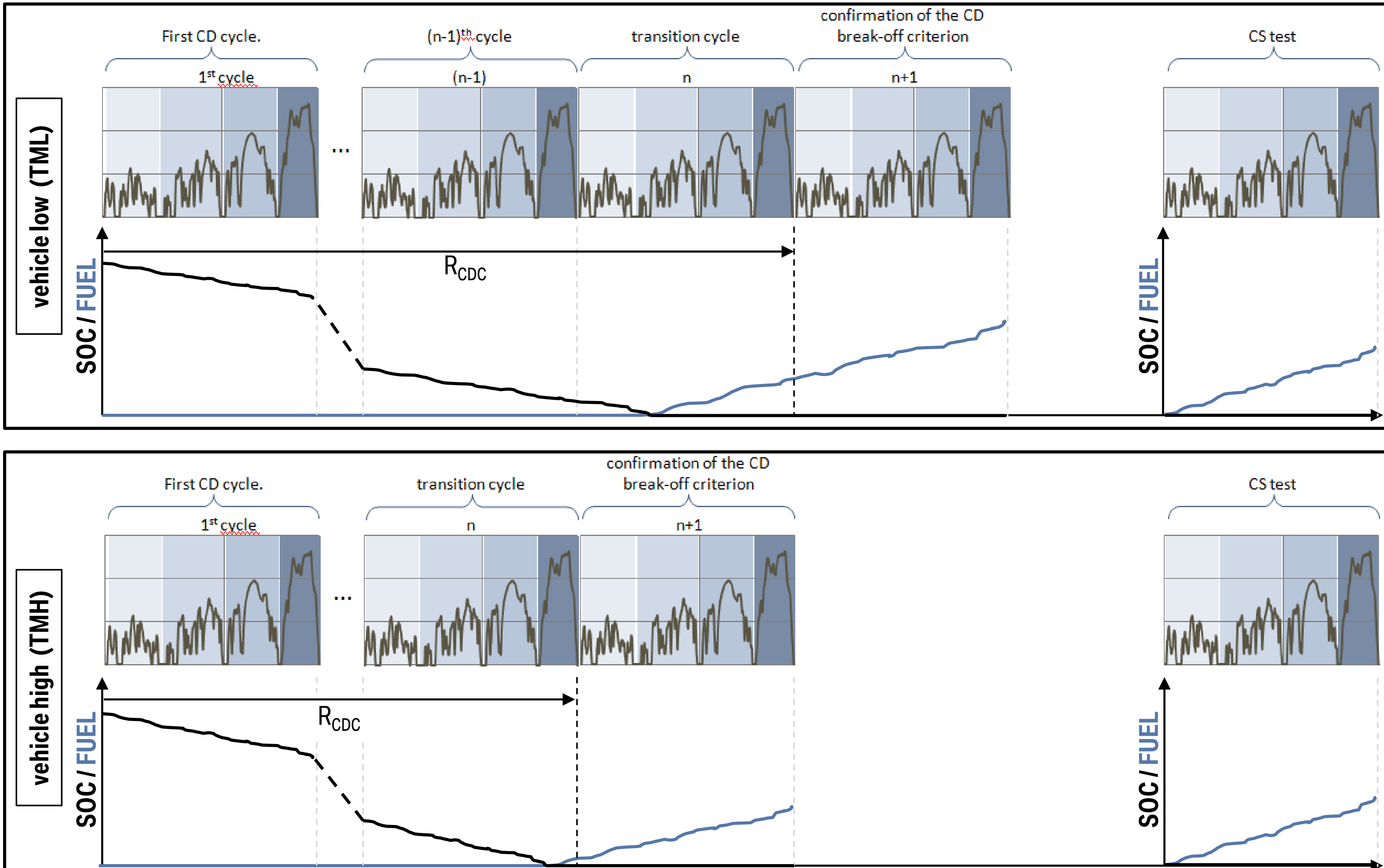
WHAT IS THE PROBLEM OF A DIFFERENT R_{CDC}?



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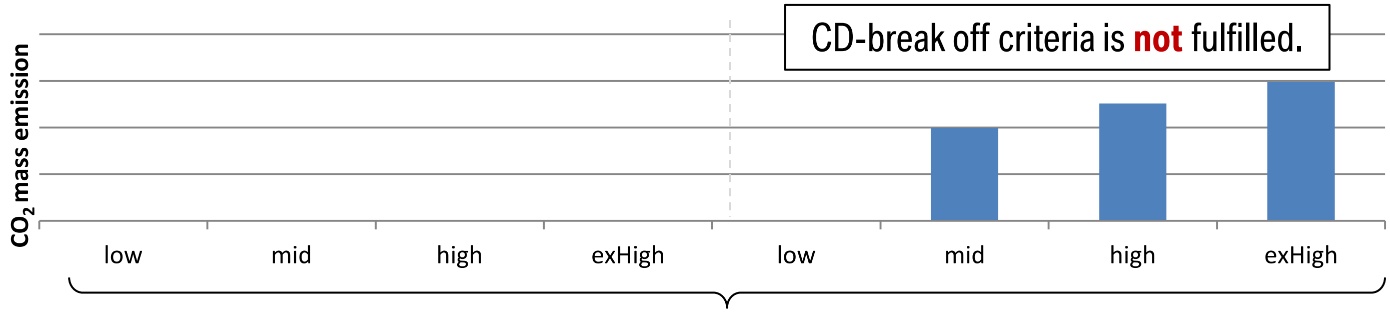
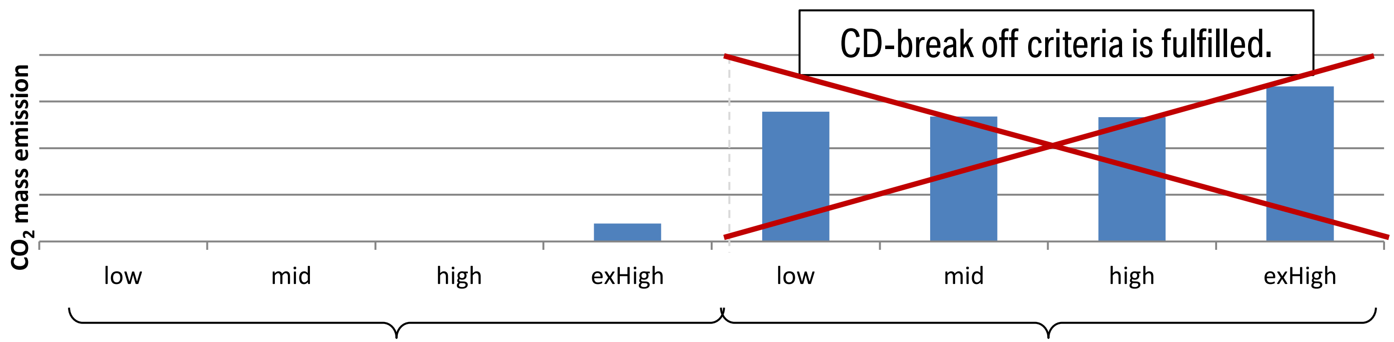
WHAT IS THE PROBLEM OF A DIFFERENT R_{CDC}?

vehicle low (TML)



8 CD-phases, 2 CD-cycles respectively, that are considered for the calculation of TML.

vehicle high (TMH)



4 CD-phases, 1 CD-cycle respectively, that are considered for the calculation of TMH.

4 CD-phases, 1 CD-cycle respectively, that are **not** considered for the calculation of TMH. → This is a test under charge-sustaining conditions!

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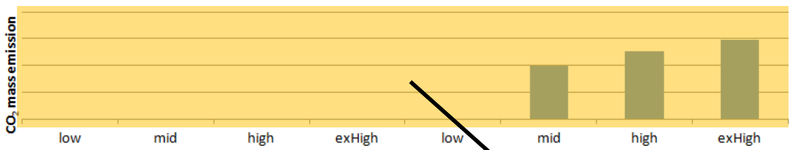
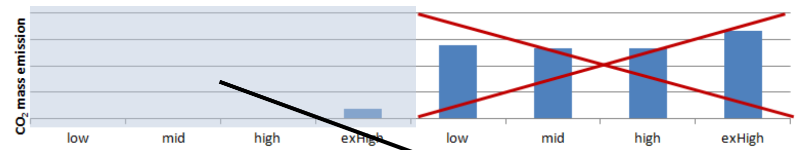
EXAMPLE: WHAT IS THE PROBLEM OF A DIFFERENT R_{CDC}?

vehicle low (TML)

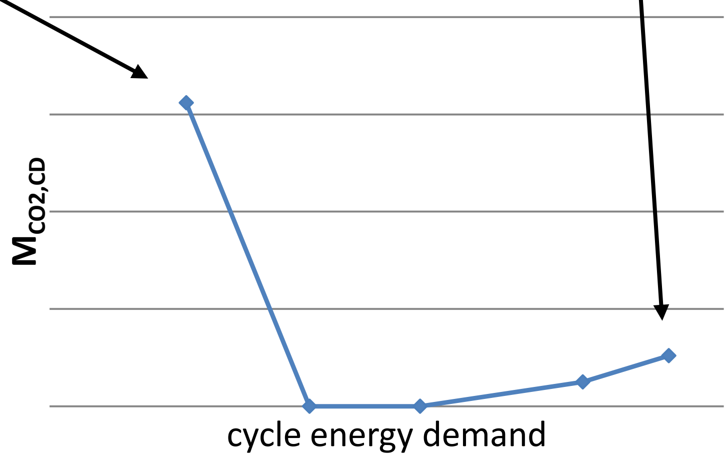


$$M_{CO2,CD} = \frac{\sum_{j=1}^{k} \left(UF_j \times M_{CO2,CD,j} \right)}{\sum_{j=1}^{k} UF_j}$$

vehicle high (TMH)



$$M_{CO2,CD} = \frac{\sum_{j=1}^{k} \left(UF_j \times M_{CO2,CD,j} \right)}{\sum_{j=1}^{k} UF_j}$$



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WHAT IS THE PROPOSAL?

- Replace the requirement "same RCDC" within one OVC-HEV interpolation family with:

  " The difference between the number of charge-depleting cycles shall not exceed the amount of one." ➔ $n_{\text{transitioncycle},TML} - n_{\text{transitioncycle},TMH} \leq 1$

- In case that the amount of charge-depleting cycles is not the same for vehicle low (TML) and vehicle high (TMH), the "confirmation cycle" for the break-off criterion shall be used for the vehicle with less amount of charge-depleting cycles.

Important:
The "**confirmation cycle**" is a cycle under **charge-sustaining conditions.** In order to avoid biases, it is necessary to apply the RCB-correction to the confirmation cycle by using the correction coefficient!

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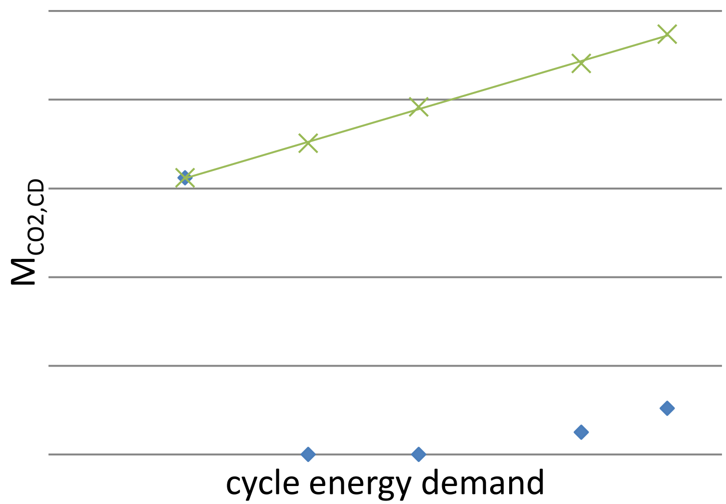
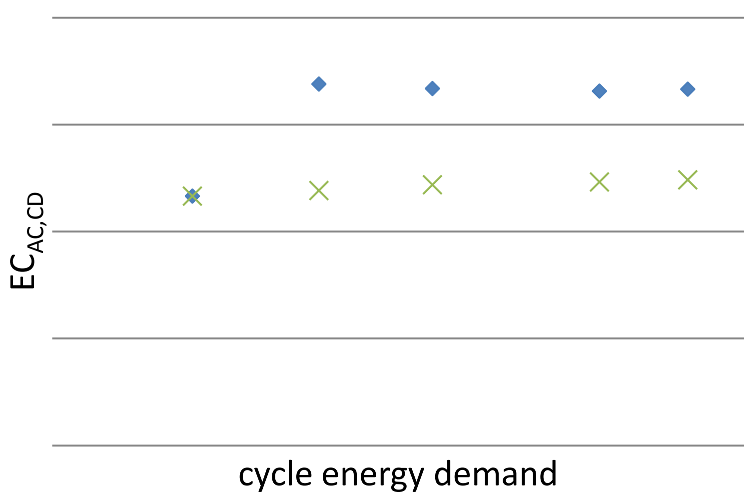
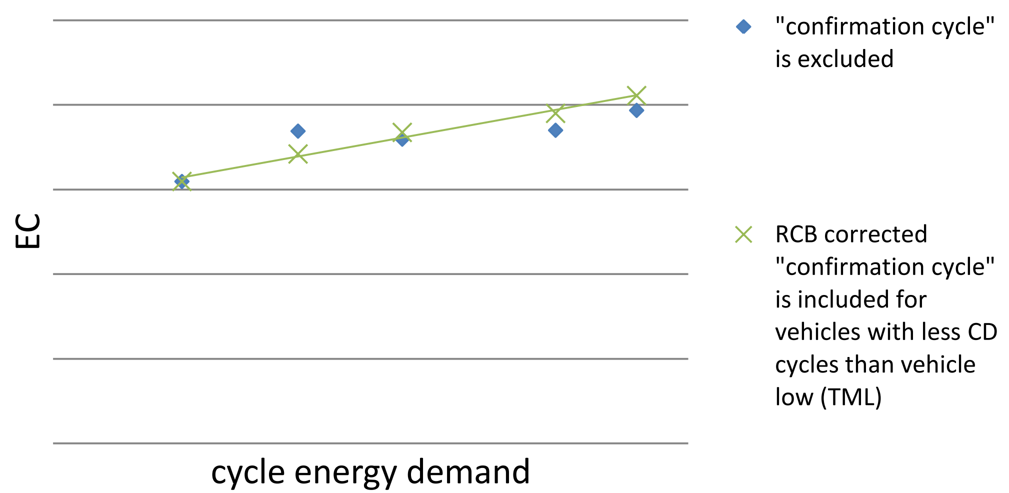
RESULTS (1).







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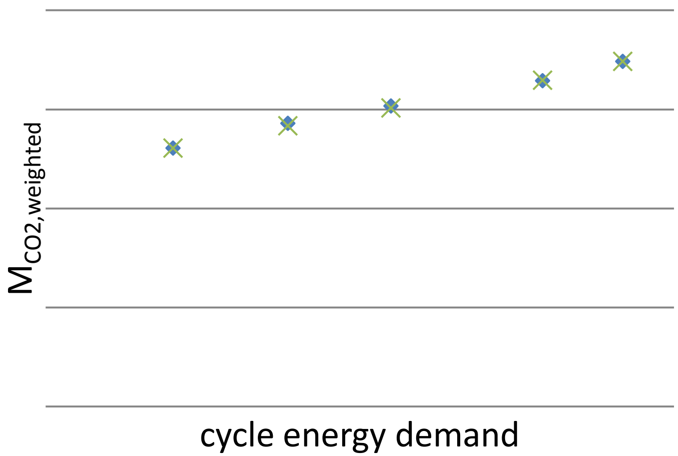
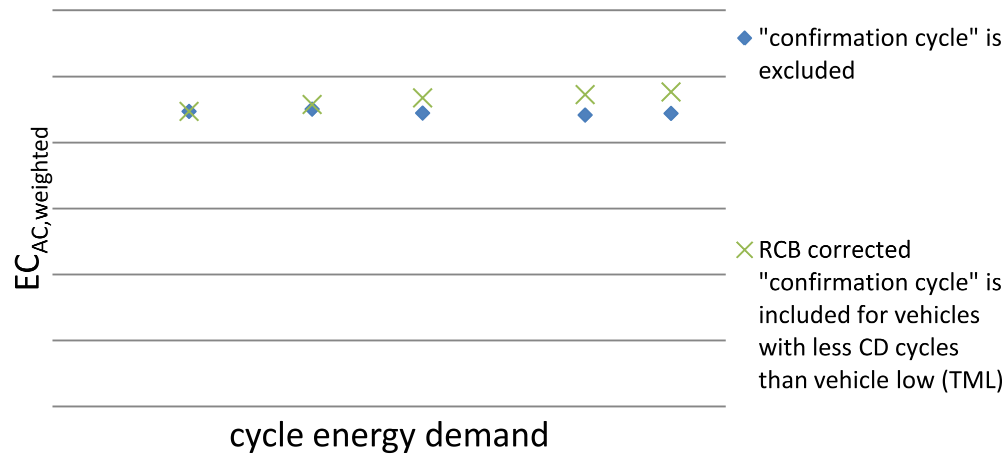
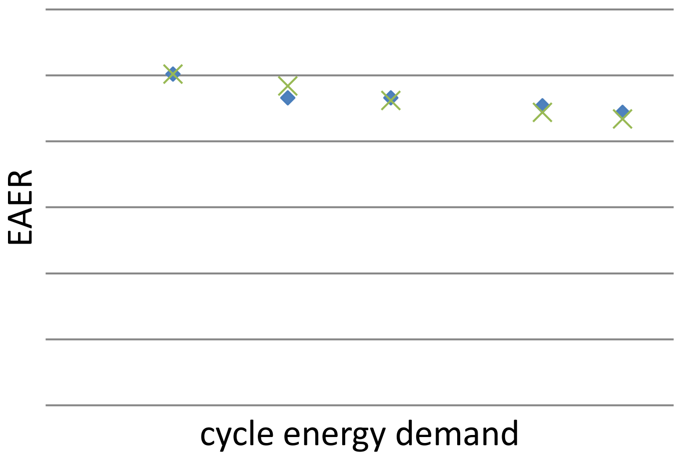
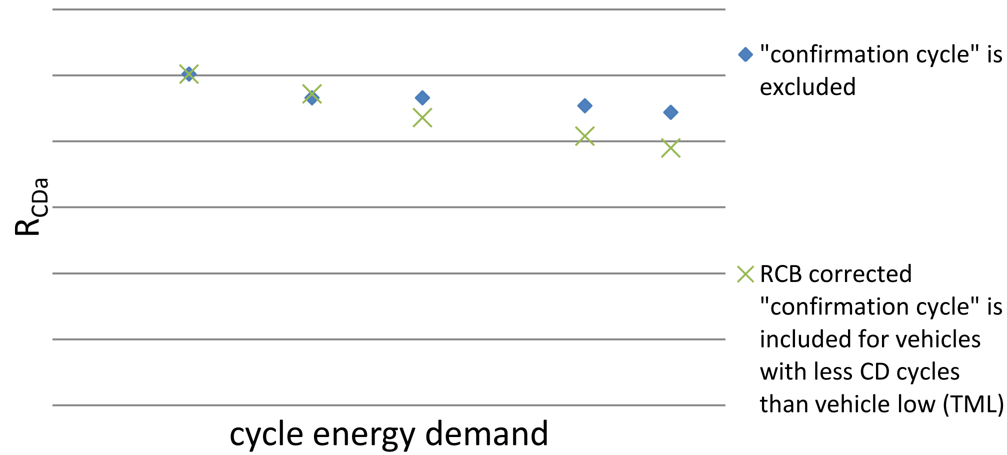
RESULTS (2).









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RESULTS (3).

value	interpolation with RCDC family criterion using old calculation	interpolation without RCDC family criterion using the old calculation	interpolation with adjusted RCDC family criterion using a new methodology
$M_{CO2,CD}$	OK	NOK	OK
$M_{CO2,CS}$	OK	OK	OK
$M_{CO2,weighted}$	OK	OK	OK
FC_{CD}	OK	NOK	OK
FC_{CS}	OK	OK	OK
$FC_{weighted}$	OK	OK	OK
$EC_{AC,CD}$	OK	NOK	OK
$EC_{AC, weighted}$	OK	OK	OK
EC	OK	NOK	OK
E_{AC}	interpolation is not necessary because other family criteria ensure a similar recharged energy (e.g. same storage, converter,...)	interpolation is not necessary because other family criteria ensure a similar recharged energy (e.g. same storage, converter,...)	interpolation is not necessary because other family criteria ensure a similar recharged energy (e.g. same storage, converter,...)
R_{CDC}	OK	NOK	OK
AER	NOK, but can be handled with AER-RCDa-ratio criterion	NOK (but can be handled with AER-RCDa-ratio criterion)	NOK, but can be handled with AER-RCDa-ratio criterion
EAER	OK	OK	OK
R_{CDa}	OK	OK	OK

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FINAL RECOMMENDATION.

Due to the advantages:

-better linearity and

-the possibility to build one OVC-HEV family even if there is one R_{CDC} switch

the proposed and analysed adjusted methodology is recommended.

I ▶ Replace the requirement "same RCDC" within one OVC-HEV interpolation family with: $n_{\text{transitioncycle},TML} - n_{\text{transitioncycle},TMH} \leq 1$

" The difference between the number of charge-depleting cycles shall not exceed the amount of one." ➔

II ▶ Add the following text to Annex 8:
In case that the amount of charge-depleting cycles is not the same for vehicle low (TML) and vehicle high (TMH), the "confirmation cycle" for the break-off criterion shall be corrected and used for the vehicle with less amount of charge-depleting cycles.