Joint Research Centre

the European Commission's in-house science service

Serving society
Stimulating innovation
Supporting legislation

Science for policy support

Amending CO_2 targets for Light Duty Vehicles in Europe

B. Ciuffo

IVT Seminar

ETH Zurich – January 29th, 2016

European Commission

Points of discussion

- The European Commission Joint Research Centre
- Science in policy-making and the role of the JRC
- The development of the WLTP
- Introducing the WLTP into the EU type-approval legislation
- CO2MPAS beyond the legislation
- Conclusions

JRC Role
Facts & Figures

- **In-house science service** of the European Commission
- Independent, evidence-based **scientific and technical support** for many EU policies
- **Established 1957**
- **7 institutes** in 6 locations
- **Around 3000 staff**, including PhDs and visiting scientists
- **1370 publications** in 2014

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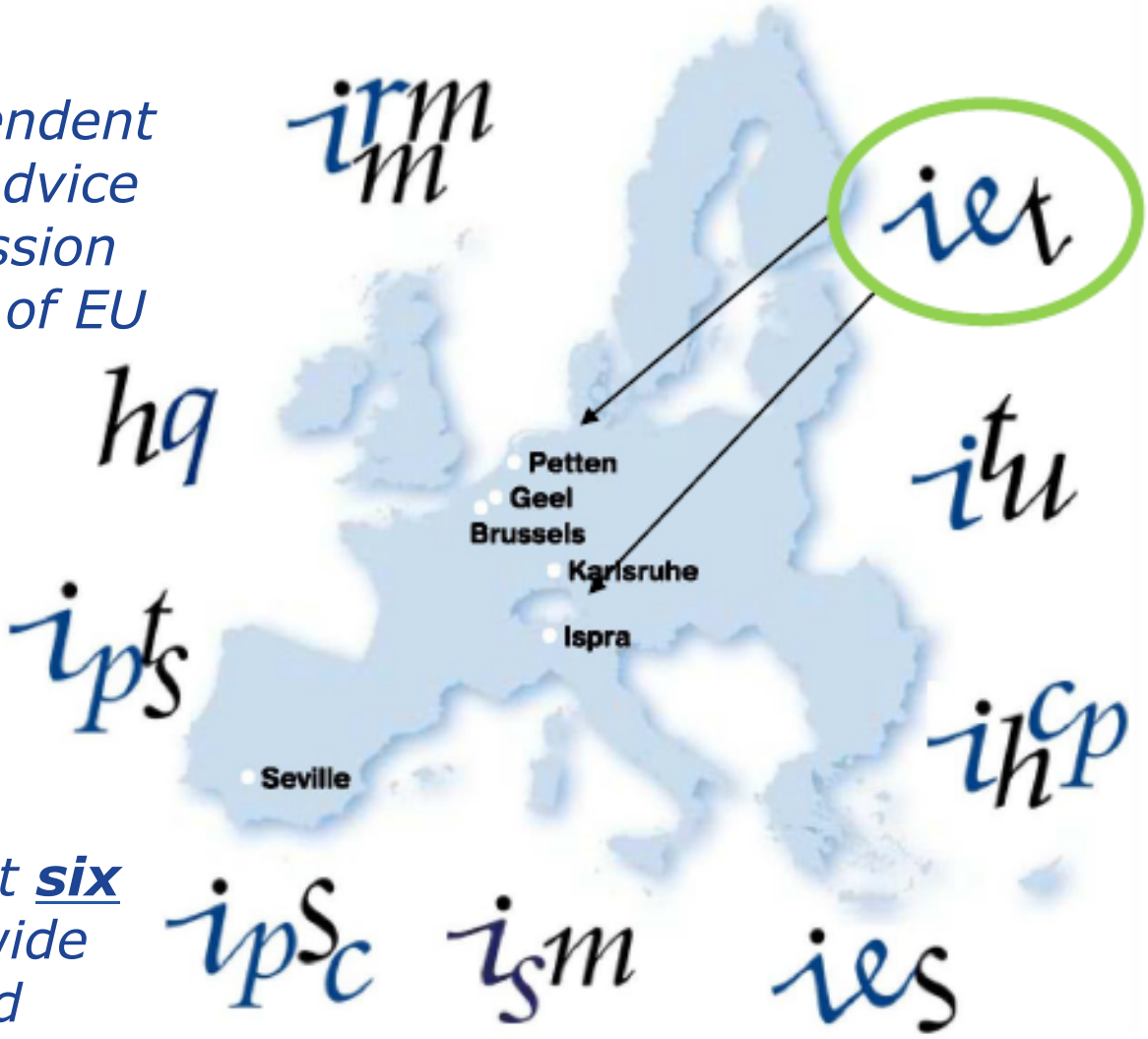
JRC in the European Commission

The JRC provides independent scientific and technical advice to the European Commission to support a wide range of EU policies.



*The **seven scientific institutes** are located at **six different sites** with a wide range of laboratories and research facilities*

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JRC: Institutes

Institute for Energy and Transport (IET)
Institute for Reference Materials and Measurements (IRMM)
Institute for the Protection and Security of the Citizen (IPSC)
Institute for Environment and Sustainability (IES)
Institute for Health and Consumer Protection (IHCP)
Institute for Transuranium Elements (ITU)
Institute for Prospective Technological Studies (IPTS)

*The **mission of the JRC-IET** is to provide support to European Union policies and technology innovation to ensure sustainable, safe, secure and efficient energy production, distribution and use and to foster sustainable and efficient transport in Europe*

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JRC-IET

Seven scientific and two supporting units

- F1 Site Management
- F2 Energy Conversion and Storage Technologies
- F3 Energy Security, Systems and Market
- F4 Innovative Technologies for Nuclear Reactor Safety
- F5 Nuclear Reactor Safety Assessment
- F6 Energy Technology Policy Outlook
- F7 Renewables and Energy Efficiency
- **F8 Sustainable Transport (65 scientists, technicians, and administration)**
  - **VELAs**

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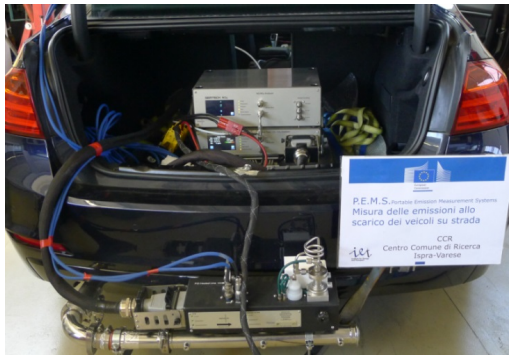
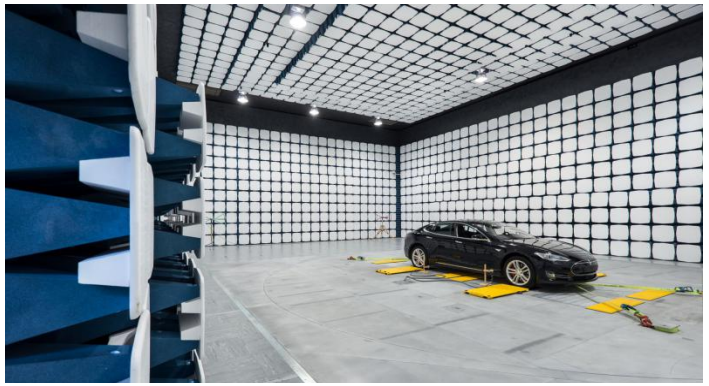
VELAs

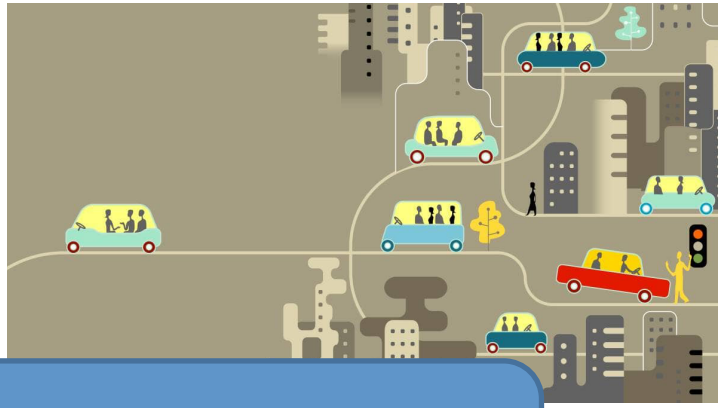


Vehicle Emission Laboratories. 9 labs **(appr. 12 persons)**

- **Engine test beds**
  - *Heavy duty engines*
  - *Small engines*
- **PEMS**
- **Vehicle chassis dynamometers**
  - Motorcycles
  - Light duty
  - Heavy duty
  - EV Electromagnetic compatibility testing
  - 4WD & -30°C capacity



Main research topics

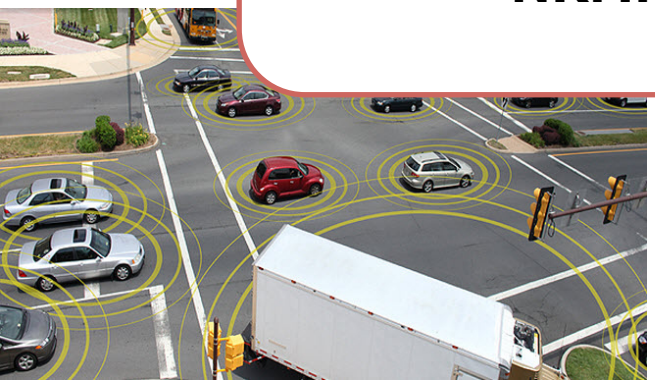


Sustainable transport

Road transport
Electro-mobility
Aviation
NRMM

Sustainable fuel

WtW analysis
Alternative fuels
Indirect land-use change



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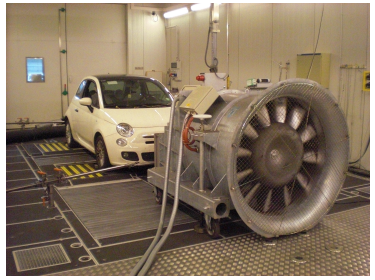
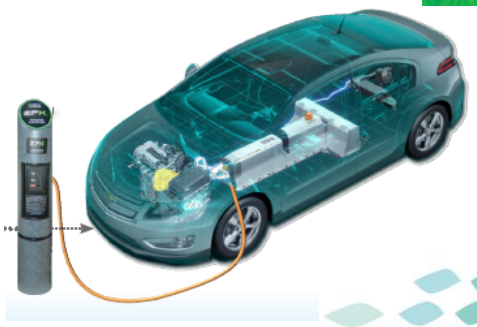
Sustainable road transport



- **Support European Commission in the development of all latest regulations concerning**
  - *Vehicle type-approval*
  - *Emission limits from LDVs, HDVs and two/ three wheelers*
  - *CO2 targets for LDVs and eco-innovation scheme*
  - *CO2 monitoring for HDVs*
- **Promote and analyze new technologies**
  - Electric vehicles
  - ITS solutions
- **Participate to international forums and research group activities**
  - ERMES
  - MULTITUDE
  - TFEIP/EIONET

VECTO
Vehicle Energy Consumption Calculation Tool



ICT-Emissions

ermes

MULTITUDE
Methods and tools for supporting the Use caLibration and validaTIon of Traffic simUlation moDEls

TFEIP

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Science in policy making

Simpler models enable scientists and stakeholders alike to understand how assumptions and outputs are linked. Complex and often overparameterized mechanistic models should be used only for more speculative investigations outside of the policy realm

A. Saltelli, S. Funtovicz. “When all models are wrong”. Winter 2014

Science in policy making

In many fields the gap between scientific knowledge and decision- and policy-making is still very wide.

The wide (public) availability of data and information and the advancement of their collection techniques is making the scientific world progressing at a continuously increasing speed.

Too much information, frequently contradictory and with uncontrolled levels of uncertainty, has often the effect of scaring the policy-maker and of jeopardizing the development of the political process.

Science in policy making

In addition, it is the belief of many scientists that the most complex models should be taken "out of the policy realm" as they are not able to allow a clear understanding of how assumptions and outputs are related.

But, then, one might argue when the most sophisticated instruments the science has developed should be used if not for the wealth of the entire society.

Are they developed for our intangible need to understand how things work or, worse, for the mere reputation of their developers?

Science in policy making

When relevant stakeholder viewpoints are neglected,
modelers may focus on or address the wrong uncertainties.
A. Saltelli, S. Funtovicz. "When all models are wrong". Winter 2014

Being a research centre part of the European Commission, the JRC is located at the border between science and policy making and is today frequently asked to bridge the gap between complexity and transparency.

The development of the WLTP

The World Forum for the Harmonization of Vehicle Regulations (WP. 29) of the United Nations Economic Commission for Europe (UNECE), through its working party on pollution and energy (GRPE), in 2009 launched a project with the aim to develop a World-wide harmonized Light duty Test cycle (WLTC) and test Procedure (WLTP)

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The WLTP (…cont…)

(a) Phase 1 (2009 ÷ 2014): development of the worldwide harmonised light duty driving cycle and associated test procedure for the common measurement of criteria compounds, $CO_{2,}$ fuel and energy consumption (*Type 1 test of EU type approval procedure*).

(b) Phase 2 (2014 ÷ 2018): low temperature/high altitude test procedure, durability, in-service conformity, technical requirements for on-board diagnostics (OBD), mobile air-conditioning (MAC) system energy efficiency, off-cycle/real driving emissions.

(c) Phase 3 (2018+): emission limit values and OBD threshold limits, definition of reference fuels, comparison with regional requirements.

The WLTP (…cont…)

Since the beginning of the WLTP process the European Union had a strong political objective set by its own legislation [Regulation (EC) 443/2009 and Regulation (EU) 510/2011] to implement a new and more realistic test cycle by 2014, which was a major political driving factor for setting the time frame of the whole WLTP and in particular of phase 1.

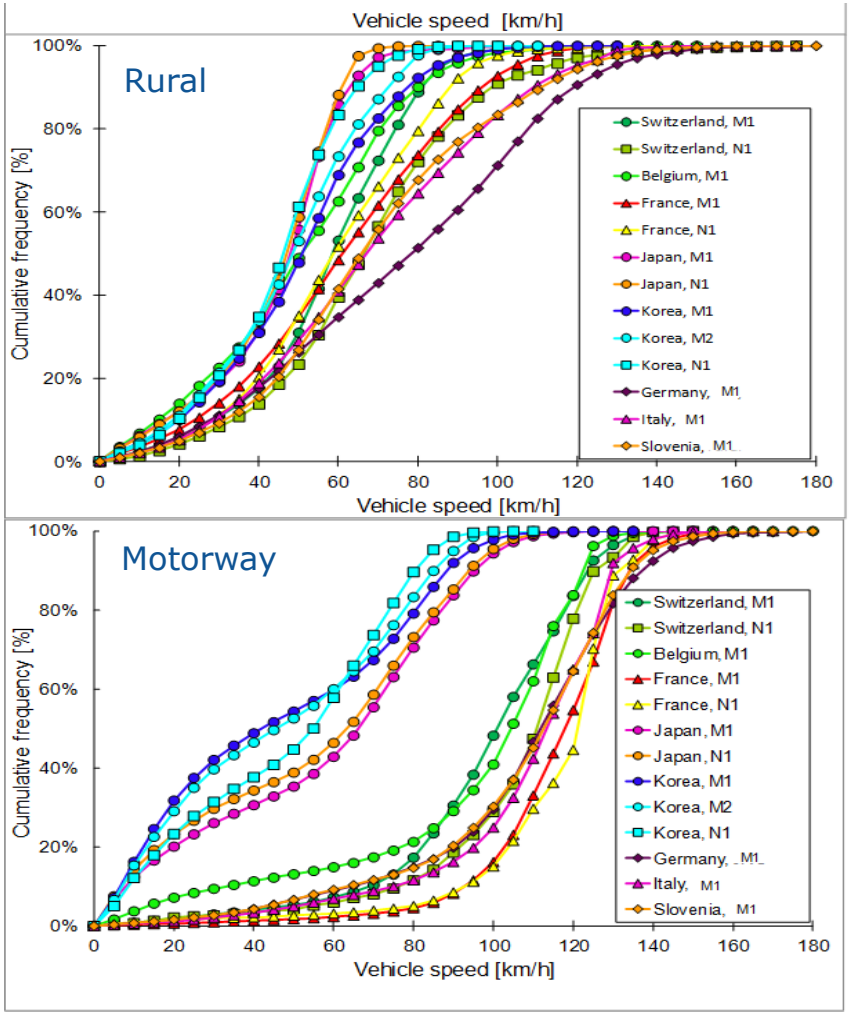
The WLTP (…cont…)

For the work of phase 1 the following working groups were established:

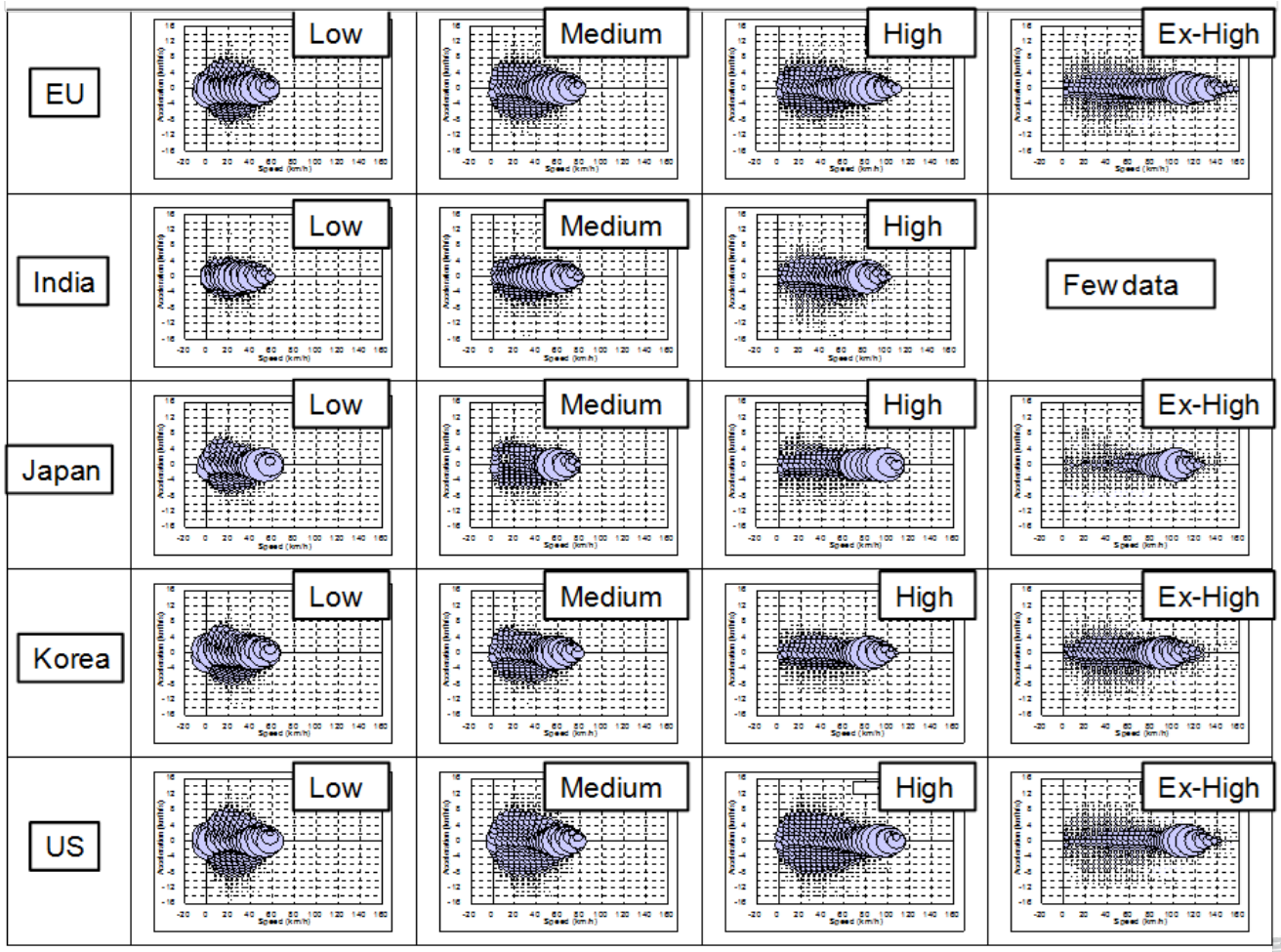
- Development of harmonised cycle (DHC): construction of a new Worldwide Light-duty Test Cycle (WLTC);
- Development of test procedures (DTP): development of test procedures.

Developing the WLTP-DHC

- The DHC is based on *vehicles' in-use data* collected in the different countries participating into the project
- Clear from the observations that a world-wide harmonization based on the concept of Urban, Rural and Motorway roads was not feasible.
- To solve this problem the WLTP working group decided to move from the Urban, Rural, Motorway approach to the *Low, Medium, High (and extra-High) speed phases*.



From driving-context to speed-range approach



This is the outcome of a series of comparisons to find the speed phase limits that would provide the best results in terms of similarity among the different regional databases.
It was found that the best solution was:

- Low speed < 60 kph
- Medium speed <80 kph
- High speed < 110 kph
- Ex-High speed > 110 kph

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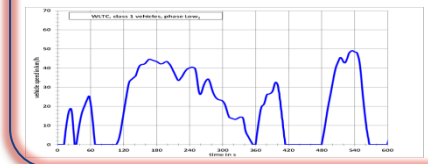
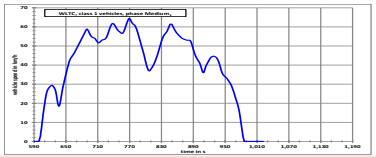
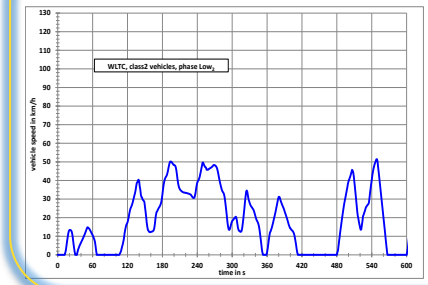
The WLTP – DHC

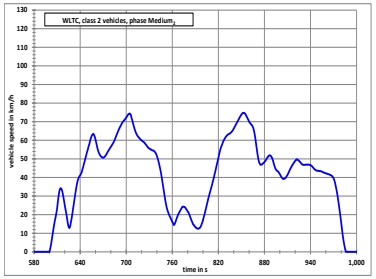
WLTP Class 1

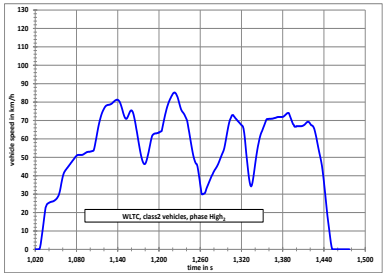


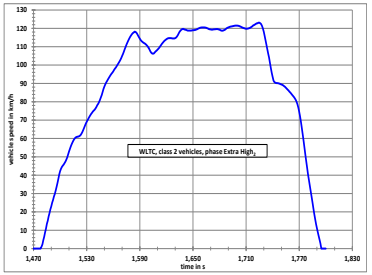


WLTP Class 2

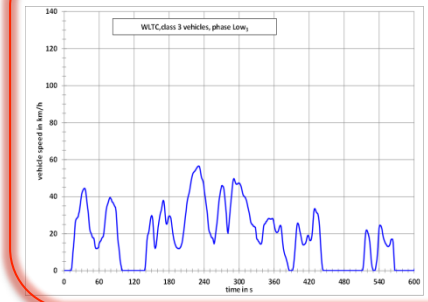


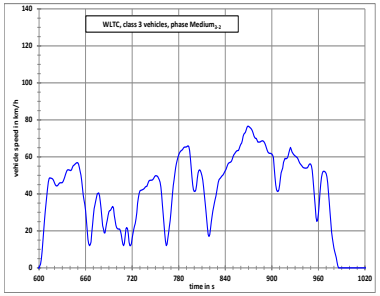


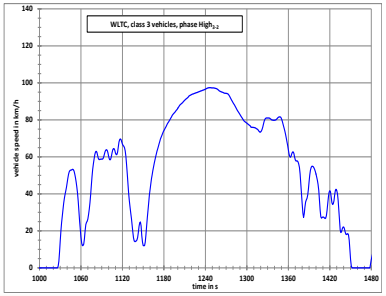


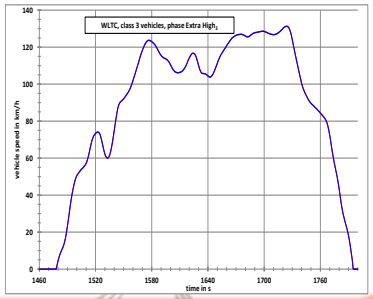


WLTP Class 3.2









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The WLTP – DTP

The DTP working group was divided in 5 subgroups:

- PM-PN: Particle mass (PM) and particle number (PN) measurements.
- APM: Additional pollutant measurements, i.e. measurement procedures for exhaust substances which are not regulated yet as compounds but may be regulated in the near future, such as NO_2, ethanol, aldehydes, and ammonia.
- LabProcICE: test conditions and measurement procedures of existing regulated compounds for vehicles equipped with internal combustion engines (other than PM and PN).
- EV-HEV: specific test conditions and measurement procedures for electric and hybrid-electric vehicles.
- REF-FUEL: definition of reference fuels.

The WLTP (…cont…)

In order to have the WLTP GTR approved in March 2014, i.e. in time for the development and finalization of the European legislative process, a formal GTR was presented to GRPE in August 2013 for acceptance in November 2013 and submission of the GTR to WP.29 for the official UNECE approval.

However it had become clear that a number of issues, in particular but not only in relation to electric and hybrid-electric vehicles, could not be resolved in time for an adoption of the first version of the WLTP GTR by WP.29 in March 2014.

The WLTP (…cont…)

Thus the concept of Phase 1a and 1b was introduced.
Phase 1a is reflected in the current GTR 15 version, approved in March 2014 by WP.29.

Meanwhile, all the remaining issues belonging to phase 1 were further worked out and agreed during 2014 and 2015 (phase 1b).

The WLTP (…cont…)

Phase 1b

DHC:

(i) speed violation criteria;

(ii) further downscaling in wide open throttle (WOT) operation;

(iii) sailing and gear shifting.

LabProcICE:

(i) normalization methods, drive trace index;

(ii) energy economy rating and absolute speed change rating for speed trace violations;

(iii) wind tunnel as alternative method for road load determination;

(iv) supplemental test with representative regional temperature and soak period.

APM:

(i) measurement method for ammonia, ethanol and aldehydes.

EV-HEV:

(i) calculation method of each phase range for pure electric vehicles (PEVs);

(ii) Shortened test procedure for PEV range test;

(iii) Combined CO_2 (fuel consumption) of each phase for off-vehicle charging hybrid electric vehicles (OVC-HEVs);

(iv) Hybrid Electric Vehicle (HEV)/PEV power and maximum speed;

(v) combined test approach for OVC-HEVs and PEVs;

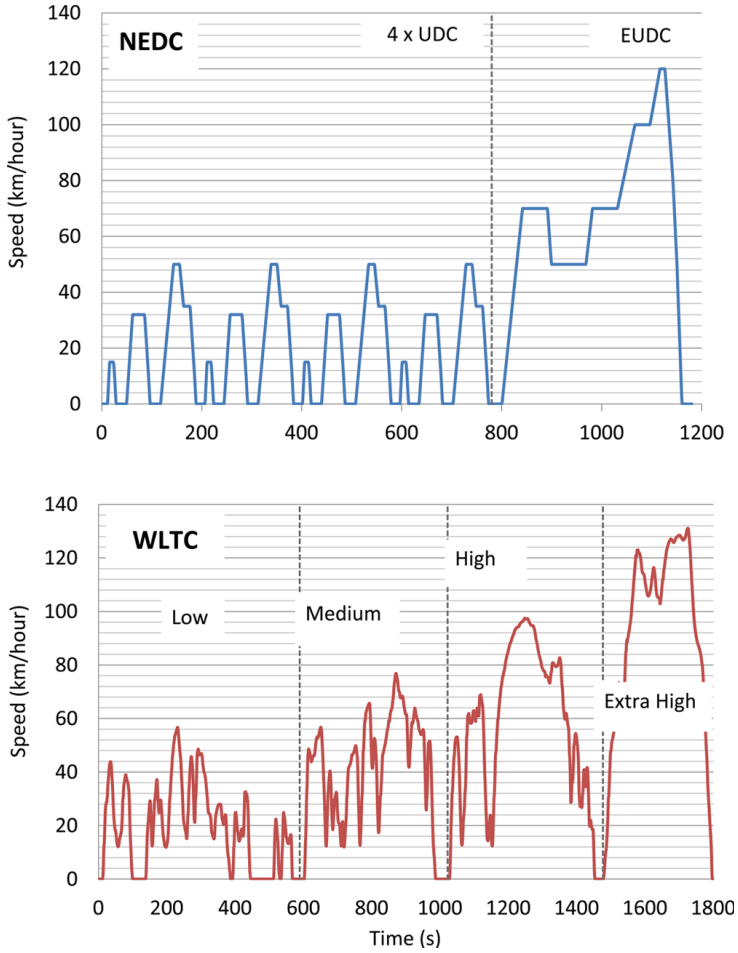
(vi) fuel cell vehicles;

(vii) utility factors;

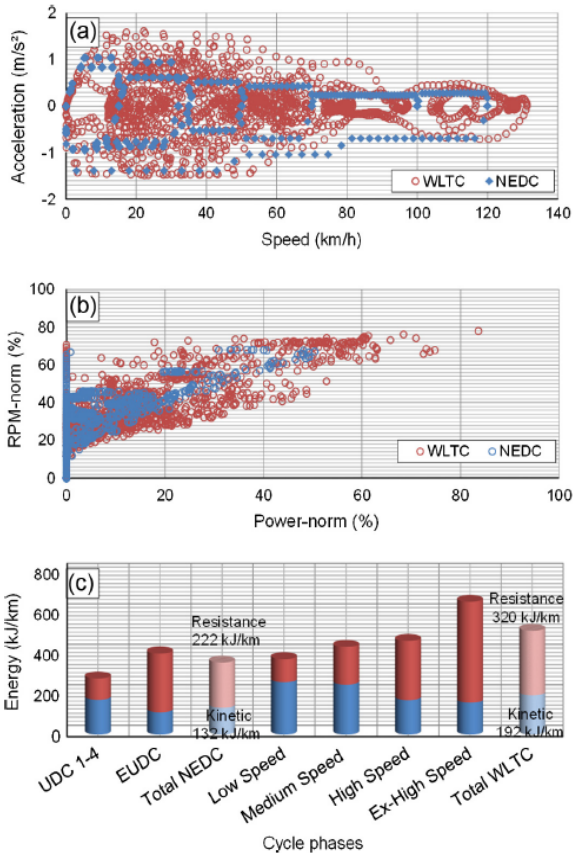
(viii) preconditioning;

(ix) predominant mode.

Differences between WLTP and NEDC (speed profile)



Key Parameters of the Driving Cycles NEDC and WLTC		
Parameters	**NEDC**	**WLTP**
duration (s)	1180	1800
distance (km)	11.03	23.27
av. speed (km/h)	33.6	46.5
maximum speed (km/h)	120	131.3
stop duration (%)	23.7	12.6
constant driving (%)	40.3	3.7
acceleration (%)	20.9	43.8
deceleration (%)	15.1	39.9
av. positive acc. (m/s2)	0.59	0.41
max positive acc. (m/s2)	1.04	1.67
av. positive “speed*acc.” (m2/s3)	1.04	1.99
max positive “speed*acc.” (m2/s3)	9.22	21.01
av. deceleration (m/s2)	−0.82	−0.45
minimum deceleration (m/s2)	−1.39	−1.50



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Differences between WLTP and NEDC (test procedure)

Category	Item	in NEDC	in WLTP	Impact on CO2
Road Load Determination	Vehicle test mass	Present	Modified	↑
	Tire selection	Present	Modified	↑
	Tire pressure	Present	Modified	↑
	Tire tread depth	Present	Modified	↑
	Calculation of resistance forces	Present	Corrected	↑
	Inertia of rotating parts	Absent	Introduced	↑
	Deafault road load coefficients	Present	Modified	?
Laboratory test	Driving cycle	Present	Modified	±
	Test temperarure	Present	Modified	↑
	Vehicle inertia	Present	Modified	↑
	Preconditioning	Present	Modified	↑
	Gear Shift strategy	Present	Modified	↓
Processing test results	SOC correction	Absent	Introduced	↑
	Correction of cycle flexibilities	Absent	Under discussion	±
CoC	CO2 type-approval extension / vehicle family	Present	Modified	↑

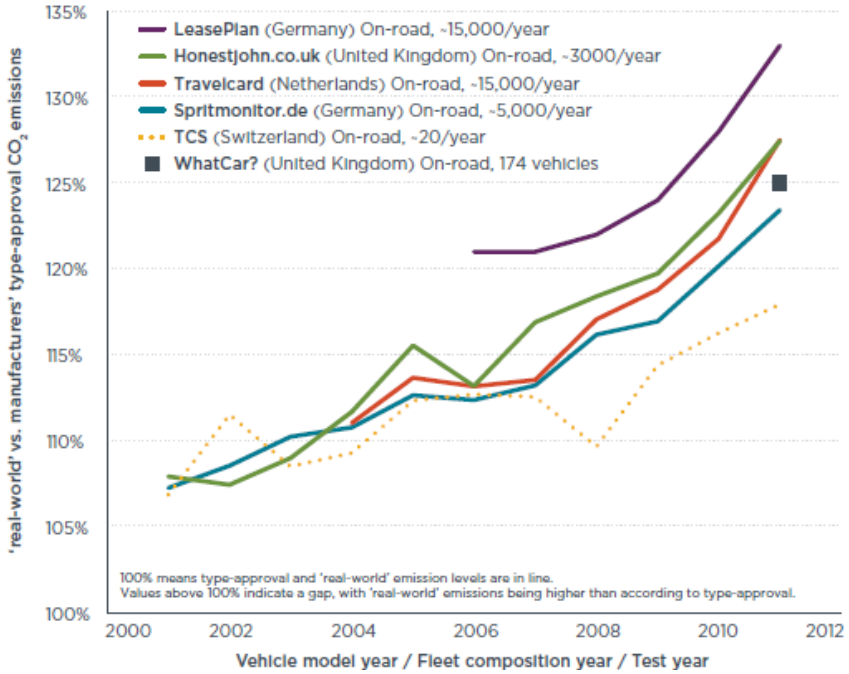
Introducing the WLTP into the EU type-approval legislation

The European Commission has targeted the introduction of the WLTP in the European Type-Approval (TA) legislation by 1 September 2017 together with the introduction of the final Euro 6c emission limits and with the procedure for measuring Real Driving Emissions. The objective is indeed to have in Europe, by 2017, the *most complete and sophisticated* legislation regulating pollutant and CO_2 emissions from light-duty vehicles

European Commission

Implementing the WLTP in the EU legislation

- NEDC is the test cycle for type-approval in EU
- There is increasing evidence that NEDC is not representative of real-world emissions
- Part of the reduction in terms of overall CO2 is likely to be connected to the flexibilities allowed by NEDC
- EC is aiming to introduce the WLTP in the shortest possible time-frame



Source: ICCT White paper 2013

European Commission

Implementing the WLTP in the EU legislation

Application of test requirements for type-approval and extensions

Vehicle category	Vehicles with positive ignition engines including hybrids								Vehicles with compression ignition engines including hybrids	
	Mono fuel				Bi fuel (1)			Flex fuel (1)	Flex fuel	Mono fuel
Reference fuel	Petrol (E5)	LPG	NG/Biomethane	Hydrogen	Petrol (E5) LPG	Petrol (E5) NG/Biomethane	Petrol (E5) Hydrogen	Petrol (E5) Ethanol (E85)	Diesel (B5) Biodiesel	Diesel (B5)
Gaseous pollutants (Type 1 test)	Yes	Yes	Yes		Yes (both fuels)	Yes (both fuels)		Yes (both fuels)		Yes
Particulates (Type 1 test)	Yes (direct injection)	—	—		Yes (direct injection) (petrol)	Yes (direct injection) (petrol)		Yes (direct injection) (both fuels)		Yes
Idle emissions (Type 2 test)	Yes	Yes	Yes		Yes (both fuels)	Yes (both fuels)		Yes (both fuels)		—
Crankcase emissions (Type 3 test)	Yes	Yes	Yes		Yes (petrol)	Yes (petrol)		Yes (petrol)		—
Evaporative emissions (Type 4 test)	Yes	—	—		Yes (petrol)	Yes (petrol)		Yes (petrol)		—
Durability (Type 5 test)	Yes	Yes	Yes		Yes (petrol)	Yes (petrol)		Yes (petrol)		Yes
Low temperature emissions (Type 6 test)	Yes	—	—		Yes (petrol)	Yes (petrol)		Yes (2) (both fuels)		
In-service conformity	Yes	Yes	Yes		Yes (both fuels)	Yes (both fuels)		Yes (both fuels)		Yes
On-board diagnostics	Yes	Yes	Yes		Yes	Yes		Yes		Yes
CO_2 emissions and fuel consumption	Yes	Yes	Yes		Yes (both fuels)	Yes (both fuels)		Yes (both fuels)		Yes
Smoke opacity	—	—	—		—	—		—		Yes

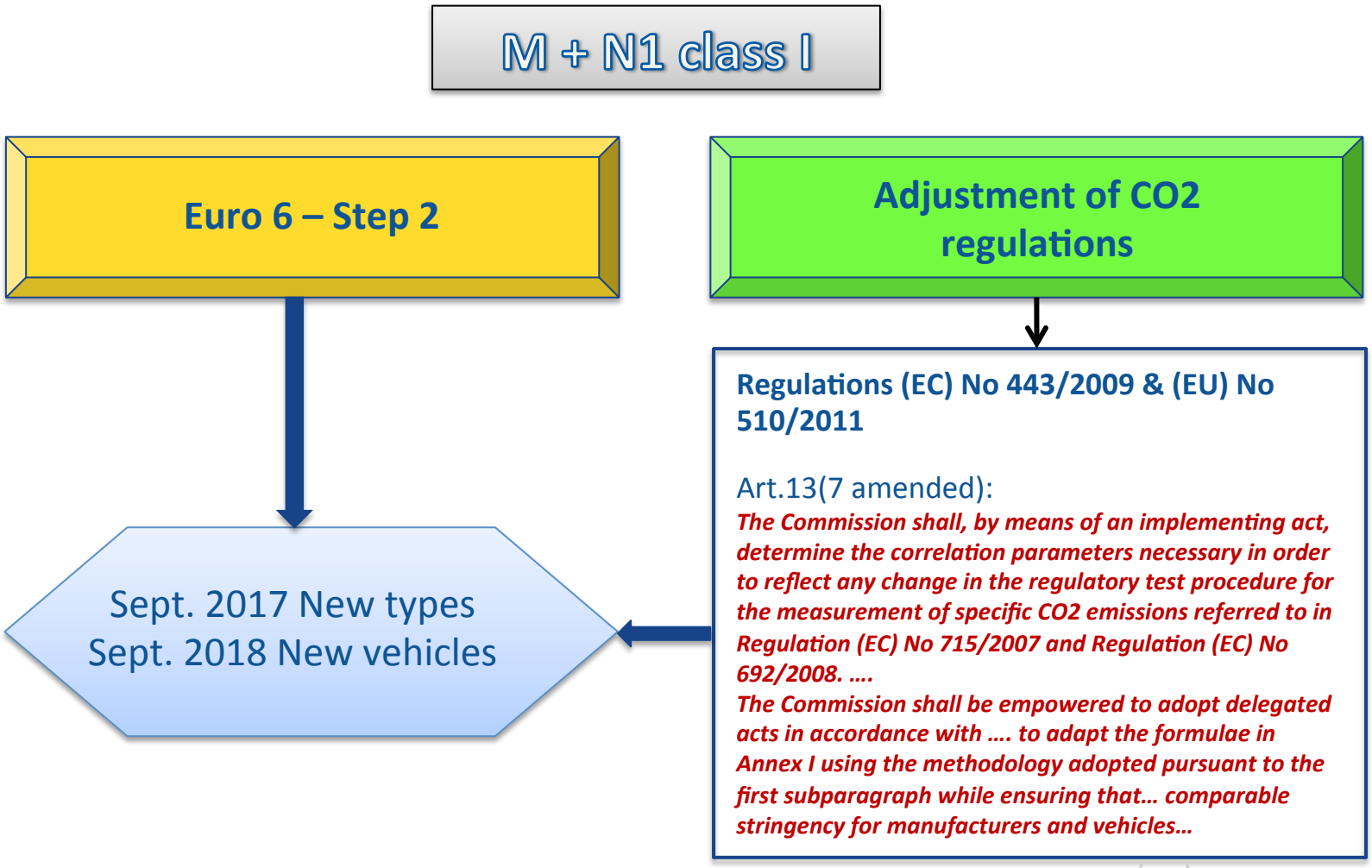
European Commission

Implementing the WLTP in the EU legislation

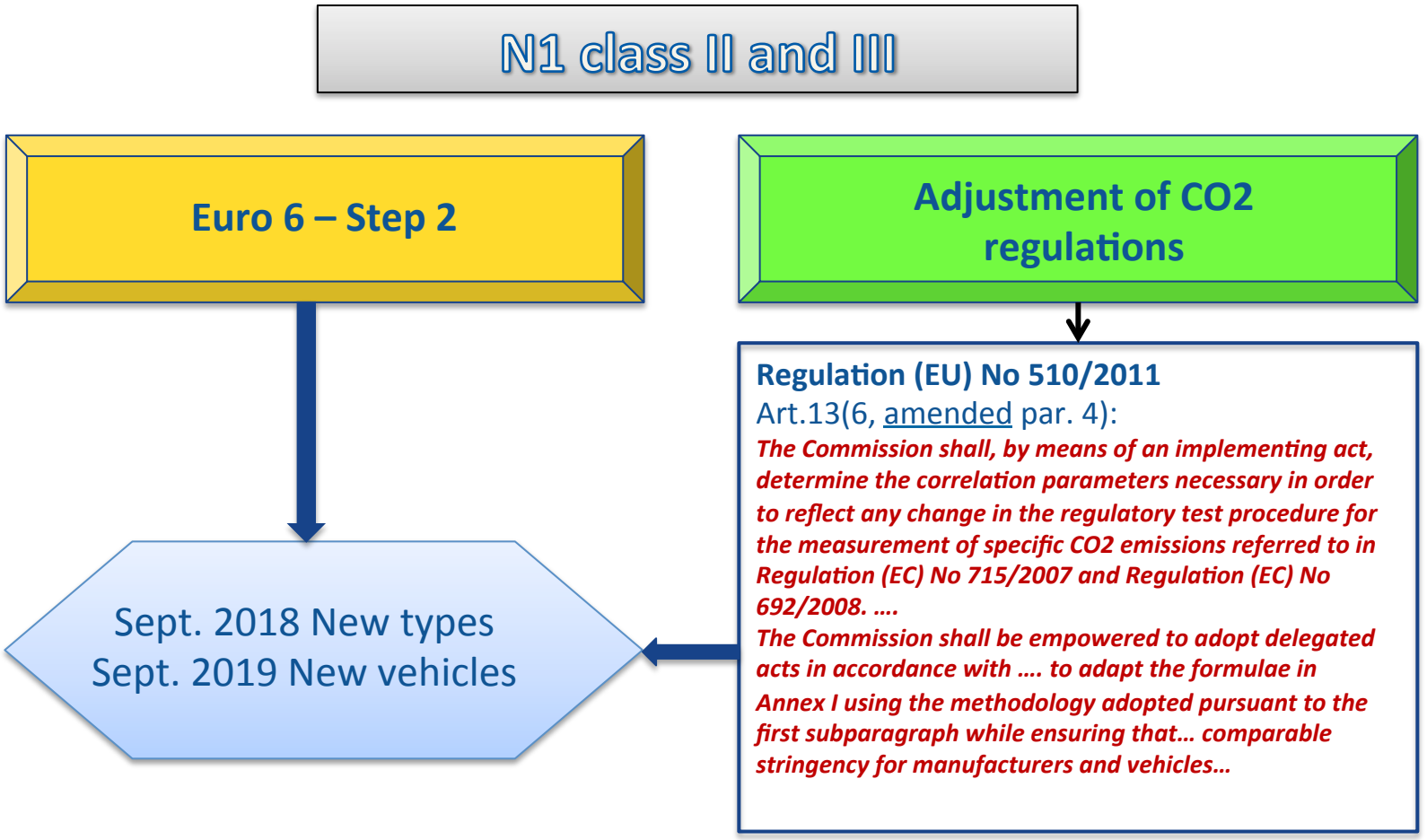
Table 1

Character	Emissions standard	OBD standard	Vehicle category and class	Engine	Implementation date: new types	Implementation date: new vehicles	Last date of registration
A	Euro 5a	Euro 5	M, N_1 class I	PI, CI	1.9.2009	1.1.2011	31.12.2012
W	Euro 6b	Euro 6-1	M, N_1 class I	PI, CI	1.9.2014	1.9.2015	31.8.2018
X	Euro 6b	Euro 6-1	N_1 class II	PI, CI	1.9.2015	1.9.2016	31.8.2019
Y	Euro 6b	Euro 6-1	N_1 class III, N_2	PI, CI	1.9.2015	1.9.2016	31.8.2019
ZA	Euro 6c	Euro 6-2	M, N_1 class I	PI, CI	1.9.2017	1.9.2018	
ZB	Euro 6c	Euro 6-2	N_1 class II	PI, CI	1.9.2018	1.9.2019	
ZC	Euro 6c	Euro 6-2	N_1 class III, N_2	PI, CI	1.9.2018	1.9.2019	

Implementing the WLTP in the EU legislation



Implementing the WLTP in the EU legislation



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Adjustment of CO2 Regulations: from NEDC to WLPT – the Correlation project

- While the introduction of WLTP as Type 1 test for the measurement of gaseous pollutants and particulates is quite straightforward (same emission limits as with NEDC), the replacement of NEDC in the CO2 Regulations is more complex.
- The reason is connected to the mandate given to the Commission to ensure that the CO2 reduction requirements are of "**comparable stringency for manufacturers and vehicles of different utility**" following the change in CO2 tests
- The boundaries for the mandate are due to the fact that CO2 targets can be decided by the EU legislator - not by the Commission… This constraint was necessary due to the way CO2 regulations for LDVs are applied in EU

EU Regulations on CO_2 from LDVs

- In the EU, CO_2 **emission targets for LDVs** are defined by Regulations 443/2009 (PC) and 510/2011 (LCV) (around 10 year lead time needed for target setting to ensure OEM planning certainty)
- Regulations define **overall targets** (fleet-wide) and **a function to relate CO_2 emission targets with the vehicle mass** for 2015 and 2020
- Regulations apply to the **average CO_2 emission** from the annual new fleet of single manufacturers or pools of them
- Compliance against the targets is assessed by a **EU-wide monitoring system** defining on a yearly basis the number of registrations per each vehicle type/variant and the corresponding type-approval CO_2 emissions (as of Regulation 715/2007) and mass

EU Regulations on CO_2 from LDVs

- If the annual target is exceeded a manufacturer will have to **pay an excess emission premium of about 95€ per each gram of CO2 exceeding the target and per each vehicle sold by the same manufacturer in the same year**
- OEMs have already programmed how the 2017-2020 NEDC-based targets should be met. The change in test procedure could have serious implications for target compliance;
- *A correlation of the NEDC-based emissions and the new WLTP-based emissions is required*
- In May 2013 a Technical Working Group composed of MSs, OEMs, technical experts and stakeholders has been set-up to support the EC for the NEDC/WLTP correlation

NEDC/WLTP Correlation: overall approach

- **Technical correlation exercise**
  This contains two sub-steps:
  - Determining CO_2 emissions evaluated on the NEDC and on the WLTP for a range of vehicle configurations and technology packages;
  - Determination of a generalised correlation function between CO_2 on the NEDC and the WLTP;

- **Correlation of CO2 emissions measured on the NEDC and on the WLTP**
  - on the basis of agreed criteria ensuring comparable stringency
  - using insights from the technical correlation exercise

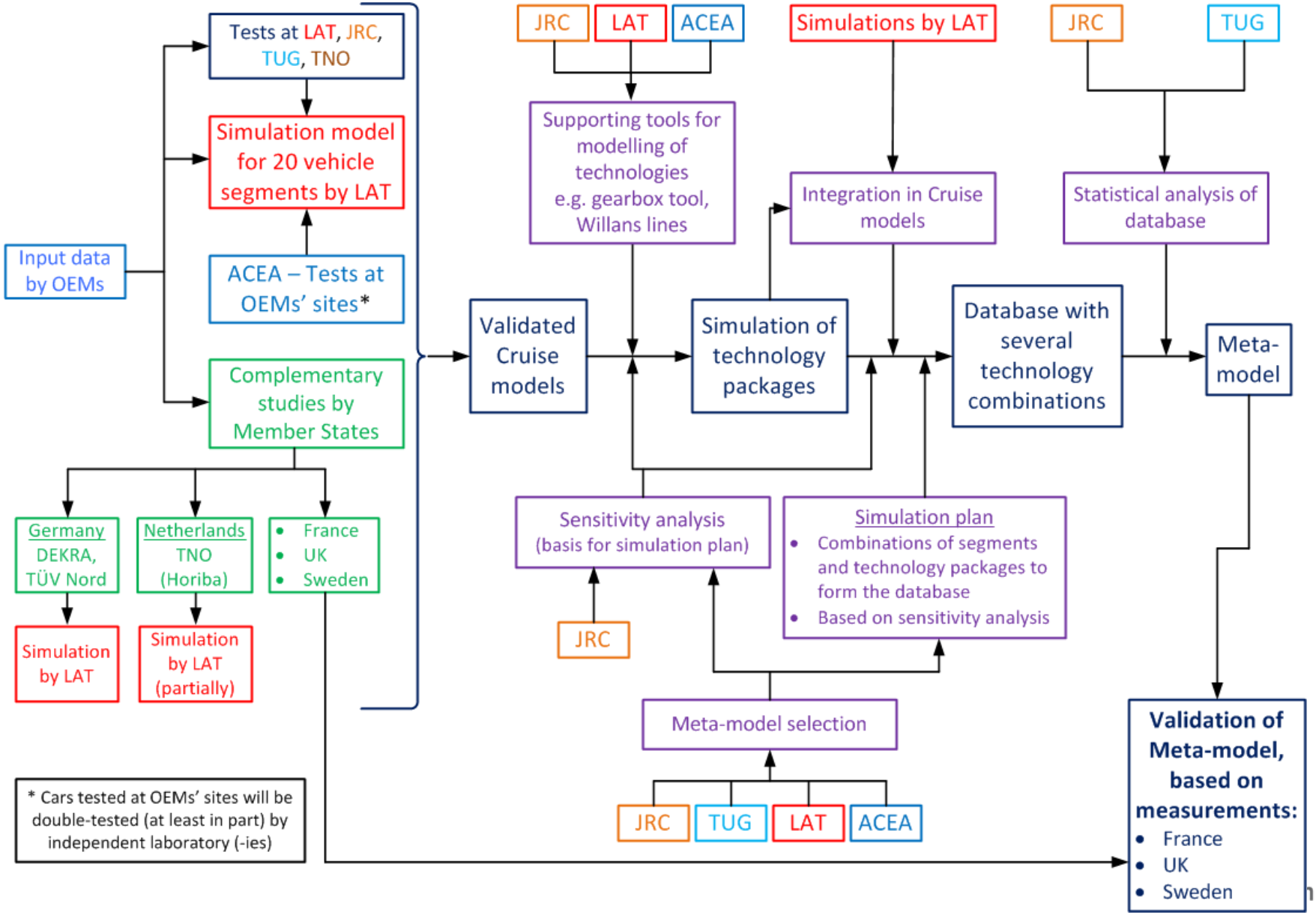
The technical correlation exercise

- Two possible approaches: testing vs. modeling/simulations
- A **mixed approach** is adopted:
  - mostly based on modeling combined with results from vehicle testing
  - Pros:
    - cost effective
    - combined pros of both approaches while avoiding many of the cons
    - improves acceptance and robustness of modeling results
    - allows evaluation of aspects of the tests that cannot be adequately simulated
  - Cons:
    - costs somewhat higher than for approach based on modeling alone

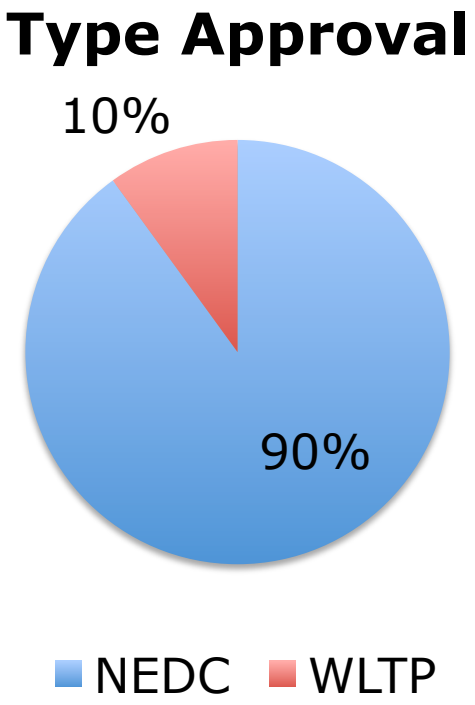
Steps in the technical correlation exercise

- Definition of a range of **vehicle configurations**:
  - Starting point is the most recent vehicle registration database available for Europe
  - The car market is divided into different technology-based segments
  - For each segment a representative vehicle model is selected
- The **simulation model** for each vehicle is developed
- Using the model, **NEDC- and WLTP-based CO2 emissions are evaluated** on different combinations of key vehicle parameters (mass, power, transmission, etc.) and technology options
- Simulation results are used to **estimate the general CO_2 correlation function**

Project structure



2017 – Average target: 130g/km



- Only new types of vehicles are Type-approved in WLTP in the period Sep-Dec
- Average CO2 emissions around 110g/km

- *No effect on compliance of possible inaccuracy of the correlation*

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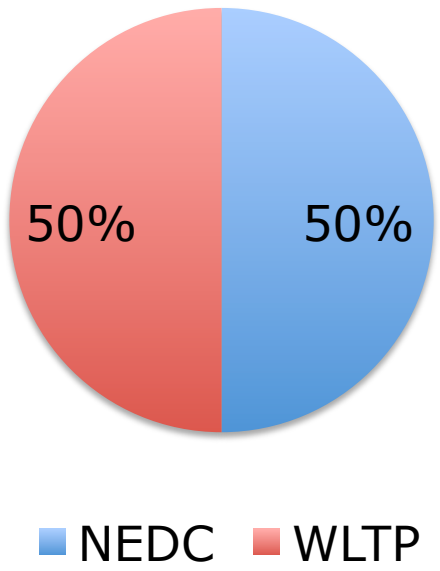
2018 – Average target: 130g/km

Type Approval



- Only new types of vehicles are Type-approved in WLTP in the period Jan-Aug
- All types Sep-Dec
- Average CO2 emissions around 105g/km

- *No effect on compliance of possible inaccuracy of the correlation*

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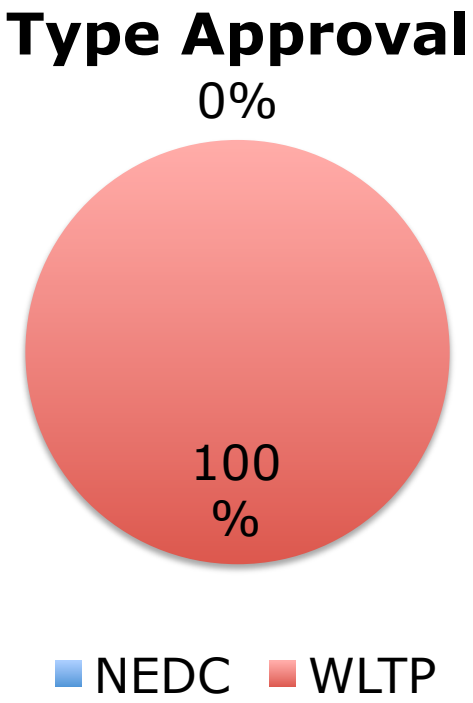
2019 – Average target: 130g/km



- All models WLTP TA
- Average CO2 emissions around 100g/km

- *Only an average bias in the correlation of around 30g/km can affect the compliance to target*

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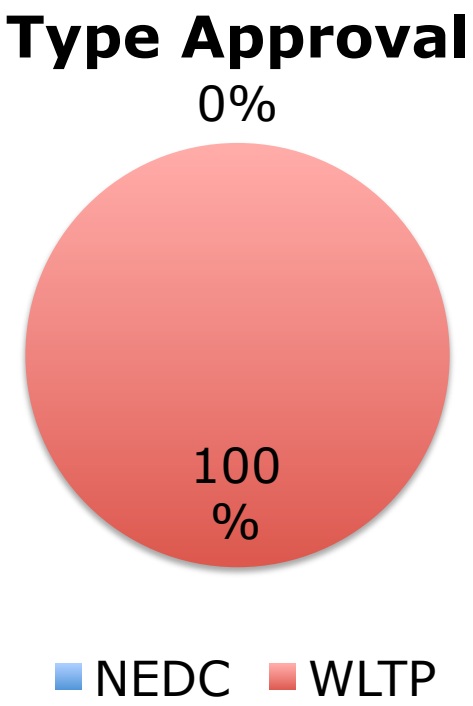
2020 – phase in of average target: 95g/km
(95% of the fleet)



- All models WLTP TA
- Average CO2 emissions around 98g/km (95g in 2021)

- *Compliance to target potentially strongly influenced by accuracy in the correlation if WLTP values are translated back to NEDC*

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Correlation of CO2 emissions and targets

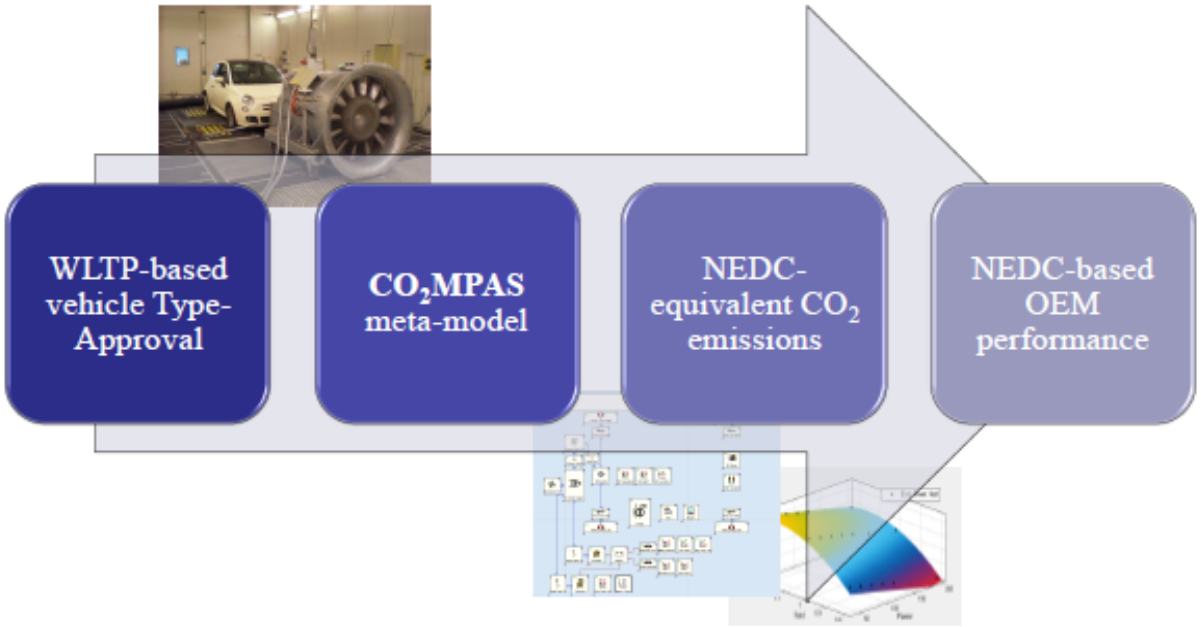
EC objective: to phase out NEDC as soon as possible whilst taking into account the need to ensure that CO2 reduction requirements are of comparable stringency:

- The ***WLTP phasing-in*** (2017-2020) will be managed, for what concerns CO_2 Regulations, using *CO_2MPAS* (CO_2 Model for PAssenger and commercial vehicles Simulation), under development at STU.

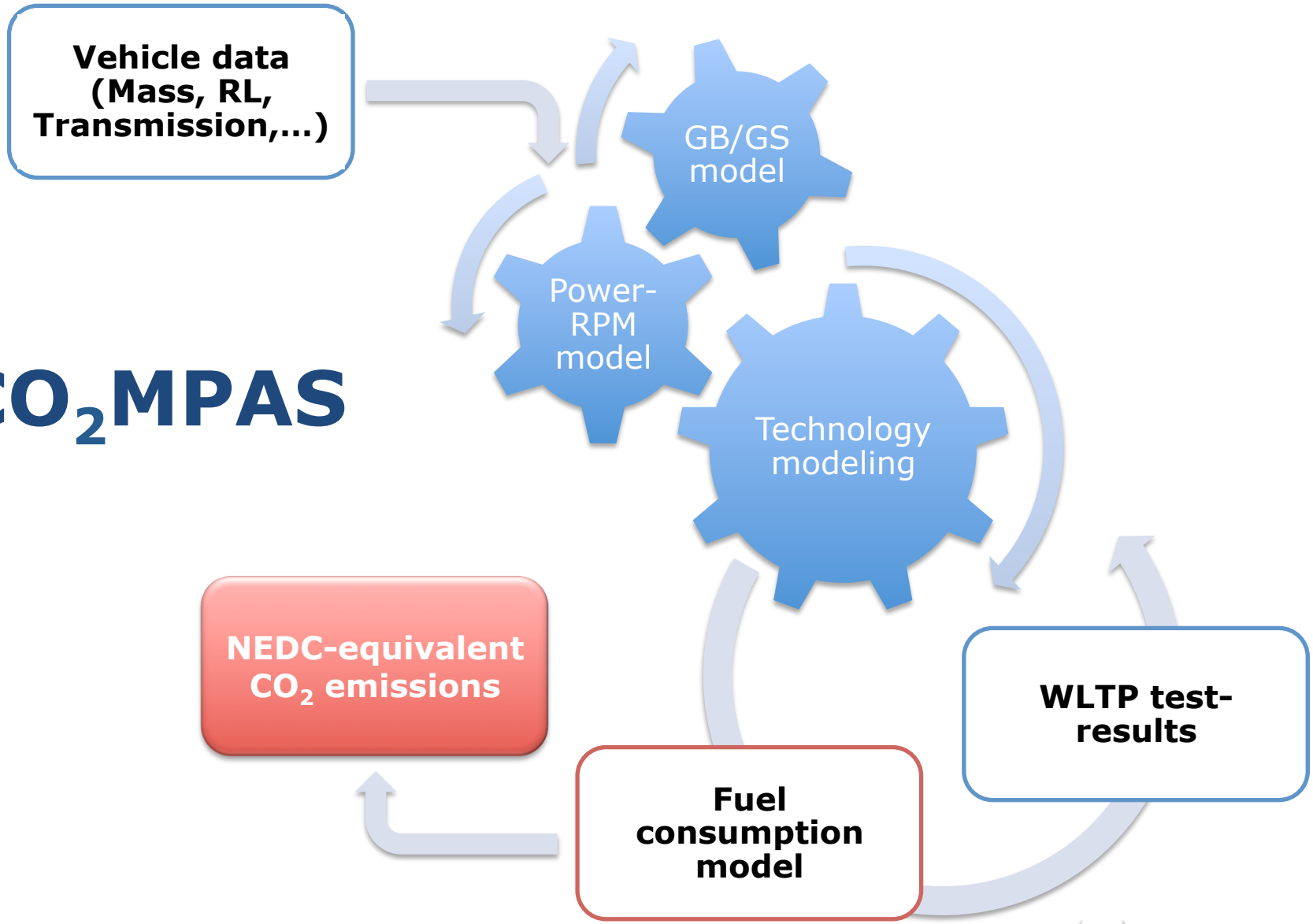
- In 2021, a new ***WLTP-based target*** can be identified, per each OEM, on the basis of the distance in 2020 of their average CO_2 emissions from the NEDC-based target.

WLTP phasing-in (2017-2020)

- ***WLTP-based CO_2 emissions (measured at type-approval) will be translated in the equivalent NEDC-based ones*** and then used in to assess the compliance towards CO_2 emission targets



CO_2MPAS



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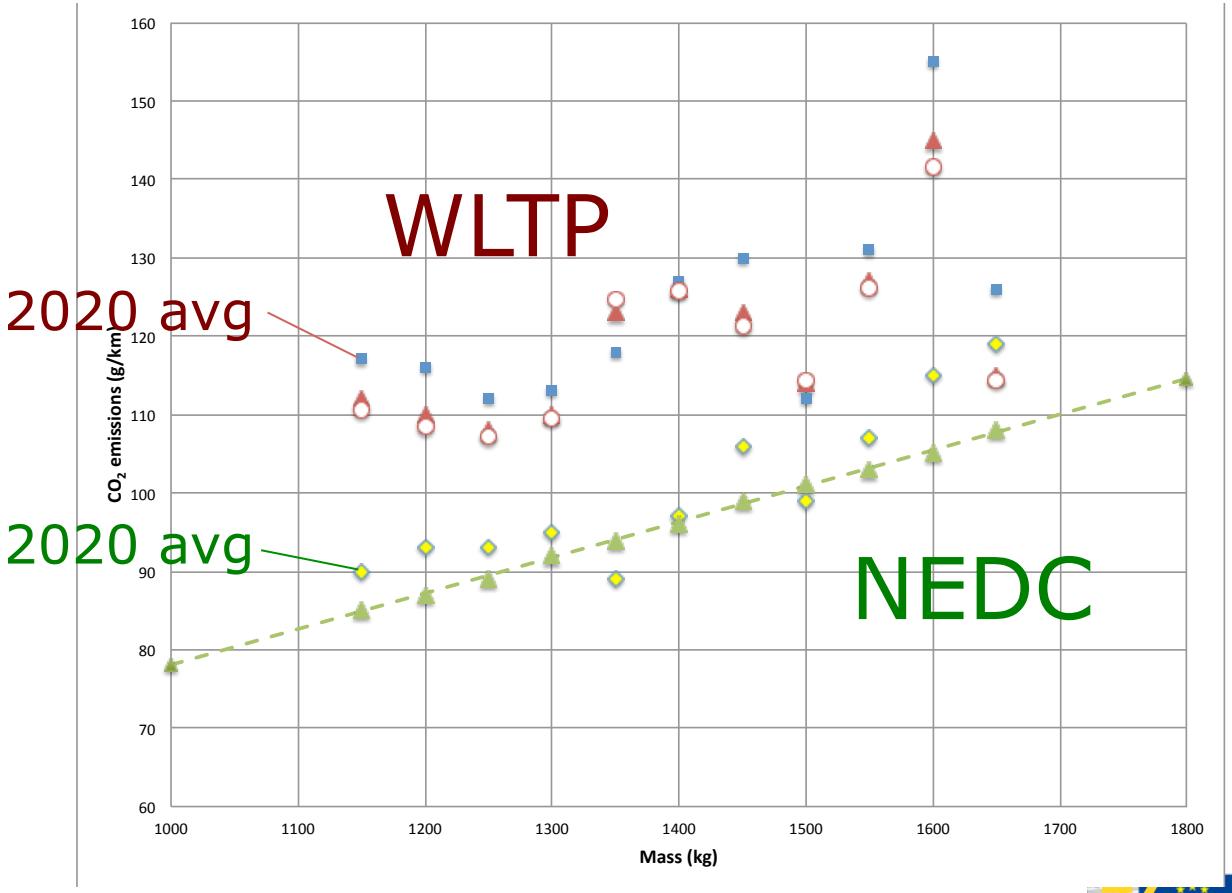
WLTP-based targets



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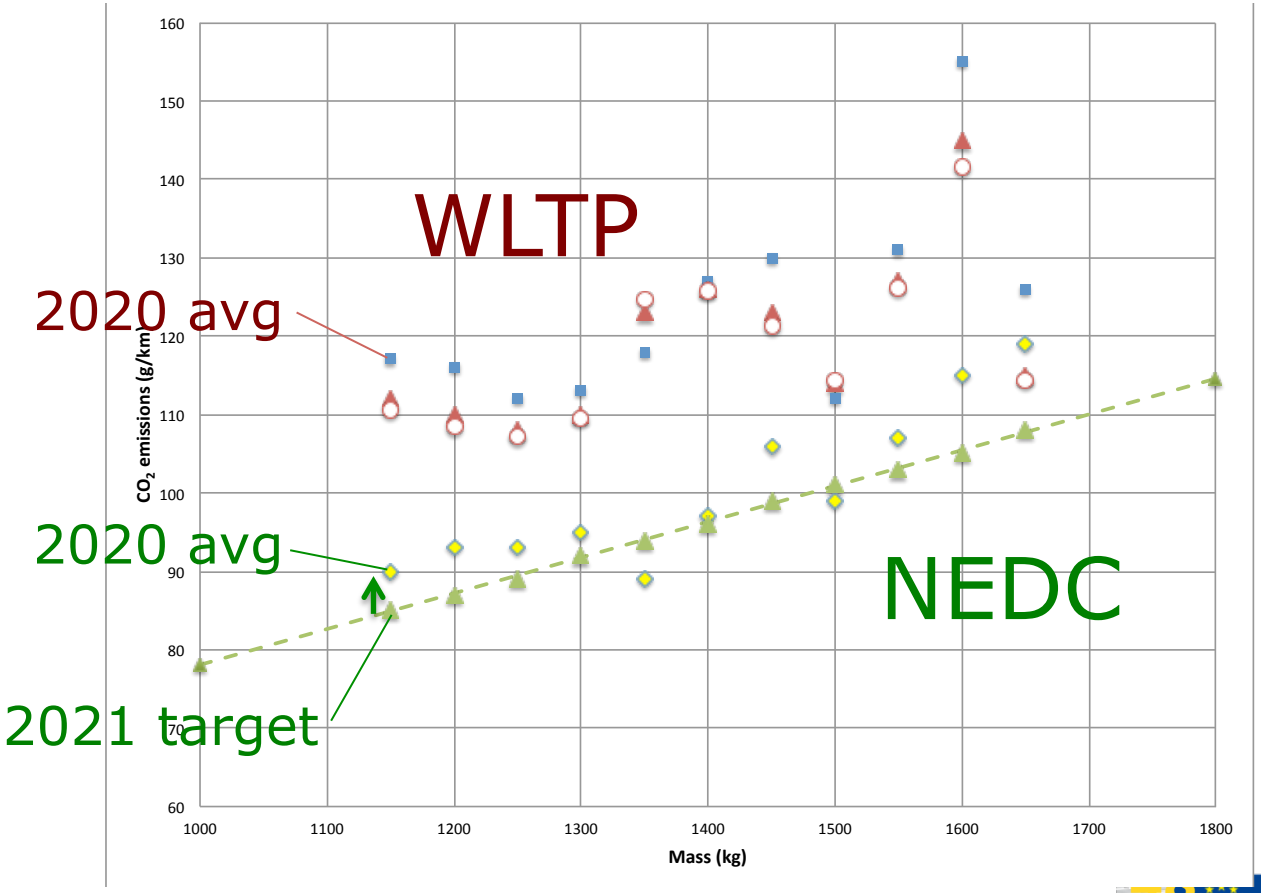
WLTP-based targets



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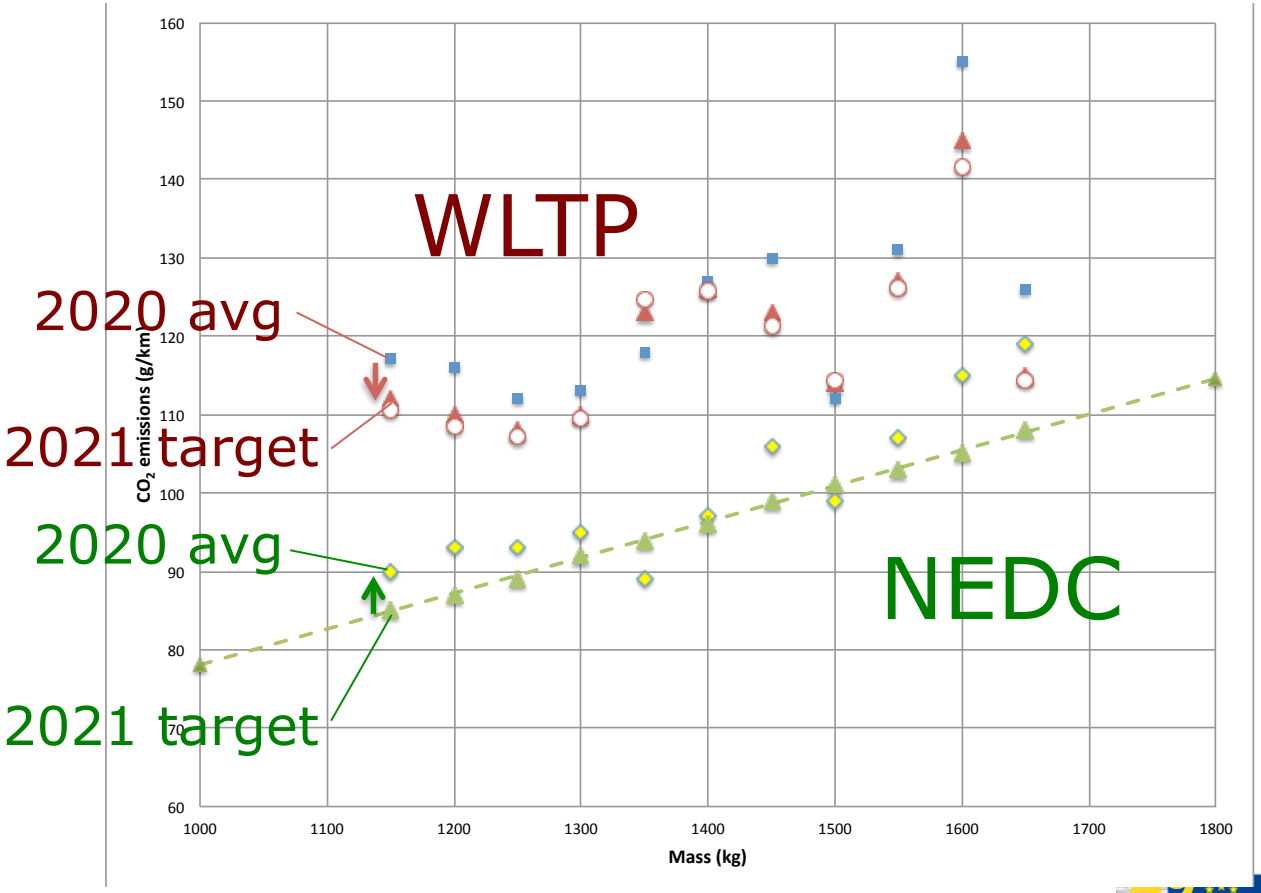
WLTP-based targets



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Relevant EU Legislation

Euro 5/6 Light Duty Vehicles

- Directive 2007/46/EC
- Regulation_EC_715_2007
- Commission_Regulation_692_2008
- Reg_459_2012_PN
- Commission_Regulation_136_2014

CO2 Passenger Cars and Light Commercial Vehicles

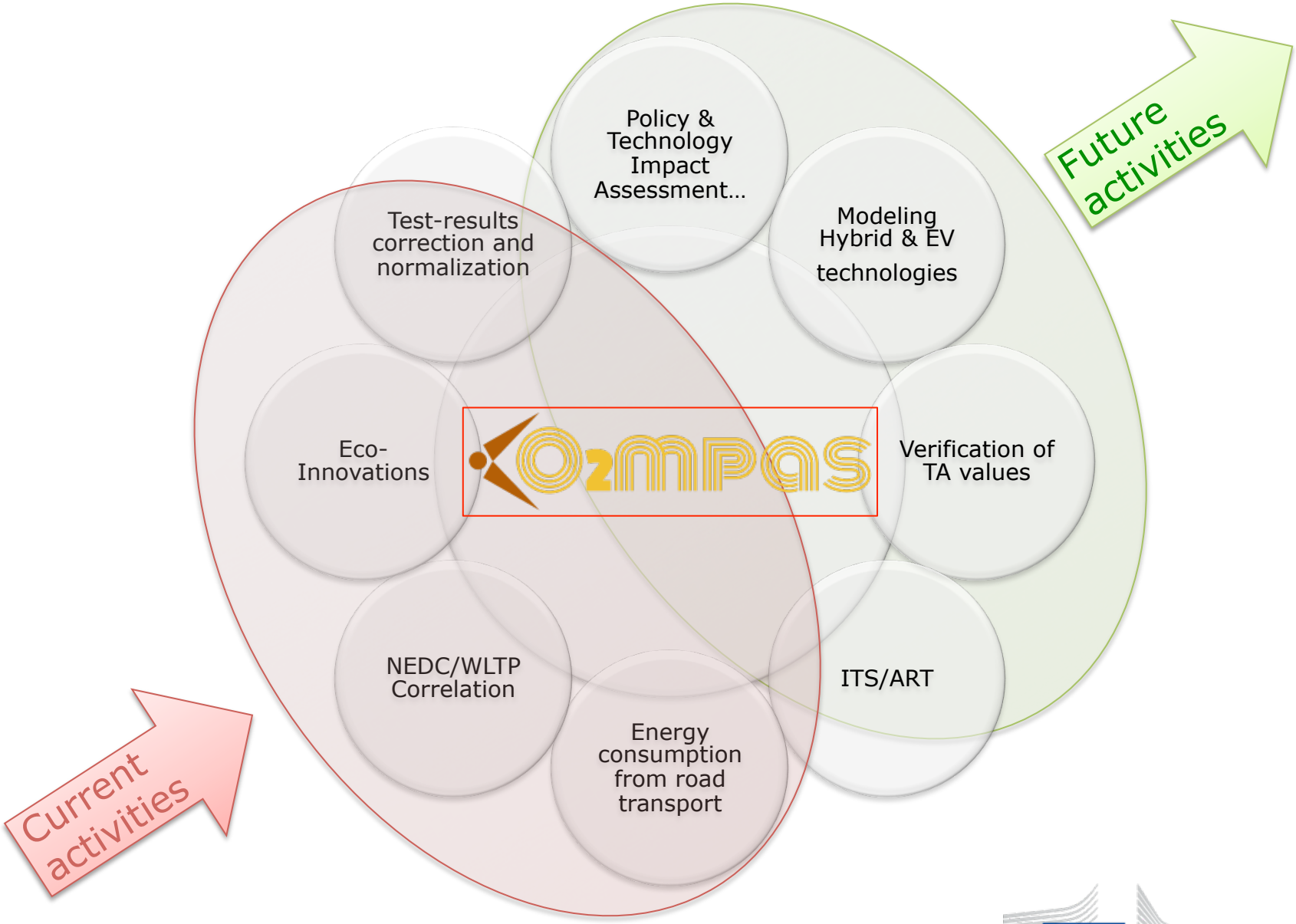
- Regulation_EC_443_2009
- Regulation_(EU)_510_2011

Latest publications

- Marotta, A., Pavlovic, J., Ciuffo, B., Serra, S., Fontaras, G. **Gaseous Emissions from Light-Duty Vehicles: Moving from NEDC to the new WLTP test procedure**. *Environmental Science and Technology*, Vol. 49 (14), pp. 8315-8322, 2015, doi: 10.1021/acs.est.5b01364.
- B. Ciuffo, A. Marotta, M. Tutuianu, G. Fontaras, J. Pavlovic, S. Tsiakmakis, K. Anagnostopoulos, S. Serra, N. Zacharof. **Development of the Worldwide Harmonized Test Procedure for Light-Duty Vehicles: Pathway for Implementation in European Union Legislation**. *Transportation Research Records, Journal of the Transportation Research Board*. Vol. 2503, pp. 110-118. 2015
- Tutuianu, M., B. Ciuffo, T. Haniu, N. Ichikawa, A. Marotta, J. Pavlovic, H. Steven. **Development of a world-wide harmonized light duty test cycle (WLTC)**. *Transportation Research part D: Transport and Environment*. Vol. 40, pp. 61-75, 2015
- A. Marotta, J. Pavlovic, B. Ciuffo, G. Fontaras, S. Tsiakmakis, K. Anagnostopoulos, S. Serra, R. Praksova, B. Ghiekaskiel. **An insight into the procedural differences between NEDC and WLTP and their possible impact on CO2 emissions from the type-approval of light duty vehicles**. *2016 TRB Annual Meeting*
- B. Ciuffo, G. Fontaras, S. Tsiakmakis, K. Anagnostopoulos, V. Arcidiacono, A. Marotta, J. Pavlovic, S. Serra, R. Praksova. **The change in the average European CO2 emissions from passenger cars due to the introduction of the WLTP. A Monte Carlo analysis based on CO2MPAS.** *2016 TRB Annual Meeting*

The use of CO2MPAS beyond the legislation

- As a vehicle simulation tool CO2MPAS is
  - Technology-specific
  - Very fast
  - Open-source (usable under EUPL) and customizable
  - Not extremely demanding in terms of input data (in any case a library of inputs for the main technology combinations have been built during the project)



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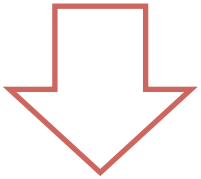
Integration of traffic/vehicle simulation

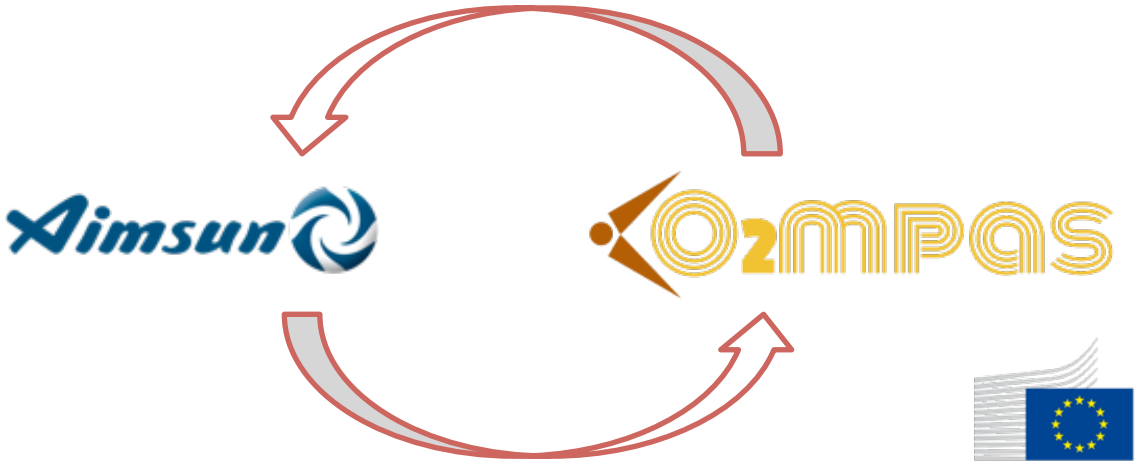
- **The characteristics of CO2MPAS make it suitable to attempt its integration with a traffic simulation model**
- ***Current traffic simulation models reproduce the behaviour of the single vehicle with the aim to correctly reproduce TRAFFIC***
- ***Vehicle technology/road geometry plays no or little role***
- ***Emissions estimations based on statistical methods***



- **Objectives**
  - **Close the loop between driver and vehicle**
  - **Open the pathway for a new type of traffic simulation in which vehicle dynamics and therefore emissions are better reproduced**

Focus of the research

- ***Improved traffic simulation to***
  - ***Reproduce and test in a reliable way different behaviours for autonomous vehicles***
  - ***Be able to evaluate fuel/energy consumption and emissions in a more reliable way***
  - ***Test different approaches to optimize the transportation system***



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Conclusions

- ***A fast-moving society calls for political bodies able to adapt to the speed of change and to the increasing complexity***

- Scientific bodies can support the political process but efforts should be made to increase the *involvement of stakeholders*. The JRC is strongly working at the interface between policy and science

- The introduction of the WLTP into the European type-approval legislation is a typical example of ***science for policy application***

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