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: $$EAER_p = \frac{\left(M_{CO2,CS,p} - M_{CO2,CDavg,p}\right)}{M_{CO2,CS,p}} \cdot d_p \cdot n_p \Rightarrow n_p = \mathrm{int}\left(\frac{R_{CDa,p}}{d_p}\right) + 1$$
- 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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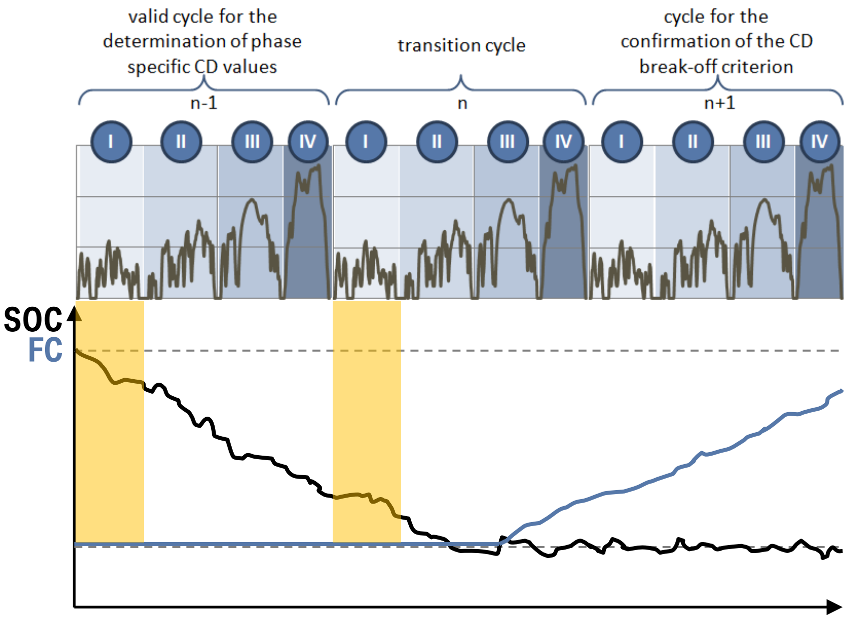
PHASE SPECIFIC EQUIVALENT ALL ELECTRIC RANGE.



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

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

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

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

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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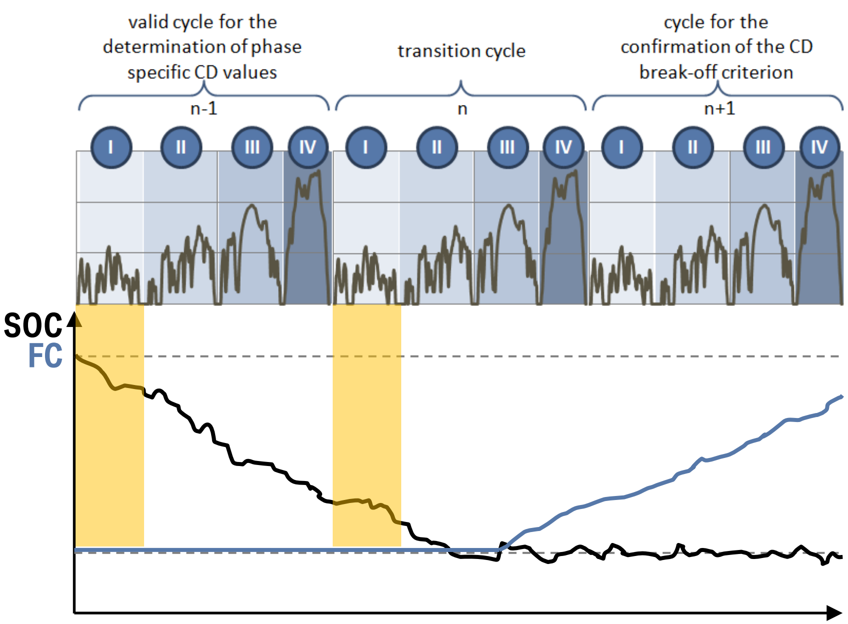
PHASE SPECIFIC EQUIVALENT ALL ELECTRIC RANGE.



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

$M_{CO2,CDavg,p}$ 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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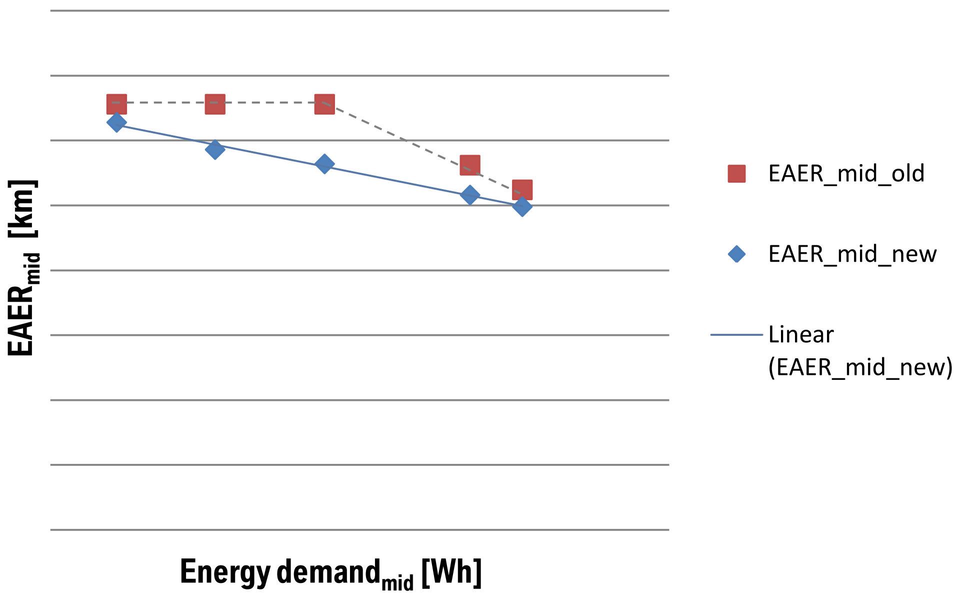
PHASE SPECIFIC EQUIVALENT ALL ELECTRIC RANGE.



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

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

- 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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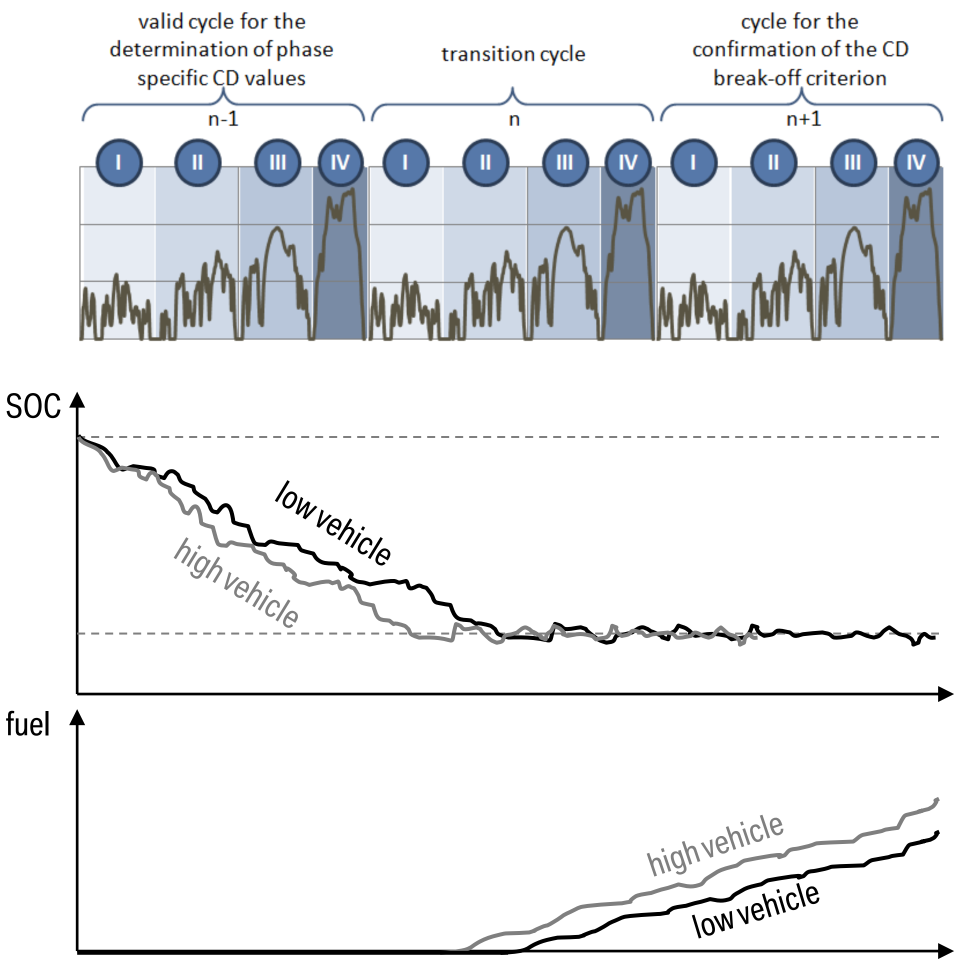
DIFFERENT CASES WITHIN ONE INTERPOLATION FAMILY.



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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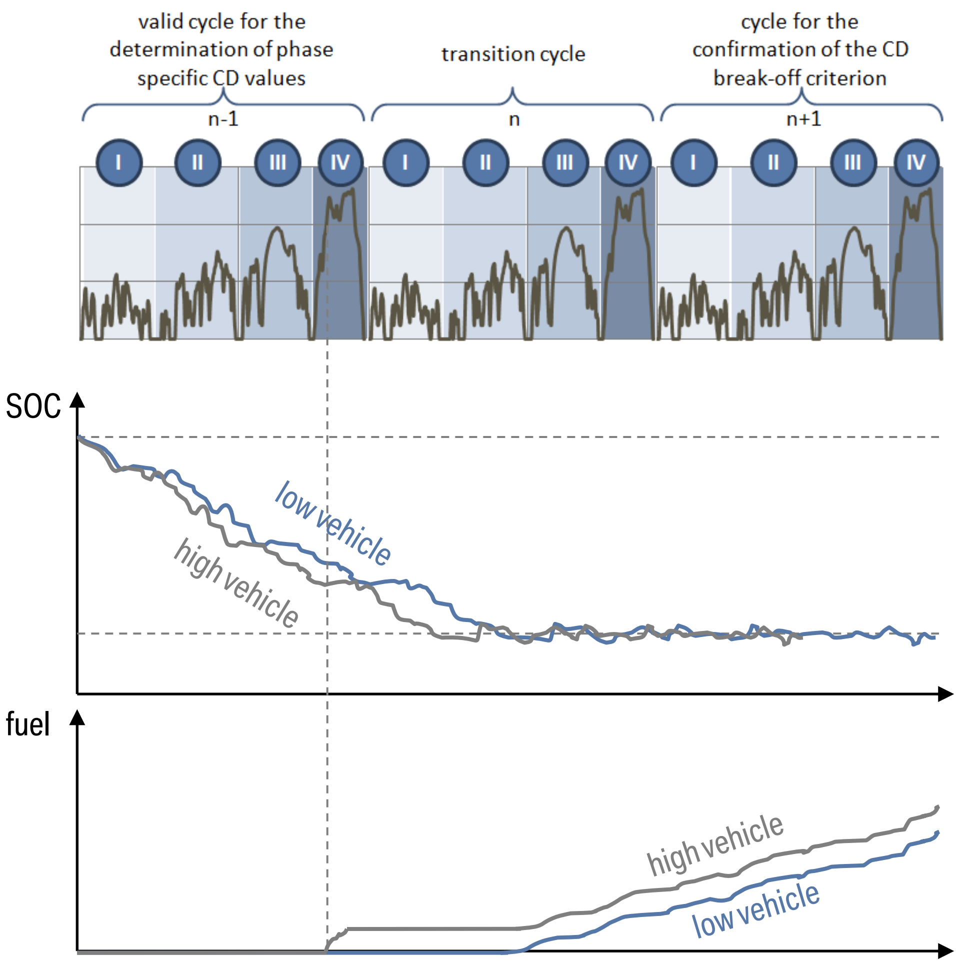
DIFFERENT CASES WITHIN ONE INTERPOLATION FAMILY.



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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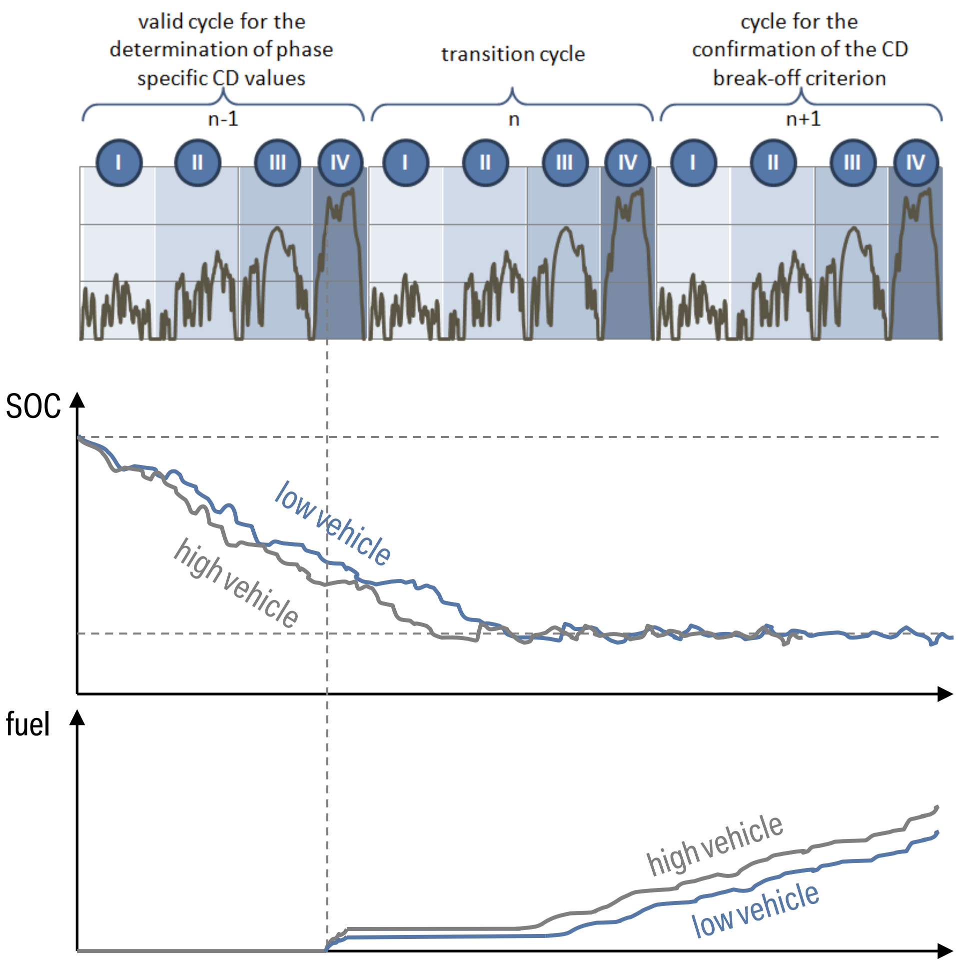
DIFFERENT CASES WITHIN ONE INTERPOLATION FAMILY.



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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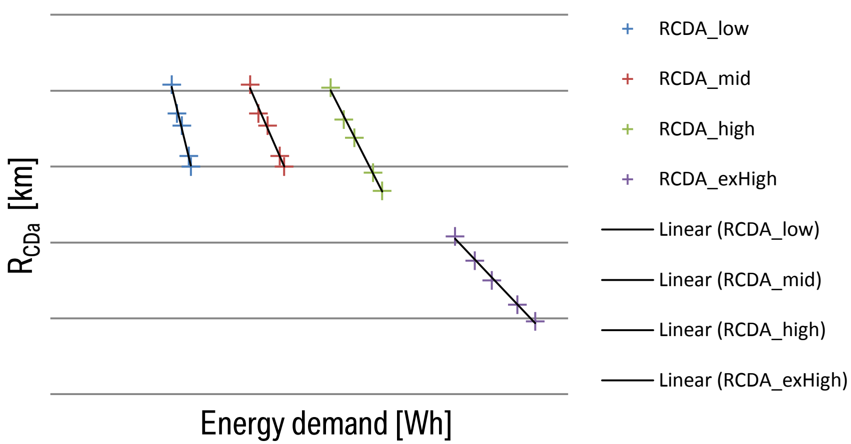
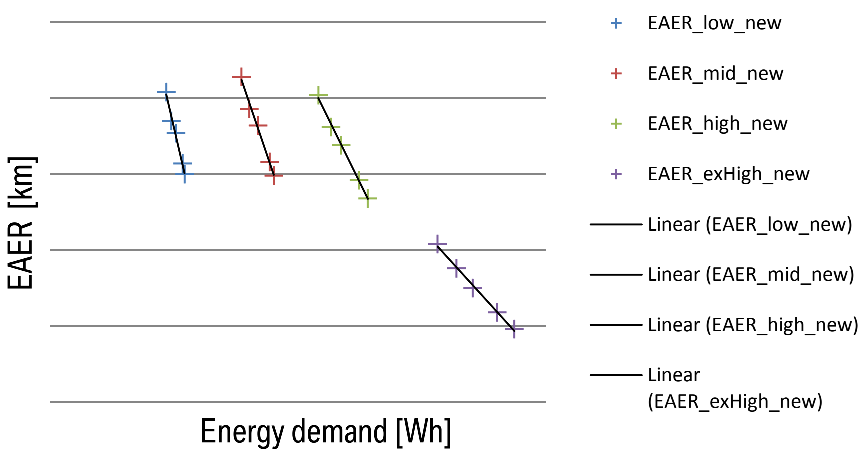
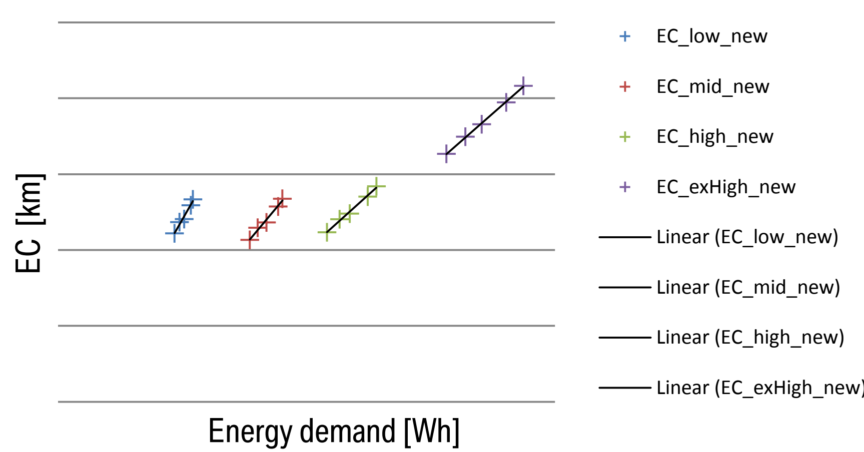
1ST CASE RESULTS.



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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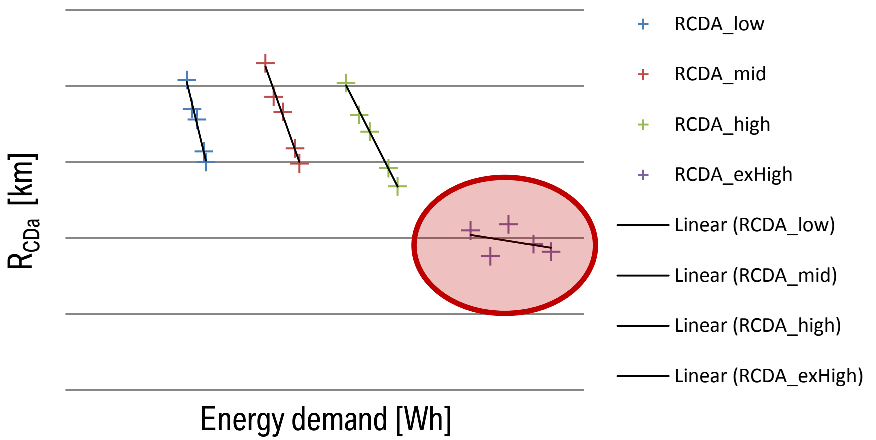
2ND CASE RESULTS.



2nd case within a vehicle family

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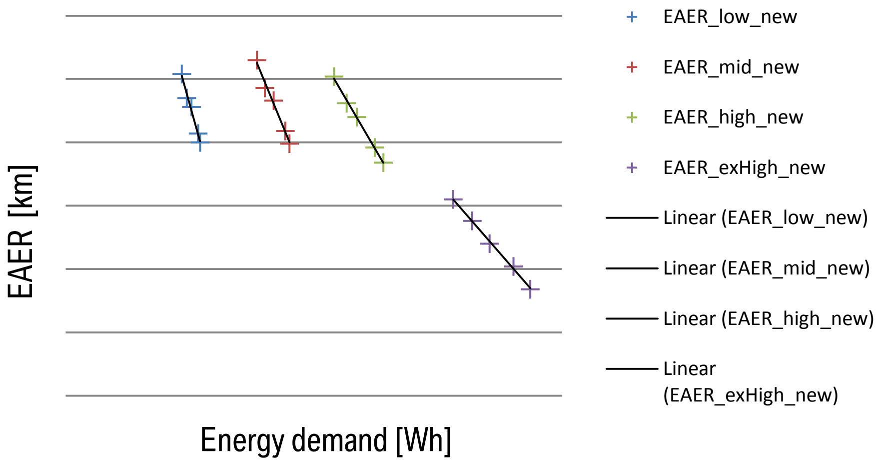
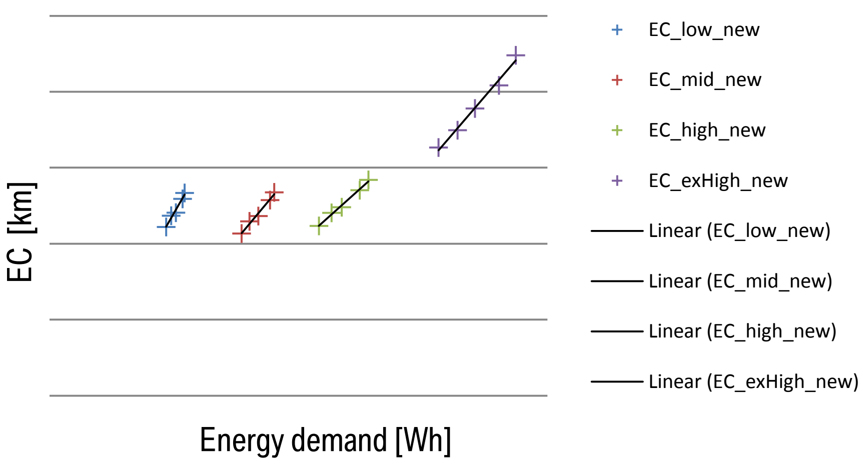
- Performance of the electric power train is higher than the power demand of the low vehicle.

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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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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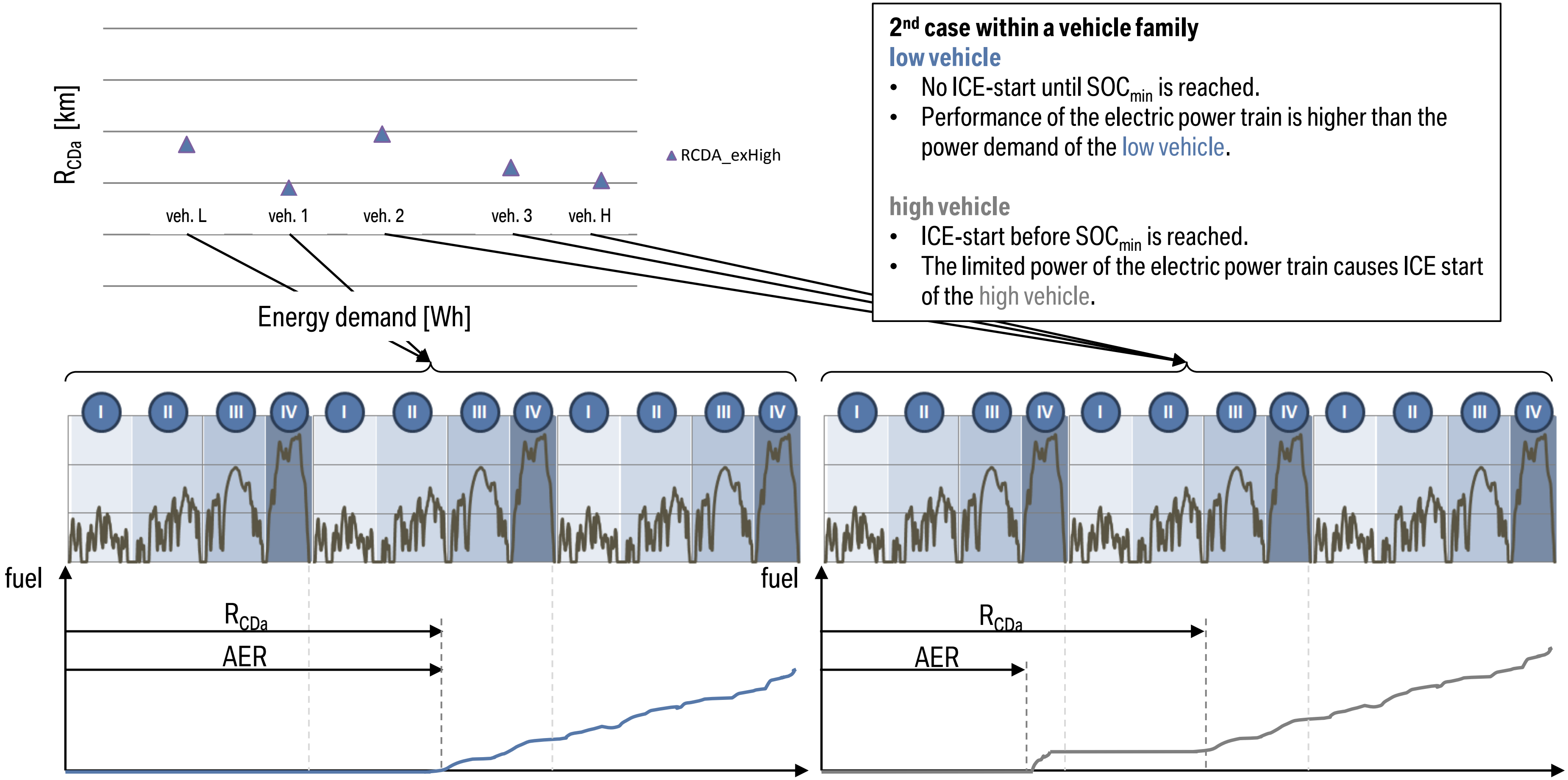
2ND CASE PROBLEM.



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.

high vehicle

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

▶ 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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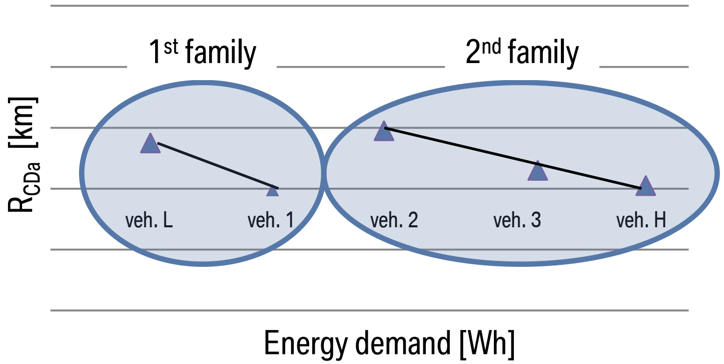
POTENTIAL 2ND CASE SOLUTIONS.

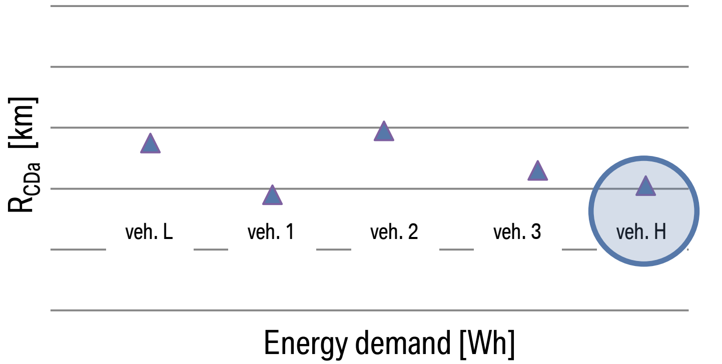
1st solution:

▶ 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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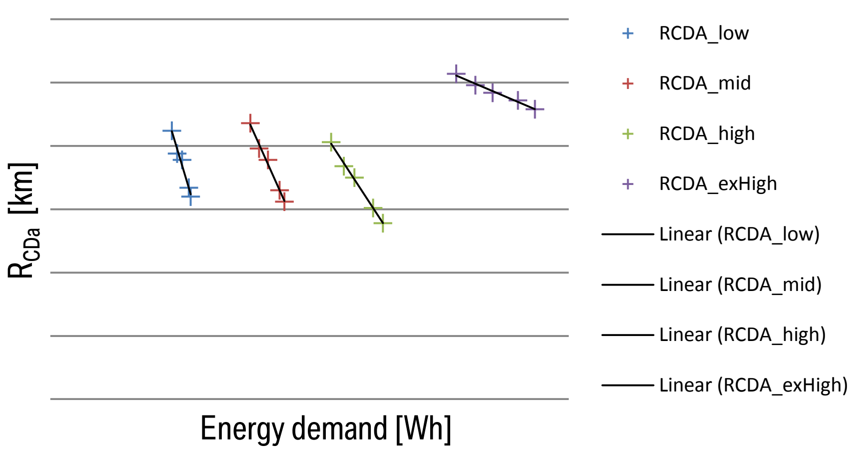
3RD CASE RESULTS.



3rd case within a vehicle family

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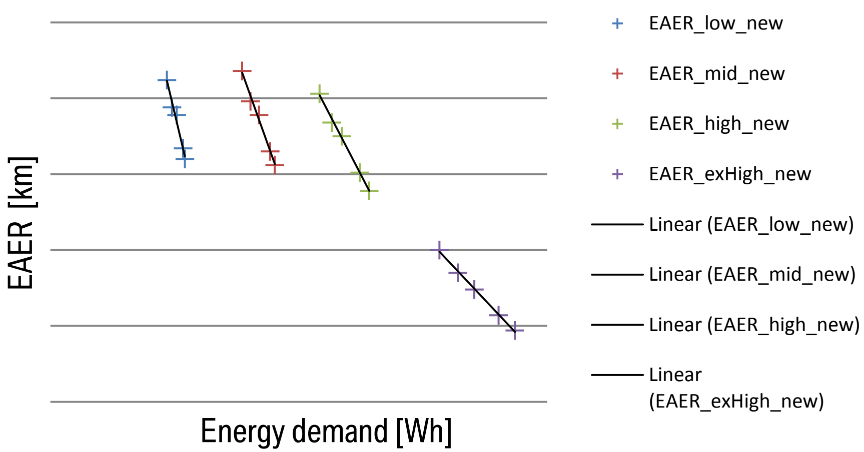

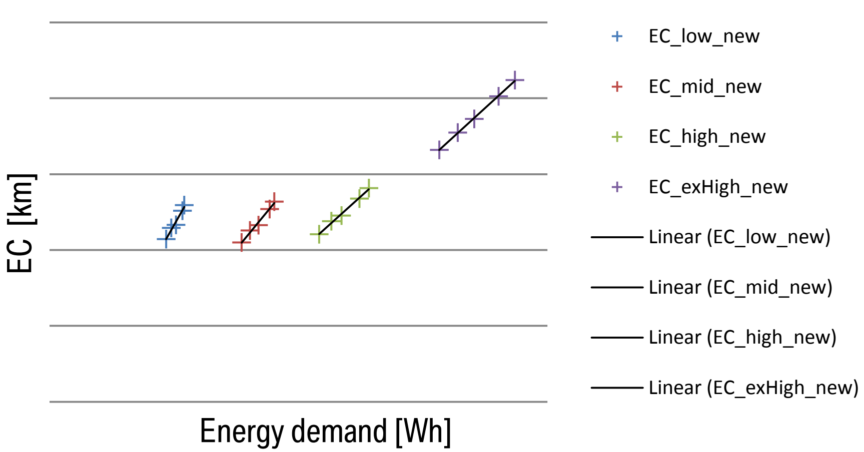

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FINAL RECOMMENDATION.

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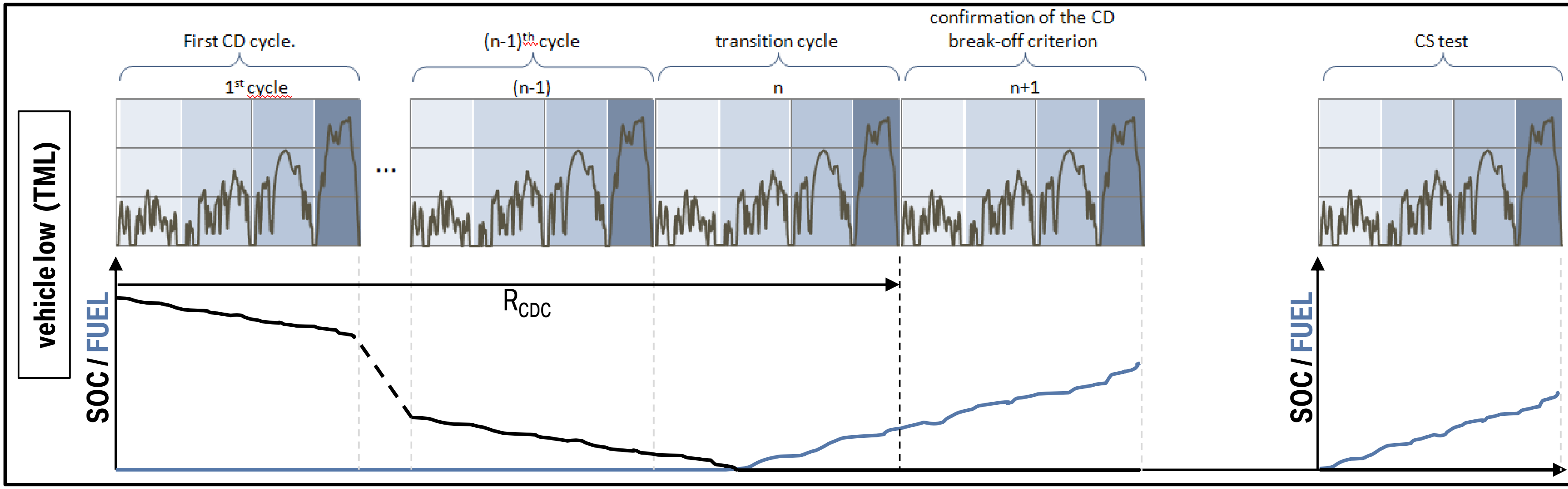
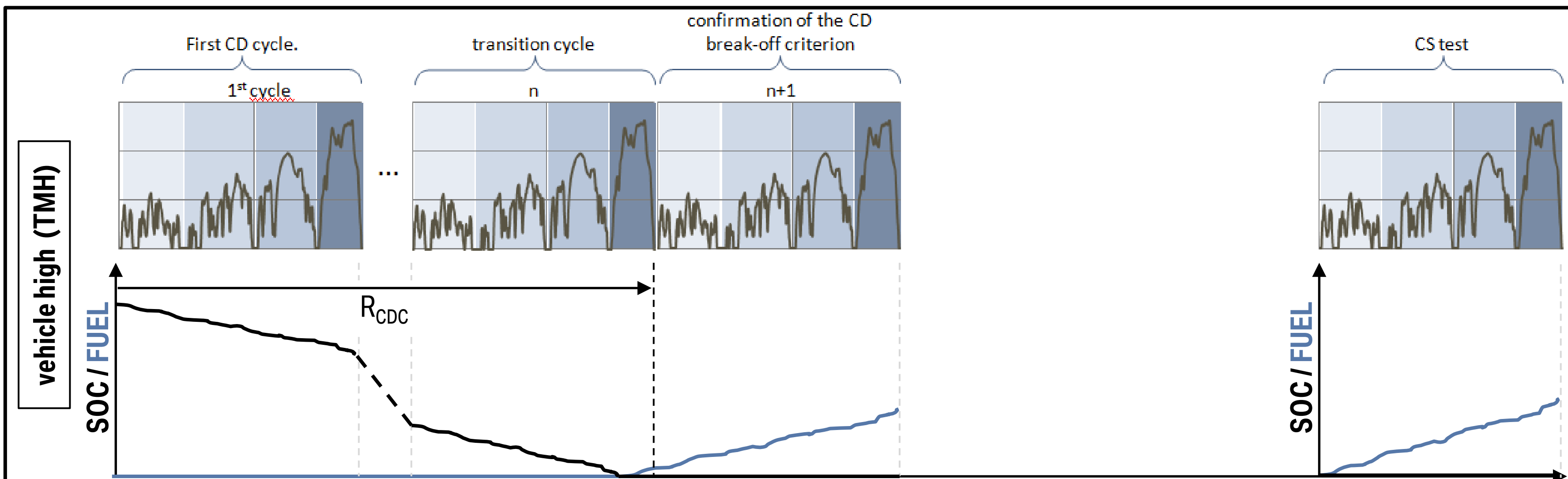
WHAT IS THE PROBLEM OF A DIFFERENT R_{CDC}?





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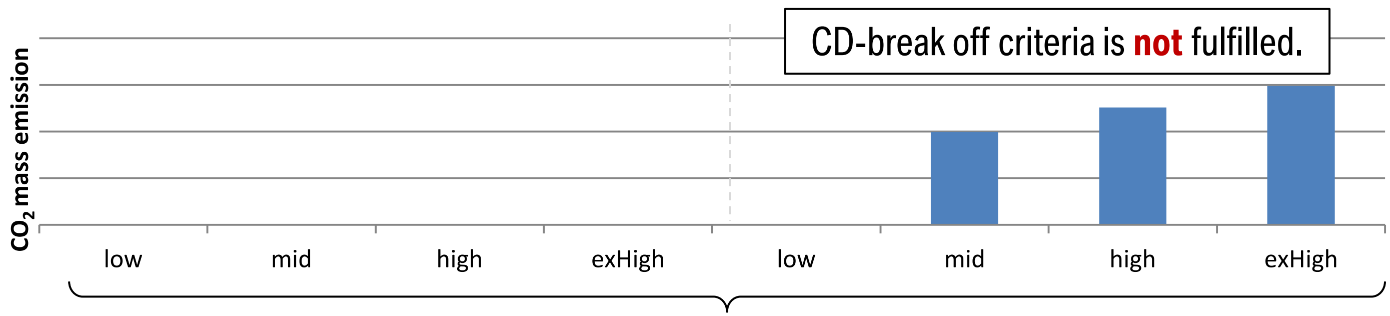
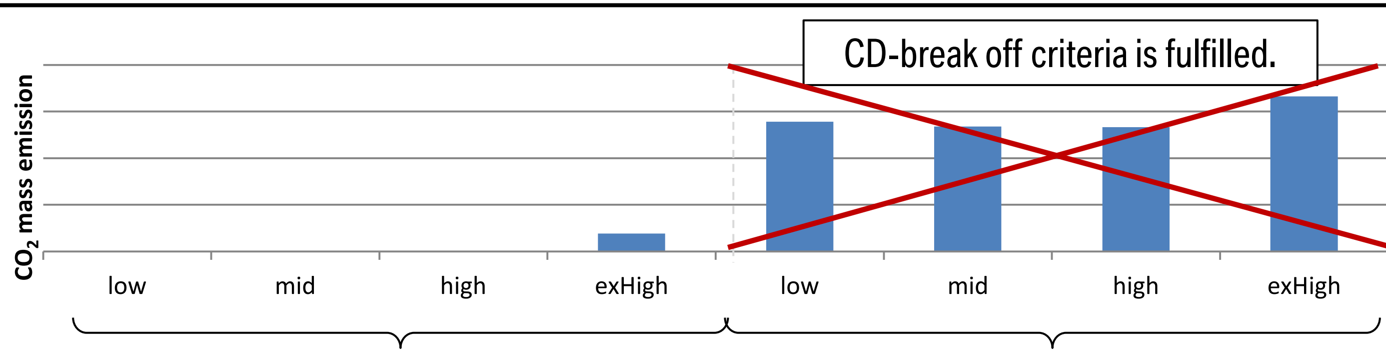
WHAT IS THE PROBLEM OF A DIFFERENT R_{CDC}?

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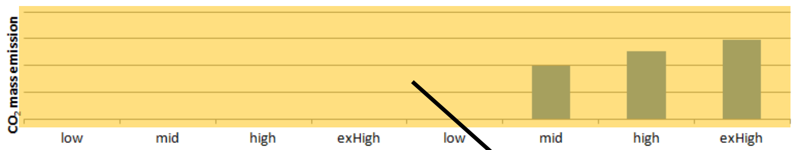
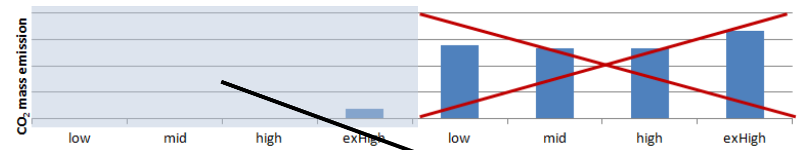
EXAMPLE: WHAT IS THE PROBLEM OF A DIFFERENT R_{CDC}?

vehicle low (TML)

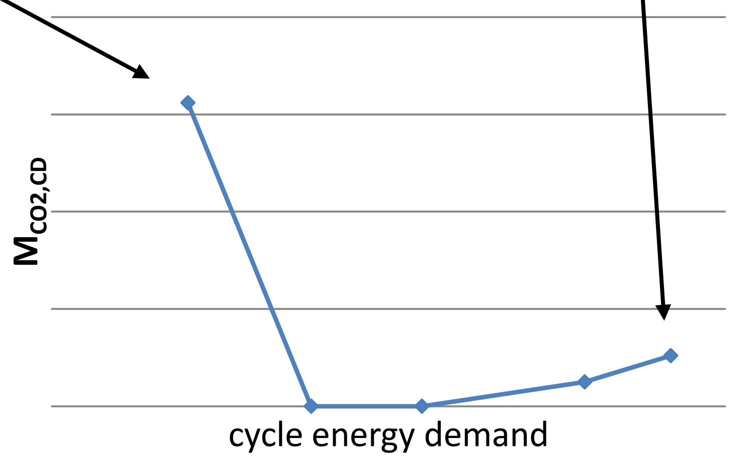


$$M_{CO2,CD} = \frac{\sum_{j=1}^{k} \left(UF_j \times M_{CO2,CD,j} \right)}{\sum_{j=1}^{k} UF_j}$$

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." ➔ $n_{\mathrm{transitioncycle},TML} - n_{\mathrm{transitioncycle},TMH} \leq 1$

- 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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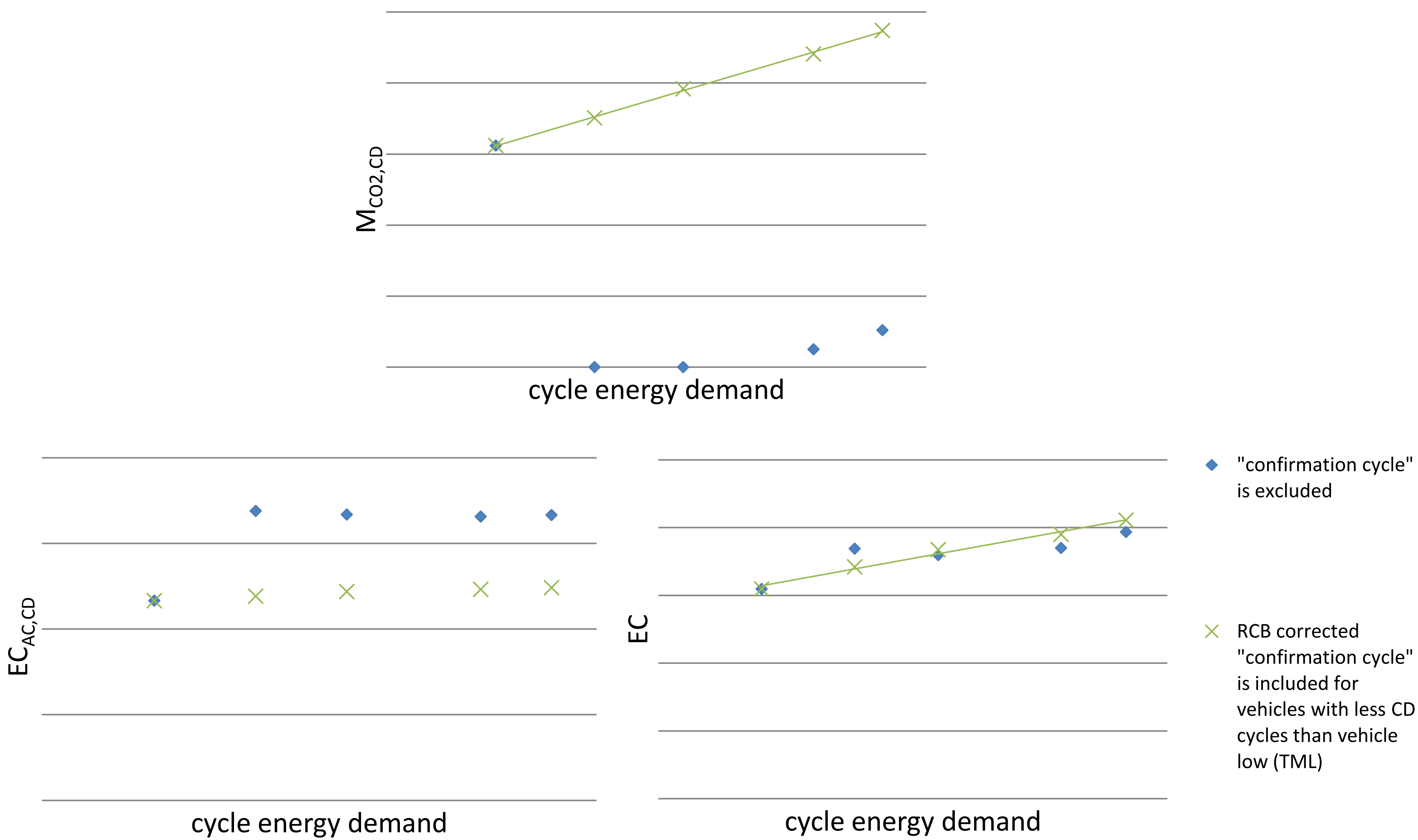
RESULTS (1).



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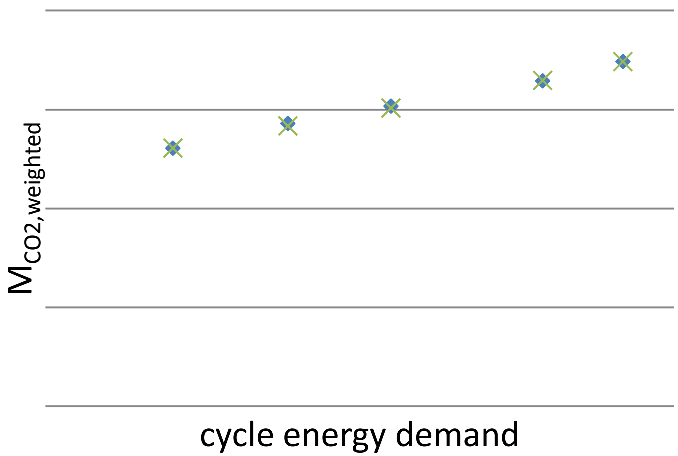
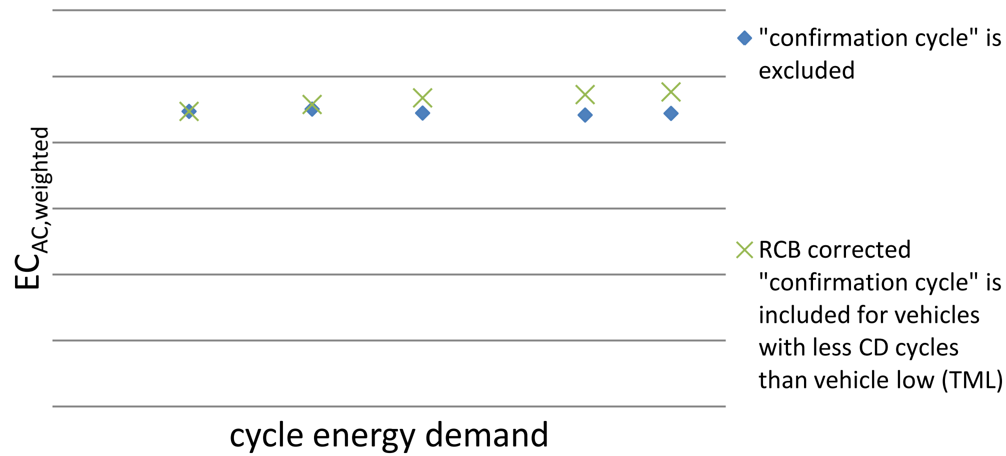
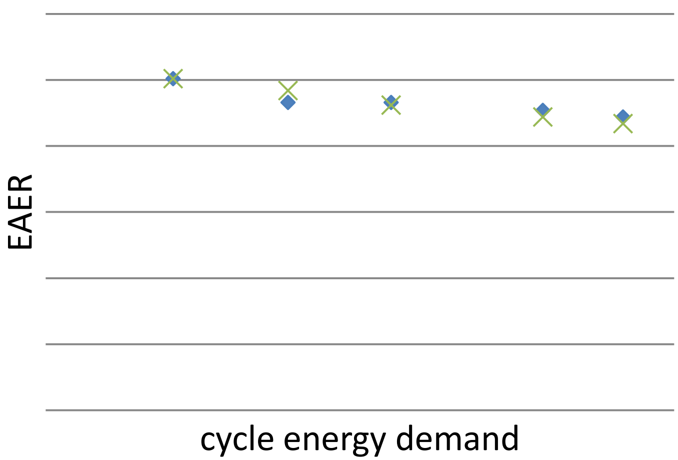
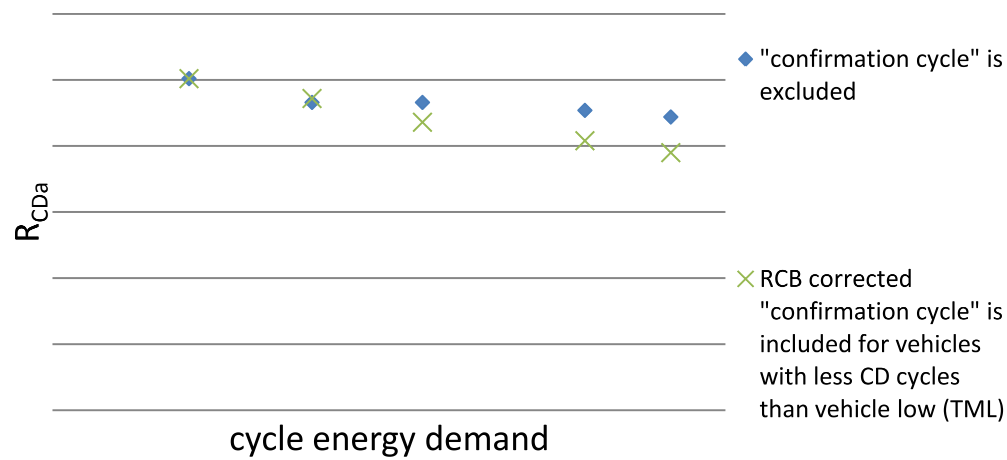
RESULTS (2).









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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

WLTP – COMBINED APPROACH FOR OVC-HEV.

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.