" 건강한 환경 행복한 미래 "

Korea HDV CO_2 regulation

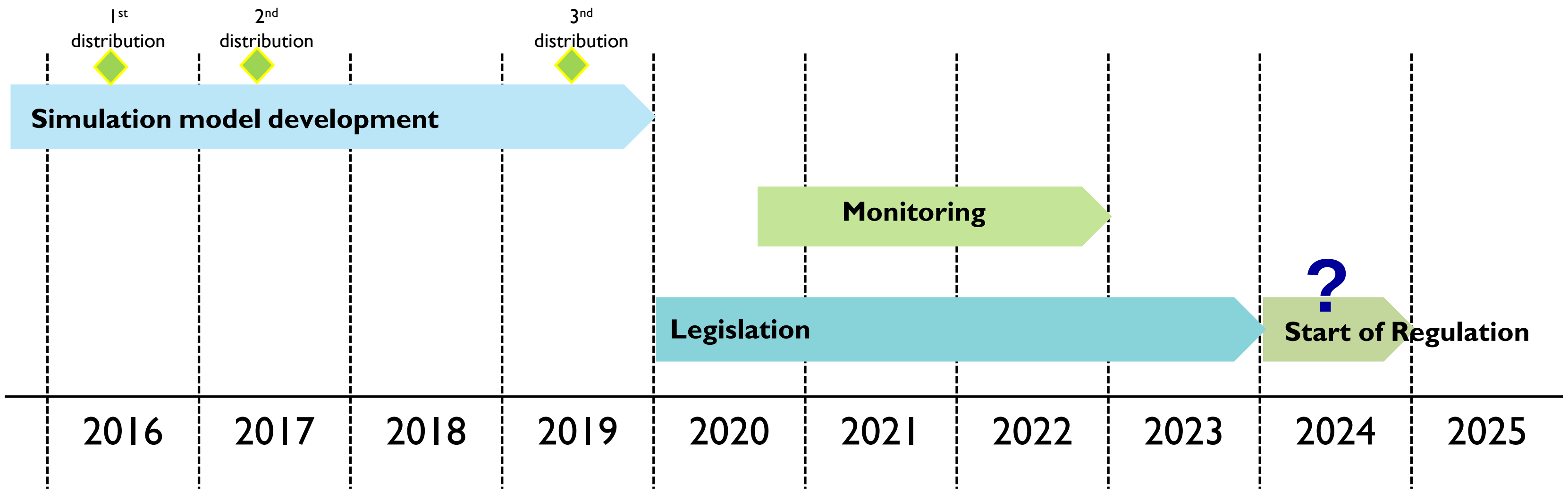
Jan. 14, 2020

Ministry of Environment, Korea

National Institute of Environmental Research

Contents

Regulatory Timeline(Proposed Rule)



- **Simulation program development**
  - ➢ Simulation model distribution to manufacturer (1st distribution in 2016, 2nd in 2017, 3rd in 2019)
- **Monitoring (3Q, 2020~), Legislation**

  CO_2 emission monitoring, Set CO_2 reduction target, super credit, eco innovation technology
- **Start of Regulation (2025 ~)**

02 HES Structure

Simulation model: HES, Heavy-duty vehicle Emission Simulator

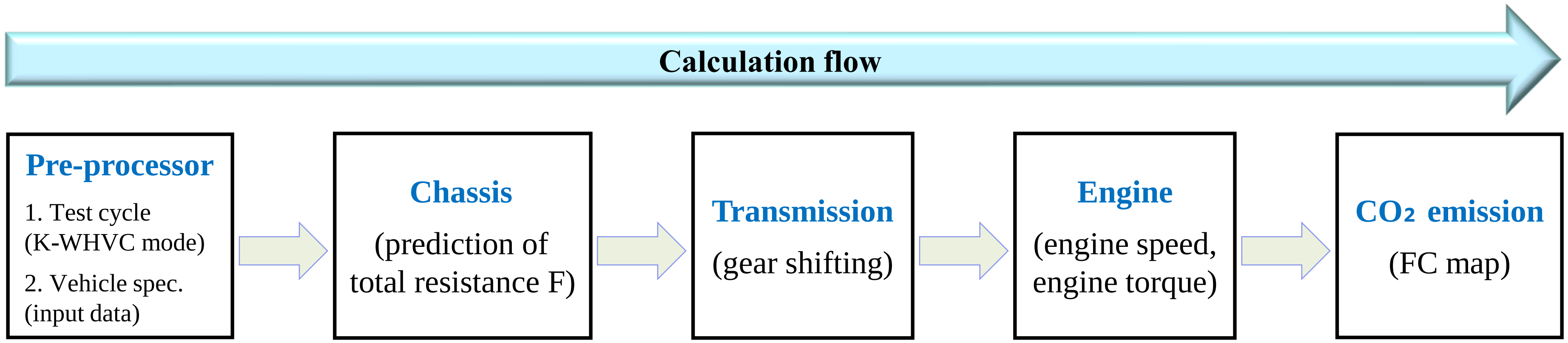


Fig. Basic model structure

- **Vehicle dynamic based simulation model for MHDVs (Medium and Heavy Duty Vehicles) in Korea**
  - MHDVs simulation model (Korea): Composed of five components as follow:
    1. **Pre-processor module**: reading input data (vehicle specifications and velocity profile)
    2. **Chassis module:** calculating total resistance force acting on vehicle
    3. **Transmission module:** predicting gear position at each time step based on engine operating condition
    4. **Engine module:** determining engine torque & speed at each time step
    5. **CO_2 emission module**: predicting CO_2 emission based on fuel map & CO_2 emission factor of fuel
- **Backward type calculation program (wheel to engine)**

Simulation model: HES, Heavy-duty vehicle Emission Simulator

- HES Engine power calculation model

	Item	Calculation	Remark
1	Acceleration	P_acc [kW] = Weight [kg] * acceleration[m/s²] * velocity [m/s] * 0.001	
2	Load inclination	P_slope [kW] = Weight [kg] * 9.81 [m/s²] * gradient(sinθ) * velocity [m/s] * 0.001	
3	Air drag	P_air [kW] = 0.5 * density [kg/m³] * CdA [m ²] * velocity³ [m/s] * 0.001 * Correction factor	density = 1.188 kg/m³
4	Rolling resistance	P_roll [kW] = RRC [-] * Weight [kg] * velocity [m/s] * 0.001	
5	Auxiliary	P_aux [kW] = auxiliary power demand[kW]	Default data
6	Engine rotational inertia	P_inertia_engine [kW] = engine inertia [kg*m²] / tire radius² [m] * acceleration[m/s²] * velocity[m/s] * 0.001	Default data
7	Tire rotational inertia	P_inertia_wheel [kW] = tire inertia [kg*m²] / tire radius² [m] * acceleration[m/s²] * velocity[m/s] * 0.001	
8	Transmission loss	P_transmission_loss [kW] = Transmission torque loss [Nm] * engine speed [rpm] * $\frac{2\pi}{60}$ * 0.001	Default data
9	Axle loss	P_axle_loss [kW] = Axle Torque loss [Nm] / transmission ratio [-] * engine speed [rpm] * $\frac{2\pi}{60}$ * 0.001	Default data
10	Retarder loss	P_retarder_loss [kW] = Retarder torque loss [Nm] / transmission ratio [-] * engine speed [rpm] * $\frac{2\pi}{60}$ * 0.001	Default data
Sum	Engine power	P_eng [kW] = P_acc [kW] + P_slope [kW] + P_air [kW] + P_roll [kW] + P_aux [kW] + P_inertia_engine [kW] + P_inertia_wheel [kW] + P_transmiss_loss [kW] + P_axle_loss [kW] + P_retarder_loss [kW]	

Test cycle (target velocity)

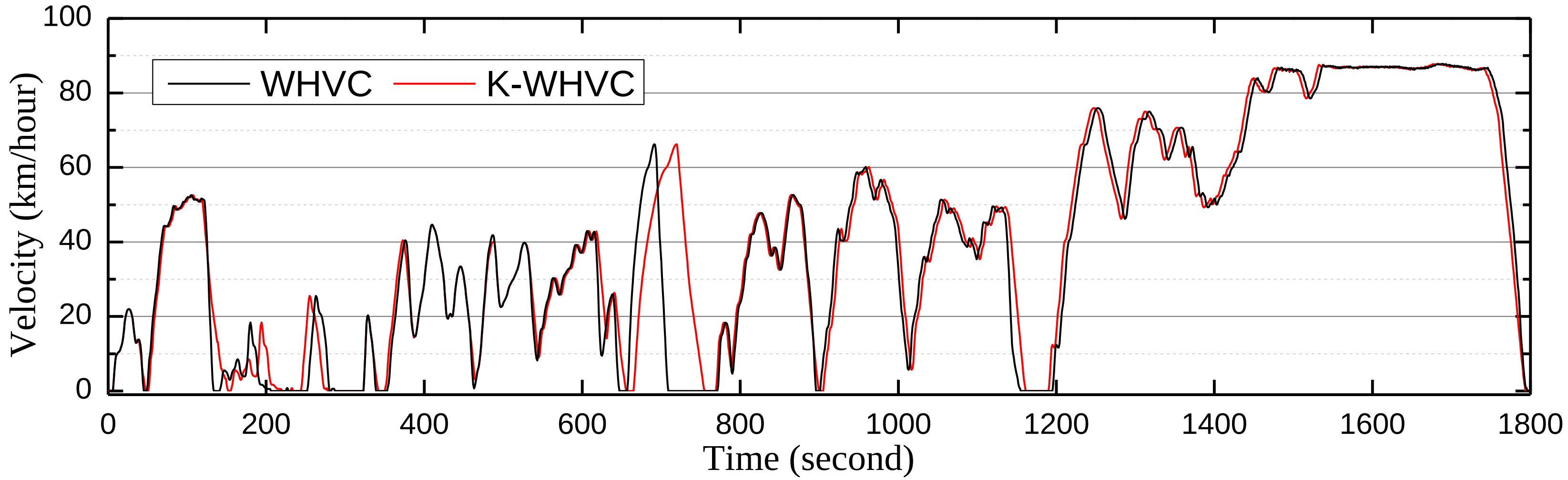
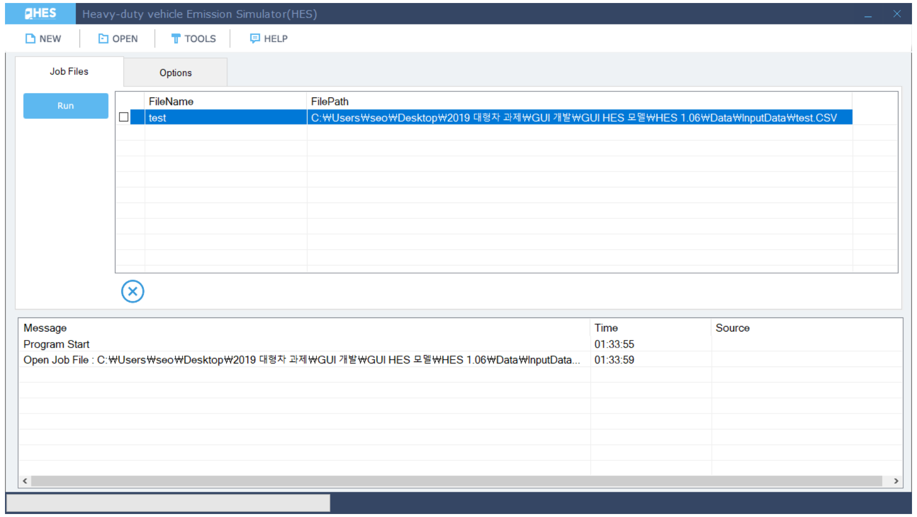


Fig. Comparison of original WHVC and K-WHVC mode (velocity profile)

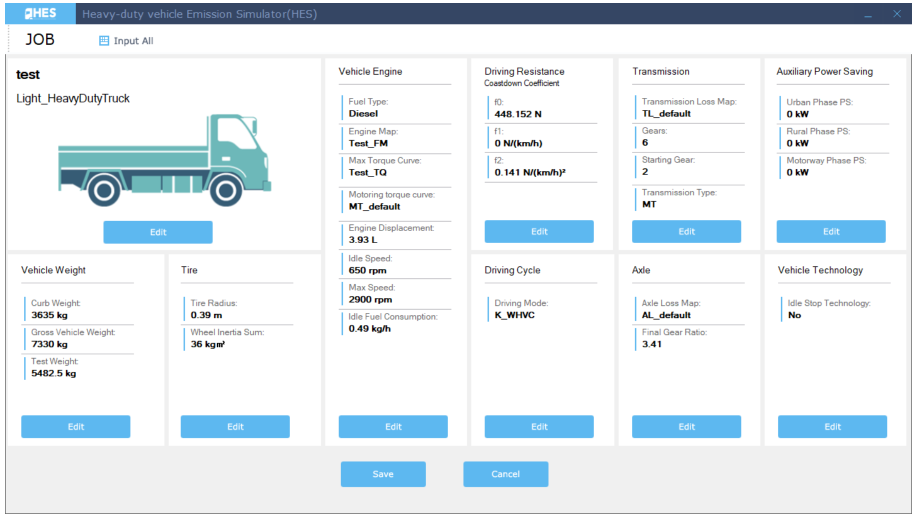
- **Modification of WHVC driving mode**
  - WHVC mode represents real driving pattern of MHDVs in Korea reasonably
  - However, **some HDVs (GVW>30 ton) are not able to follow the WHVC** in specific acceleration regions

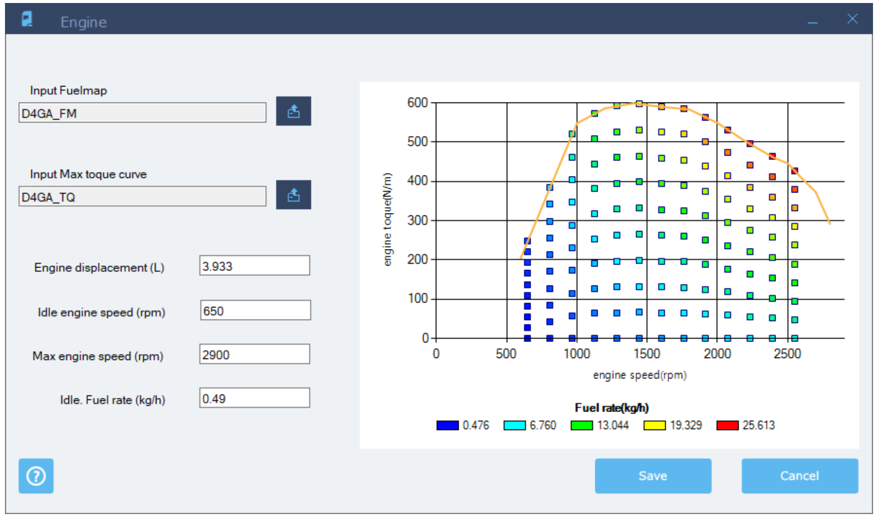
⇨ **K-WHVC** driving cycle had been developed to **enhance a correlation between simulation and test results**

HES interface



HES
Heavy-duty vehicle Emission Simulator





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HES interface

HES result file(.pdf)

test1

Input Data	Date / Time : 2019.10.24 08:39

Vehicle type : Light_HeavyDutyTruck

Vehicle type	Light_HeavyDutyTruck
Transmission type	MT
Curb weight [kg]	3635
GVW [kg]	7330
f0 [N] {RRC*test weight*9.8}	448.152
f1 [N/(km/h)]	0
f2 [N/(km/h)²] {0.5*1.188*CdA/3.6²}	0.141
Engine displacement [L]	3.93
Max. gear position	6
Tire radius [m]	0.39
Fuel Type	Diesel
Fuel map	Test_FM
Max TQ curve	Test_TQ

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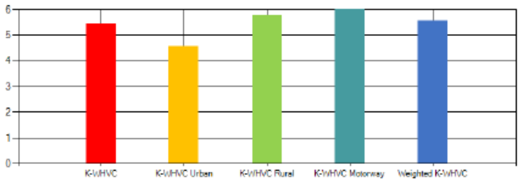
test1

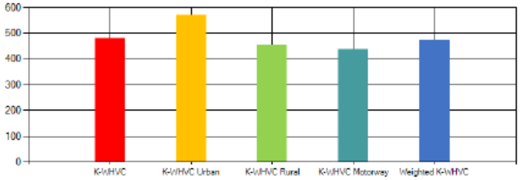
Result	Date / Time : 2019.10.24 08:39

	Fuel_economy[km/L]	CO2 [g/km]
K-WHVC	5.452	480
K-WHVC Urban	4.576	572
K-WHVC Rural	5.765	454
K-WHVC Motorway	5.989	437
Weighted K-WHVC	5.559	470.8

Fuel economy (km/L)



CO2(g/km)



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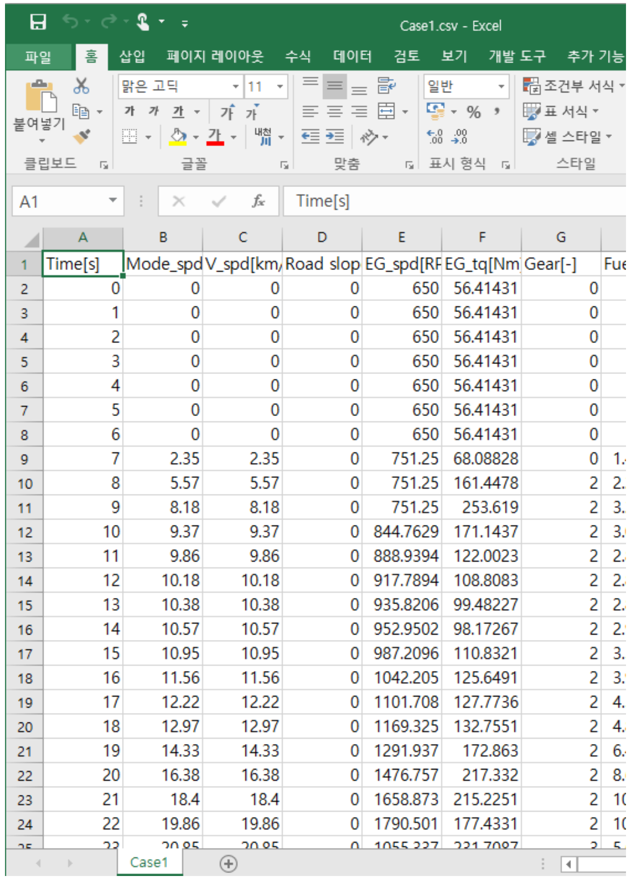
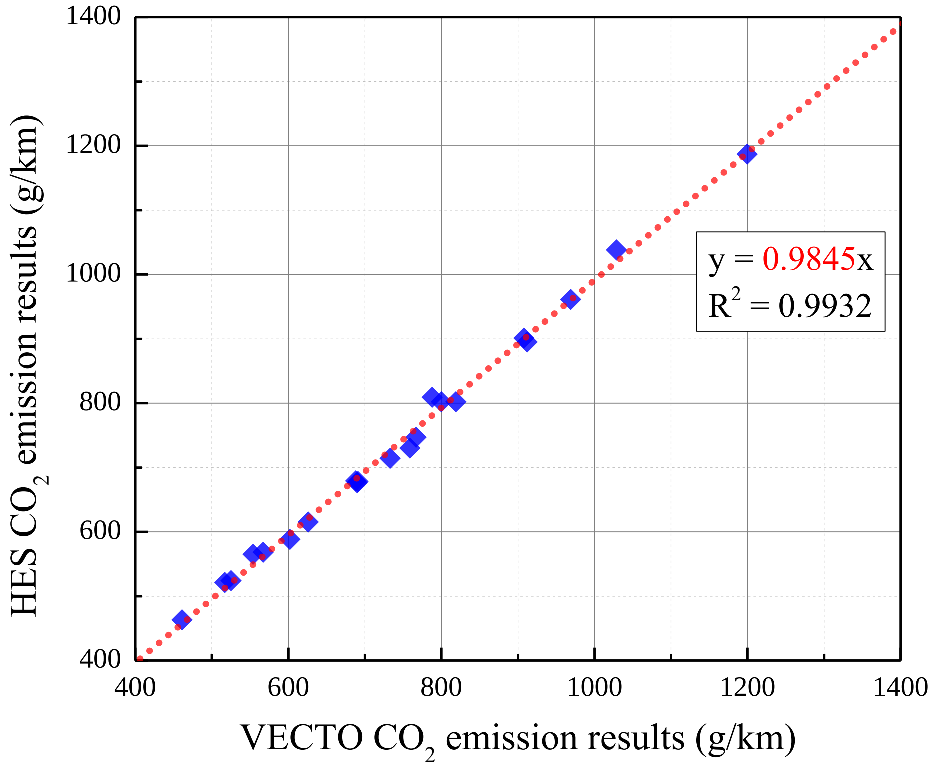
raw file(.csv)



	A	B	C	D	E	F	G	
1	Time[s]	Mode_spd	V_spd[km/	Road slop	EG_spd[RF	EG_tq[Nm	Gear[-]	Fue
2	0	0	0	0	650	56.41431	0	
3	1	0	0	0	650	56.41431	0	
4	2	0	0	0	650	56.41431	0	
5	3	0	0	0	650	56.41431	0	
6	4	0	0	0	650	56.41431	0	
7	5	0	0	0	650	56.41431	0	
8	6	0	0	0	650	56.41431	0	
9	7	2.35	2.35	0	751.25	68.08828	0	1.
10	8	5.57	5.57	0	751.25	161.4478	2	2.
11	9	8.18	8.18	0	751.25	253.619	2	3.
12	10	9.37	9.37	0	844.7629	171.1437	2	3.
13	11	9.86	9.86	0	888.9394	122.0023	2	2.
14	12	10.18	10.18	0	917.7894	108.8083	2	2.
15	13	10.38	10.38	0	935.8206	99.48227	2	2.
16	14	10.57	10.57	0	952.9502	98.17267	2	2.
17	15	10.95	10.95	0	987.2096	110.8321	2	3.
18	16	11.56	11.56	0	1042.205	125.6491	2	3.
19	17	12.22	12.22	0	1101.708	127.7736	2	4.
20	18	12.97	12.97	0	1169.325	132.7551	2	4.
21	19	14.33	14.33	0	1291.937	172.863	2	6.
22	20	16.38	16.38	0	1476.757	217.332	2	8.
23	21	18.4	18.4	0	1658.873	215.2251	2	10
24	22	19.86	19.86	0	1790.501	177.4331	2	10

Correlation analysis between HES and VECTO



$$\frac{\text{HES } CO_2 \text{ emissions}}{\text{VECTO } CO_2 \text{ emisssions}} = 0.9845$$

$R^2 = 0.9932$

- 42 cases of input data are simulated in HES and VECTO
- HES results are very similar to VECTO results

03 HES Validation

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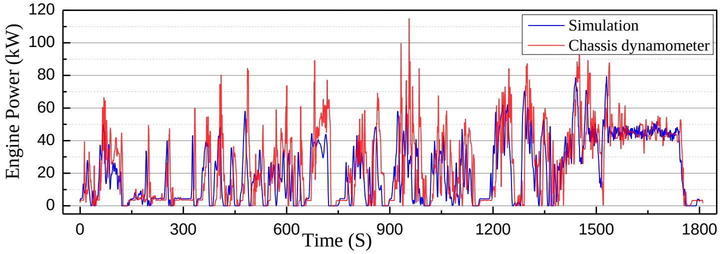
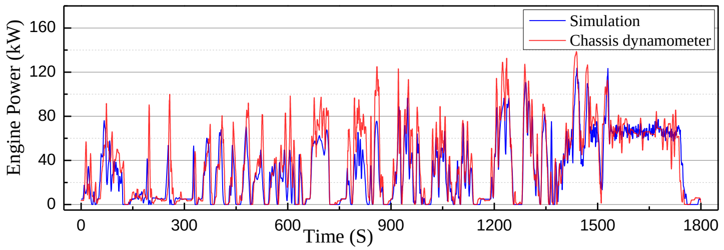
Chassis dynamometer test

Type	GVW	Max payload	Engine	Model year	Chassis dynamo result (g/km)	HES result (g/km)	Error (%)
Truck	39 ton	25 ton	12.7 L	2011	853	909	6.5
Truck	7.2 ton	2.5 ton	3.9 L	2017	339 357 359	371	3.7
Truck	10.4 ton	3.5 ton	6.3 L	2017	476 508 511	522	4.7
Bus	14.8 ton	54 passenger	11.6 L (CNG)	2016	596 598 600	599	0.2

Engine power (7 ton truck)



Engine power (10 ton truck)



- HES result validation with chassis dynamometer results
- About average error: 5%

HDV CO_2 Monitoring and legislation

- 2020~: CO_2 emission monitoring for rigid trucks (including tractors and buses)
  - Considering phased obligation rate with regard to the monitoring and reporting timetable for each type of category

- 2022~: Legislation process

  Determination of CO_2 reduction rate

Thanks for your attention

Please Contact, If you have question about HES

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