Impacts and Mitigation of Excess Diesel NOx Emissions in 11 Major Vehicle Markets

Global Webinar

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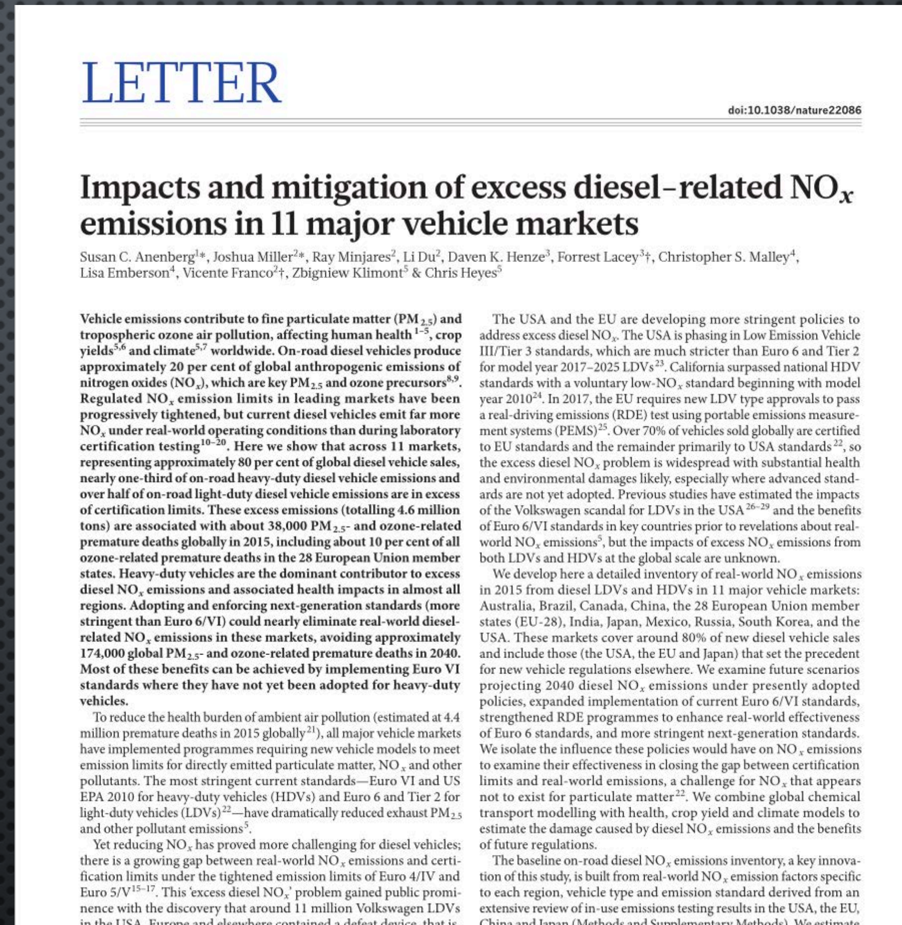

LETTER

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Impacts and mitigation of excess diesel-related NO_x emissions in 11 major vehicle markets

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Vehicle emissions contribute to fine particulate matter ($PM_{2.5}$) and tropospheric ozone air pollution, affecting human health[1–5], crop yields[5,6] and climate[5,7] worldwide. On-road diesel vehicles produce approximately 20 per cent of global anthropogenic emissions of nitrogen oxides (NO_x), which are key $PM_{2.5}$ and ozone precursors[8,9]. Regulated NO_x emission limits in leading markets have been progressively tightened, but current diesel vehicles emit far more NO_x under real-world operating conditions than during laboratory certification testing[10–20]. Here we show that across 11 markets, representing approximately 80 per cent of global diesel vehicle sales, nearly one-third of on-road heavy-duty diesel vehicle emissions and over half of on-road light-duty diesel vehicle emissions are in excess of certification limits. These excess emissions (totalling 4.6 million tons) are associated with about 38,000 $PM_{2.5}$- and ozone-related premature deaths globally in 2015, including about 10 per cent of all ozone-related premature deaths in the 28 European Union member states. Heavy-duty vehicles are the dominant contributor to excess diesel NO_x emissions and associated health impacts in almost all regions. Adopting and enforcing next-generation standards (more stringent than Euro 6/VI) could nearly eliminate real-world diesel-related NO_x emissions in these markets, avoiding approximately 174,000 global $PM_{2.5}$- and ozone-related premature deaths in 2040. Most of these benefits can be achieved by implementing Euro VI standards where they have not yet been adopted for heavy-duty vehicles.

To reduce the health burden of ambient air pollution (estimated at 4.4 million premature deaths in 2015 globally[21]), all major vehicle markets have implemented programmes requiring new vehicle models to meet emission limits for directly emitted particulate matter, NO_x and other pollutants. The most stringent current standards—Euro VI and US EPA 2010 for heavy-duty vehicles (HDVs) and Euro 6 and Tier 2 for light-duty vehicles (LDVs)[22]—have dramatically reduced exhaust $PM_{2.5}$ and other pollutant emissions[5].

Yet reducing NO_x has proved more challenging for diesel vehicles; there is a growing gap between real-world NO_x emissions and certification limits under the tightened emission limits of Euro 4/IV and Euro 5/V[15–17]. This 'excess diesel NO_x' problem gained public prominence with the discovery that around 11 million Volkswagen LDVs in the USA, Europe and elsewhere contained a defeat device, that is,

The USA and the EU are developing more stringent policies to address excess diesel NO_x. The USA is phasing in Low Emission Vehicle III/Tier 3 standards, which are much stricter than Euro 6 and Tier 2 for model year 2017–2025 LDVs[23]. California surpassed national HDV standards with a voluntary low-NO_x standard beginning with model year 2010[24]. In 2017, the EU requires new LDV type approvals to pass a real-driving emissions (RDE) test using portable emissions measurement systems (PEMS)[25]. Over 70% of vehicles sold globally are certified to EU standards and the remainder primarily to USA standards[22], so the excess diesel NO_x problem is widespread with substantial health and environmental damages likely, especially where advanced standards are not yet adopted. Previous studies have estimated the impacts of the Volkswagen scandal for LDVs in the USA[26–29] and the benefits of Euro 6/VI standards in key countries prior to revelations about real-world NO_x emissions[5], but the impacts of excess NO_x emissions from both LDVs and HDVs at the global scale are unknown.

We develop here a detailed inventory of real-world NO_x emissions in 2015 from diesel LDVs and HDVs in 11 major vehicle markets: Australia, Brazil, Canada, China, the 28 European Union member states (EU-28), India, Japan, Mexico, Russia, South Korea, and the USA. These markets cover around 80% of new diesel vehicle sales and include those (the USA, the EU and Japan) that set the precedent for new vehicle regulations elsewhere. We examine future scenarios projecting 2040 diesel NO_x emissions under presently adopted policies, expanded implementation of current Euro 6/VI standards, strengthened RDE programmes to enhance real-world effectiveness of Euro 6 standards, and more stringent next-generation standards. We isolate the influence these policies would have on NO_x emissions to examine their effectiveness in closing the gap between certification limits and real-world emissions, a challenge for NO_x that appears not to exist for particulate matter[22]. We combine global chemical transport modelling with health, crop yield and climate models to estimate the damage caused by diesel NO_x emissions and the benefits of future regulations.

The baseline on-road diesel NO_x emissions inventory, a key innovation of this study, is built from real-world NO_x emission factors specific to each region, vehicle type and emission standard derived from an extensive review of in-use emissions testing results in the USA, the EU, China and Japan (Methods and Supplementary Methods). We estimate

Anenberg, S. C., Miller, J., Minjares, R., Du, L., Henze, D. K., Lacey, F., et al. (2017). Impacts and mitigation of excess diesel-related NOx emissions in 11 major vehicle markets. *Nature*, *545*(7655), 467–471. http://doi.org/10.1038/nature22086

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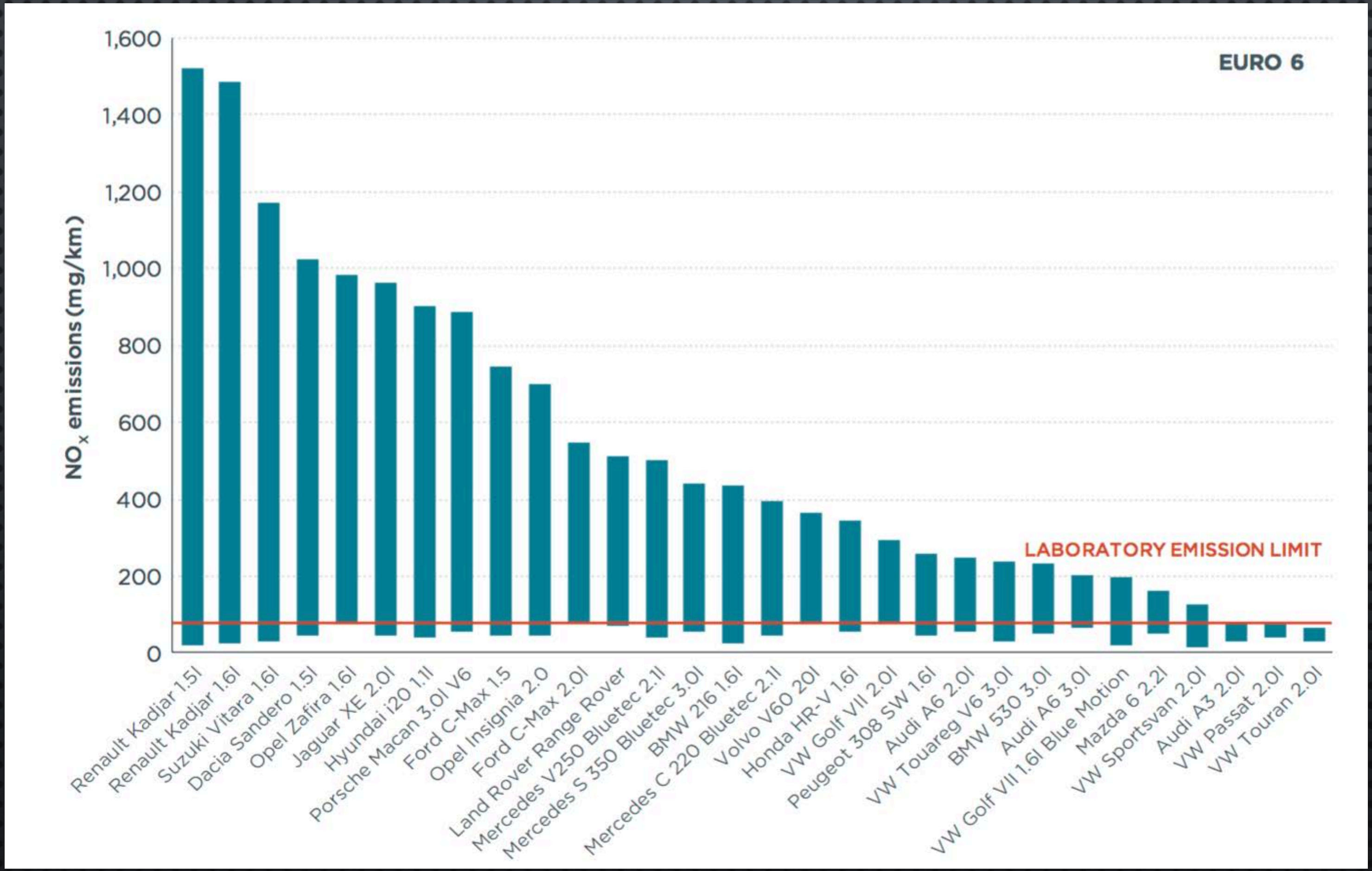
- Zbigniew Klimont and Chris Heyes, International Institute for Applied Systems Analysis, Laxenburg, Austria

Why and How We Did This Study

Susan Anenberg, Ph.D

Principal and Co-Founder, Environmental Health Analytics, LLC

REAL-WORLD EXCESS DIESEL CAR NO_X EMISSIONS IN EUROPE



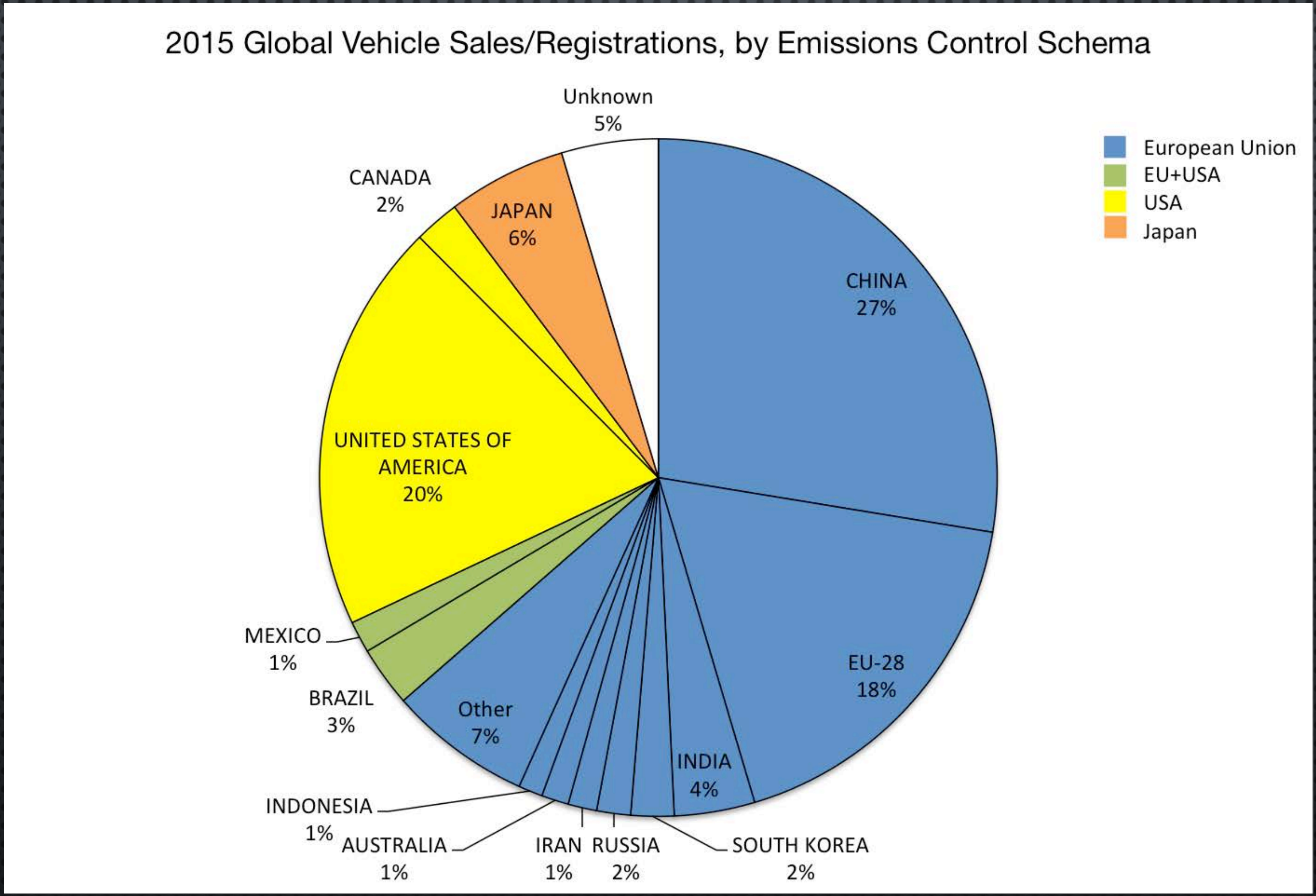
http://www.theicct.org/nox-europe-hdv-ldv-comparison-jan2017

IN-USE EMISSION TESTING STUDIES SHOW THAT THE PROBLEM OF EXCESS DIESEL NO_X EXTENDS TO TRUCKS AND BUSES

Portable Emissions Measurement System (PEMS)

Roadside remote sensing

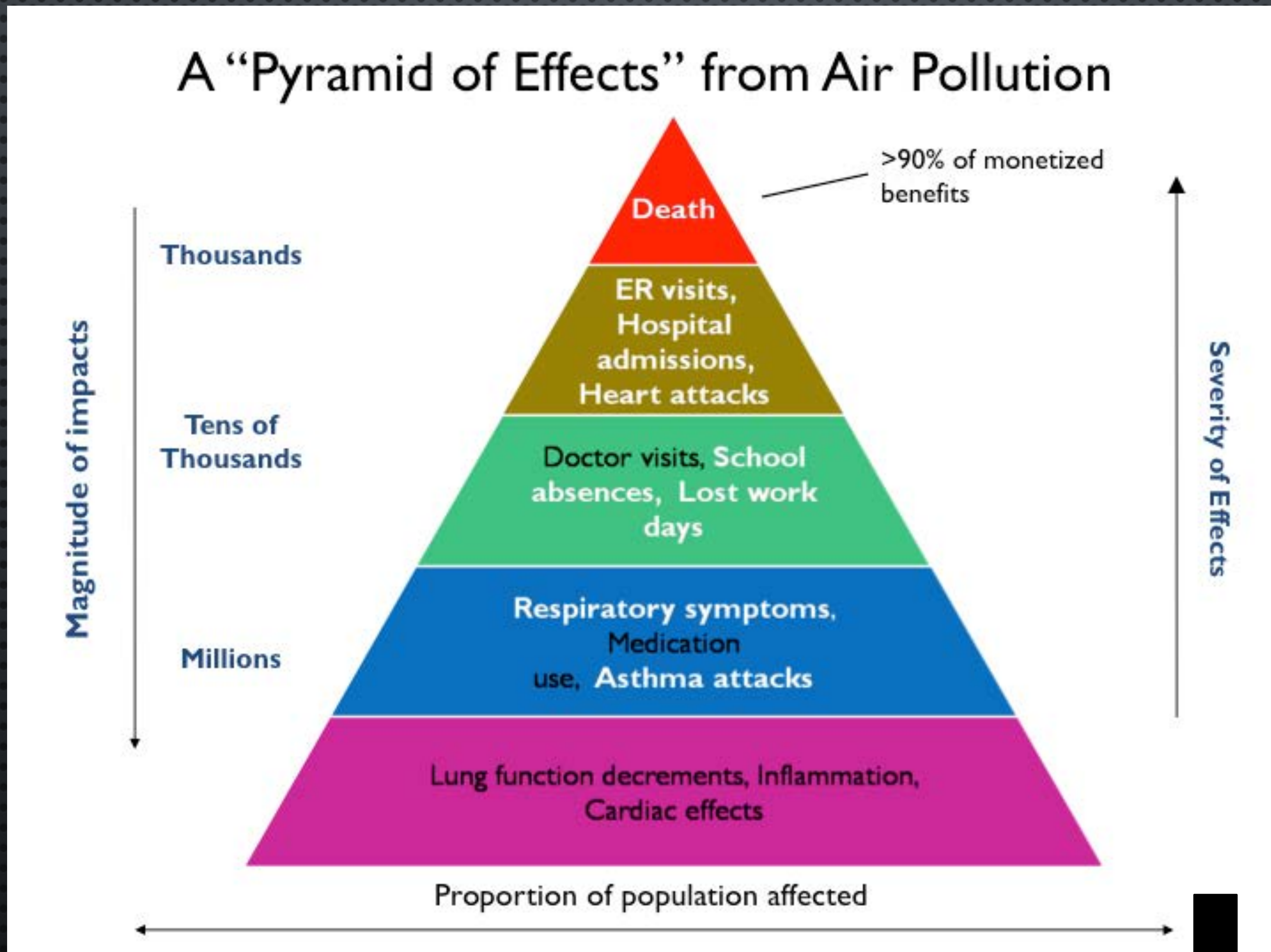
2/3 OF ALL VEHICLES ARE DESIGNED TO EUROPEAN EMISSION SPECIFICATIONS



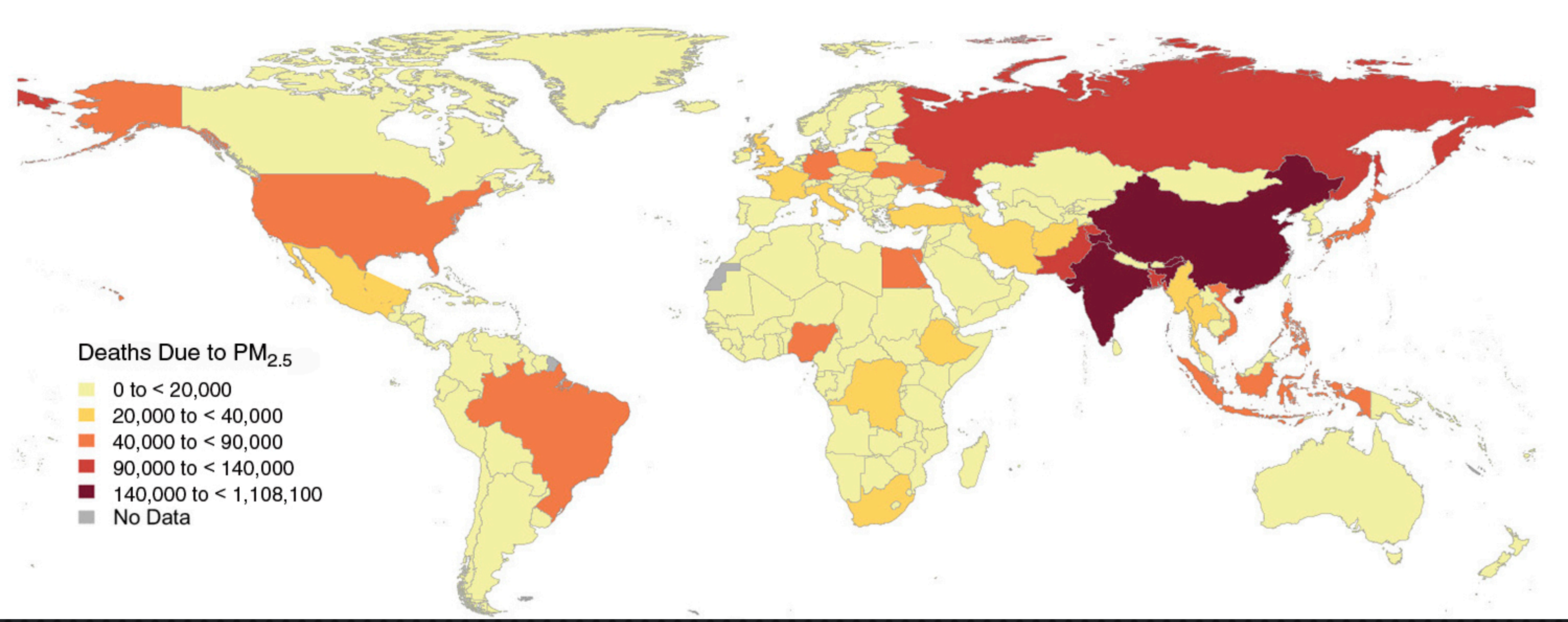
Nitrogen Oxides (NO_X)

- $NO_X = NO + NO_2$
- Key precursors to outdoor air pollution
  - Ground-level ozone (smog)
  - Secondary fine particulate matter ($PM_{2.5}$ or soot)
- Exposure to these pollutants linked to adverse health outcomes, including disability and years of life lost due to:
  - Stroke
  - Ischemic heart disease
  - Chronic obstructive pulmonary disease
  - Lung cancer
  - Lower respiratory infections
- Ozone and $PM_{2.5}$ can also cause damage to crop yields and other vegetation (ecosystems)
- NO_X forms pollutants that affect the climate system in different ways

HEALTH EFFECTS OF OUTDOOR AIR POLLUTION

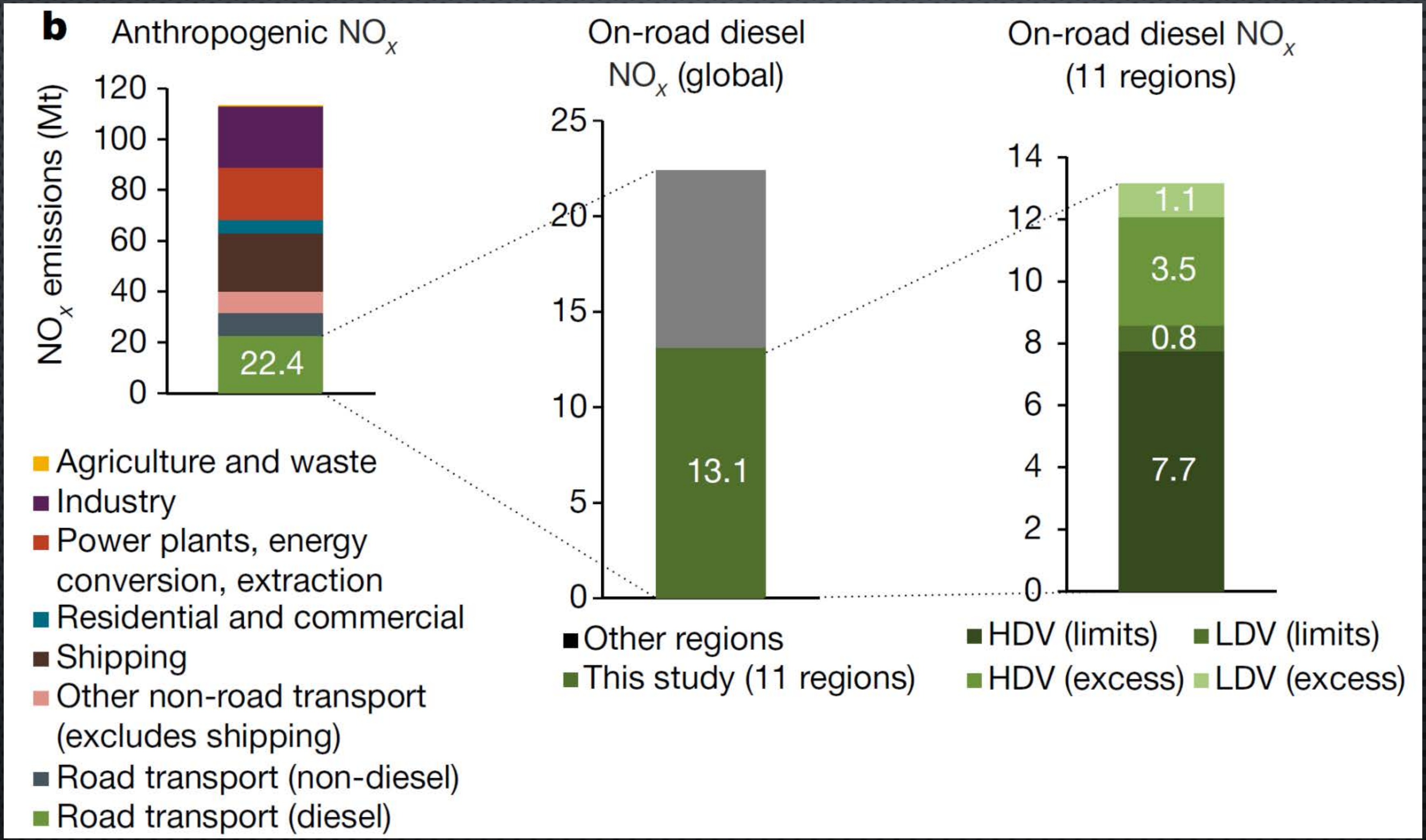


4.5 MILLION PREMATURE DEATHS FROM OUTDOOR AIR POLLUTION (2015)



https://www.stateofglobalair.org

ON-ROAD DIESELS PRODUCE >20% OF GLOBAL ANTHROPOGENIC NO_X EMISSIONS



RESEARCH QUESTIONS

1. What are the health, climate, and crop yield impacts of "excess" diesel NOx emissions in the current global vehicle fleet?
2. How are impacts divided among cars and trucks? Where are the impacts the greatest?
3. How much of these impacts could be avoided in the future?

OVERVIEW OF ANALYTICAL STEPS

In-use NO_X emission factors → In-use NO_X emission inventories → Ozone and particulate matter levels → Health, climate, and crop yield impacts

In-use NO_X emission factors

Review of >30 in-use emission testing studies using PEMS, remote sensing, and other techniques

In-use NO_X emission inventories

Emission factors combined with activity level information, such as number of vehicles and average distance driven

Ozone and particulate matter levels

State-of-the science global atmospheric model accounting for meteorology and chemistry, combined with satellite observations

Health, climate, and crop yield impacts

Established health, climate, and crop yield impact assessment models

POLICY IMPLICATIONS

- For heavy-duty trucks and buses, implementing Euro VI where not yet adopted is key next step.
- For light-duty vehicles, strong Real-Driving Emissions programs can make Euro 6 and similar standards more effective in real-world driving.
- Adopting and enforcing next-generation standards (more stringent than Euro 6/VI) could nearly eliminate real-world diesel NOx emissions and associated health impacts in these 11 markets.

Acknowledgements

- Team members: Susan Anenberg, Josh Miller, Ray Minjares, Li Du, Vicente Franco, Lisa Emberson, Daven Henze, Forrest Lacey, Chris Malley, Zbigniew Klimont, Chris Heyes
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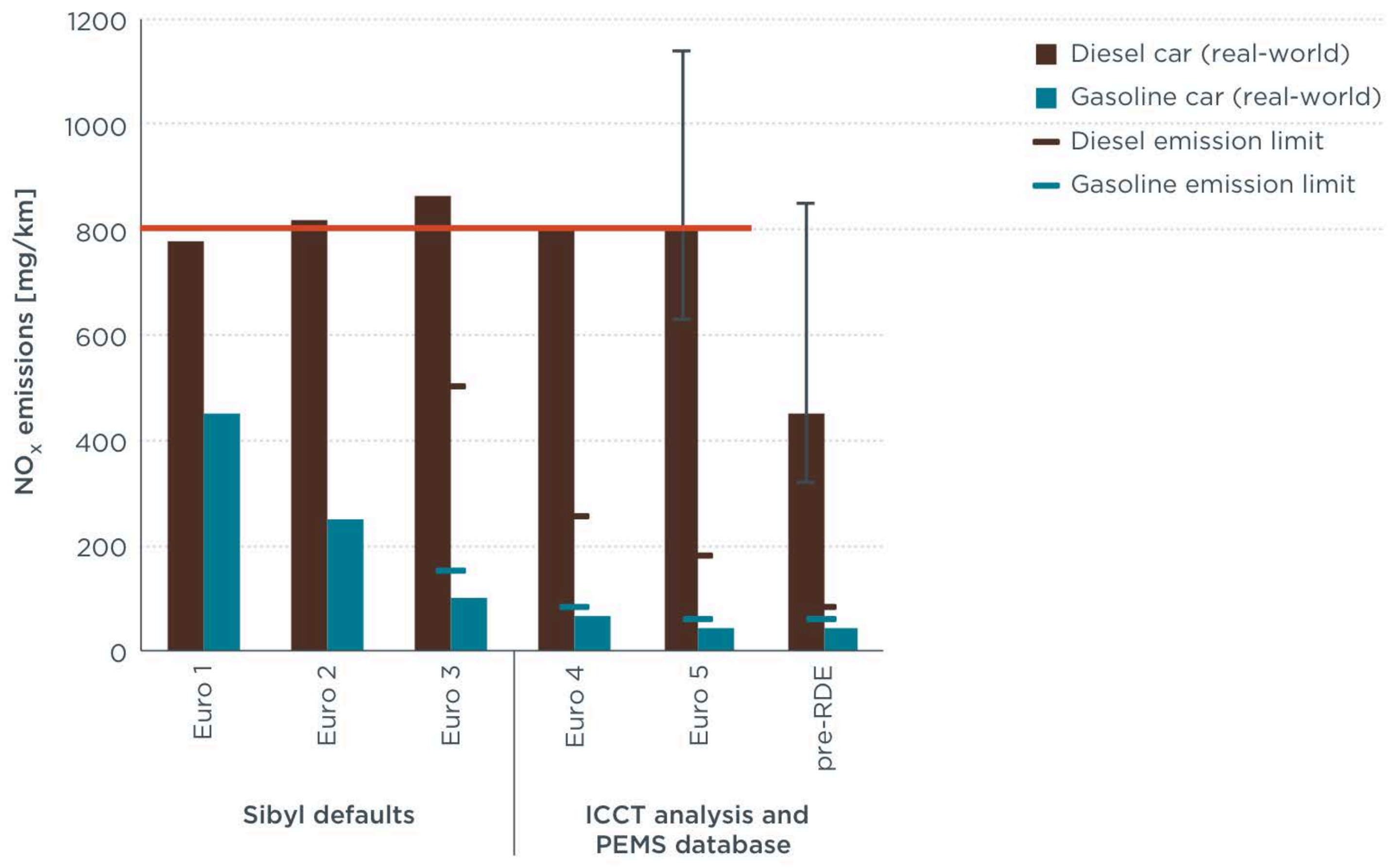
  - Francisco Posada, Tim Dallmann, John German, Rachel Muncrief, Anup Bandivadekar, Hui He, Dan Rutherford, and Fanta Kamakaté for assistance with regional diesel NOx emission inventories
  - Gary Bishop for access to remote sensing data in the US
  - Josh Apte and Neal Fann for discussions on the health impacts
  - Rita van Dingenen for assistance with the crop impacts

REAL-WORLD AND EXCESS DIESEL NOX EMISSIONS

Joshua Miller

Researcher, International Council on Clean Transportation

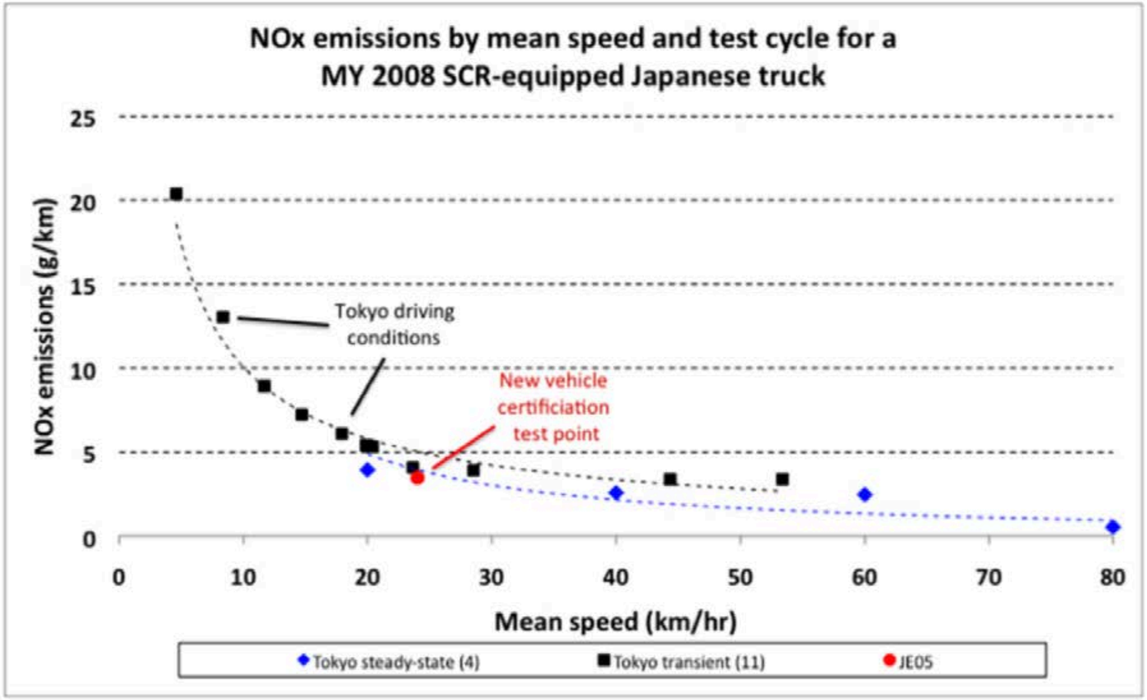
NOX EMISSIONS OF DIESEL CARS IN THE EU HAVE NOT CHANGED IN MORE THAN 15 YEARS.



Source: Miller and Franco (2017). http://www.theicct.org/rde-passenger-car-nox-impacts-eu

BUSES AND TRUCKS HAVE HAD LOW-SPEED NOX PROBLEMS SINCE 2005.

Figure 4: NOx emissions (g/km) versus average speed for a Japanese SCR-equipped truck*

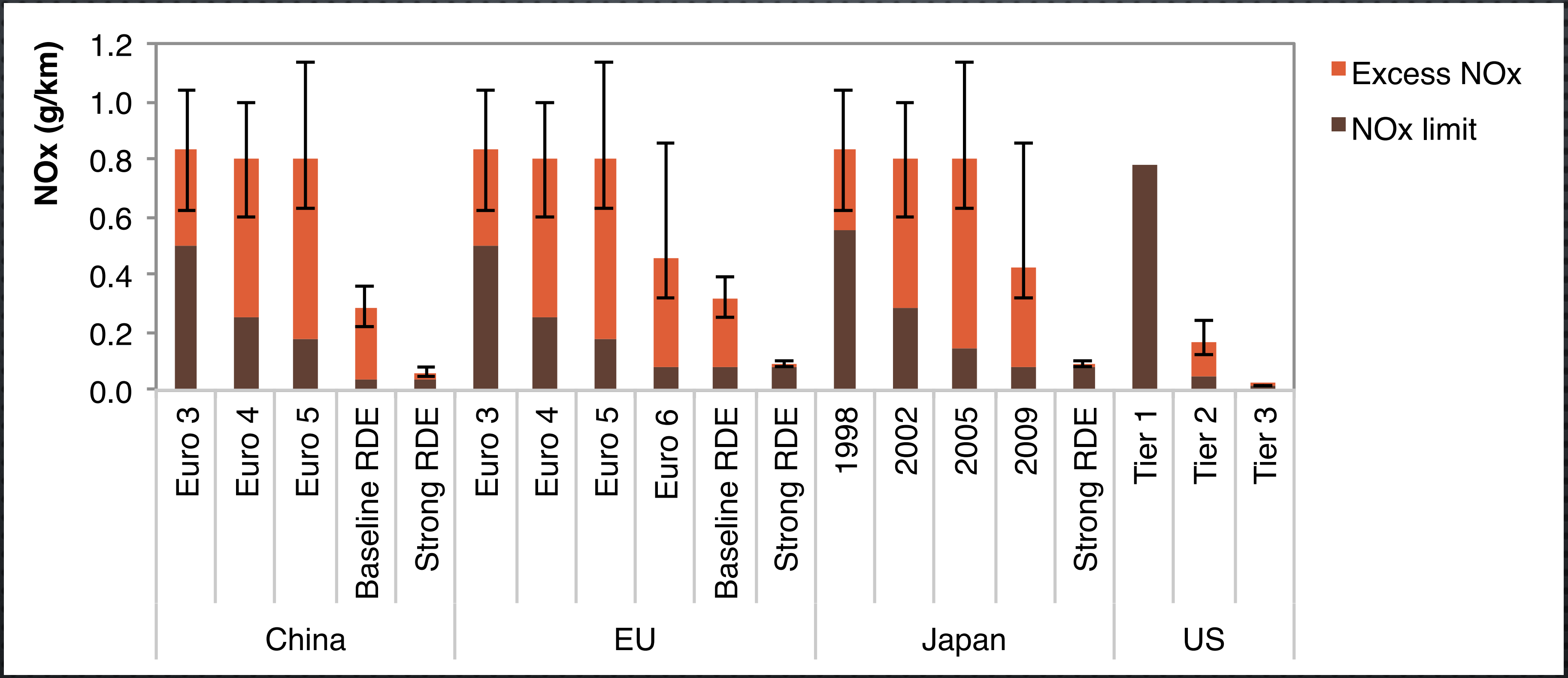


*Source: TMRI (2009). Reproduced with permission.

Source: ICCT (2012). Urban Off-Cycle NOx Emissions from Euro IV/V trucks and buses.

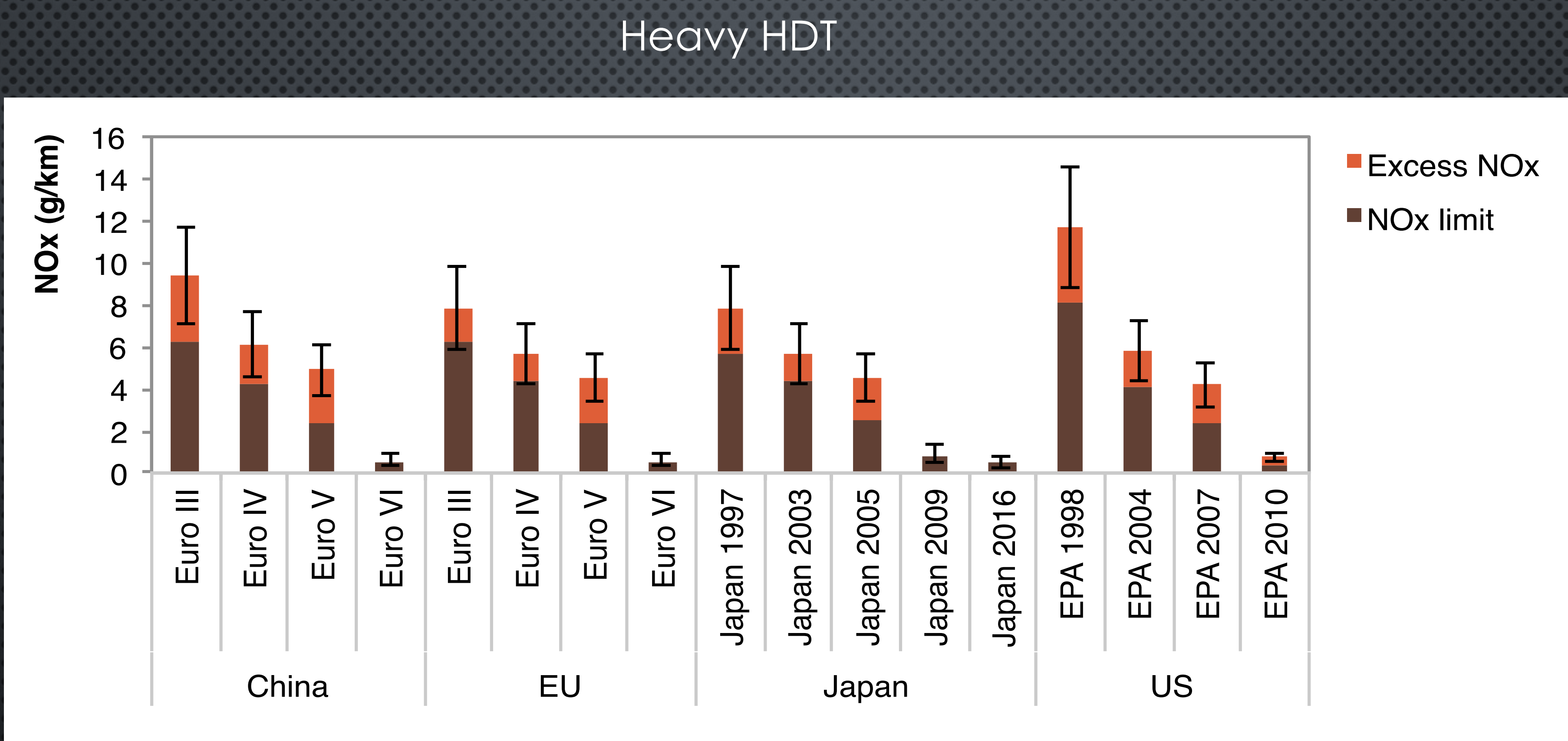
DATASET OF REAL-WORLD NOX EMISSION FACTORS FOR EACH REGION, VEHICLE TYPE, AND STANDARD REFLECTS THE RESULTS OF >30 EMISSION TESTING STUDIES.

Passenger cars



Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

EURO VI-EQUIVALENT STANDARDS HAVE PERFORMED VERY WELL COMPARED TO EURO IV AND V.



Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

POLICY SCENARIOS REFLECT THEORETICAL COMPLIANCE, CURRENT POLICIES, AND NEW POLICIES—EURO 6/VI "AS-IS", STRONG RDE, AND NEXT-GENERATION.

Region	Type	Baseline[2]	Euro 6/VI	Strong RDE[3]	Next Gen
EU-28	Light	Euro 6 in 2014; adopted RDE phase-in 2017-2020	–	Strong RDE phase-in 2017-2020	Euro 7 in 2021
	Heavy	Euro VI in 2014	–	–	Euro VII in 2025
S. Korea	Light	Euro 6 in 2014	–	**1 year** after EU	**1 year** after EU
	Heavy	Euro VI in 2015	–	–	
Australia	Light	Euro 6 in 2018	–	**3 years** after EU	**3 years** after EU
	Heavy	Euro V in 2011	Euro VI in 2018	–	
India	Light	Bharat 6 in 2020[4]	–	**6 years** after EU	**6 years** after EU
	Heavy	Bharat VI in 2020	–	–	**4 years** after EU
Brazil	Light	Euro 4 in 2009	Euro 6 in 2018	**4 years** after EU	**4 years** after EU
	Heavy	Euro V in 2012	Euro VI in 2018	–	
Russia	Light	Euro 5 in 2016	Euro 6 in 2020	**5 years** after EU	**5 years** after EU
	Heavy	Euro V in 2016	Euro VI in 2020	–	
Mexico	Light	Euro 4 in 2009	Euro 6 in 2018	–	Tier 3 2021-2025
	Heavy	Euro IV in 2008	Euro VI in 2018	–	Same as U.S.
China	Light	China 5 in 2018[5]	China 6a in 2020; China 6b in 2023[6]	Strengthened RDE with China 6b	China 6b equivalent to U.S. Tier 3
	Heavy	China V in 2017	China VI in 2021	–	**2 years** after EU
United States	Light	Tier 3 phase-in 2017-2025	–	–	–
	Heavy	Tier 3[7]/EPA 2010	–	–	Next generation in 2025
Canada	Light	Harmonized with U.S.	–	–	–
	Heavy		–	–	Same as U.S.
Japan	Light	PNLTES[8] 2009	–	Same as EU	Same as EU
	Heavy	PNLTES 2016	–	–	Same as EU

Dash indicates no change from previous scenario.

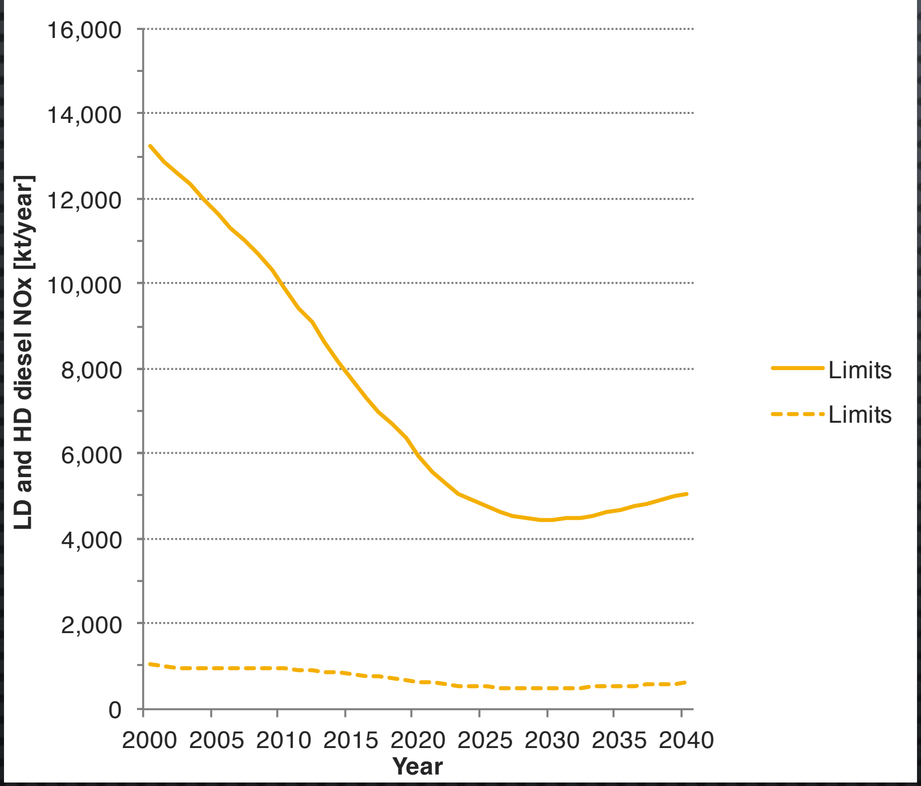
Grey fill indicates regions that have developed their own emission control programs from the ground up.

Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

LIMITS SCENARIO REFLECTS COUNTERFACTUAL COMPLIANCE WITH CERTIFICATION LIMITS OF ADOPTED REGULATIONS.

LIMITS: COUNTERFACTUAL WHERE REAL-WORLD NO_X EMISSIONS ARE EQUIVALENT TO CERTIFICATION LIMITS.

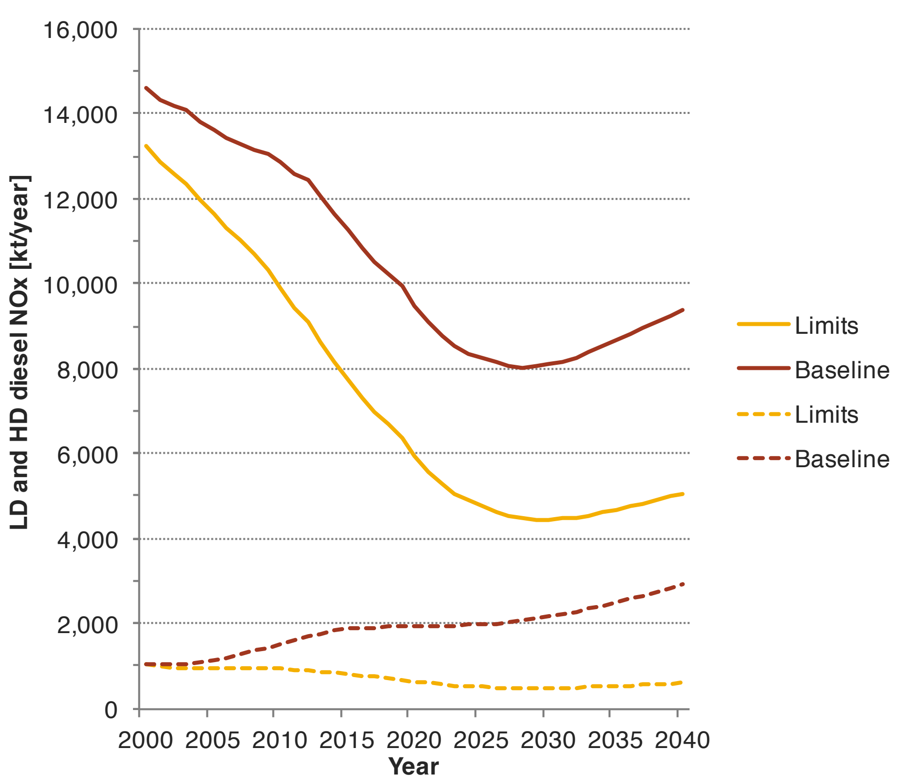
Solid = HDV; Dashed = LDV



Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

BASELINE REFLECTS BEST ESTIMATE OF REAL-WORLD NOX PERFORMANCE.

Solid = HDV; Dashed = LDV



LIMITS: COUNTERFACTUAL WHERE REAL-WORLD NO_X EMISSIONS ARE EQUIVALENT TO CERTIFICATION LIMITS.

BASELINE: BEST ESTIMATE OF HOW ADOPTED NO_X EMISSION STANDARDS PERFORM IN THE REAL WORLD.

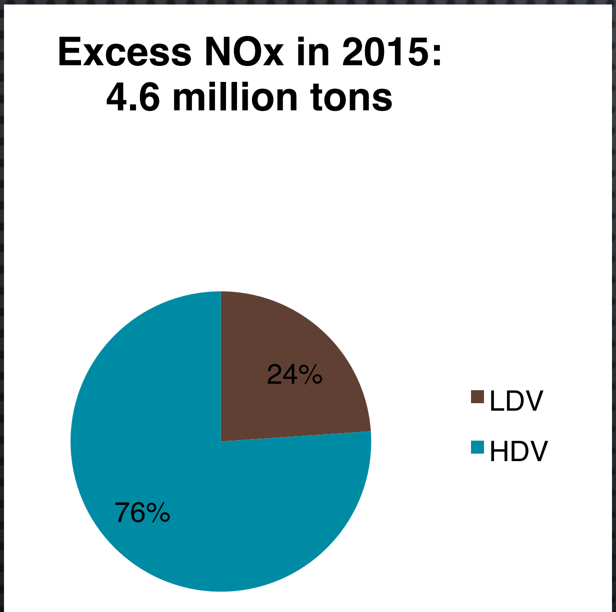
Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

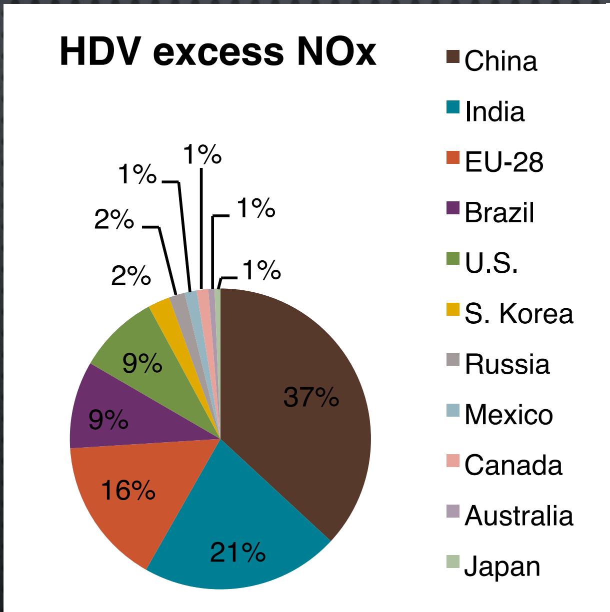
EXCESS NOX APPLIES TO DIESEL CARS, TRUCKS, AND BUSES.

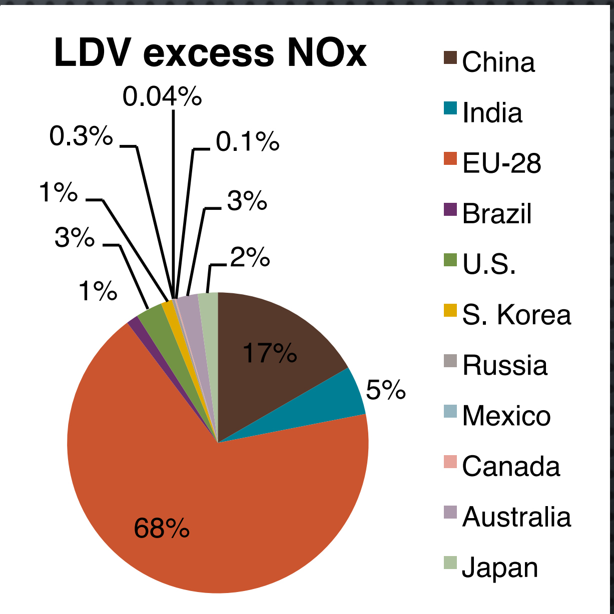
Most "excess NOx" is from HDVs.

Five markets—China, India, EU, Brazil, US—contribute ~90% of HDV excess NOx.

Most LDV excess NOx is emitted in EU, China, India—all have adopted Euro 6 standards.



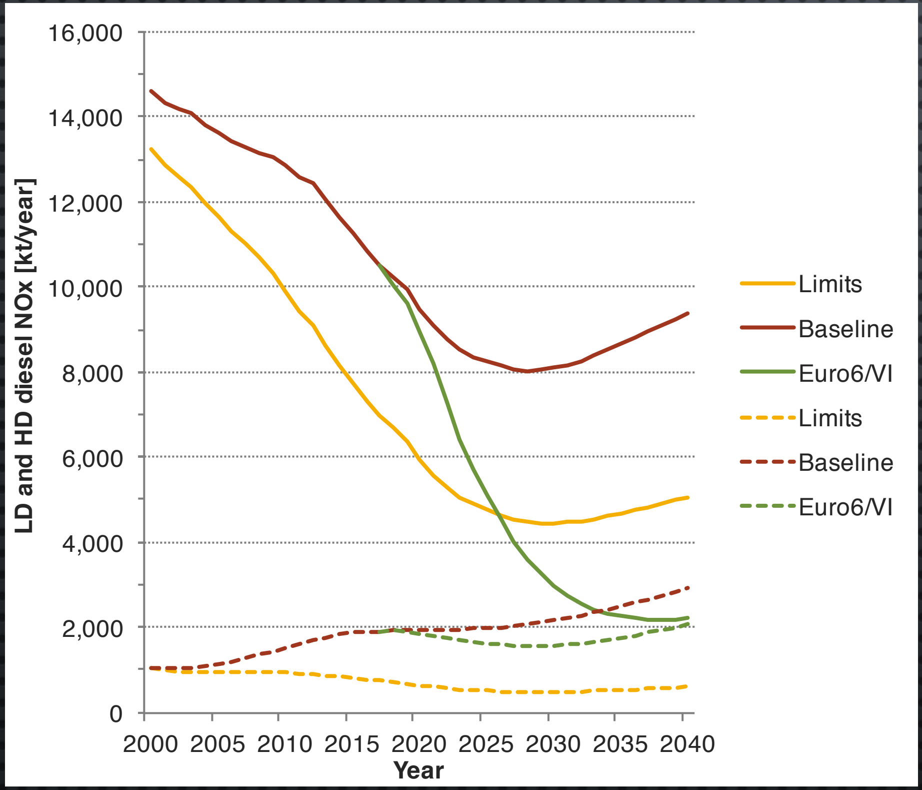




Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

EURO VI HDV STANDARDS ARE MOST IMPORTANT IN CHINA, BRAZIL, MEXICO, RUSSIA, AND AUSTRALIA—ALONG WITH EFFECTIVE IMPLEMENTATION IN INDIA.

Solid = HDV; Dashed = LDV



LIMITS: COUNTERFACTUAL WHERE REAL-WORLD NO_X EMISSIONS ARE EQUIVALENT TO CERTIFICATION LIMITS.

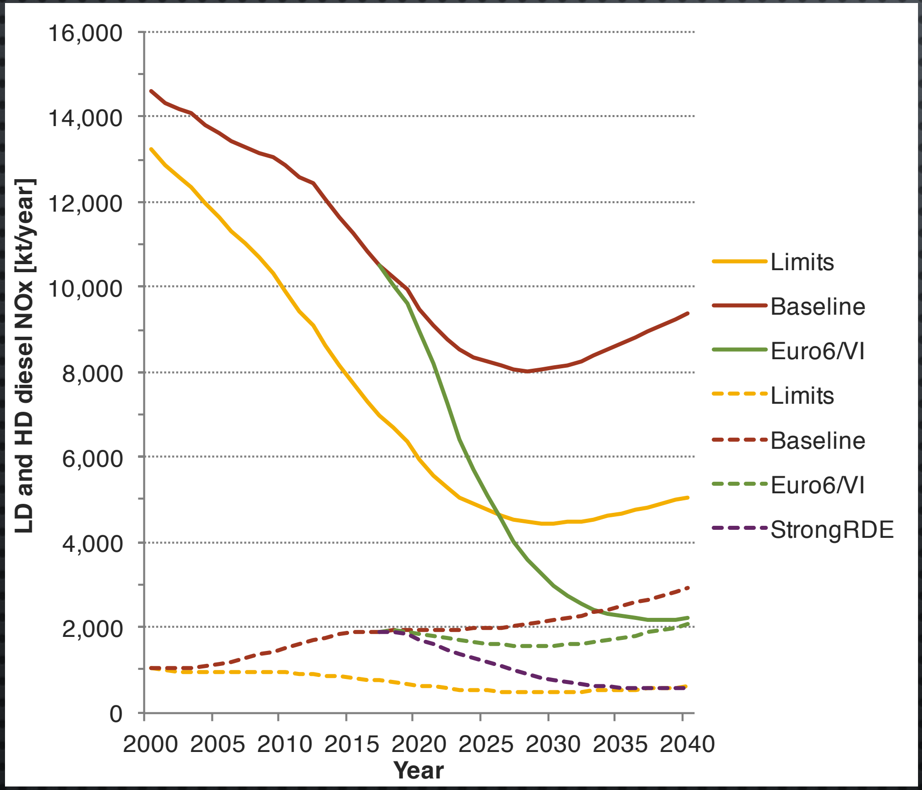
BASELINE: BEST ESTIMATE OF HOW ADOPTED NO_X EMISSION STANDARDS PERFORM IN THE REAL WORLD.

EURO6/VI: COUNTRIES THAT HAVEN'T YET DONE SO ADOPT EURO 6/VI EQUIVALENT STANDARDS "AS IS"

Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

THE MOST CRITICAL REGIONS FOR STRENGTHENED LDV RDE PROGRAMS ARE EU, CHINA AND INDIA.

Solid = HDV; Dashed = LDV



LIMITS: COUNTERFACTUAL WHERE REAL-WORLD NO_X EMISSIONS ARE EQUIVALENT TO CERTIFICATION LIMITS.

BASELINE: BEST ESTIMATE OF HOW ADOPTED NO_X EMISSION STANDARDS PERFORM IN THE REAL WORLD.

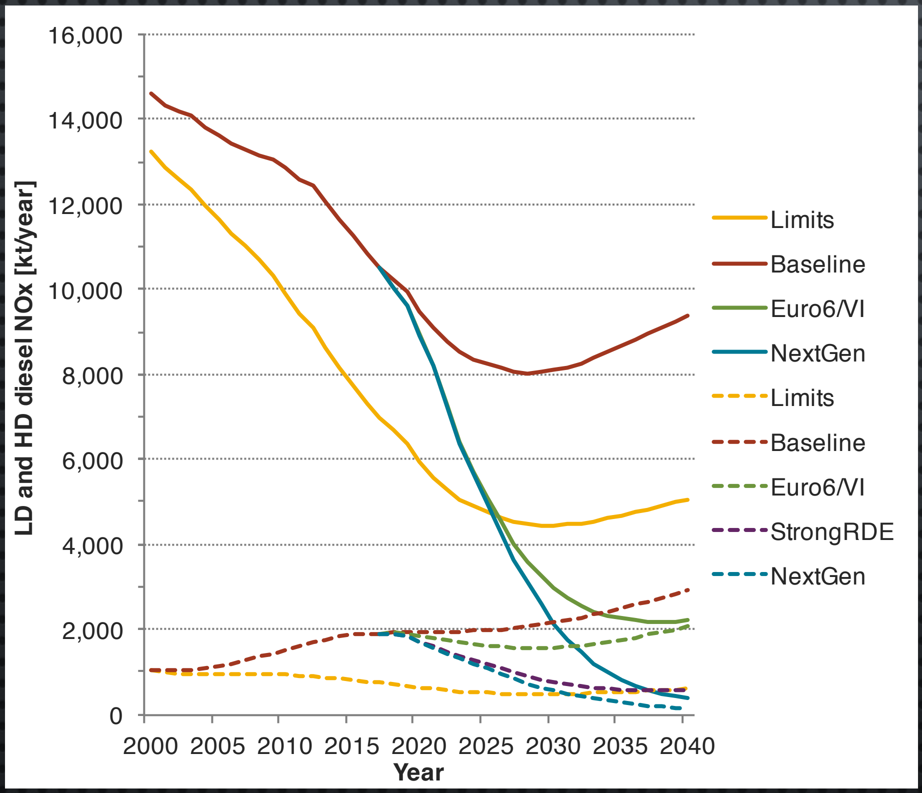
EURO6/VI: COUNTRIES THAT HAVEN'T YET DONE SO ADOPT EURO 6/VI EQUIVALENT STANDARDS "AS IS"

STRONGRDE: EURO 6/VI SCENARIO + IDEALIZED LDV RDE PROGRAMS THAT TEST IN-SERVICE VEHICLES, MONITOR IN-USE EMISSIONS, COVER A BROAD SET OF DRIVING CONDITIONS, AND ALLOW FOR INDEPENDENT VERIFICATION.

Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

NEXT GENERATION STANDARDS ARE KEY TO STEEP LONG-TERM EMISSION REDUCTIONS POST-2025.

Solid = HDV; Dashed = LDV



LIMITS: COUNTERFACTUAL WHERE REAL-WORLD NO_X EMISSIONS ARE EQUIVALENT TO CERTIFICATION LIMITS.

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EURO6/VI: COUNTRIES THAT HAVEN'T YET DONE SO ADOPT EURO 6/VI EQUIVALENT STANDARDS "AS IS"

STRONGRDE: EURO 6/VI SCENARIO + IDEALIZED LDV RDE PROGRAMS THAT TEST IN-SERVICE VEHICLES, MONITOR IN-USE EMISSIONS, COVER A BROAD SET OF DRIVING CONDITIONS, AND ALLOW FOR INDEPENDENT VERIFICATION.

NEXTGEN: STRONGRDE SCENARIO + STANDARDS EQUIVALENT TO US TIER 3 AND CA VOLUNTARY HDV NO_X RULE IN ALL MARKETS

Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

POLICY IMPLICATIONS

1. HDV Euro VI is a priority for any market without such standards.
2. Euro 6 must be accompanied by strong RDE programs to be fully effective.
3. Adopting and enforcing next-generation standards (more stringent than Euro 6/VI) could nearly eliminate real-world diesel NOx emissions in these 11 markets.
4. Lowering emission limits and strengthening compliance and enforcement are both essential to achieving low real-world diesel NOx emissions.

Source: Impacts and mitigation of excess diesel NOx emissions in 11 major vehicle markets

Global Air Quality and Climate Impacts of Real-World Diesel NOx

Daven Henze, PhD

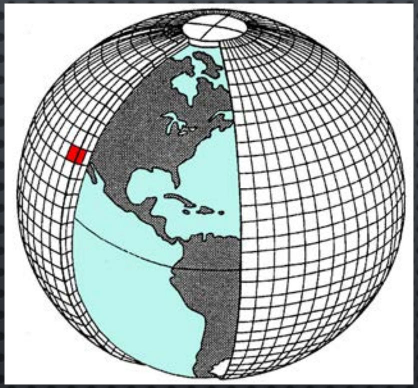
Associate Professor, University of Colorado, Boulder

GLOBAL MODELING METHODS FOR AIR QUALITY EXPOSURE AND SOURCE APPORTIONMENT

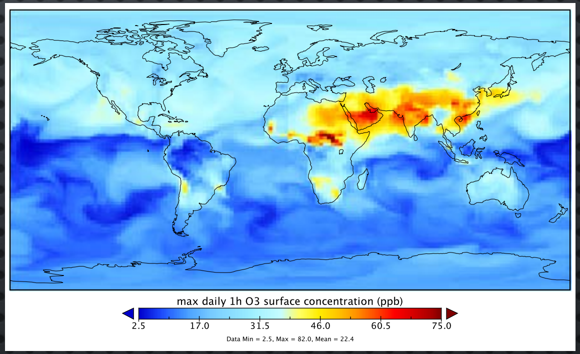
Chemical Transport Model (CTM)

GEOS-Chem *Bey et al.*, 2001; *Park et al.*, 2004, www.geoschem.org

Input: Emissions (diesel NOx, + other anthropogenic, natural emissions) & Meteorology (wind, T, RH,…)



Output: O_3 and $PM_{2.5}$



High-performance computing simulations

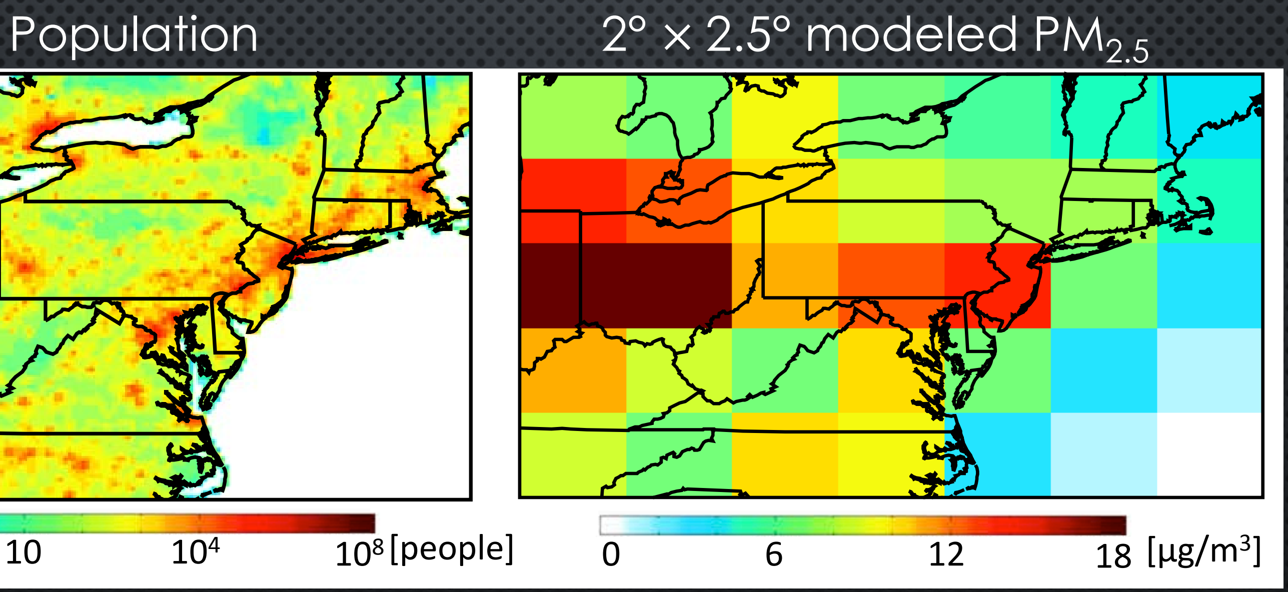
Transport, chemistry aerosol thermodynamics, convection, deposition, turbulent mixing

GLOBAL MODELING CHALLENGES FOR $PM_{2.5}$ EXPOSURE ESTIMATION

Many previous global modeling studies of $PM_{2.5}$ health impacts, e.g.:

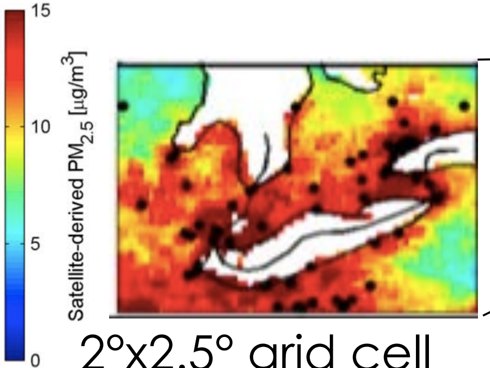
- global reductions to fossil and biofuel (Jacobson, 2010)
- global BC (Anenberg et al., 2011; 2012)
- widespread adoption of vehicle standards (Shindell, 2011)

However, these models have trouble estimating $PM_{2.5}$ exposure at typical global resolutions:

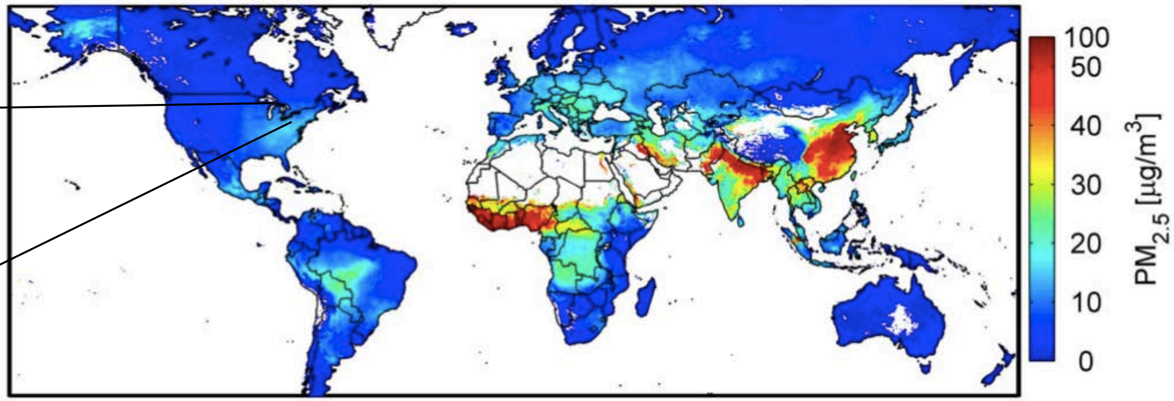


$PM_{2.5}$ exposure underestimated by 5-40% in 2°x2.5° simulation over the US (Punger & West, 2012; Li et al., 2015). Resolution error ***not*** globally heterogeneous.

USING SATELLITE-DERIVED $PM_{2.5}$ FOR MODEL BIAS CORRECTION AND DOWNSCALING



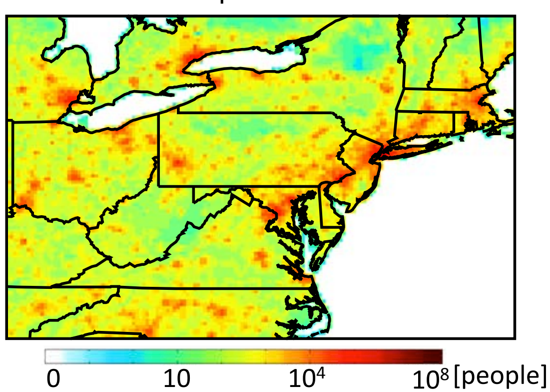
2°x2.5° grid cell

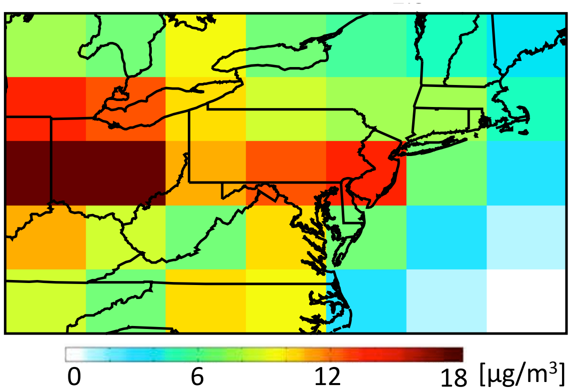


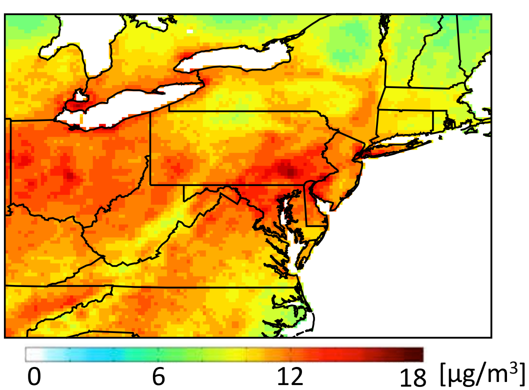
- MODIS, MISR, SeaWiFS, CALIOP, geo info., 0.1°x0.1° (van Donkelaar et al., ES&T, 2016)

Satellite data used for:

- downscaling (present & future simulations)
- bias correction (present simulations)





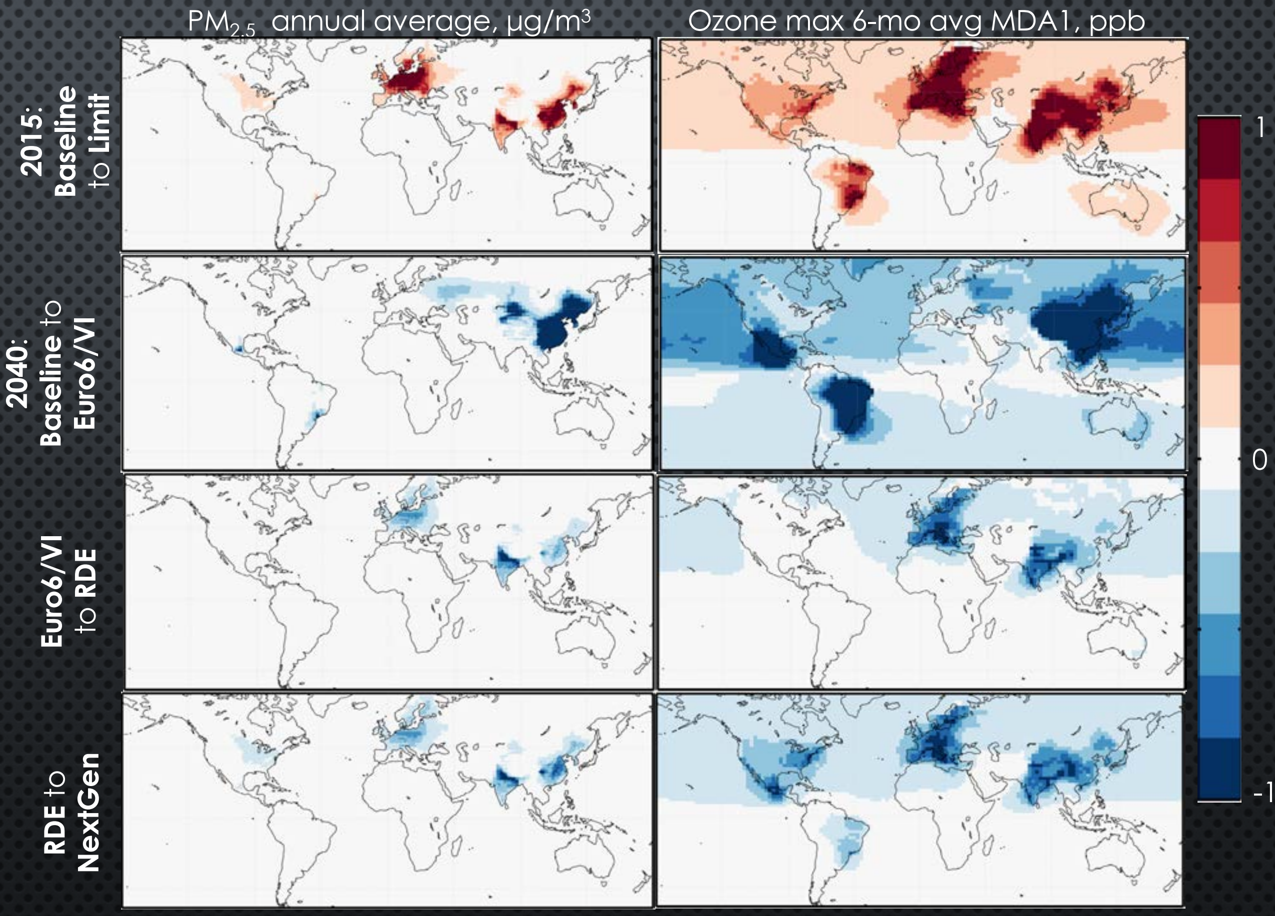


Impacts on surface concentrations of $PM_{2.5}$ and Ozone

Emissions:
- other anthropogenic emissions from ECLIPSE v5 baseline
- 2015 natural emissions (burning, lightning, soil, biogenic, etc.)

Modeling:
- GEOS-Chem
- GEOS-5 meteorology for 2015
- Precomputed radiative forcing efficiencies for O_3 (Henze & Bowman, 2012; Naik et al., 2005) and aerosols (Henze et al., 2012)

Satellite-based downscaling: $PM_{2.5}$ downscaled to 0.1°x0.1° using sat-based $PM_{2.5}$ (van Donkelaar et al., 2016)



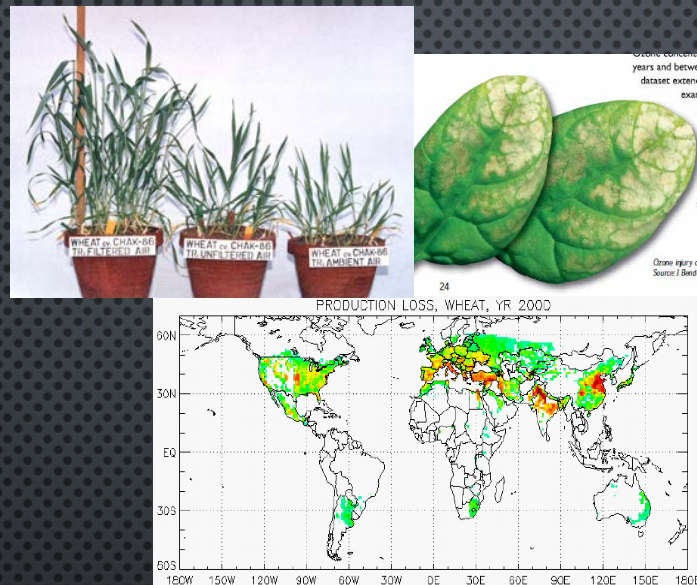
O_3 (tropospheric lifetime ~month) is affected far beyond regions where emissions are changing in these scenarios.

Climate impacts of diesel NOx

Radiative forcing from the change in each pollutant (mW m^{-2}) using forcing efficiencies (Henze et al., 2012; Henze & Bowman, 2012; Naik et al., 2005)

	Change due to excess NOx	Change due to future policies relative to baseline in 2040 (scenario - baseline)		
Species	Baseline – Limit 2015	Euro6	RDE	NextGen
Aerosol	-7.94	14.53	17.11	20.59
	(-15.64 to -2.34)	(4.28 to 28.59)	(5.05 to 33.67)	(6.07 to 40.51)
Ozone	2.68	-6.03	-6.89	-8.28
	(±0.62)	(±1.35)	(±1.53)	(±1.83)
Methane	-3.43	7.24	8.32	10.05
	(±0.62)	(±1.35)	(±1.53)	(±1.83)
Total	-8.69	15.74	18.54	22.46
	(-16.39 to -3.07)	(5.18 to 30.03)	(6.03 to 35.42)	(7.09 to 42.84)

- Small net negative radiative forcing (climate benefit) from current excess diesel NOx
- Small net positive radiative forcing (climate disbenefit) from these NOx (only) policy scenarios
- Policy disbenefits countered by benefits of reduced co-emitted black carbon
- Complete lifecycle analysis evaluating aerosol and GHG climate impacts, including CO_2, of attaining diesel NOx standards a subject for further research.



CROP IMPACT ASSESSMENT OF REAL-WORLD DIESEL NOX EMISSIONS

Chris Malley & Lisa Emberson

Stockholm Environment Institute (SEI), University of York

Why Consider Crop Impacts ?

NOx is a precursor to ozone and aerosol (PM) pollution

Ozone is a phytotoxic pollutant; aerosol affects quality and quantity of solar radiation

Ozone effects include visible injury, biomass losses, crop yield losses, forest productivity and changes in grassland species composition

Aerosols will alter photosynthesis, C assimilation and hence biomass

Pollutants affect ecosystems services (e.g. hydrology, C sequestration, atmosphere-biosphere exchange and energy budgets)

We wanted to get some idea of the role of excess diesel NOx - **focussed on ozone effect on crop yields for 3 staple crops**

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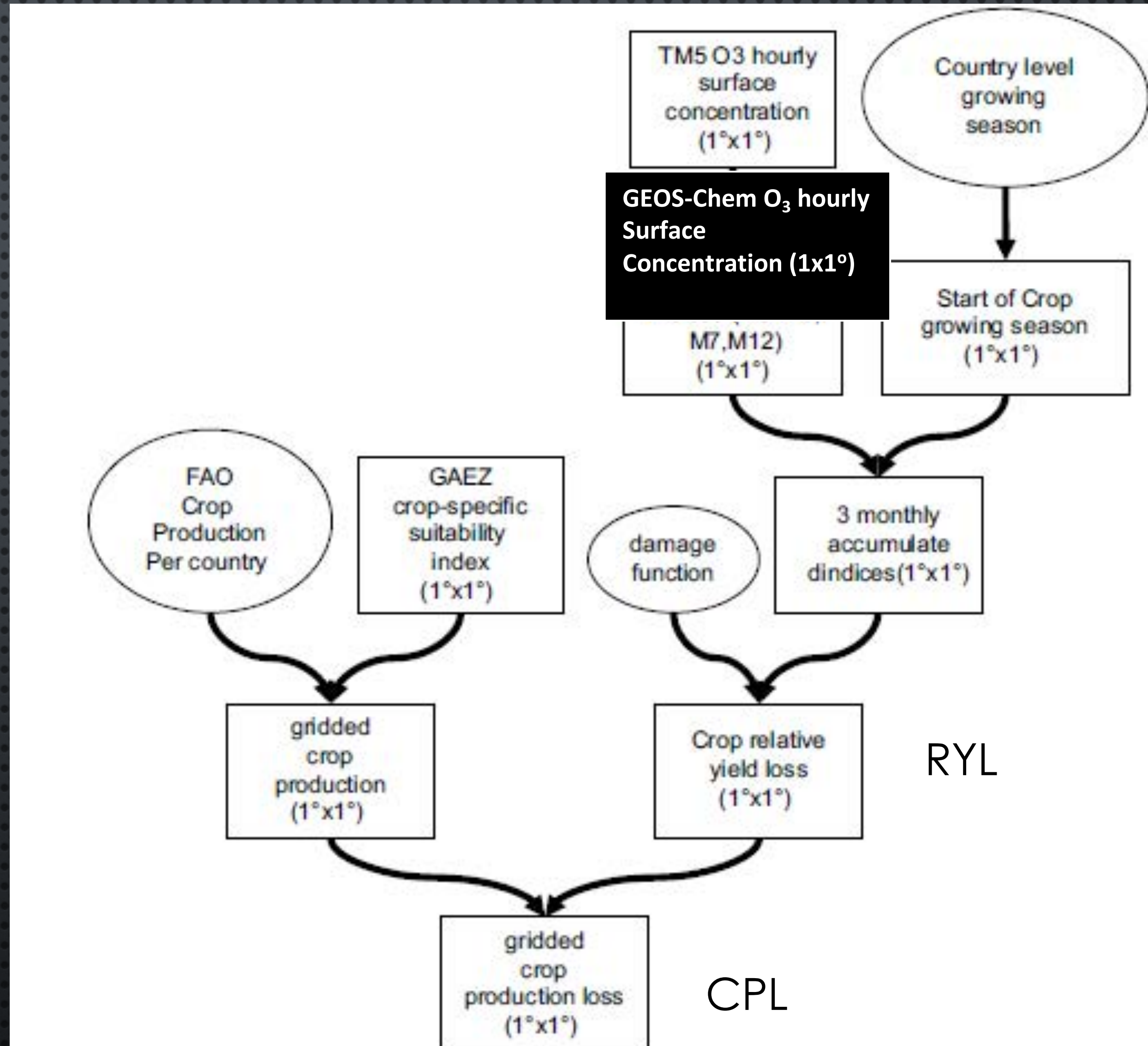
Methodology



Van Dingenen et al(2009)

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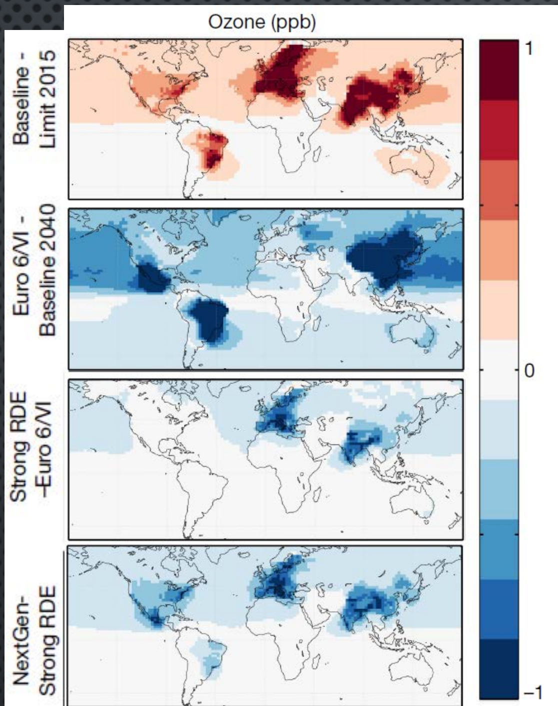
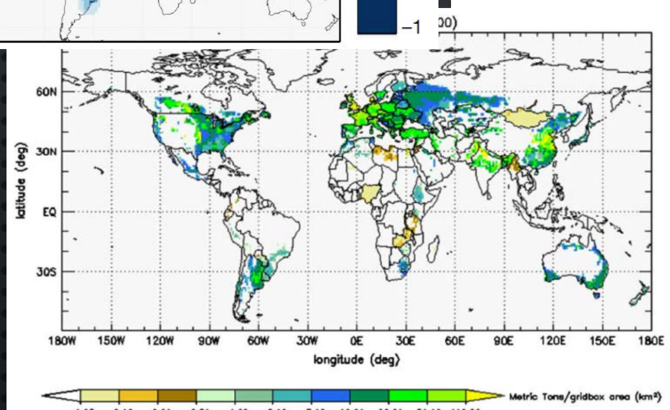
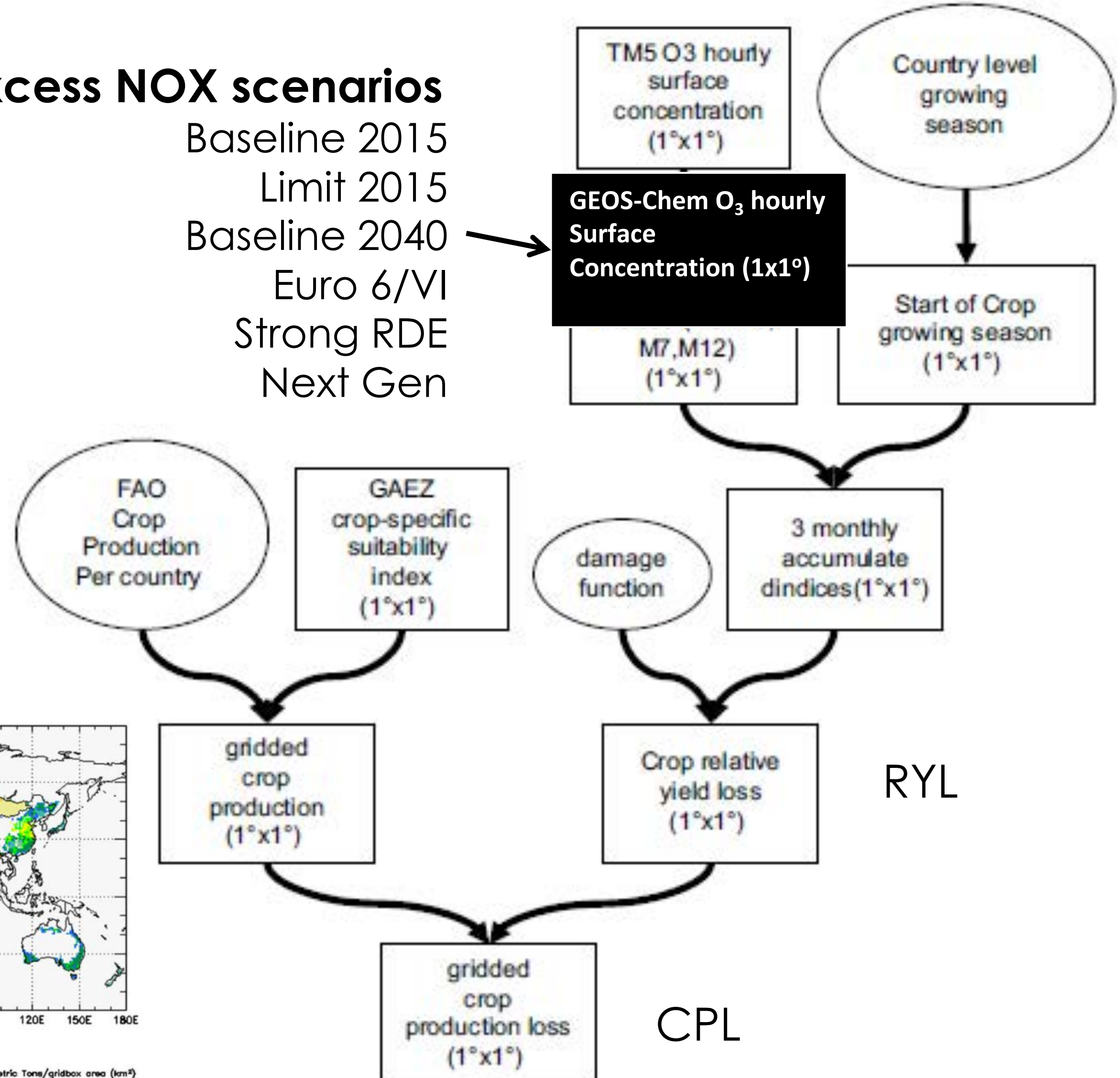
Methodology





Excess NOX scenarios

Baseline 2015
Limit 2015
Baseline 2040
Euro 6/VI
Strong RDE
Next Gen



Van Dingenen et al(2009)

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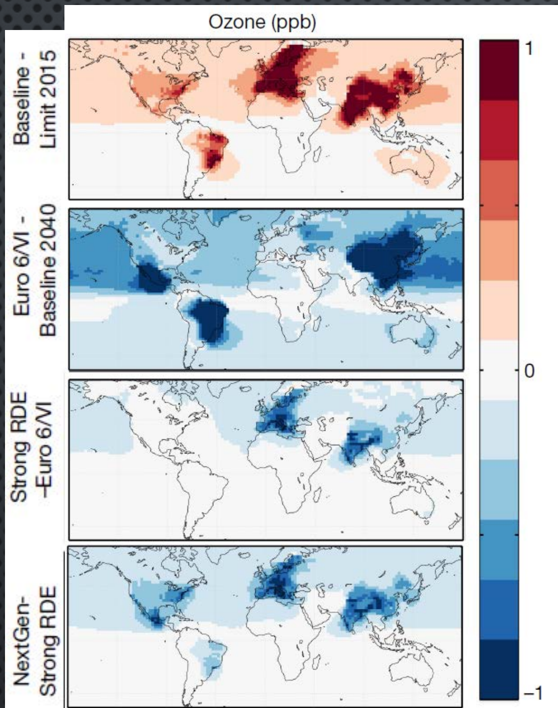
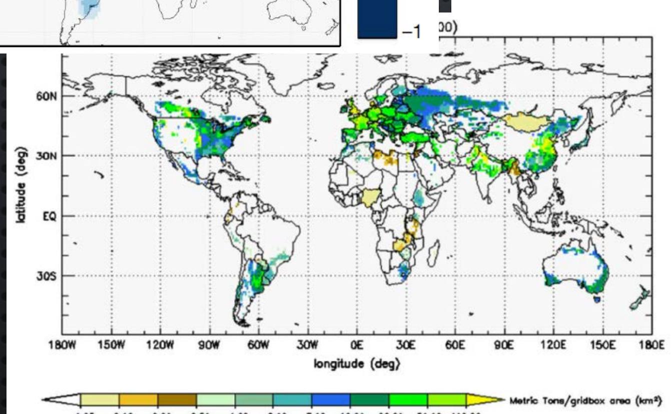
Methodology





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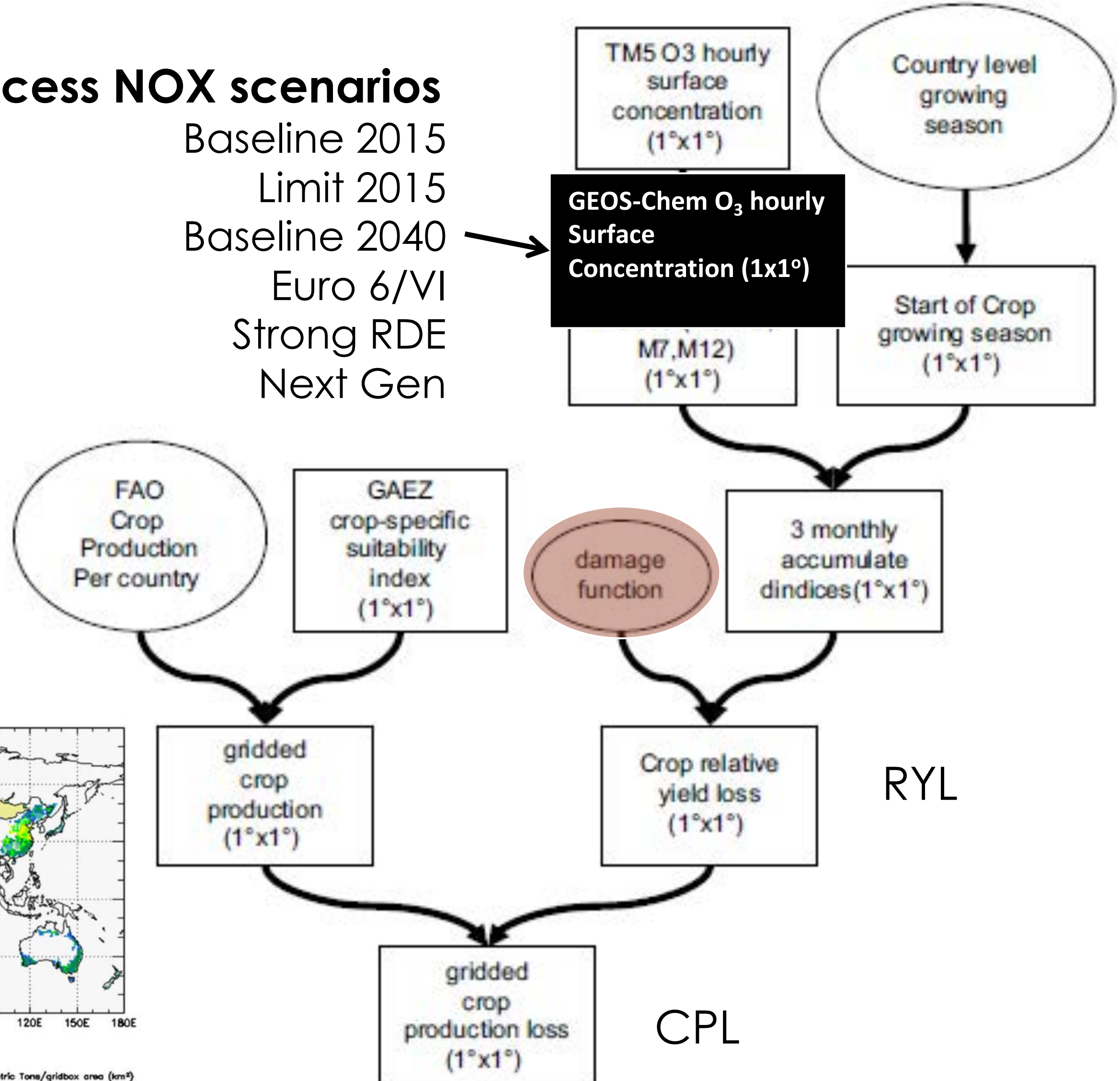

Van Dingenen et al(2009)

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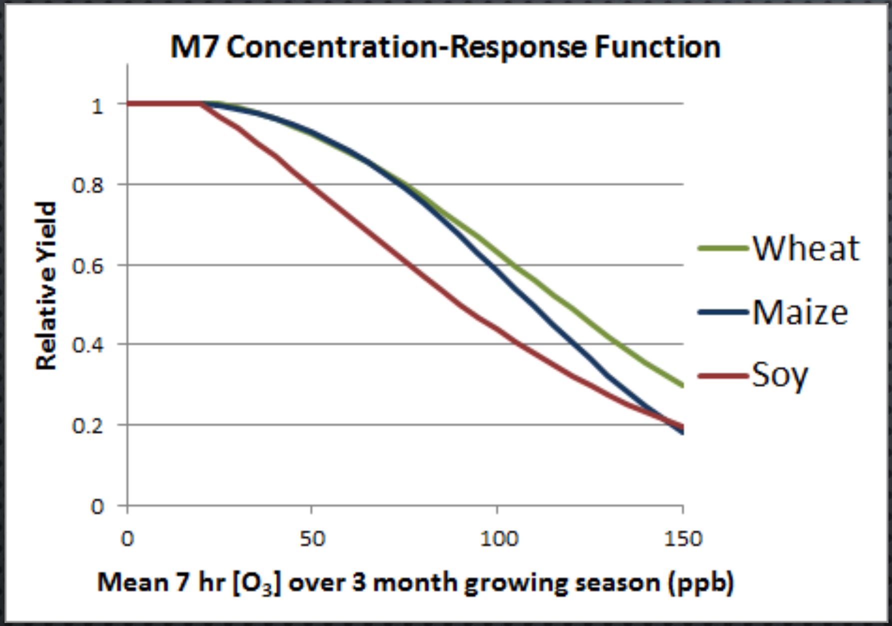
Methodology

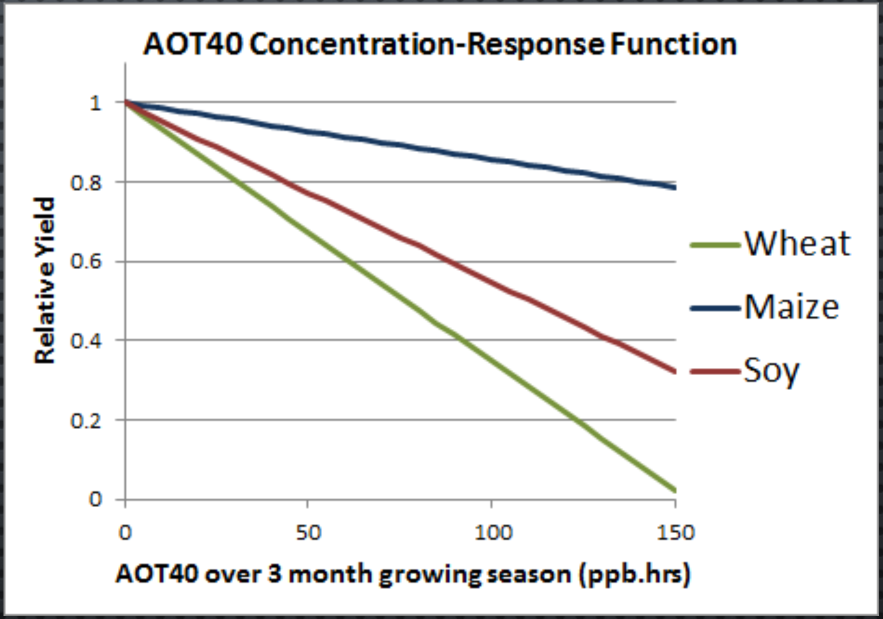
Damage (Concentration-Response) functions

M7



Chronic O_3 pollution

AOT40



Acute, peak O_3 pollution episodes

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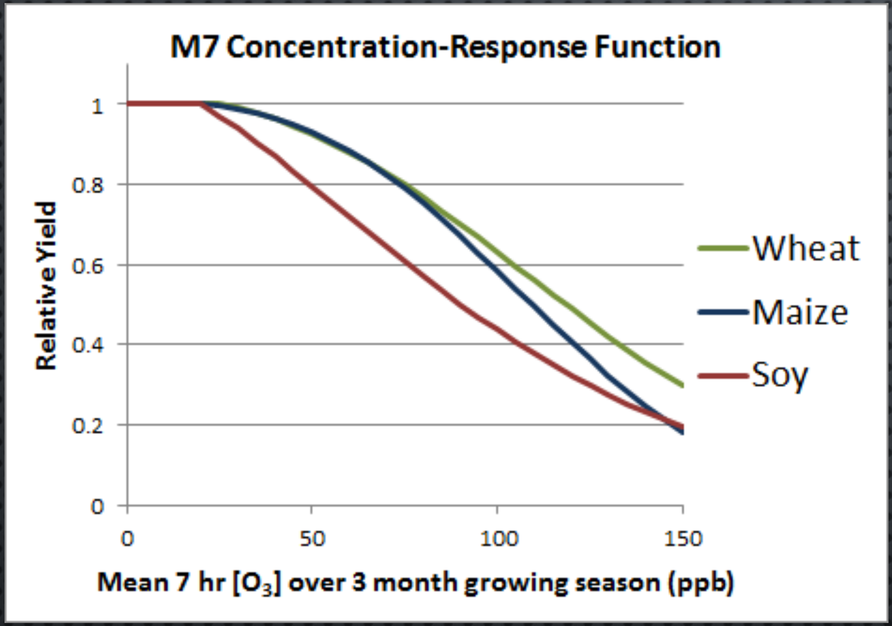
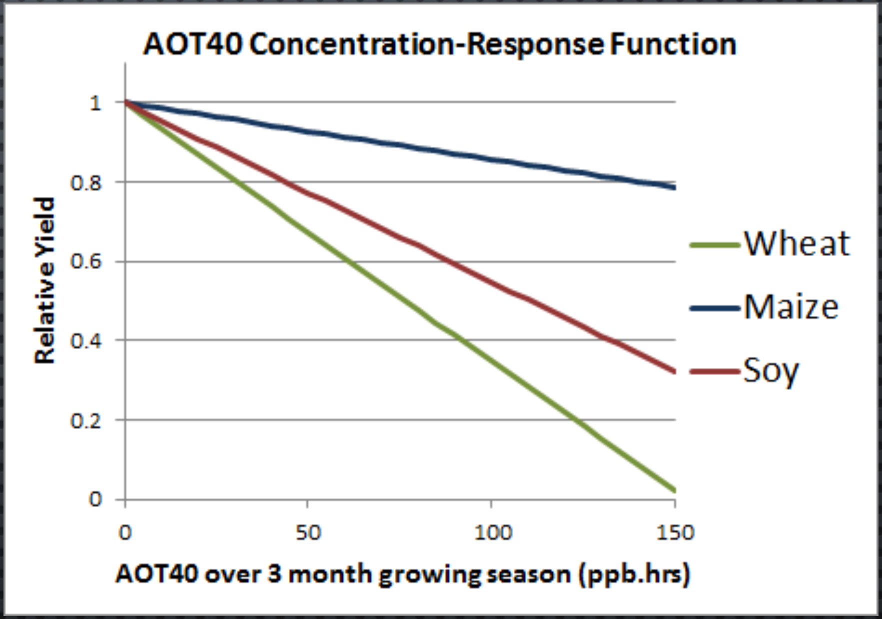
Methodology

Damage (Concentration-Response) functions

M7



AOT40



Chronic O_3 pollution ⟷ Acute, peak O_3 pollution episodes

Provide uncertainty of RLY estimates

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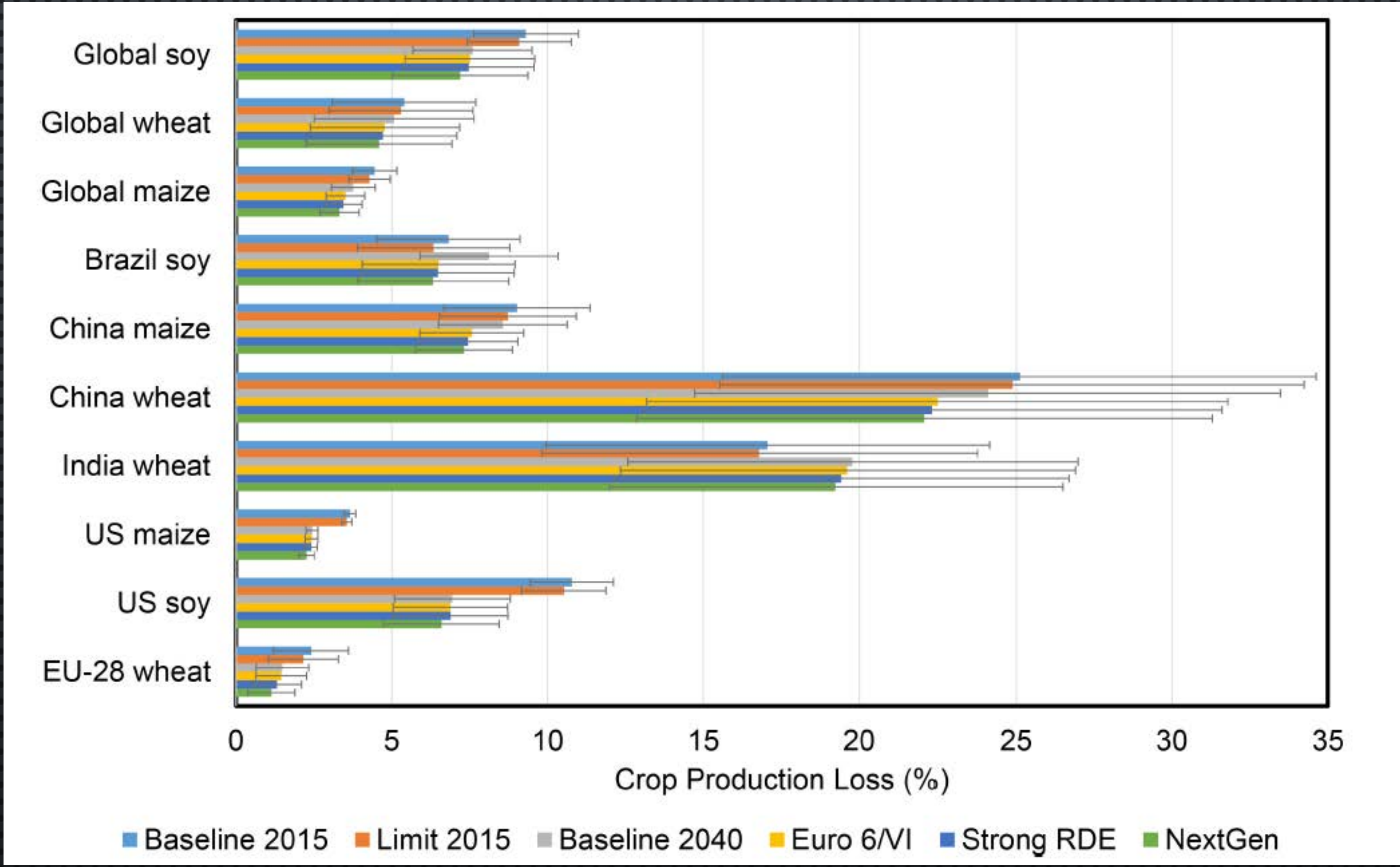
Results



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Results

With no interventions how would CPL change ?
Comparison of CPL Baseline 2040 vs Baseline 2015

Globally, generally see improvements in crop production.

Soy has the biggest improvement with reduced CPL losses of ~2%; then Maize with ~0.8% and wheat with ~0.4%.

At the regional level there is variation dependant upon region and crop

Brazil soy sees in increase in CPL of ~1.2% and Indian wheat sees an increase of ~2.8%

The largest improvements are in US soy and US maize of ~ 4% and 1.2% respectively. EU wheat sees a ~1% reduction in CPL.

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Results

How much better could things be ?
Comparison of CPL 2040 Scenarios vs Baseline 2040

Globally, would see small improvements in crop production of around 0.1 to 0.2% for soy, wheat and maize which increment with the increased stringency of each intervention…Euro 6/VI; Strong RDE; NextGen

There are some 'stand out' results dependent on region and crop type.

Brazil Soy sees a ~1.6% reduction in CPL from Baseline 2040 to Euro 6/VI

China maize and wheat also see 1% and 1.6% reduction in CPL from Baseline 2040 to Euro 6/VI

For US Maize and US Soy only with NextGen will there be any reduction in CPL.

Conclusions

- Effects of changes in 'excess diesel NOx' on CPL depend on crop distribution in relation to current 2015 and projected 2040 ozone concentration levels.
- This effect sees some substantial differences in 'Limit 2015' to 'Baseline 2040' CPLs with some crops & regions seeing large improvements in crop production (e.g. US Soy ~3.6% reduction in CPL) and others seeing worsening crop production (e.g. Indian Wheat ~2% increase in CPL).
- However, in all cases more stringent NOx emission controls will see improvements in crop production. Most notably Soy in Brazil, and Wheat and Maize in China.
- There is uncertainty in the CPLs estimated which we attempt to quantify through use of two different damage (C-R) functions (M7 & AOT40). This sees %CPL estimates vary by ±0.2% to ±10% for the regions and crops selected.
- The study only looks at the effects of excess diesel NOx on yields of 3 staple crops due to ozone. This misses other crops; quality of crops (e.g. visible damage); effects on productive grasslands (e.g. forage quality); effects on forest productivity and other ecosystem services. It also misses effects of aerosol (PM) on plant productivity.

SEI STOCKHOLM ENVIRONMENT INSTITUTE

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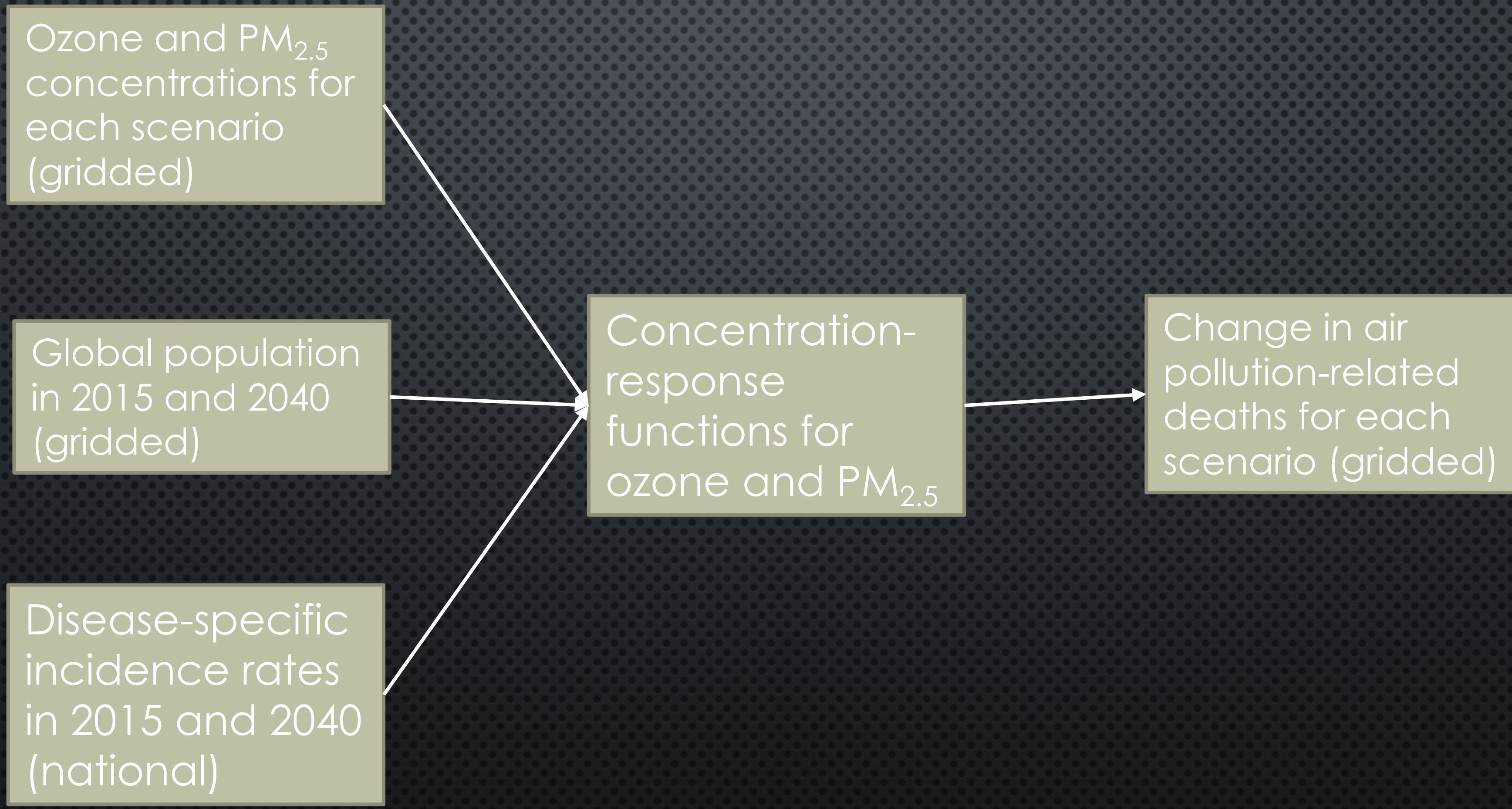
HEALTH IMPACTS OF REAL-WORLD DIESEL NOX EMISSIONS

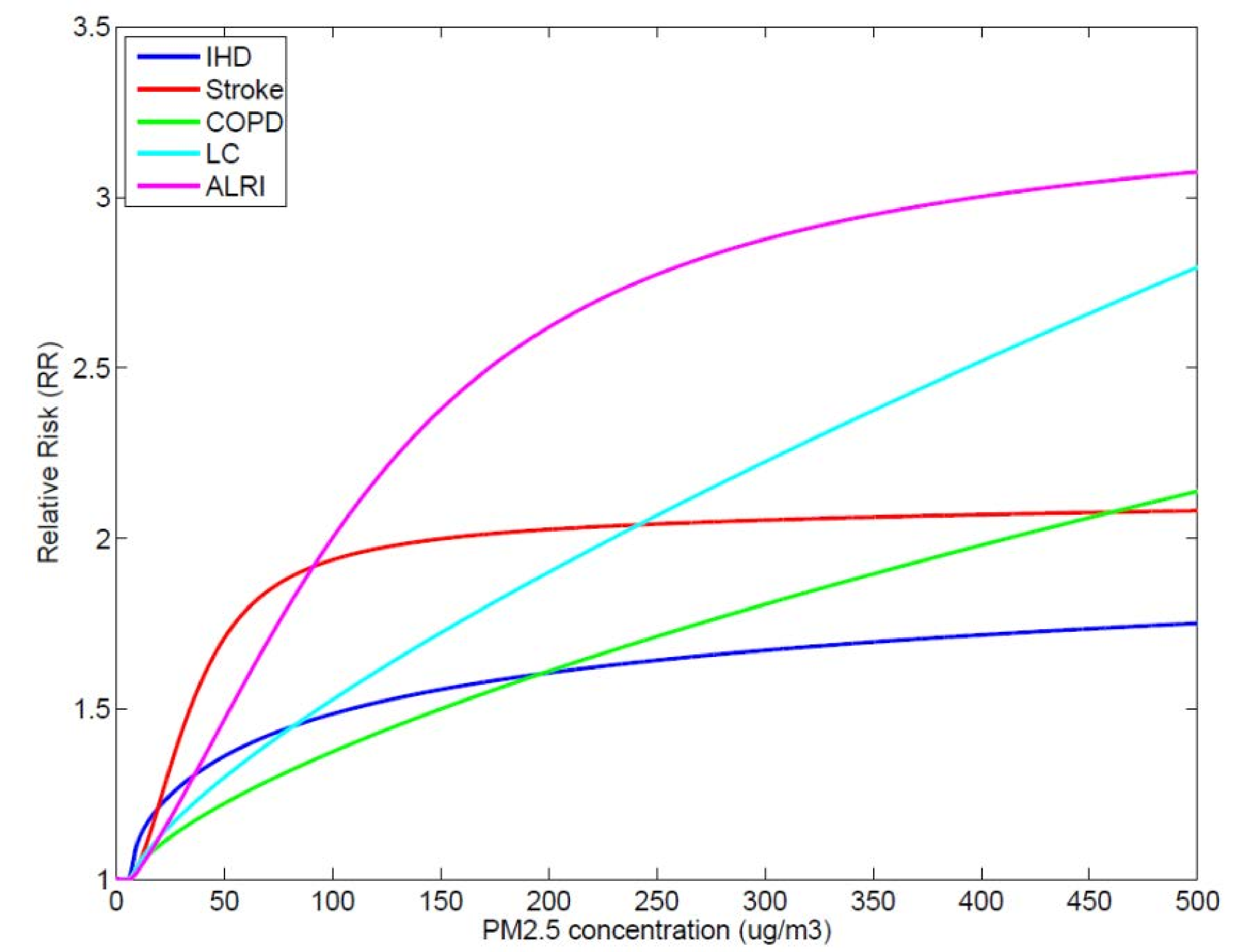
SUSAN ANENBERG, PH.D

PRINCIPAL AND CO-FOUNDER, ENVIRONMENTAL HEALTH ANALYTICS, LLC

HEALTH IMPACT ANALYSIS BASED ON GLOBAL BURDEN OF DISEASE METHODOLOGY

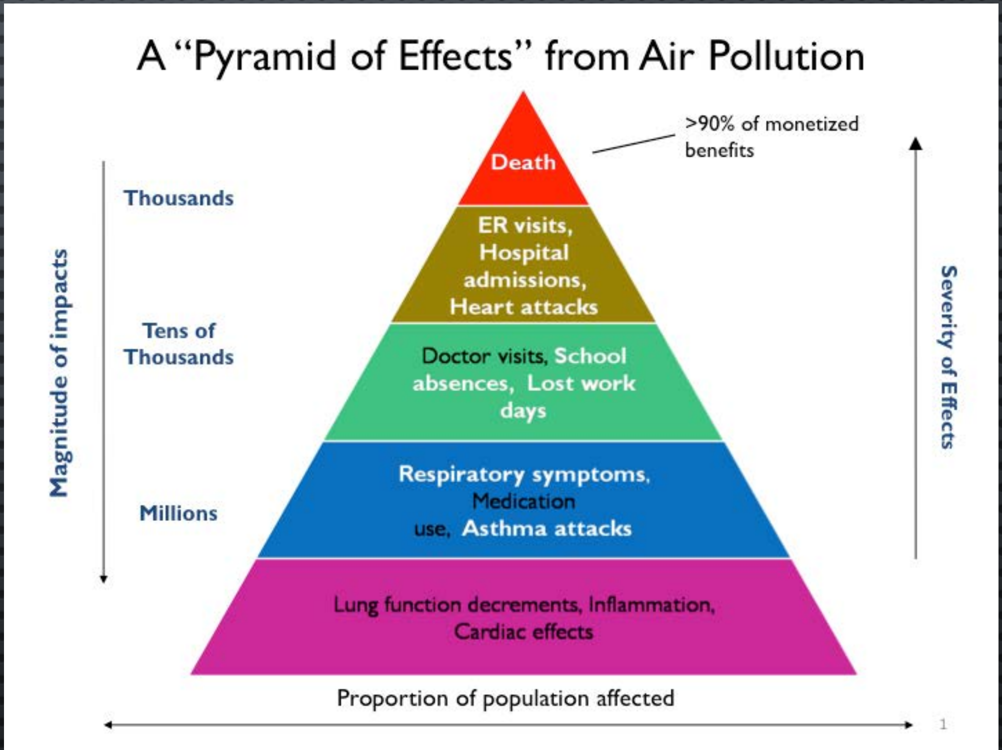


$PM_{2.5}$ INTEGRATED EXPOSURE RESPONSE CURVES

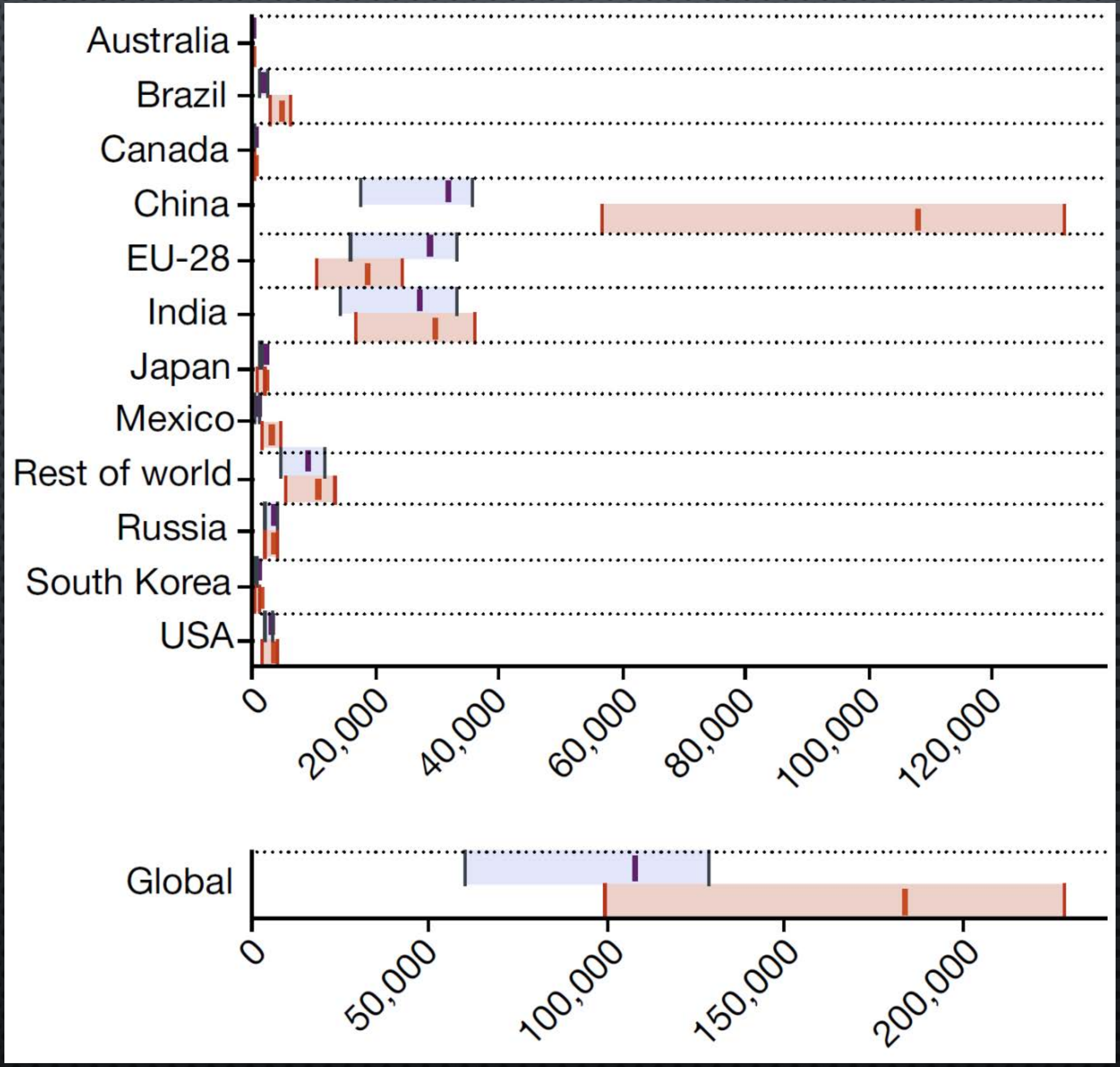


Health Impacts of Diesel NOx Emissions Underestimated

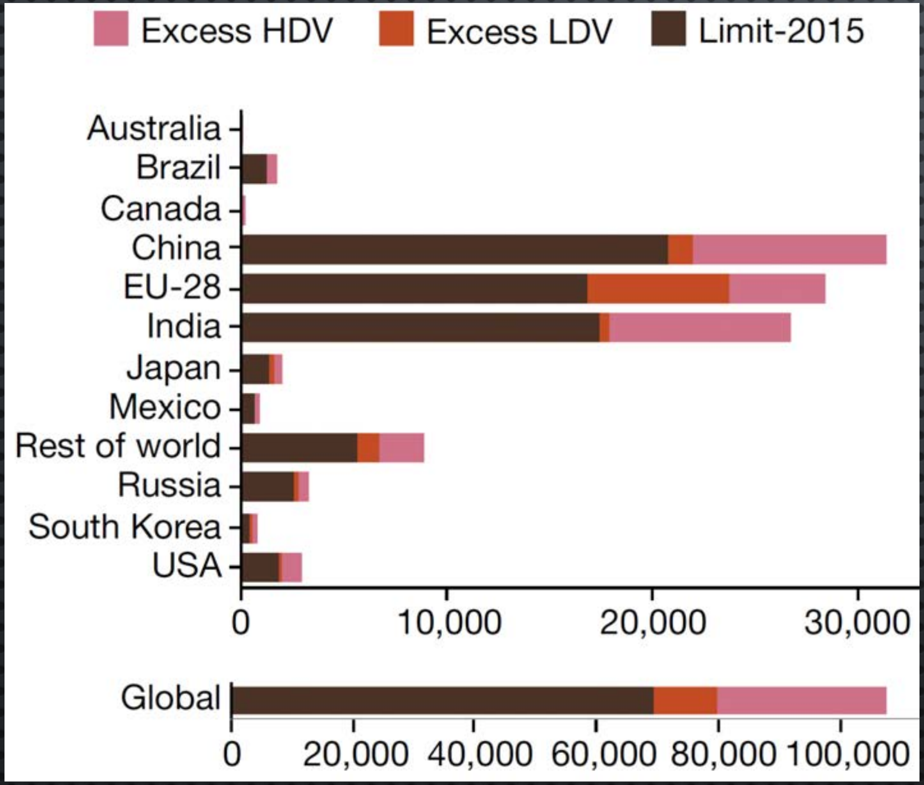
- Premature deaths are only the most severe health outcome associated with ozone and $PM_{2.5}$
- Direct exposure to NO_2 can lead to aggravated asthma and other respiratory diseases, hospital admissions, and emergency department visits



MORE THAN 100,000 GLOBAL AIR POLLUTION DEATHS ANNUALLY FROM ON-ROAD DIESEL NO_X EMISSIONS



38,000 GLOBAL DEATHS ANNUALLY FROM EXCESS DIESEL NOX – 80% IN CHINA, INDIA, AND EU-28



EU-28
~ 28,000 deaths from diesel NOx
~ 11,500 from all excess diesel NOx
~ 6,900 from excess LD diesel NOx

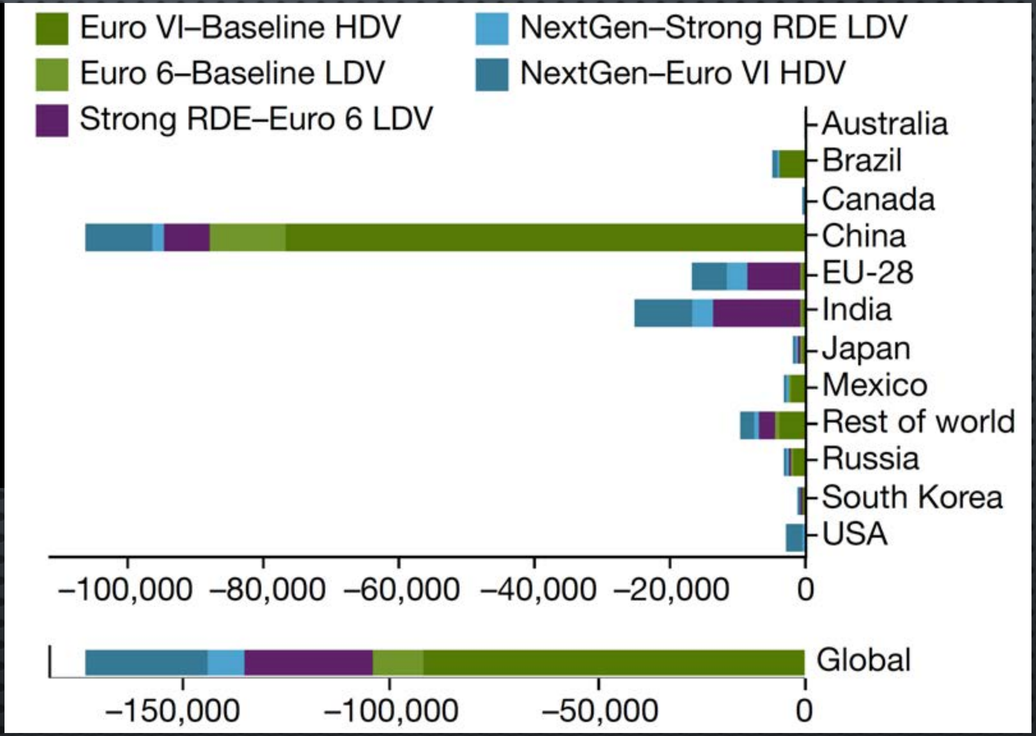
United States
~ 3,000 deaths from diesel NOx
~ 1,100 from all excess diesel NOx
~ 100 from excess LD diesel NOx

China
~ 31,000 deaths from diesel NOx
~ 10,600 from all excess diesel NOx
~ 1,300 from excess LD diesel NOx

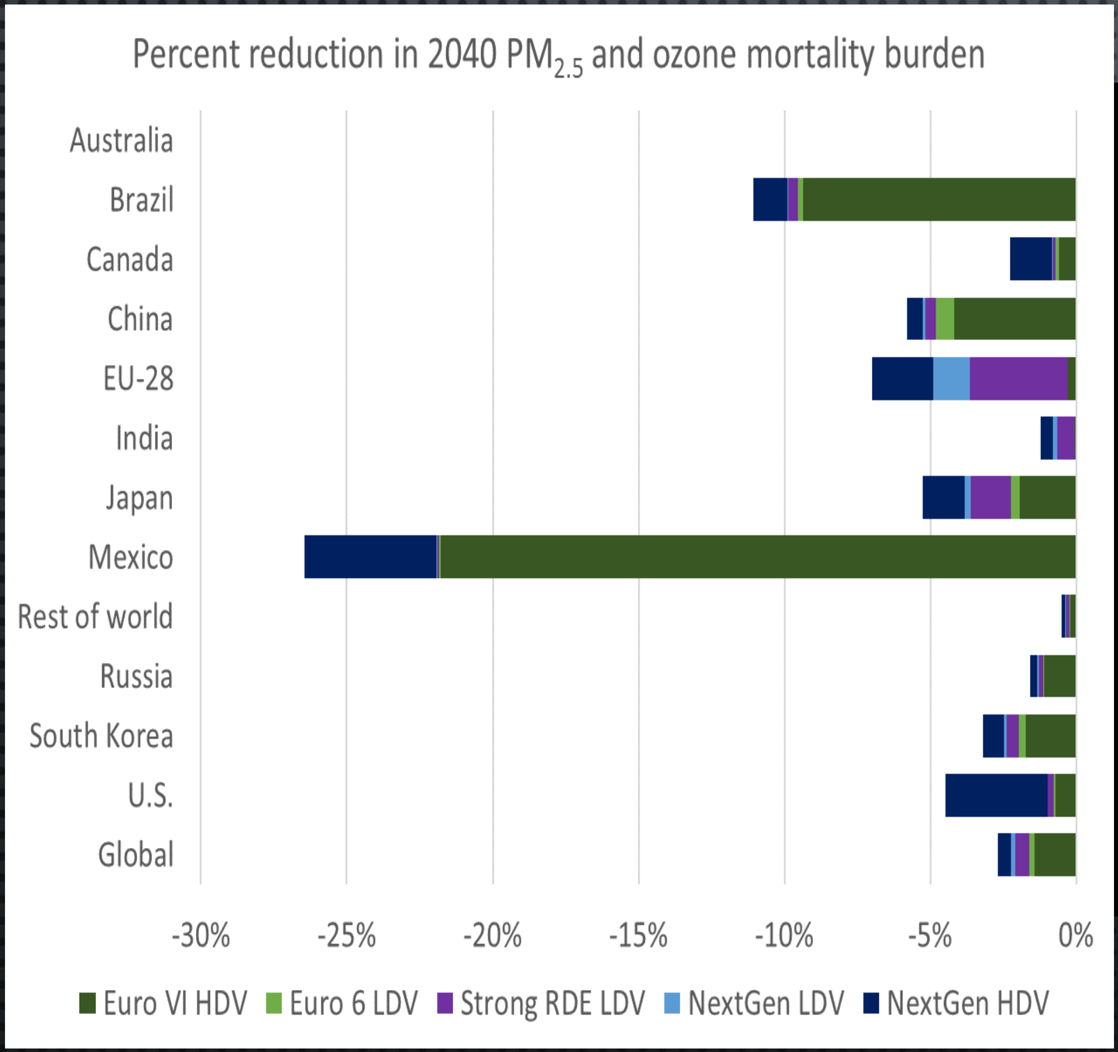
HEALTH IMPACTS EVALUATED: PREMATURE DEATHS AVOIDABLE WITH NEW DIESEL CONTROL POLICIES

Approximately 174,000 $PM_{2.5}$- and ozone-related premature deaths avoidable in 2040 with NO_X regulations in 11 markets.

Translates to 2% of $PM_{2.5}$ and 7% of ozone deaths globally, and 3 million years of life lost.



PERCENT REDUCTIONS IN REGIONAL AIR POLLUTION MORTALITY BURDENS



Next generation standards reduce regional $PM_{2.5}$ and ozone mortality burdens in 2040:

- By 26% in Mexico (22% for Euro 6/VI standards alone).
- By 11% in Brazil (10% for Euro 6/VI).
- By 7% in EU-28 (4% for StrongRDE).

POLICY IMPLICATIONS

- For heavy-duty trucks and buses, implementing Euro VI where not yet adopted is key next step.
- For light-duty vehicles, strong Real-Driving Emissions programs can make Euro 6 and similar standards more effective in real-world driving.
- Adopting and enforcing next-generation standards (more stringent than Euro 6/VI) could nearly eliminate real-world diesel NOx emissions and associated health impacts in these 11 markets.

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Nature article available online at https://t.co/9qHbcv7JEV
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CONCLUSION