EURO 5 EFFECT STUDY FOR L-CATEGORY VEHICLES

7.12.2016 MCWG meeting, Brussels

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PROJECT OUTLINE

- **Tender ID:**
  - Title: Euro 5 Effect study for L-category vehicles
  - Tender No: 465/PP/GRO/IMA/15/11825
  - Contract No: SI2.713570
  - Client: European Commission - DG-GROWTH

- **Consortium performing the work:**
  - TNO - The Netherlands
  - EMISIA - Greece
  - Laboratory of Applied Thermodynamics (LAT) - Greece
  - Heinz Steven Data Analysis and Consultancy (HSDAC) - Germany

MAIN REQUIREMENTS OF THE STUDY

- Perform an **experimental assessment and verification programme** to **underpin the measures within the Euro 5 stage**.

- Assess the feasibility and cost-effectiveness of **possible post Euro 5 elements**:
  - **in-service conformity** testing requirements
  - **off-cycle emission** requirements
  - **Expand PM limit scope and introduction of a PN emission limit** for certain (sub-)categories of L-category vehicles.

  Based on the results, the Commission will consider introducing these new elements into future type-approval legislation (beyond Euro 5).
  - A cost-benefit analysis is currently on going in these issues

- **This presentation contains the results for the measures within the Euro 5 stage**

PROGRAMME TASKS AND TIMING

			2015		2016												2017					
	TASKS	**responsible**	**nov** 1	**dec** 2	**jan** 3	**feb** 4	**mrt** 5	**apr** 6	**mei** 7	**jun** 8	**jul** 9	**aug** 10	**sep** 11	**okt** 12	**nov** 13	**dec** 14	**jan** 15	**feb** 16	**mrt** 17	**apr** 18	**mei** 19	**jun** 20
1.1	Type I test: WMTC	EMISIA																				
1.2	Type II test: (increased) idle and free acceleration	EMISIA																				
1.3	Type III test: Emissions of crankcase gases	TNO																				
1.4	Type IV test: Evaporative emissions test	EMISIA																				
1.5	Type V – Durability of pollution control devices	TNO																				
1.6	Type VII – Energy efficiency tests	TNO																				
1.7	Type VIII OBD	EMISIA																				
2.1	Off-cycle emissions testing	TNO																				
2.2	In-service conformity verification testing	TNO																				
2.3	assessment of PM limit and introduction of a PN limit	EMISIA																				
3	Validation programme and final report	EMISIA																				

		2015		2016												2017					
MILESTONES	**responsible**	**nov** 1	**dec** 2	**jan** 3	**feb** 4	**mrt** 5	**apr** 6	**mei** 7	**jun** 8	**jul** 9	**aug** 10	**sep** 11	**okt** 12	**nov** 13	**dec** 14	**jan** 15	**feb** 16	**mrt** 17	**apr** 18	**mei** 19	**jun** 20
Final report phase 1	JRC	▲																			
End of Task 1 and 2	Consortium														▲						
draft Final report task 1	Consortium												▲	▲							
Final report phase 1 - 3	Consortium															▲					
Presentation of the final report in Parliament	Consortium															▲					
Final presentation UN L-EPPR	Consortium															▲					
Final presentation MCWG	Consortium																		▲		
Contract end																					▲

		2015		2016												2017					
MEETINGS		**nov** 1	**dec** 2	**jan** 3	**feb** 4	**mrt** 5	**apr** 6	**mei** 7	**jun** 8	**jul** 9	**aug** 10	**sep** 11	**okt** 12	**nov** 13	**dec** 14	**jan** 15	**feb** 16	**mrt** 17	**apr** 18	**mei** 19	**jun** 20
MCWG meetings			M				M					M			M				M		
UN L-EPPR				M		M			M				M			M					
Workshop Parliament																M					
Monthly review with Commission		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

M = live meeting

C = conference call

achieved milestone

COST-BENEFIT ANALYSIS APPROACH AND FIGURES

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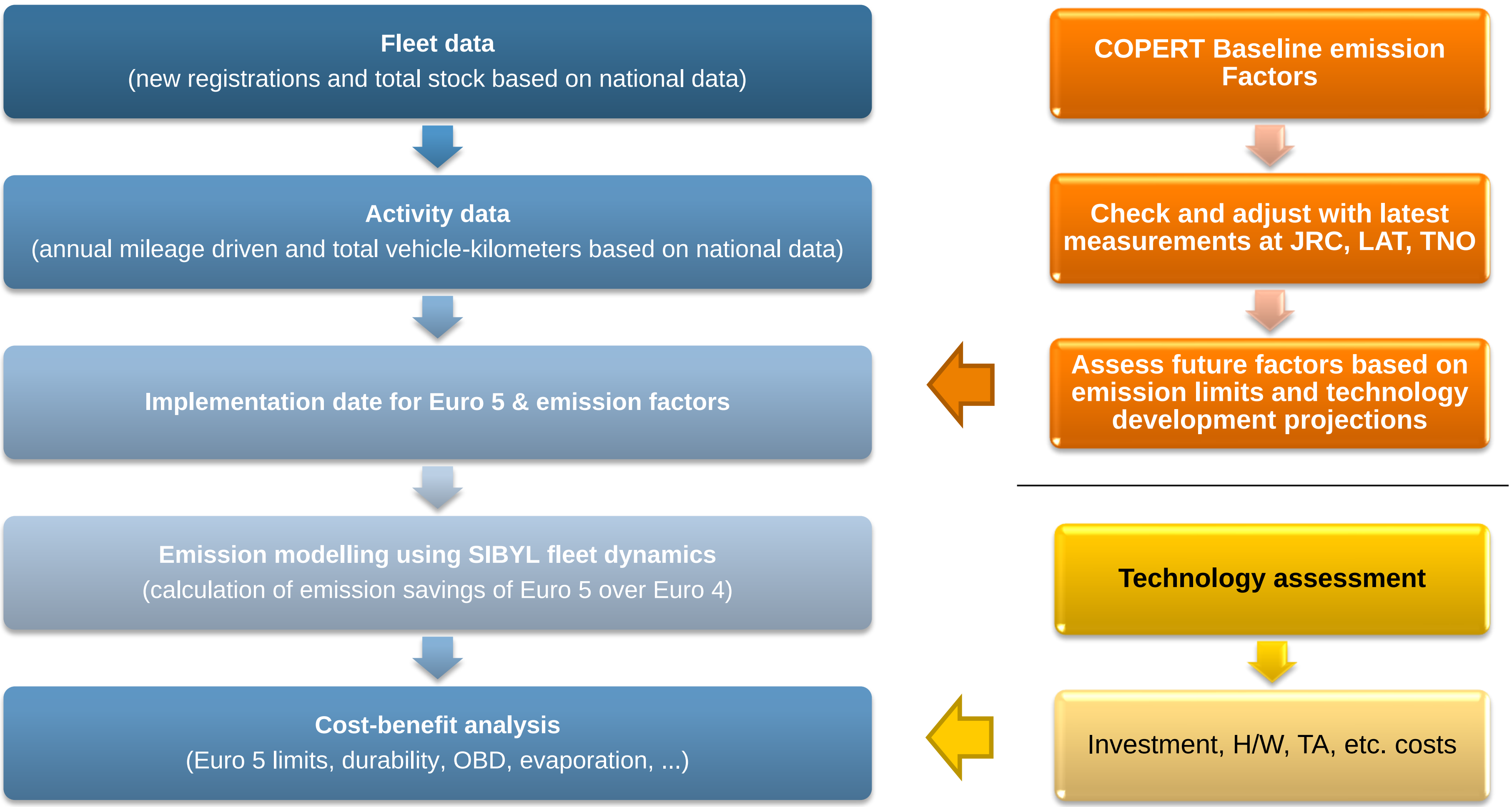
OVERVIEW OF CBA APPROACH



THREE SCENARIOS FOR THE FLEET/ACTIVITY DATA

Baseline

Business as usual after an initial sales rebound

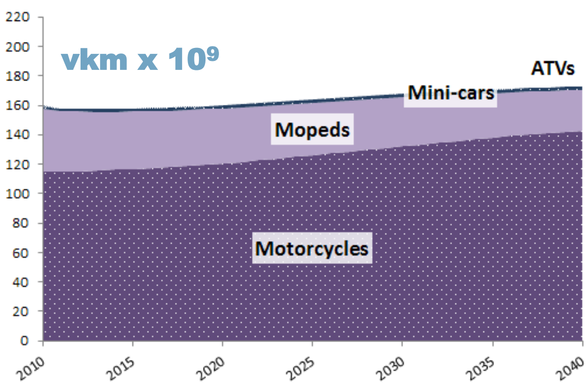
High growth

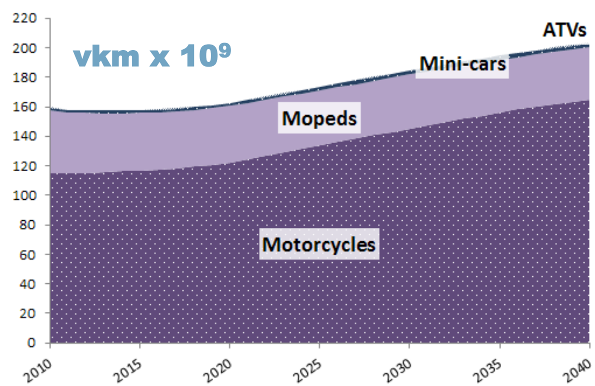
Increased number of registrations reflecting a vibrant economy

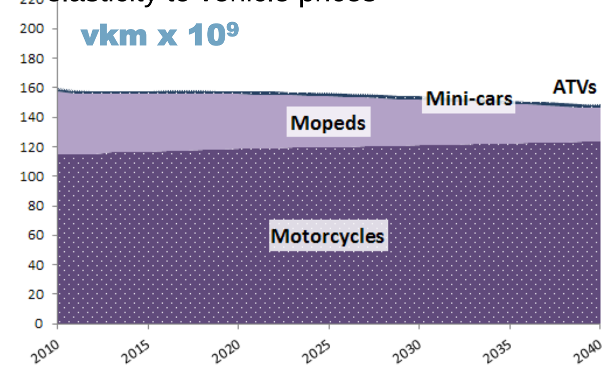
Low growth[1]

Decreased number of registrations reflecting GDP pressures

[1] This does not reflect market elasticity to vehicle prices







- **Motorcycles:** their contribution to activity dominates in all 3 scenarios (mainly due to shrinkage of mopeds sector and higher mileage/annual distance driven)
- **Mopeds:** their contribution to activity presents a decrease from 2010 to 2040 practically in all scenarios
- **Mini-cars and ATVs:** Small overall contribution to total activity but effects on local air quality

EMISSION FACTORS (EFs)

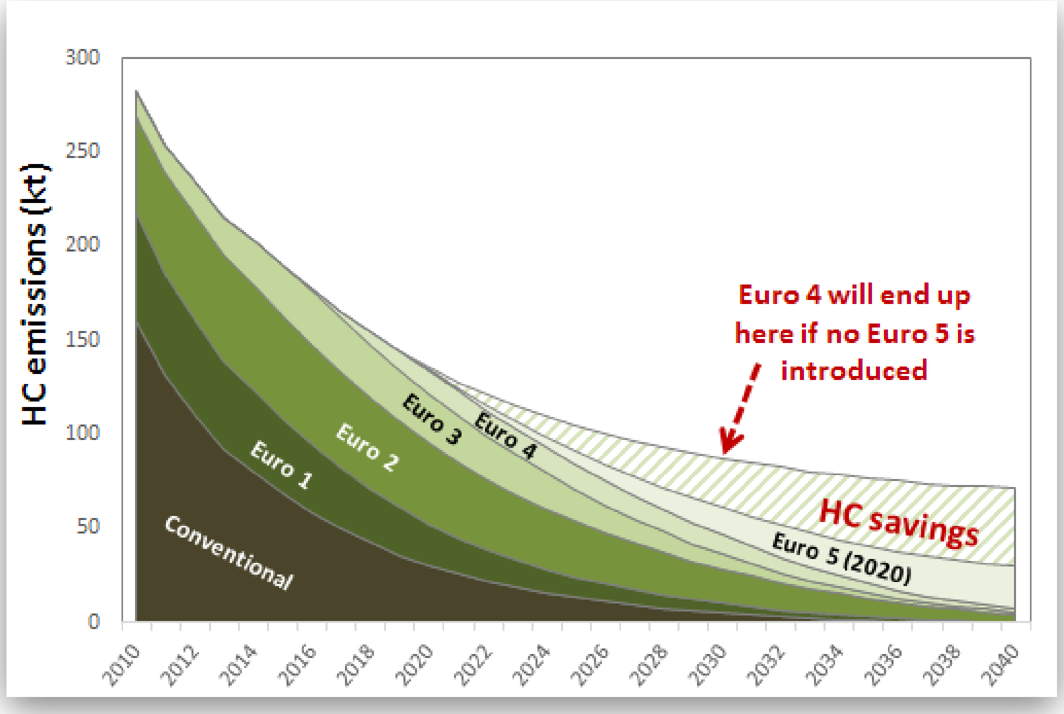
- A set of **base** emission factors (EFs) has been used to produce results on emission **savings** from the introduction of Euro 5. **Sources** utilized for legacy EFs:
  - Previous (2009) environmental effect study[1]
  - COPERT[2]
  - TNO report on moped emission factors[3]
  - New experimental data obtained in the course of the study at the Joint Research Centre (JRC) and Laboratory of Applied Thermodynamics (LAT) testing labs
- In general, reliable EFs **up to Euro 3** are already available from COPERT and previous (2013) environmental effect study (cross-checked with new JRC data)
- For **Euro 4** and **Euro 5**, emission standard equivalencies, emission limits, or justified estimates based on the expected technology are used
- **0.5/0.5** cold/warm weighing factors as the base case, **0.3/0.7** also examined for mopeds and L3-A1 motorcycles
- Emission factors **deteriorate** with age of vehicles, e.g. due to an aged catalyst, resulting in higher emissions after a few years of use

(1) Ntziachristos et al. (2009) Study on possible new measures concerning motorcycle emissions, LAT Report 08.RE.0019.V4

(2) Computer Programme to calculate Emissions from Road Transport, www.emisia.com/copert

(3) van Zyl, P.S. (2015) Update emission model for two-wheeled mopeds, TNO 2014 R11088

EMISSION SAVINGS EXAMPLE



HC emission savings from the introduction of Euro 5 emission limits

(all L-vehicles)

- **~509** kt HC can be saved when Euro 5 is introduced in 2020 for all L-vehicles
    - **~52%** emission savings over Euro 4

      2020-2040 period: HC savings / Euro 4 vehicle emissions = 509kt / 979kt = 52%
    - **~26%** emission savings of the whole L-category fleet emissions

      2020-2040 period: HC savings / total L-fleet emissions = 509kt / 1,950kt = 26%

TEST VEHICLES AND TESTS

ACTUAL TEST VEHICLE FLEET

- 1x L1e-A — powered cycle
- 3x L1e-B — low speed moped
- 6x L1e-B — high speed moped
- 2x L3e-A1 — low performance motorcycle
- 4x L3e-A2 — medium performance motorcycle
- 2x L3e-A3 — high performance motorcycle
- 3x L5e-A — tricycle
- 2x L6e — light quadri-mobile
- 3x L7e-B1 — heavy all terrain quad
- 1x L7e-B2 — side-by-side buggy
- 1x L7e-CP — heavy quadri-mobile







ACTUAL TEST VEHICLE FLEET (FOR REFERENCE)

Vehicle ID no.	category	category name	engine capacity class [cc]	rated power [kW]	engine combustion type*	# of cylinders	Maximum design speed [km/h]	Transmission	Euro class	Fuel delivery system	SAS	catalyst**	reference mass class [kg]	year	mileage [km]***
J05	L1e-A	powered cycle	30	1	G-2S	1	25	Fixed	Euro 1	carburettor	No	n.a.	100	2009	200
J06	L1e-B	low speed moped	50	3	G-2S	1	25	Fixed	Euro 2	carburettor	Yes	2w	120	2010	200
J07	L1e-B	low speed moped	50	3	G-2S	1	25	CVT	Euro 2	carburettor	No	2w	170	2010	200
J10	L1e-B	low speed moped	50	3	G-4S	1	25	CVT	Euro 2	carburettor	Yes	2w	160	2010	0
J02	L1e-B	high speed moped	50	2	G-2S	1	45	Manual	Euro 2	carburettor	Yes	2w	190	2015	0
J03	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	Yes	2w	160	2015	0
J04	L1e-B	high speed moped	50	3	G-2S	1	45	CVT	Euro 2	carburettor	Yes	2w	160	2015	0
J12	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	injection	Yes	2w	170	2013	846
J14	L1e-B	high speed moped	50	3	G-2S	1	45	CVT	Euro 2	carburettor	Yes	2w	180	2015	500
J17	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	Yes	2w	170	2013	4926
J19	L3e-A1	low perf. motorcycle	130	7	G-4S	1	90	CVT	Euro 3	carburettor	No	2w	180	2012	1372
J23	L3e-A1	low perf. motorcycle	130	11	G-4S	1	105	CVT	Euro 3	injection	No	3w	240	2010	0
J11	L3e-A2	medium perf. motorcycle	160	10	G-4S	1	95	CVT	Euro 3	injection	No	3w	200	2015	950
J26 (valid.)	L3e-A2	medium perf. motorcycle	300	16	G-4S	1	125	CVT	Euro 3	injection	No	3w	260	2015	500
J13	L3e-A2	medium perf. motorcycle	280	19	G-4S	1	128	CVT	Euro 4	injection	Yes	3w	240	2015	2871
J15	L3e-A2	medium perf. motorcycle	690	32	G-4S	1	>150	Manual	Euro 4	injection	Yes	3w	230	2016	1000
J18	L3e-A3	high perf. motorcycle	1170	92	G-4S	2	>150	Manual	Euro 4	injection	No	3w	300	2015	1156
T01	L3e-A3	high perf. motorcycle	1170	92	G-4S	2	>150	Manual	Euro 3	injection	No	3w	300	2016	385
J21	L5e-A	tricycle	300	18	G-4S-H	1	125	CVT	Euro 2	injection	0	3w	340	0	773
L01	L5e-A	tricycle	1330	84	G-4S	3	>150	Semi-AUT	Euro 4	injection	No	3w	530	2015	200
J24	L5e-A	tricycle	200	8	G-4S	1	55	Manual	Euro 2	carburettor	No	2w	420	2016	100
J01	L6e-BP	light quadri-mobile	480	4	D-4S	2	45	CVT	Euro 2	injection	No	2w	470	2015	0
J22	L6e-BU	light quadri-mobile	400	4	D-4S	2	45	CVT	Euro 2	injection	No	n.a.	480	0	988
J16	L7e-B1	all terrain quad	980	15	G-4S	2	65	CVT	Euro 2	injection	No	3w	470	2016	538
J08	L7e-B1	all terrain quad	570	11	G-4S	1	70	CVT	Euro 2	injection	No	2w	450	2015	900
J25 (valid.)	L7e-B1	all terrain quad	440	17	G-4S	1	67	CVT	Euro 2	injection	No	3w	370	2016	17
J09	L7e-B2	side-by-side buggy	700	15	G-4S	2	78	CVT	Euro 2	injection	No	2w	570	2016	638
J20	L7e-CP	heavy quadri-mobile	n.a.	13	E	n.a.	80	Fixed	n.a.	n.a.	n.a.	n.a.	570	0	0

* G = gasoline; D = Diesel; E=Electric; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

*** mileage at vehicle take-in, before any applied degreening

n.a. = not applicable

(valid.) = this vehicle was part of the validation testing programme

TYPE I: TAILPIPE EMISSIONS TEST AFTER COLD START

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TYPE I – TASK DESCRIPTION

- ***Background:*** A new driving procedure and emission limits are introduced at Euro 5 step for the Type I test – Tailpipe emissions test after cold start
- ***Specific objective:*** Check technical feasibility and cost-benefit of revised testing procedure and associated emission limits
- ***Specific tasks***
  - Assessment of the applicability of WMTC Stage 3 to all L-category vehicle types
  - Assessment of the appropriateness of the Euro 5 emission limits
  - Assessment of the separate NMHC limit
  - Assessment of the impact of ethanol in the reference fuel on the test type I results [post Euro 5 – not included in this presentation]

WMTC CYCLE IS NOT VIOLATED BY ANY OF THE VEHICLES MEASURED SO FAR

Vehicle	Transmission	Driveability WMTC		Driveability ECE	
J05 – L1e-A	Fixed	A	maxS		
J06 – L1e-B, low speed	Fixed	A			
J07 – L1e-B, low speed	CVT				
J10 – L1e-B, low speed	CVT				
J02 – L1e-B, high speed	Manual				
J03 – L1e-B, high speed	CVT				
J04 – L1e-B, high speed	CVT				
J12 – L1e-B, high speed	CVT				
J14 – L1e-B, high speed	CVT				
J17 – L1e-B, high speed	CVT				
J01 – L6e-BP	CVT				
J22 – L6e-BU	CVT				
J08 – L7e-B1	CVT		maxS		
J16 – L7e-B1	CVT				
J09 – L7e-B2	CVT				
J20 – L7e-CP	Fixed				
L2e-U	Manual	Under testing / processing			
L5e-A	Semi-automatic				
L5e-A	Manual				

Legend

A: demanded cycle acceleration was not met, this is no violation of the procedure

maxS: demanded cycle speed was higher than the maximum design speed of the vehicle, this is no violation of the procedure

GENERALLY THE WMTC COVERS A WIDER ENGINE OPERATION AREA

Vehicle	Transmission	WMTC coverage	ECE coverage	Wider engine map area coverage [WMTC / ECE]
J05 (L1e-A)	Fixed	7%	3%	Neutral, low coverage *
J06 (L1e-B, LS)	Fixed	6%	11%	Neutral, low coverage *
J07 (L1e-B, LS)	CVT	9%	14%	Neutral, low coverage *
J10 (L1e-B, LS)	CVT	5%	11%	Neutral, low coverage *
J02 (L1e-B, HS)	Manual	47%	17%	WMTC
J03 (L1e-B, HS)	CVT	38%	10%	WMTC
J04 (L1e-B, HS)	CVT	48%	10%	WMTC
J12 (L1e-B, HS)	CVT	34%	9%	WMTC
J14 (L1e-B, HS)	CVT	44%	9%	WMTC
J17 (L1e-B, HS)	CVT	38%	9%	WMTC
J01 (L6e-BP)	CVT	39%	7%	WMTC
J22 (L6e-BU)	CVT	30%	3%	WMTC
J08 (L7e-B1)	CVT	25%	25%	Neutral
J16 (L7e-B1)	CVT	57%	38%	WMTC
J09 (L7e-B2)	CVT	38%	19%	WMTC
L2e-U	Manual	Under testing / processing		
L5e-A	Semi-automatic			
L5e-A	Manual			

* Low engine map coverage also encountered in real-drive conditions

TYPE I:
ASSESSMENT OF THE EURO 5 LIMITS

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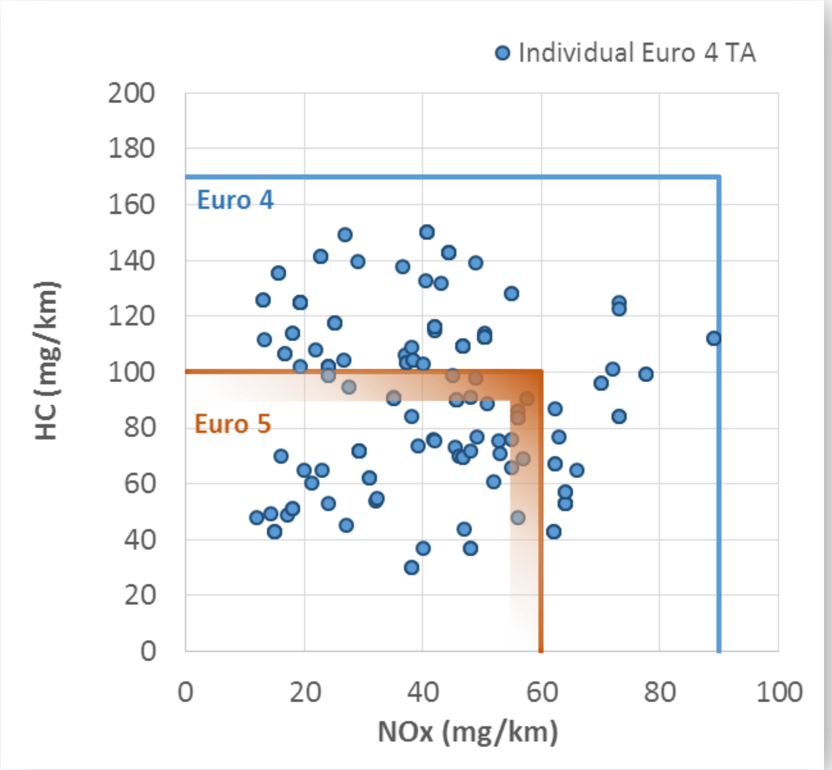
WHERE CURRENT TYPE APPROVAL VALUES STAND



Source: Sept. ‘16 Kraftfahrt-Bundesamt L3e Type Approval data

Note: Euro 5 limit uncertainty range due to 0.5/0.5 weighing factors

- Already ~40% of L3e TAs comply with Euro 5 **numerical** HC/NOx limits
- CO compliance reaches 96%

TECHNOLOGY ASSESSMENT AND COST ESTIMATE FOR EURO 5 (WF: 0.5/0.5)

Vehicle	Moped	Motorcycle (incl. ATVs)
Engine	▪ 4S engines with EFI ▪ Recalibration and design refinements	▪ Improved engine calibration for start-up emission suppression
Aftertreatment	▪ Exhaust line redesign ▪ Thermally optimized TWC for fast light-off ▪ Higher PGM loading	▪ Marginally larger catalyst and/or higher PGM loading ▪ Some models: CC pre-cat + main catalyst or closer placement of main catalyst
Assessment	Significant but incremental technology improvements	Incremental technology improvements
Cost (€/veh.) 2020-2040 horizon	78-111	38-49 ('Average' L3e vehicle, not only L3e-A1 one)

RATIOS FOR COLD/HOT WMTC PARTS CONSIDERED (REF: EURO 4)

Pollutant	WMTC Cold/warm ratio for Euro 5 L1e-B and L3e-A1 vehicles	Relative increase in Euro 5 EFs by using 0.3/07 WFs
HC	6.0	1.4*
CO	1.6	1.10
NOx	1.5	1.09

* Same value also for PM

- Values based on 4 Euro 4 motorcycle results with adjustment for expected Euro 5 technology
  - Higher HC, NO_x
  - CO is irrelevant for the cost-benefit analysis

EURO 5 LIMITS FOR MOPEDS AND MOTORCYCLES COST-BENEFIT AND ASSESSMENT

Cost-benefit over 2020-2040 (Values in M€)	0.5/0.5 cold/warm weighing factors	0.3/0.7 cold/warm weighing factors
Mopeds	137^{+76}_{-63}	135^{+74}_{-59}
Motorcycles (including ATVs)	85^{+106}_{-104}	16^{+93}_{-116}

- Euro 5 limits appear technically feasible for introduction in 2020/21 (new/all types)
- Both sets of weighing factors offer net monetary benefits
  - 0.3/0.7 assumes 20% less calibration costs/model and 10% less H/W cost
- Delay in introducing these limits, while keeping 2040 as the same horizon decreases environmental (monetary) benefits

EURO 5 LIMITS FOR MINI-CARS
COST-BENEFIT AND CURRENT ASSESSMENT

(Values in M€)	Cost-benefit
Retaining diesel mini-cars (introd. in 2020)	-21^{+49}_{-55}
Advanced mini-cars (introd. in 2024)	468^{+63}_{-92}

- Introduction of the new limits implies significant technology investment, if retaining diesel powertrains.
- Electric vehicles or in-series hybrids bring large overall benefits, also in monetary terms,
  - even when delaying their introduction in 2024/5 (new/all types)

CONCLUSIONS

- Proposed Euro 5 emission limits are technically feasible to be reached by 2020/1 (new/all types)
  - Moderate improvements requested for motorcycles (+ATVs)
  - More significant investments for mopeds

- Positive effects, in monetary terms, achieved regardless of weighing factors used

- Change of powertrain to electric or series-hybrid for mini-cars beneficial over diesel + aftertreatment, even when introduced in 2024/5 (new/all types)
  - Short term approach could be based on increasing the petrol engine capacity but safety and standardisation issues (non UN L6 anymore) could provide obstacles

TYPE I: ASSESSMENT OF THE SEPARATE NMHC LIMIT

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COST-BENEFIT AND CURRENT ASSESSMENT

Cost-benefit over 2020-2040 (Values in M€)	Scenario: Fixed ratio for CH4
Mopeds	$0.44^{+0.04}_{-0.05}$
Motorcycles	$1.75^{+0.18}_{-0.17}$

- Introducing a fixed ratio for CH_4/THC may offer some cost advantages for petrol vehicles due to decreased development costs
  - Benefits of using a fixed ratio are marginal
  - Retaining distinct NMHC and THC values (as in (EU) 168/2013) provides better information in light of upcoming GHG reporting requirements

TYPE III: CRANKCASE EMISSIONS

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TYPE III – CRANKCASE GASES TASK DESCRIPTION

- ***Background:*** Assessment of a test procedure to verify that engines are so constructed as to prevent any fuel, lubrication oil or crankcase gases from directly escaping, without being combusted, to the atmosphere from the crankcase gas ventilation system.

- ***Specific objective:*** Verify the two alternative test procedures set out in Annex IV to Regulation (EU) No 134/2014.

- ***Specific tasks:*** Carry out the Type III test on the test vehicles, identify and report any potential issue in the application of the two applicable test procedure described in Regulation (EU) No 134/2014, make recommendations to improve the test procedures if necessary.

CRANKCASE EMISSION TEST METHODS BACKGROUND

- Basic method:
  - Measure $p_{crankcase}$ over load-points on chassis dyno. $p_{crankcase}$ should be < $p_{ambient}$

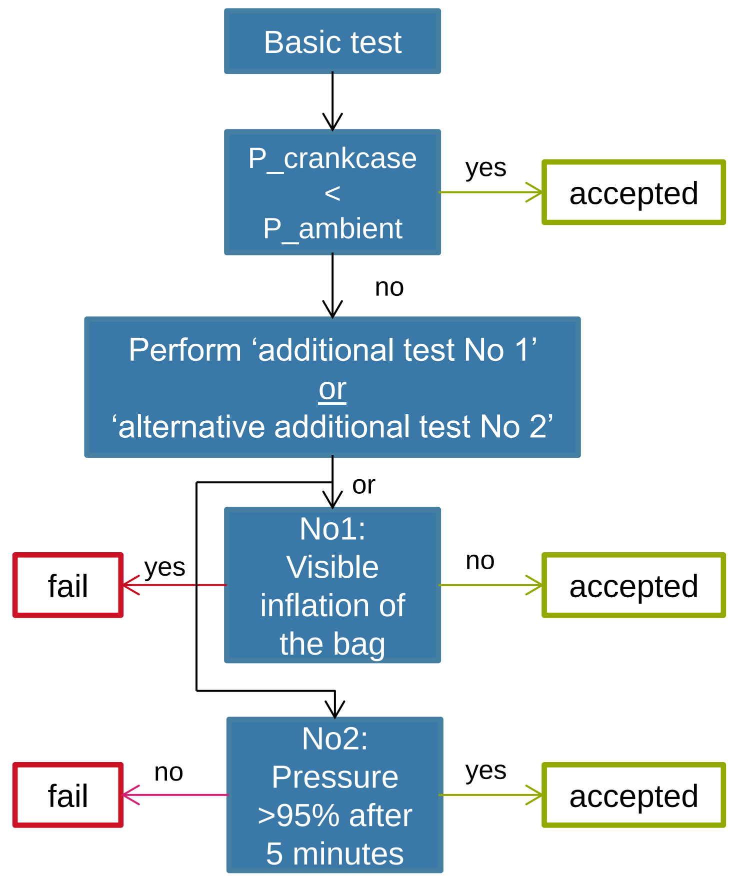
Additional test method No 1:

- Connect plastic bag to the dipstick hole. The test is passed if no visible bag inflation occurs over conditions on chassis dyno of basic method

Alternative additional test method No 2:

- Leak check of the engine with compressed air. Test is passed if crankcase pressure remains at > 95% of the initial pressure after 5 minutes.

Flowchart Type III



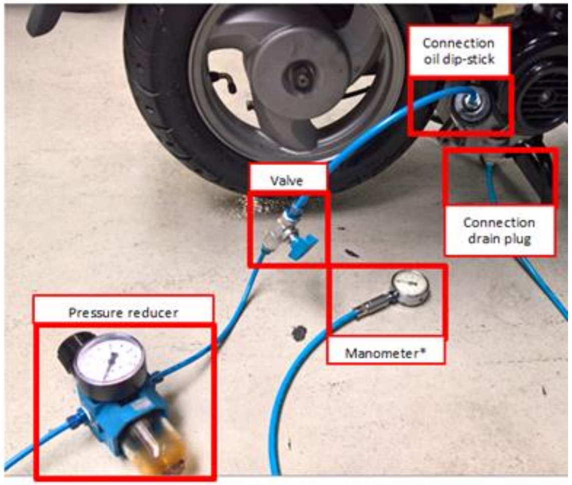
Type III: Crankcase emissions

CRANKCASE EMISSIONS TESTING

TEST RESULTS

- 2 / 7 vehicles pass the basic test
- 6 / 7 vehicles pass the additional test no 1
  - Except for veh. J22, the vehicles were tested with a one liter bag instead of the prescribed five liter bag

Vehicle class	Vehicle ID	Fuel type	Basic test method	Additional test method No 1
L1e-B	J03	Gasoline	Fail	Pass
L1e-B	J17	Gasoline	Fail	Pass
L3e-A1	J19	Gasoline	Fail	Pass
L3e-A2	J15	Gasoline	Fail	Pass
L3e-A3	J18	Gasoline	Fail	Fail
L6e-B	J22	Diesel	Pass	Pass
L7e-B1	J08	Gasoline	Pass	Pass



CRANKCASE EMISSIONS TESTING

RESULTS OF THE ASSESSMENT

Actual situation:

- Basic method is always performed during TA testing, most of the times this is not passed.
- When basic test is not passed during TA testing, most of the times additional test method 2 is chosen as alternative test.

Assessment of basic and additional test method No1:

- Basic test and additional test method No1 both check if the crankcase ventilation system works properly, but do not check if the crankcase is gas leak-tight.
- Pulsations are the root cause of failure for basic method, this is an issue specifically for typical L-category vehicle engines.
- The five litre sample bag used in the additional test method No1 is identical to demands for passenger cars. Five litre is too large for most of the L-cat vehicles, especially for mopeds and light motorcycles with small engine volumes. Most of the tested vehicles within this study pass the test with a sample bag of one litre.

Assessment alternative additional test method No2:

- Checks if crankcase is gas leak-tight but it does not check if the crankcase ventilation system works properly;

CRANKCASE EMISSIONS

CONCLUSIONS

- Prevention of crankcase emissions is not guaranteed by the actual testing procedure
  - Basic test and additional test no 1 can be passed when the engine is not gas leak-tight
  - The alternative additional test no 2 can be passed while the crankcase ventilation system is not working
- The basic test and additional test no 1 are good methods to assess if the crankcase ventilation system works properly. However, some small revisions are recommended to make the test methods better applicable to L-category vehicles (next slide).
- Alternative additional test no 2 is a good method to assess if the engine is gas leak-tight.
- The engineering assessment of the crankcase ventilation system by the TAA or TS is an important part of the procedure.

CRANKCASE EMISSIONS

RECOMMENDATIONS

- Create a provision to allow pulsations in the basic test.
- Limit the size of the sample bag in additional test no1 to a factor 3 of the engine swept volume.
- Make the basic and additional test method No 1 as the two alternatives to choose from and to introduce alternative additional test method No 2 as a complementary test (mandatory or to be requested by the TAA).
- More explicitly describe in 2.2 of Annex IV of Reg. 134 (Regulation (EU) no 134/2014, 2013) when the Type III test is mandatory for new engine types
- Adopt these recommendations made for improvement of the Type III test procedures in the proposal for Technical Report on the development of UNECE global technical regulation for test Type III (crankcase emissions)

TYPE IV: EVAPORATIVE EMISSIONS

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TYPE IV – TASK DESCRIPTION

- ***Background***: Fuel evaporation is a significant source of NMHC emissions and need to be reduced. Addition of EtOH in fuel may further aggravate the problem.

- ***Specific objectives:*** Examine the need to introduce SHED testing for special vehicle types and assess the impact of EtOH on fuel evaporation control

- ***Specific tasks:***

1. Assessment of evaporative emission test procedure set our in Annex V to Regulation (EU) No 134/2014, in particular the permeation and SHED test procedures
2. Investigation of the cost effectiveness of a 25% lower Euro 5 evaporative emission limit compared to the Euro 4 limit for vehicles subject to the SHED test
3. Investigation of the impact of fuel quality on he evolution of fuel permeation rate over time as well as the ageing effects of the carbon canister

EVAPORATIVE EMISSIONS CBA EURO 5

INTRODUCE FUEL SYSTEM PERMEATION TEST FOR L1E, L2E, L5E-B, L6E, L7E-B, L7E-C

(Values in M€)	Cost-benefit over 2020-2040
Mopeds	$19.4^{+7.7}_{-11.2}$
Tricycles (L5e-B)	$0.5^{+0.1}_{-0.1}$
Other types (L6e-L7e)	$4.2^{+1.3}_{-1.9}$

Assessment:

- Introduction of a permeation test has clear benefits
- The benefit of permeation test is highest for mopeds because of the significant NMHC savings offered by low-permeability fuel tanks and their relatively low cost
- For L5e-B Tricycles, mini-cars and ATVs the benefits are lower because of the much smaller population of these vehicle types

EVAPORATIVE EMISSIONS CBA EURO 5

INTRODUCE SHED TESTING FOR L1E, L2E, L5E-B, L6E, L7E-B, L7E-C

(Values in M€)	Cost-benefit over 2020-2040
Mopeds	$-1.4^{+0.2}_{-0.2}$
Tricycles (L5e-B)	$-0.03^{+0.01}_{-0.00}$
Other types (L6e-L7e)	$-10.2^{+2.6}_{-5.0}$

Assessment

- The NMHC savings of the SHED test are lower than the permeation test for all categories because there is no need to equip vehicles with low-permeability fuel tanks to pass the SHED test
- The costs are higher than for the permeation test mainly because of the R&D costs to develop the vapour control system (carbon canister, purging strategy, etc.)

EVAPORATIVE EMISSIONS CBA EURO 5

LIMIT OF 1.0 G/TEST FOR L3E, L4E, L5E-A AND L7E-A

(Values in M€)	Cost-benefit over 2020-2040
otorcycles and tricycles (L3e, L4e, L5e-A)	-30^{+9}_{-20}

Discussion

- The NMHC savings of lowering the SHED test limit by 0.5 g/test are marginal because most of the emissions in real-world occur during longer parking events (above 24 hours) which are not captured by the current SHED test procedure
- Considering the additional costs for re-designing and calibrating the vapour control system there are no additional net benefits estimated

EVAPORATION EMISSIONS

CURRENT ASSESSMENT

- Introduction of fuel system permeation testing for L1e, L2e, L5e-B, L6e, L7e-B and L7e-C is a measure technically feasible. Environmental benefits by far exceed technology costs.
- Introduction of SHED testing for L1e, L2e, L5e-B, L6e, L7e-B and L7e-C vehicles is not environmentally interesting as this mostly addresses breathing emissions while most evaporation emissions from these vehicles come from permeation losses.
- Reducing the Euro 5 limit to 1 g/test for L3e, L4e, L5e-A and L7e-A makes little environmental difference as evaporation emissions of these vehicles mostly occur during longer parking events, which an 1-h long test does not address. A longer (12 to 24 hours) diurnal test would be more appropriate to capture these emissions.

TYPE V: DURABILITY REQUIREMENTS

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TYPE V – DURABILITY OF POLLUTION CONTROL DEVICES

- ***Background***: A physical method for ageing of emission control devices is proposed, together with a new mileage accumulation procedure.
- ***Specific objectives:*** Validate the new mileage accumulation cycle, the assigned deterioration factors and the useful life values. And provide a cost effectiveness analysis based on the measurement programme
- ***Specific tasks:***

1. Supplemental validation of SRC-LeCV, appropriateness of useful life distances and determine by when after 2020 the AMA shall be phased out.
2. Assess the appropriateness of the useful life values defined in the Annex VII(A) of Regulation 168/2013 as well as of the deterioration factors to be used in the mathematical durability procedure.

ASSESSMENT OF THE CYCLES BASED ON THERMAL LOAD

- **durability demonstration process** should be designed not to reflect realistic ageing conditions but to **predict expected in-use deterioration rates and emission levels** [EPA*]
- WMTC operation conditions are considered as realistic ageing conditions and WMTC shall be the benchmark for the analysis of mileage accumulation cycles [TRL study**]
- The catalyst is considered to be the most relevant emission control device for L-category vehicles [TRL study**]
- On average **thermal load can be seen as the main contributor to catalyst deterioration**

*   (EPA)

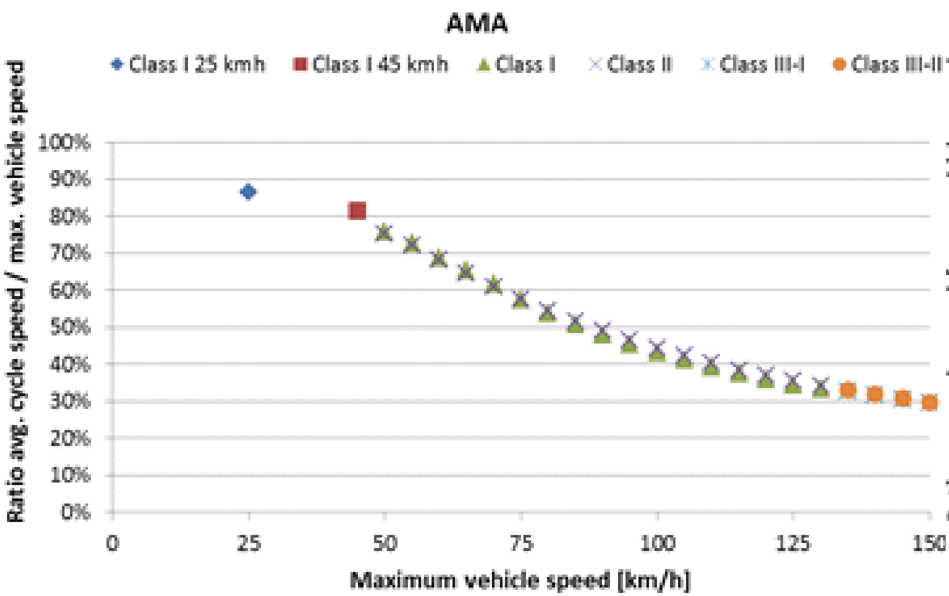
** (A.Nathanson, et al., 2012)

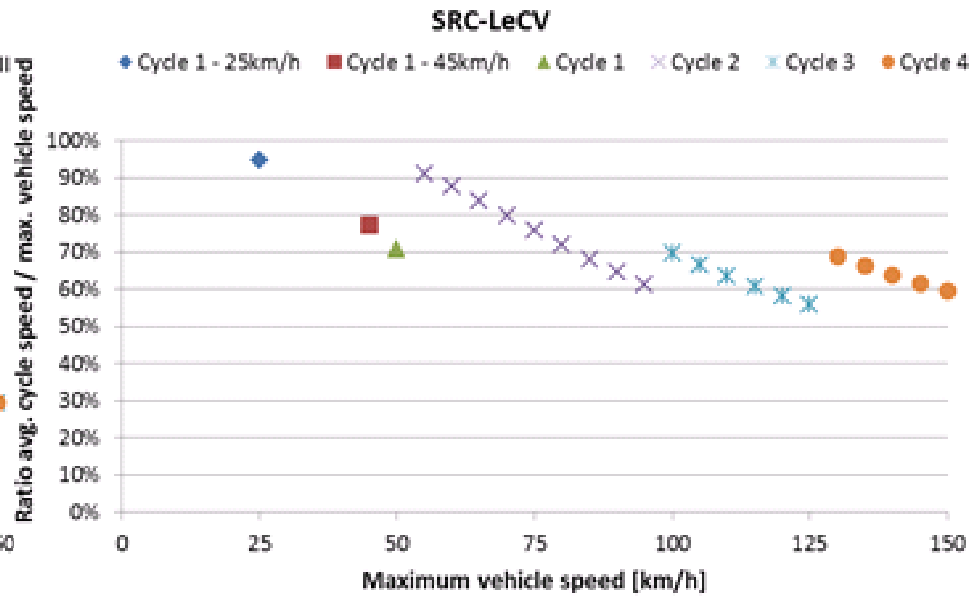
ASSESSMENT OF THE CYCLES COMPARISON OF SRC-LeCV AND AMA

Three approached were applied:

- A theoretical comparison of the share of high speed driving in the different cycles as a proxy for engine load (which is a proxy for thermal load)
- Assessment of the engine load/speed map coverage
- Assessment of the thermal load (both of measurement data and modelled data)

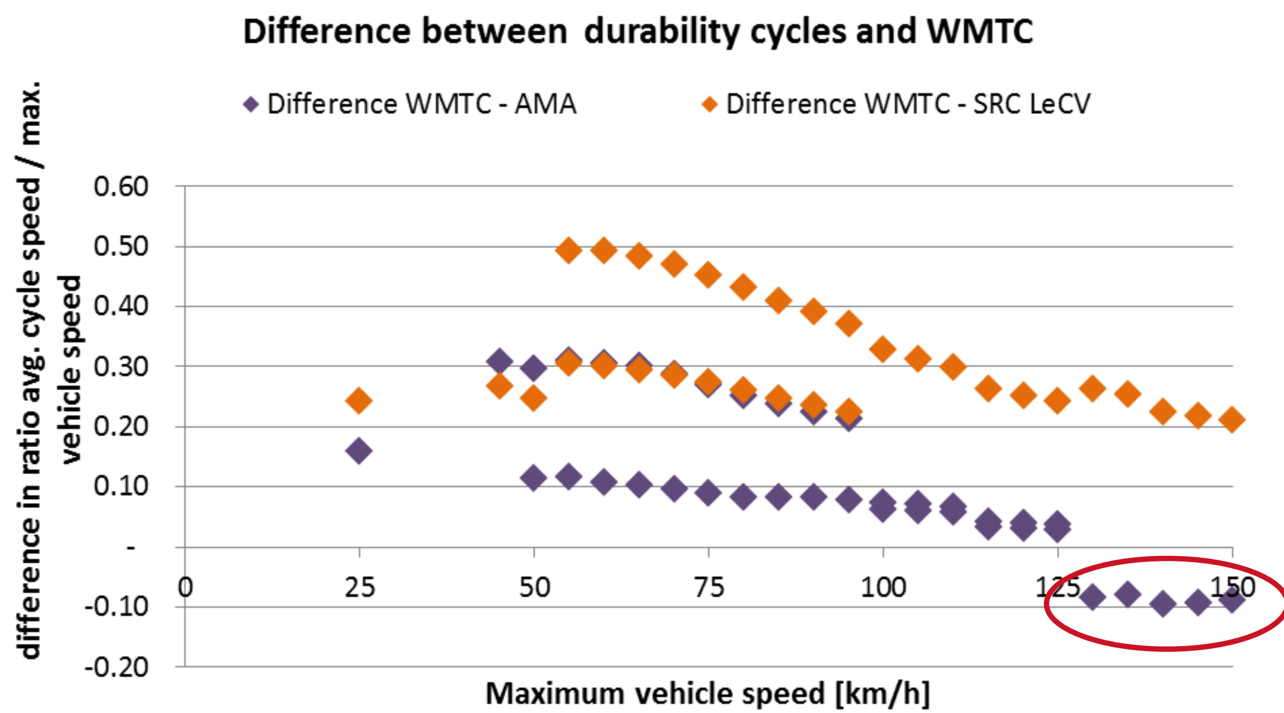
SHARE OF HIGH SPEED DRIVING AS A PROXY FOR ENGINE LOAD (APPROACH 1)





- SRC-LeCV consists of a relatively larger share of high speed driving
- A comparison with WMTC is required →

SHARE OF HIGH SPEED DRIVING AS A PROXY FOR ENGINE LOAD (APPROACH 1)



- Both cycles have more high speed driving than WMTC, except for vehicles with a maximum speed > 130 km/h (WMTC class 3)
- SRC-LeCV contains significantly more high speed driving for mid classes than AMA and WMTC

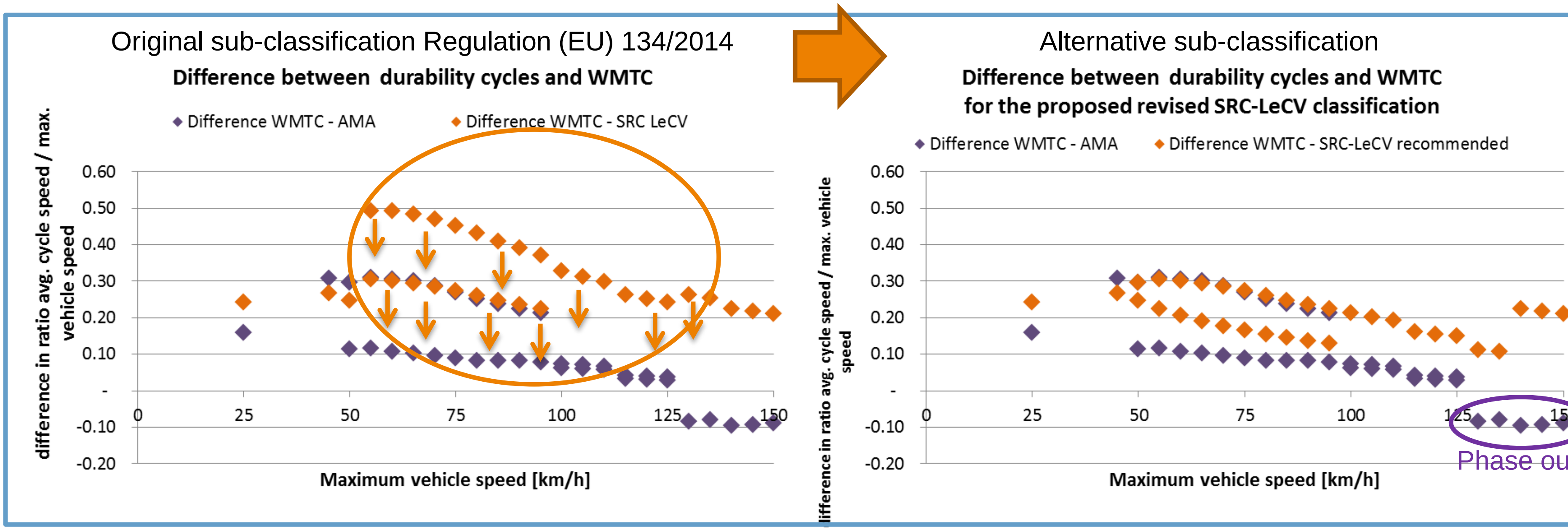
RECOMMENDATION FOR REVISED SUB-CLASSIFICATION IN SRC-LECV

- Currently, WMTC and SRC-LeCV sub-classification are not aligned
- Aligned and revised sub-classification is recommended:

WMTC class	Vehicle maximum design speed		Vehicle engine capacity		WMTC cycle	Current SRC cycle classification	Recommended SRC cycle classification
	min	max	min	max			
Class 1	-	≤ 50 km/h	-	≤ 50 cm3	Part 1_R (2x)	Cycle 1	Cycle 1
	> 50 km/h	< 100 km/h	> 50 cm3	< 150 cm3		Cycle 2	
Class 2-1	≥ 100 km/h	< 115 km/h	-	< 150 cm3	Part 1_R + part 2_R	Cycle 2 or 3	Cycle 2
	-	< 115 km/h	≥ 150 cm3	≤ 1500 cm3			
Class 2-2	≥ 115 km/h	< 130 km/h	-	≤ 1500 cm3	Part 1 + part 2		
Class 3-1	≥ 130 km/h	< 140 km/h	-	≤ 1500 cm3	Part 1 + part 2 + part 3_R	Cycle 4	Cycle 3
Class 3-2	≥ 140 km/h	-	-	> 1500 cm3	Part 1 + part 2 + part 3		Cycle 4

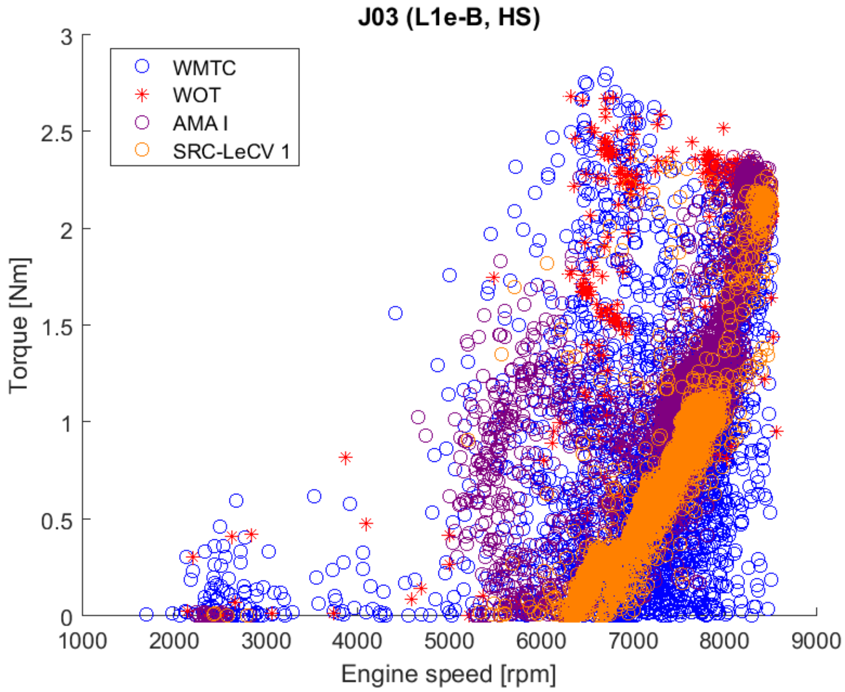
- For example: In the current situation, a vehicle with a maximum speed of 90 km/h and an engine capacity of 160 cm3, can be placed in both SRC-LeCV 2 and SRC-LeCV 3.

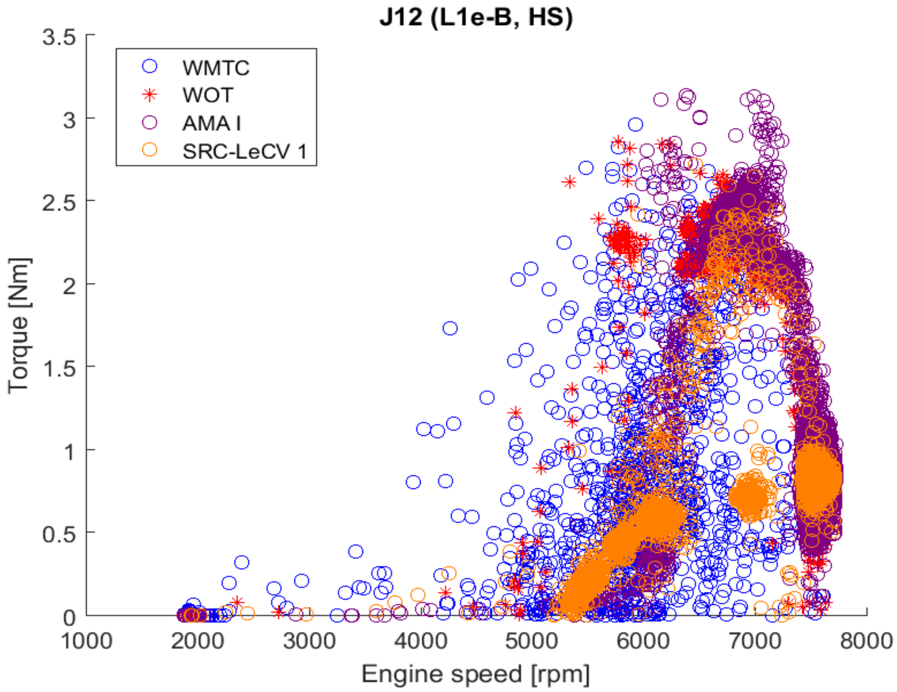
RECOMMENDATION FOR REVISED SUB-CLASSIFICATION IN SRC-LeCV



- A revision of the SRC-LeCV sub-classification – as proposed – leads to vehicle speed (aka engine load) that lies closer to WMTC and AMA
- Phase-out of AMA for WMTC class 3 vehicles can be justified by this assessment

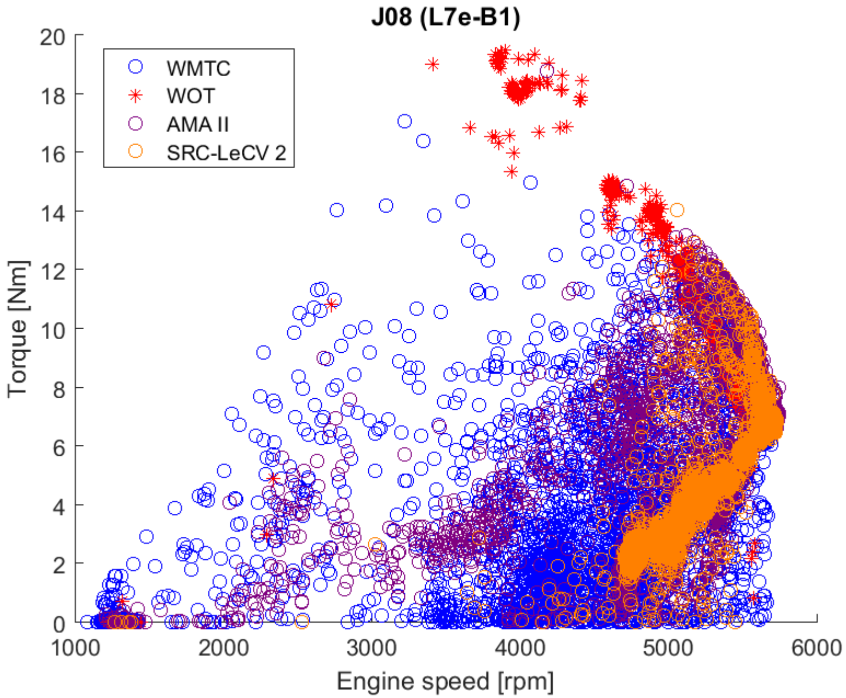
ENGINE MAP COVERAGE (APPROACH 2) FOR MOPEDS (L1E-B)

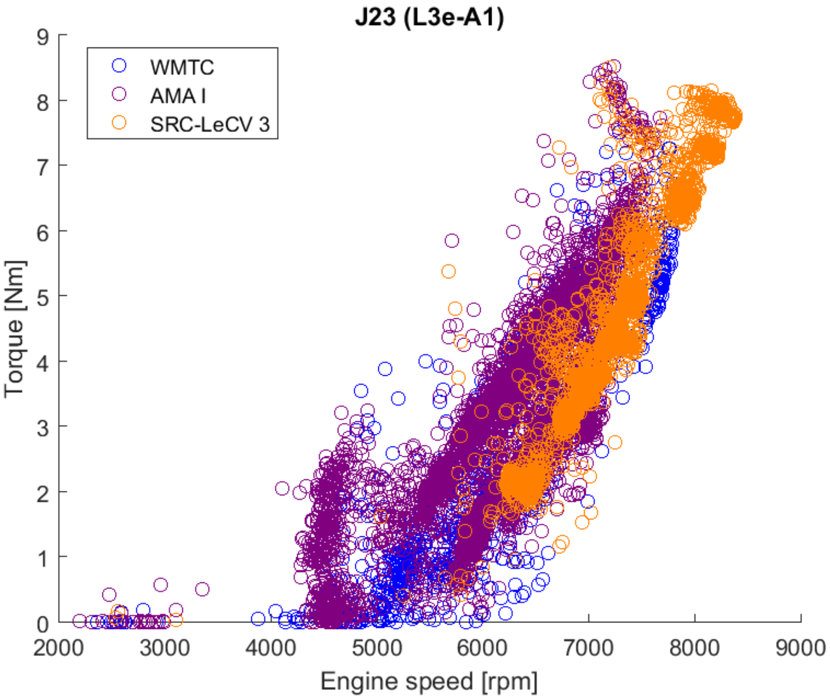




- AMA covers a larger part of the engine map than SRC-LeCV

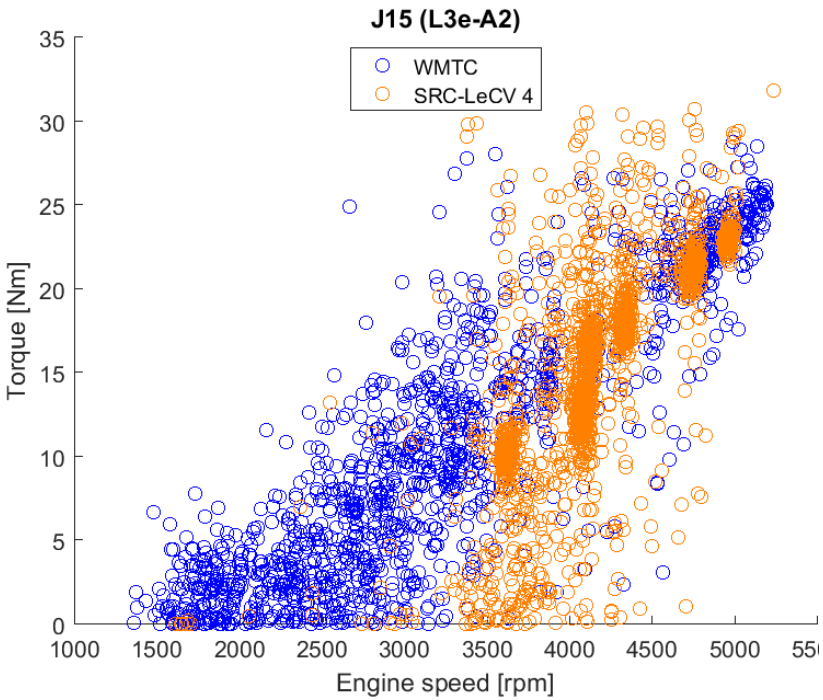
ENGINE MAP COVERAGE (APPROACH 2) WMTC CLASS 1 AND 2 (EXCEPT MOPEDS)

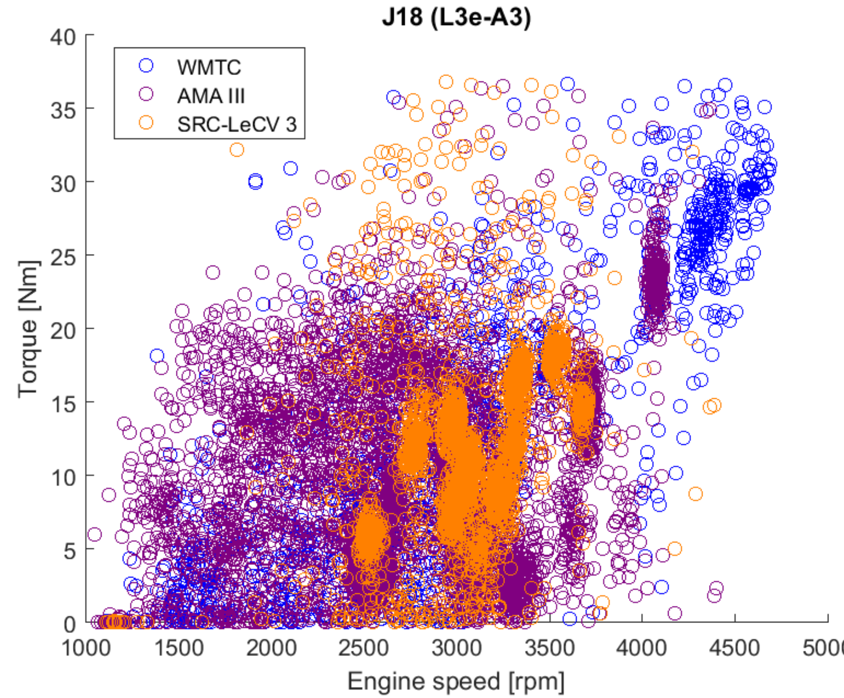




- AMA covers a larger part of the engine map than SRC-LeCV
- SRC-LeCV covers high engine speed and engine load area

ENGINE MAP COVERAGE (APPROACH 2) WMTC CLASS 3 VEHICLES

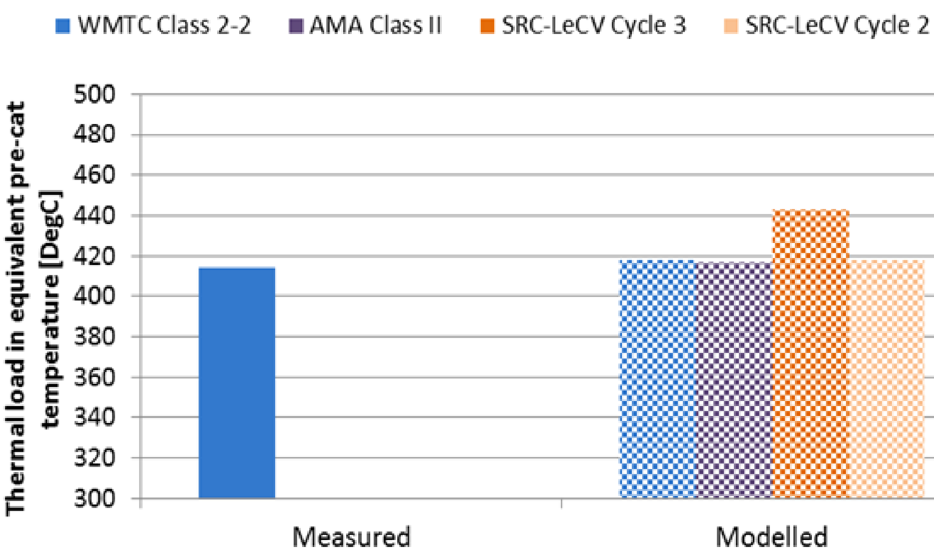




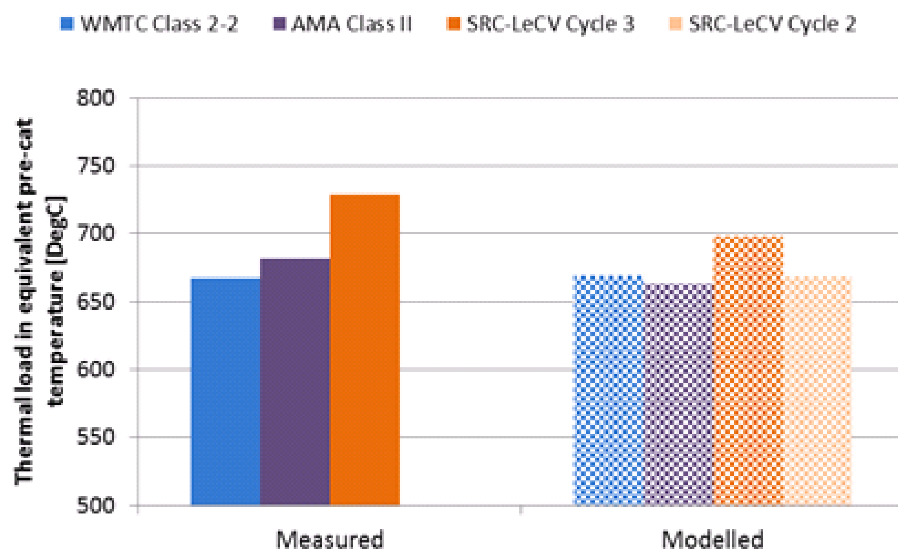
- AMA covers a larger part of the engine map than SRC-LeCV
- Though AMA covers lower engine speed and load area than WMTC

THERMAL LOAD – MEASURED AND MODELLED (APPROACH 3)

Example (vehicle J21 – L5e-A) of a measured and modelled thermal load result



Example (vehicle J13 – L3e-A2) of a measured and modelled thermal load result



- Thermal load assessment confirms results of approach 1 and 2
- SRC-LeCV thermal load is on average higher than WMTC
- The recommended revised sub-classification brings thermal load to a level that is comparable to WMTC

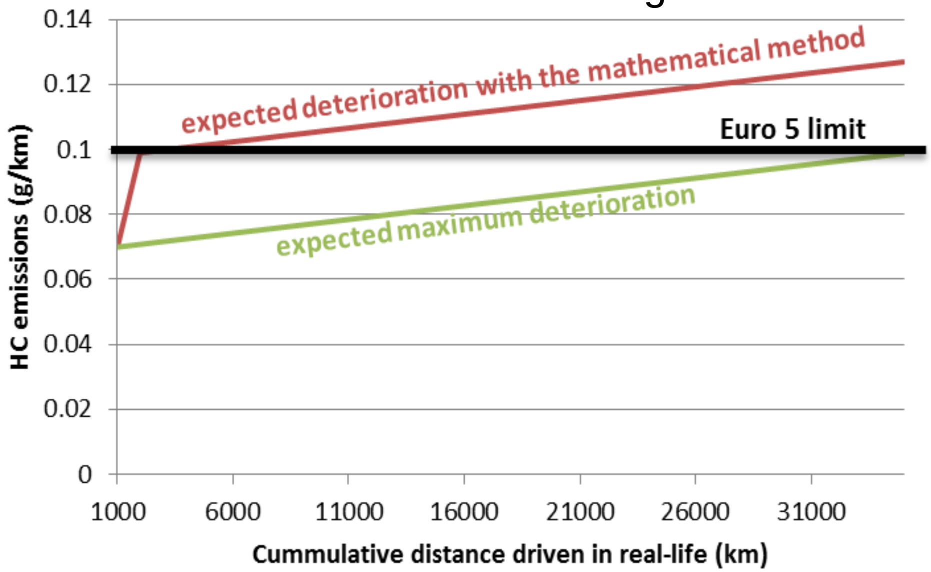
ASSESSMENT OF THE CYCLES COMPARISON OF SRC-LeCV AND AMA

CONCLUSIONS AND RECOMMENDATIONS

- The differences between AMA and SRC-LeCV thermal load results are mostly vehicle specific and highly depending on the vehicle classification;
- The AMA is in general as severe or less severe than the SRC-LeCV in terms of thermal load;
- The AMA thermal load is mostly lower than the WMTC thermal load for vehicles which have a maximum speed higher than 130 km/h, phase-out of AMA for WMTC class 3 vehicles can be justified;
- AMA well simulates ageing conditions for vehicles of WMTC classes 1 and 2
- Revision of SRC-LeCV sub-classification and alignment with the WMTC sub-classification is recommended to make the SRC-LeCV more comparable to the WMTC in terms of thermal load and engine load.

REPRESENTATIVENESS OF THE “MATHEMATICAL METHOD”

The mathematical method allows quickly deteriorating emissions, compared to the expected maximum deterioration according to the deterioration factor of 1.3



- Mathematical method does not safeguard low emissions over vehicle useful life
- Solutions can be found in phase-out of the mathematical method and mandating physical degradation/ageing
- Or in additional measures that close the potential loop-hole like for example in-service conformity (in-use compliance) requirements (currently not in Euro 5)

MULTIPLICATIVE AND / OR ADDITIVE DETERIORATION FACTOR (DF)

- For L-category vehicles, only the multiplicative DF is applied, for passenger cars also an additive DF is allowed (UNECE R.83).

Summary of durability procedures for L-category and passenger cars

Category	Deterioration factors		Mileage accumulation	
	Multiplicative	Additive	Full	Partial
L-category vehicles	√	x	√	√
Passenger cars	√	√	√	x

Findings from a sensitivity analysis of both methods:

- The multiplicative calculation method can lead to scientifically incorrect deteriorated emission values. This can occur when the measured emission values deviate substantially from a linear trend.
- The introduction of the additive calculation method – as an alternative method to the multiplicative method – makes the procedure more robust without considerable negative counter effects

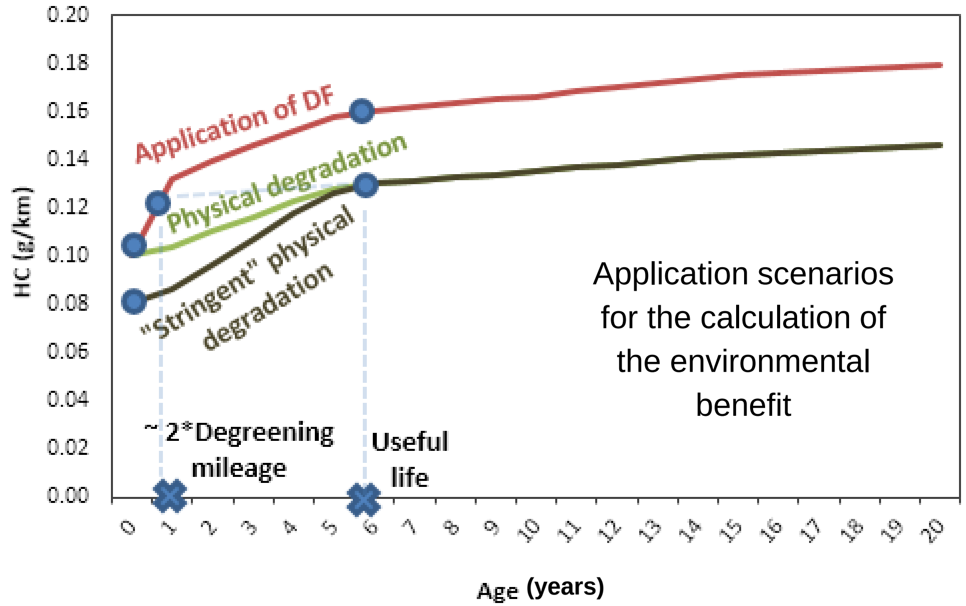
ASSESSMENT OF USEFUL LIFE VALUES COMPARED WITH FLEET ACTIVITY DATA

		Fleet activity data			
Vehicle category name in fleet data	**Vehicle category**	**Annual average mileage (km)**	**Effective average age (Y)**	**Average calculated useful life mileage (km)**	**ULV from (Regulation (EU) No 168/2013, 2013)**
“mopeds”	L1e-B L2e	~2900	11*	~31 900	11 000
“motorcycles A1”	L3e-A1 and L4e-A1	~4600	7 to 8	~34 500	20 000
“motorcycle A2 and A3”	L3e-A2/A3 and L4e-A2/A3	~5500	7 to 8	~41 250	35 000
“L5e tricycles”	L5e	~5500	7 to 8	~41 250	20 000
“ATVs”	L6e-A L7e-B	~600**	5 to 6	3 300**	11 000
“minicars”	L6e-B L7e-C	~5000	6	30 000	20 000

* the moped fleet decreases and only partly renewed, as a result the average age is high

** these vehicles should mostly be counted to hours of operation per year, on-road ones do not exceed 40-50 hours annually. This is much lower than off-road vehicles, which are often used professionally for farming and forestry activities and other purposes

THREE MAIN SCENARIOS FOR THE DEGRADATION OF EMISSIONS



- **Baseline Scenario: Application of DF:** Scenario representing **<u>current situation</u>**
  - Mathematical method with potential loophole: very quick deterioration of catalyst (i.e. in ~2,000km for motorcycles) → resulting in higher EF values in useful life (~35,000km)
- **Scenario 1 "Stringent" physical degradation:** Method in which catalyst is being aged with actual mileage accumulation (i.e. physical degradation) over the SRC-LeCV according to current sub-classification. Aged catalyst does not exceed the DF*EF_5 value in useful life (UL)
- **Scenario 2 Physical degradation:** Equal to Scenario 1, but with revised SRC-LeCV sub-classification. Aged catalyst does not exceed the DF*EF_5 value in useful life (UL)

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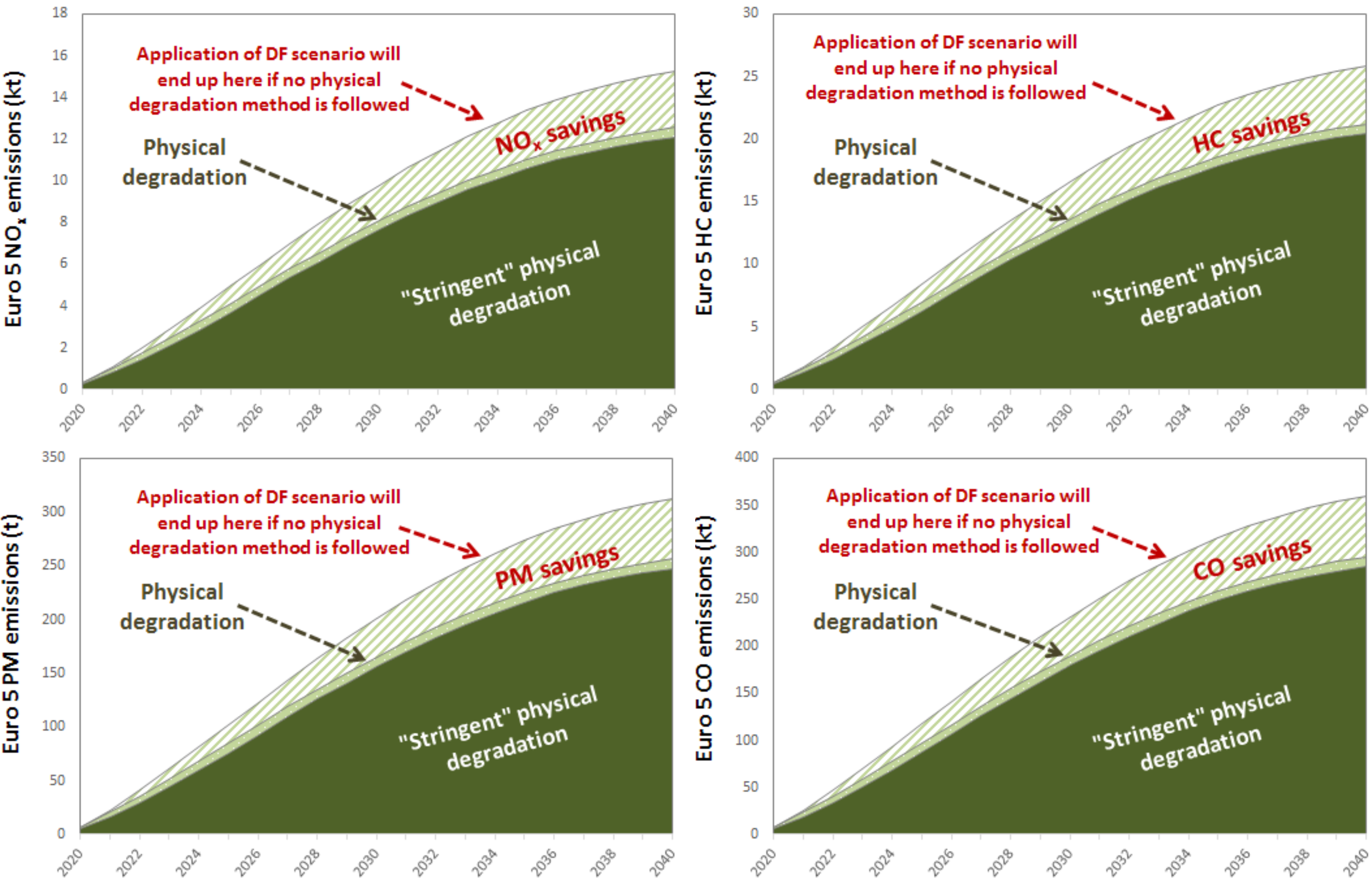
ENVIRONMENTAL BENEFIT OF PERFORMING PHYSICAL DEGRADATION



Emission savings

	Scenario 1	Scenario 2
HC	62 kt	50 kt
NO_x	41 kt	33 kt
PM	0.85 kt	0.68 kt
CO	982 kt	787 kt

- 22% emission reduction with “stringent” physical degradation (scenario 1)
- 18% emission reduction with physical degradation (scenario 2)

COST BENEFIT ANALYSIS OF DIFFERENT APPLICATION SCENARIOS

Scenario	Cost-benefit over 2020-2040
Baseline scenario	0
Scenario 1 "stringent physical degradation"	-22^{+47}_{-58}
Scenario 2 "physical degradation"	0.5^{+42}_{-37}
Scenario 3 "physical degradation with bench ageing"	71^{+33}_{-28}
Scenario 4 : "physical degradation + rearrange ULVs for mopeds and tricycles "	*
Scenario 5: "physical degradation with bench ageing+ rearrange ULVs for mopeds and tricycles"	*
Scenario 6: "baseline scenario with introduction of new measures like ISC requirements"	*
Scenario 7: "baseline scenario with introduction of new measures like ISC requirements + rearrange ULVs for mopeds and tricycles"	*

* Other implementation scenarios, outside the original scope of the study. Calculation of the CBA for these scenarios is only qualitative.

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TYPE V: DURABILITY REQUIREMENTS

CONCLUSIONS AND RECOMMENDATIONS

- Phase-out of AMA for WMTC class 3 vehicles is recommended
- AMA well simulates ageing conditions for vehicles of WMTC classes 1 and 2
- Revision of SRC-LeCV sub-classification and alignment with the WMTC sub-classification is recommended to make the SRC-LeCV more comparable to the WMTC in terms of thermal load and engine load.
- The mathematical method does not secure environmental performance of L-category vehicles over the useful life. Solutions can be found in phase-out of the mathematical method, or in additional measures like in-service conformity requirements (currently not in Euro 5 package)
- Physical ageing procedures are cost beneficial after revision of the SRC-LeCV classification and phasing out of AMA for WMTC class 3 vehicles, or when alternative procedures are introduced. Adoption of the passenger car bench ageing procedure is recommended to be investigated as candidate procedure.

TYPE VII:
ENERGY EFFICIENCY TEST

TYPE VII – TASK DESCRIPTION

- **Background:** "The measurement of CO_2 emissions, fuel/energy consumption of passenger cars and light commercial vehicles has been required since many years and the related procedure is defined in UN Regulation No 101. This procedure is now extended to L-category vehicles which however may have specific features requiring some fine-tuning of the above mentioned procedure."

- **Specific objective:** "Verify and if necessary improve the test procedure to measure energy efficiency from L-category vehicles.

- **Specific tasks:** " On the basis of the results of the tests on hybrid and electric vehicles, the contractor shall assess and verify the appropriateness of the test procedure for the measurement of energy efficiency (CO_2 emissions, fuel/ energy consumption and range)."

TYPE VII: ENERGY EFFICIENCY TEST

CONCLUSIONS AND RECOMMENDATIONS

- No major issues found in the procedure for L-category vehicles with all drivetrain types
- The WMTC sub-classification in some occasions leads to scientifically unexpected classification for electric and hybrid vehicles in comparison to a vehicle with a conventional powertrain and comparable performance.
  - For example: An electric vehicle with a maximum speed lower than 100 km/h is always put into class 1. A comparable vehicle with a conventional powertrain with an engine displacement larger than 150 cm3 would drive the more demanding WMTC 2-1, while the electric vehicle with comparable or even higher performance capabilities drives the relatively mild WMTC class 1.
- It is recommended to introduce an engine power criterion in the WMTC sub-classification criteria (Reg.134, Annex II) to better reflect the electric and hybrid electric powertrain. The net power criteria from the SRC-LeCV classification can be used as a basis. However, more research is needed to validate the net power value of the SRC-LeCV for this purpose.

TYPE VII: ENERGY EFFICIENCY TEST

CONCLUSIONS AND RECOMMENDATIONS

- It is recommended to include an instruction in Annex VII of Reg.134 to secure that mopeds with a speed limiter are driven at their maximum speed and at full throttle position
- For vehicles with a hybrid drivetrain, D_{av} value (average distance between two battery charges) seems to be too low, when compared to fleet activity data. Recommendation to further investigate the appropriateness of D_{av} based on the average trip length, availability of charging facilities and charging behaviour. This can only be done when more hybrid electric L-category vehicles penetrate the market and more real-world data becomes available

TYPE VIII:
FUNCTIONAL OBD REQUIREMENTS AND TYPE VIII TEST

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TYPE VIII – TASK DESCRIPTION

- ***Background***: Environmental Study should report on all new types of vehicles in (sub-) categories L3e, L5e, L6e-A and L7e-A that shall, in addition to OBD stage I, also be equipped with OBD stage II at the Euro 5 level;

- ***Specific objectives:*** Assessment of the technical feasibility, benefits and costs from extending OBD-I (Euro 4) to OBD-II (Euro 5) for L3e-, L5e-A, L6e-A and L7e-A vehicles.

- ***Specific tasks:***

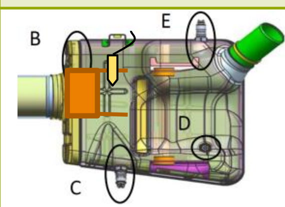
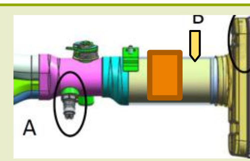
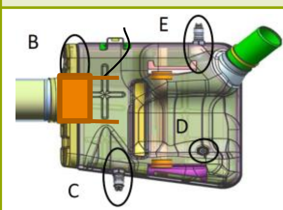
1. On-board diagnostic requirements — expansion functionality OBD stage I to OBD stage II — relevance for effective and efficient vehicle repair
2. Type VIII test - assessment of the OBD emission thresholds (OTLs) set out in the table laid down in Annex VI (B2) to Regulation (EU) No 168/2013 [IN PROGRESS]
3. On-board diagnostic requirements — assessment of the cumulative cost effectiveness of previous tasks and technical feasibility of supplemental OBD stage II [IN PROGRESS]

SOME REMARKS ON OUR ANALYSIS

- Technical assessment referring only to PI vehicles (only relevant for OBD-II based on the previous list)
- PM emission monitoring is not included in our analysis
  - No diesel sub-category affected by OBD-II (no L-diesels foreseen in the future)

- Assessed elements for OBD Stage II functionality include:
  - Catalytic converter
  - Oxygen sensor (not a significant challenge if no backflow)
  - In-use performance ratios (IUPR)
  - Misfiring

CATALYST MONITORING FEASIBILITY ASSESSMENT

Vehicle Type	(Typical) catalyst position	Downstream O_2/λ		Technical concerns	Technical difficulty
L3e Street	Post downpipe	On downpipe		▪ Space availability ▪ Wiring (and thermal protection)	Slight to moderate
L7e	Underbody	On downpipe		Wiring	Slight
L3e Scooter	Current: In muffler	On muffler (expansion chamber)		▪ Backflow, mixing, location, thermal protection wiring ▪ Requires redesign of muffler	High to impossible
	Option 1: In muffler, on primary line (downstream catalyst)	In muffler		▪ Requires new design of lambda sensor ▪ Sensor and muffler become one piece (redesign muffler) ▪ Electrical connection to muffler	High
	Option 2: Catalyst @ downpipe	On downpipe		▪ Space for both catalyst and lambda (requires increasing distance and even frame changes). Optimum for Euro 5	High
	Option 3: Alternative technique	In muffler		▪ Option would be exothermy measurement ▪ Sensitivity needs to be proven ▪ Model specific calibration necessary	High

CATALYST MONITORING RECOMMENDATIONS

- Catalyst monitoring does not appear technically possible for all OBD-II compliant vehicle models, currently being designed
  - Catalyst monitoring for all new models to be introduced in 2020 appears as a real technology bottleneck
- Catalyst monitoring is necessary to achieve low OBD-II thresholds, hence inability to monitor catalyst performance means inability to attain low OBD thresholds in real terms
- Providing additional time (1 vehicle model major revision round, i.e. ~4 years) seems therefore justified
- We are currently calculating impacts of CBA
  - Delays encountered due to late arrival of experimental results

MAIN TECHNIQUES AVAILABLE FOR MISFIRING DETECTION

Technique	Principle / Characteristics	Advantages	Disadvantages	High-speed possibility
Crankshaft Velocity Fluctuation	Abnormal engine rotation pattern detected by engine position sensor	▪ No new sensors required ▪ Large experience from M1 ▪ Engine-torque models reduce risk of false detection	▪ Vulnerable to external noise ▪ Detects impact not reason of misfiring ▪ Transmission issues falsely detected as misfiring	No
Combustion Ion-Current	Combustion produces chemi-ions which are detected by in-sparkplug circuitry	▪ May detect electrical problems ▪ May detect good combustion ▪ Intermittent spark technique could be used at high speeds	▪ Lack of experience ▪ Availability of suppliers (patents) ▪ Additional cost of circuitry	Possibly (under development)
In-cylinder pressure measurement	Pressure waves measured by in-cylinder pressure transducer	▪ High speed, high resolution ▪ Safe detection of misfiring ▪ Can be used for next-cycle combustion optimisation	▪ Cost of sensor/ECU ▪ Space concerns ▪ High temperature durability	Yes
Oxygen sensor signal	Oxygen sensor signal distortion may point to misfiring events	▪ No new sensor required ▪ May detect malfunctioning cylinder	▪ Not known commercial applications ▪ Unsafe for sporadic misfiring	No

IMPACTS OF LEAVING PART OF THE ENGINE MAP AREA UNDETECTED

- Immediate HC emissions exceedances
  - This is a combination of how much time engines spend at high RPM and what are the emission levels compared to normal emission levels
    - In continuous misfire HC emissions may increase substantially but rider will become aware of this
    - In intermittent misfire HC emission levels increase for some operation cycles only (not big environmental impact)

- Catalyst degradation impacts
  - Catalyst degradation due to high speed misfiring will also show at lower speeds => if misfiring destroys the catalyst, this will be picked up by OBD II
  - Precautionary measures expected to be taken from manufacturers to avoid early catalyst deactivation

- Assessment:
  - **Limiting misfiring monitoring to a narrower engine range achieves technical feasibility of detection w/o large direct or indirect environmental consequences**

FURTHER IMPROVEMENT OF MISFIRE MONITORING AND DIAGNOSIS

- Frequency of operation and emission rates outside of the WMTC region have to be better understood. Off-cycle emissions monitoring and the possibilities offered by PEMS and PAMS systems will have to be utilized in this direction.

- Statistics of misfire diagnosis and its association with real engine malfunctions will have to be collected. IUPR provisions require collection of data in this area and will be a useful tool towards improving detection algorithms.

- Technical developments in the area of combustion control and in particular the extend of using alternative techniques such as ion current and in-cylinder pressure sensors has to be monitored. Such techniques offer additional potential that may enable more thorough misfire detection possibilities.

IUPR DISCUSSION

- Reg. (EU) 44/2014 does not contain all details on how IUPR checking will be performed
  - Selection criteria
  - IUPR families
  - etc.

- These do not relate to the technical implementation of OBD-II, they are rather safeguards that the OBD-II performs in real terms as designed
  - It is up to the manufacturers to propose relevant statistics for sampling criteria that can be solid and feasible in guaranteeing good diagnosis in the real world
  - Not having solid IUPR criteria at the moment is not an argument in failing to design a robust OBD

ACKNOWLEDGMENTS

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THANK YOU FOR YOUR ATTENTION

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