Department of Engineering Science

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Air pollution from vehicles – legislation and low emissions zones – unintended consequences and nudges

Felix Leach

Scottish Air Quality Database Annual Seminar
22 Jan 2018
Glasgow

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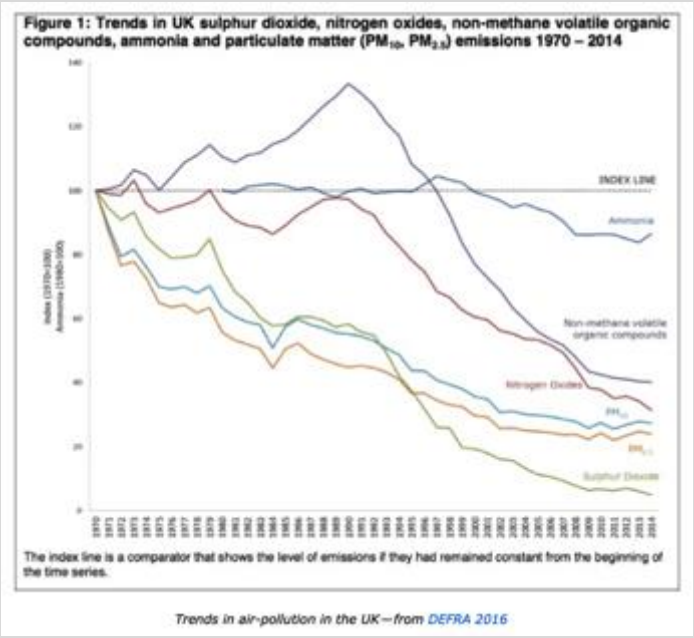
Contents

- Perception and reality
- Emissions legislation & success stories
- Particulates – a forgotten problem?
- LEZs
- Unintended consequences
- Nudges?
- What next?

Perception and reality

UK air quality crisis ?



Trends in air-pollution in the UK—from DEFRA 2016

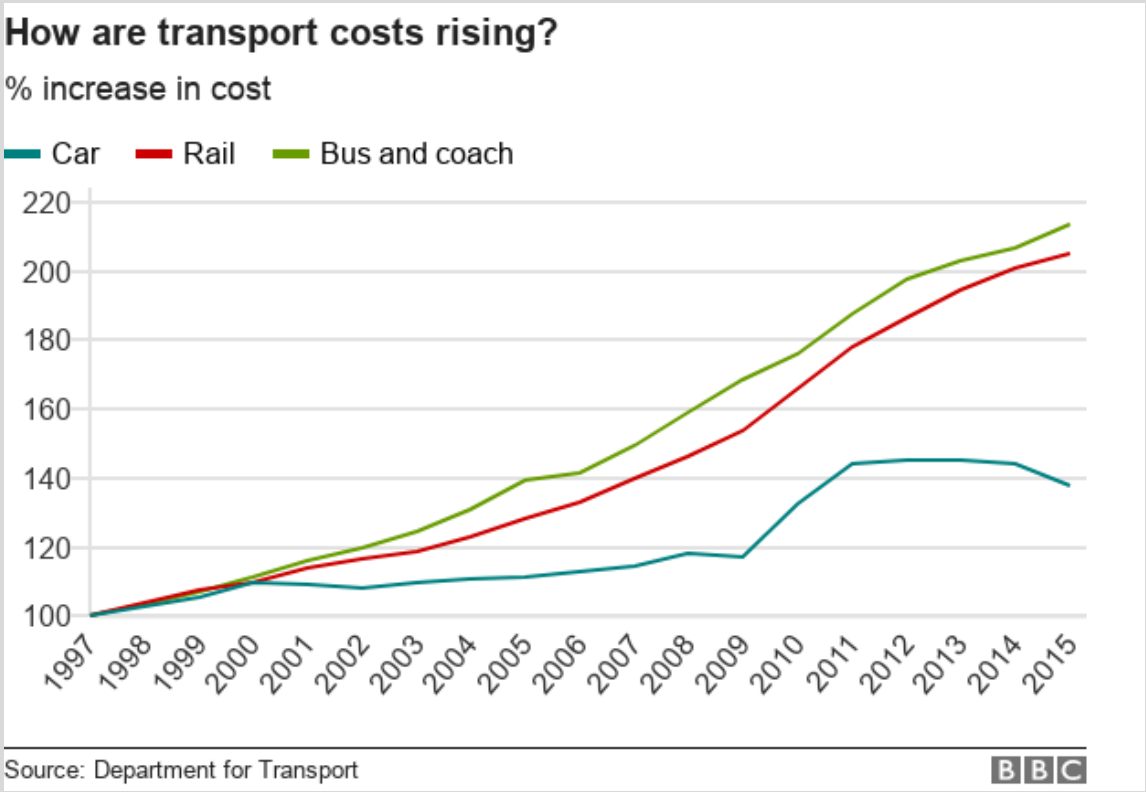
UK Emissions Trends 1970 – 2014 (DEFRA)

- 69% reduction in NO_x
- 72% reduction in PM_{10}
- 76% reduction in $PM_{2.5}$
- 95% reduction in SO_2

- NO_x projection continues steep decline

Perception and reality

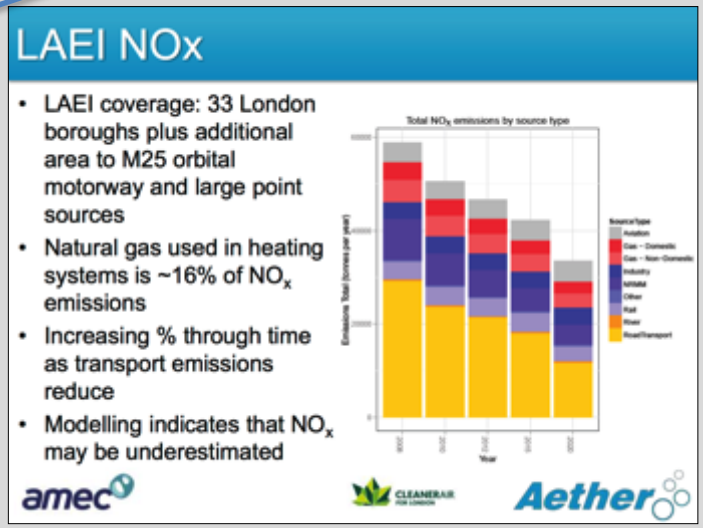
War on the motorist?



Perception and reality

Science behind this figure
https://wintoncentre.maths.cam.ac.uk/news/does-air-pollution-kill-40000-people-each-year-uk

My diesel car is killing me…



NO_x Emissions from Domestic Boilers in London
Katie King
TFEIP Workshop, 12th May 2014

Study suggests domestic boiler contribution may be gross (100%) underprediction

…as is my house

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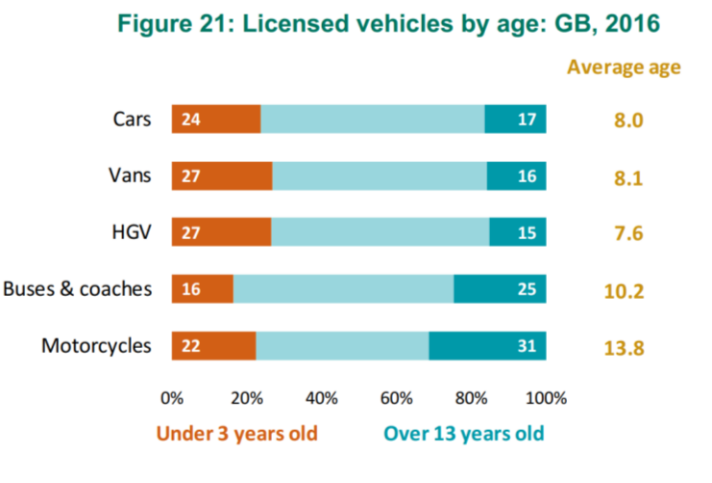
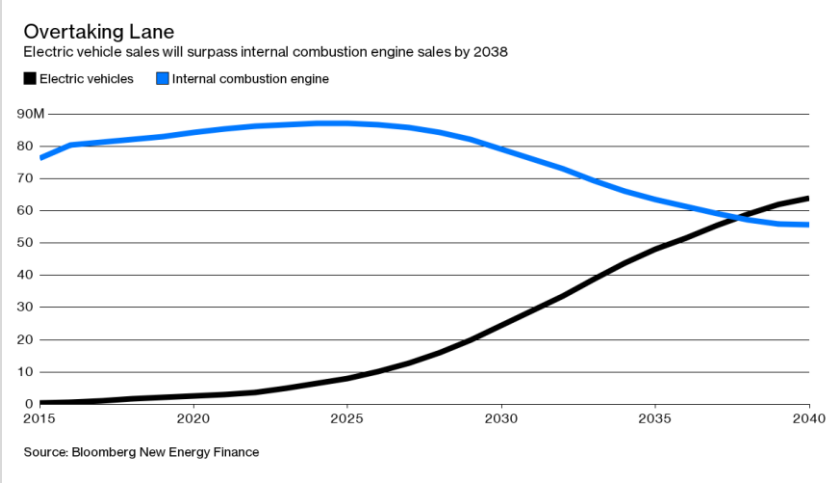
The clock is ticking

- Urban air quality needs to be improved **NOW**
- Fleet renewal important
- **Cost matters**
- EVs will take too long to have a meaningful impact





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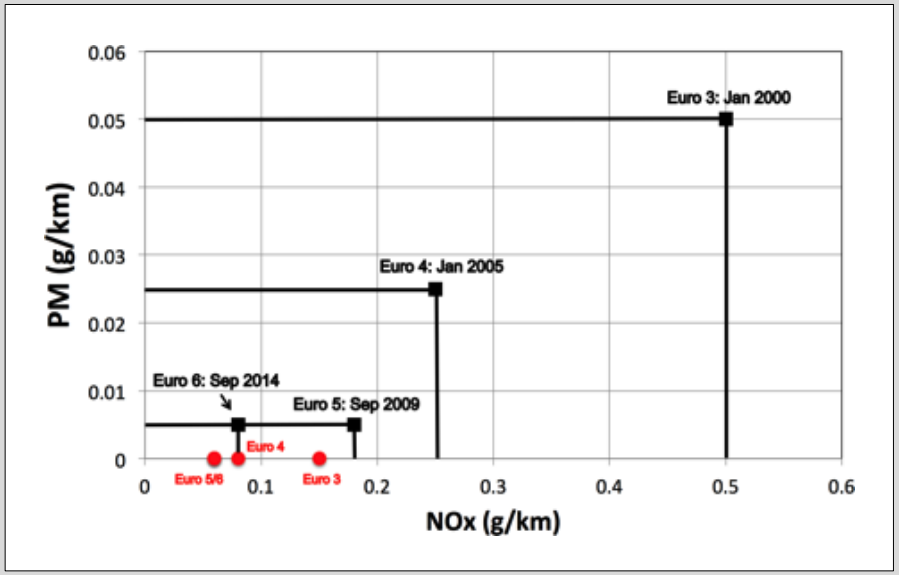
Emissions legislation

Euro 1 (1992)
Public perception of the diesel engine ?



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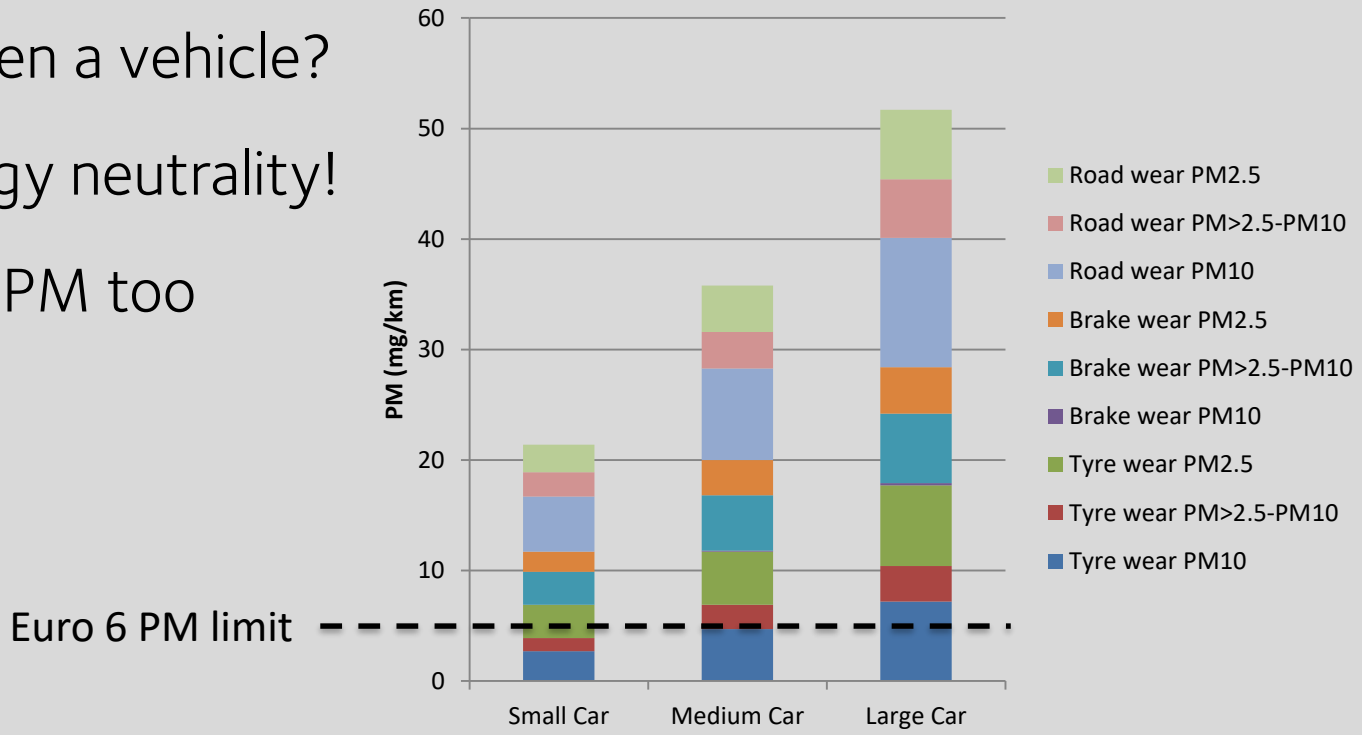
Emissions legislation

- Do I care what emitted the pollution I'm breathing?
- Was it even a vehicle?
- Technology neutrality!
- EVs emit PM too



EEA Report No 21/2016

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Success stories

- 1970s – Pb ➔ unleaded gasoline
- 1980s - S ➔ low sulphur gasoline & diesel
- 1990s – CO ➔ Catalysts

Effectively eliminated

- 2000s – PM ➔ effectively eliminated from diesel
- 2000s – CO_2 ➔ downsizing & biofuels
- 2010s - NO_x ➔ ?

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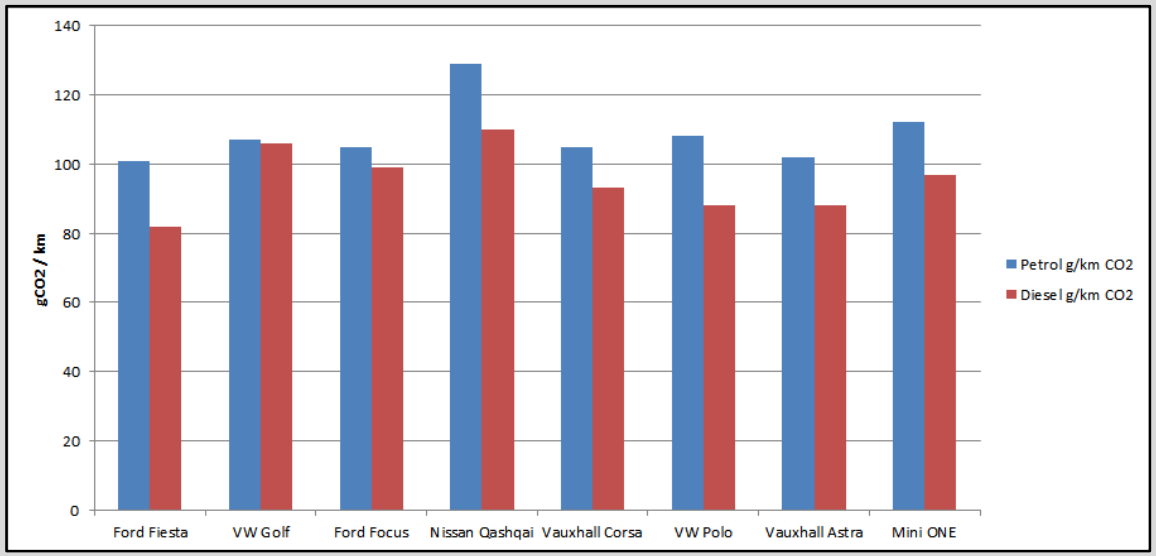
Bandwagons?

- CO_2 ➔ More diesel
- NO_x ➔ Less diesel



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Car Reviews & News

News

CO2 emissions rise amid diesel confusion

Uncertainty over diesel engines has resulted in a rise in average CO2 emissions from cars, according to new figures from the automotive industry

Words by: Erin Baker First published: 5th January 2018

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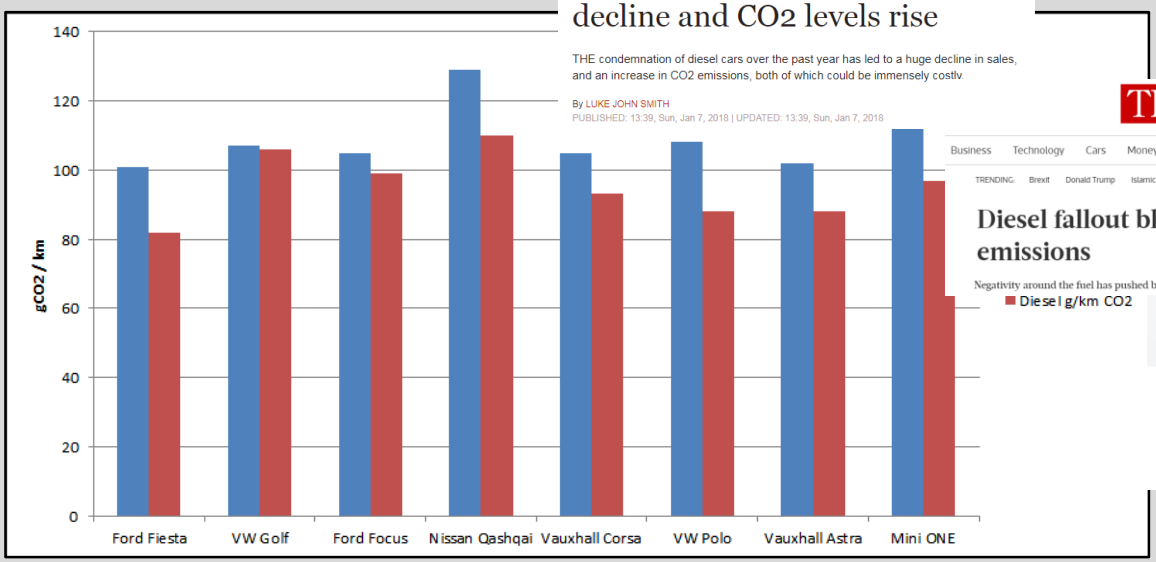
Home > Life & Style > Cars > Diesel car death sees sales decline and CO2 levels rise

Diesel car death sees sales decline and CO2 levels rise

THE condemnation of diesel cars over the past year has led to a huge decline in sales, and an increase in CO2 emissions, both of which could be immensely costly.

By LUKE JOHN SMITH

PUBLISHED: 13:39, Sun, Jan 7, 2018 | UPDATED: 13:39, Sun, Jan 7, 2018



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Diesel fallout blamed for rise in new car CO2 emissions

Negativity around the fuel has pushed buyers towards petrol cars

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CO2 'own goal': Emissions up as new car sales fall

The motor industry says a fall in new diesel sales mainly explains the first rise in CO2 emissions from exhausts in 20 years.

11:08, UK, Friday 05 January 2018

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Particulates – a forgotten problem?

- The smaller the worse
- "Kill" more people than NO_x (29,000 vs 23,500)
- Diesel – effectively removed with DPF from 2011

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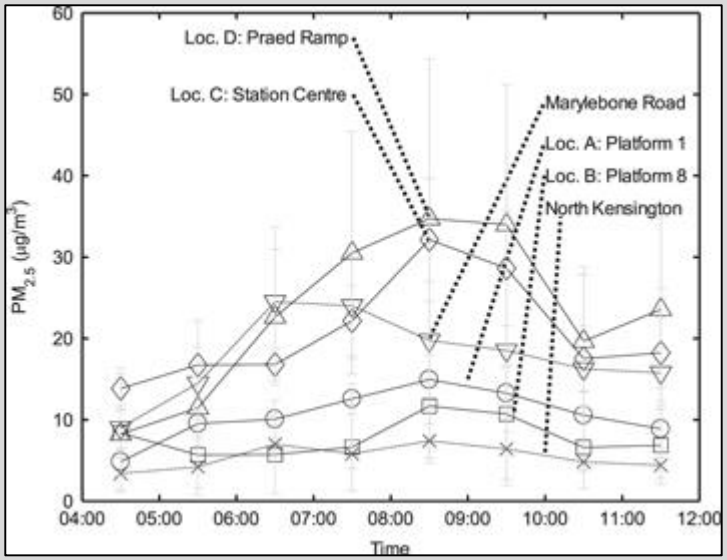
Particulates – a forgotten problem?

- The smaller the worse
- "Kill" more people than NO_x (29,000 vs 23,500)
- Diesel – effectively removed with DPF from 2011

  but…
- Gasoline Direct Injection – good for CO_2 bad for PM
- Emit very small PN (UFPs 10nm and below)
- AQ legislation looks at PM2.5 nearly 1000x bigger

Particulates – multiple sources

- Do I care what emitted the pollution I'm breathing?



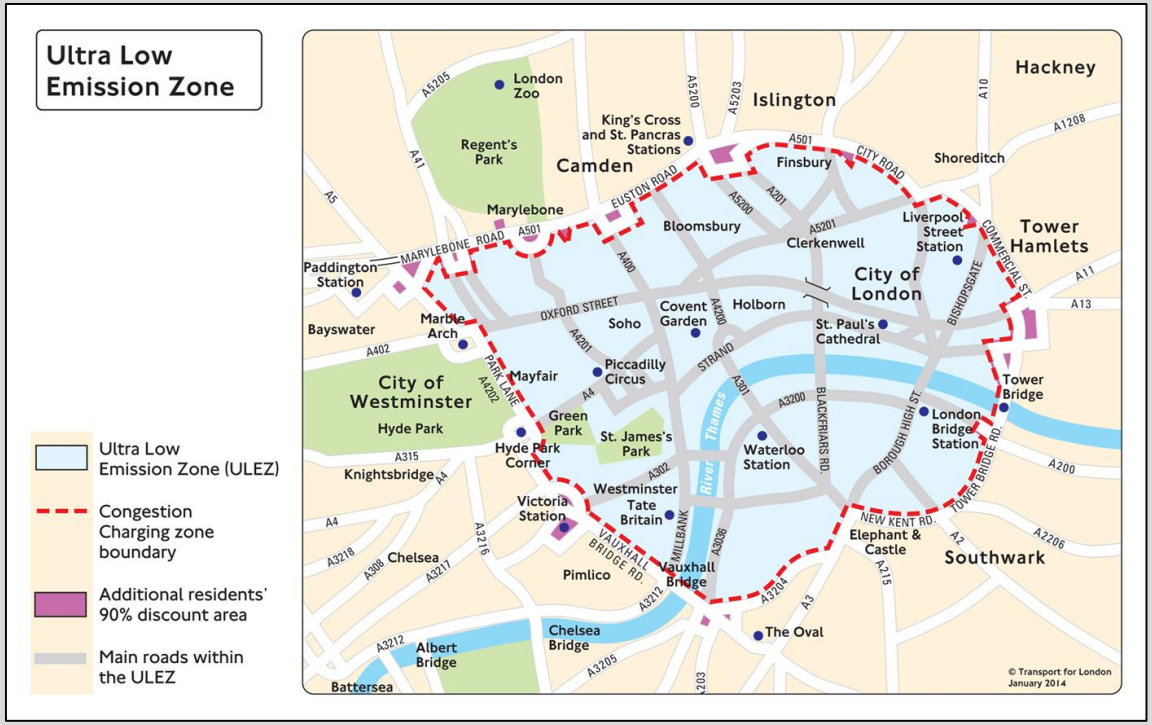
Paddington station (Boies *et al.*)

Highest concentrations of PM not from (unregulated) diesel trains but <u>fast food and smokers</u>

London ULEZ

From 8 Apr 2019

Euro 3 for motorcycles
Euro 4 for petrol
Euro 6 for diesel
Euro VI for lorries & buses

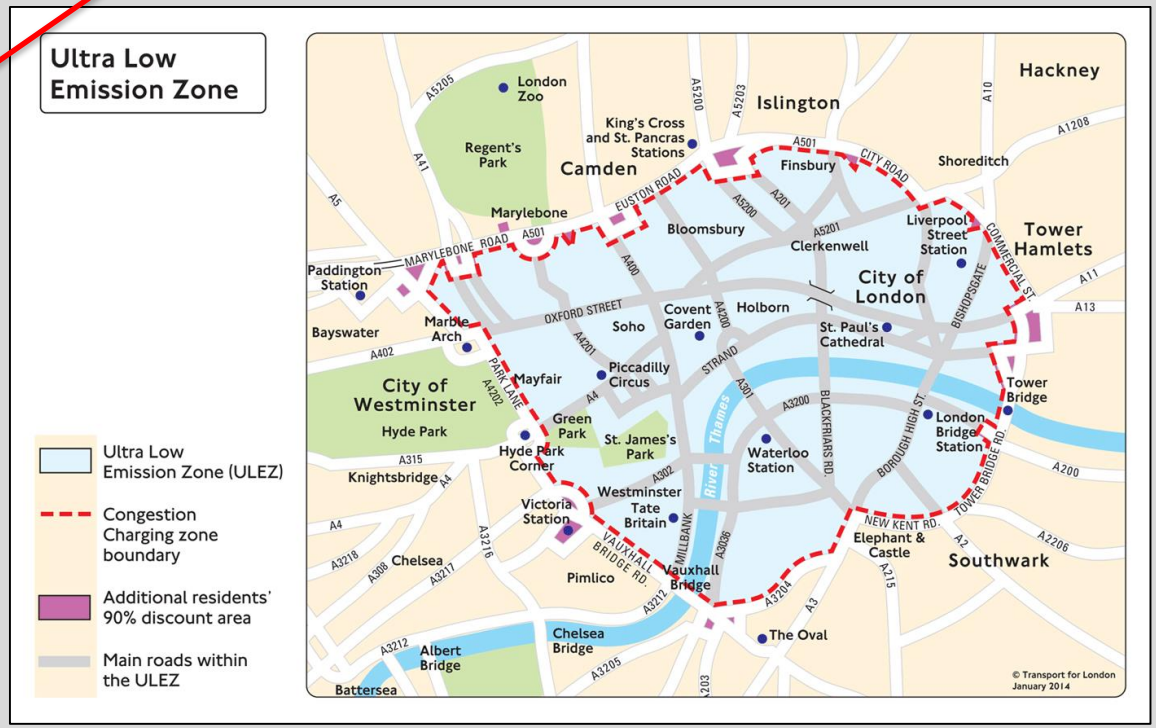


London ULEZ

From 8 Apr 2019

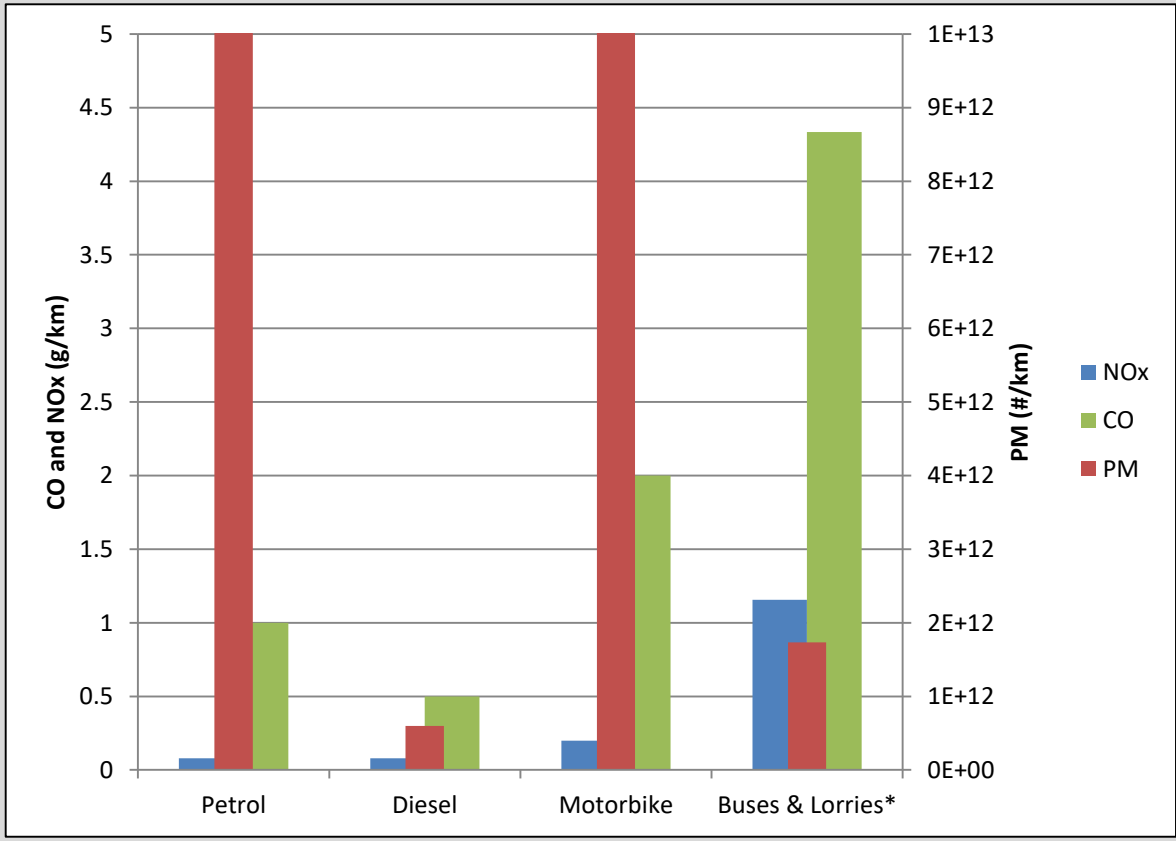
Are these the appropriate technology levels?

Euro 3 for motorcycles
Euro 4 for petrol
Euro 6 for diesel
Euro VI for lorries & buses



London ULEZ

Euro 3 for motorcycles
Euro 4 for petrol
Means:-

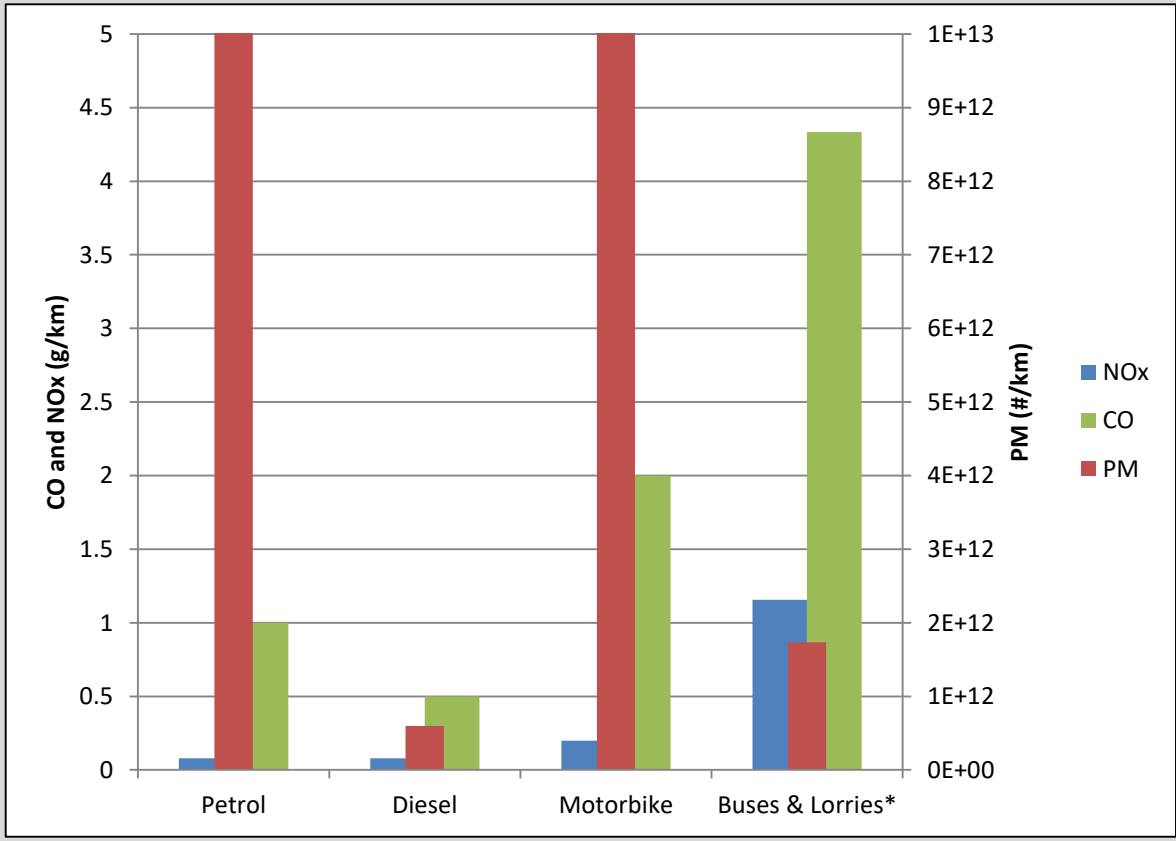


* - different measurement method, assumes Euro VI double decker bus

London ULEZ

Euro 3 for motorcycles
Euro 4 for petrol
Means:-

Unregulated particulates from Petrol and motorbikes



* - different measurement method, assumes Euro VI double decker bus

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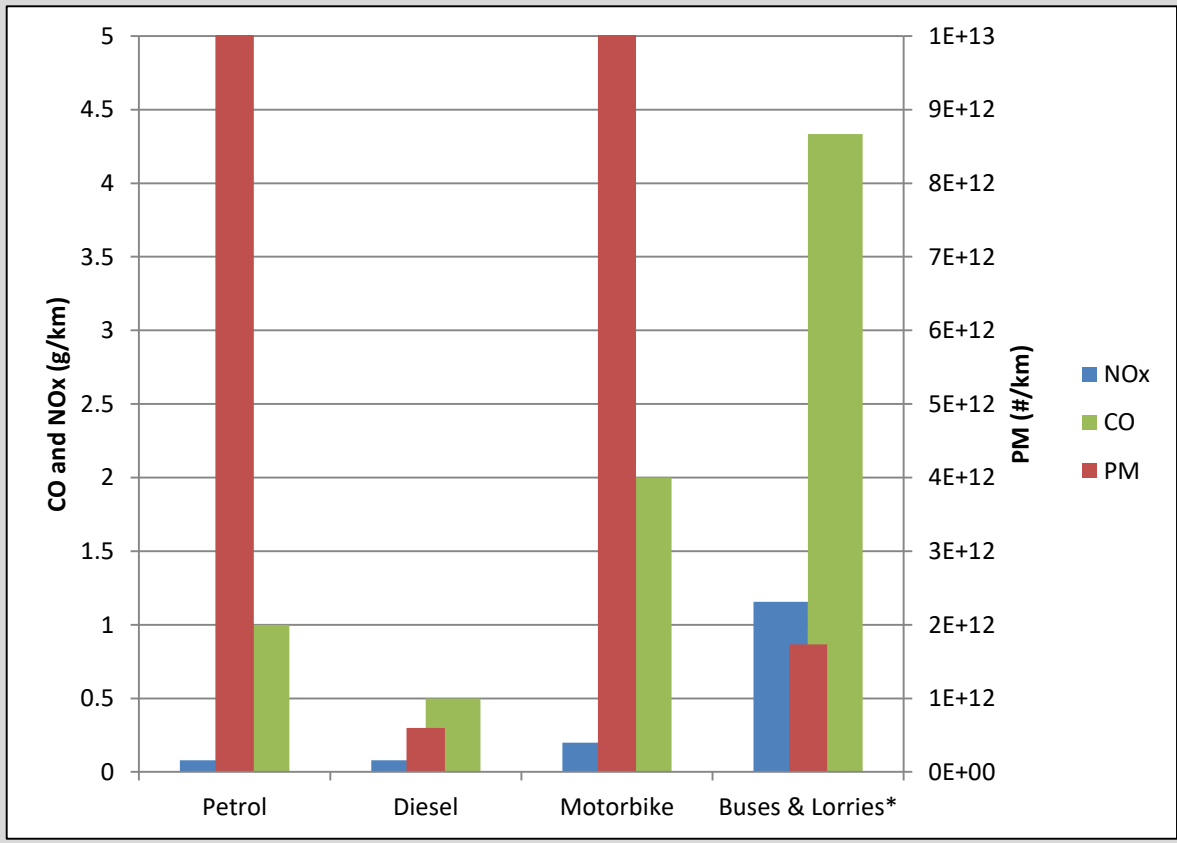
London ULEZ

Unregulated particulates from Petrol and motorbikes

Have we forgotten about PM?



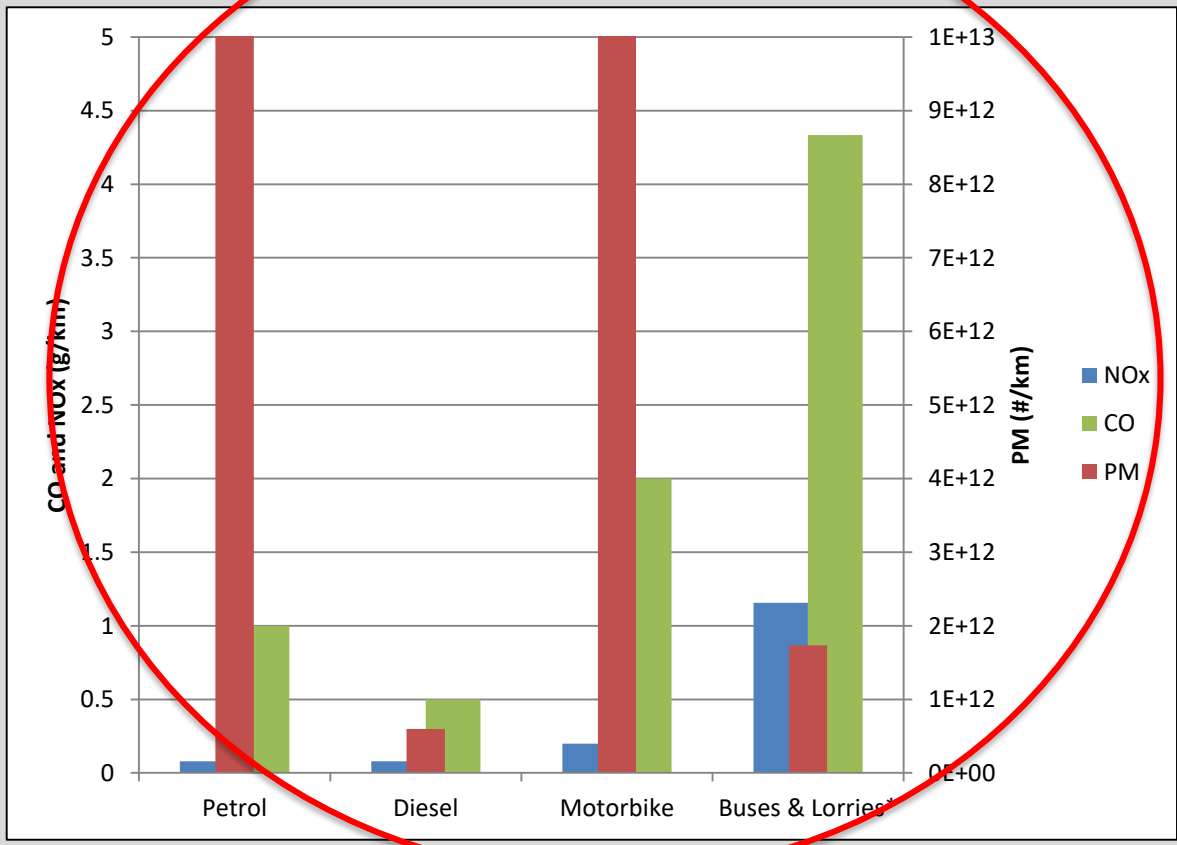
* – different measurement method, assumes Euro VI double decker bus

London ULEZ

Can this really happen?

Unregulated particulates from Petrol and motorbikes

Have we forgotten about PM?



* - different measurement method, assumes Euro VI double decker bus

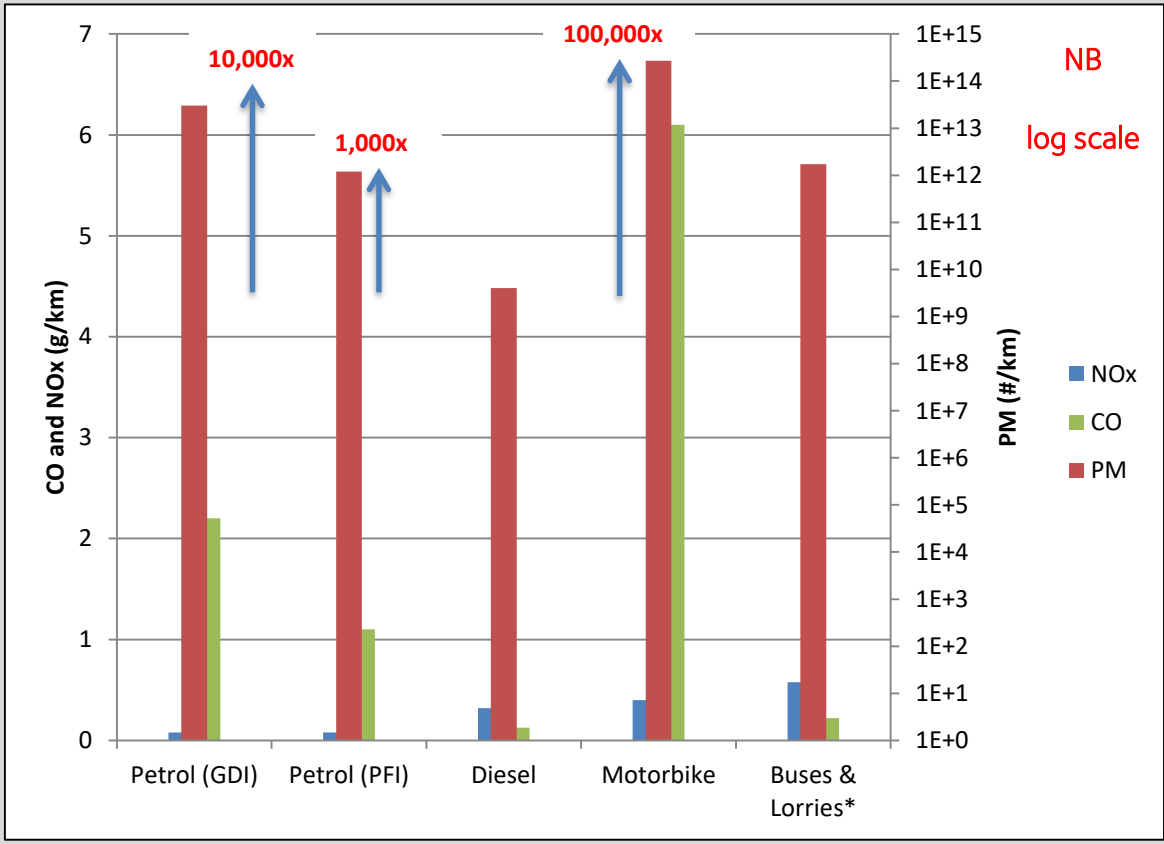
Data from: Braisher 2010-01-0786, TFL In-service emissions performance of Euro 6/VI vehicles, https://doi.org/10.1016/j.scitotenv.2017.11.271, 2009-01-1841, equaindex.com, Particle Emissions of Powered Two Wheelers AECC, 2017-01-0985

London ~~ULEZ~~

YES! – over 1000x more PN from Euro 4 petrol

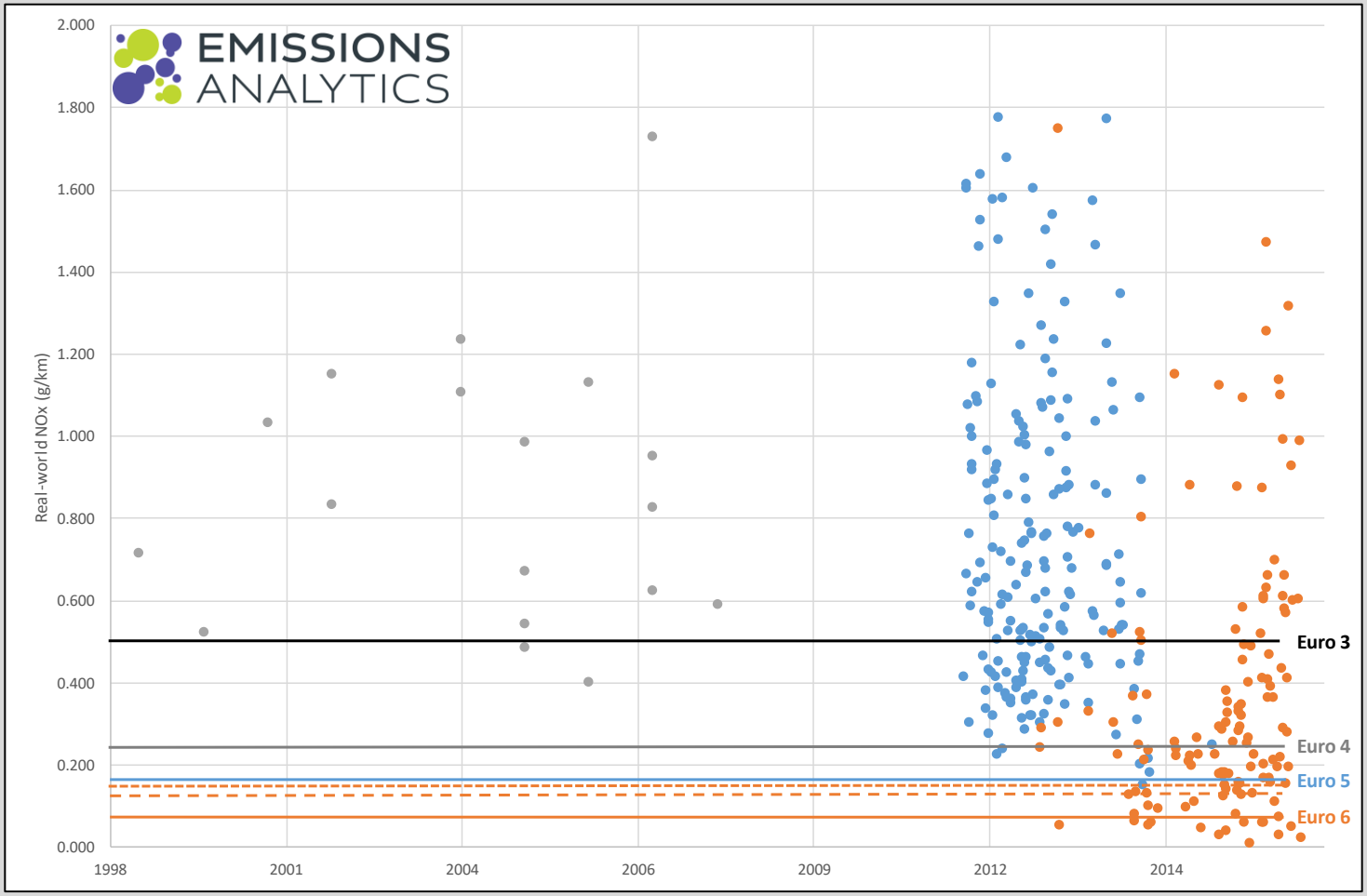
Unregulated particulates from Petrol and motorbikes

Have we forgotten about PM?



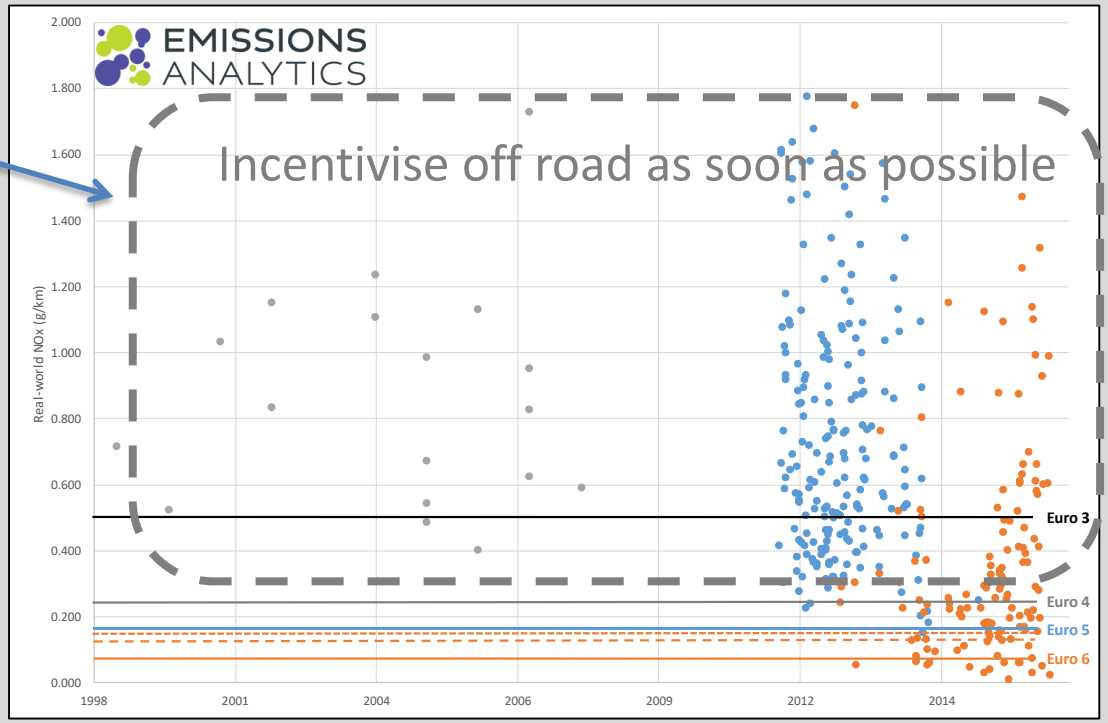
* – different measurement method, assumes Euro VI double decker bus

Legislation is not reducing real emissions?



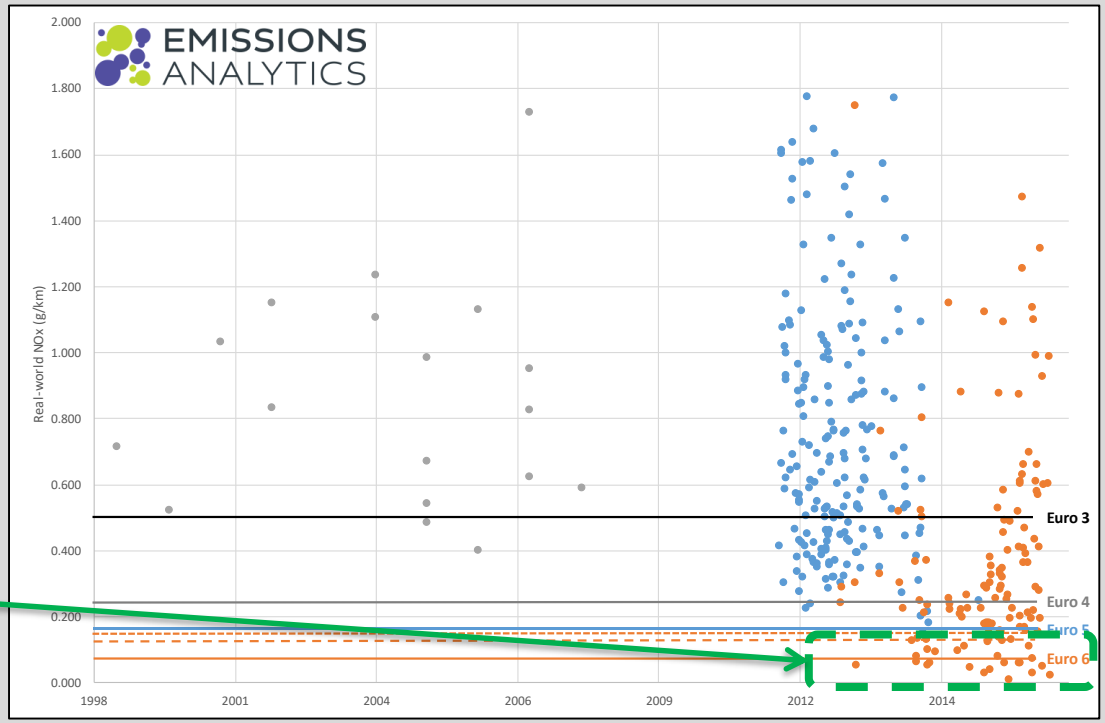
Legislation is not reducing real emissions?

Policy opportunity to remove these vehicles?



Legislation is not reducing real emissions?

What are these vehicles?



Clean diesels?

EQUA® INDEX Aq AIR QUALITY

Clear filters

Show 100 entries

Search:

Make	Model	Fuel Type	Model Year	Engine Size L	Power Bhp	Drive Train	Driven Wheels	Transmission	Euro Stage	EQUA Aq Rating
		Diesel								A
Audi	A5	Diesel	2014	2.0	161	FWD	2	Manual	Euro 6	A
Audi	Q2	Diesel	2017	2.0	148	4WD	4	Automatic	Euro 6	A+
BMW	3 Series	Diesel	2013	2.0	181	RWD	2	Manual	Euro 6	A+
BMW	5 Series	Diesel	2016	2.0	187	RWD	2	Automatic	Euro 6	A+
BMW	5 Series	Diesel	2017	3.0	261	RWD	2	Automatic	Euro 6	A+
BMW	7 Series	Diesel	2016	3.0	316	4WD	4	Automatic	Euro 6	A+
BMW	X3	Diesel	2018	3.0	261	4WD	4	Automatic	Euro 6	A+
Mercedes-Benz	C Class	Diesel	2017	2.1	201	RWD	2	Automatic	Euro 6	A
Mercedes-Benz	E Class	Diesel	2017	2.0	191	RWD	2	Automatic	Euro 6	A+
MINI	Hatch	Diesel	2015	2.0	168	FWD	2	Manual	Euro 6	A
Porsche	Panamera	Diesel	2017	4.0	415	4WD	4	Automatic	Euro 6	A+
SEAT	Alhambra	Diesel	2016	2.0	148	FWD	2	Manual	Euro 6	A+
Volkswagen	Golf SV	Diesel	2015	2.0	148	FWD	2	Automatic	Euro 6	A+
Volkswagen	Passat	Diesel	2016	1.6	118	FWD	2	Manual	Euro 6	A+
Volkswagen	Scirocco	Diesel	2015	2.0	148	FWD	2	Manual	Euro 6	A
Volkswagen	Tiguan	Diesel	2016	2.0	148	4WD	4	Automatic	Euro 6	A
Volkswagen	Tiguan	Diesel	2017	2.0	237	4WD	4	Automatic	Euro 6	A
Volkswagen	Touran	Diesel	2016	1.6	108	FWD	2	Manual	Euro 6	A+

Showing 1 to 18 of 18 entries (filtered from 640 total entries)

Clean diesels?

Big, heavy, expensive cars

Big, powerful engines

All are Euro 6

1/3 are VWs…

All will have near zero PM

Make	Model	Fuel Type	Model Year	Engine Size L	Power Bhp	Drive Train	Driven Wheels	Transmission	Euro Stage
		Diesel							
Audi	A5	Diesel	2014	2.0	161	FWD	2	Manual	Euro 6
Audi	Q2	Diesel	2017	2.0	148	4WD	4	Automatic	Euro 6
BMW	3 Series	Diesel	2013	2.0	181	RWD	2	Manual	Euro 6
BMW	5 Series	Diesel	2016	2.0	187	RWD	2	Automatic	Euro 6
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MINI	Hatch	Diesel	2015	2.0	168	FWD	2	Manual	Euro 6
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Volkswagen	Golf SV	Diesel	2015	2.0	148	FWD	2	Automatic	Euro 6
Volkswagen	Passat	Diesel	2016	1.6	118	FWD	2	Manual	Euro 6
Volkswagen	Scirocco	Diesel	2015	2.0	148	FWD	2	Manual	Euro 6
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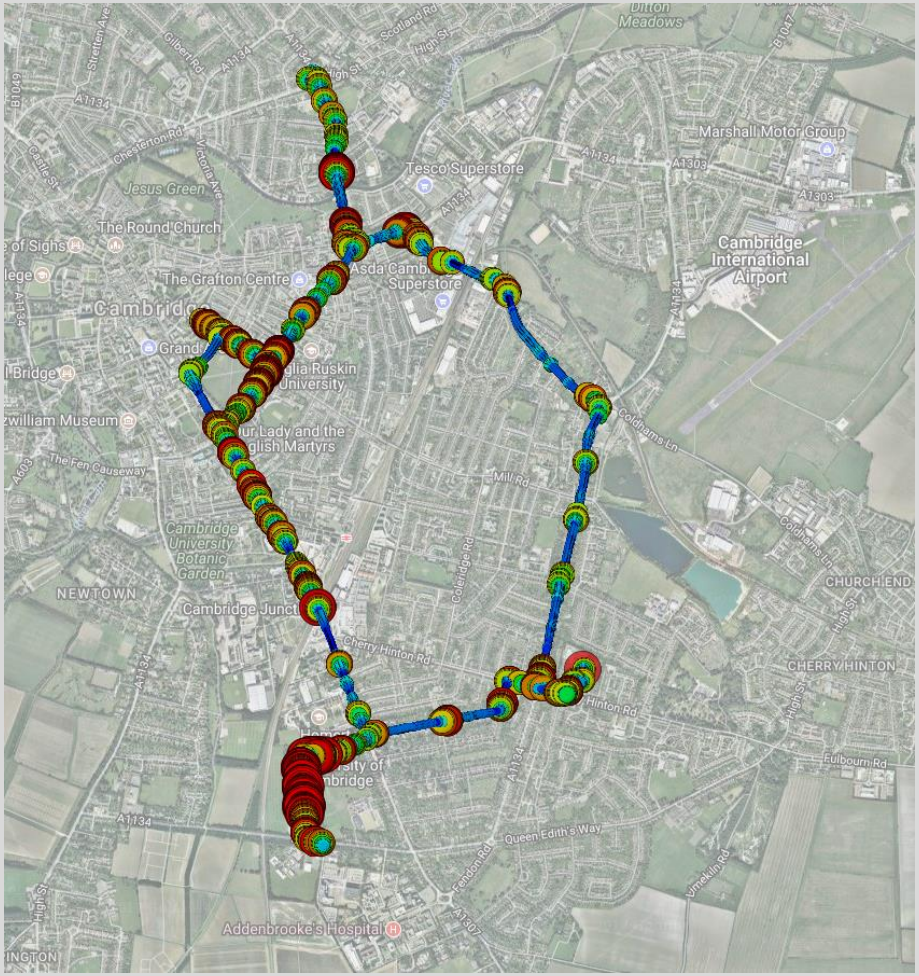
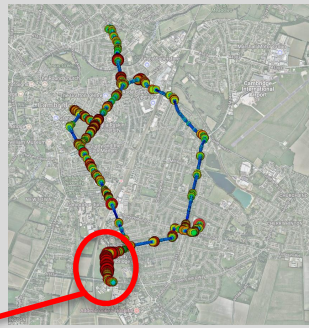
Showing 1 to 18 of 18 entries (filtered from 640 total entries)

Unintended consequences?



Transient RDE (Cambridge)

Unintended consequences



Transient RDE
(Cambridge)

Unintended consequences?

Speed bump (PHEV)

Speed bump (PHEV)

Plugin hybrid emits ~1km worth of NO_x per speed bump

Unintended consequences?

- Catalyst – ~300°C
- Engine off >2 mins – SCR temp ➔ ~ambient
  - ~200s to get back to temp
- Assume 30s at bus stop – SCR temp drop by ~85°C
  - ~50s to get back to temp

Unintended consequences?

- Engine off >2 mins – SC
  - ~200s to get back to
- Assume 30s at bus stop – SCR temp drop by ~85 °C
  - ~50s to get back to temp

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Unintended consequences?

- Engine off >2 mins – SC
  - ~200s to get back to
- Assume 30s at bus stop – SCR temp drop by ~85 °C
  - ~50s to get back to temp ➔ NO_x "puff" at bus stop

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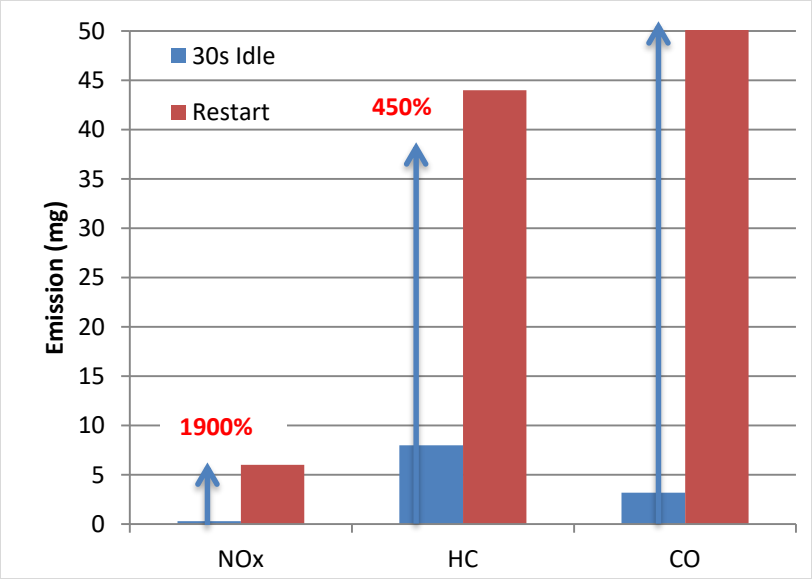
Unintended consequences?

- 2011 Ford Fusion petrol



Unintended consequences?

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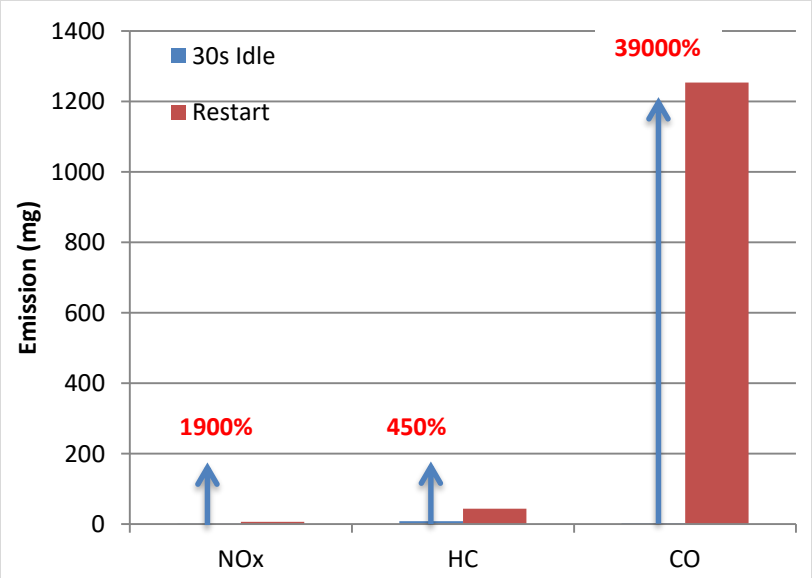
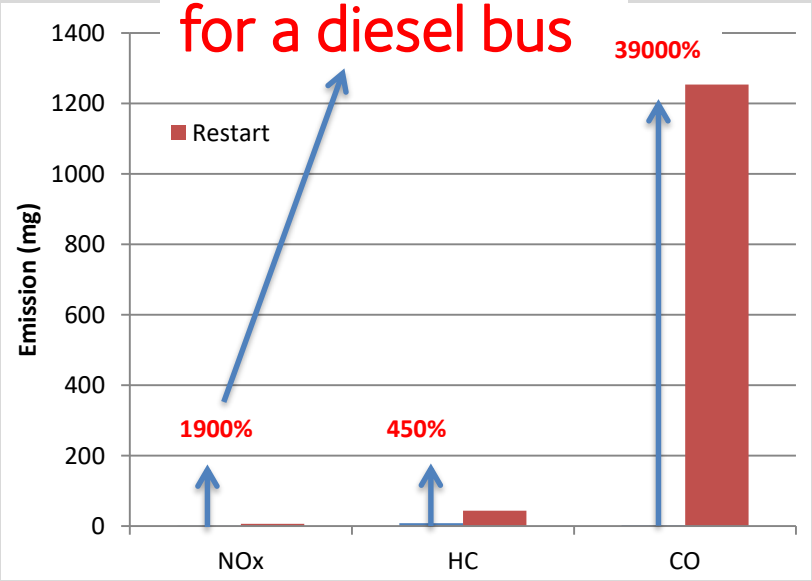


	HC	NOx	CO
'Hot' restart	2.75 mins	10 mins	3.3 hrs
Cold restart	11.9 mins	6.3 hrs	7.7 hrs

Unintended consequences?

- 2011 Ford Fusion petrol

NO_x will be MUCH WORSE for a diesel bus



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Unintended consequences?

- CO_2 focus (2000s)
  - More diesels
  - More NO_x

➔

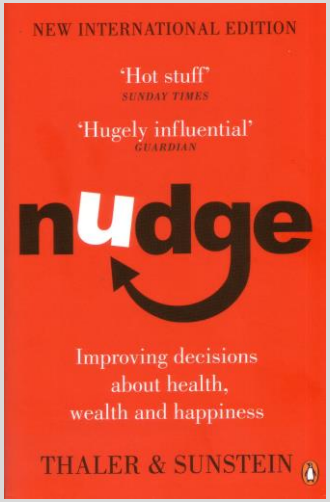
- NO_x focus (2010s)
  - Fewer diesels
  - More CO_2

- Road geography / speed bumps?
- Buses with stop/start / hybrid buses
- Hybrids / PHEVs
  - Turning on engines in city centres?

Nudges

"arranging choice architecture such that individual's freedom of choice is preserved"

- Encourage change in behaviour



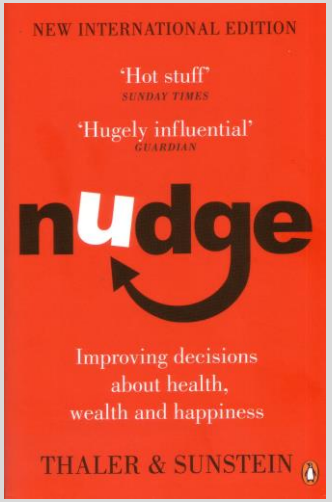
Nudges

"arranging choice architecture such that individual's freedom of choice is preserved"

- Encourage change in behaviour
- Report NO_x, PM, and CO_2 emissions with road tax

Skoda Citigo 2014 petrol

NO_x	PM	CO_2
C	A	B
Bottom 2/3	Top 10%	Top 20%
😕	😀	🙂



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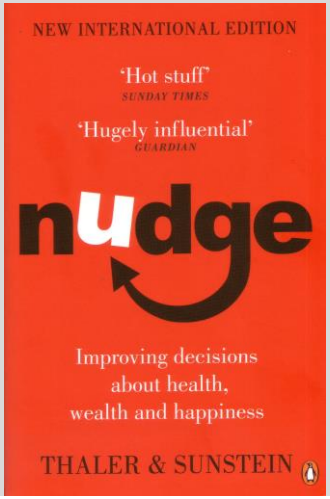
Nudges

"arranging choice architecture such that individual's freedom of choice is preserved"

- Encourage change in behaviour
- Oblige local authorities to consider pollution in LEZs



The Public Sector Equality Duty (PSED) requires organisations to consider the potential and actual impact on equality of all their policies, procedures, decisions, informal practices, etc.

Agenda

1. Minutes of the meeting of [redacted]
2. Matters arising

6. Equality issues

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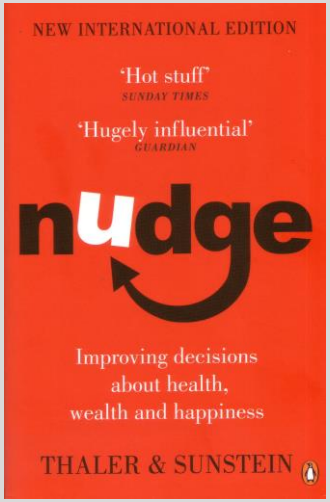
Nudges

"arranging choice architecture such that individual's freedom of choice is preserved"

- Encourage change in behaviour
- Oblige local authorities to consider pollution in LEZs



Council Meeting

Agenda

1. Minutes of previous meeting
2. Matters arising
3. Buying new coal powered car
4. Installation of new speed bumps outside school
5. Installation of engine stop signs at bus stops
6. Air pollution issues
7. Any other business

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Nudges

- Enforce emissions recalls #dieselgate
- Report emissions with road tax
- Public Sector Air Pollution Duty?
- Journey emissions?

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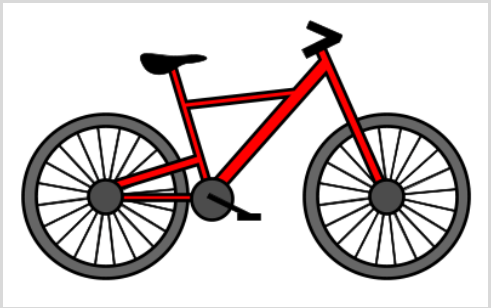
Smart (and not so smart) solutions

- PHEVs with GPS? ➔ Save EV mode for LEZs
- Rail electrification
- Modal shifts
- Encourage ZEVs



Further ahead

- Electric road – Sweden

- Battery trams – Seville

- Trolley buses ➔ off-wire capability

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Conclusions

- Crisis?
- Time matters
  - EVs won't help ➔ Technology neutrality
- NO_x? What about PM and CO_2?
- London ~~ULE~~EZ
- Not an Engineering **Science** problem – **COST** problem
- Not just vehicle factors – speed bumps!
- A number of cheap & simple solutions exist to improve things quickly

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Questions?

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Health effects

HARVARD T.H. CHAN SCHOOL OF PUBLIC HEALTH

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News

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Short-term exposure to low levels of air pollution linked with premature death among U.S. seniors

For immediate release: December 26, 2017

Boston, MA – Short-term exposures to fine particulate air pollution and ozone—even at levels well below current national safety standards—were linked to higher risk of premature death among the elderly in the U.S. according to a new study from Harvard T.H. Chan School of Public Health.

The risk was even higher among elderly who were low-income, female, or Black.

The study was published December 26, 2017 in the *Journal of the American Medical Association (JAMA)*.

"This the most comprehensive study of short-term exposure to pollution and mortality to date," said Francesca Dominici, professor of biostatistics, co-director of the Harvard Data Science Initiative, and senior author of the study. "We found that the mortality rate increases almost linearly as air pollution increases. Any level of air pollution, no matter how low, is harmful to human health."

Studies have shown that fine inhalable particles ($PM_{2.5}$) and ozone—particularly 'warm-season ozone,' which occurs from April to September—are linked with increased mortality rates. Under the National Ambient Air Quality Standards (NAAQS) set by the U.S. Environmental Protection Agency (EPA), long-term exposures to $PM_{2.5}$ are considered safe if they average 12 micrograms per cubic meter of air (12 $\mu g/m^3$) or less per day over the course of a year. The 24-hour standard is 35 $\mu g/m^3$. For warm-season ozone there is no

Health effects

- This study is not about NO_x (directly)
- PM and Ozone

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Vehicle emissions control

- Passive vs active
- Temperature matters
  - Ecatalysts?
  - Hybrids?
- All add cost and efficiency penalties

Diesel	Pollutant	
Vehicle calibration	All	Active
DOC	HC, CO, NO	Passive
DPF	PM	Passive
EGR	NOx	Active
~~LNT~~	NOx	Passive
SCR	NOx	Active
Gasoline	**Pollutant**	
Vehicle calibration	All	Active
TWC	HC, CO, NOx	Passive
GPF	PM	Passive

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Emissions legislation

Different for gasoline and diesel…

Unregulated regions…

Different for different types of gasoline

EVs unregulated…

Diesel	Date	CO	THC	NMHC	NO_x	$HC+NO_x$	PM	PN [#/km]
Euro 1	1992	2.72	-	-	-	0.97	0.14	-
Euro 2	1996	1.0	-	-	-	0.7	0.08	-
Euro 3	2000	0.66	-	-	0.50	0.56	0.05	-
Euro 4	2005	0.50	-	-	0.25	0.30	0.025	-
Euro 5a	2009	0.50	-	-	0.180	0.230	0.005	-
Euro 5b	2011	0.50	-	-	0.180	0.230	0.005	6×10^{11}
Euro 6	2014	0.50	-	-	0.080	0.170	0.005	6×10^{11}
Gasoline								
Euro 1	1992	2.72 (3.16)	-	-	-	0.97 (1.13)	-	-
Euro 2	1996	2.2	-	-	-	0.5	-	-
Euro 3	2000	2.3	0.20	-	0.15	-	-	-
Euro 4	2005	1.0	0.10	-	0.08	-	-	-
Euro 5	2009	1.0	0.10	0.068	0.060	-	0.005*	-
Euro 6	2014	1.0	0.10	0.068	0.060	-	0.005*	6×10^{11}**

* Applies only to vehicles with direct injection engines
** 6×10^{12}/km within first three years from Euro 6 effective dates

RDE Summary

- Legislation is not reducing real emissions
- Lowest NO_x diesels are big, expensive vehicles
- Thanks to Nick Molden – Emissions Analytics

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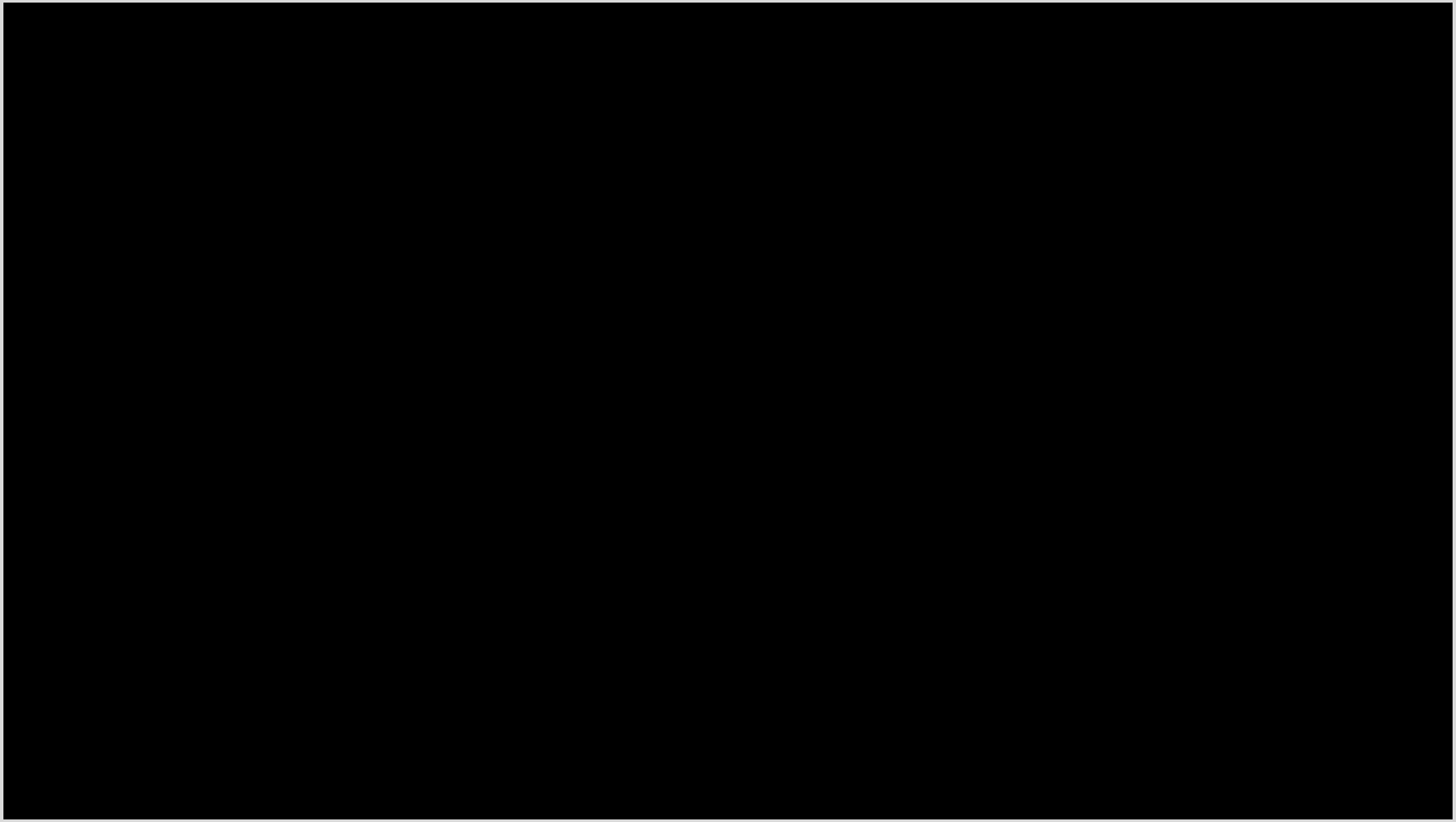
Causes of emissions

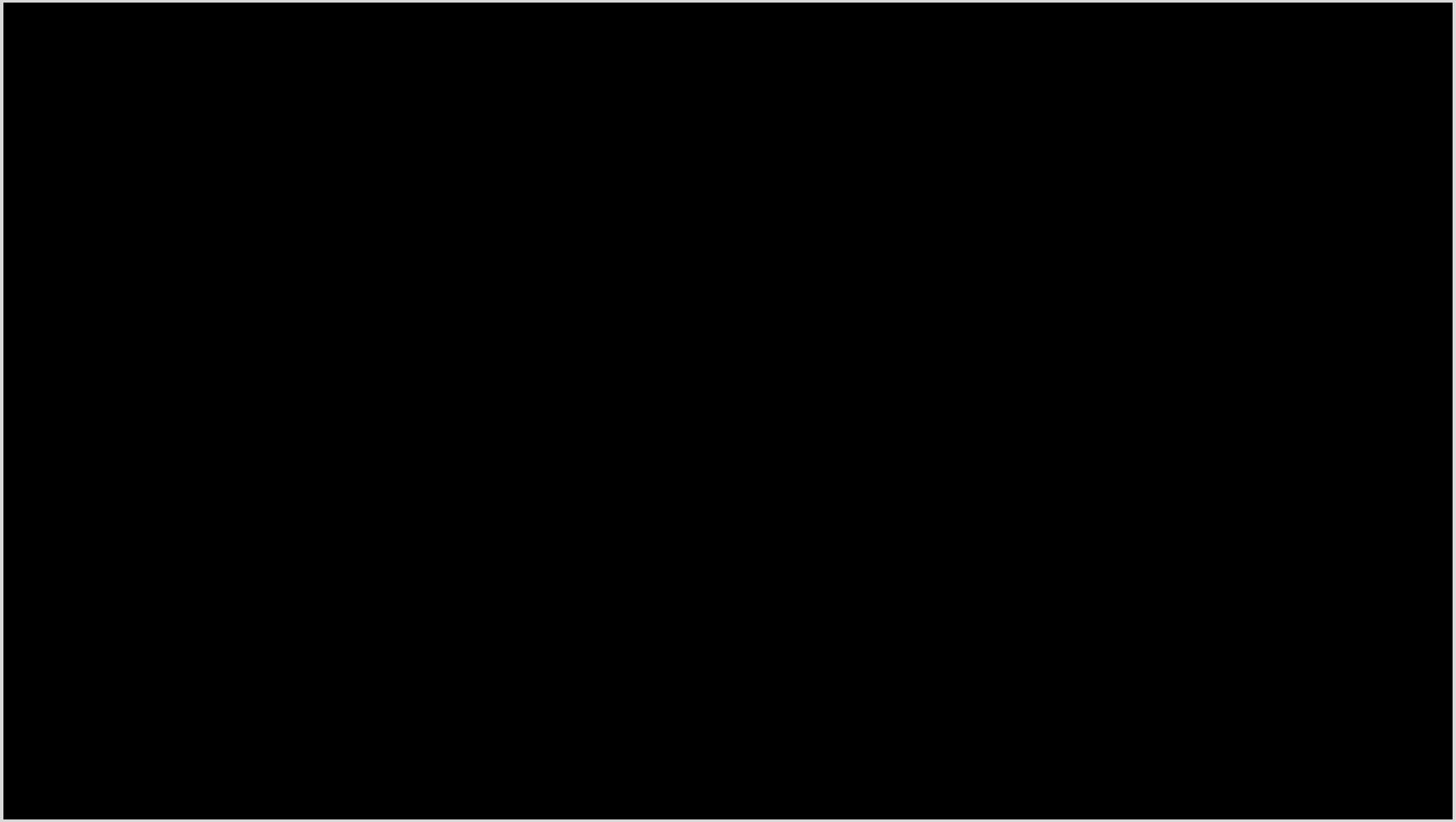
- Cold starts
- Vehicle transients
  - Dominate in urban environments
  - Vehicle cals and aftertreatment can't keep up
- Standard RDE will spot this, but with poor resolution

Speedbump (gasoline)

Joining the M1 (Euro 5 diesel)



PHEV at Swiss Cottage (London)



Transient RDE Summary

- Aggressive transients lead to high emissions
  - Speed bumps – often in residential areas and SCHOOLS
  - Joining fast traffic
  - Difficult road layouts
- Euro 5 Diesel emits 4.5g NOx joining M1
  - Euro 5 limit is 0.28g/km
- PHEV emits ~1km worth of NO_x per speed bump and in complicated road layouts
- Thanks to Mark Peckham - Cambustion