

Study on Drive Trace Index

~ Proposal of applicable drive trace indexes and
criteria~

Prepared by Japan
18th WLTP IWG
18-20 April 2017

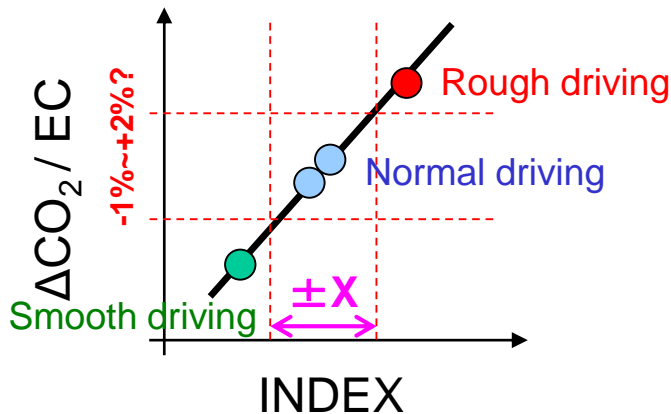
Approach for possible criteria

◆ Consideration of the possible criteria

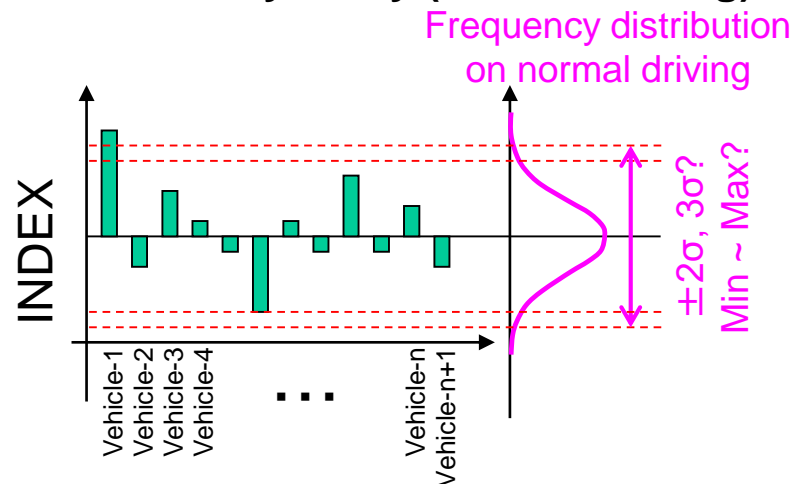
1. based on the relationship between each index and performance values (CO₂, EC, range)
2. based on the feasibility study (Check the deviation of each index under the Normal driving*)

*) Normal driving: trace the target speed as much as possible

1. Relationship between each index value and performance value



2. Feasibility study (Normal driving)



Proposed criteria and next action

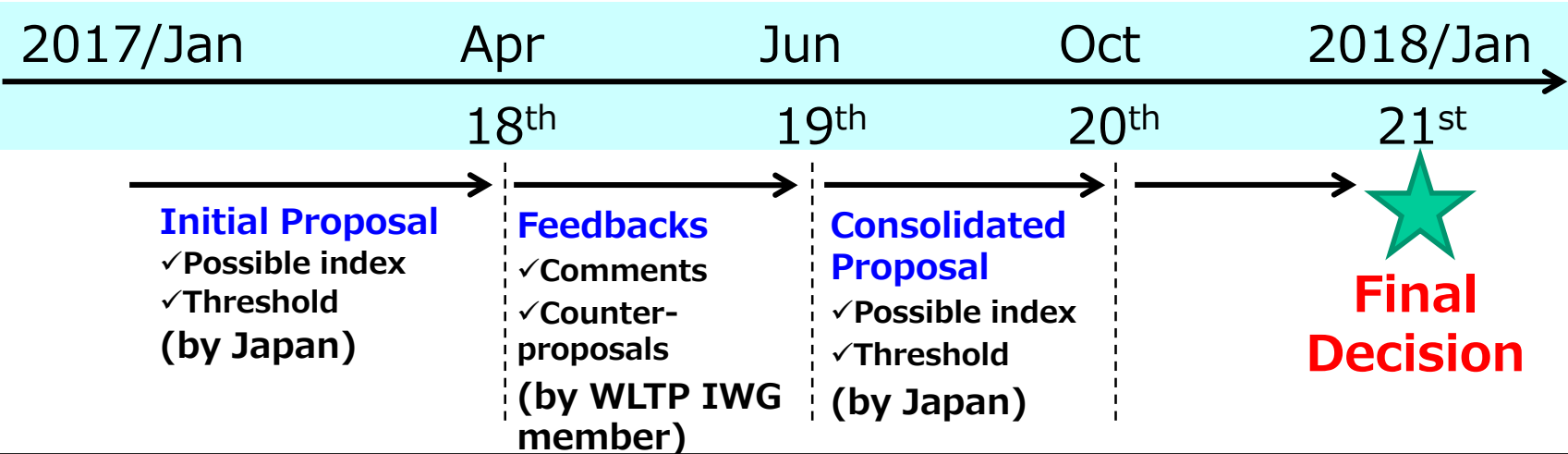
1. Tentative proposed indexes and criteria

INDEX	Proposed Criteria
RMSSE (km/h)	< +0.8
IWR (%)	-2.0 ~ +4.0

*) need further study on unique vehicle configurations (i.e. single clutch Automated Manual Transmission)

*) Apply only for type approval test (not apply for CoP)

2. Next actions



Summary of study on drive trace index

- ASCR, IWR and RMSSE are significantly changed according to the driving style. On the other hand it was also observed that ER, DR and EER are not able to detect intentional smooth/rough driving.
- Both ASCR and IWR relate to acceleration. The IWR value is approximately equal to ASCR. Since IWR takes into account vehicle speed in addition to acceleration, IWR express approximated engine power ($P \approx V \cdot A$).
- RMSSE value always become large when the speed deviations are observed. RMSSE has an ability to evaluate conformity between the actual and target speeds.
- According to the relationship between drive trace index and performance parameter, if the CO2 impact for ICE vehicles is limited to in the range from -1% to +2%, the range of IWR should be set from -2.0 to +4.0.
- The impact on performance parameter for the electrified vehicles is lower than that of ICE vehicles. However, since the electrified vehicles is driven by motor and it doesn't have a transmission, the electrified vehicles follow the target speed more easily and then the drive trace indexes become smaller.
- According to feasibility study, almost of RMSSE values under the normal driving were less than 0.8 and almost of IWR values were in the range from -2.0 to +4.0.
- Thus, the proposed indexes and threshold should be set "IWR: -2.0~+4.0 and RMSSE: <+0.8"
- The specific threshold value for IWR and RMSSE can be positive alternative of "normalization" which will not work for electrified vehicles.


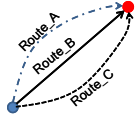
Comparison table

Indexes	ICE	HEV	OVC-HEV		PEV		Feasibility	Past proposals				
	CO2 deviation (+/- 2.0 %)	CO2_CS deviation (+/- 2.0 %)	EAER deviation (+/- 2.0 %)	EC_AC, weighted deviation (+/- 2.0 %)	EC deviation (+/- 2.0 %)	PER deviation (+/- 2.0 %)	JAMA data	PSA 2013*	FORD 2015*	BMW HS 2015	HONDA 2015	JPN 2015
	LMH/ LMHxH	LMH/ LMHxH	LMHxH	LMHxH	LMH/ LMHxH	LMH/ LMHxH	LMH/ LMHxH	LMHxH (phase)	LMHxH	LMHxH	-	-
ER	+/- 1.0	-3.0 ~ +1.0	-3.0 ~ +1.5	+/- 4.0	-3.0 ~ +0.5	-3.0 ~ +1.5	-	-	-	-	-	-
DR	-	-	-	-	-	-	-	-	-	-	-	-
EER	+/- 1.0	-3.0 ~ +1.0	-3.0 ~ +1.5	-3.0 ~ +4.0	-2.5 ~ +1.5	-3.0 ~ +1.5	+/- 1.5	+/- 2.0 (+/- 4.0)	+	+/- 2.0	-	-
ASCR	-4.0 ~ +3.0	-5.0 ~ +2.0	-7.0 ~ +3.0	-7.0 ~ +9.0	-4.0 ~ +3.0	+/- 4.0	-2.0 ~ +4.0	+/- 6.0 (+/- 8.0)	-2.0 ~ +4.0	+/- 3.0	-1.0 ~ +3.0 (ICE) -2.0 ~ +3.0 (HEV)	-
IWR	+/- 4.0	-6.0 ~ +2.0	-10.0 ~ +4.0	-10.0 ~ +9.0	+/- 5.0	+/- 5.0	-2.0 ~ +4.0	-	IWR is very similar to ASCR	-	-	-2.0 ~ +4.0
RMSSE (km/h)	< +0.8	< +0.8	< +0.8	< +0.8	< +0.8	< +0.8	< +0.8	-	< +1.3	< +1.3	≤ +0.9	< +0.8

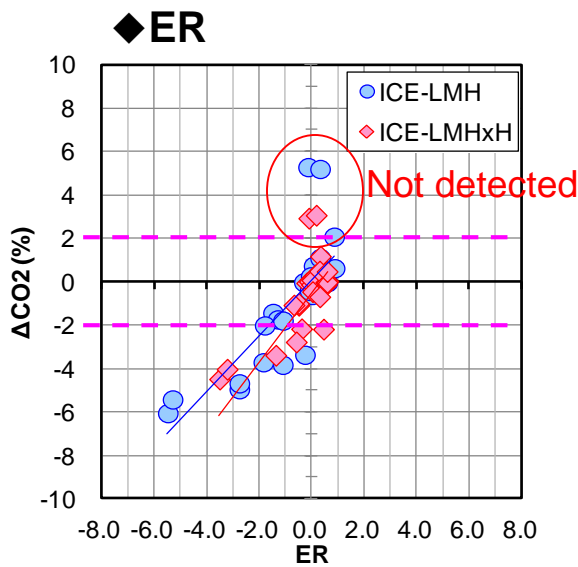
(*) PSA_WLTC Cycle violations status and proposals.pptx

(*) driving trace index - Ford - WLTP.pdf

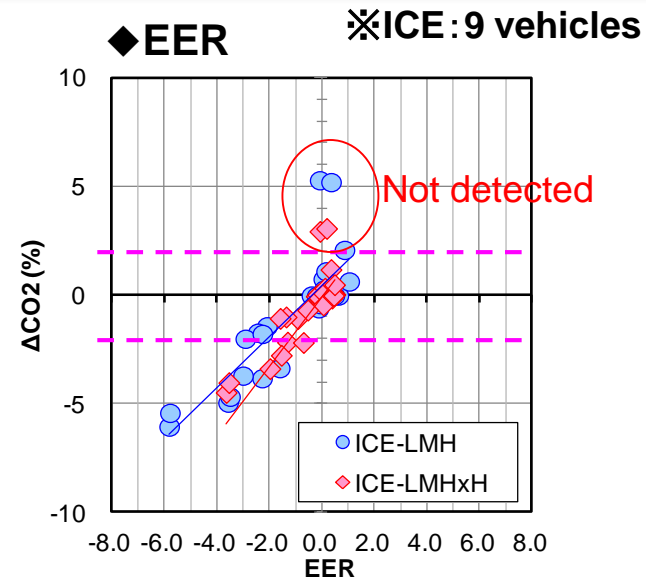
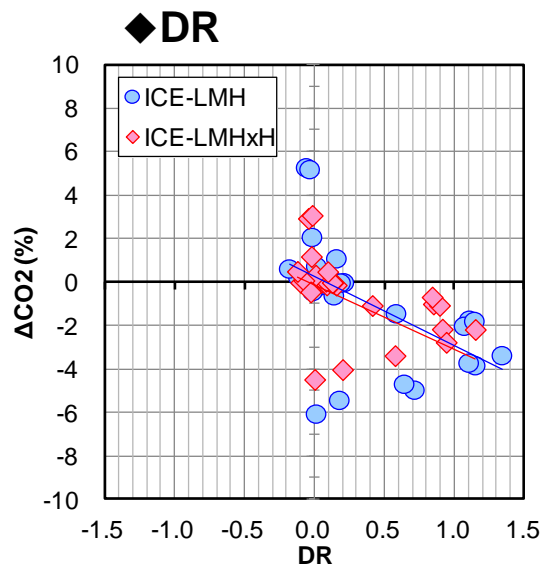
(Ref.) Characteristics of each index

INDEX	EVALUATION	CHARACTERISTICS
Energy Rating (ER)	Change rate on the cycle energy	<ul style="list-style-type: none"> • Capable of evaluating the change of driving energy. • It is not able to detect the driving style that repeat acceleration and deceleration. (Like a wave ) • The detection ability become lower if the extra-high phase is included. (Cycle energy of Ex-high is relatively bigger than that of L/M/H)
Distance Rating (DR)	Change rate on the distance	<ul style="list-style-type: none"> • Capable of evaluating the change of driving distance. • It is not able to detect the driving style that repeat acceleration and deceleration.
Energy Economy Rating (EER)	Change rate on the distance per energy	<ul style="list-style-type: none"> • Capable of evaluating the change of the distance per energy • Since EER consider both energy and distance, it can evaluate driving style more appropriately compared to ER and DR • It is not able to detect the driving style that repeat acceleration and deceleration. • The detection ability become lower if the extra-high phase is included. (Cycle energy of Ex-high is relatively bigger than that of L/M/H)
Absolute Speed Change Rating (ASCR)	Change rate on the integral of the absolute magnitude of acceleration	<ul style="list-style-type: none"> • Capable of evaluating the change of the integral of the absolute magnitude of acceleration • It is able to detect the driving style that repeat acceleration and deceleration • ASCR value doesn't change if the route from point A to point B is different. 
Root Mean Squared Speed Error (RMSSE)	Speed deviation	<ul style="list-style-type: none"> • RMSSE value always become large when the speed deviations are observed. RMSSE has a ability to evaluate conformity between the actual and target speeds. • It is not able to detect whether smooth driving or rough driving
Inertial Work Rating (IWR)	Change rate on the inertial work	<ul style="list-style-type: none"> • It is able to detect the driving style that repeat acceleration and deceleration • Since IWR takes into account vehicle speed in addition to acceleration, IWR express approximated engine power ($P \approx V \cdot A$)

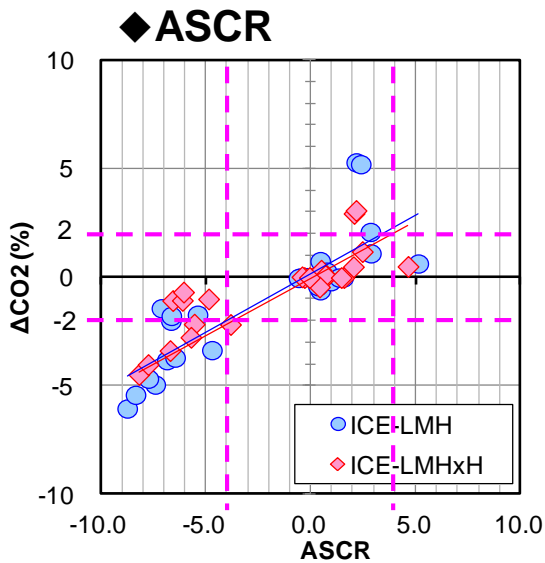
Relationship between indexes and CO2 of ICEVs



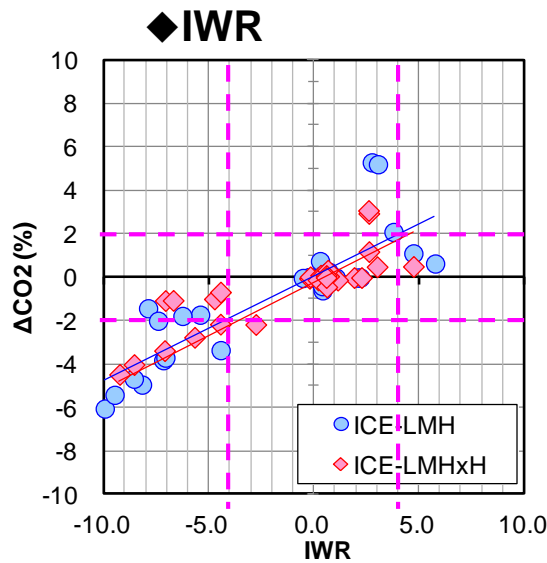
possible criteria: -



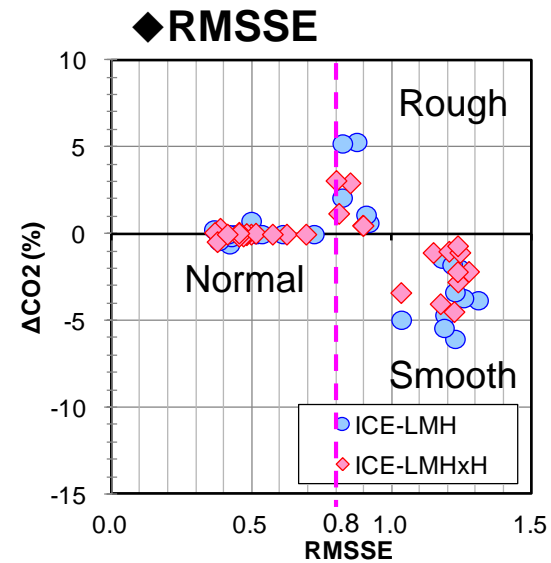
possible criteria: -



CO2: +/- 2% => ASCR: +/- 4.0

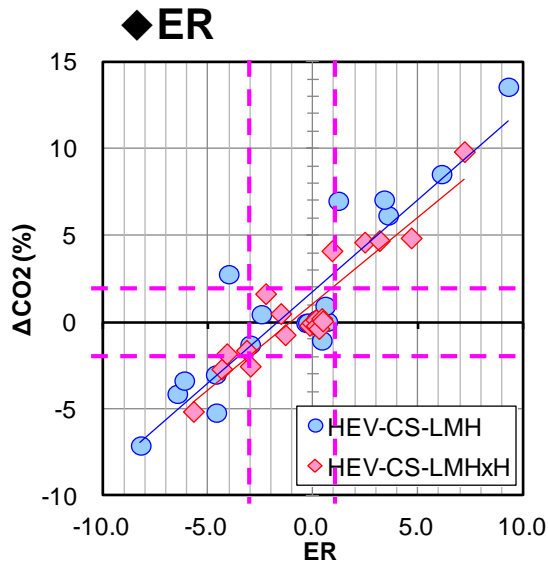


CO2: +/- 2% => IWR: +/- 4.0

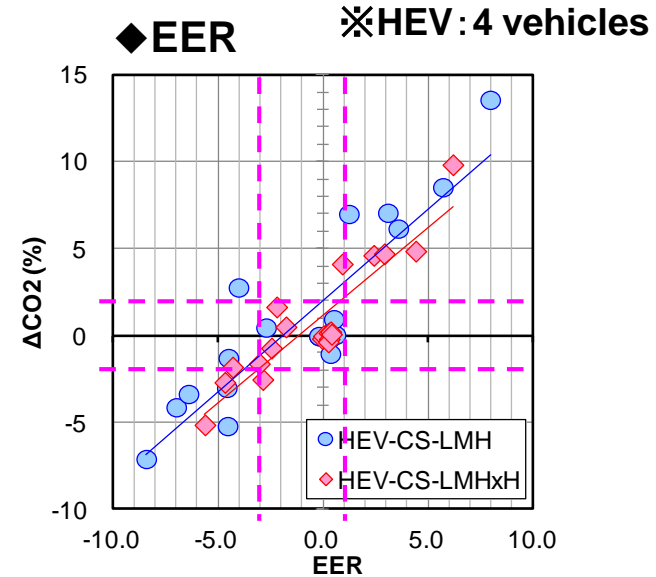
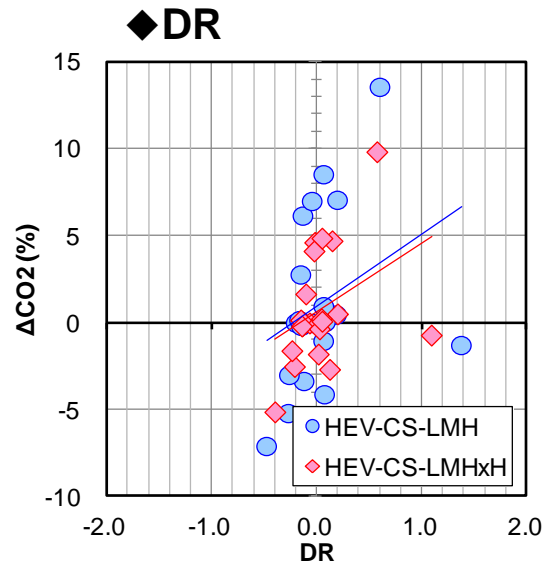


possible criteria: < +0.8

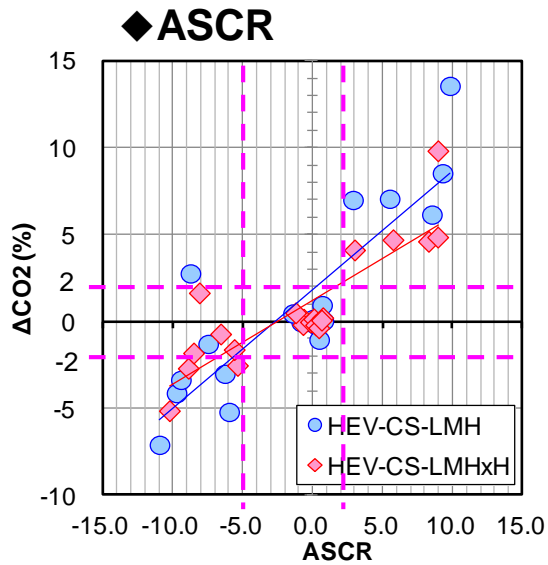
Relationship between indexes and CO2_CS of HEVs



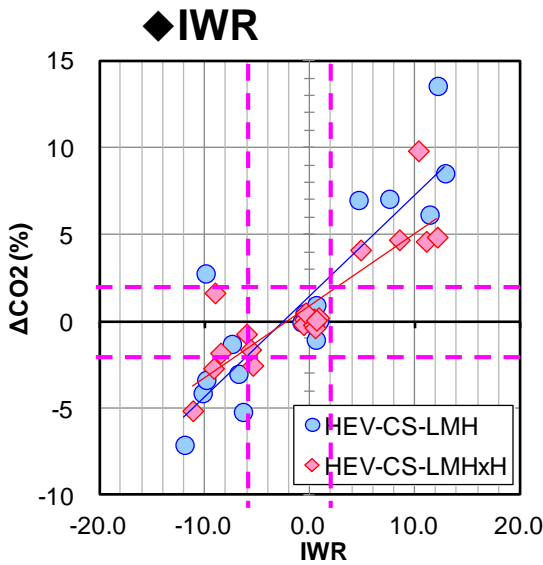
CO2: +/- 2% => ER: -3.0 ~ +1.0



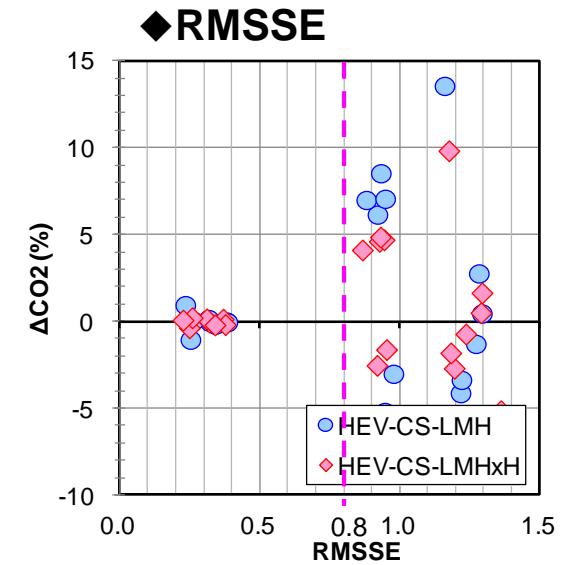
CO2: +/- 2% => EER: -3.0 ~ +1.0



CO2: +/- 2% => ASCR: -5.0 ~ +2.0

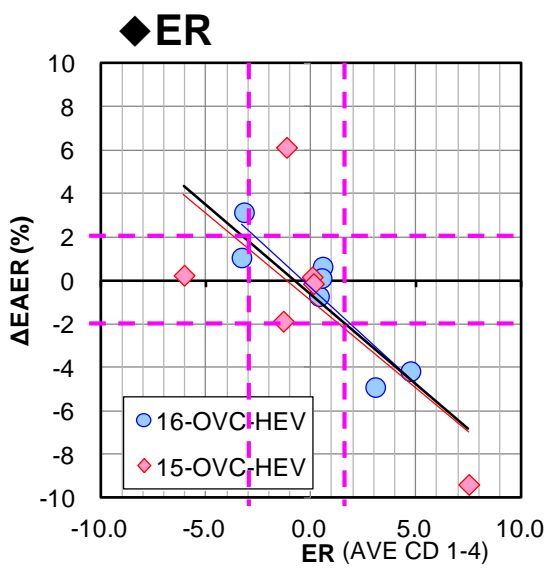


CO2: +/- 2% => IWR: -6.0 ~ +2.0

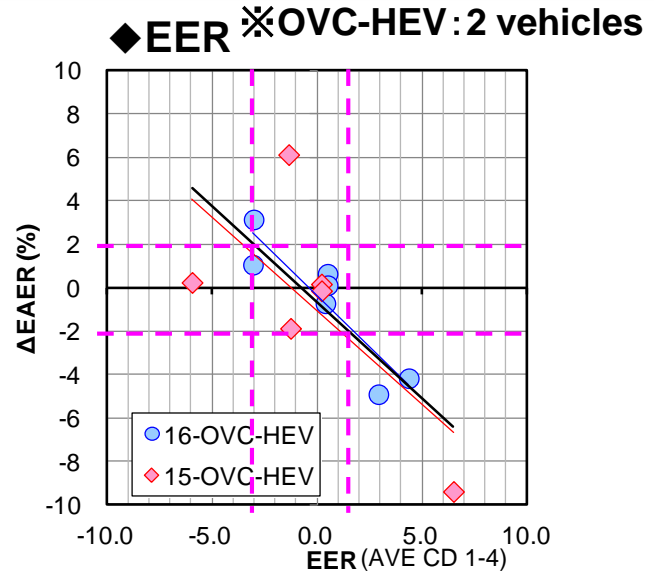
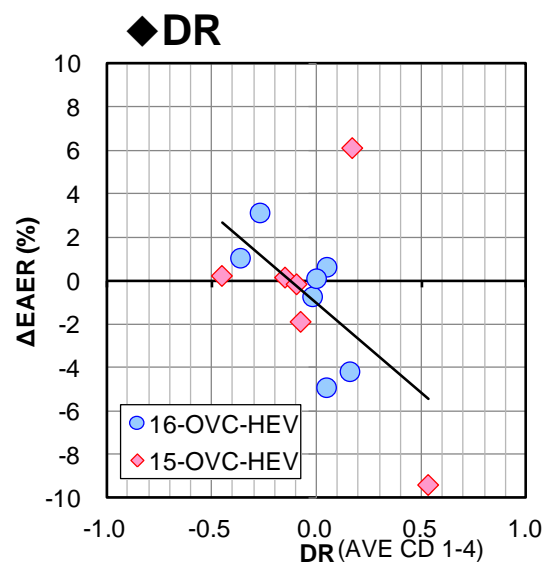


possible criteria: < +0.8

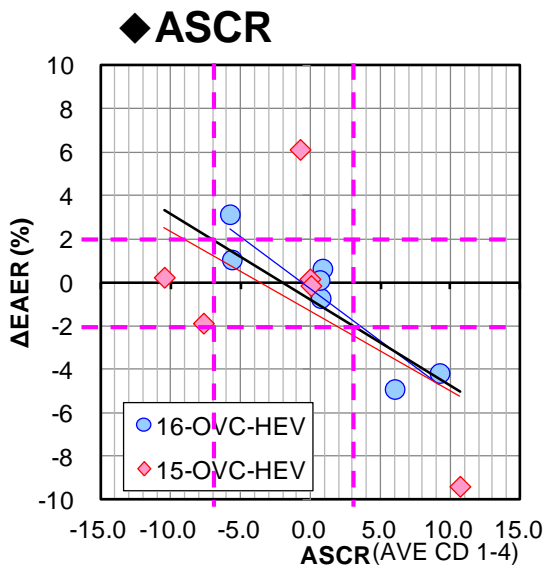
Relationship between indexes and EAER of OVC-HEV



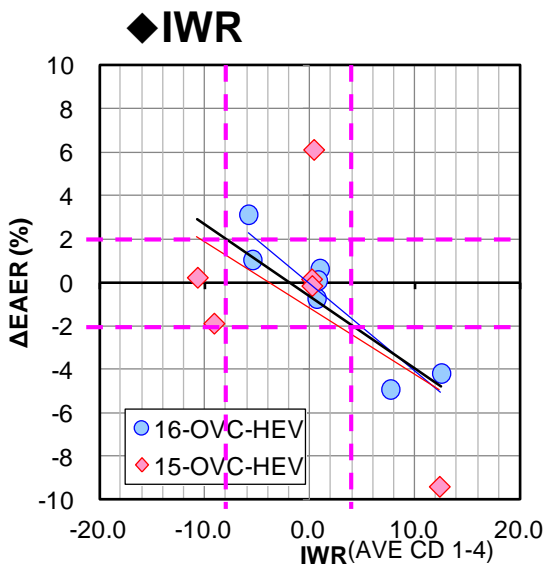
EAER: +/- 2% => ER: -3.0 ~ +1.5



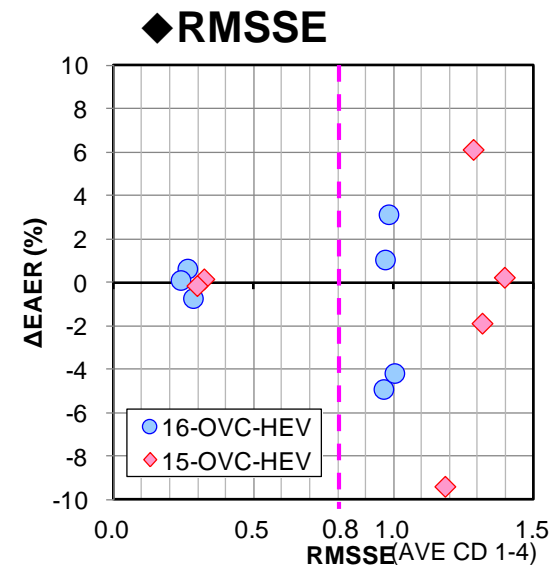
EAER: +/- 2% => EER: -3.0 ~ +1.5



EAER: +/- 2% => ASCR: -7.0 ~ +3.0

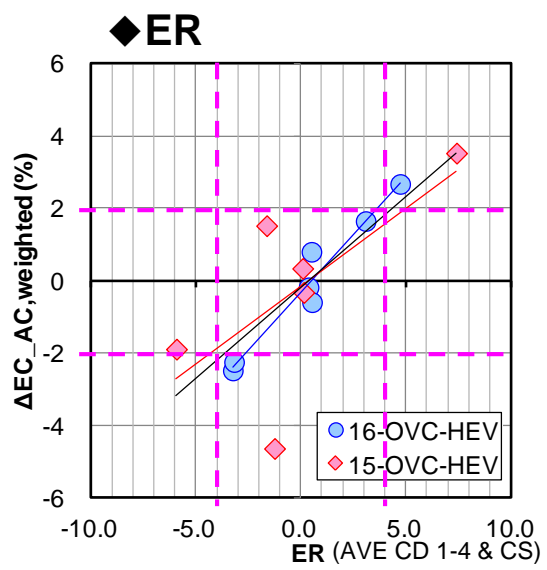


EAER: +/- 2% => IWR: -10.0 ~ +4.0

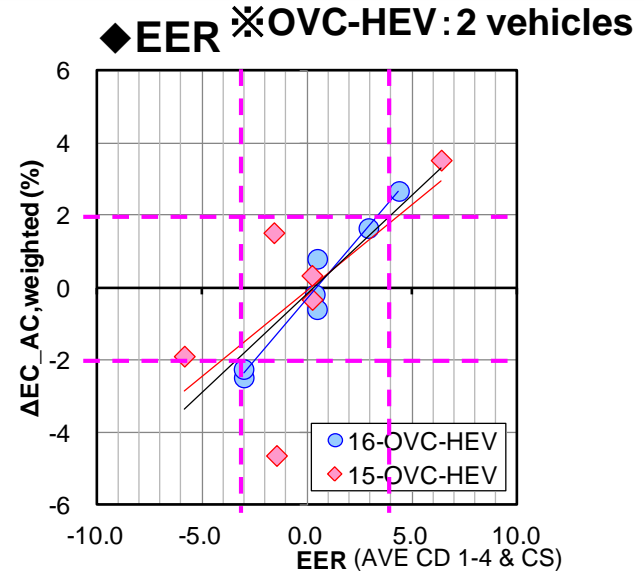
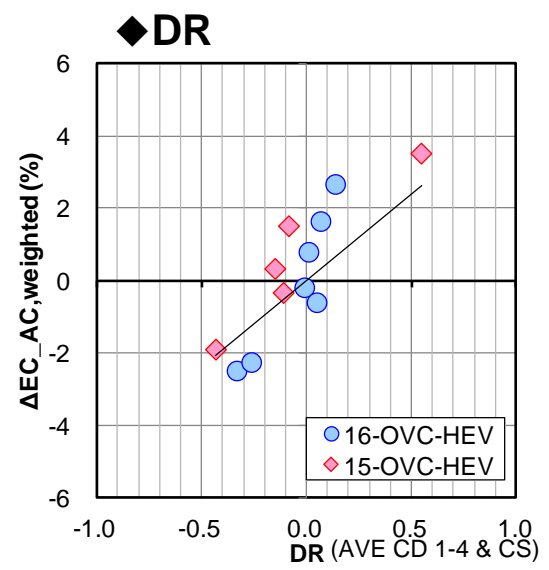


possible criteria: < 0.8

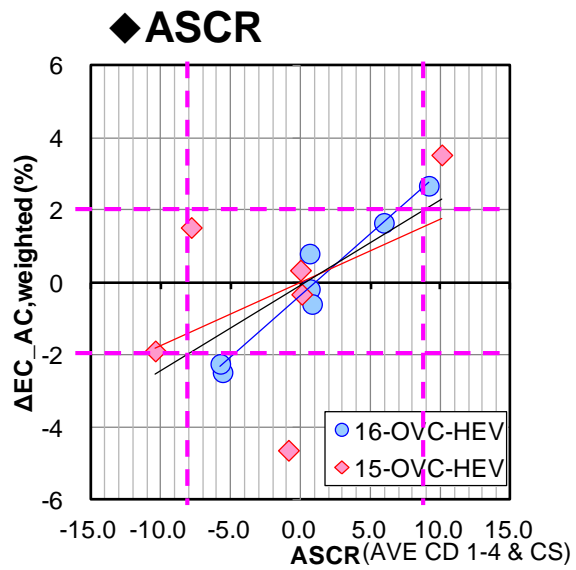
Relationship between indexes and EC_AC,weighted of OVC-HEV



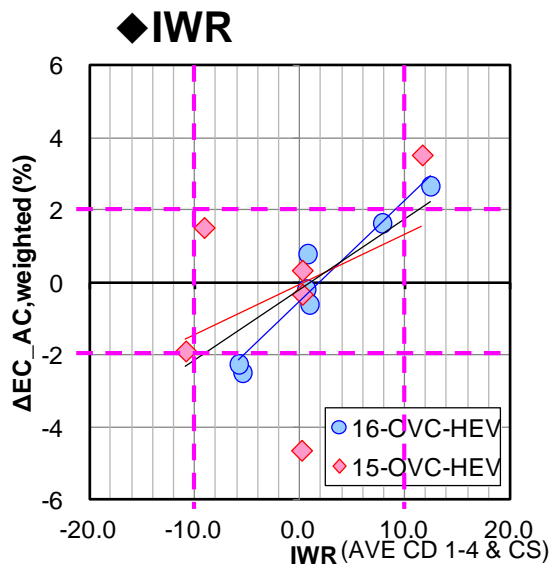
EC: +/- 2% => ER: +/- 4.0



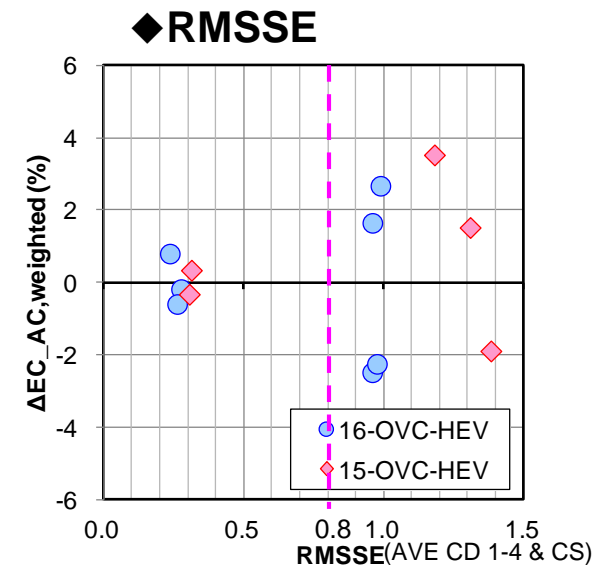
EC: +/- 2% => EER: -3.0 ~ +4.0



EC: +/- 2% => ASCR: -7.0 ~ +9.0

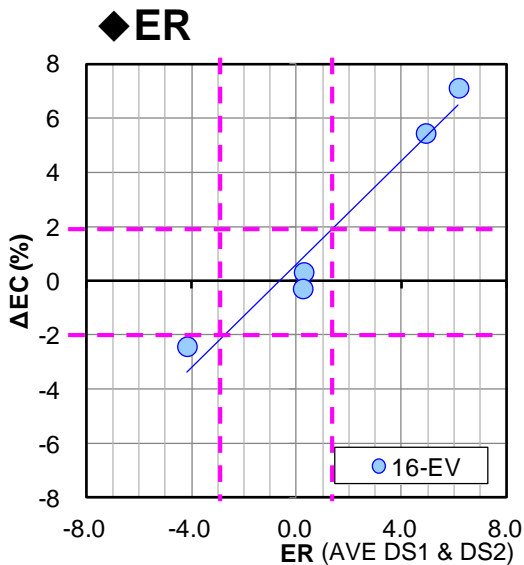


EC: +/- 2% => IWR: -10.0 ~ +9.0

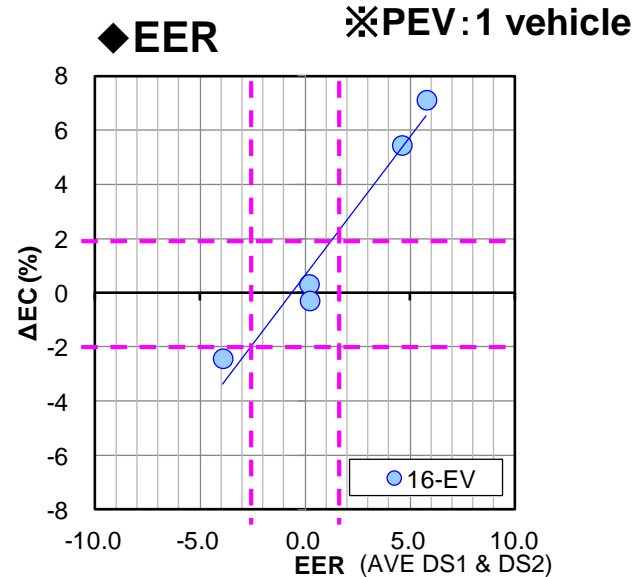
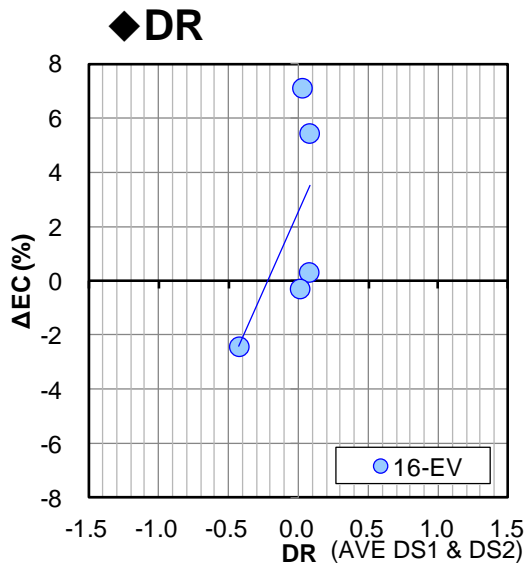


possible criteria: < +0.8

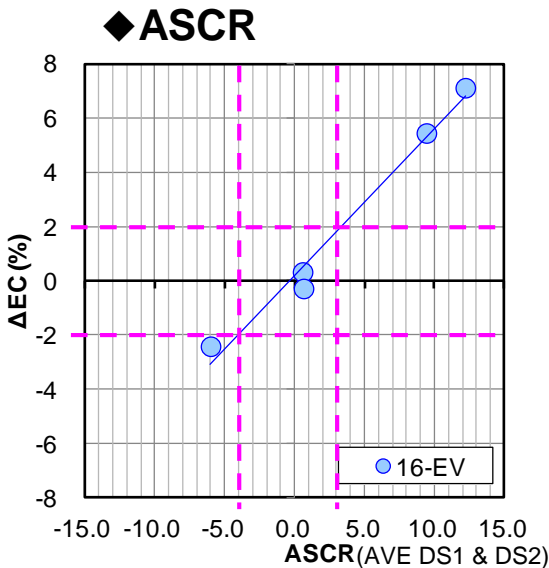
Relationship between indexes and EC of PEVs



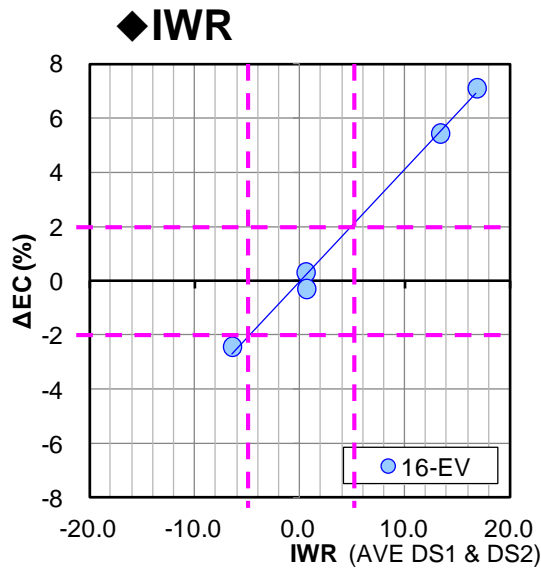
EC: +/- 2% => ER: -3.0 ~ +0.5



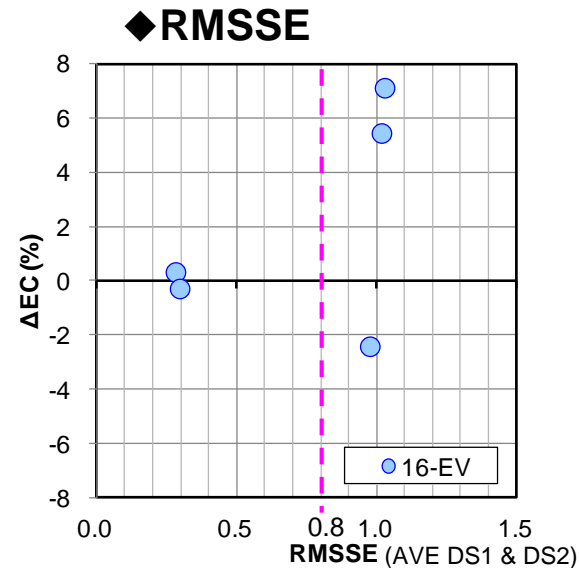
EC: +/- 2% => EER: -2.5 ~ +1.5



EC: +/- 2% => ASCR: -4.0 ~ +3.0

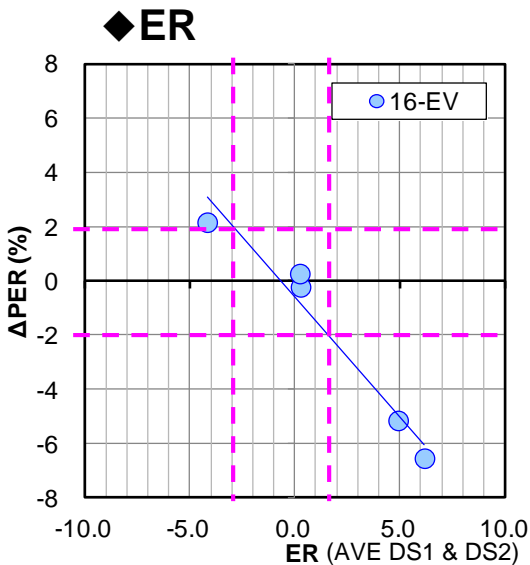


EC: +/- 2% => IWR: +/- 5.0

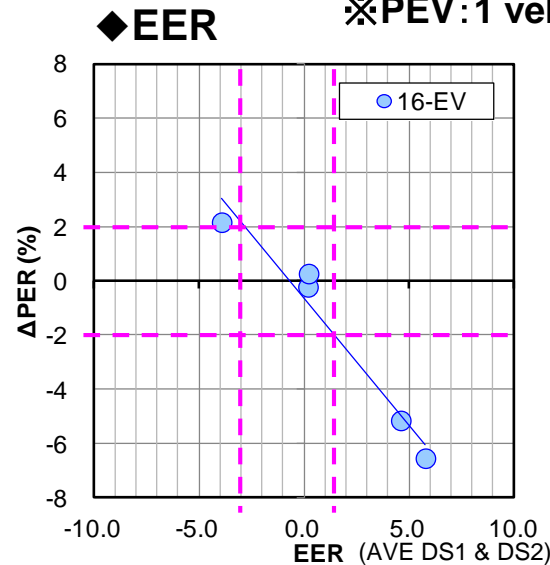
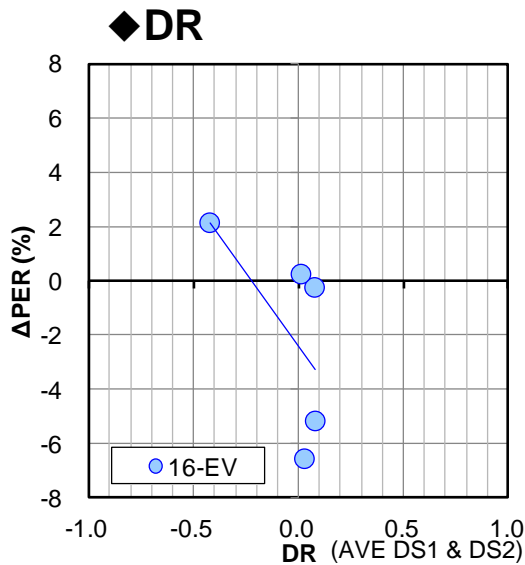


possible criteria: < +0.8

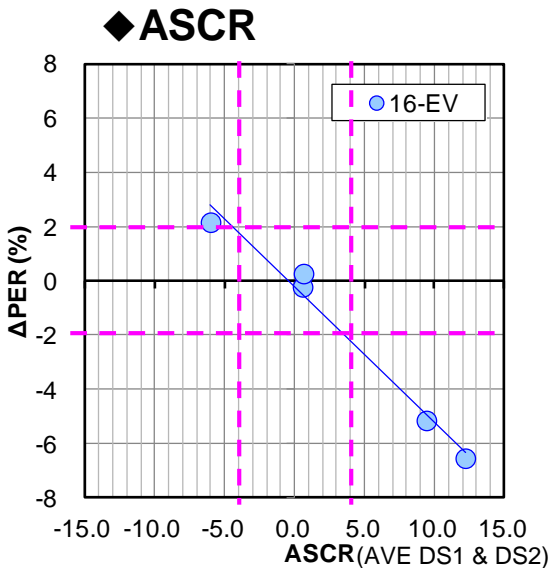
Relationship between indexes and PER of PEV



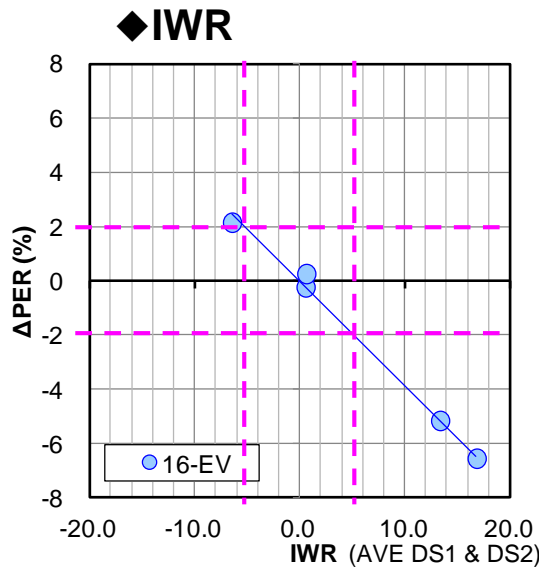
PER: +/- 2% => ER: -3.0 ~ +1.5



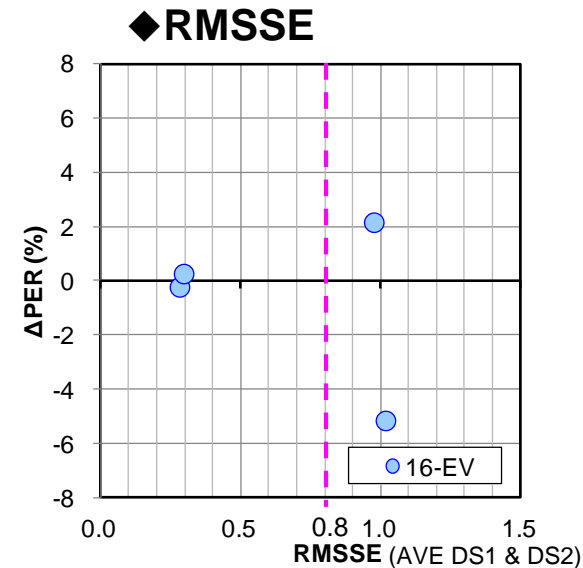
PER: +/- 2% => EER: -3.0 ~ +1.5



PER: +/- 2% => ASCR: +/- 4.0



PER: +/- 2% => IWR: +/- 5.0

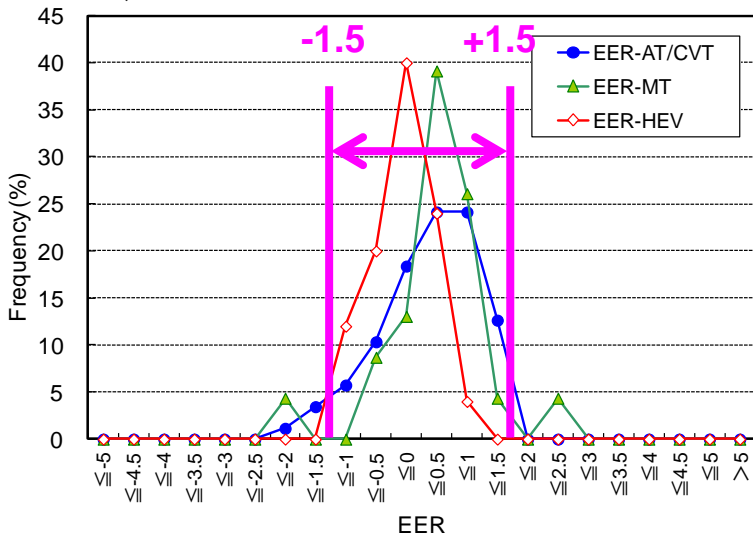


possible criteria: < +0.8

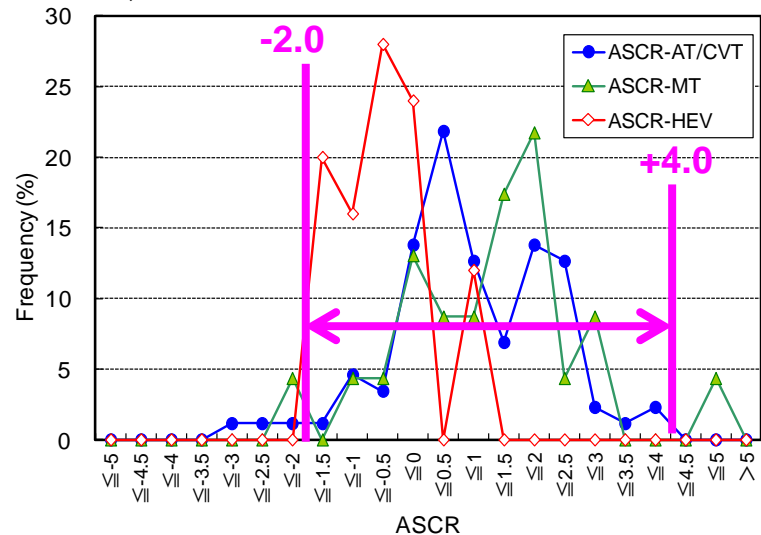
Feasibility study (JAMA-JARI data)

The frequency distribution in each index is as follow;

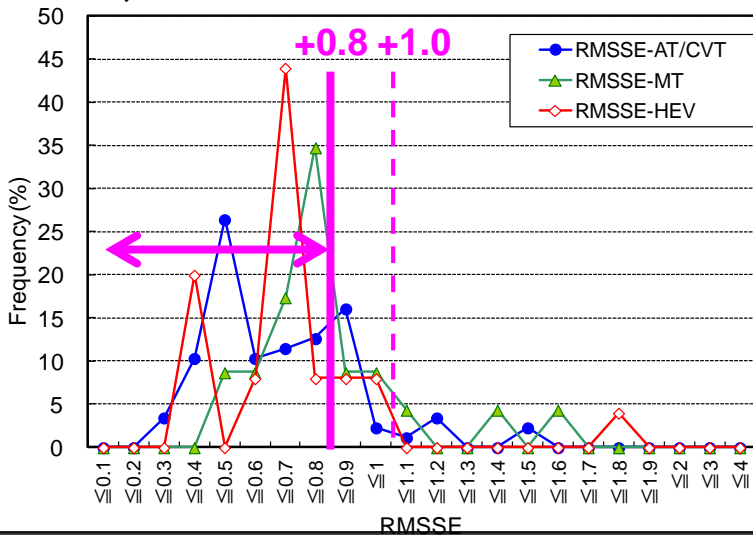
◆ EER



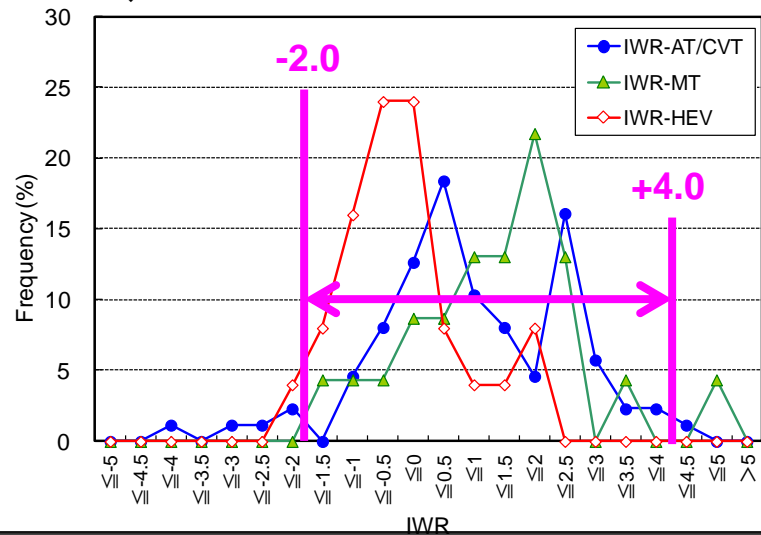
◆ ASCR



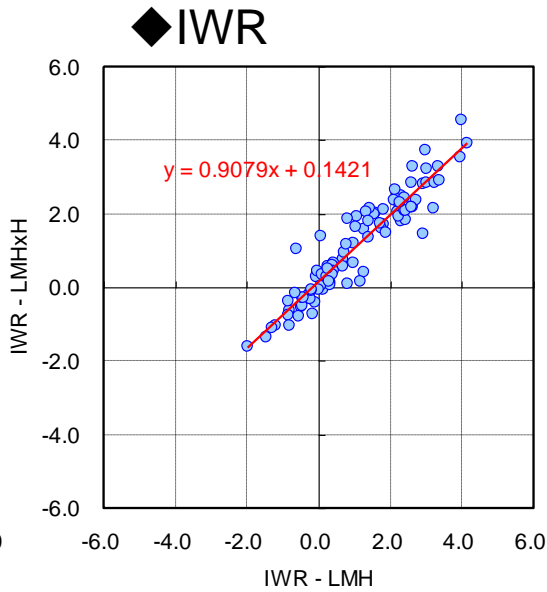
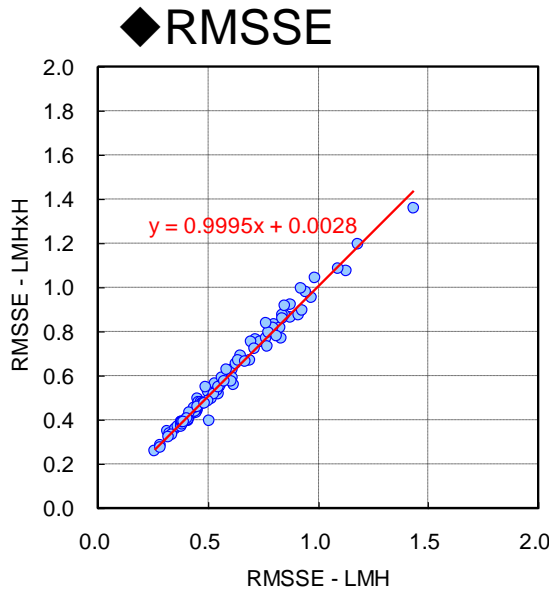
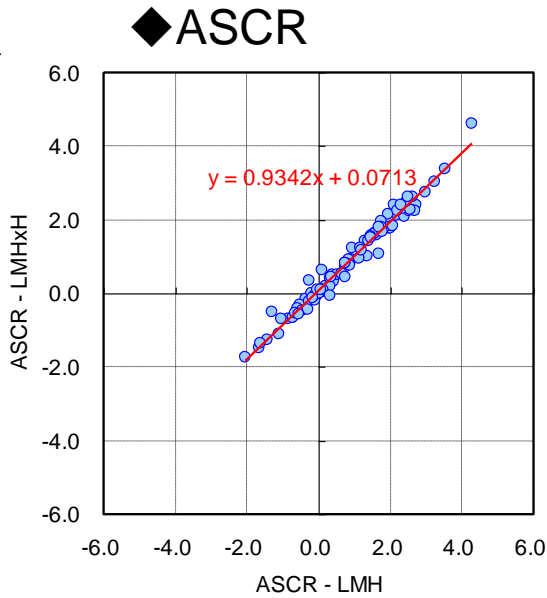
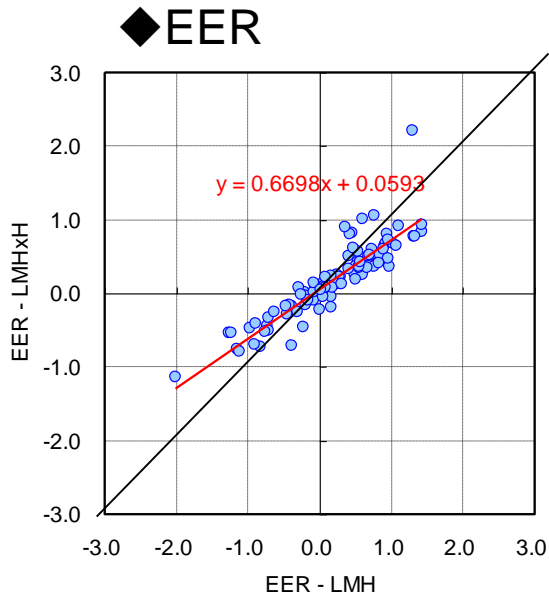
◆ RMSSE



◆ IWR

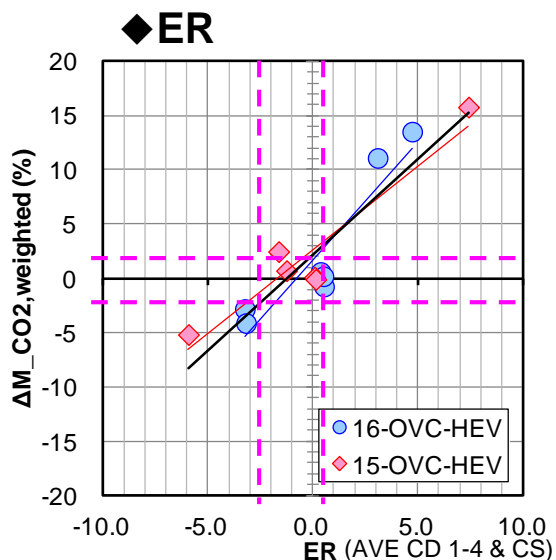


Comparison between 3 phase and 4 phase

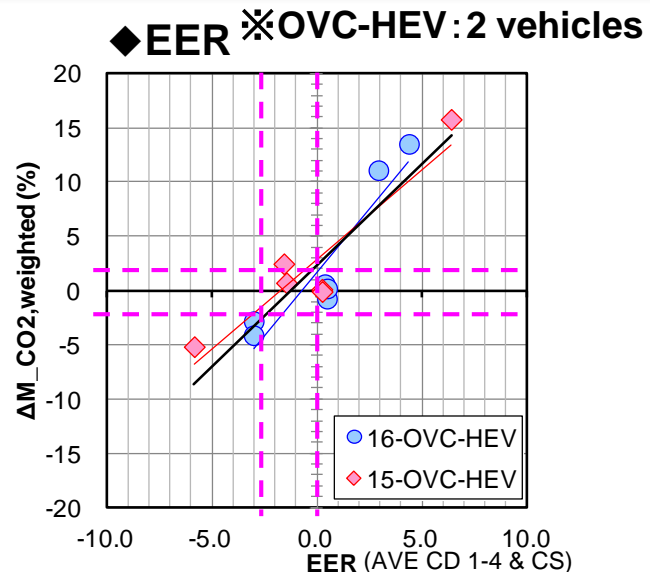
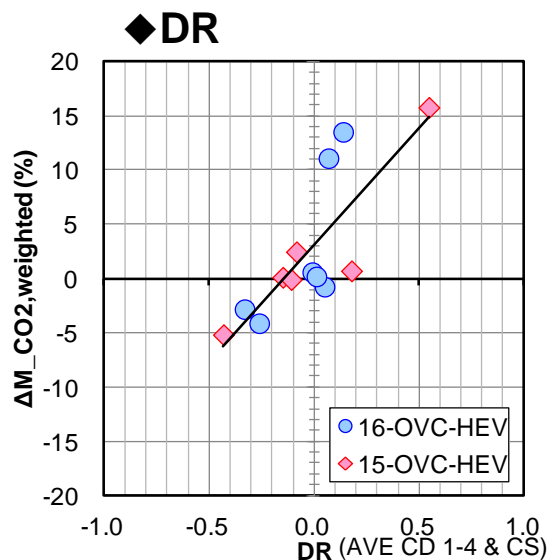


- EER value of 4 phase is smaller than that of 3 phase. Since the cycle energy of Extra high phase is approx. 40% of total, the effect of driving style in L/M/H phase become relatively smaller.
- Regarding ASCR, IWR and RMSSE, the index of 3 phase and the index of 4 phase are almost same.

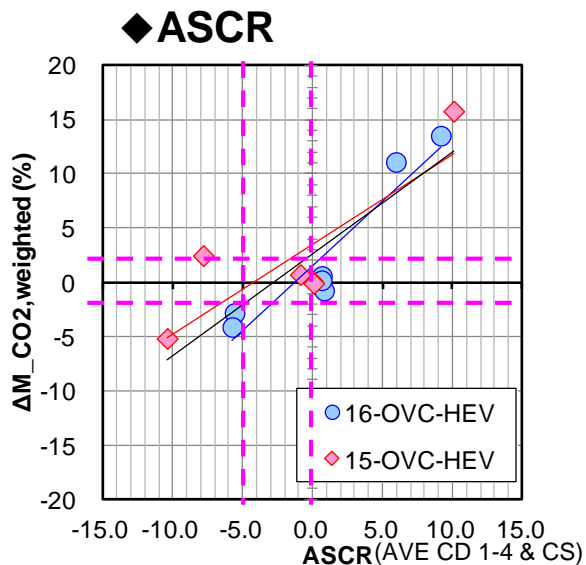
(Ref.) Relationship between indexes and $\Delta M_CO2,weighted$ of OVC-HEV



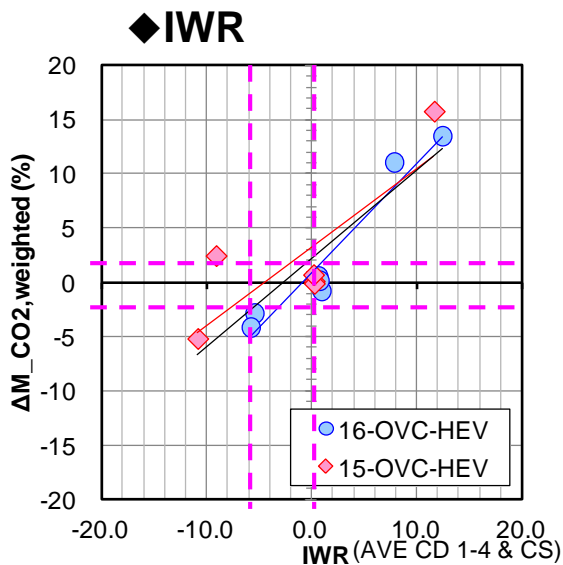
possible criteria: -2.5 ~ +0.5



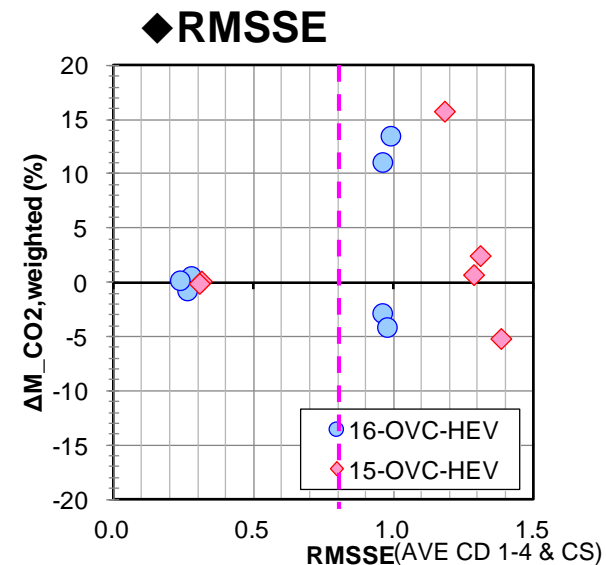
possible criteria: -2.5 ~ 0



possible criteria: -5.0 ~ 0



possible criteria: -6.0 ~ 0



possible criteria: < +0.8

(Ref.) Drive Trace Index (SAE J2951)

- **Energy Rating (ER)**

is defined as the percent difference between the total driven and target cycle energy.

$$ER = \frac{CE_D - CE_T}{CE_T} \cdot 100$$

- **Distance Rating (DR)**

is defined as the percent difference between the total driven and scheduled distance.

$$DR = \frac{D_D - D_T}{D_T} \cdot 100$$

- **Energy Economy Rating (EER)**

is defined as the percentage difference between the distance per unit cycle energy for the driven and target traces. Since fuel economy is a measure of the distance traveled per unit of fuel consumed, the effect of distance driven must also be considered in an assessment of a drive quality that is intended to correlate with fuel economy.

$$EER = \left[1 - \frac{DR / 100 + 1}{ER / 100 + 1} \right] \cdot 100$$

- **Absolute Speed Change Rating (ASCR)**

is defined as the percentage difference between the ASC for the driven and target traces. It provides an indicator of the "smoothness" of the driven trace relative to the scheduled trace. A driven trace that is "smoother" will have a lower ASC than the scheduled trace and so will result in a negative ASCR.

$$ASCR = \frac{ASC_D - ASC_T}{ASC_T} \cdot 100$$

$$ASC = \sum_{i=1}^N |a_i|$$

- **Inertial Work Rating (IWR)**

is defined as the percentage difference between the inertial work for the driven and target traces. It can indicate when the drive style might substantially impact the overall efficiency of the engine, such that a metric based strictly on cycle energy might not fully characterize observed deviations from expected emission rates.

$$IWR = \frac{IW_D - IW_T}{IW_T} \cdot 100$$

$$IW = \sum_{i=1}^N [(1.015 \cdot ETW \cdot a_i) \cdot d_i]^+$$

- **Root Mean Squared Speed Error (RMSSE)**

provides the driver's performance in meeting the schedule speed trace throughout the test cycle in terms of the Root Mean Squared Speed Error. The value is always a positive number with lower values (closer to zero) indicating better performance. RMS Speed Error has units of kilometer per hour (km/h) in this study.

$$RMSSE = 3.6 \cdot \sqrt{\frac{\sum_{i=1}^N (V_{Di} - V_{Ti})^2}{N}}$$

* D: Driven, T: Target