

Real driving emissions: Challenges to regulating diesel engines in Europe

Vicente Franco & Peter Mock

vicente@theicct.org

Anil Agarwal Dialogue. New Delhi, March 11-12 2015



The European Problem with Diesels

Early Concerns about Mis-Aligned Diesel Policies in Europe

Table 2

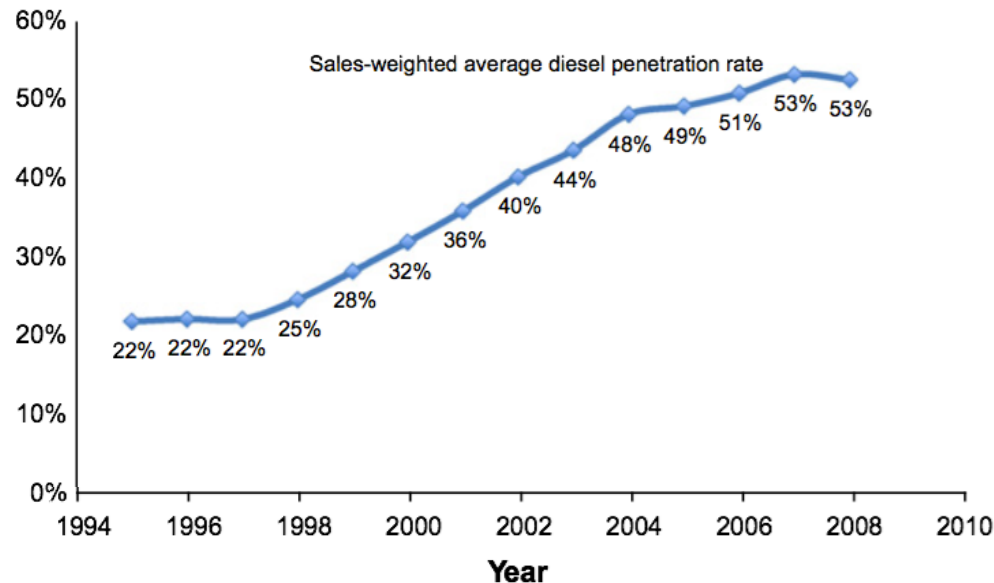
Carbon dioxide-equivalent PM_{2.5} emissions from new light-duty gasoline and diesel vehicles (g/km).

Source: Emission factors based on Bond et al., 2007. GWP values from Bond et al., 2011.

	No control	Engine Mods	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Gasoline	−0.3	−0.3	0.5	0.3	0.3	0.3	0.3	0.3
Diesel	251.7	167.9	129.7	54.6	30.2	15.4	0.7	0.7

Note: Based on GWP-100 values of 2800 for black carbon and −154 for organic carbon. Negative values can be considered equivalent to a negative radiative forcing

EU Diesel Penetration



Today's Problem: Real-world diesel NO_x emissions enforcement is non-existent

Results from a remote sensing study in Zurich (Switzerland)

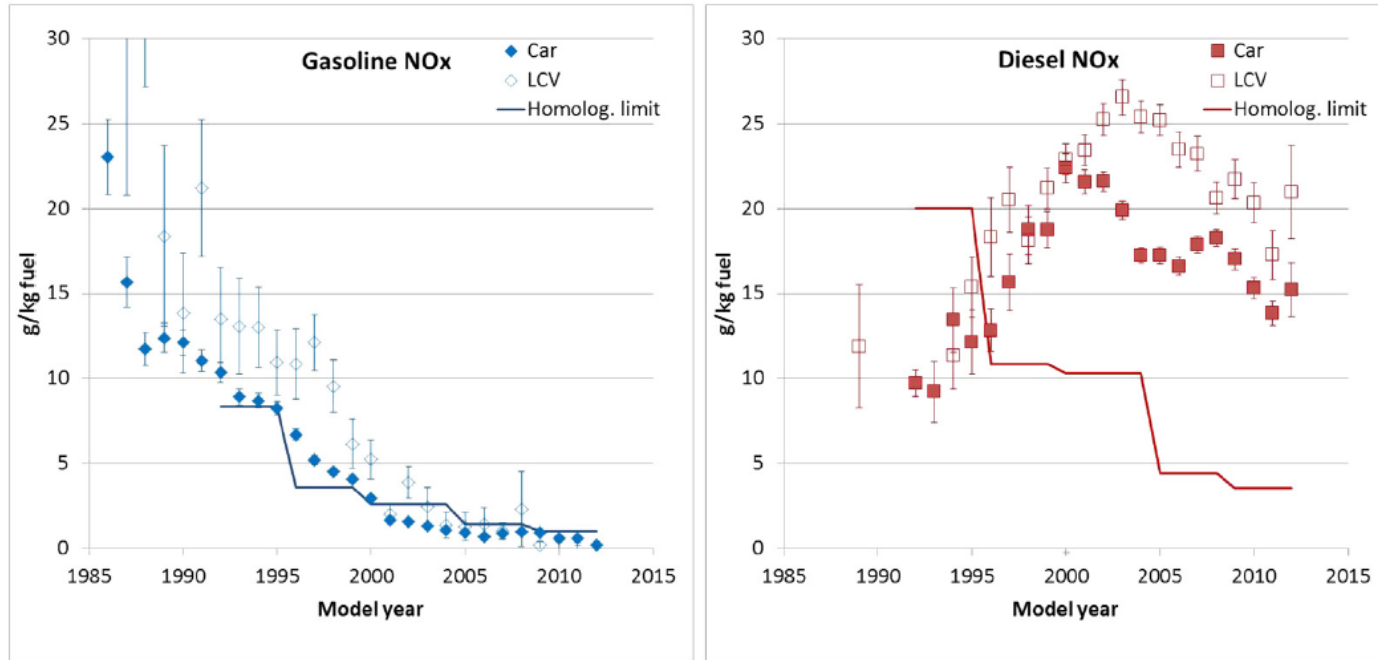
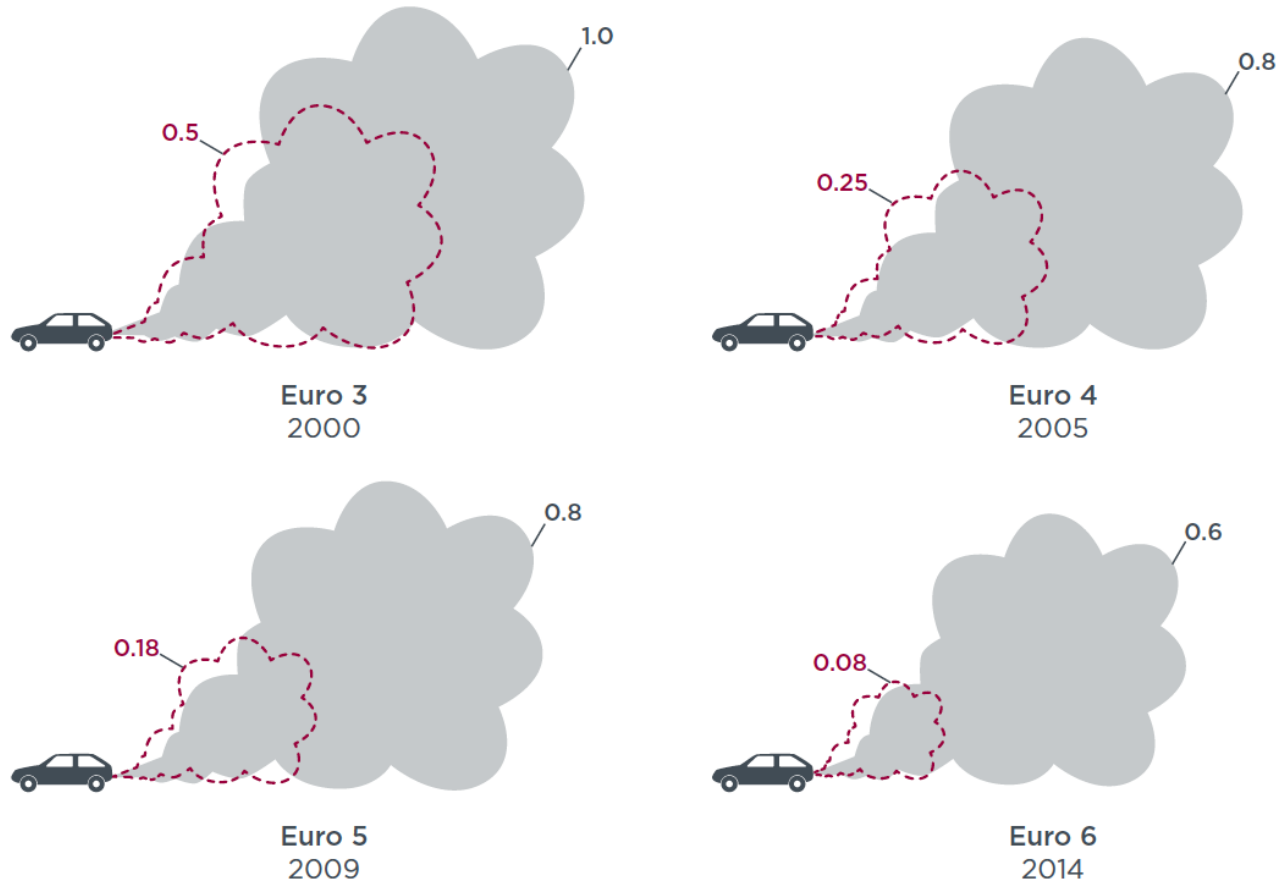


Fig. 4. Mean hot NO_x emission factors of gasoline (left) and diesel (right) passenger cars and light commercial vehicles as a function of model year. Whiskers represent the 95% confidence interval over the mean. Added are the type approval limit values for Euro 1 to Euro 5 passenger cars over the homologation test cycle in force in the respective year. For conversion from limit values in g per km see SI (using measured fuel consumption rates from [Hausberger \(2010\)](#)). For color plot consult online version.

New Diesel Car Emissions in Europe are Worse (on average) than 15 years ago

Diesel cars: Nitrogen oxides (NO_x) emissions (in g/km)



Awareness of the 'Diesel problem' has triggered initiatives at the local level

the **guardian**

Car makers face 'real world' emissions tests in EU pollution clampdown

Europe to become first place in world to force car makers to undergo more realistic tests in bid to reduce nitrogen oxide emissions

The Telegraph

London will follow Paris and ban diesel cars, campaigners warn

Pollution is so high in the capital, and diesel fumes so damaging, experts believe Boris Johnson will follow Paris' lead and ban the cars from London's roads within the decade

FINANCIAL TIMES

Carmakers stuck in slow lane over fuel data and air pollution, say researchers

Key message from Europe: Avoid our mistakes!



A solid pollutant regulation requires:

- A modern test procedure
- Independent retests
- On-road testing
- Transparency of test results

More info:



<http://www.theicct.org/blogs/staff/trend-that-cant-continue-europes-car-co2-emissions-gap>

<http://www.theicct.org/blogs/staff/will-new-test-procedure-solve-problem-latest-developments-eu-vehicle-testing>

<http://www.theicct.org/blogs/staff/art-cooking-popcorn-and-2013-eu-statistical-pocketbook>

<http://www.theicct.org/wltp-how-new-test-procedure-cars-will-affect-fuel-consumption-values-eu>

<http://www.theicct.org/laboratory-road-2014-update>

<http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars>

<http://www.theicct.org/wltp-november2013-update>

Assessing the
problem

ICCT Diesel Passenger
Car Meta-Study

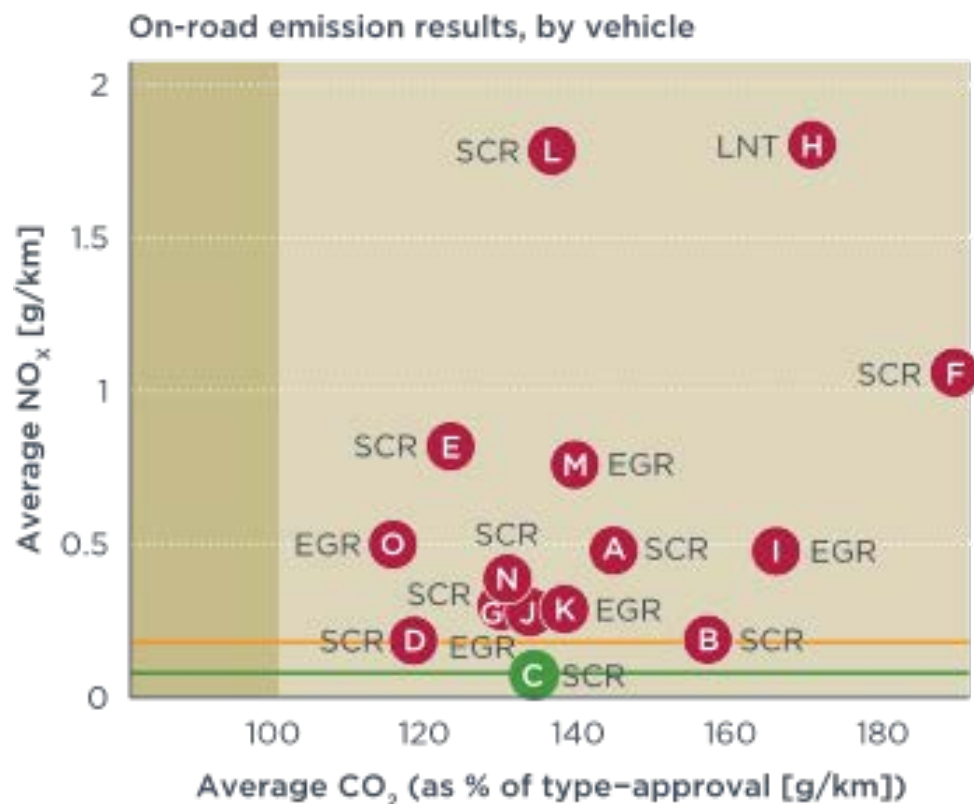
ICCT Report: Real-World Exhaust Emissions from Modern Diesel Cars (October 2014)

- Multiple data sources
 - 15 vehicles (3 Tier 2 Bin 5 + 12 Euro 6)
 - 5 different sources
 - 96 trips/ 140 hrs / 6,400 km of recorded data
- One multi-level analysis and reporting framework
 - Raw emission factors (trip averages)
 - Windowed emissions ('on-road compliance')
 - Situation-specific emissions
 - Instantaneous emissions



Overall Results

'Raw' average distance-specific emissions, by vehicle



15 test vehicles in total (6 manufacturers), with different NO_x control technologies:

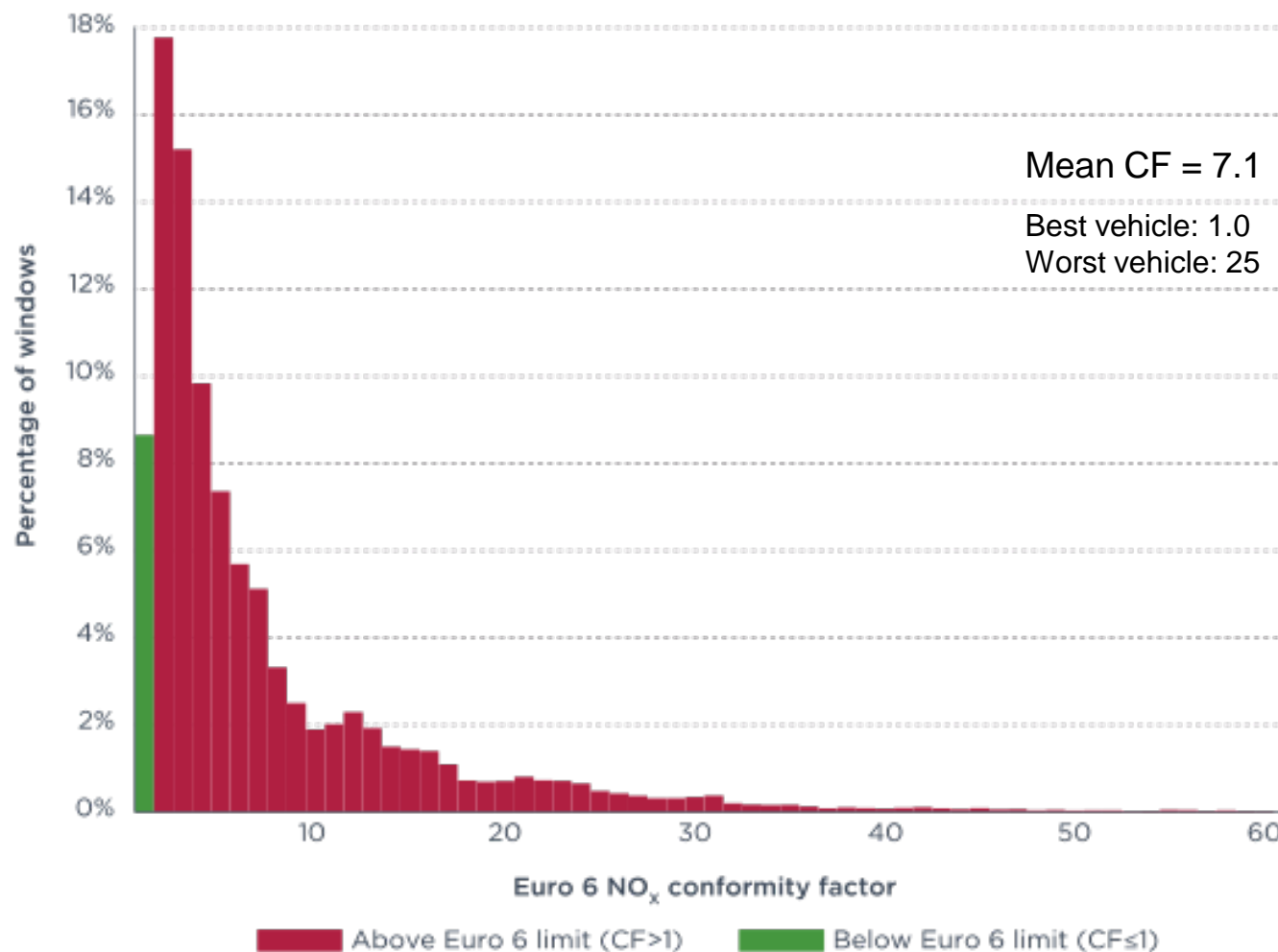
- 10 selective catalytic reduction (SCR)
- 4 exhaust gas recirculation (EGR)
- 1 lean NO_x trap (LNT)

Average Euro 6 NO_x conformity factors (ratio of on-road emissions to legal limits):

- all cars: 7.1
- best performer (Vehicle C, SCR): 1.0
- bad performer (Vehicle H, LNT): 24.3
- worst performer (Vehicle L, SCR): 25.4

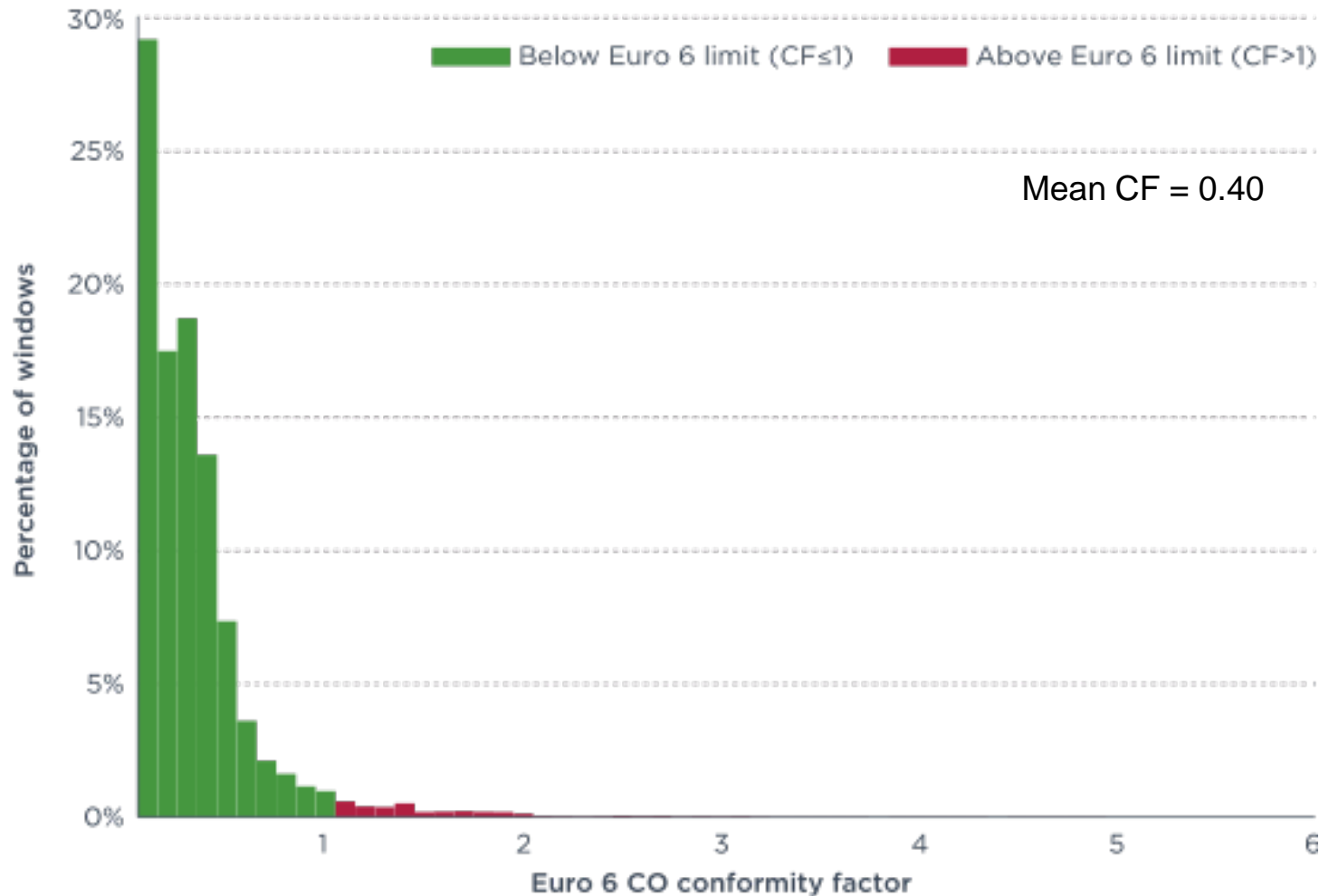
Meta-study: Results for NO_x

Euro 6 conformity factor for NO_x, all vehicles



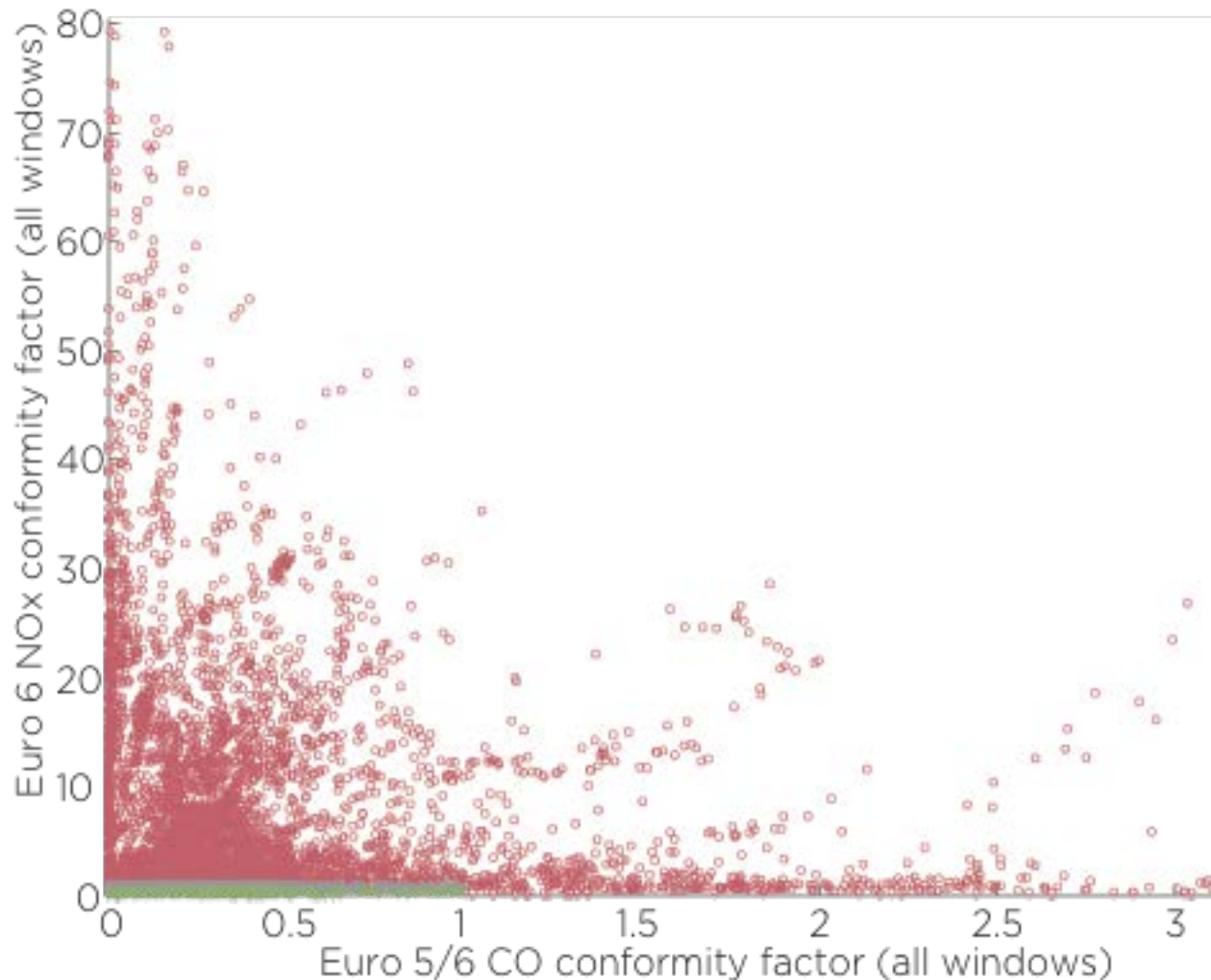
Meta-study: Results for CO

Euro 6 conformity factor for CO, all vehicles



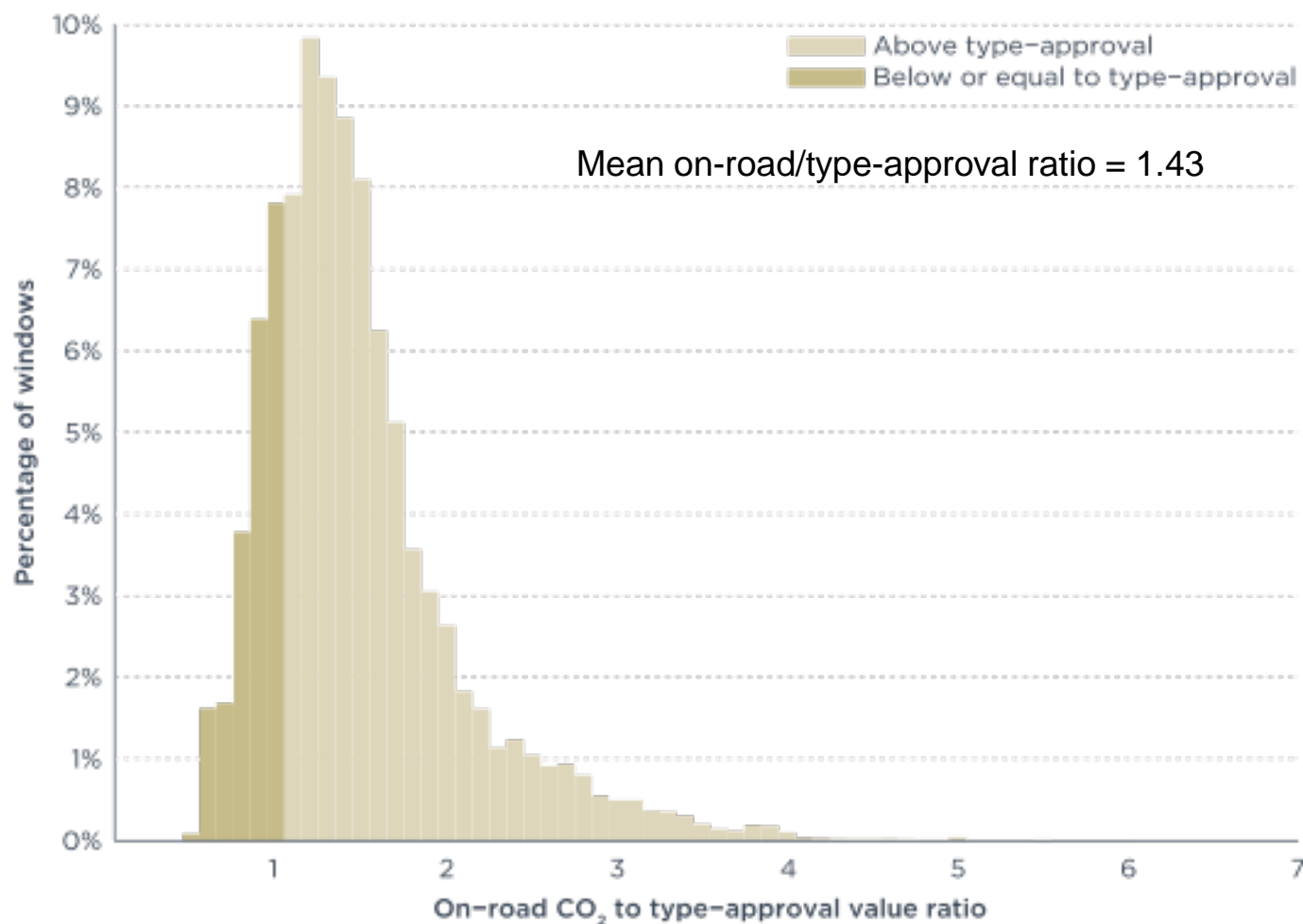
Diesel PC meta-study: Results

On-road compliance (all CO₂ windows of all trips)



Meta-study: Results for CO₂

Real-world CO₂ ratios, all vehicles



The solution to the EU Diesel NOx problem

Learn from others: Dramatic Differences Between US and European Enforcement Schemes



Manufacturer

Pre-production testing
Certificate of Conformity

1

vehicle design and build 0 km

50,000 km

100,000 km

Manufacturer

Pre-production testing
Certificate of Conformity

1

Manufacturer

In-use verification
tests on random sample

4

EPA

Conformity tests
about 10% of vehicles

2

EPA

In-use surveillance
random / selected sample

5

EPA

**Selective Enforcement Audit +
Confirmatory Road Load Testing**

3

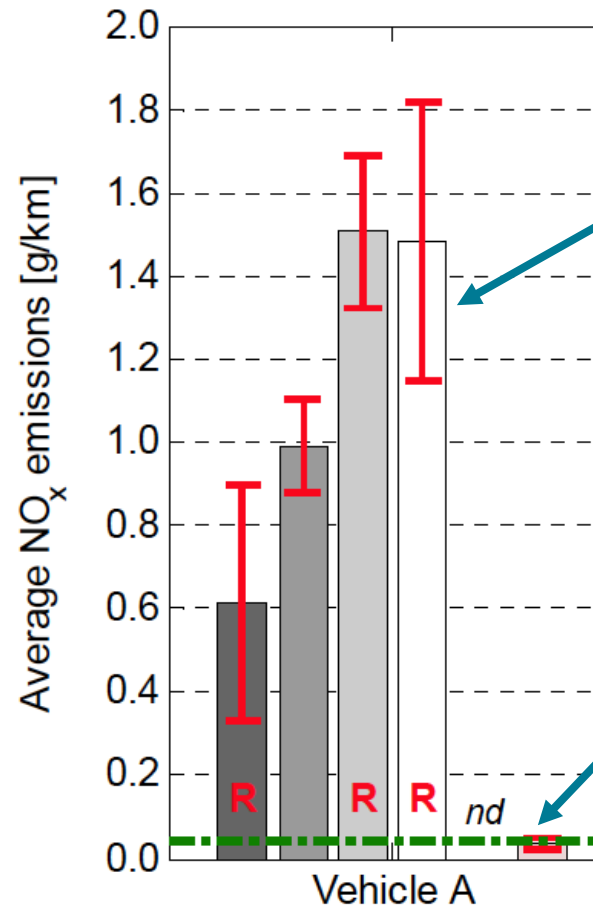
**BMW to fix fuel economy labels on
Mini Coopers after U.S. EPA test**

DETROIT | Wed Oct 22, 2014 11:08am EDT

U.S. Fines Hyundai, Kia for Fuel Claims

Penalty of \$300 Million Is Largest Ever, Could Set Pricey Precedent for Other Auto Makers

From laboratory to road: PEMS makes it possible to accurately measure real-world emissions



Road tests with PEMS



Chassis dyno measurements



The Fix: Euro 6 RDE-LDV Process

1. An amendment to Euro 6 standards to make on-road testing with PEMS part of type-approval. Triggered by high on-road Diesel NO_x results
2. Stakeholder WG is defining how the tests should be conducted (boundary conditions), how the data should be analyzed and reported
3. Pilot phase to start in 2015, implementation in 2017. On-road emission limits TBD, likely 2X chassis dynamometer limits



Conclusions

- ✦ A high share of European diesel passenger cars do not comply with the Euro 6 emission standard in the real-world
- ✦ An enforcement loophole allows cars to pass certification tests and still exceed emission limits in the real-world
- ✦ This problem will be addressed in Europe through:
 - ✦ Amend Euro 6 to require PEMS testing
 - ✦ Define testing process, data collection and reporting
 - ✦ Pilot testing in 2015 with full implementation by 2017
- ✦ Indian Bharat 6 regulations should leap-forward to this approach or adopt US best practices for enforcement to avoid high diesel NOx emissions

Thank you!

Vicente Franco,
vicente@theicct.org

Peter Mock, ICCT Managing Director for Europe
peter@theicct.org

Additional Slides

Meta-study: Results by driving condition

NO_x emission factors [mg/km]

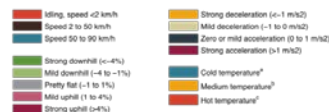
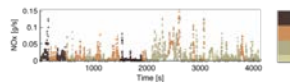
	All driving conditions					Undemanding 1			Undemanding 2		
	Raw	Idle*	Urb.	Rur.	Mwy.	Urb.	Rur.	Mwy.	Urb.	Rur.	Mwy.
Vehicle A	482	17	234	177	841	142	121	136	160	126	110
Vehicle B	235	12	206	331	81	65	27	31	77	68	26
Vehicle C	72	14	93	79	47	85	88	33	85	78	32
Vehicle D	171	35	253	130	82	247	112	62	227	126	62
Vehicle E	819	114	860	521	982	917	471	631	853	470	545
Vehicle F	908	183	1522	1083	533	1433	664	297	1429	792	426
Vehicle G	294	49	373	231	268	348	207	143	361	211	201
Vehicle H	1809	423	2166	1906	1471	1684	1232	1350	2054	1617	1380
Vehicle I	438	30	561	373	332	372	321	192	386	310	177
Vehicle J	279	12	362	317	199	360	277	163	364	288	151
Vehicle K	289	34	533	236	147	547	162	89	527	182	114
Vehicle L	1783	222	2350	1478	1544	2511	1250	1272	2346	1265	1290
Vehicle M	758	59	884	716	653	907	663	629	906	712	591
Vehicle N	388	45	558	297	271	545	277	165	558	275	172
Vehicle O	504	89	325	428	631	316	337	390	320	386	516

*Idling emissions in mg/min

Meta Study: Results in more detail









Diesel PC meta-study: Part 2



Coming soon: detailed investigation of on-road emissions from the vehicles studied in Part 1

Meta-study: Results by driving condition

Situation-specific analysis: undemanding driving conditions

<i>Combination</i>	<i>Filtering</i>	<i>Descriptor</i>	<i>Color ID</i>
Undemanding driving (1)	Data are binned by velocity. Only Points with motorway speed below 120 km/h are included. Likewise, only the points in the 'Pretty flat', 'Medium temperature' and 'Mild negative a*v' or 'Zero or mild positive a*v' bins are included.	Undemanding Urban 1	
		Undemanding Rural 1	
		Undemanding Motorway 1	
Undemanding driving (2)	Same as 'Undemanding driving (1)', but including the 'Mild uphill' and 'Mild downhill' bins.	Undemanding Urban 2	
		Undemanding Rural 2	
		Undemanding Motorway 2	

Real Driving Emissions

Regulatory aspects of on-road emission measurements

Real Driving Emissions

Conclusions

Conclusions

- Euro 6 Diesel PCs have no on-road compliance issues for CO and THC.
- On-road Diesel NO_x compliance issue present across aftertreatment techs, manufacturers and driving situations, not just in the more demanding operating conditions (e.g., uphill driving, instances of high acceleration*velocity), but also during the situations that would in principle be most favorable to achieve low NO_x emissions.
- This is the result of insufficient regulation, which incentivized manufacturers to design their aftertreatment control systems to pass the dynamometer test instead of achieving low real-world emissions.

Conclusions

- NO_x mass emissions concentrate in small events (transient load increases: gradient and acceleration); setting dynamic boundary conditions/data exclusions can dramatically affect results.
- No regulation is perfect, but the RDE amendment should improve Euro 6, providing manufacturers with the right incentives to design robust aftertreatment systems.
- India could benefit from RDE tests tailored to reflect Indian driving conditions, which would give its regulators further assurance that real-world emissions are kept under control.

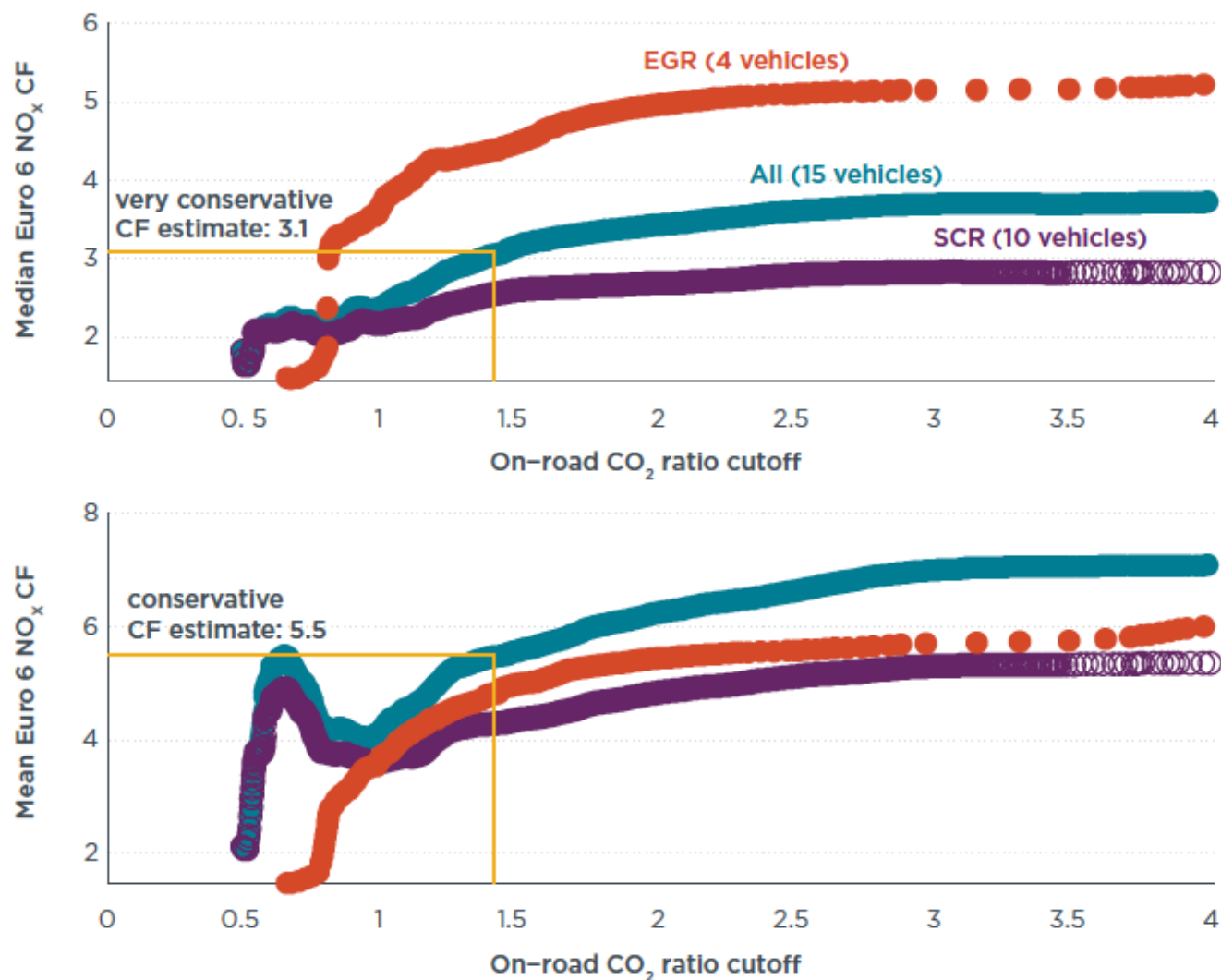
Real Driving Emissions: regulating Diesel passenger car emissions in Europe

- ★ Current challenges: results from Diesel PC meta-study
- ★ Regulatory aspects of on-road emission measurements
- ★ Conclusions

Real Driving Emissions

**Current challenges:
results from Diesel PC
meta-study**

Diesel PC meta-study: Results



Benefits of RDE-LDV Process

- Novel application of on-road tests to pollutant regulations, fundamentally different from chassis dynamometer cycles (more representative of real-world conditions)
- Europe, India are the markets with the largest Diesel share
- Some markets to follow Europe soon (e.g., South Korea)
- Driver of changes in Diesel NO_x aftertreatment; implications on viability of small Diesel PC market

