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WLTP:

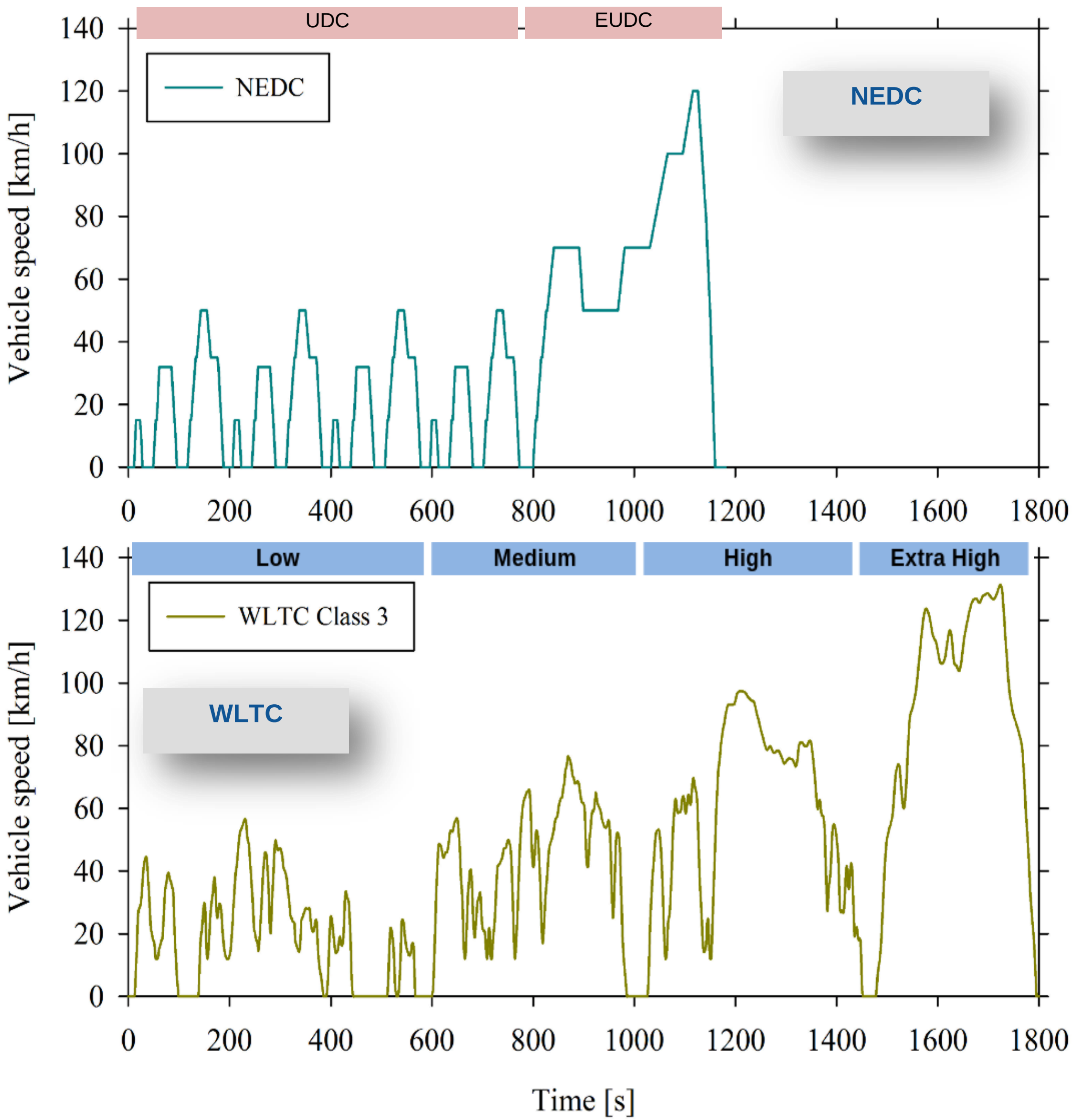
How will the new Regulation affect CO_2 emissions from modern passenger cars?

Lisbon, 7 June 2016

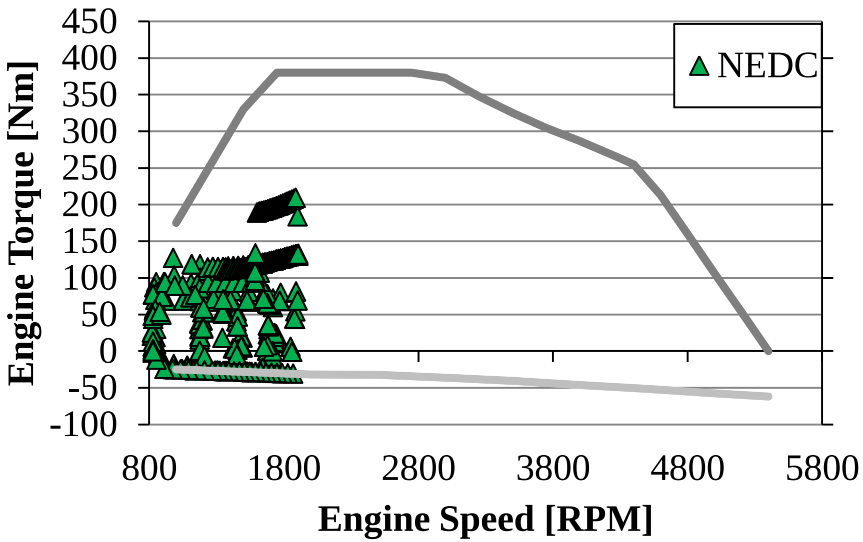
Outline

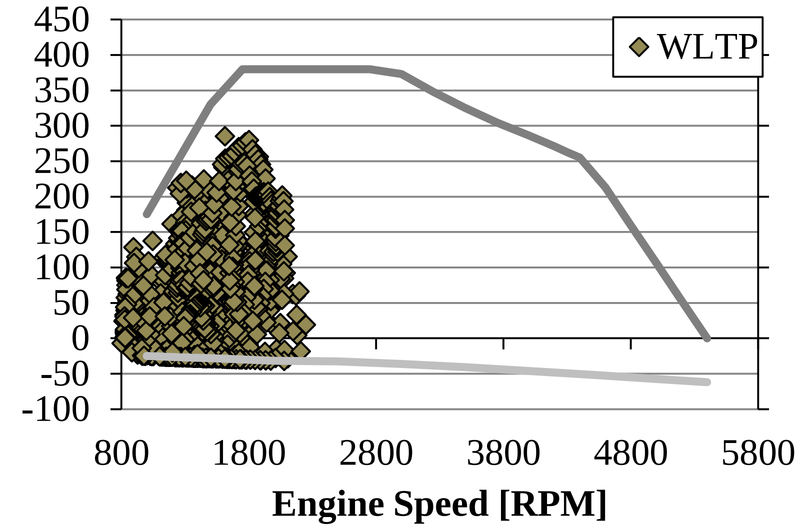
- Introduction – The NEDC-WLTP Correlation Exercise
- Measurement findings and ΔCO_2 analysis
- Evaluation of current CO2 reduction technologies
- CO_2MPAS validation campaign
- A look to Japan
- Concluding remarks

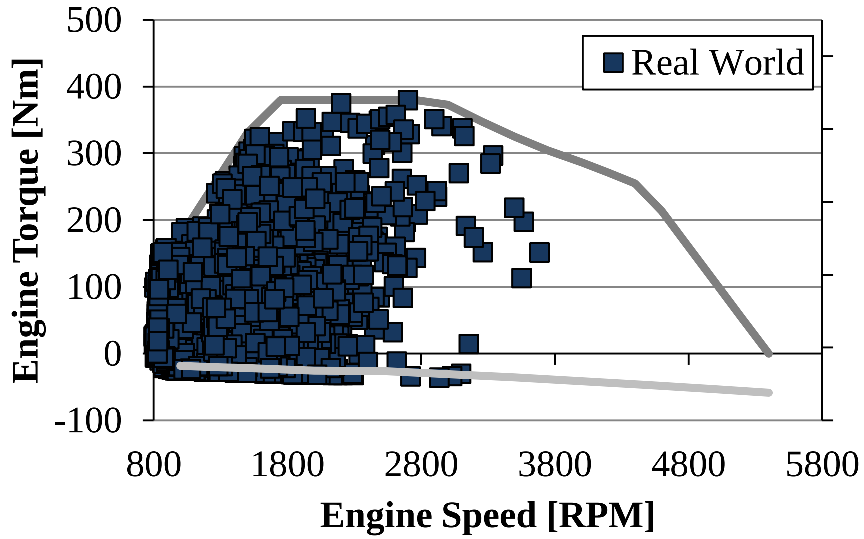
The driving cycles: NEDC vs. WLTP



Engine map area wider than in NEDC and WLTP







2,0 l diesel
midsize car

Test differences between WLTP and NEDC

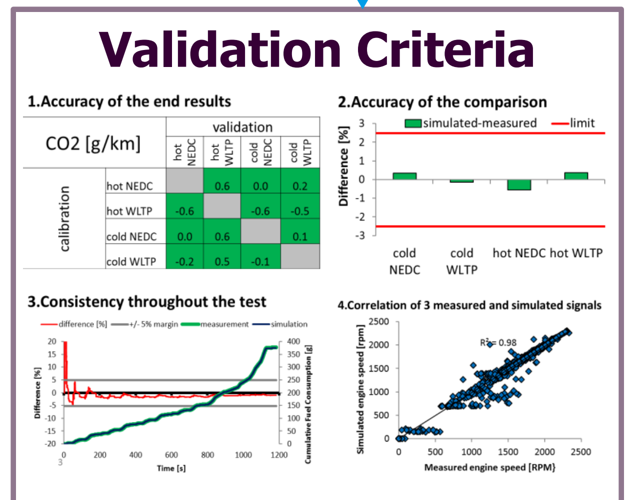
		NEDC	WLTP
Mass	Test	Reference mass: Unladen + 100 kg	TMH ("worst" case) and TML ("best" case) defined from min/max unladen mass and max laden mass
	Inertia	Inertia classes	Inertia mass = Test mass
	Rotating parts	Not applied	+1.5% for 1-axle chassis dyno
Road load	Origin	Provided by manufacturer – derived by the coast-down method	Calculated from NEDC RL taking into account masses, Cd*A, tyres – derived by the coast-down method in future
	Preconditioning	Vehicle and gear box type dependent (typical values 0 to 20 N)	
Driven wheels	4WD	1-axle dyno allowed	2-axle dyno mandatory
Engine	Preconditioning	1 NEDC + 1 EUDC (gasoline) 3 EUDC (diesel)	WLTP
Gear shifting		Fixed points	Vehicle specific - derived from a function of mass, RL, drivetrain, full load curve
Temperature	Soak	20 to 30 °C	23 °C ± 3 °C
	Oil, coolant	± 2°C to soak temperature	23°C ± 2°C
	Test initiation	25 °C ± 3 °C	23 °C ± 3 °C
RCB Correction		Not applied	Post-test correction

WLTP-NEDC Correlation Methodology

- Division of vehicle fleet into characteristic segments, measurement of representative vehicles in NEDC and WLTP and develop/validate a vehicle simulation model.

ID	Transmission	Fuel	Turbo	Displacement
1	Manual	diesel	turbo	displacement cluster 1
2	Manual	diesel	turbo	displacement cluster 2
3	Manual	diesel	turbo	displacement cluster 3
4	Manual	diesel	turbo	displacement cluster 4
5	Manual	gasoline	turbo	displacement cluster 1
6	Manual	gasoline	turbo	displacement cluster 2
23	Automatic	full-hybrid gasoline	turbo	displacement cluster 3
24	Automatic	full-hybrid Diesel	turbo	displacement cluster 1
25	Automatic	full-hybrid Diesel	turbo	displacement cluster 2
26	Automatic	plugin-hybrid gasoline	turbo	displacement cluster 1
27	Automatic	plugin-hybrid gasoline	turbo	displacement cluster 2
28	Automatic	plugin-hybrid Diesel	turbo	displacement cluster 1
29	Automatic	plugin-hybrid Diesel	turbo	displacement cluster 2

Vehicle fleet → 1 representative vehicle per segment → NEDC and WLTP measurements → Simulation model



- Vehicle pool in this exercise
- 23 passenger cars (M1) and 5 light duty vehicles (N1)
- 25 conventional, 1 Hybrid, 2 PHEV
- 15 gasoline and 13 diesel
- 14 with manual transmissions and 14 with automatic transmission

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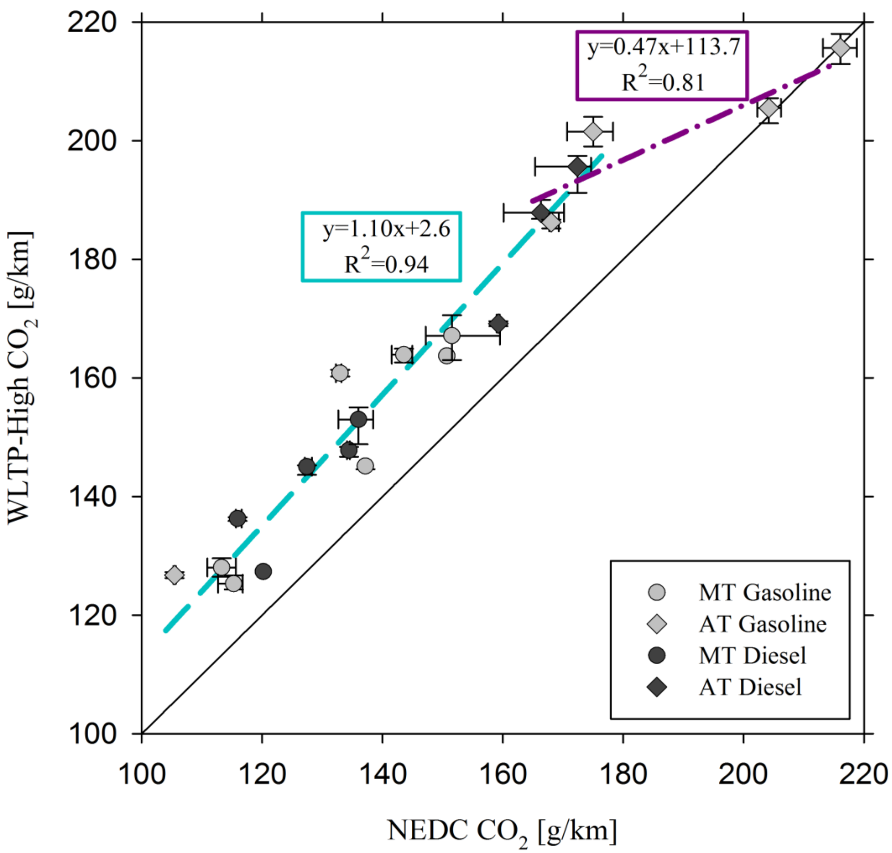
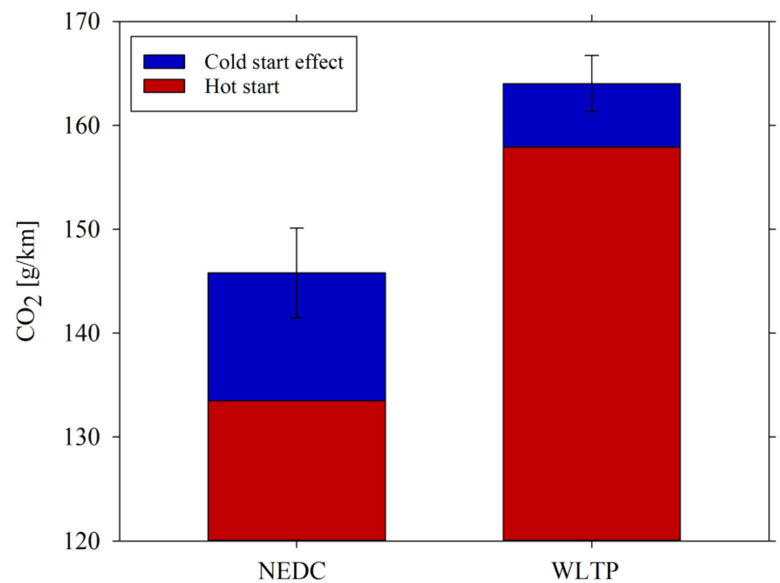
Results: WLTP vs NEDC

- Results from measurements in 20 passenger cars

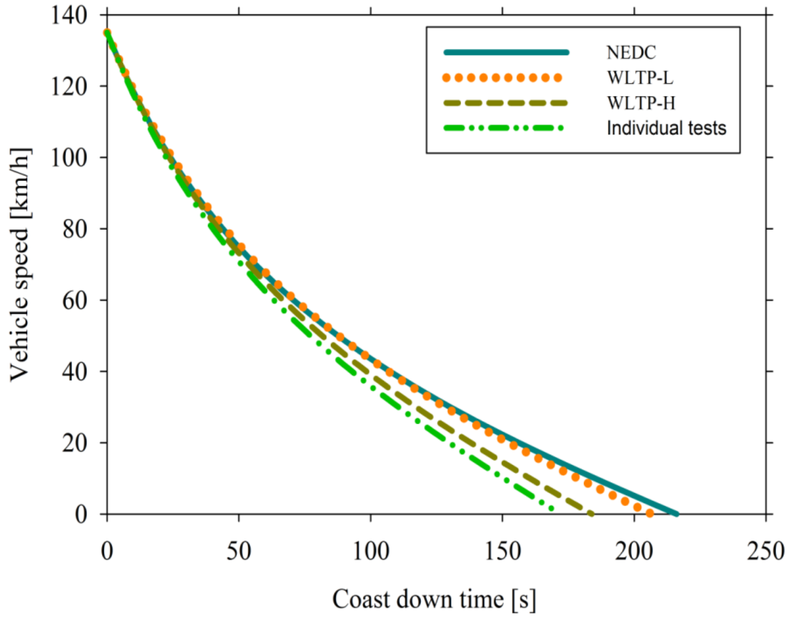


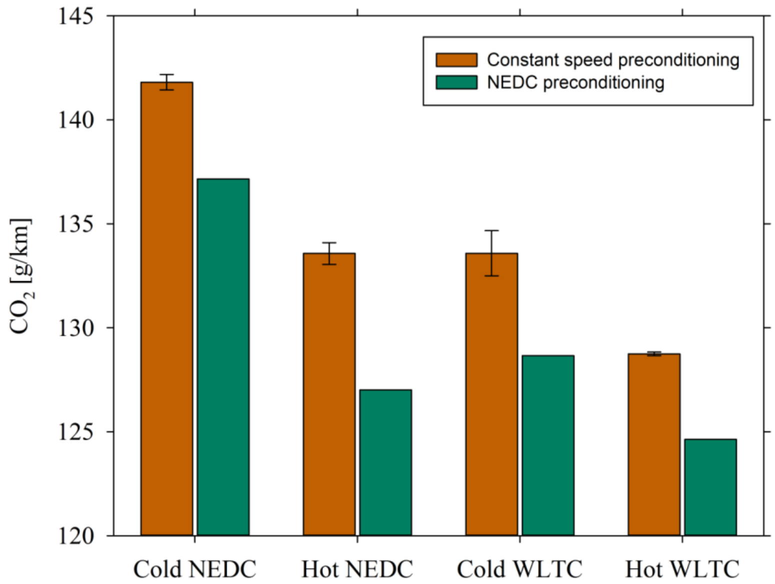


- Cold start effect (measurements)
  - NEDC: 12.3±4.3 g/km
  - WLTP-High: 6.1±2.7 g/km

- Increasing trend: 100 – 180 g/km
- Decreasing trend: 180 – 220 g/km
- Transitional area: 160 – 180 g/km

Results: Coast-down-time – Chassis preconditioning

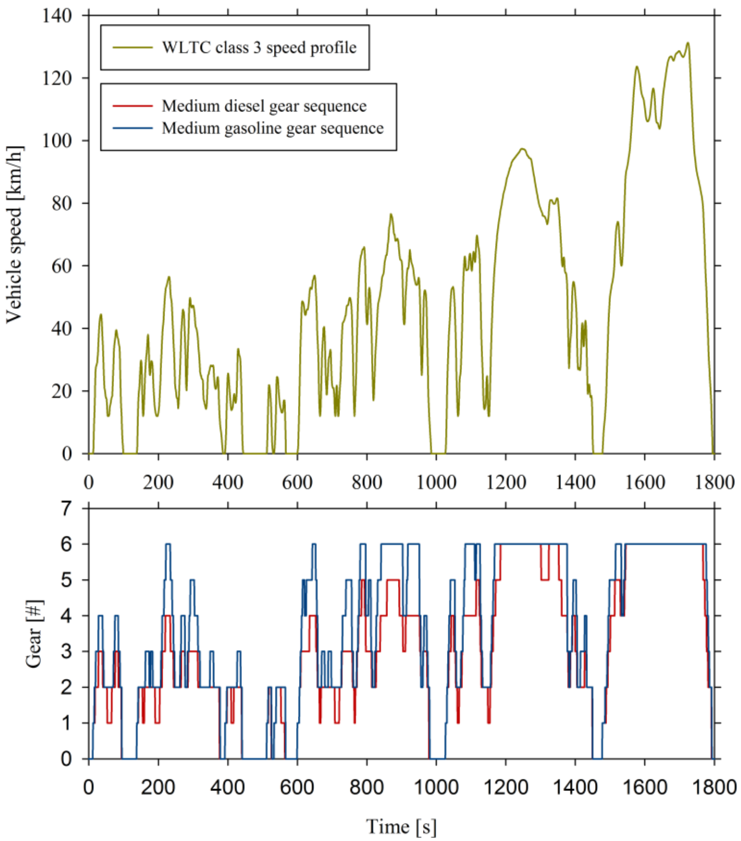




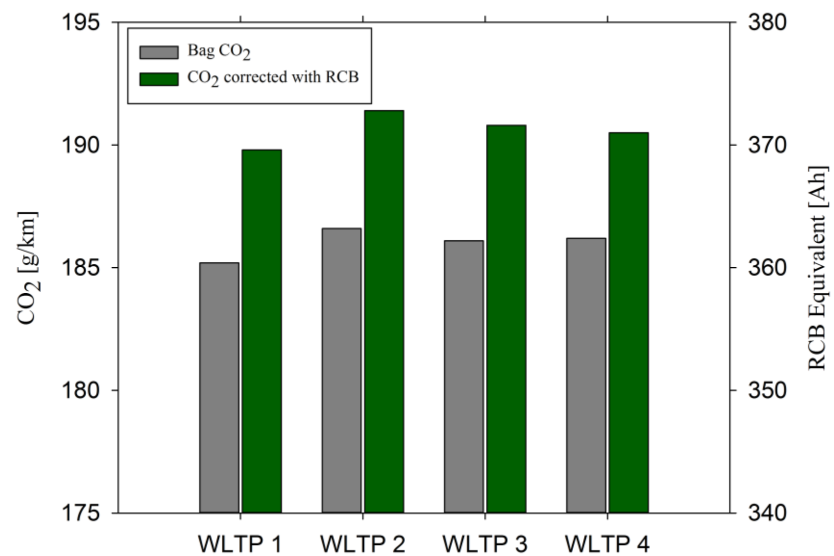
- WLTP-High driving resistance effect for a medium diesel vehicle
  - With NEDC driving resistance the vehicle stops 32 sec after the WLTP-High driving resistance
  - ~13.5 g/km over NEDC and WLTP-High (simulation)

- Small gasoline vehicle with manual transmission in LAT chassis dynamometer
  - ~5 g/km over cold and hot NEDC and WLTC (measurement)
  - Preconditioning cycle effect is a function of the vehicle's topology and the chassis dynamometer
  - Ongoing investigation

Results: Gear shifting sequence – charge balance correction

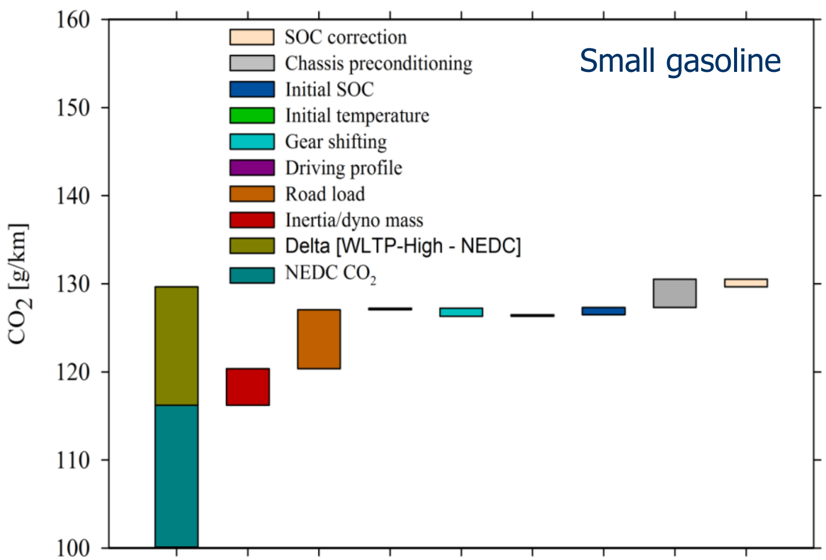


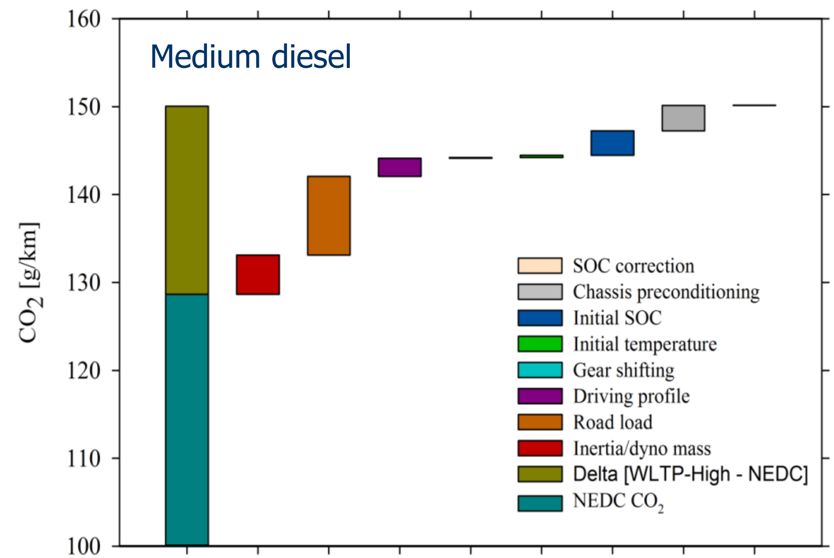
- WLTP-High gear shifting effect over NEDC fixed points
  - Medium diesel: -1 g/km (simulation)
  - Medium gasoline: -6 g/km (simulation)



- Charge balance correction effect for a large gasoline
  - 4.6 g/km (measurement)

Results: ΔCO2 analysis for a small gasoline and a medium diesel





- Most significant parameters for the ΔCO_2 observed between WLTP-H and NEDC:
  - Inertia mass
  - Road load
  - Chassis preconditioning
  - Post test charge balance correction

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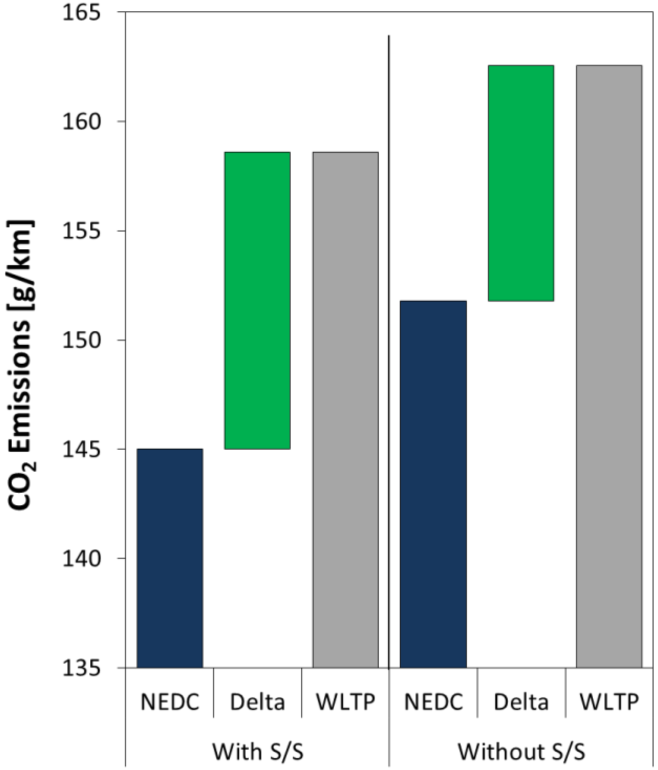
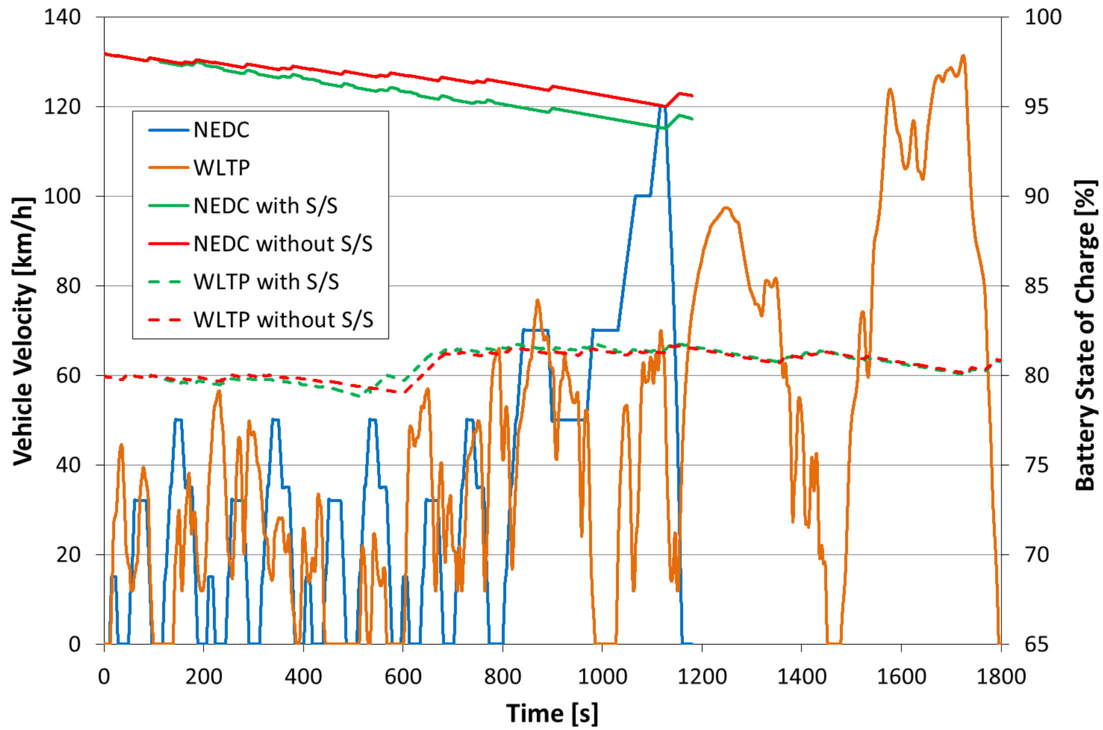
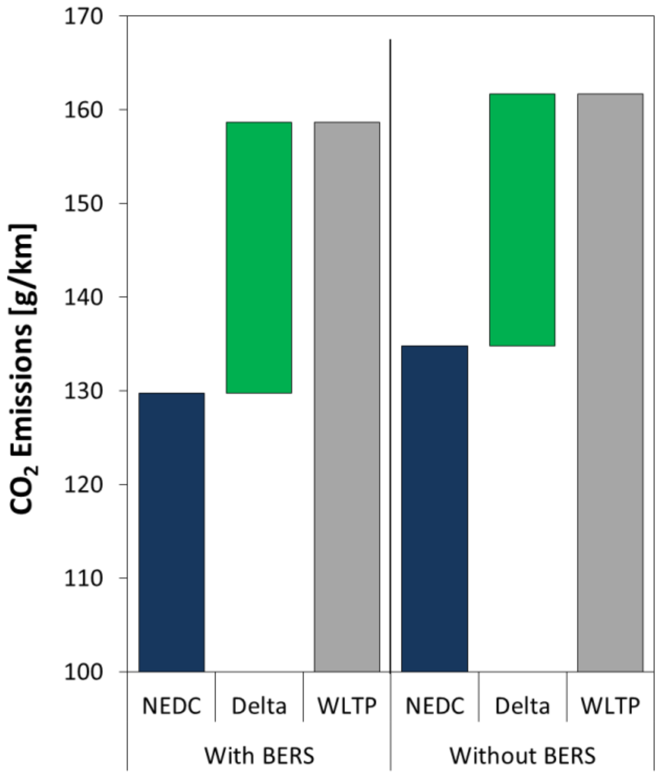
Start & Stop (SS)

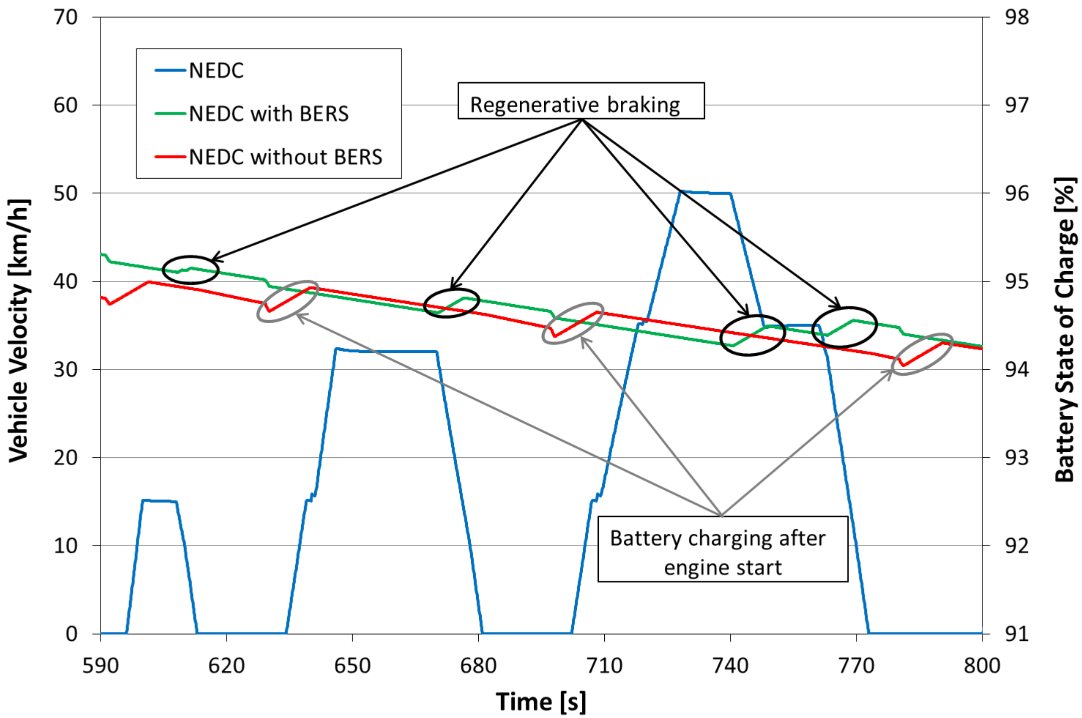




- Engine deactivation when vehicle stands still
- Elimination of fuel consumption at idle
- <u>CO_2 reduction effect</u>
  - 2.5 – 4.8% in NEDC
  - 1.2 – 2.6% in WLTP
- <u>Idling duration</u>
  - 22.6% in NEDC
  - 13.4% in WLTP
- Battery charging after starting may counterbalance the positive effect of start-stop

Brake Energy Recuperation (BERS)

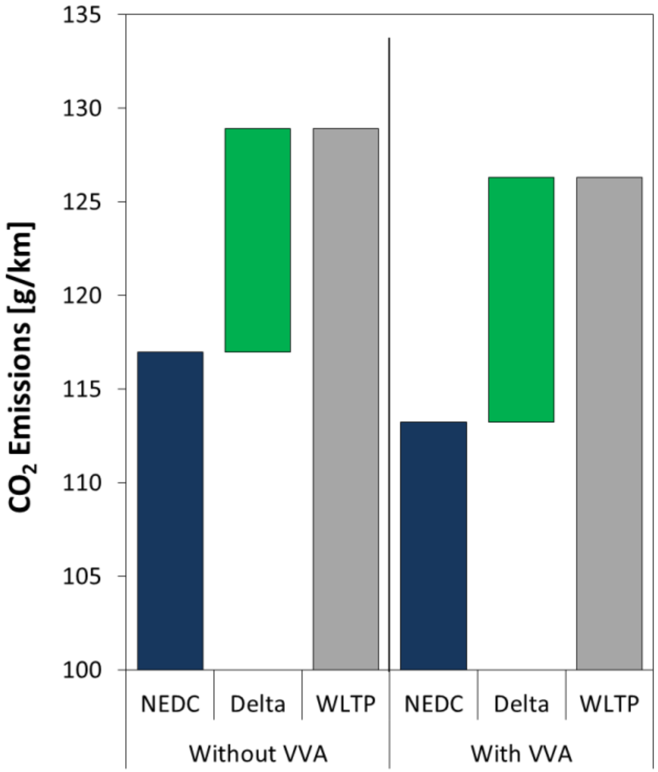


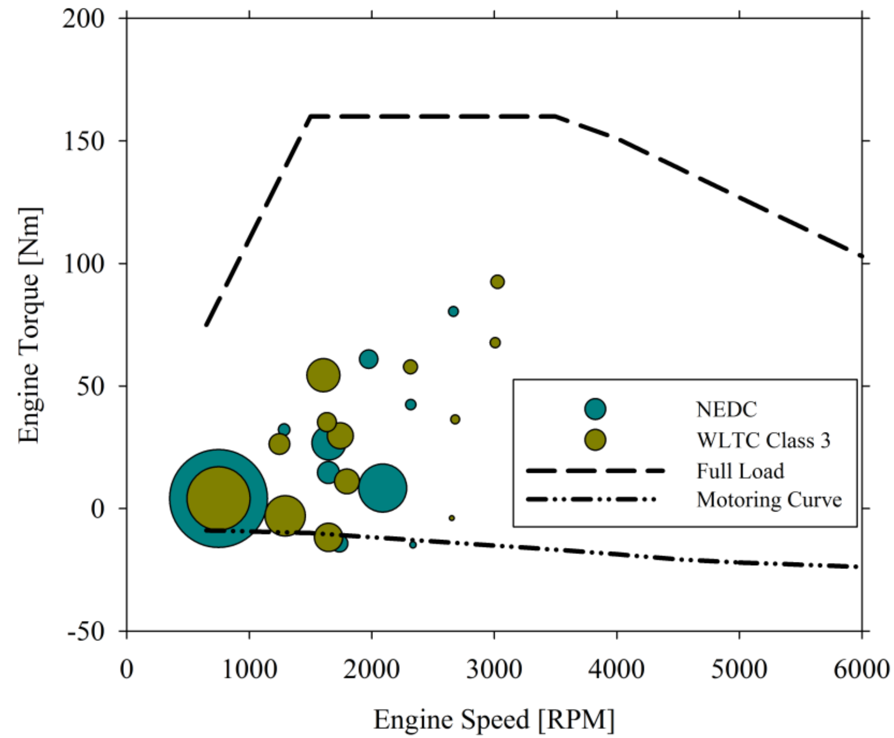


- Battery charging during braking – regenerative braking
- <u>CO_2 reduction effect</u>
  - 1.9 – 4.0% in NEDC
  - 1.3 – 1.6% in WLTP

- <u>With BERS</u>
  - SoC kept above a critical value
  - No need for battery charging after engine start
- <u>Without BERS</u>
  - Battery depletion during braking
  - Battery charging after engine start

Variable Valve Actuation (VVA)

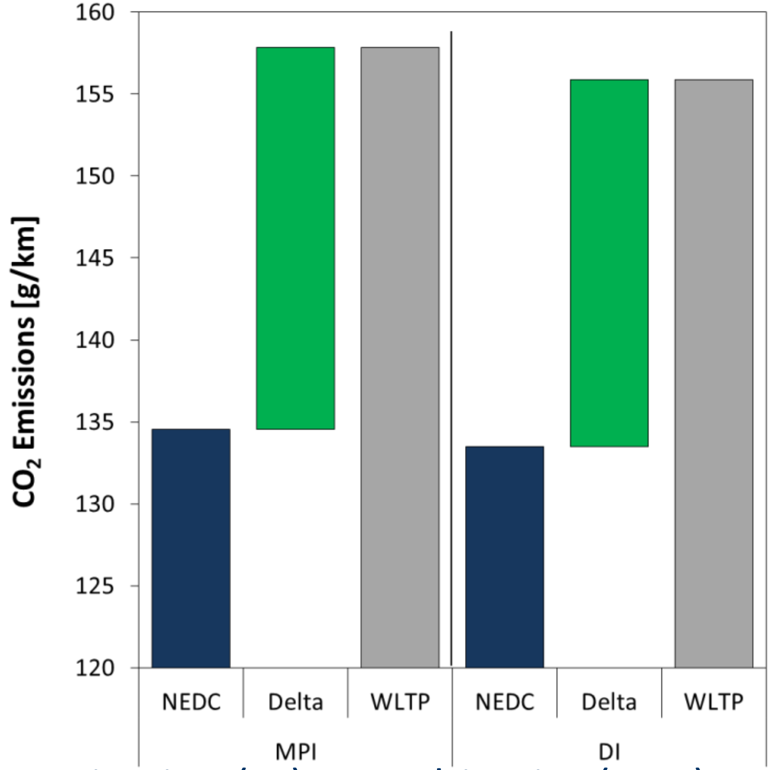


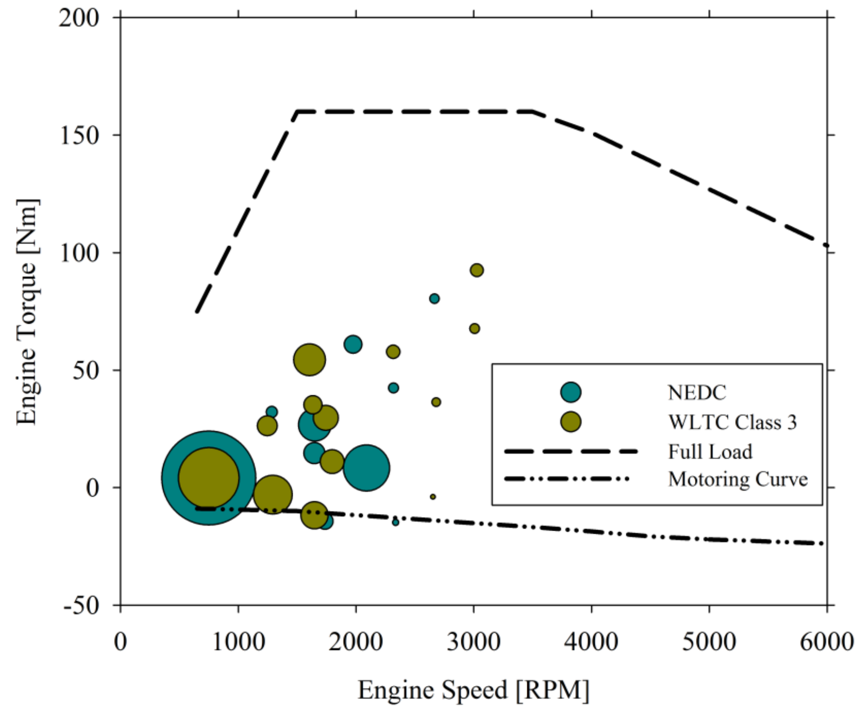


- Variable Valve Timing & Lift
- Optimisation of cylinder charging
- Main effect on the lower operating range of the engine

- Simulation approach: Modify the fuel consumption map
- CO_2 reduction effect
  - 2.5 – 5.0% in NEDC
  - 1.4 – 2.1% in WLTP

Gasoline Injection

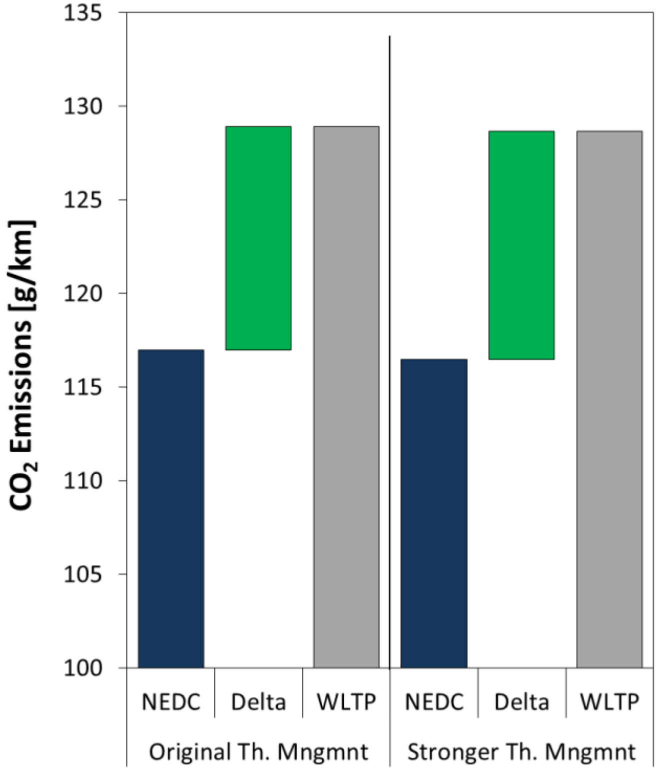


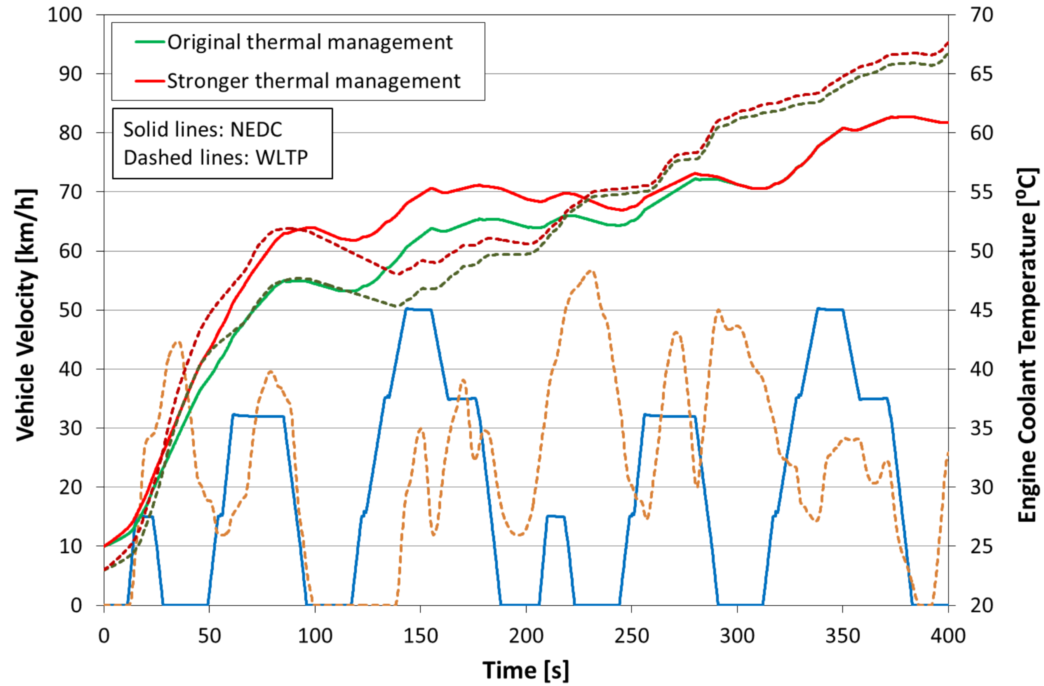


- Direct Injection (DI) vs Multi Point (Port) Injection (MPI)
- Injection at higher pressure – optimisation of injection strategy
  - Homogeneous combustion
- Main effect at the lower operating range

- Simulation approach: Modify the fuel consumption map
- CO_2 reduction effect
  - 1.5% in NEDC
  - 0.8% in WLTP

Engine Thermal Management

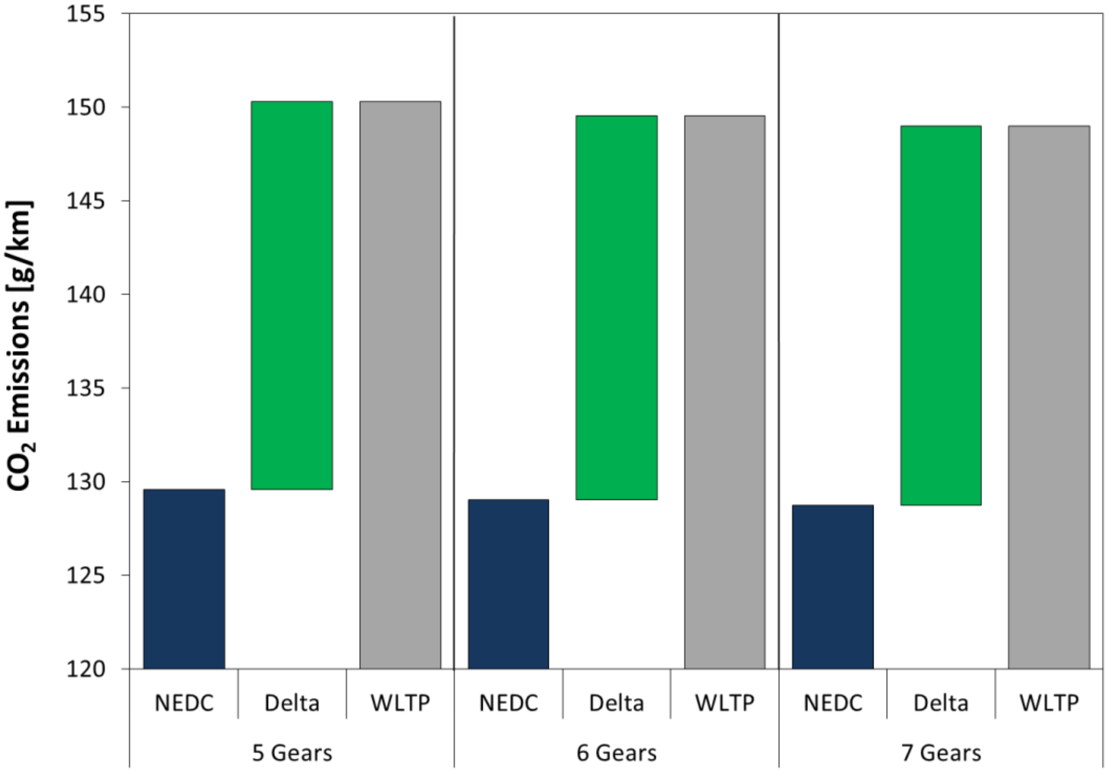




- Advanced cooling systems/strategies
  - separate cooling circuits (engine block/head)
  - cooled exhaust manifold
  - exhaust heat recovery
- Cold start effect 10% in NEDC vs 5% in WLTP

- Faster engine warm-up after cold start
- CO_2 reduction effect
  - <1% in both NEDC and WLTP

Gearbox variations



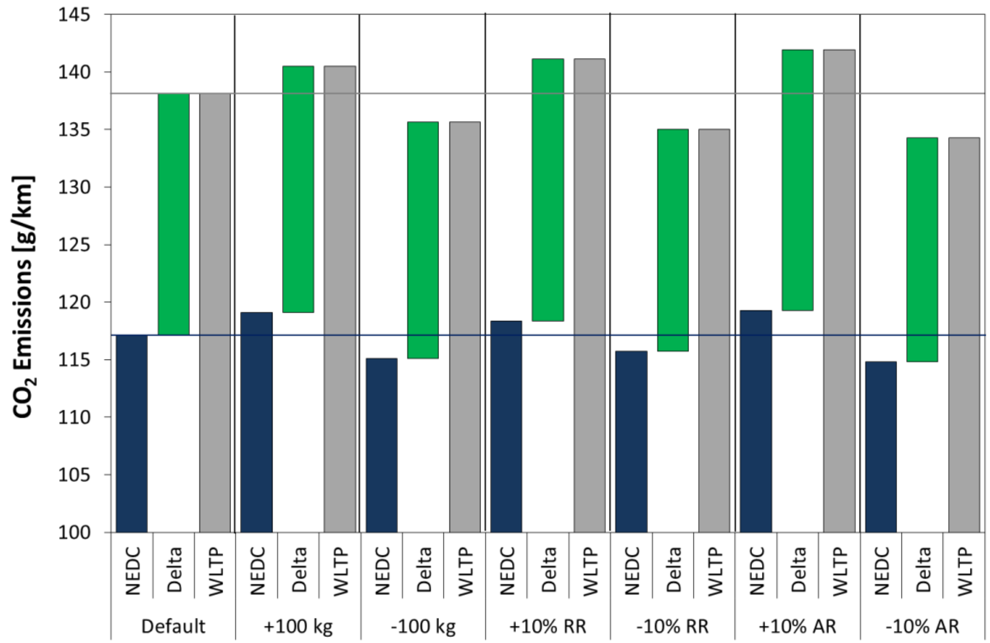
Gear	5G	6G	7G
1	4.11	4.11	4.11
2	2.25	2.25	2.25
3	1.40	1.40	1.43
4	1.00	1.00	1.00
5	0.80	0.80	0.77
6	—	0.66	0.66
7	—	—	0.56

- Downspeeding: Driving the engine to lower rotational speeds
- Variation of gear number and ratio
- Final drive is kept constant
- Up to 7 gears in manual transmission
- CO_2 reduction effect
  - 1.0% in NEDC
  - 3.0% in WLTP
- Optimised gear shifting in WLTP

Road Load and inertia

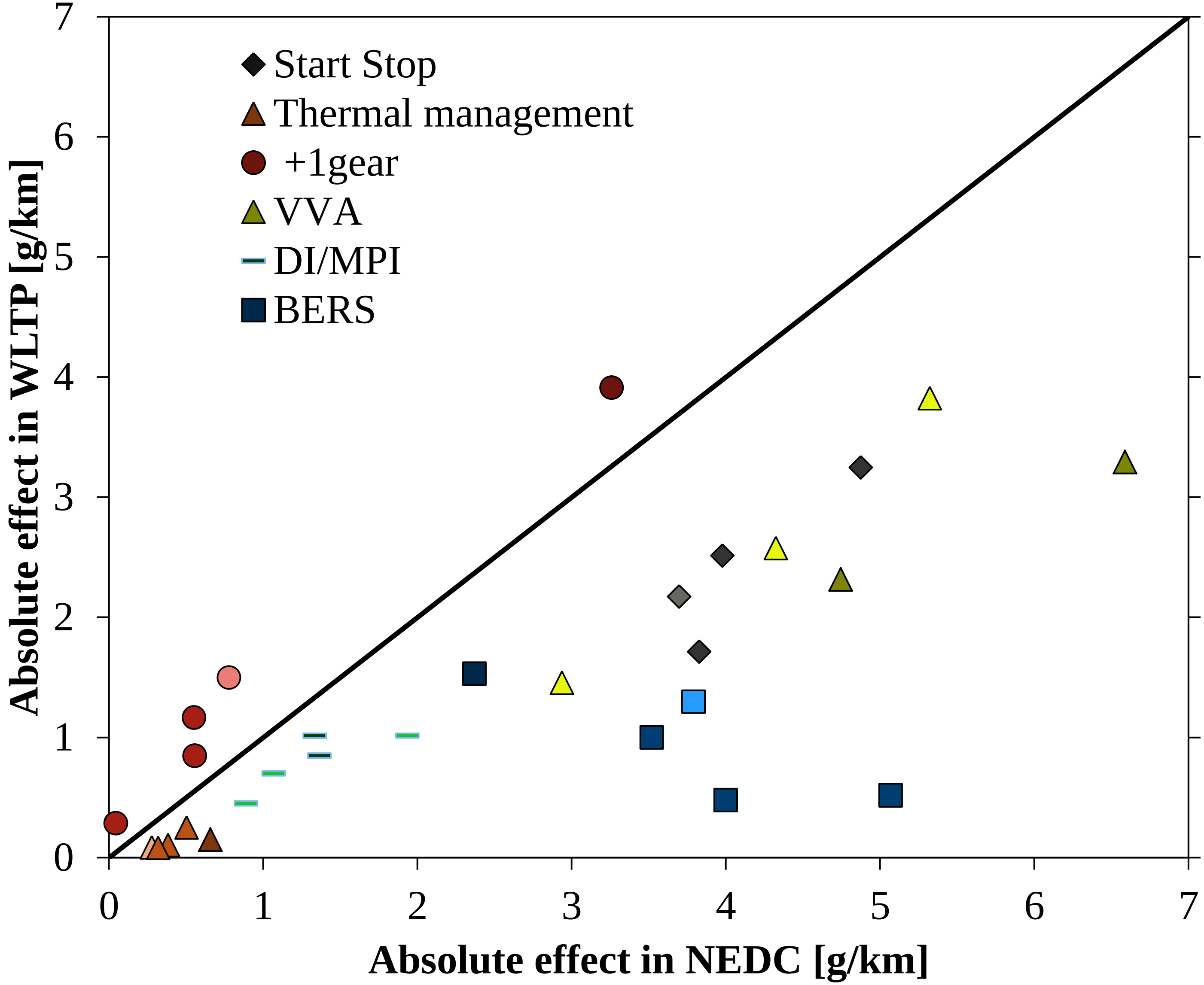
- Different vehicle variations (additional equipment, tires, chassis body version)
  - lighter or heavier
  - lower rolling resistance
  - lower aerodynamic drag
- CO_2 reduction effect

Scenario	NEDC	WLTP
-100kg	2.0%	2.0%
-10% RR	1.2%	2.2%
-10% AR	2.0%	2.8%

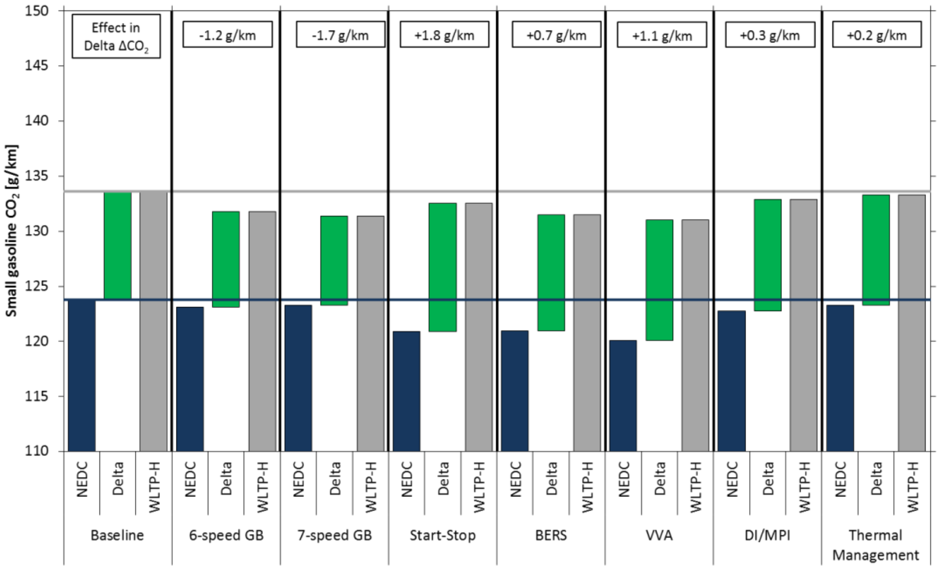


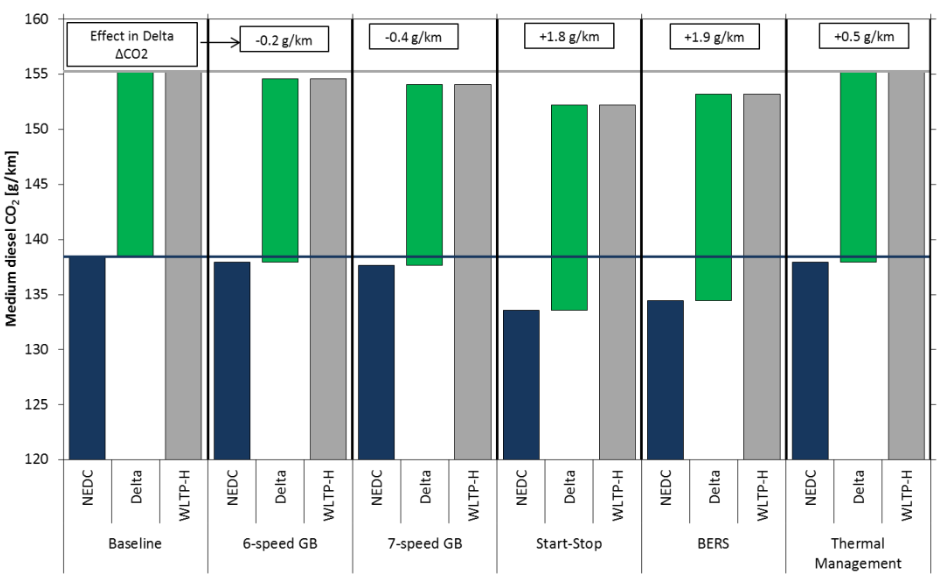
- RL effect stronger in WLTP due to higher velocities
- -10% AR has stronger effect that -10%RR, as aero drag is proportional to v^2

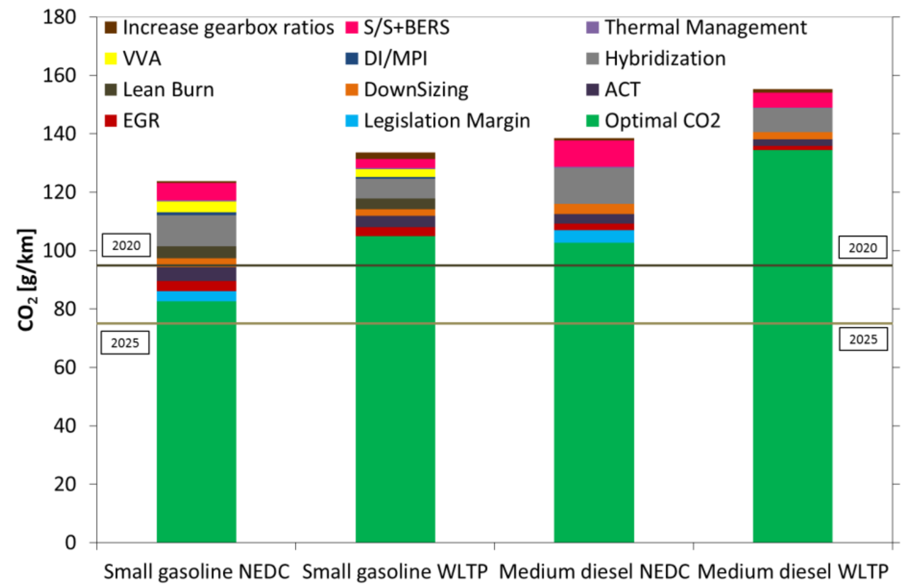
ΔCO2 WLTP/H – NEDC: Which cycle is affected more?



CO2 reduction technologies applied to a small gasoline and a medium diesel







- Hybridization scenario has the largest impact as regards CO_2 reduction, followed by Start Stop and BERS for both driving cycles.
- The reduction effect for the different technologies cannot be integrated. Currently, the overlapping between them cannot be estimated.
- Optimal CO_2 refers to the minimum simulated value

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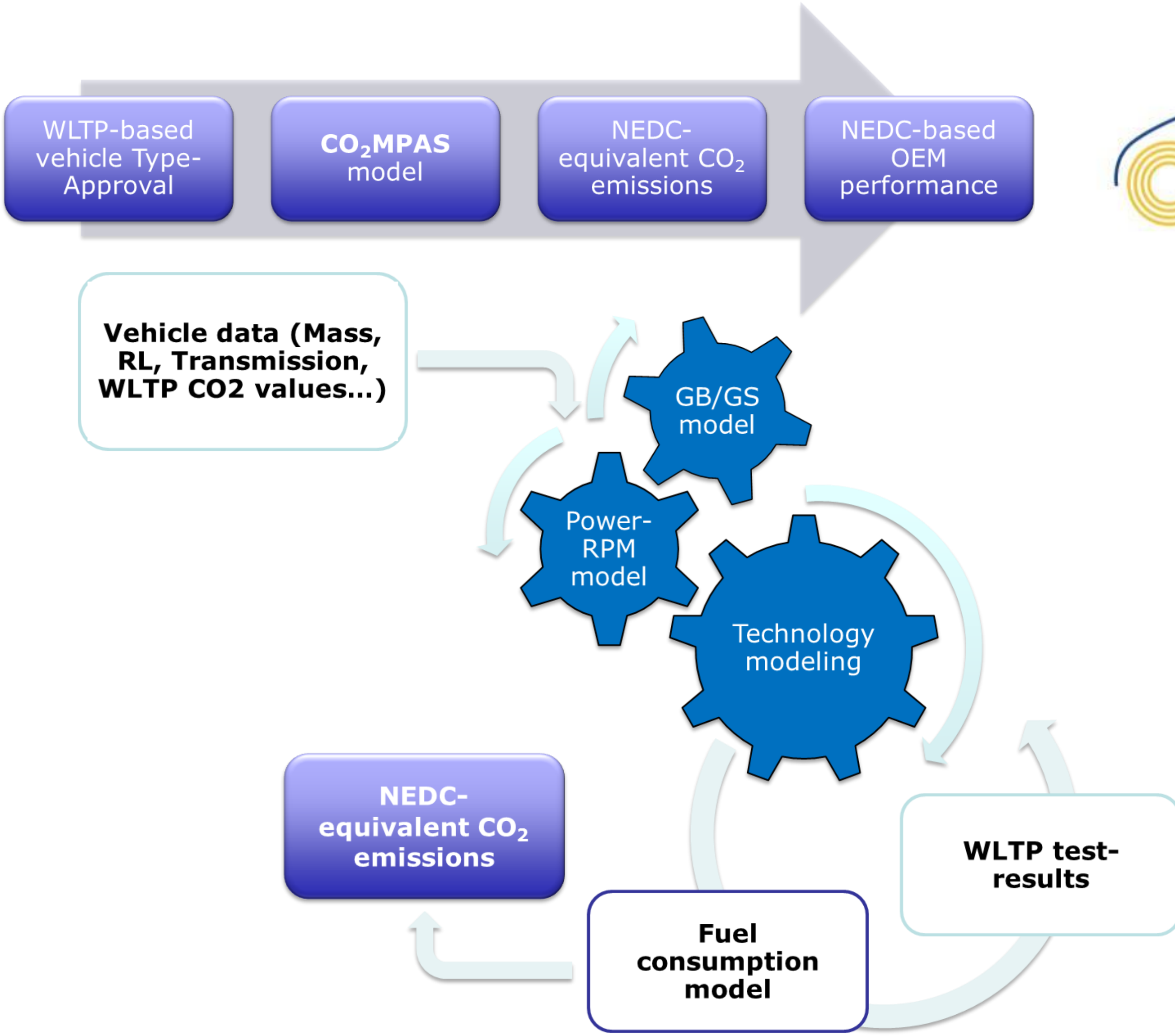
CO_2MPAS Description



Source: G. Fontaras, JRC, 2016

Validation campaign

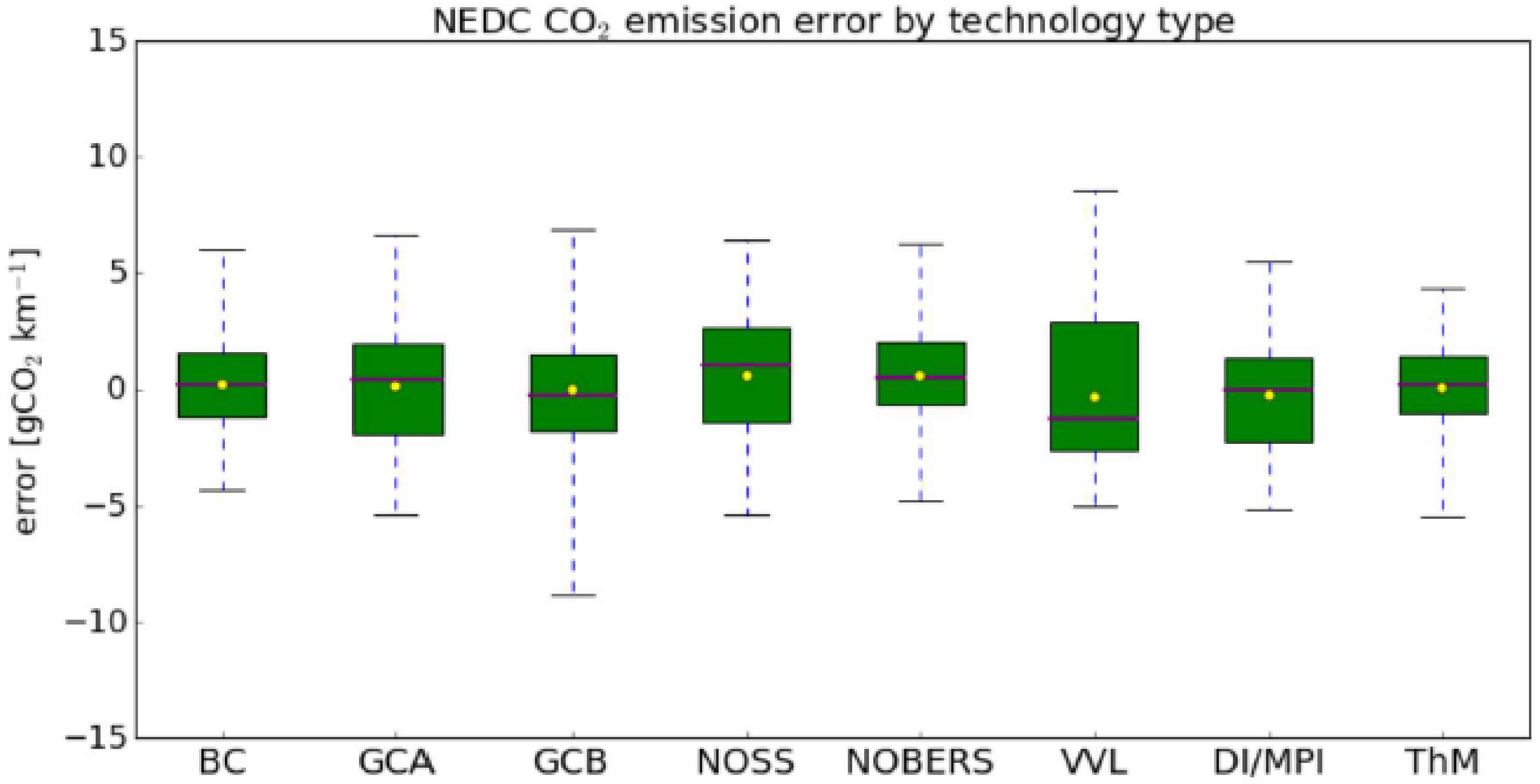
➢ Test cases examined

- 12 MT vehicle models in Cruise (synthetic based on real tests)
- 6 AT vehicle models in Cruise (synthetic based on real tests)
- 22 Real vehicles (tested in both NEDC and WLTP)
- Total 2169 synthetic MTs, 1138 synthetic ATs, 22 real cars (increasing)

Technology	Variation	Technology Acronym
Base variation Weight	± 100kg	
Base variation Road load	± 10% in F0, F1	
	± 10% in F2	
Gearbox: Number of gears	+1 gear ratio, +2 gear ratios	+ 1 gear (GCA) + 2 gears (GCB)
Start-stop	Active – Inactive	Base case with tech. Alternative case (NoSS)
Brake Energy Recuperation (BERS)	Active – Inactive	Base case with BERS Alternative case (NoBERS)
Variable Valve Actuation	Present/not present	Base case without tech Alternate case with (VVL)
Direct Injection/Multiple Injection	Present / not present	Base case without tech. Alternate case with (DI/MPI)
Thermal Management	Faster warm-up	Base case without tech. Alternate case with (ThM)

Source: G. Fontaras, JRC, 2016

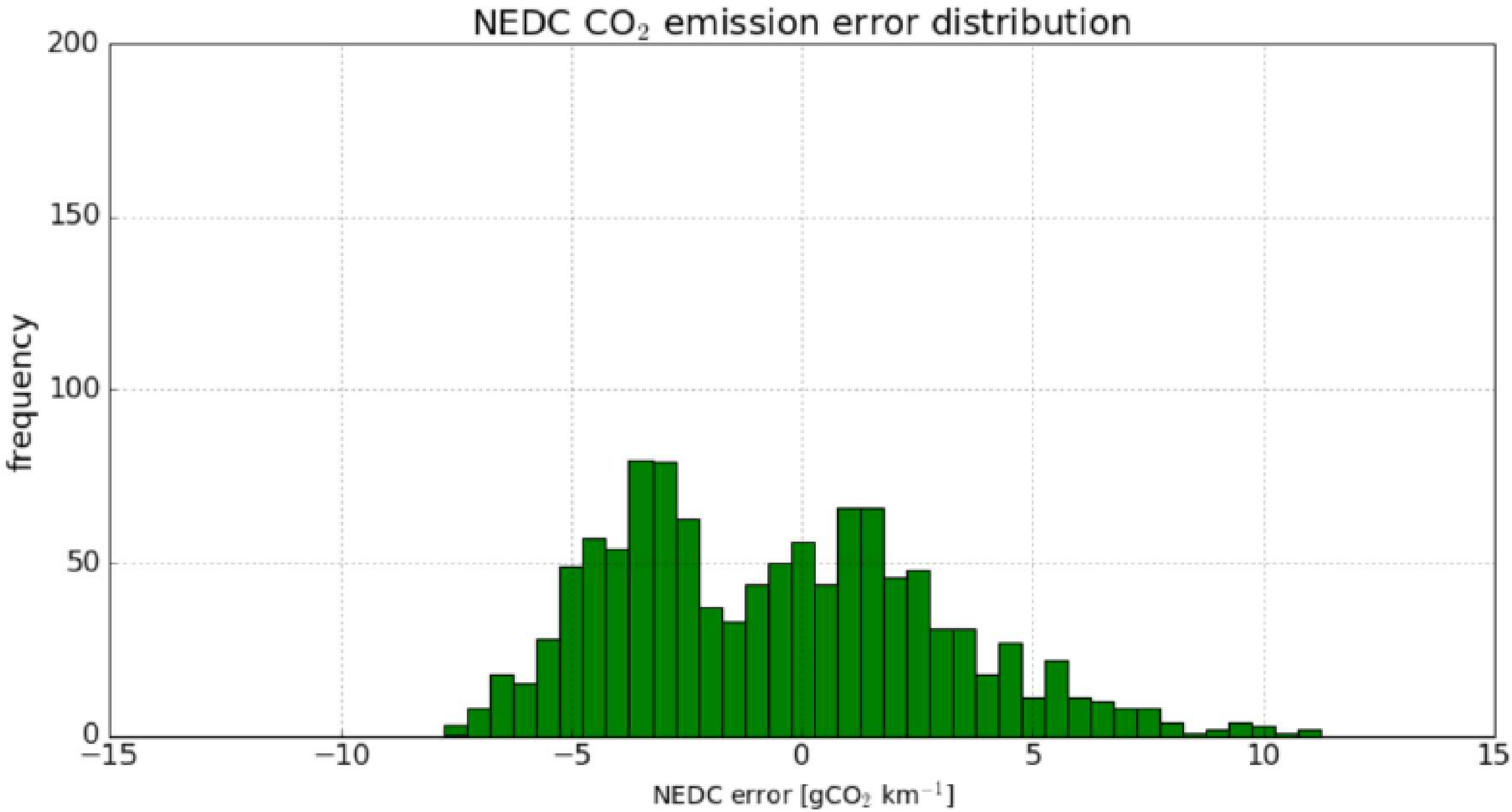
Results per technology - MTs



The green box represents the 1st and 3rd quartile.
The dark purple line is the median.
The yellow dot is the mean.
the whiskers show the min and max values.

Source: G. Fontaras, JRC, 2016

Results NEDC and sub-cycles synthetic data - ATs



Source: G. Fontaras, JRC, 2016

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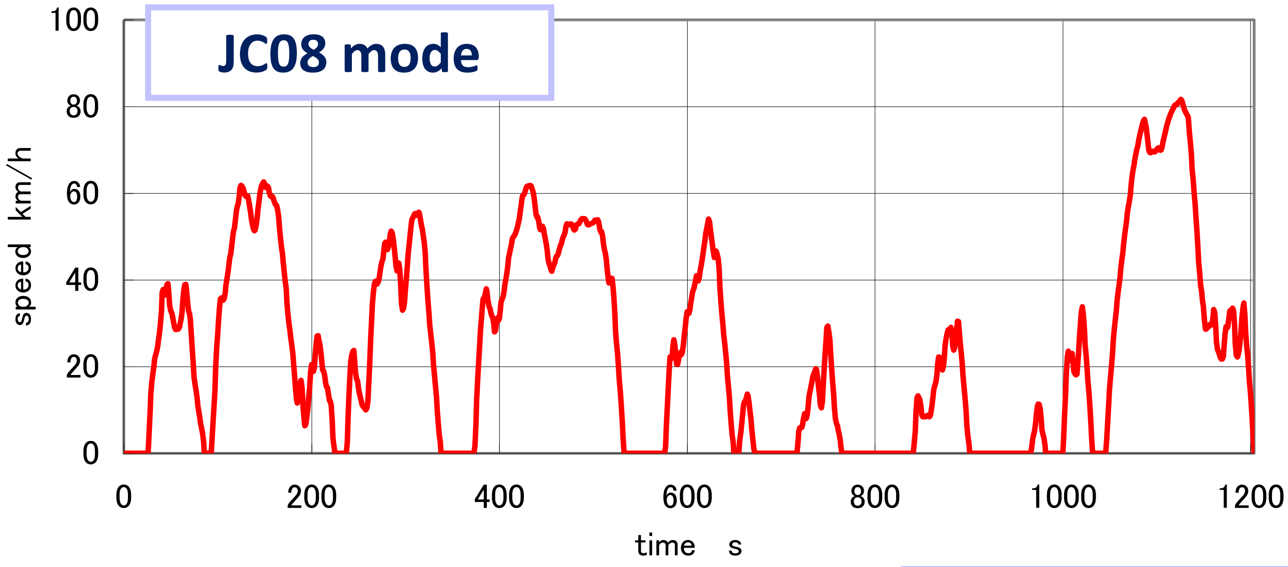
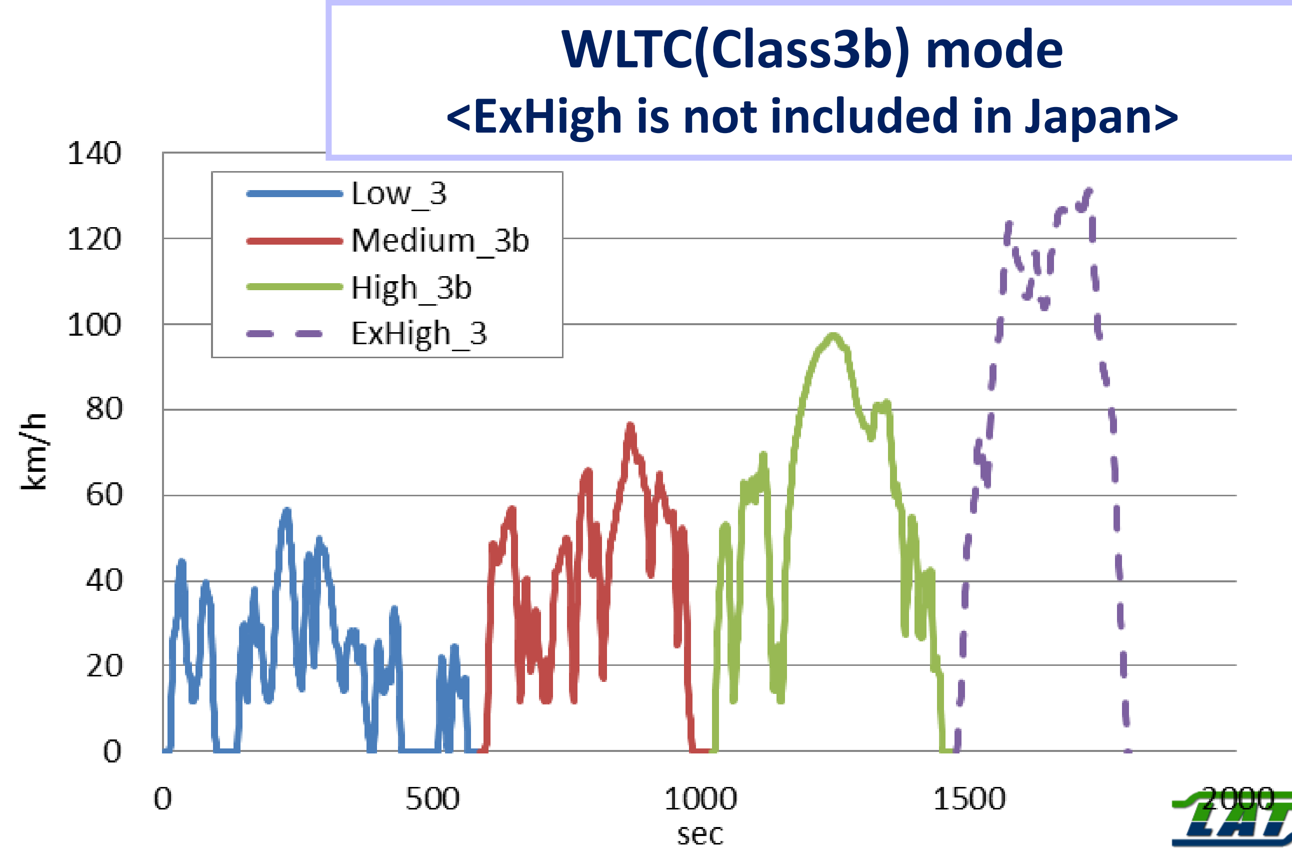




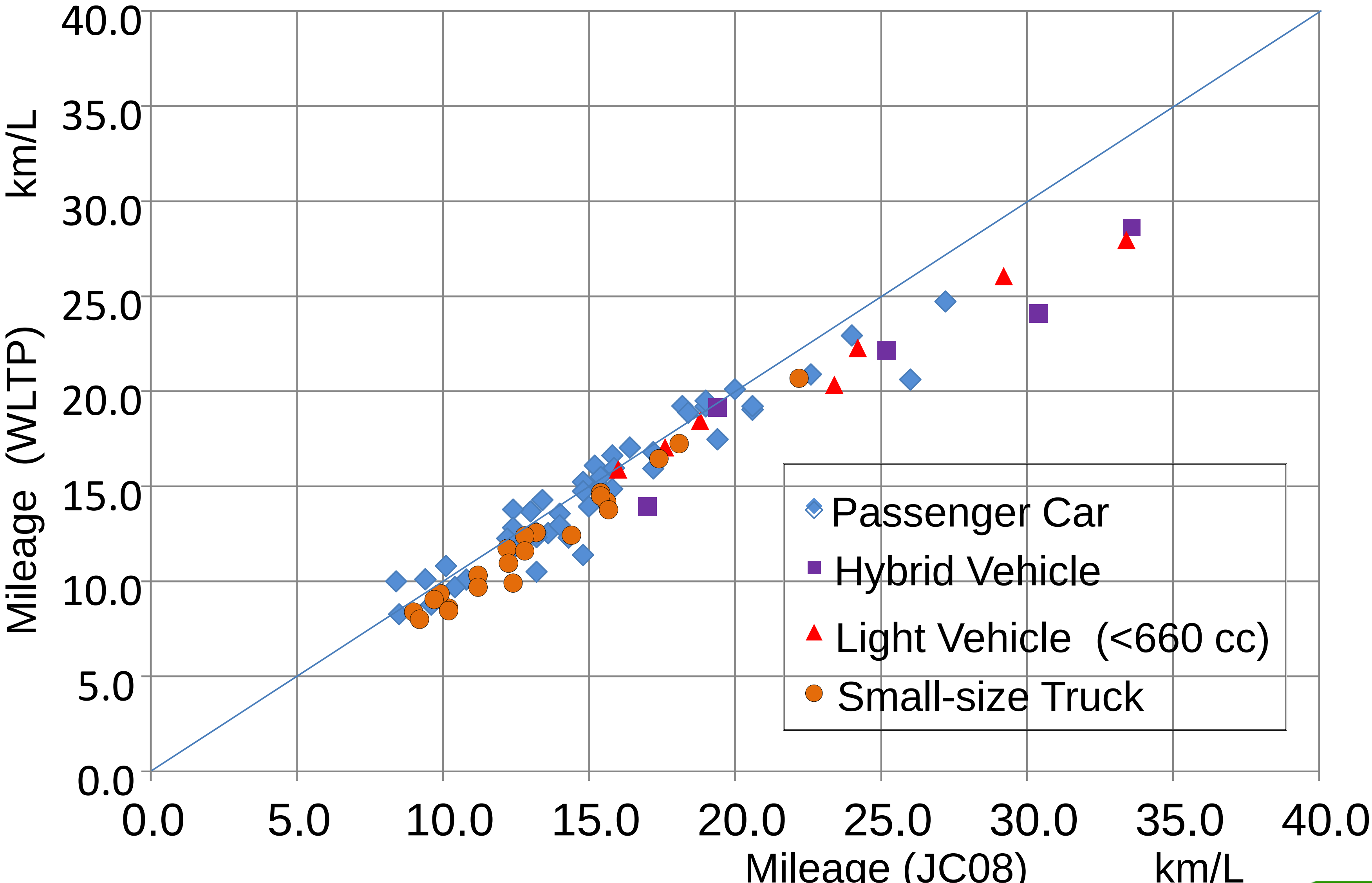
Source: M. Shioji, Kyoto Univ., 2015

Comparison of JC08 and WLTP

	JC08	WLTP (Class3b)
Average Speed (km/h)	24.41	36.57
Ratio of Idling Time (%)	29.7	15.4
Ratio of Cold Test (%)	25	100
Maximum Speed (km/h)	81.6	97.4
Maximum Acceleration (positive only) (km/h/s)	5.5	5.7
Test Duration (s)	1204	1477
Total Running Distance (km)	8.17	15.01

Source: M. Shioji, Kyoto Univ., 2015

CO2 Correlation between JC08 and WLTP



Source: M. Shioji, Kyoto Univ., 2015

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Conclusions (1/2)

- WLTP is a step forward - Its introduction will contribute to closing the gap between real world and reported fuel consumption
- WLTP higher fuel consumption compared to the NEDC does not come from the driving cycle. It comes from the test conditions!
- The dominant impacts are found to be
  - the higher test mass,
  - the driving resistance,
  - the preconditioning cycle and
  - the post test charge balance correction.
- Care has to be taken by the regulator as regards
  - The road loads to be used for certification purposes

Conclusions (2/2)

- Most technologies have stronger effect on NEDC
- Therefore the technologies introduced for fuel efficiency so far should be revisited
- Also some attention is needed to the fact that WLTP compared to NEDC has
  - Less stop periods
  - Less cold start

- WLTP is a cycle for development purposes
- RDE and other initiatives can play a very important role in ensuring that CO2 reduction actually takes place as foreseen

Thank you for your attention!

Back up

Different parameters in gear shifting generation algorithm

Gear shifting input	Diesel vehicle	Gasoline vehicle
Idle engine speed [RPM]	830	750
Engine speed at maximum power [RPM]	4000	5500
Maximum power [kW]	120	125
Engine to vehicle speed ratio for 1st gear	98.92	134.85
Engine to vehicle speed ratio for 2nd gear	54.14	73.23
Engine to vehicle speed ratio for 3rd gear	33.69	51.31
Engine to vehicle speed ratio for 4th gear	24.06	38.59
Engine to vehicle speed ratio for 5th gear	19.25	31.02
Engine to vehicle speed ratio for 6th gear	15.88	26.52
Delta in curb mass [kg]	-	-200
Delta in WLTP-High mass [kg]	-	-231
Delta in WLTP-High F0 [N]	-	-5.8
Delta in WLTP-High F1 [N/(km/h)]	-	0.0561
Delta in WLTP-High F2 [N/(km/h)^2]	-	0.0025

Measured vehicles

Fuel	Vehicle	Emission Standard	I*/A**/T***	Start/Stop	Displacement [cc]	Max Power [kW]	Max Torque [Nm]	Curb mass [kg]
Gasoline	G01	EURO5	PFI/NA/MT6	YES	1368	125	250	1290
	G02	EURO5	DI/T/MT6	YES	1798	125	318	1450
	G03	EURO6	DI/T/MT6	YES	1600	100	240	1300
	G04	EURO5	DI/T/AT8	YES	1995	180	350	1510
	G05	EURO5	PFI/NA/MT5	YES	875	77	145	930
	G06	EURO5	PFI/NA/MT5	YES	1368	57	115	1025
	G07	EURO5	DI/T/MT6	YES	999	92	170	1179
	G08	EURO5	DI/T/AT7	YES	3498	200	370	1635
	G09	EURO5	PFI/NA/AT5	YES	999	52	92	750
	G10	EURO5	DI/T/AT6	NO	2497	187	360	1456
	G11	EURO5	DI/T/MT5	NO	1197	66	160	1102
	G12	EURO5	DI/T/AT6	YES	1390	110	240	1623
Diesel	D01	EURO5	DI/T/AT8	YES	2967	190	580	1880
	D02	EURO5	DI/T/MT6	YES	1995	120	380	1465
	D03	EURO5	DI/T/MT5	NO	1248	55	190	1090
	D04	EURO5	DI/T/AT7	NO	2030	120	360	2030
	D05	EURO5	DI/T/MT5	YES	1248	70	190	1393
	D06	EURO5	DI/T/AT6	NO	1686	95	300	1309
	D07	EURO6	DI/T/MT6	YES	1598	90	320	1601
	D08	EURO5	DI/T/MT6	YES	1560	82	270	1293

*I = Injection: DI = Direct Injection; PFI = Port Fuel Injection

**A = Aspiration: T = Turbo; NA = Naturally Aspirated

***T = Transmission: ATn = Automatic Transmission with n gears, MTn = Manual Transmission with n gears