Climate Change and Air Pollution: The Final Frontier for Progress

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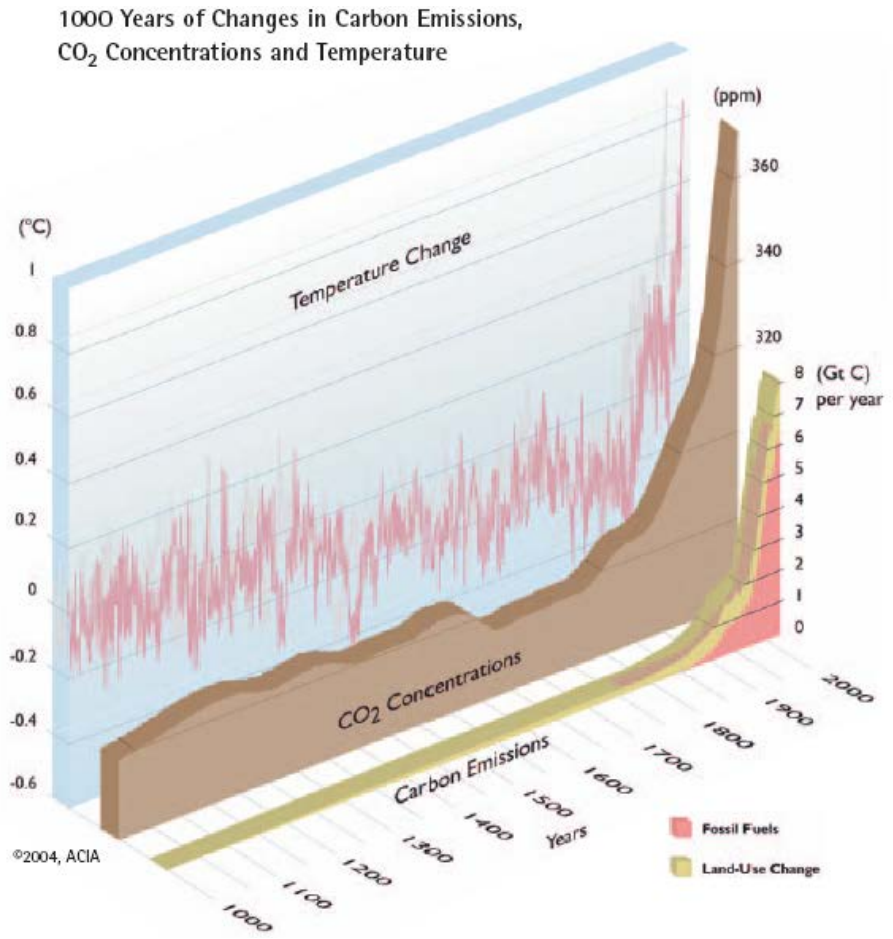
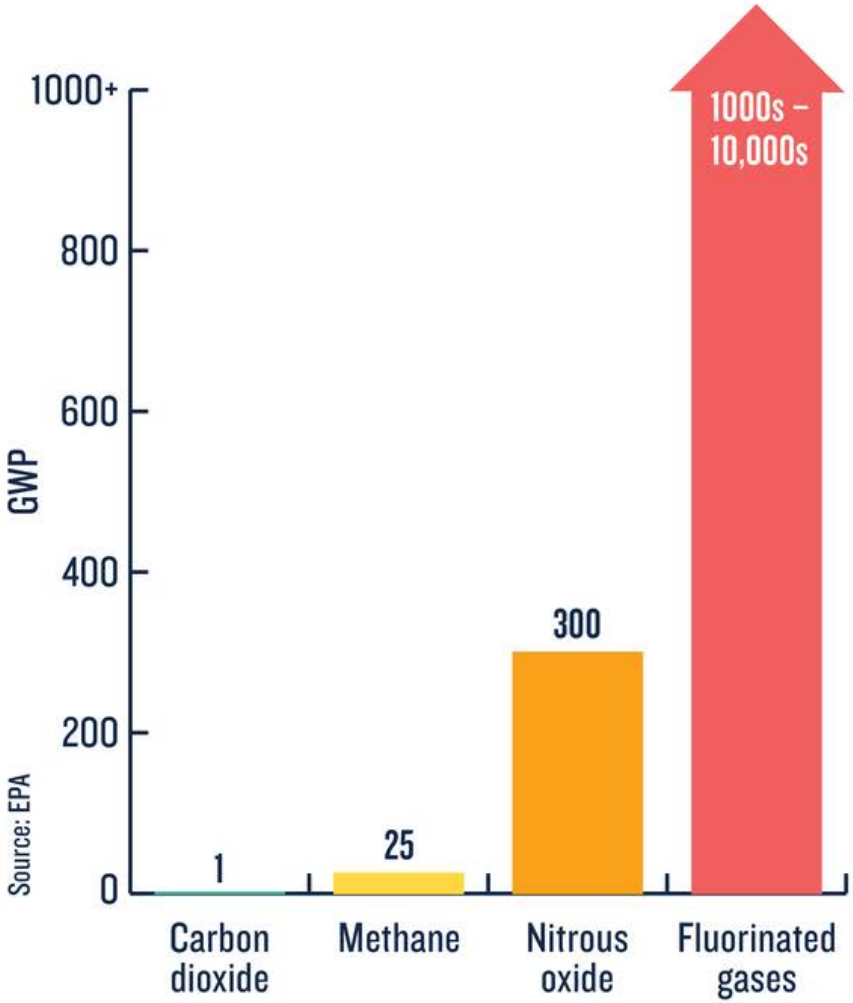
Temperatures are rising rapidly, following increases in CO_2 emissions and concentrations

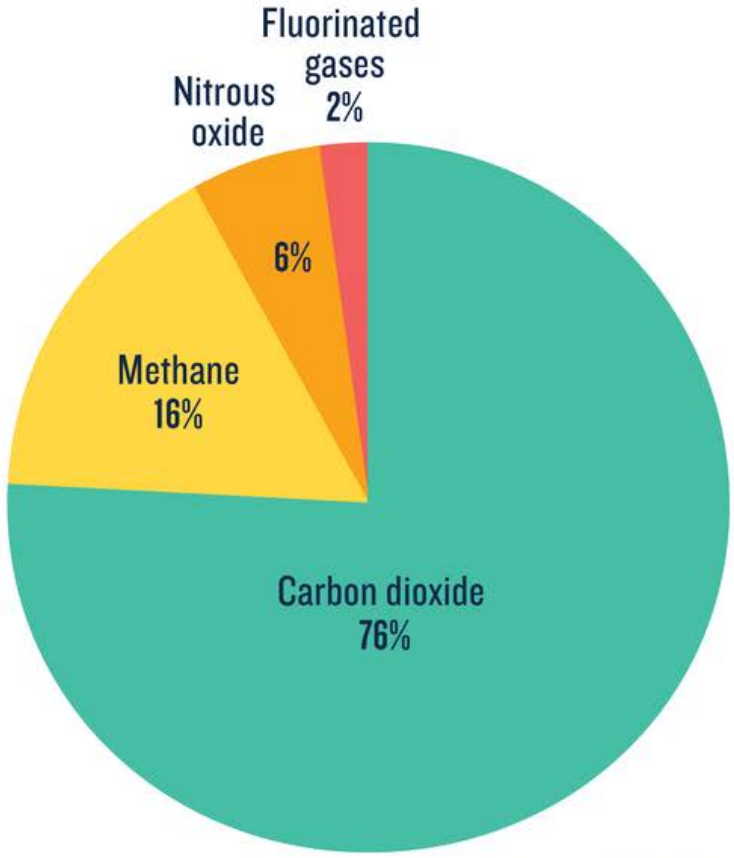


World Health Organization

HOW GREENHOUSE GASES WARM OUR PLANET



The global warming potential (GWP) of human-generated greenhouse gases is a measure of how much heat each gas traps in the atmosphere, relative to carbon dioxide.



How much each human-caused greenhouse gas contributes to total emissions around the globe.

Article

A decline in global CFC-11 emissions during 2018–2019

https://doi.org/10.1038/s41586-021-03260-5

Received: 1 July 2020

Accepted: 11 December 2020

Published online: 10 February 2021

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Article

A decline in emissions of CFC-11 and related chemicals from eastern China

https://doi.org/10.1038/s41586-021-03277-w

Received: 1 July 2020

Accepted: 10 December 2020

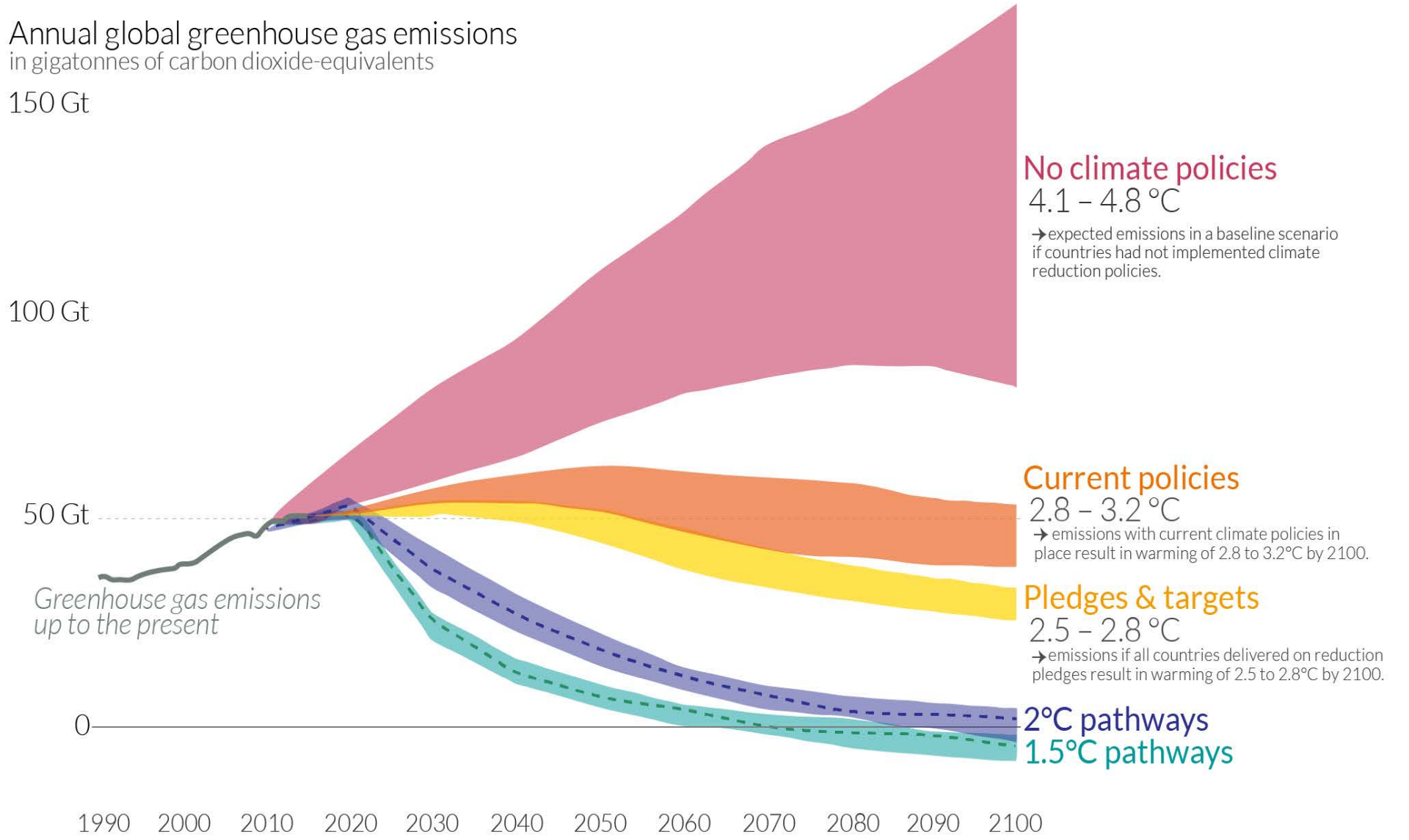
Published online: 10 February 2021

Sunyoung Park[1,14], Luke M. Western[2,14]✉, Takuya Saito[3,14], Alison L. Redington[4,14], Stephan Henne[5,14], Xuekun Fang[6,7,14], Ronald G. Prinn[7]✉, Alistair J. Manning[4], Stephen A. Montzka[8], Paul J. Fraser[9], Anita L. Ganesan[10], Christina M. Harth[11], Jooil Kim[11], Paul B. Krummel[9], Qing Liang[12], Jens Mühle[11], Simon O'Doherty[2], Hyeri Park[1], Mi-Kyung Park[13], Stefan Reimann[5], Peter K. Salameh[11], Ray F. Weiss[11] & Matthew Rigby[2]✉

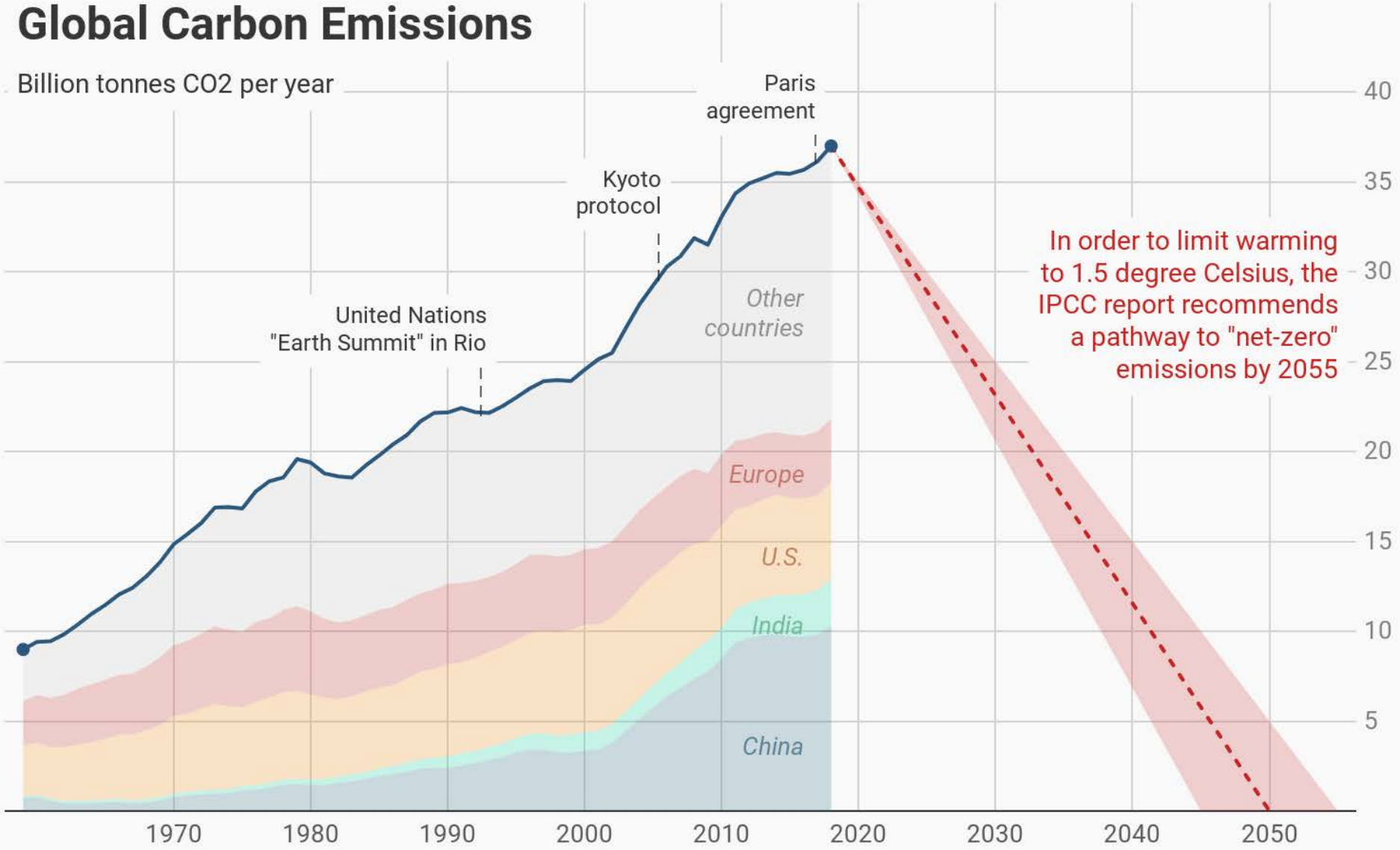
Global greenhouse gas emissions and warming scenarios

Our World in Data

– Each pathway comes with uncertainty, marked by the shading from low to high emissions under each scenario.
– Warming refers to the expected global temperature rise by 2100, relative to pre-industrial temperatures.

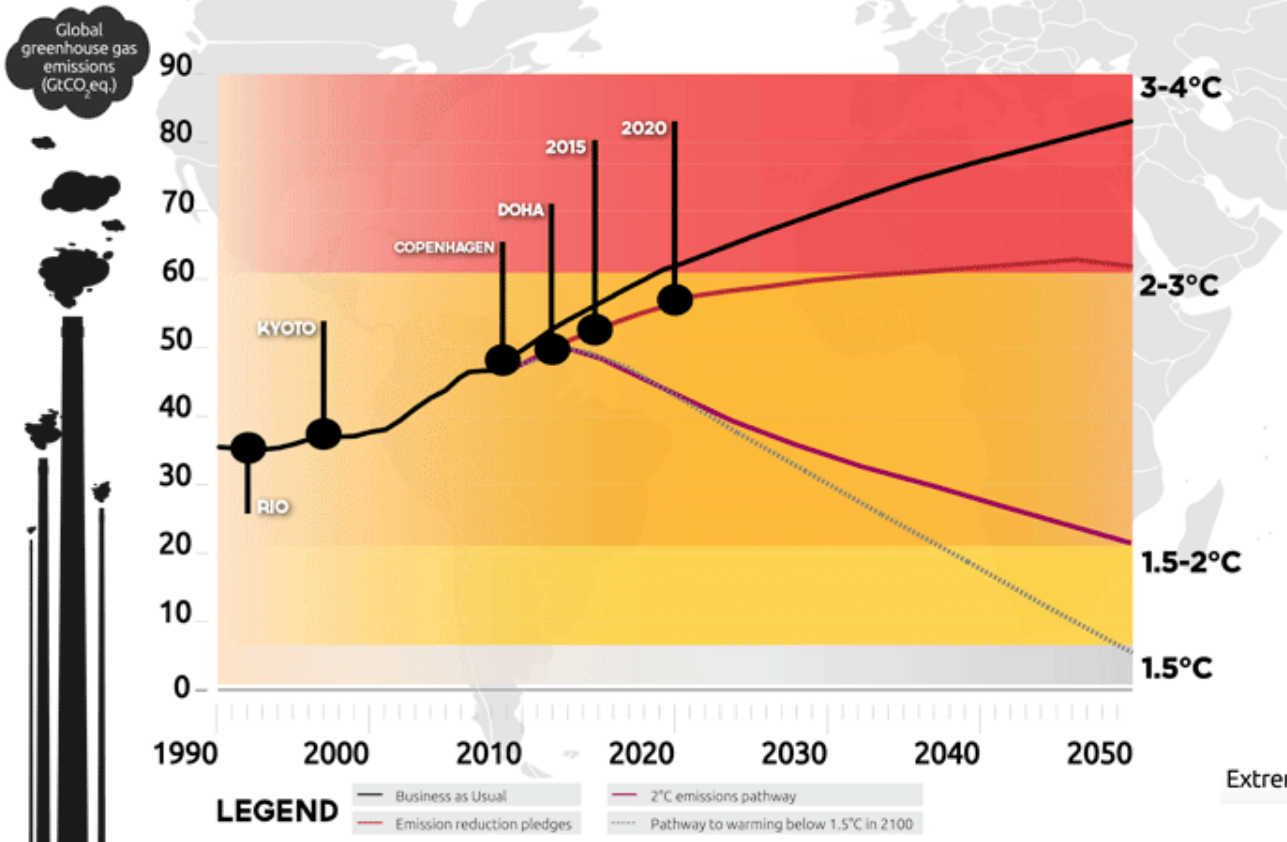


Data source: Climate Action Tracker (based on national policies and pledges as of December 2019).


Global Carbon Emissions
Billion tonnes CO2 per year
Paris agreement
Kyoto protocol
United Nations "Earth Summit" in Rio
Other countries
Europe
U.S.
India
China
In order to limit warming to 1.5 degree Celsius, the IPCC report recommends a pathway to "net-zero" emissions by 2055
40
35
30
25
20
15
10
5
1970
1980
1990
2000
2010
2020
2030
2040
2050
Source: Global Carbon Budget 2018 • Get the data

STAYING BELOW 2°C: THE CHOICES WE FACE

With current pledges on the table to cut emissions, we are heading to a 3.3° C warming future. No further action before 2020 will limit society's choices. As temperatures rise, so do the impacts.



Adaptation highly questionable

Unprecedented heat waves

20-30% increase extreme precipitation

Risk of global mass extinctions

Global crop decline

Significant Amazon dieback

Millions risk displacement by sea level rise

Tipping point for Greenland Ice Sheet

High risks for regional food security

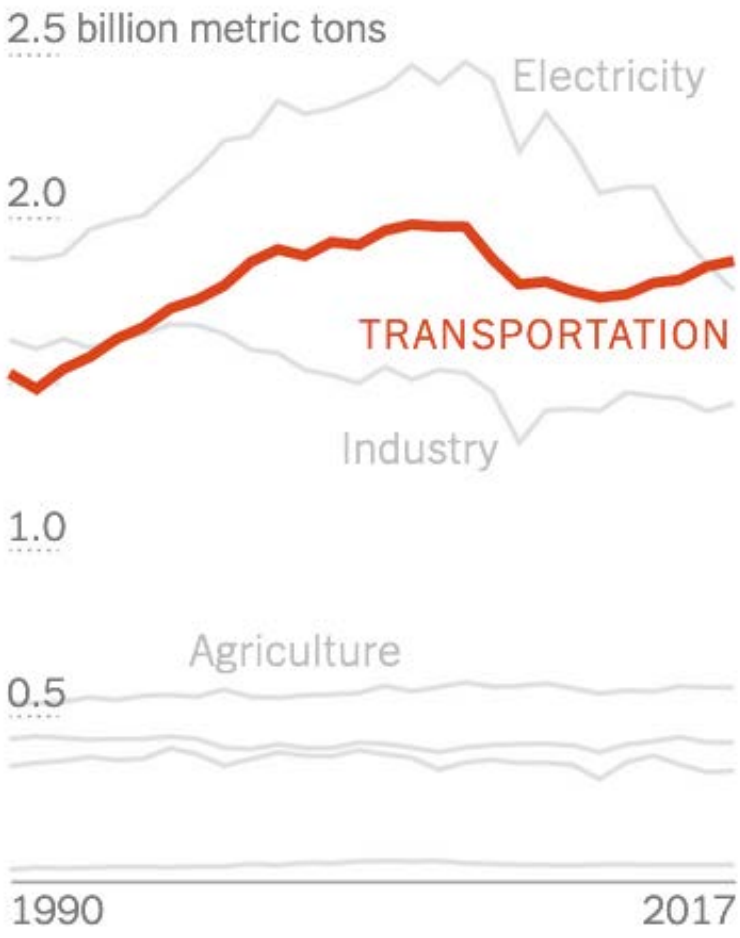
Major risk to most coral reefs

Food production losses

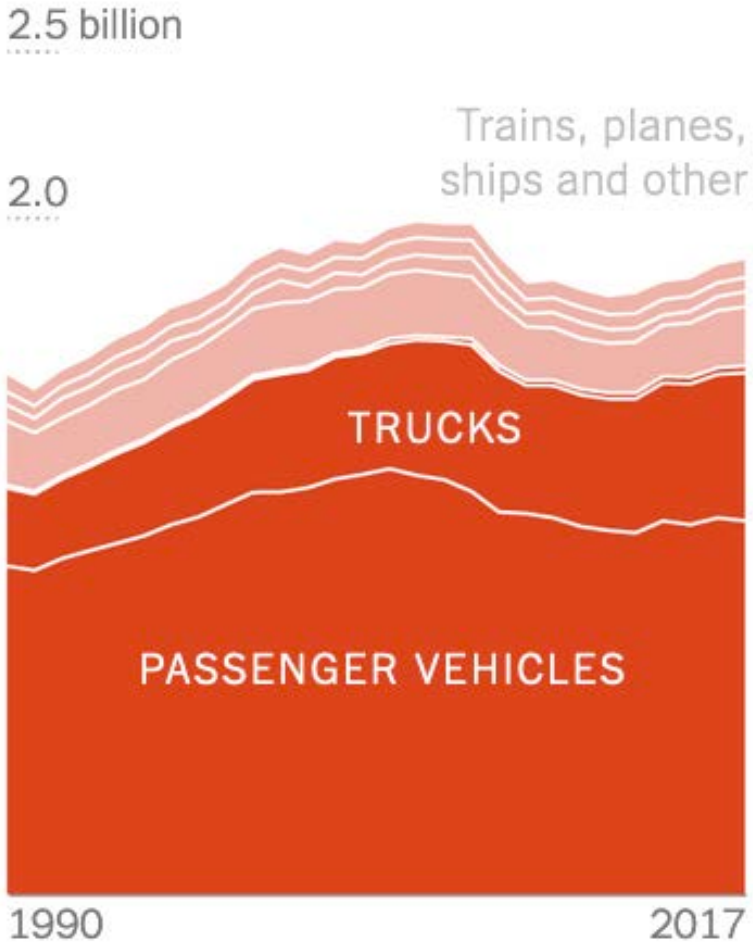
Extreme heat waves with severe societal impacts

What is Leading Source of GHG Emissions in the US?

In 2017, **transportation** was the top source of greenhouse gases.

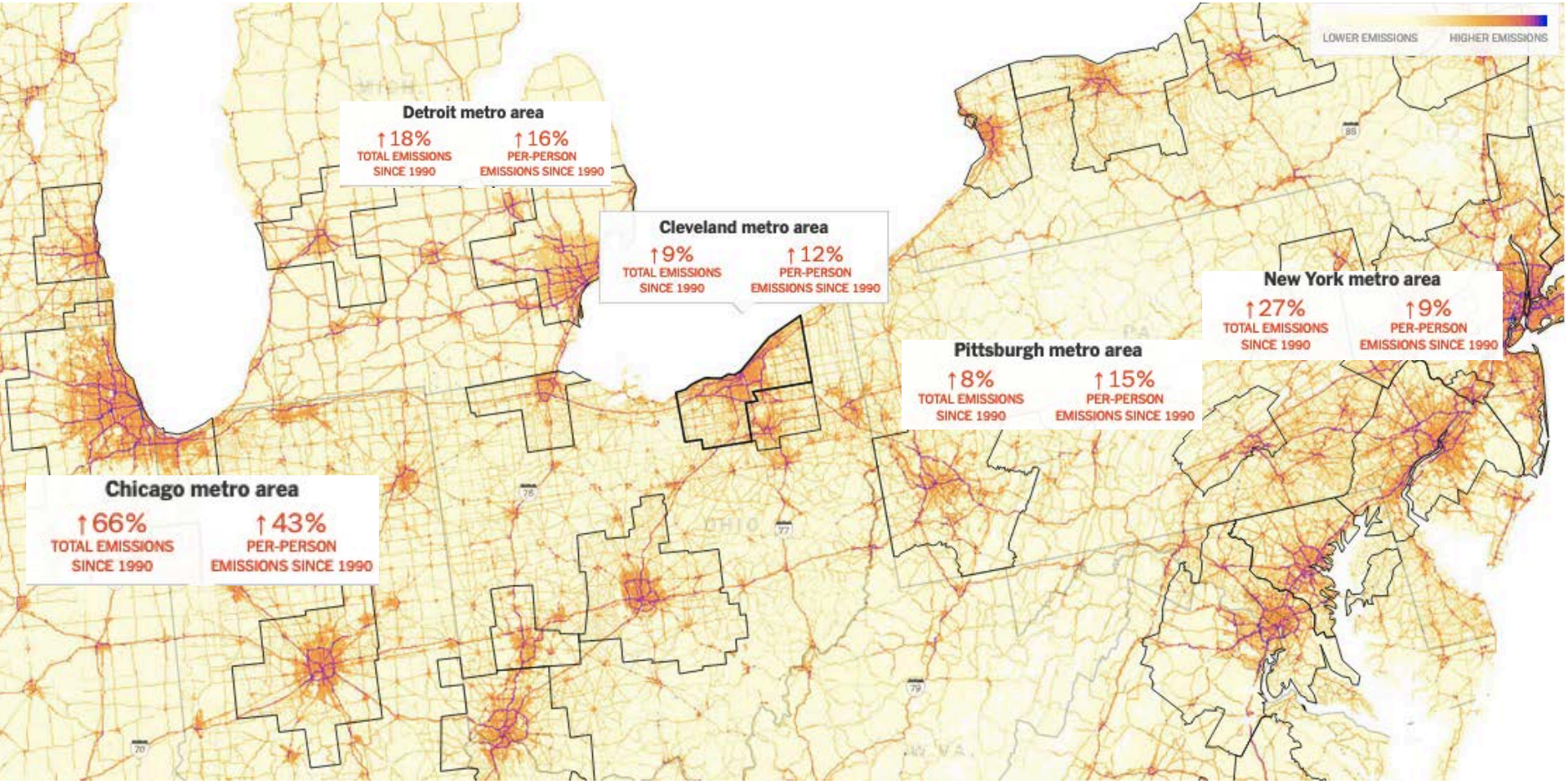


The vast majority of those emissions came from **driving**.



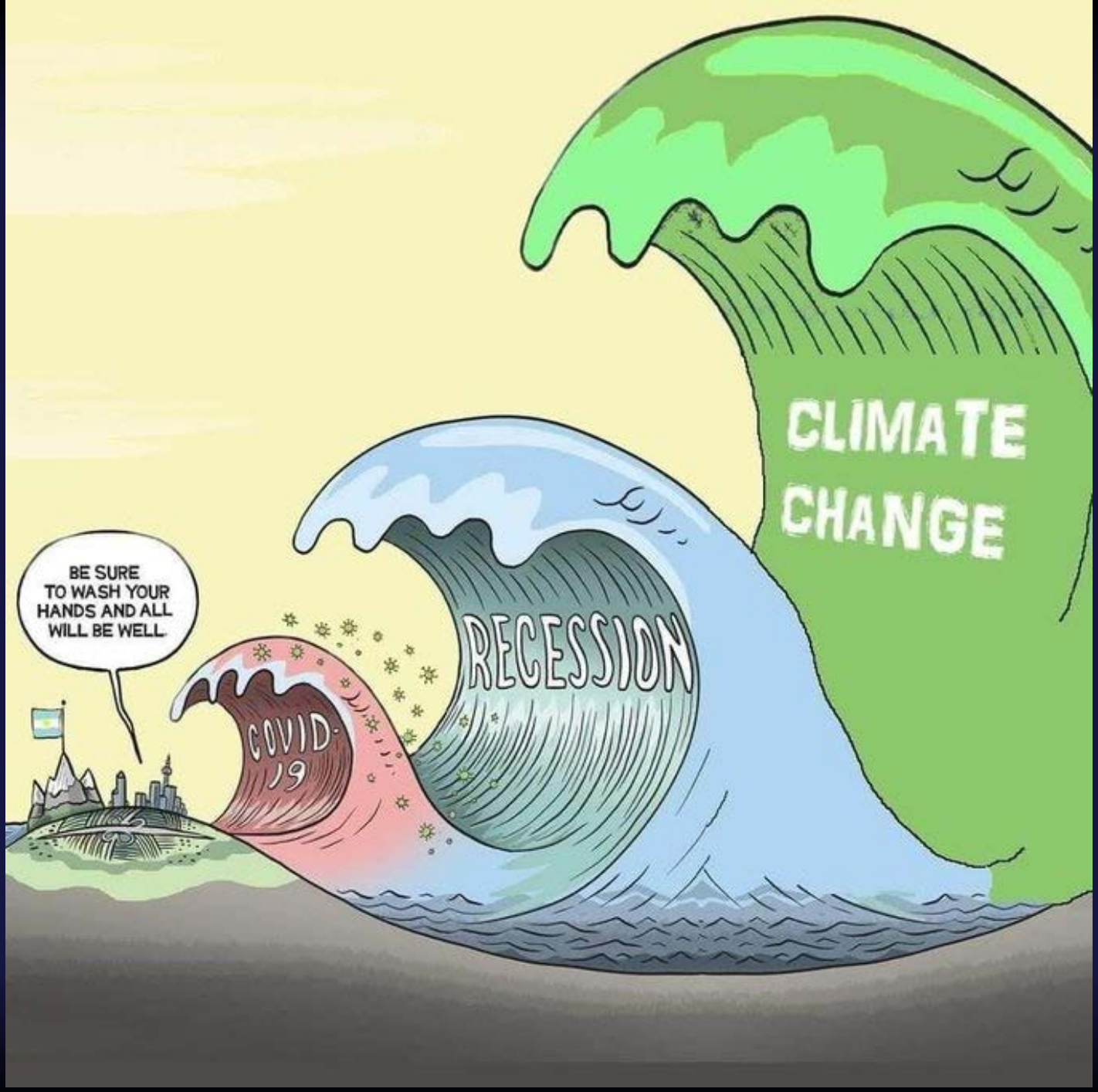
Charts show the carbon dioxide equivalent of greenhouse gas emissions. ·Source: Environmental Protection Agency

DARTE Annual On-road CO_2 Emissions on a 1-km Grid, Conterminous USA, V2, 1980-2017



EARTHDATA Other DAACs
ORNL DAAC
DISTRIBUTED ACTIVE ARCHIVE CENTER FOR BIOGEOCHEMICAL DYNAMICS

https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1735


BE SURE TO WASH YOUR HANDS AND ALL WILL BE WELL
COVID-19
RECESSION
CLIMATE CHANGE

2020 Global Emissions Fell by 7%

Meeting the Paris Agreement Target of 1.5

Will Require 7% Decreases Every Year for 10 years

Low Oil Prices

COVID-19 and Emissions: An Opportunity for Sustainable Global Health. Rajagopalan S, Jackson S et al. EHJ 2021 (In press)

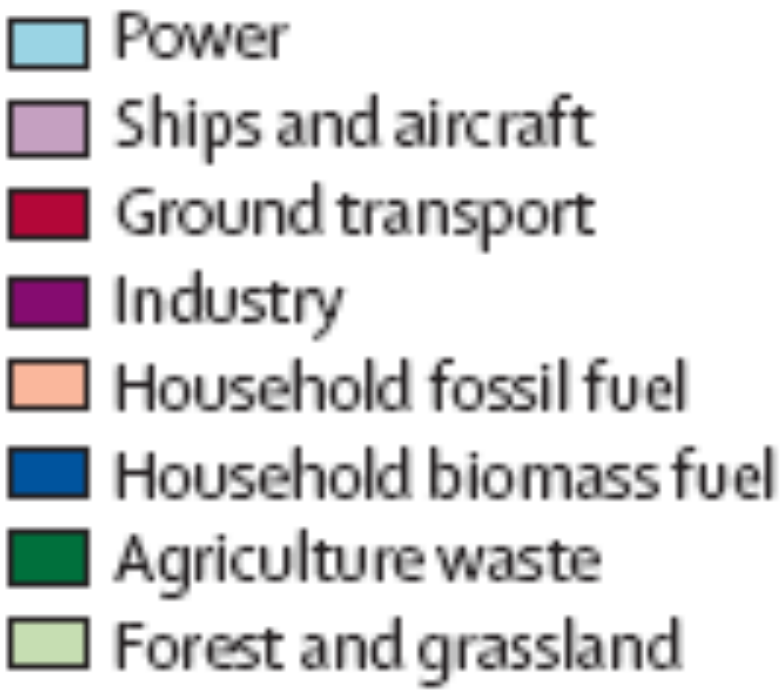
Emissions Influence Climate

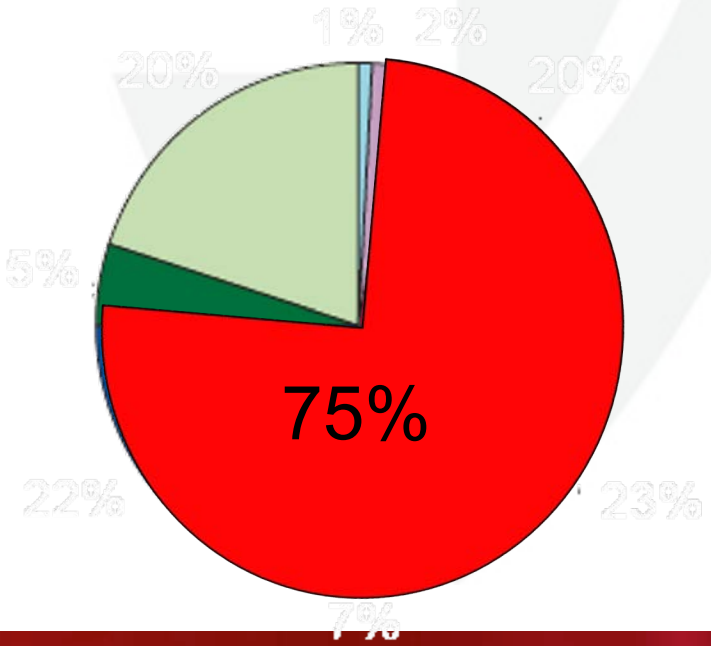
Positive Proof of Global Warming

The Same emissions (other than CO_2) from the same sources that affect global warming…..also affect global health!

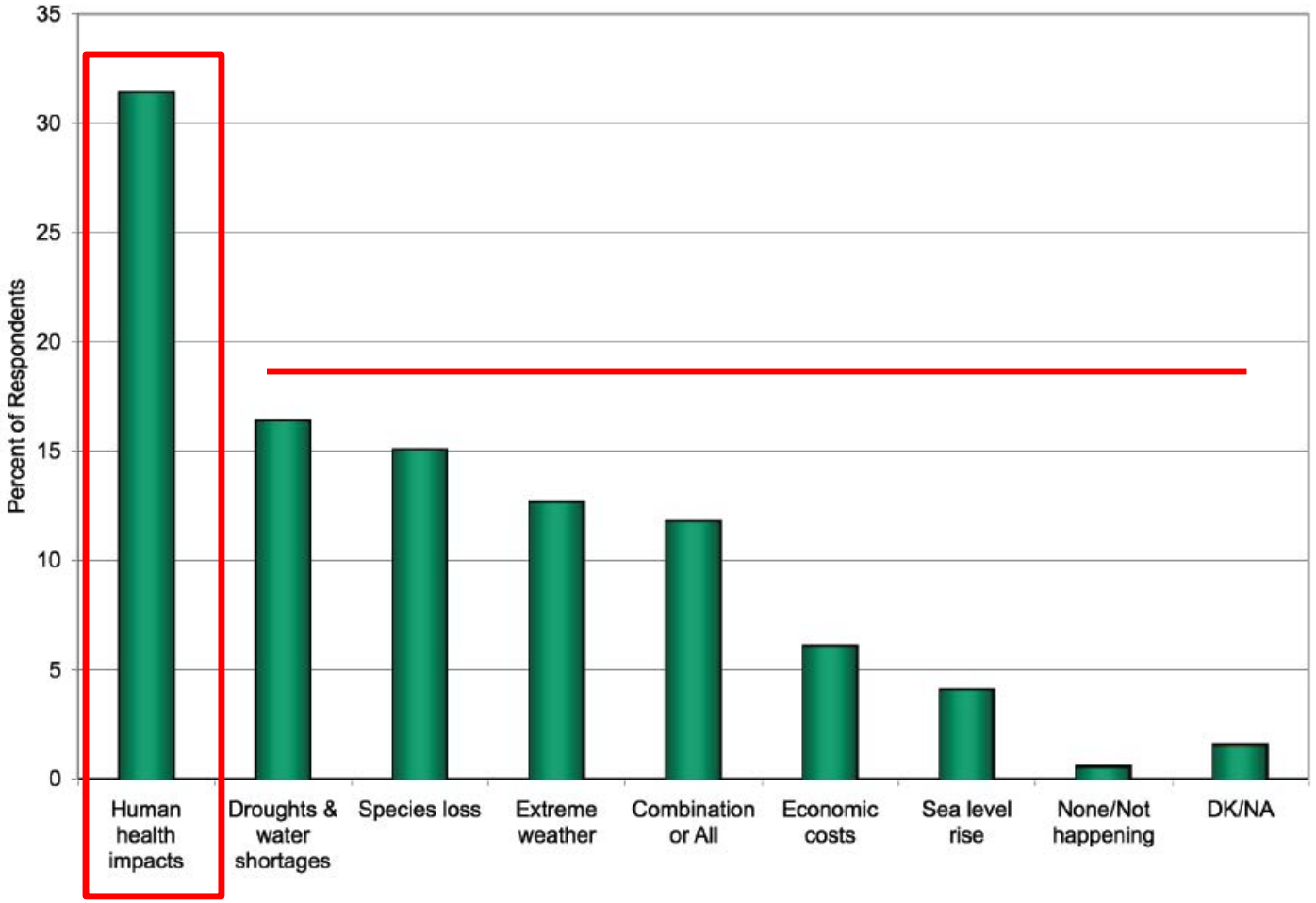
The Focus Should be on Air Pollution

Black Carbon Emissions





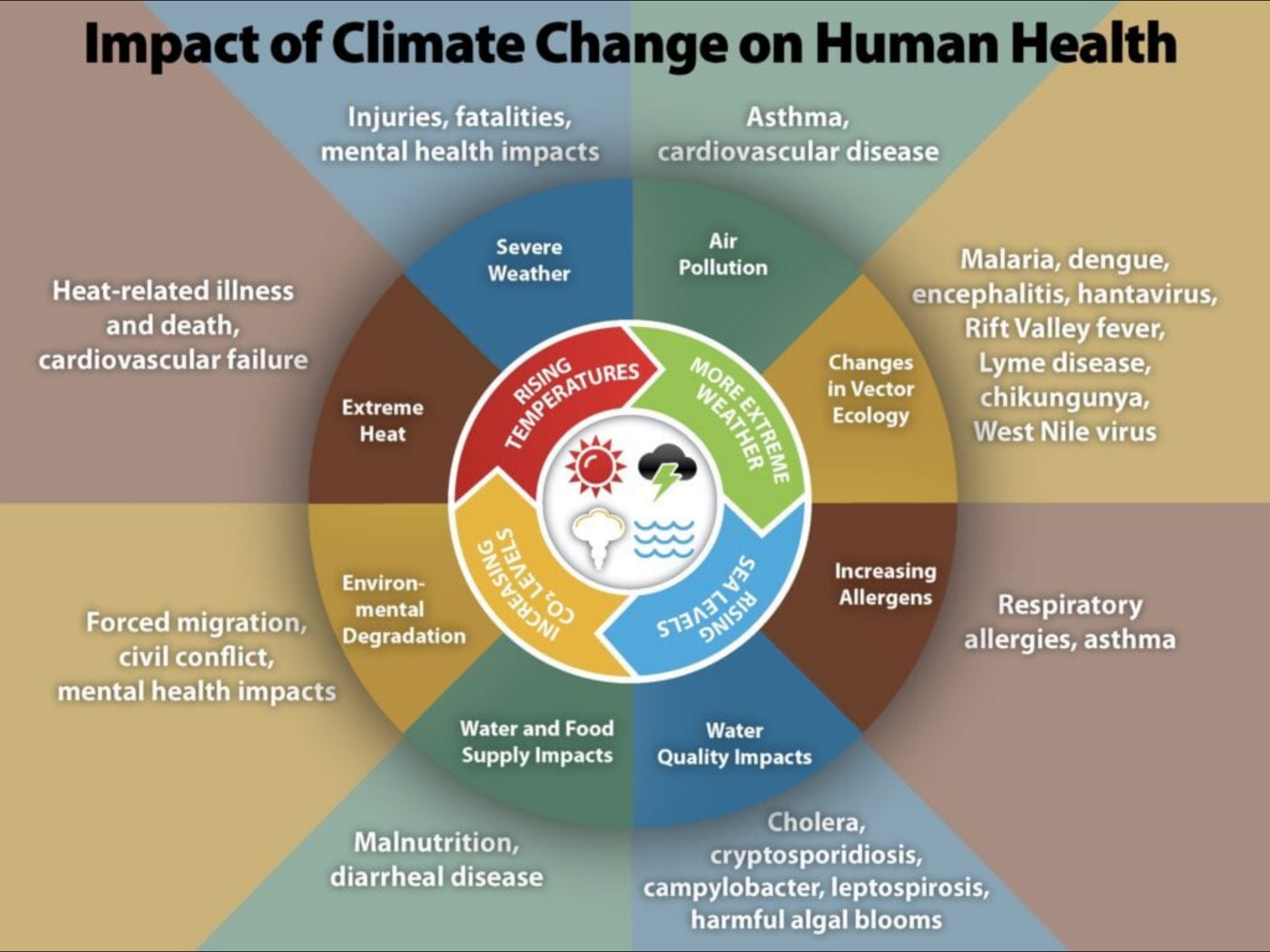
High public concern over Climate Risks to Health



Globescan poll in 30 countries (UNDP):

Which ONE of the following possible impacts most concerns you personally, if any?”

Impact of Climate Change on Human Health



HYPOTHESIS

Choice of Policies With Short Term Health and Ecosystem (Climate) Co-Benefits Provide Biggest Bang for the Buck

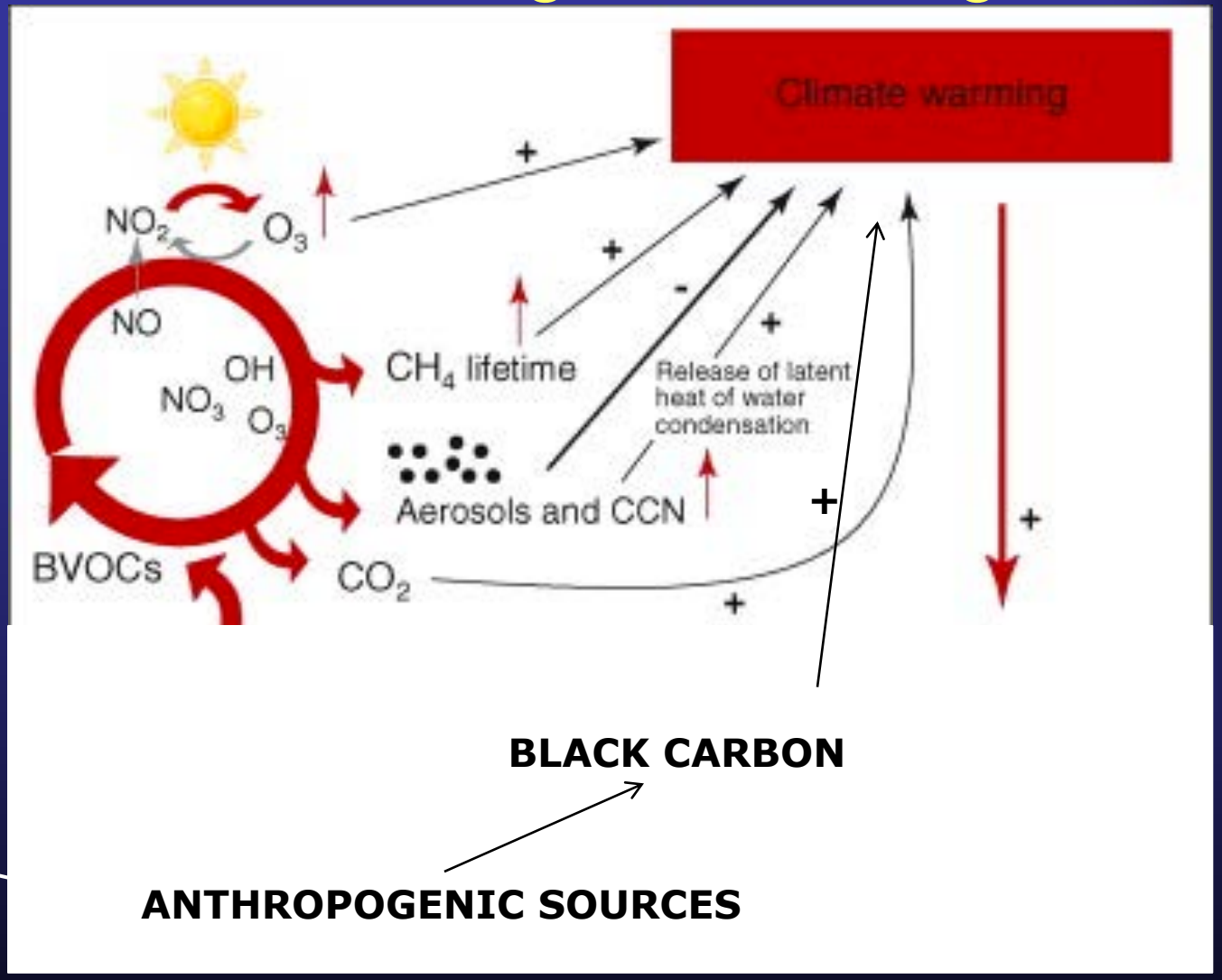
SHORT TERM POLLUTANTS

ANYTHING WITH CARBON RELEASED INTO THE ATMOSPHERE

Anthropogenic Sources of Air Pollution: Implications for Warming and Cooling

OZONE

CH_4
CO
NO_2



GASES/VAPORS NO_x, CO, SO_2, O_3 VOC, SVOC

- Anthropogenic emissions
- extraordinarily complex

UFP

PM2.5

PM10

Composition
Primary combustion – hydrocarbons (PAH), metals, organic carbon
Sources
Fresh automobile and combustion emissions, diesel emissions
Distribution
Minutes to hours. Distributes 100s of meters

Composition
Organic/elemental carbon (hydrocarbon, PAH); Metals, Inorganic ions: NH4-SO4, NO2
Sources
Fossil fuel, Power, Industry . Traffic, Biomass, heating, cooking
Distribution
Airborne for days
Distribute regionally (>1000 Km)

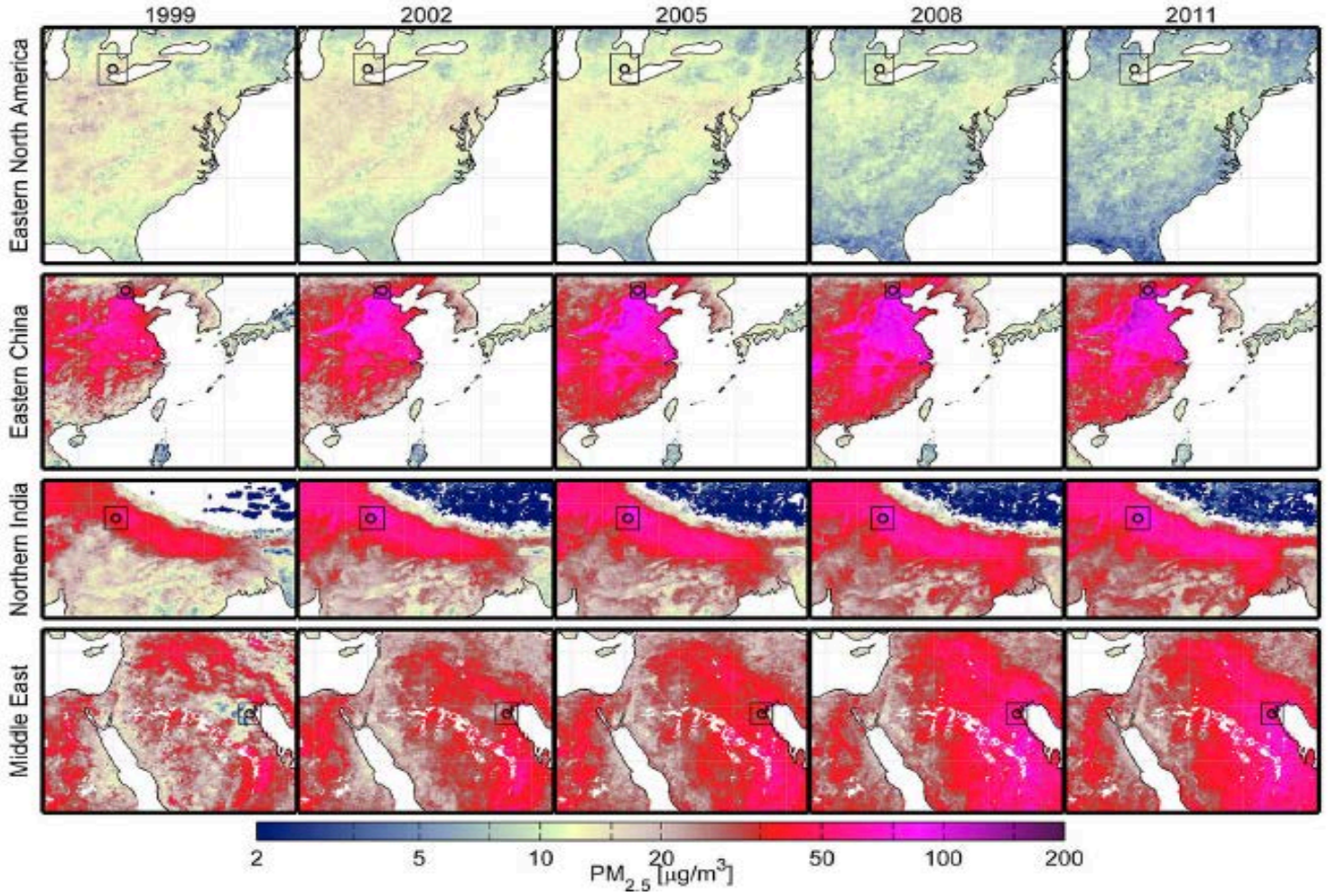
Composition
Road dust, erosion
Agriculture sources
Biologics (pollen, spore)
Sources
Agriculture, Deserts
Distribution
Airborne for days
Distribute regionally

US Air Quality Regulations

- 1970: EPA formed, Clean Air Act (Richard Nixon)
- 1971: NAAQS (National Ambient Air Quality Standards)
- 2006: Tightened NAAQS

Pollutant	Day ($\mu g \cdot m^{-3}$)	Annual ($\mu g \cdot m^{-3}$)
$PM_{2.5}$	35 (was 65)	15 (no change)
• 2013	35 (NC)	12
WHO $PM_{2.5}$	25	10

Global Trends in $PM_{2.5}$

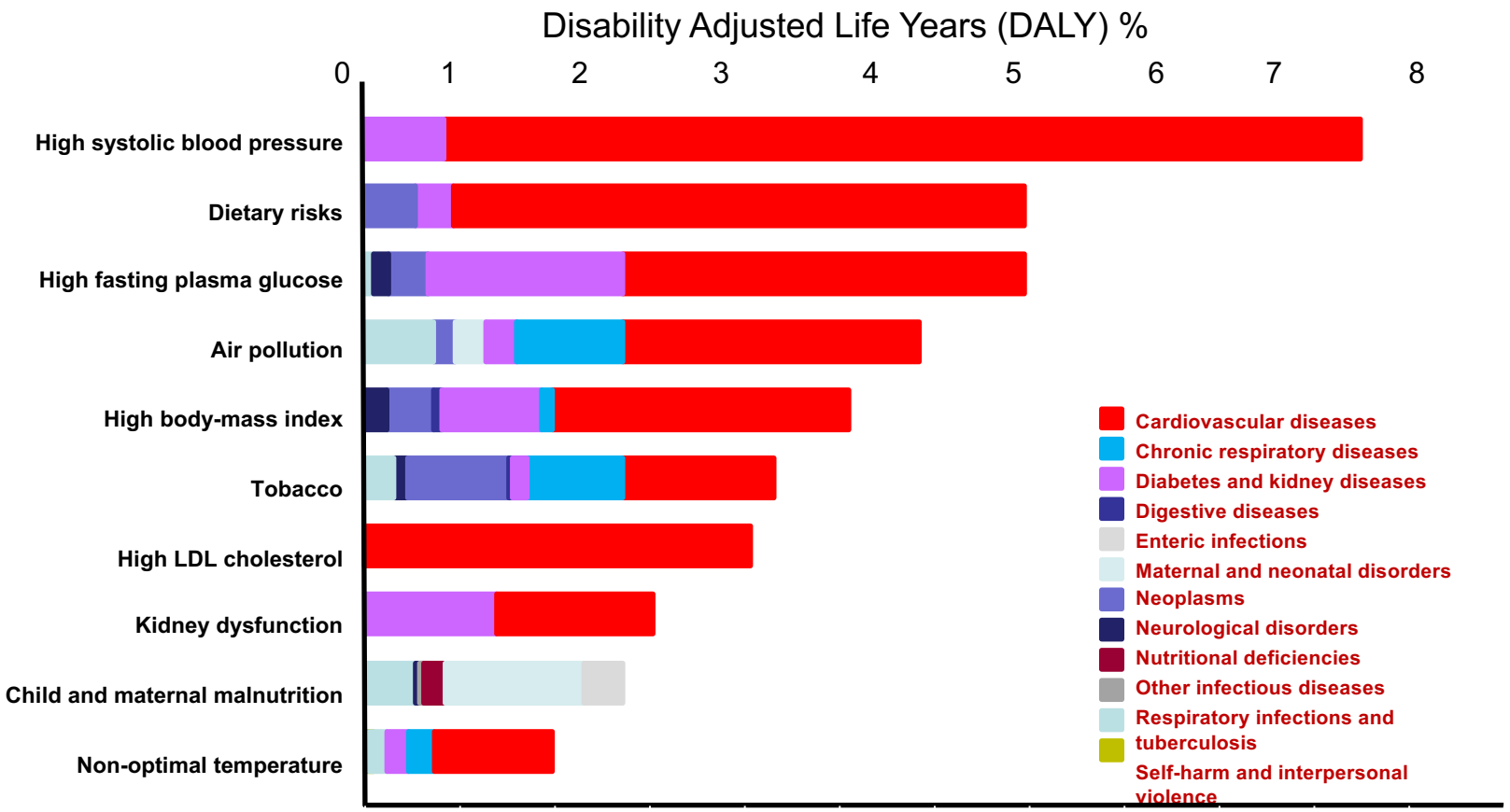


Target	1998-2000	2010-2012
Living Above WHO Interim Target 1 of 35	51%	70%
Living Above WHO AQ Guideline of 10	62%	19%

Van Donkelaar et al. EHP October 2014

Key Point 1. Air Pollution is a Leading Cause of Global CV Morbidity and Mortality

Estimates of Global Attributable Deaths from Various Risk Factors



DALYs= Years lived with Disability + years of life lost

Adapted from GBD 2019 Risk Factors Collaborators. *Lancet* 2020; 396: 1223–49

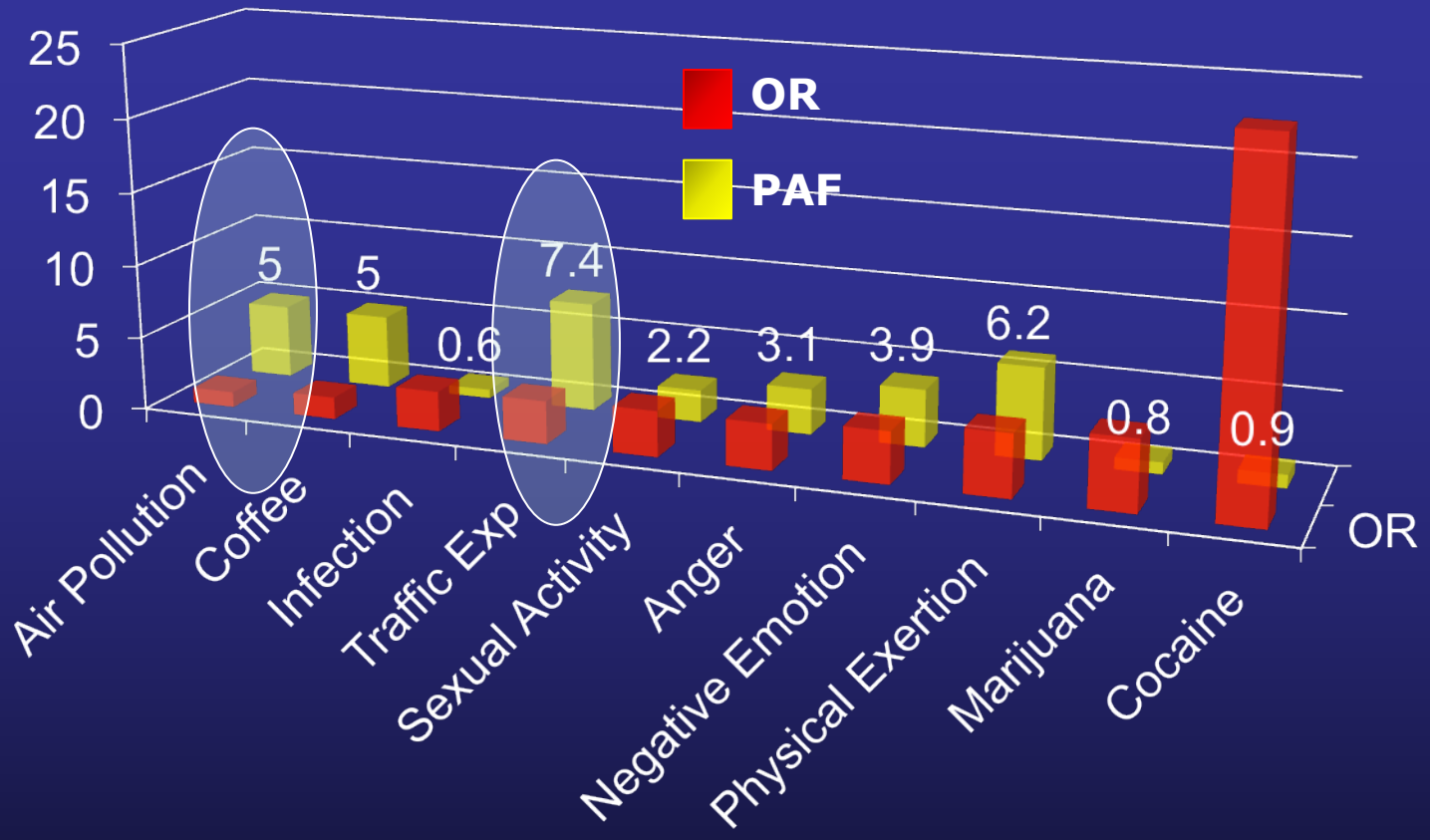
Revised Estimates of Outdoor Air Pollution Mortality: Chemical Transport Models

- Outdoor air pollution ($PM_{2.5}$) leads to 3.3 million premature deaths per year, worldwide (predominantly in Asia)
- CVD and IHD top reasons for death
- Emissions from residential power/cooking important in India/China;Traffic/Power in US/Europe' Agricultural in Russia
- Business as usual emissions=Doubling by 2050

Lelieveld et al. Nature. 2015 Sep 17;525(7569):367-71

nature

Public Health Importance of Myocardial Infarction: A Comparative Assessment



Nawrot et al Lancet February 26, Vol 377; 732-40; 2011

Acute and Chronic Effects of PM

- Preponderant effects of PM Cardiovascular
- An acute (days) 10 μg•m^3 increase in PM2.5 elevates CV mortality by 1% (1 death / day / 5 million people). Predisposition important
- Chronic exposure increases risk by ≥ 10%

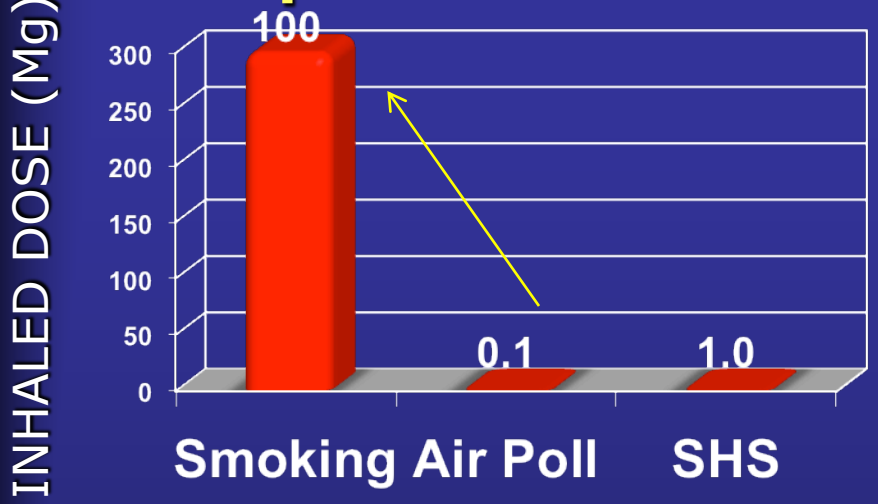
EVENT	HAZARD RATIOS
MACE	1.24 (1.09-1.41)
CV Death	1.76 (1.25 to 2.47

✓ 65,893 postmenopausal women 36 U.S. cities. NEJM 2007

1. Samet JM et al. Fine particulate air pollution and mortality in 20 U.S. cities, 1987–1994. N Engl J Med. 2000; 343: 1742–1749. 2. Dominici F et al. Mortality among residents of 90 cities. In: Revised Analyses of Time-Series Studies of Air Pollution and Health. Boston, Mass: Health Effects Institute; 2003: 9–24. 3. Katsouyanni K, et al. Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 Project. Epidemiology. 2001; 12: 521-23. 4. Pope CA et al. JAMA 2002; 287: 1132-41; 5. Kaufman JD et al NEJM. 2007;356:447-58

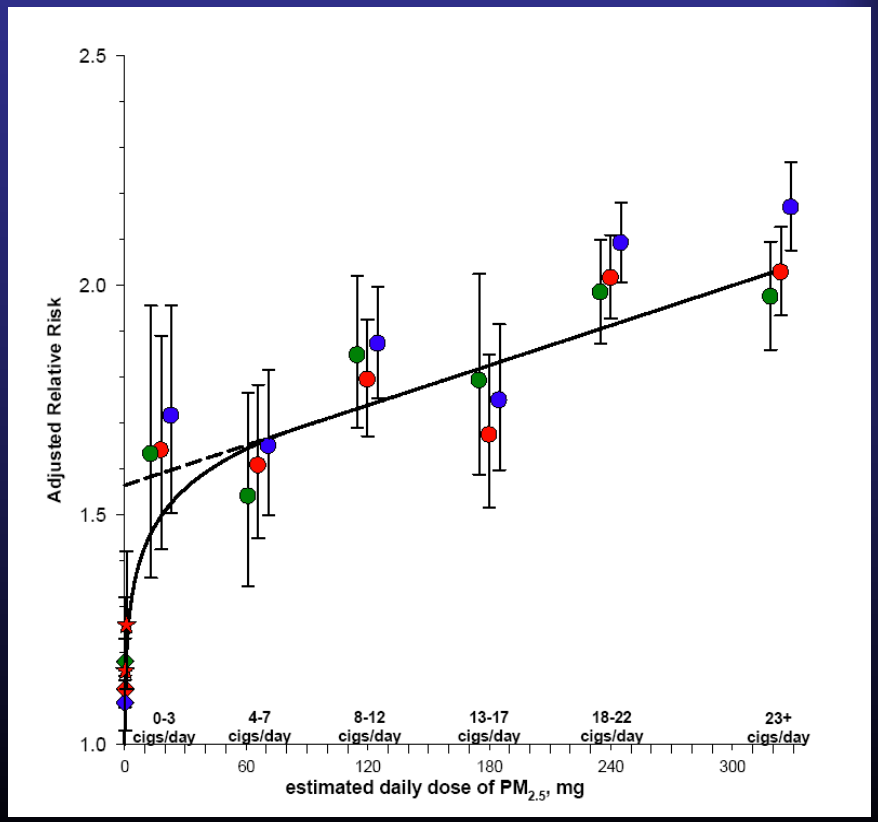
Key Point 2. Even a little Dose of Air Pollution is Bad from a CV Perspective!

What Dose Are We Talking About?: Dose Response of Particle Exposure and CV Risk



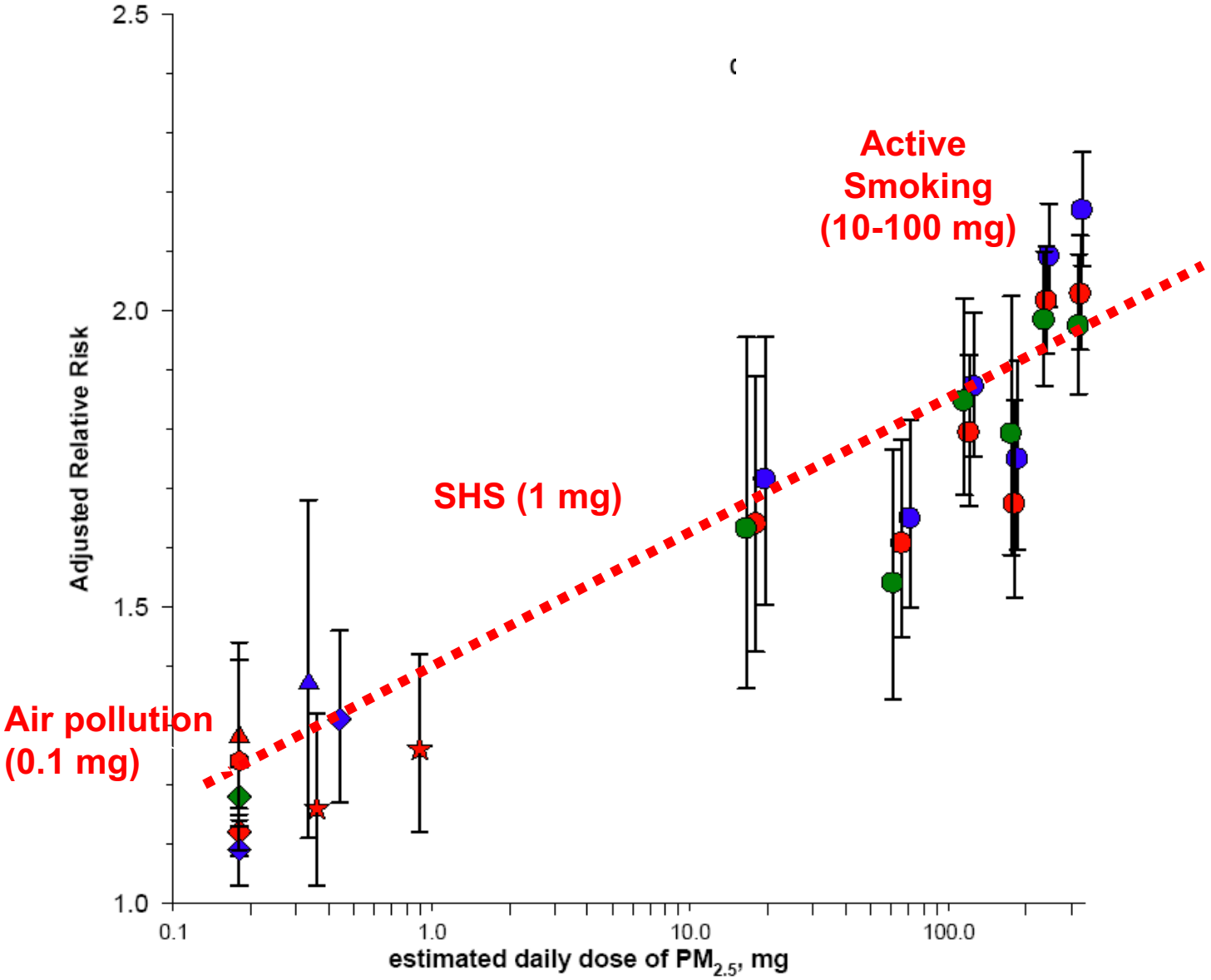
PM mass inhaled per day

Outdoor $PM_{2.5}$	~ 0.1 mg
Secondhand smoke	~ 1 mg
Smoking (1 PPD)	~ 100 mg

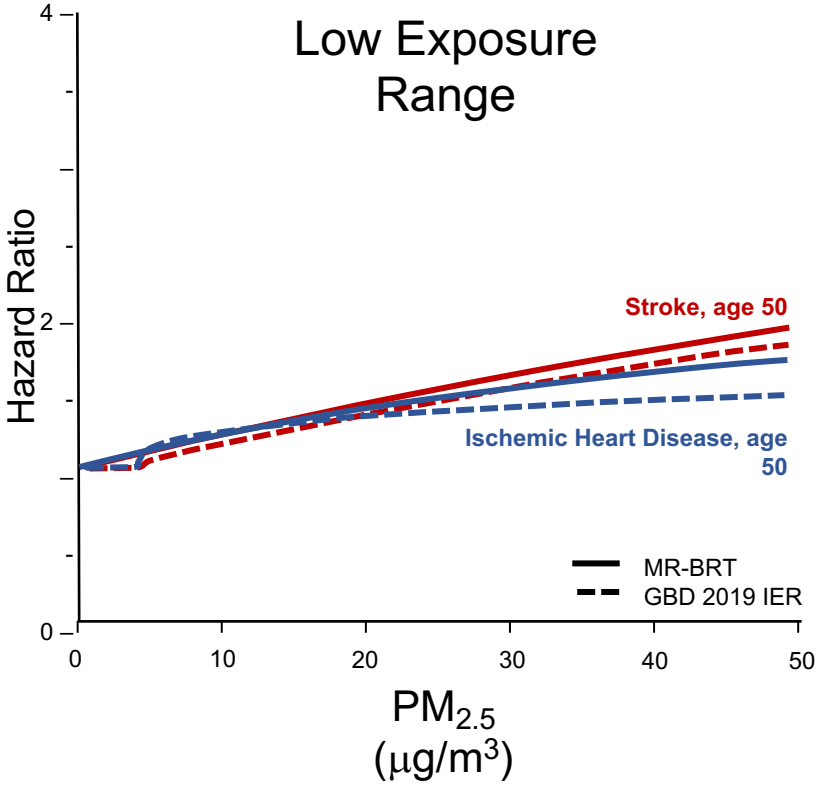


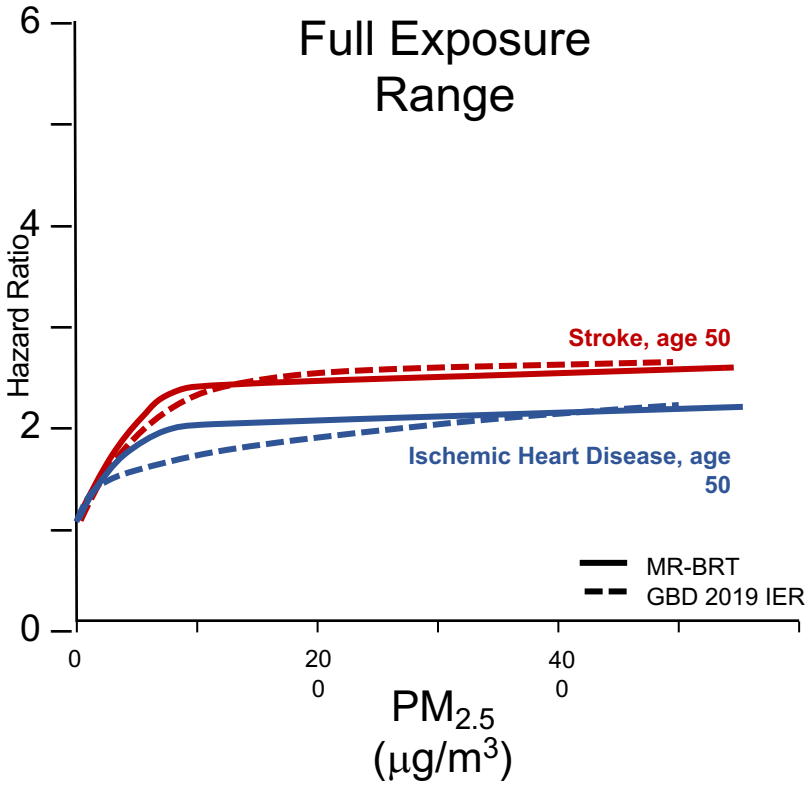
***Inhalation rate of 18 m^3/d and a dose of 12 mg per cigarette and ambient levels of air-pollution**

Reverse Log-Linear Dose-CV Response Relationship



Ischemic Heart Disease (IHD) and Stroke Outcomes with $PM_{2.5}$

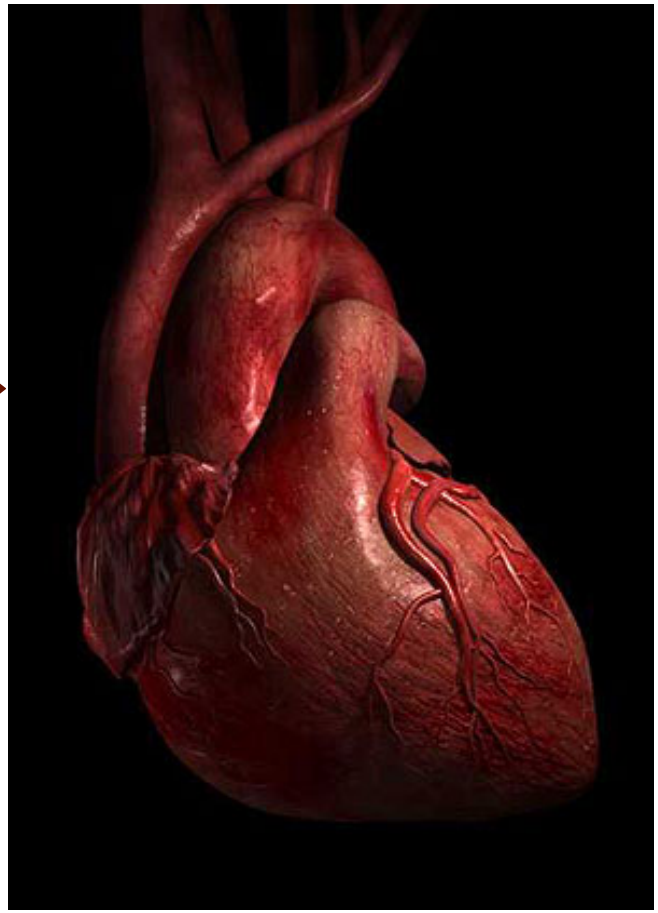


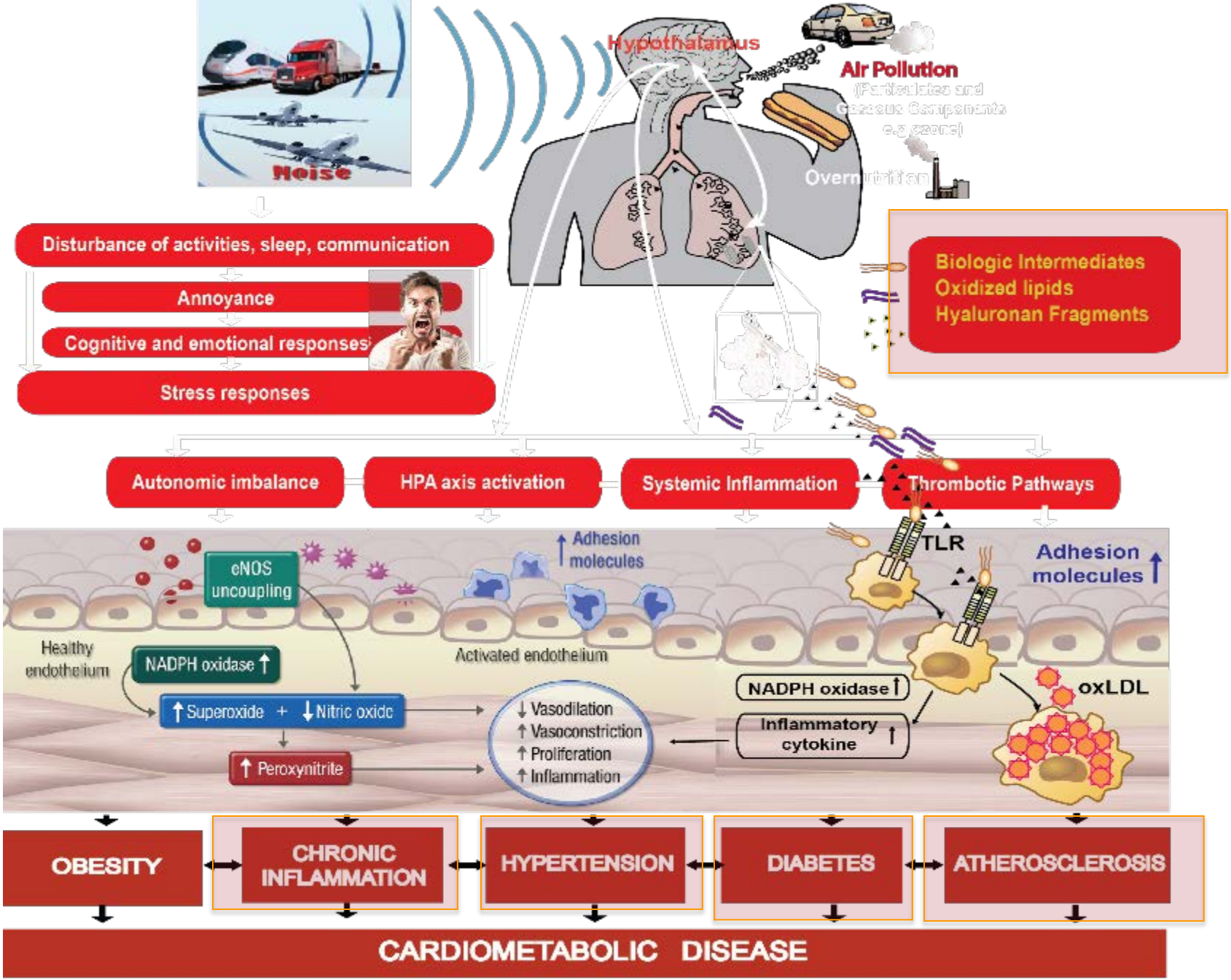


Adapted from GBD 2019 Risk Factors Collaborators. *Lancet* 2020; 396. (Appendix). Meta-regression Bayesian, regularized, trimmed (MR-BRT). In GBD 2019, for a selected set of continuous risk factors, we modelled RRs using meta-regression; Bayesian, regularized, trimmed (MR-BRT), relaxing the log-linear assumption to allow for monotonically increasing or decreasing but non-linear functions using cubic splines.

What are the mechanisms relating PM to CVD?

?

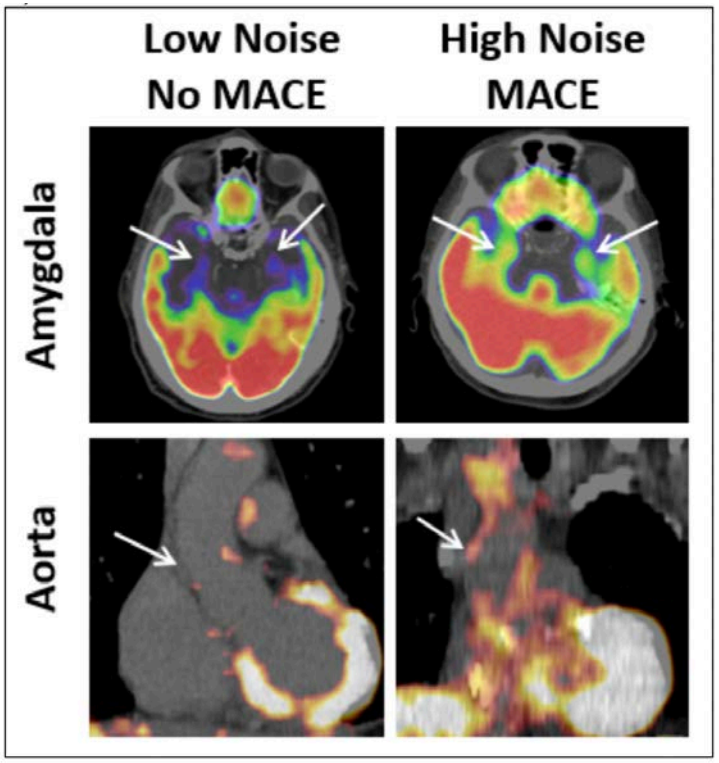


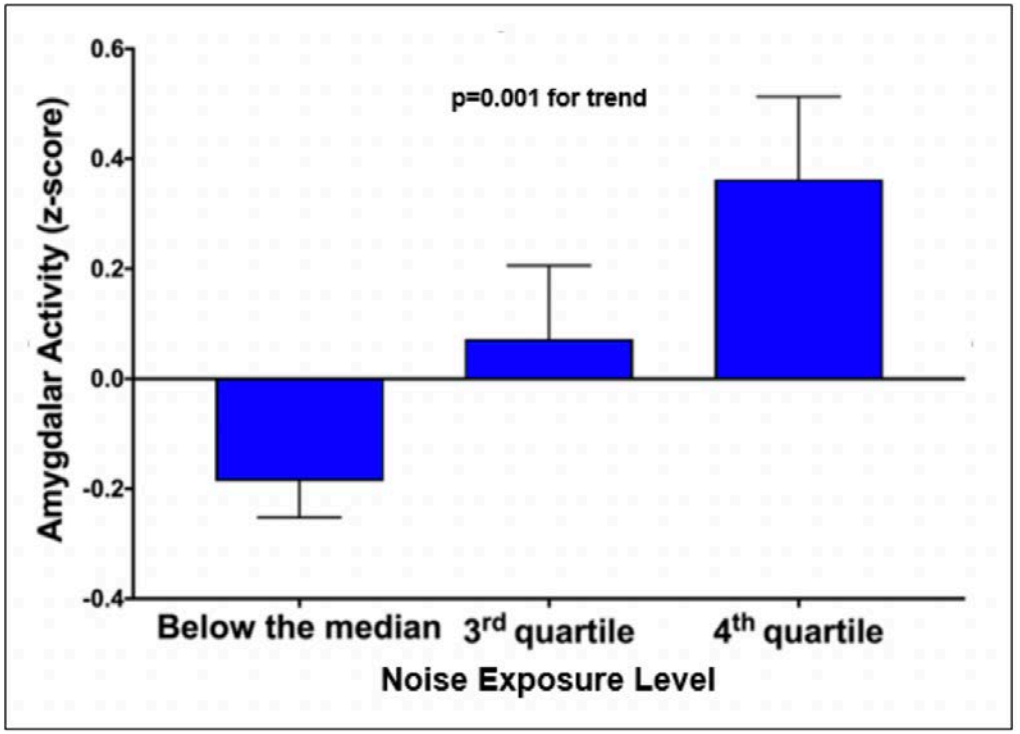


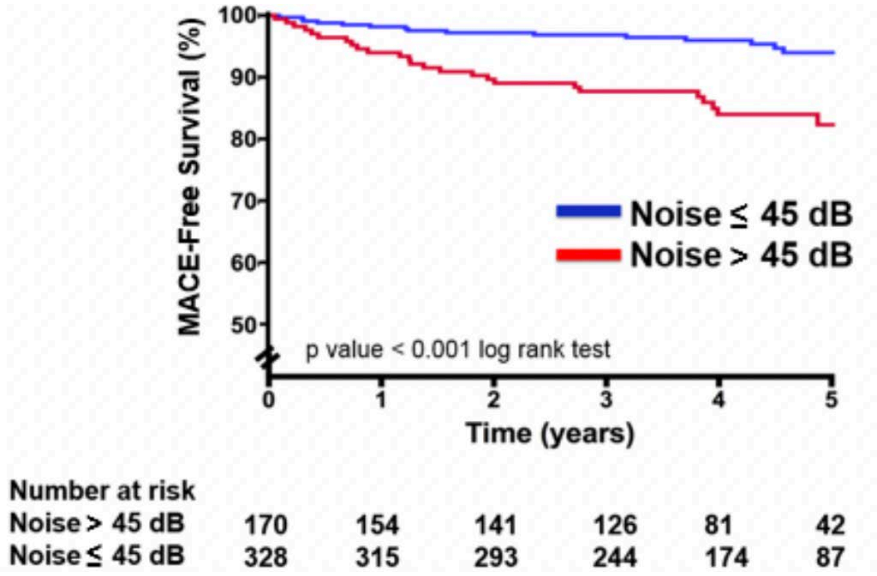
Environmental stressors and cardio-metabolic disease: part II-mechanistic insights. Munzel, Rajagopalan S et al. Eur Heart J. 2017

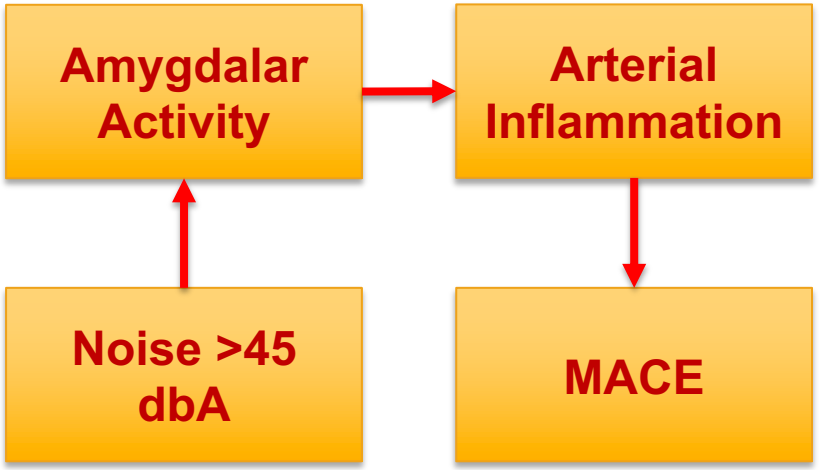
Two years ago a new runway opened at Frankfurt Airport and now there are ~5000 flights over the university hospital each month. ‘The noise level has increased substantially and this is not acceptable’, says Münzel.

Cardiopulse: http://dx.doi.org/10.1093/eurheartj/ehu089 821-825 First published online: 1 April 2014





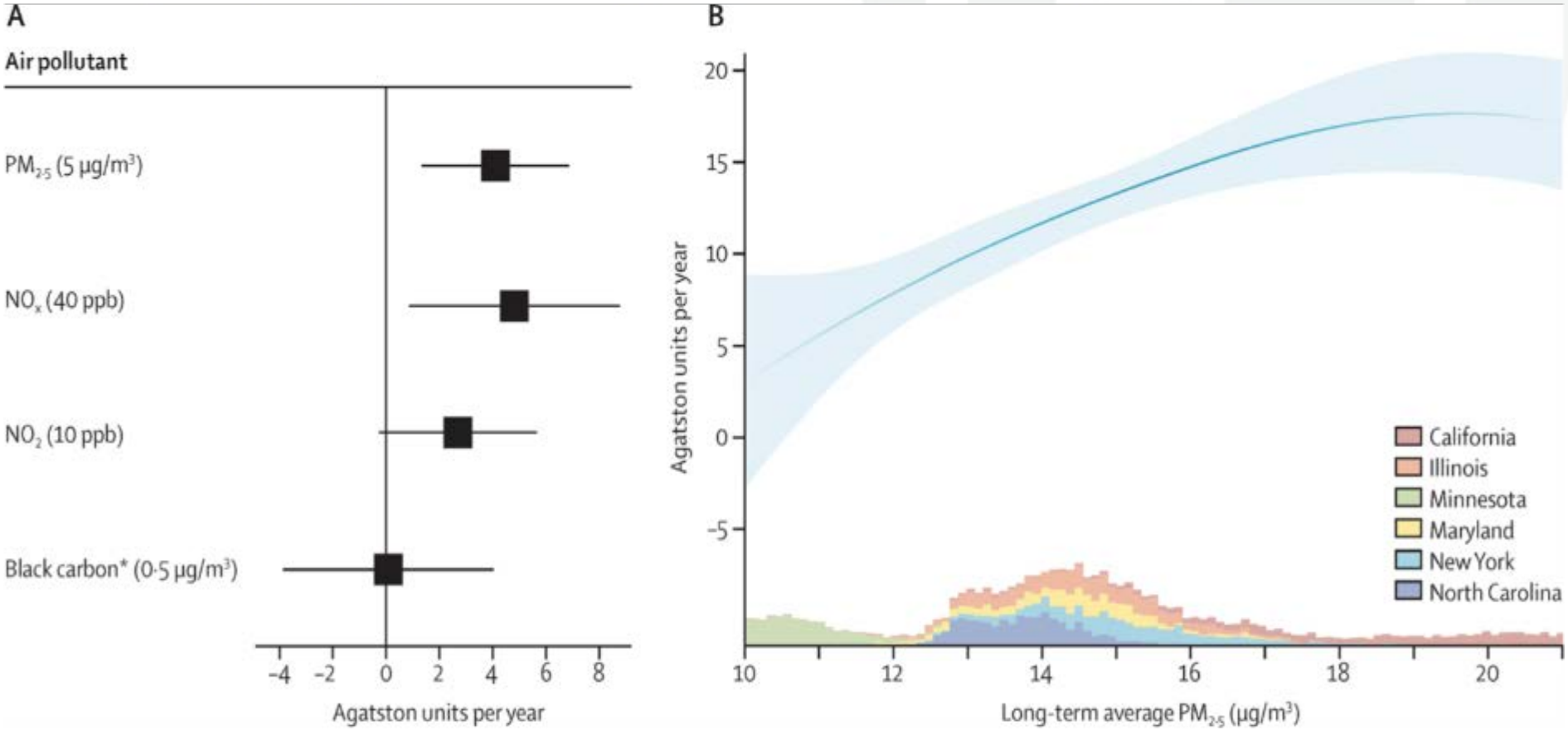




Osborne MT, Rajagopalan, Tawakol A et al. Eur Heart J. 2020 Feb 1;41(6):772-782.

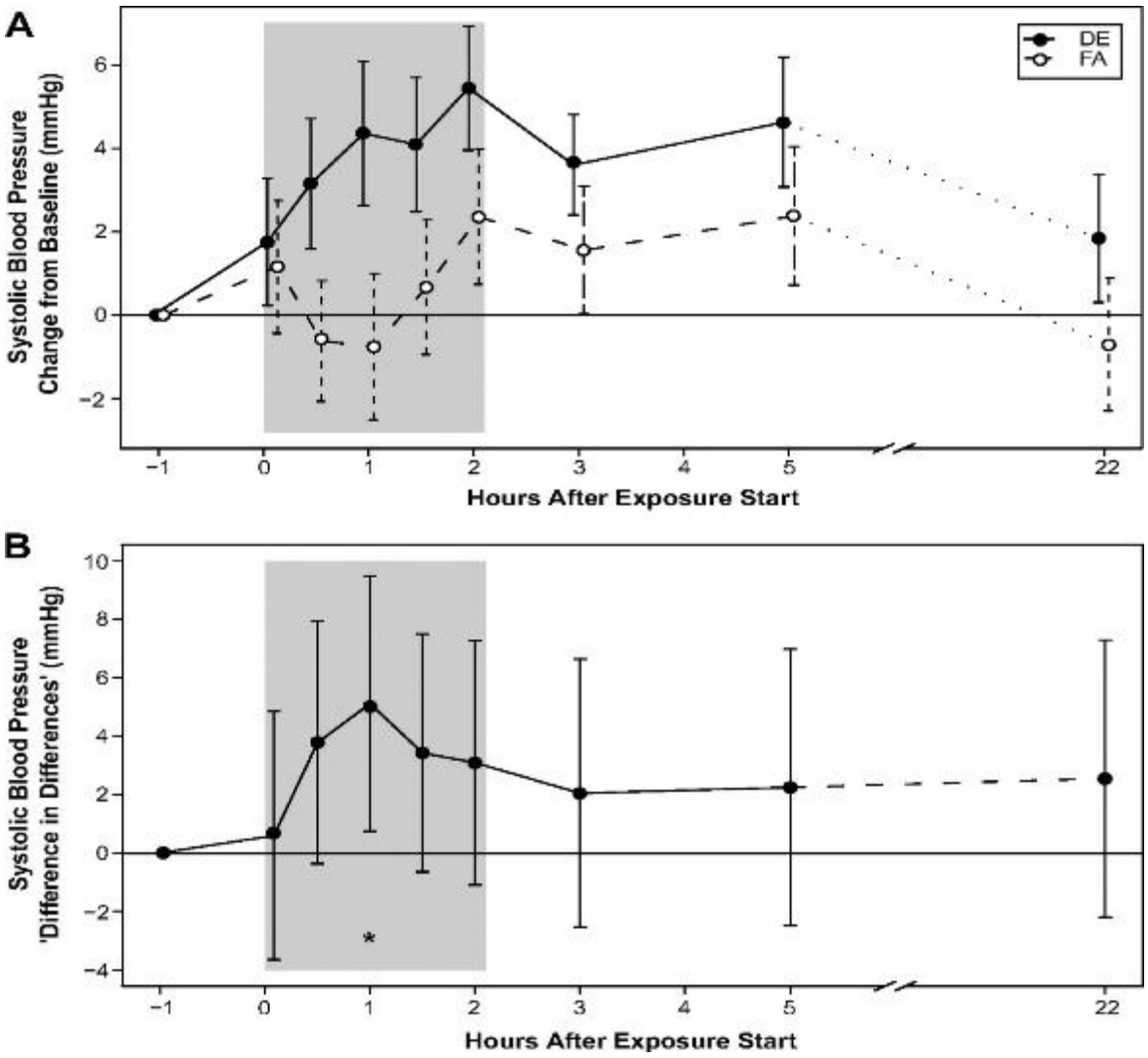
Coronary Atherosclerosis Progression With Air Pollution: Insights from MESA-Air

Every 5 µg/m3 PM2·5 =4·1 Agatston units/year (95% CI 1·4–6·8)
Every 40 ppb Nox 4·8 Agatston units per year (0·9–8·7)



Kaufman JD, Adar S et al. Lancet. 2016 Aug 13;388(10045):696-704

Blood Pressure Increase With Controlled Ultrafine (Diesel Exhaust) Exposure

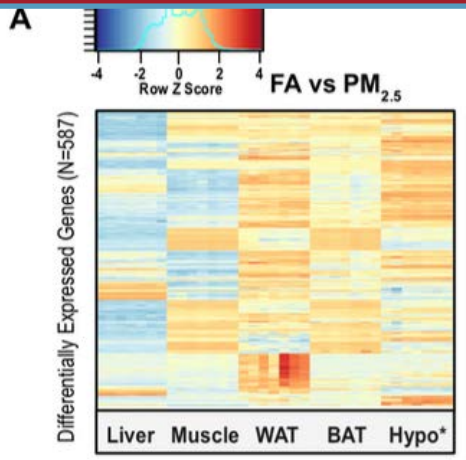


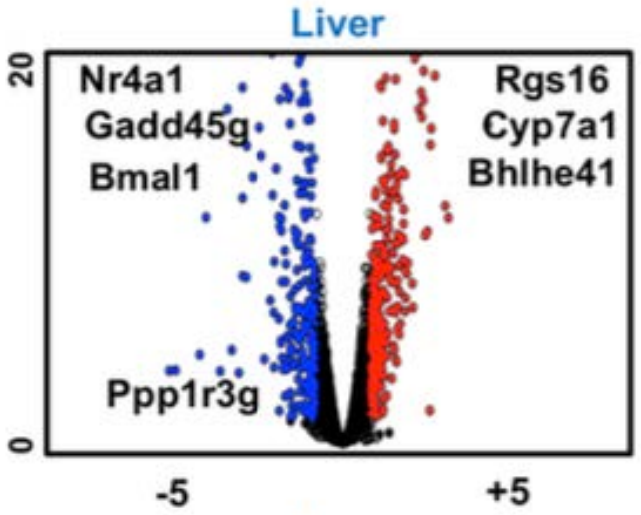
- 45 subjects (14 with MS)
- 120 minute exposure to DE (200 $\mu g/m^3$) PM2.5
- Double blind randomized cross-over exposures
- Effects rapid and persistent

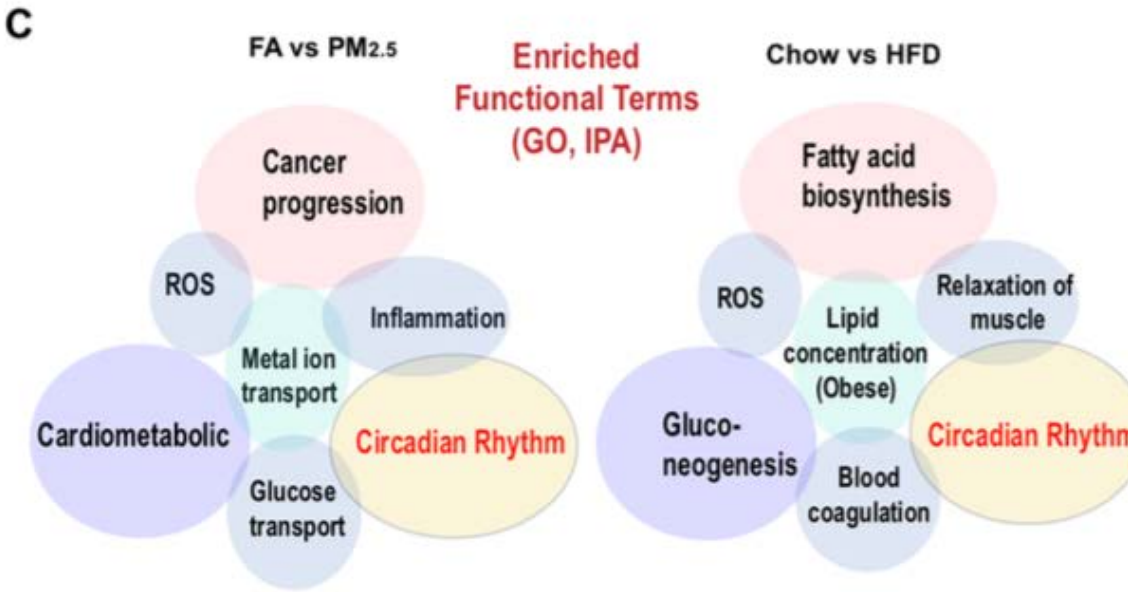
Results similar to findings from Mills et al (8 mm Hg ↑ SBP 2 hours post exposure)
Mills Circ 2005

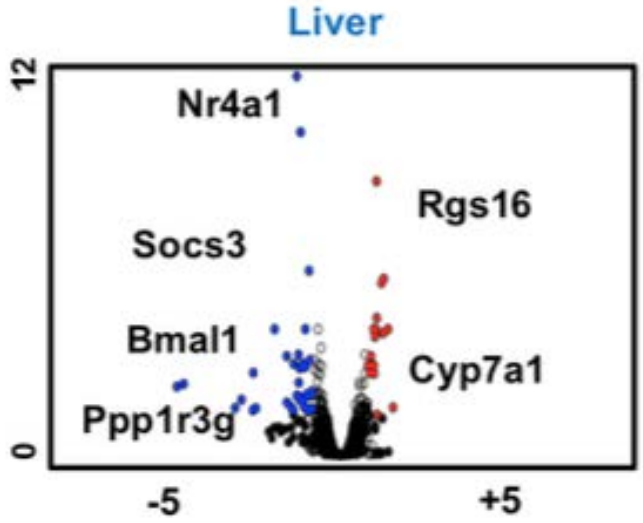
Mean change in systolic blood pressure (SBP) from baseline. Cosselman K E et al. Hypertension 2012;59:943-948

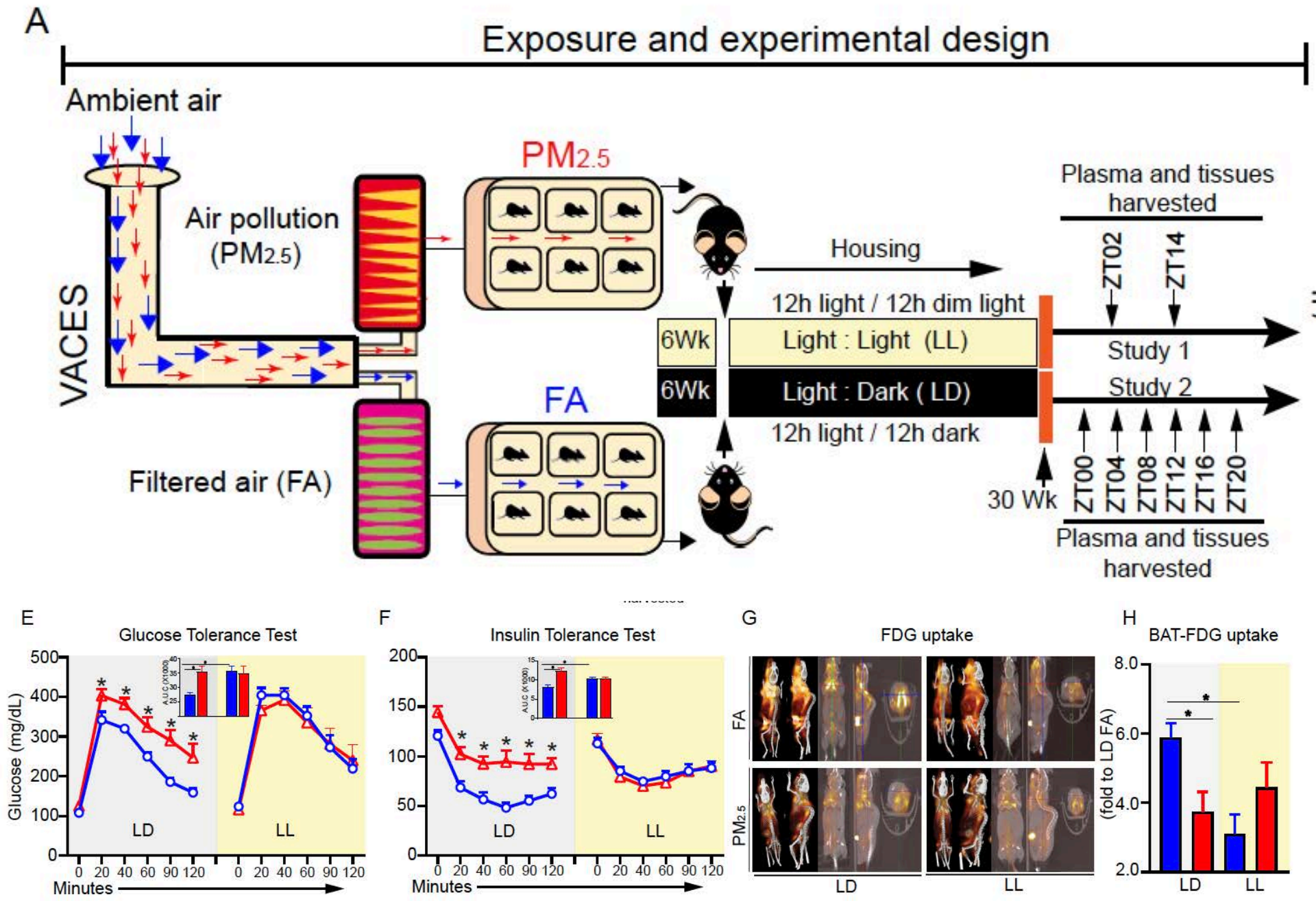
PM2.5 Exposure Induces Widespread Transcriptional Reprogramming



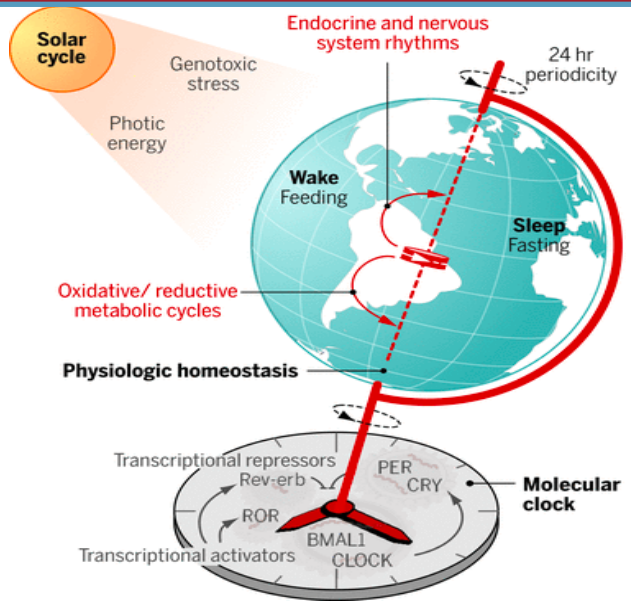


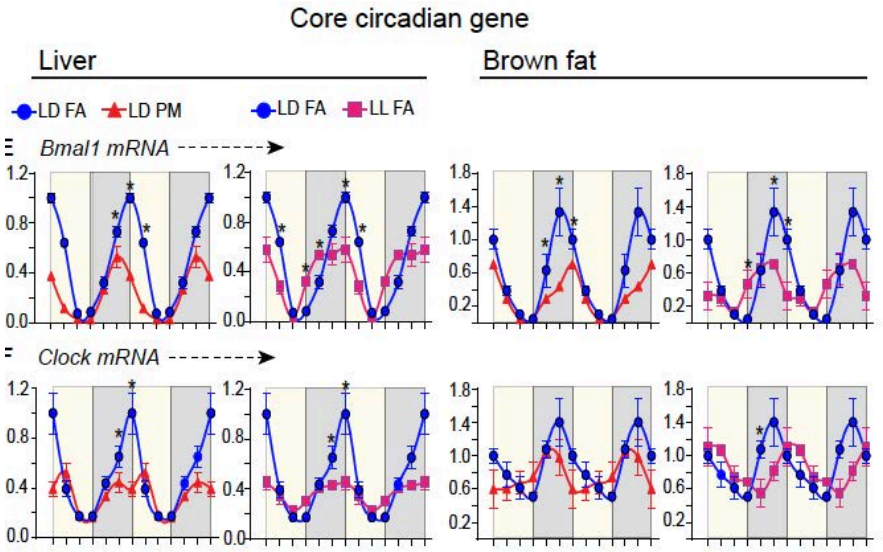


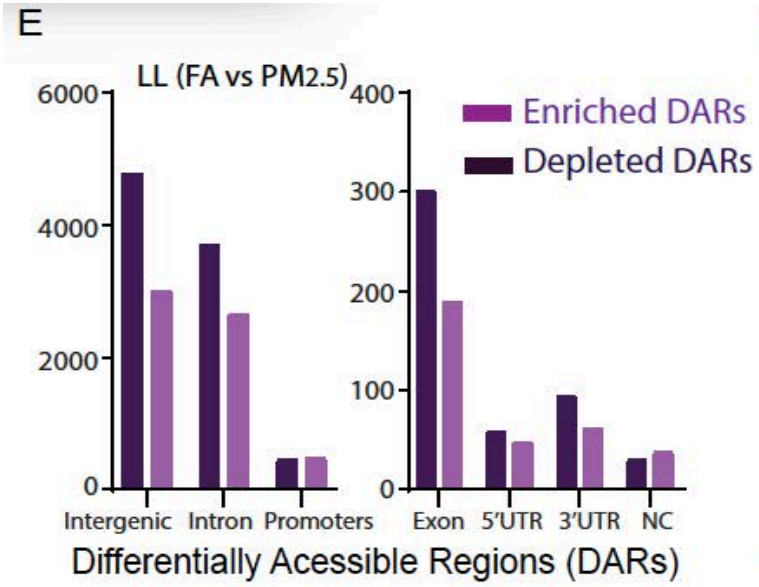


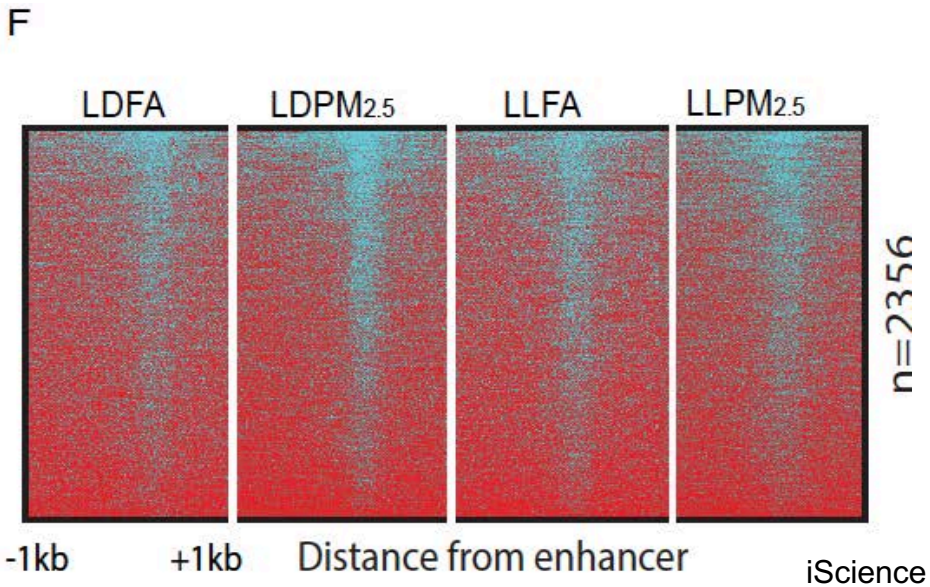

A
Exposure and experimental design
Ambient air
VACES
Air pollution
(PM2.5)
Filtered air (FA)
PM2.5
FA
Housing
12h light / 12h dim light
6Wk
Light : Light (LL)
6Wk
Light : Dark (LD)
12h light / 12h dark
30 Wk
Plasma and tissues harvested
ZT02
ZT14
Study 1
Study 2
ZT00
ZT04
ZT08
ZT12
ZT16
ZT20
Plasma and tissues harvested
E
Glucose Tolerance Test
Glucose (mg/dL)
Minutes
LD
LL
F
Insulin Tolerance Test
Minutes
LD
LL
G
FDG uptake
FA
PM2.5
LD
LL
H
BAT-FDG uptake
(fold to LD FA)
LD
LL

Chronic PM2.5 Exposure Induces Circadian Disruption





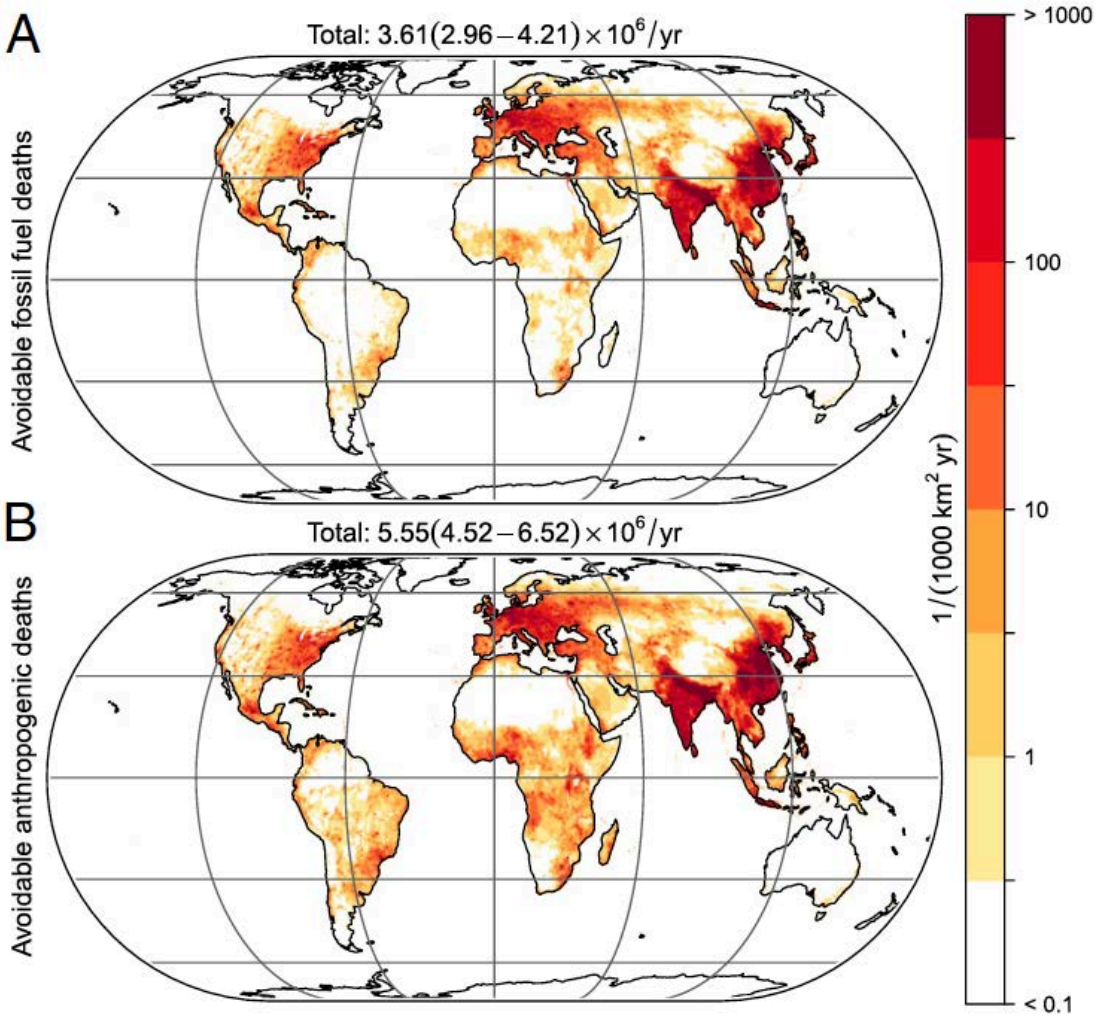




iScience 2020

Is the Future Bleak?

Avoidable excess mortality rate from air pollution



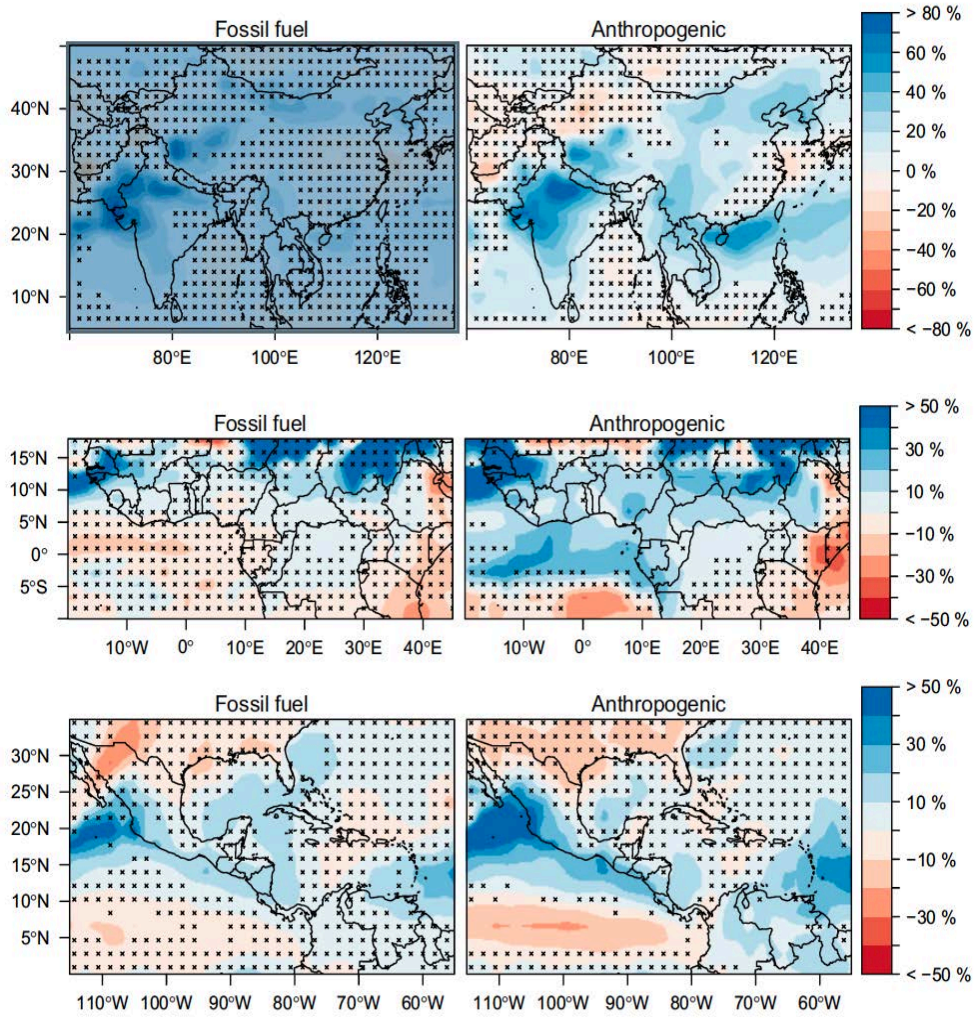
- (A) Excess deaths that may be
- avoided by the phasing out of fossil
- (B) By all anthropogenic emissions.

Units: deaths per 1,000 km2/y.

The darkblue regions would profit more from removing fossil-fuel-related emissions

Lelieveld J et al. Proc Natl Acad Sci U S A. 2019 Apr 9;116(15):7192-7197

Effects of removal of fossil-fuel-related and all anthropogenic pollution emissions in Asia, Africa, and Central America.

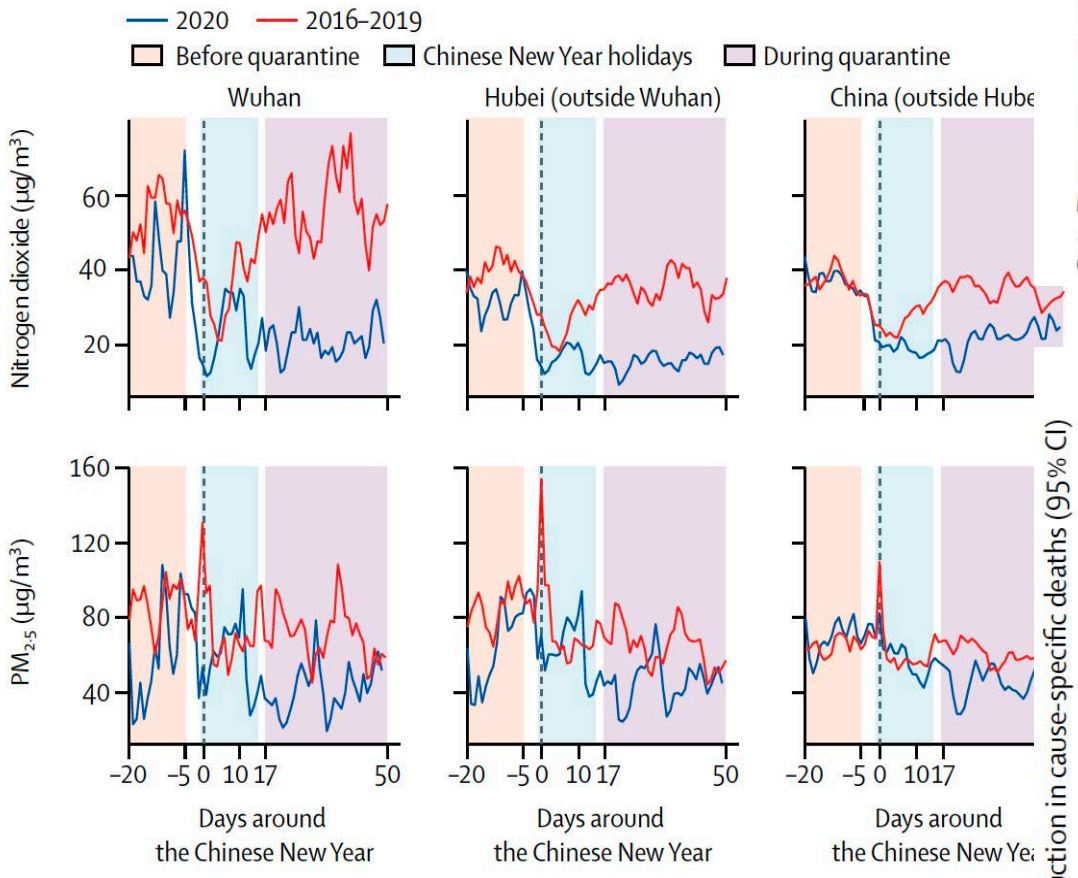


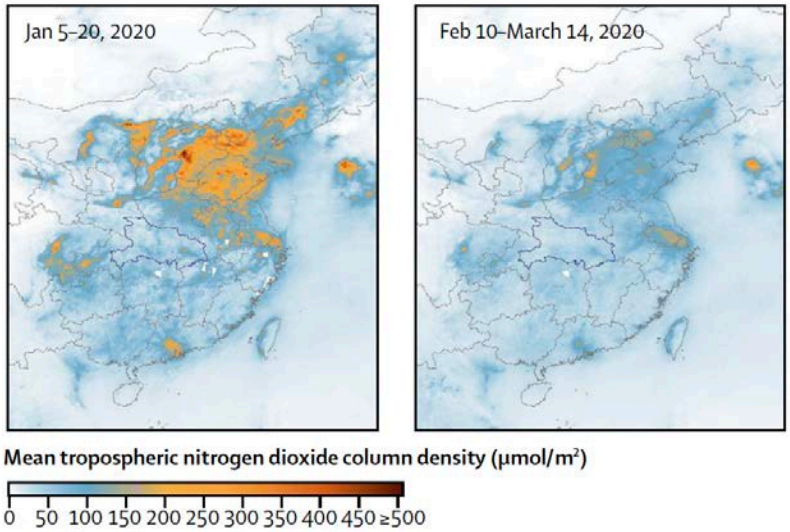
Phaseout of air pollution emissions leads to substantial precipitation increases throughout the planet

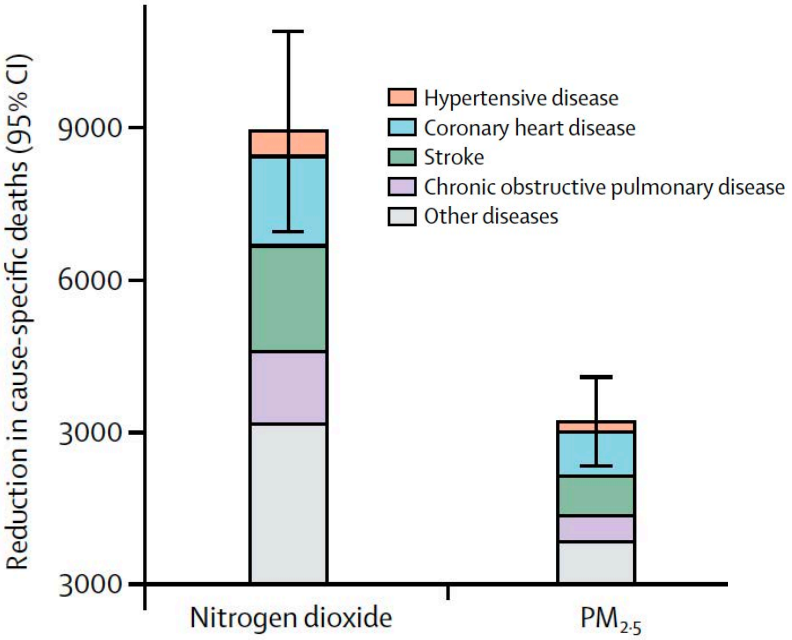
Fractional precipitation changes at the surface. Effects from the removal of fossil-fuel-related a nd all anthropogenic pollution emissions in Asia, Africa, and Central America

Lelieveld J et al. Proc Natl Acad Sci U S A. 2019 Apr 9;116(15):7192-7197

Reduction in Air Pollution and Mortality Benefit







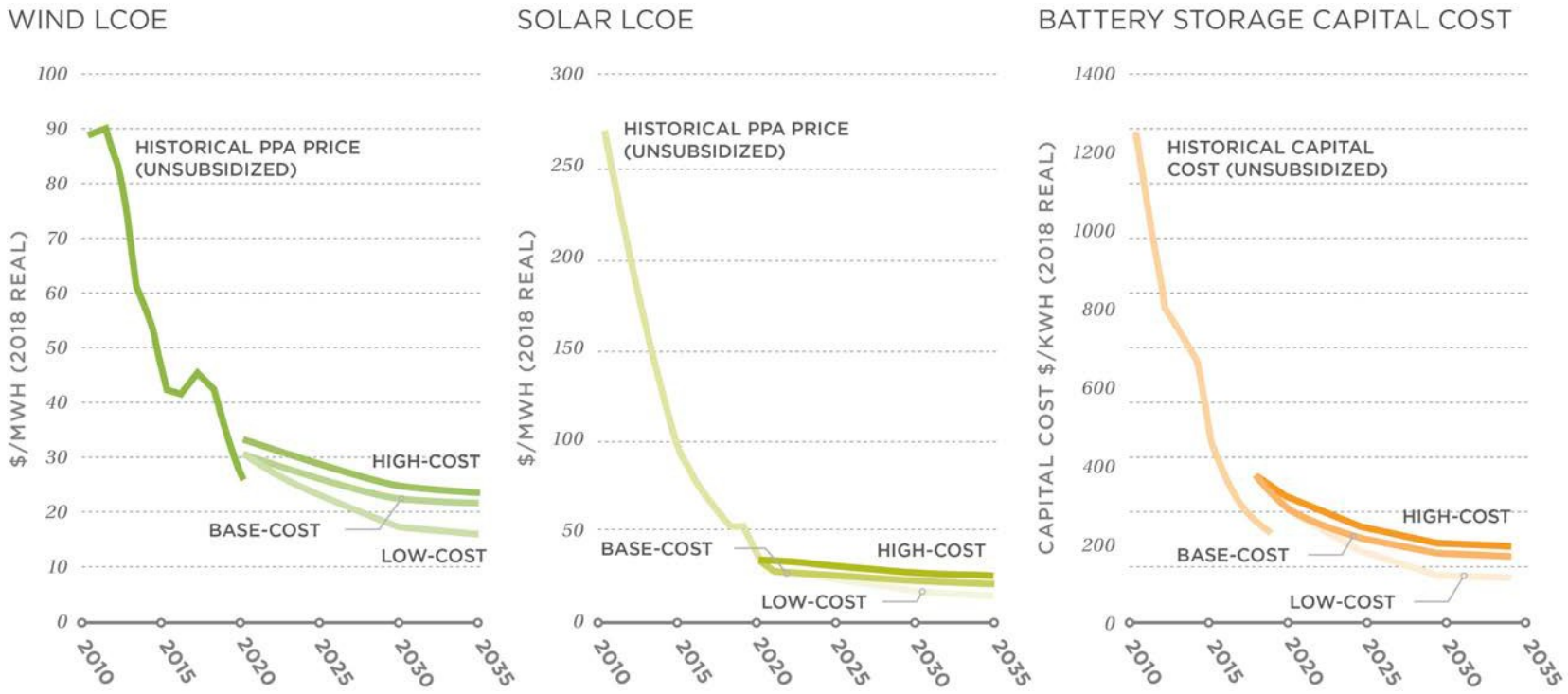
Lancet Planet Health 2020

Lessons Learned…

The rapid response and high levels of compliance/commitment shown in this crisis tells us that we can change our behavior…..


2035
THE REPORT
PLUMMETING SOLAR, WIND,
AND BATTERY COSTS
CAN ACCELERATE OUR
CLEAN ELECTRICITY FUTURE

DRAMATIC COST DECLINES ARRIVED SOONER THAN ANTICIPATED



CLEAN ELECTRICITY IS THE ROAD TO RECOVERY

- Economic recovery opportunity
- Jobs and infrastructure
- No increased costs for customers

SOCIETAL AND GOVERNMENTAL INTERVENTIONS

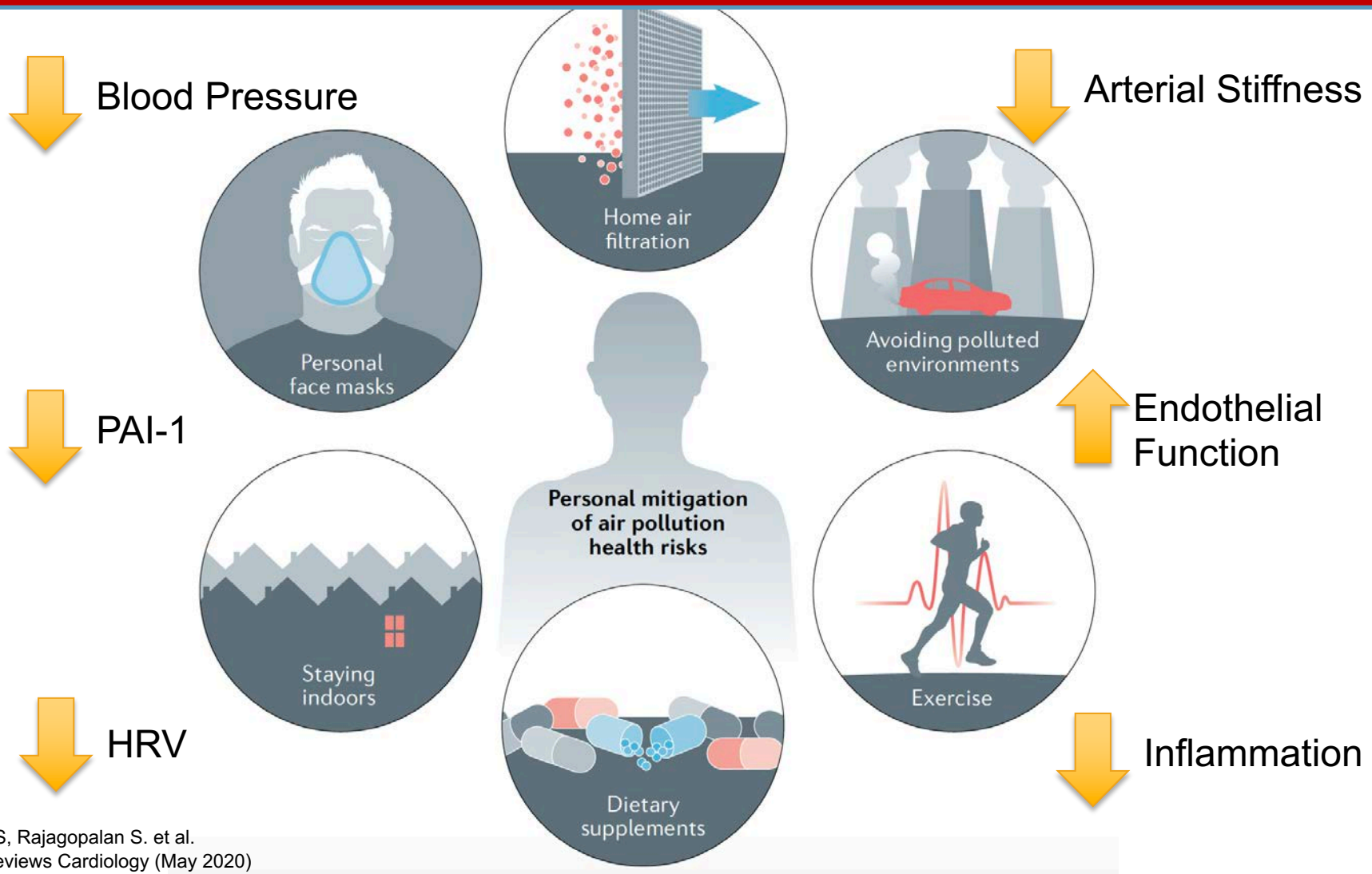
Shifting to Clean Fuels	• Switch coal-fired power plants to low-polluting renewable energy sources such as wind, tidal, geothermal, and solar. These
Transportation Reform	• Promote use of low-emission and zero-emission vehicles, Reduce sulfur content of motor fuels, Restrict trucks from city centers, encourage active transport (walking and cycling)
Reduce Traffic Emission(s)	• Diesel particle traps, catalytic converters, alternative fuels (natural gas, electric cars)
Urban landscape reform	• Land use assessment, minimum distances between sources and people, relocation of traffic sources (including major trafficked roads), avoidance of mixed-use areas (industrial-residential)
Emission Trading Programs	• Revenues raised through taxes can be directed to pollution control. Emissions trading programs compensate companies who adhere to controls through credits that can be traded akin to carbon credits
Redirection of science and funding	• Modifying priorities of climate change mitigation investments to a focus on near-term health co-benefits. Focus on the imminent near term danger of health effects of air pollution.
Empowering civil society	• Publicity and awareness campaigns through local data on air pollution within cities, counties
Governmental and NGO-led publicity	• Hard-hitting media campaigns akin to smoking on media to mitigate lobbying by industries involved in power and automobiles

PERSONAL INTERVENTIONS

Face masks and Air purifiers	• Wearing face masks and installing air purifiers in homes
Reduce in-traffic exposures	• Avoid commutes during rush hour
Reduce in-home penetration of outdoor air pollution	• Indoor air purifiers and closing windows; Air conditioners
Lifestyle changes and Preventive Medicine	• Exercise and healthy diet • Preventive medications and screening programs

J Am Coll Cardiol. 2018 Oct 23;72(17):2054-2070

Personal Protection Equipment



Al-Kindi, S, Rajagopalan S. et al.
Nature Reviews Cardiology (May 2020)

Air Pollution and Climate Change

- Emissions powerful determinant of global warming
- Same emissions that cause cardiovascular effects like heart attack and stroke also influence climate change
- The discussion on climate change must include health effects of air pollution as more immediately actionable
- COVID-19 provides a unique opportunity to fast-track climate change goals
- Net Zero 2035 is possible given technological progress and potential for infrastructure investment

Thank you for your attention!