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ENERGY RESOURCES ENGINEERING

Energy, Climate, Health and Justice

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We need energy.

But energy comes at an environmental cost.

Climate Change

Fossil Energy Use

Climate change a key issue for our generation

Photo from: Paco Freire / SOPA Images / LightRocket via Getty Images

This means we need decarbonize sectors that are… difficult to decarbonize.

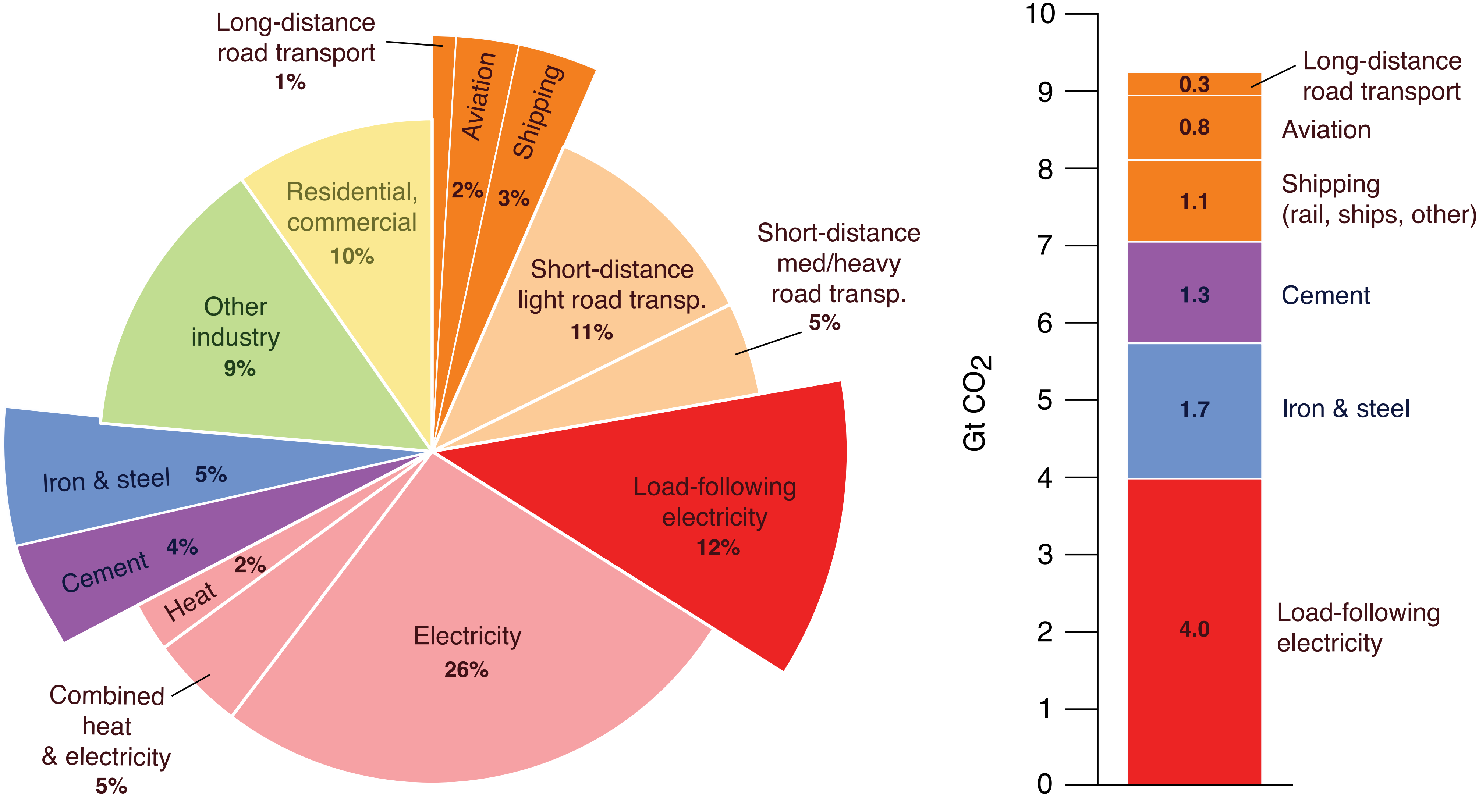
ENERGY

Net-zero emissions energy systems

Steven J. Davis[1,2], Nathan S. Lewis[3], Matthew Shaner[4], Sonia Aggarwal[5], Doug Arent[6,7], Inês L. Azevedo[8], Sally M. Benson[9,10,11], Thomas Bradley[12], Jack Brouwer[13,14], Yet-Ming Chiang[15], Christopher T. M. Clack[16], Armond Cohen[17], Stephen Doig[18], Jae Edmonds[19], Paul Fennell[20,21], Christopher B. Field[22], Bryan Hannegan[23], Bri-Mathias Hodge[6,24,25], Martin I. Hoffert[26], Eric Ingersoll[27], Paulina Jaramillo[8], Klaus S. Lackner[28], Katharine J. Mach[29], Michael Mastrandrea[4], Joan Ogden[30], Per F. Peterson[31], Daniel L. Sanchez[32], Daniel Sperling[33], Joseph Stagner[34], Jessika E. Trancik[35,36], Chi-Jen Yang[37], Ken Caldeira[32]

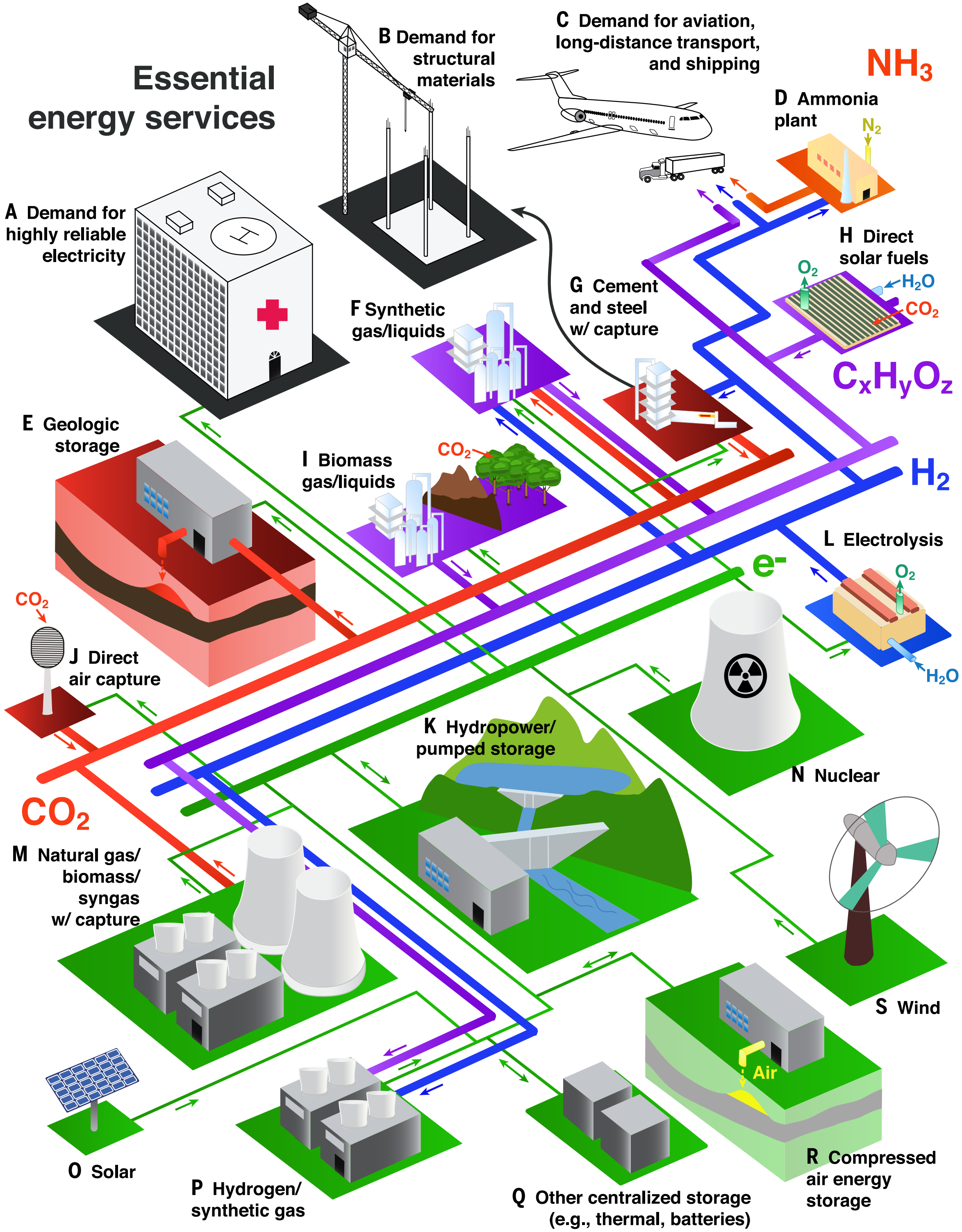
Some energy services and industrial processes—such as long-distance freight transport, air travel, highly reliable electricity, and steel and cement manufacturing—are particularly difficult to provide without adding carbon dioxide (CO_2) to the atmosphere. Rapidly growing demand for these services, combined with long lead times for technology development and long lifetimes of energy infrastructure, make decarbonization of these services both essential and urgent. We examine barriers and opportunities associated with these difficult-to-decarbonize services and processes, including possible technological solutions and research and development priorities. A range of existing technologies could meet future demands for these services and processes without net addition of CO_2 to the atmosphere, but their use may depend on a combination of cost reductions via research and innovation, as well as coordinated deployment and integration of operations across currently discrete energy industries.

Davis, Lewis, Shaner, Aggarwal, Arent, Azevedo, Benson, Bradley., Brouwer., Chiang, Clack, Cohen, Doig, Edmonds, Fennell, Field, Hannegan, Mathias Hodge, Hoffert, Ingersoll, Jaramillo, Lackner, Lynd, Mach, Mastrandrea, Ogden, Peterson, Sanchez, Sperling, Stagner, Trancik, Yang, Caldeira, (2018). ***Science***.



A **Global fossil fuel & industry emissions, 2014 (33.9 Gt CO_2)**

B **Difficult-to-eliminate emissions, 2014 (9.2 Gt CO_2)**



Essential energy services
A Demand for highly reliable electricity
B Demand for structural materials
C Demand for aviation, long-distance transport, and shipping
NH_3
D Ammonia plant
N_2
H Direct solar fuels
O_2
H_2O
CO_2
F Synthetic gas/liquids
G Cement and steel w/ capture
$C_xH_yO_z$
E Geologic storage
I Biomass gas/liquids
CO_2
H_2
L Electrolysis
O_2
H_2O
e^-
CO_2
J Direct air capture
K Hydropower/ pumped storage
N Nuclear
CO_2
M Natural gas/ biomass/ syngas w/ capture
S Wind
Air
R Compressed air energy storage
O Solar
P Hydrogen/ synthetic gas
Q Other centralized storage (e.g., thermal, batteries)

Energy comes at an environmental cost.

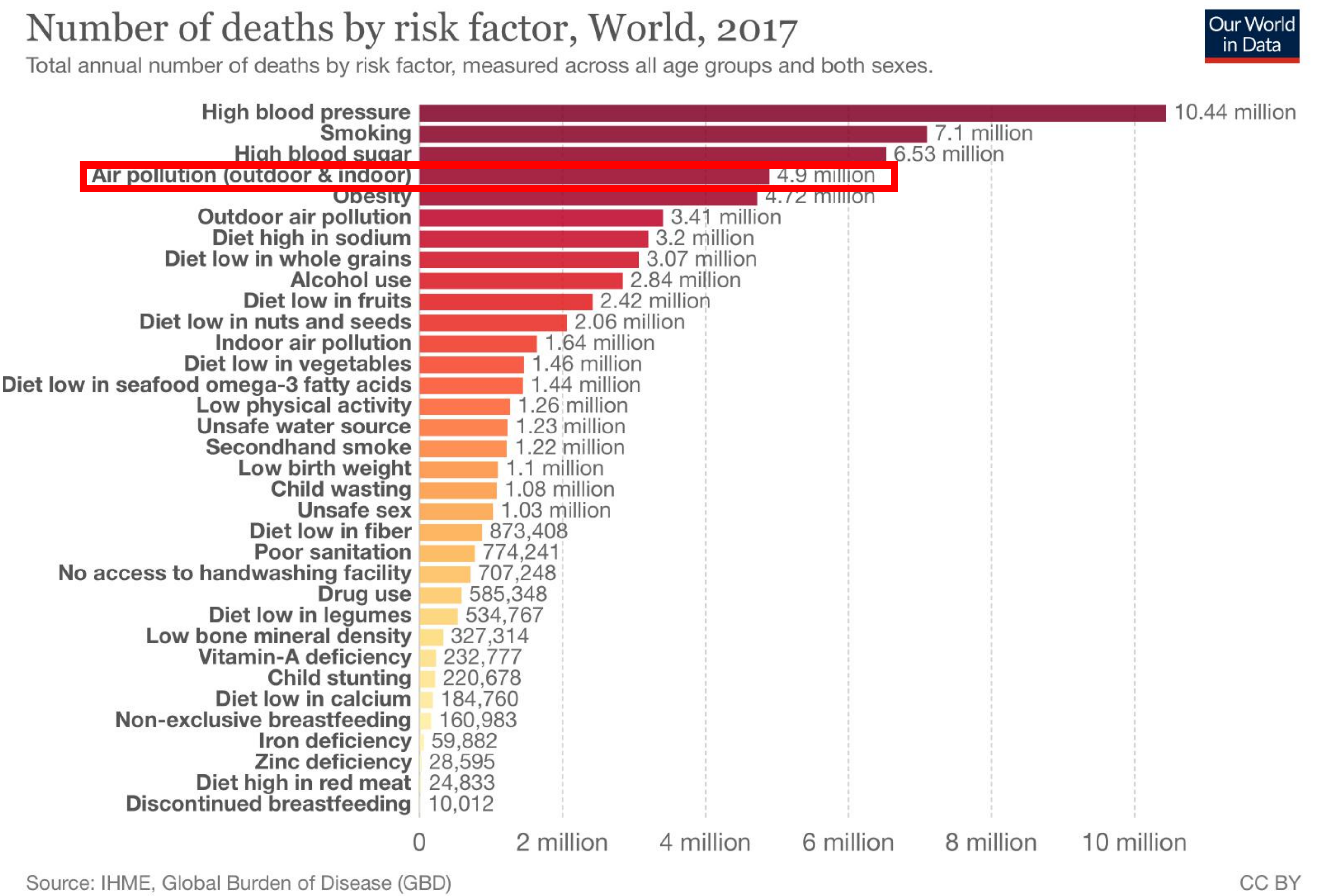
Energy

Climate Change

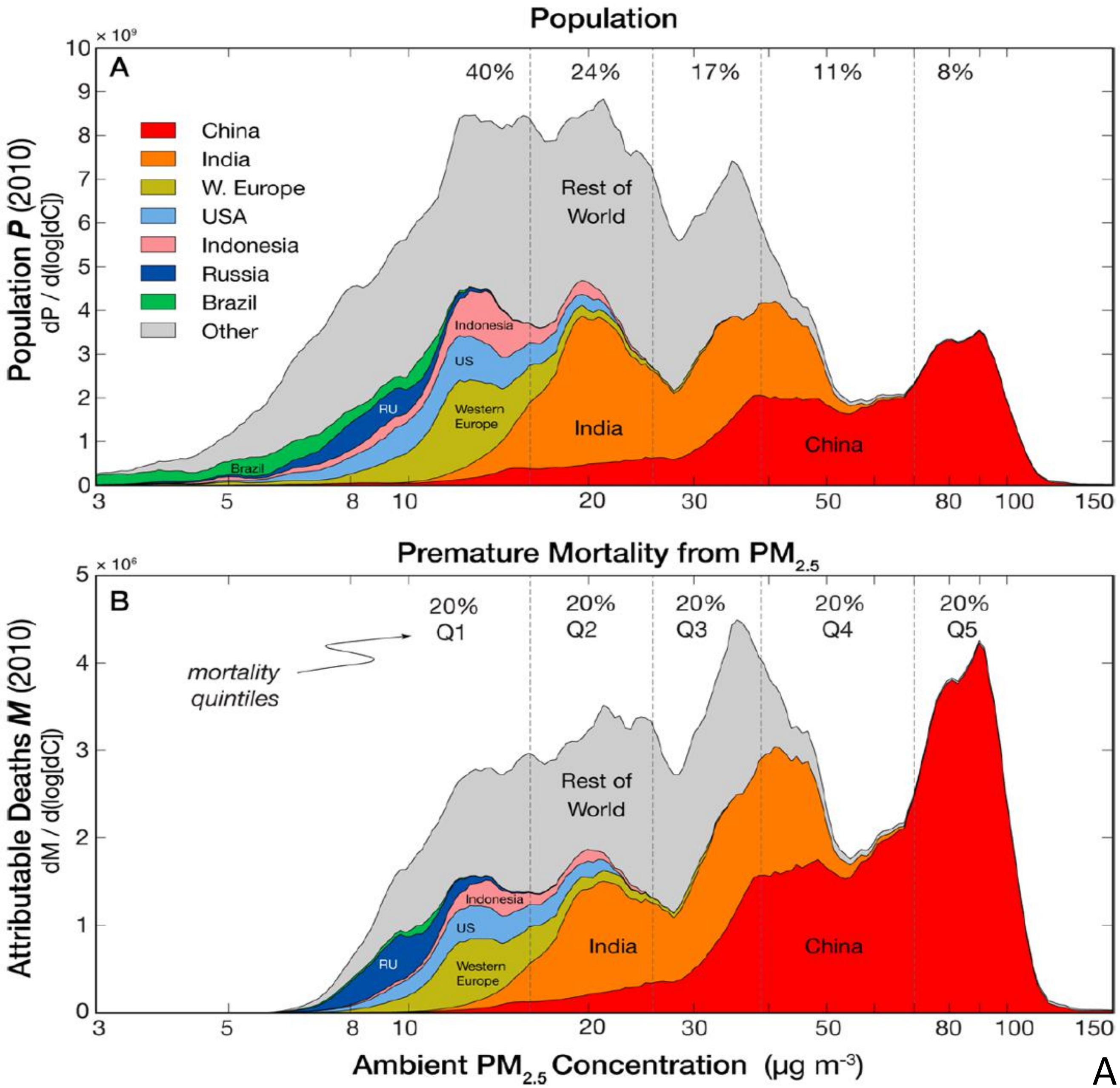
Health damages from air pollution

Air pollution causes premature mortality

- Fine particulate matter ($PM_{2.5}$) is the largest environmental global health risk, responsible for about 5 million deaths annually.
- $PM_{2.5}$ is associated with increased mortality rates from cardiovascular disease (ischemic heart disease and stroke), chronic obstructive pulmonary disease, and lung cancer.
- Fuel combustion emits $PM_{2.5}$ directly (primary $PM_{2.5}$) as well as sulfur dioxide (SO_2) and oxides of Nitrogen (NO_x), which can react with ammonia (NH_3) in the atmosphere to form $PM_{2.5}$ (secondary $PM_{2.5}$).


Number of deaths by risk factor, World, 2017
Total annual number of deaths by risk factor, measured across all age groups and both sexes.
Our World in Data
High blood pressure 10.44 million
Smoking 7.1 million
High blood sugar 6.53 million
Air pollution (outdoor & indoor) 4.9 million
Obesity 4.72 million
Outdoor air pollution 3.41 million
Diet high in sodium 3.2 million
Diet low in whole grains 3.07 million
Alcohol use 2.84 million
Diet low in fruits 2.42 million
Diet low in nuts and seeds 2.06 million
Indoor air pollution 1.64 million
Diet low in vegetables 1.46 million
Diet low in seafood omega-3 fatty acids 1.44 million
Low physical activity 1.26 million
Unsafe water source 1.23 million
Secondhand smoke 1.22 million
Low birth weight 1.1 million
Child wasting 1.08 million
Unsafe sex 1.03 million
Diet low in fiber 873,408
Poor sanitation 774,241
No access to handwashing facility 707,248
Drug use 585,348
Diet low in legumes 534,767
Low bone mineral density 327,314
Vitamin-A deficiency 232,777
Child stunting 220,678
Diet low in calcium 184,760
Non-exclusive breastfeeding 160,983
Iron deficiency 59,882
Zinc deficiency 28,595
Diet high in red meat 24,833
Discontinued breastfeeding 10,012
0
2 million
4 million
6 million
8 million
10 million
Source: IHME, Global Burden of Disease (GBD)
CC BY

The burden of the environmental cost is not uniformly distributed

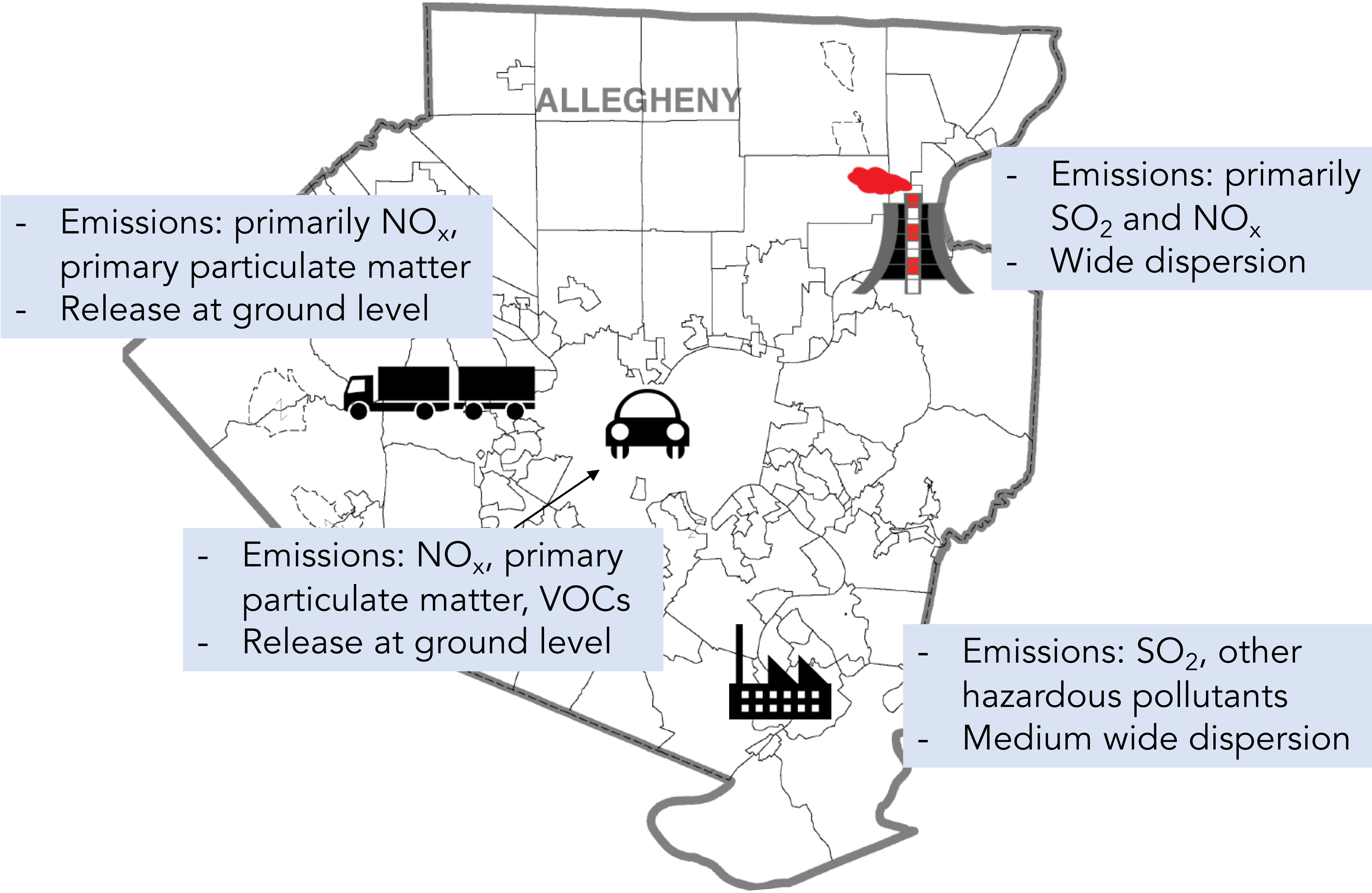


Apte et al., 2015

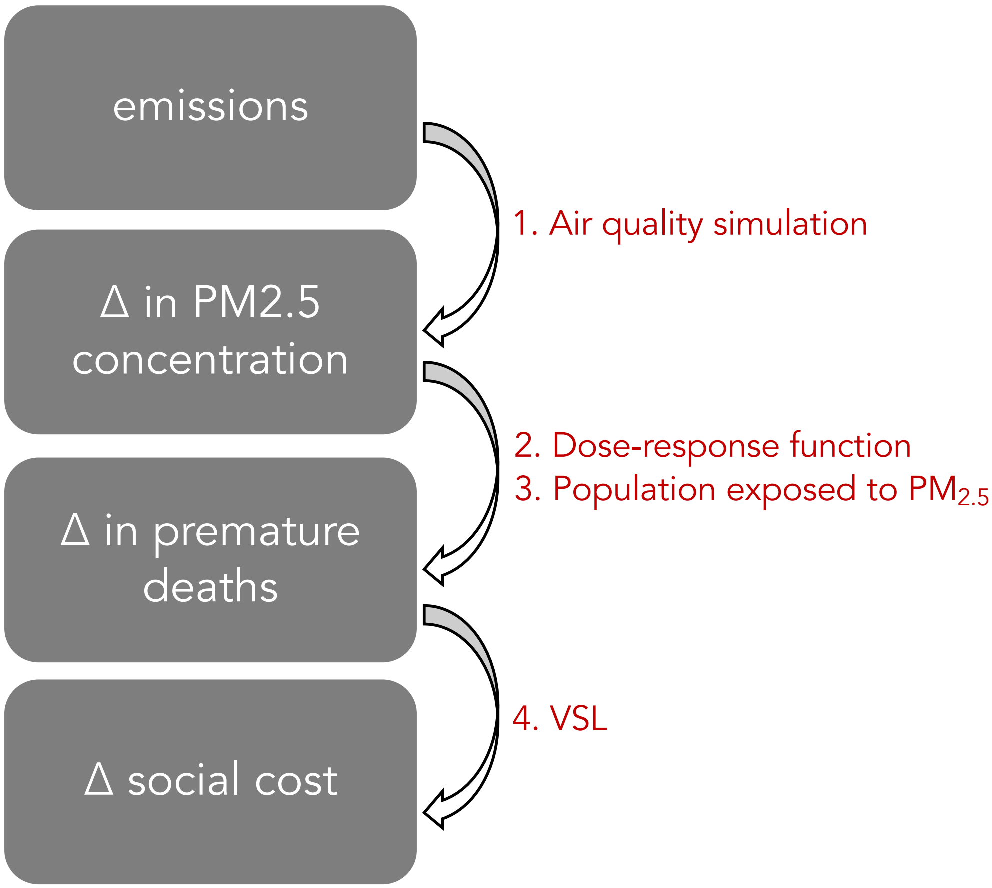
Questions

- How have the effects from air pollution from economic activities changed over time in the United States?

- How do do the health damages from air pollution compare to the value added by economic activities?


ALLEGHENY
- Emissions: primarily NO_x, primary particulate matter
- Release at ground level
- Emissions: primarily SO_2 and NO_x
- Wide dispersion
- Emissions: NO_x, primary particulate matter, VOCs
- Release at ground level
- Emissions: SO_2, other hazardous pollutants
- Medium wide dispersion

Computing Marginal Damages with IAMs



Key results: National Trends

- Nationwide GED attributable to production within economic sectors has decreased by 22% from $1,010 billion to $790 billion ($2018) from 2008 to 2014.
- These damages comprised 5.9% of GDP in 2008, 4.6% in 2011, and 4.2% in 2014.
- Hence, through 2014, the US economy continues on its path to become less pollution intensive.

Crucial for future pollution control efforts is the fact that nearly 75% of attributable GED occurs in just 4 sectors of the economy: agriculture, utilities, manufacturing, and transportation.

Each of these 4 major contributors to GED exhibit falling damages over this time period.

Utility sector GED fell by more than 50% over this 6-year time period.

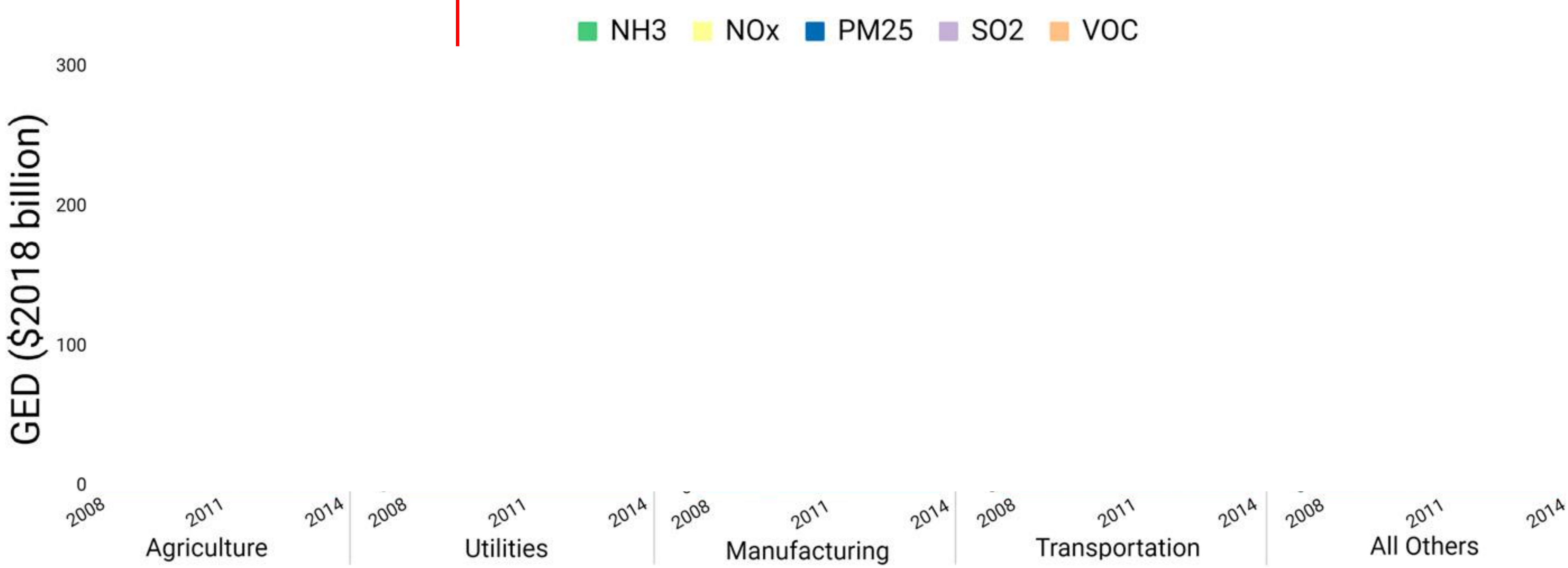


Fig. 2. GED (in $2018) attributable to economic sectors and their respective precursor pollutants (NH_3, NO_x, primary $PM_{2.5}$, SO_2, and VOCs). GED was calculated for the 3 most recent NEI years: 2008, 2011, and 2014.

Utility emissions and GED are dominated by SO_2 from coal-fired power plants, but the addition of air pollution control technologies, recent closures of coal plants and fuel-switching to natural gas have drastically reduced damages from that sector.

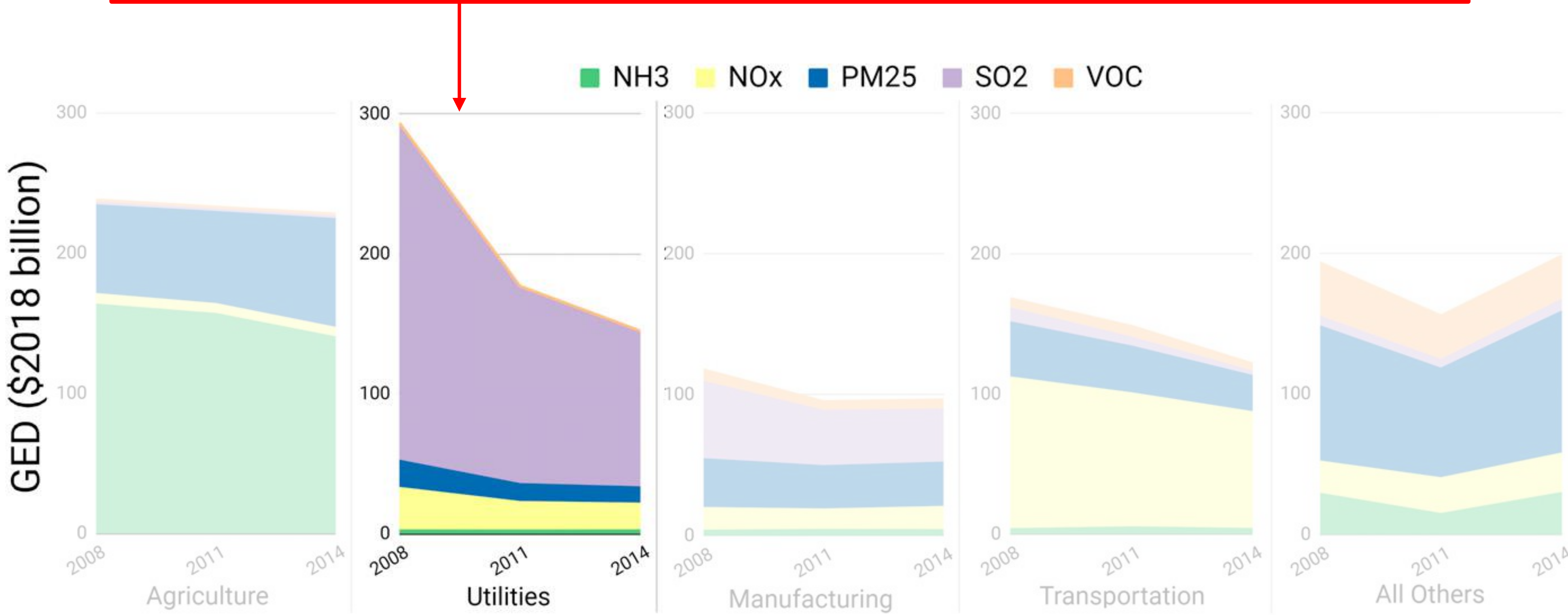


Fig. 2. GED (in $2018) attributable to economic sectors and their respective precursor pollutants (NH_3, NO_x, primary $PM_{2.5}$, SO_2, and VOCs). GED was calculated for the 3 most recent NEI years: 2008, 2011, and 2014.

Agriculture is the economic sector that generates the largest sectoral gross external damages in the US economy.

Emissions in Ag are caused primarily by livestock emissions and fertilizer application (NH3), and field burning, as well as combustion emissions from agricultural equipment and other crop-related activities (primary $PM_{2.5}$).

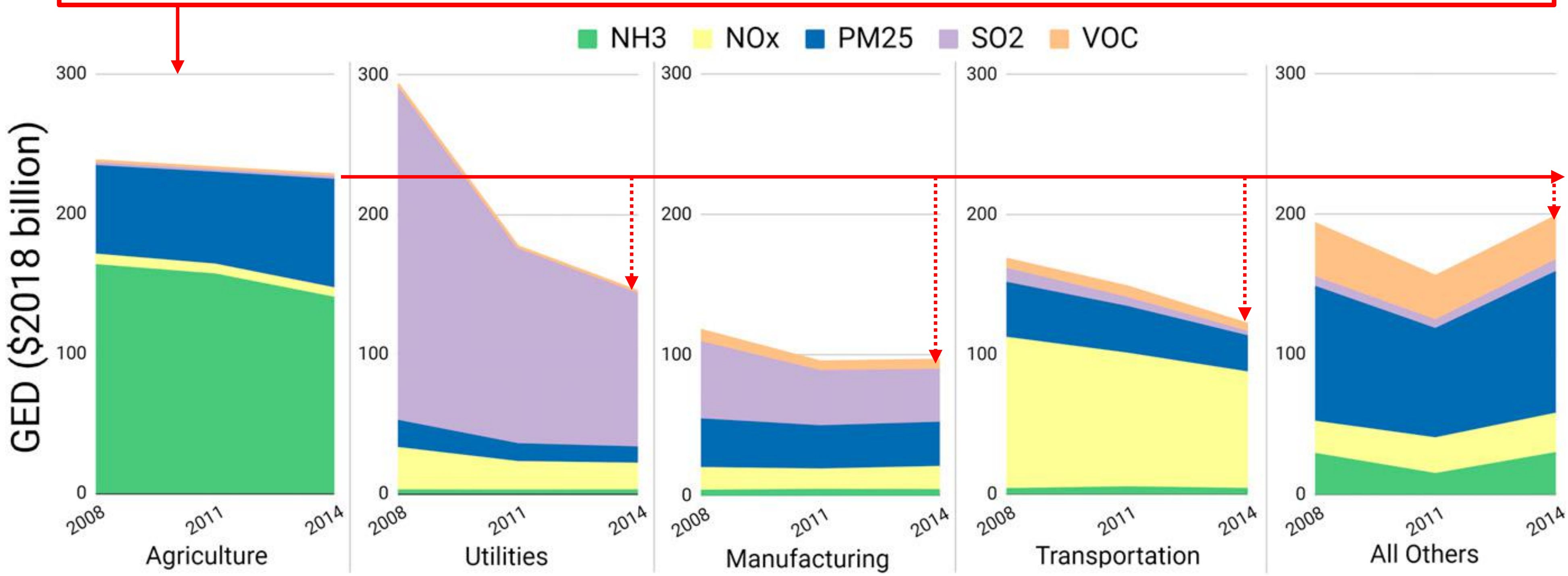


Fig. 2. GED (in $2018) attributable to economic sectors and their respective precursor pollutants (NH_3, NO_x, primary $PM_{2.5}$, SO_2, and VOCs). GED was calculated for the 3 most recent NEI years: 2008, 2011, and 2014.

"All Others" represented the remaining 16 sectors of the economy altogether. Here, primary $PM_{2.5}$ is the predominant contributor to GED (a large portion of that occurs in the construction subsector).

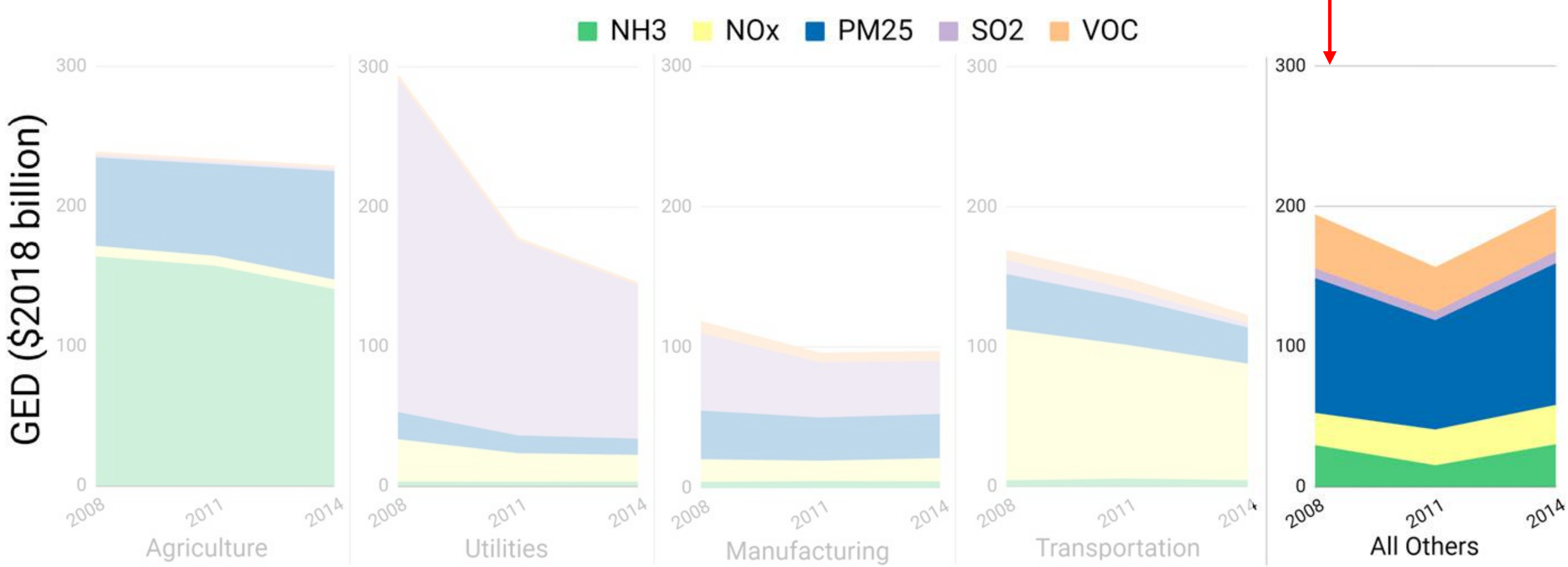


Fig. 2. GED (in \$2018) attributable to economic sectors and their respective precursor pollutants (NH_3, NO_x, primary $PM_{2.5}$, SO_2, and VOCs). GED was calculated for the 3 most recent NEI years: 2008, 2011, and 2014.

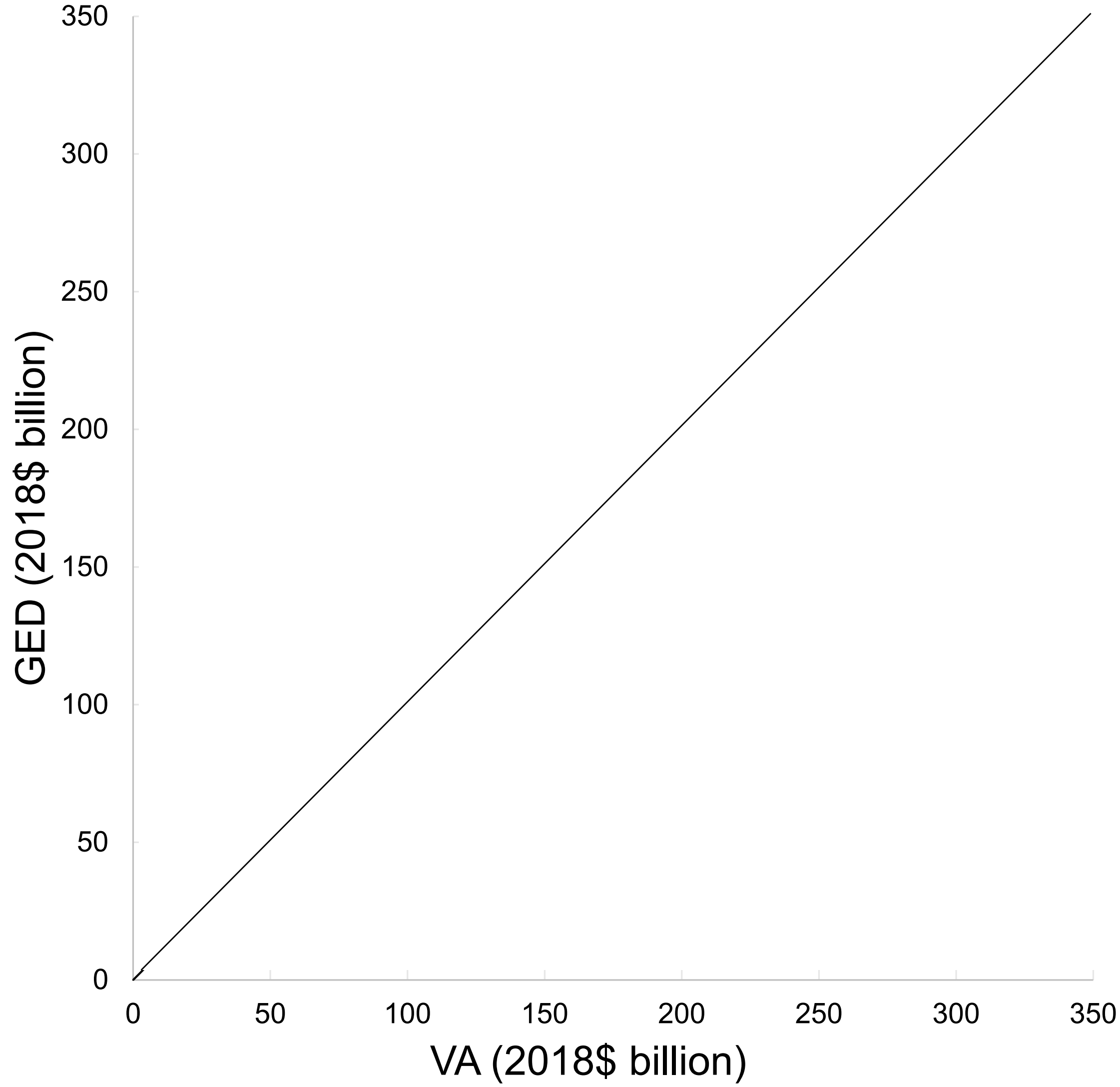


Fig. 3. GED versus VA for 2008, 2011, and 2014 for select subsectors in $2018 billion. The dividing line signifies a ratio of 1 between damages and VA.

Subsectors are displayed if they showed either GED of $30 billion or higher (the exception for this is "other services, except government," which includes emissions attributed to private households), a GED/VA ratio of 0.4 or higher, or both.

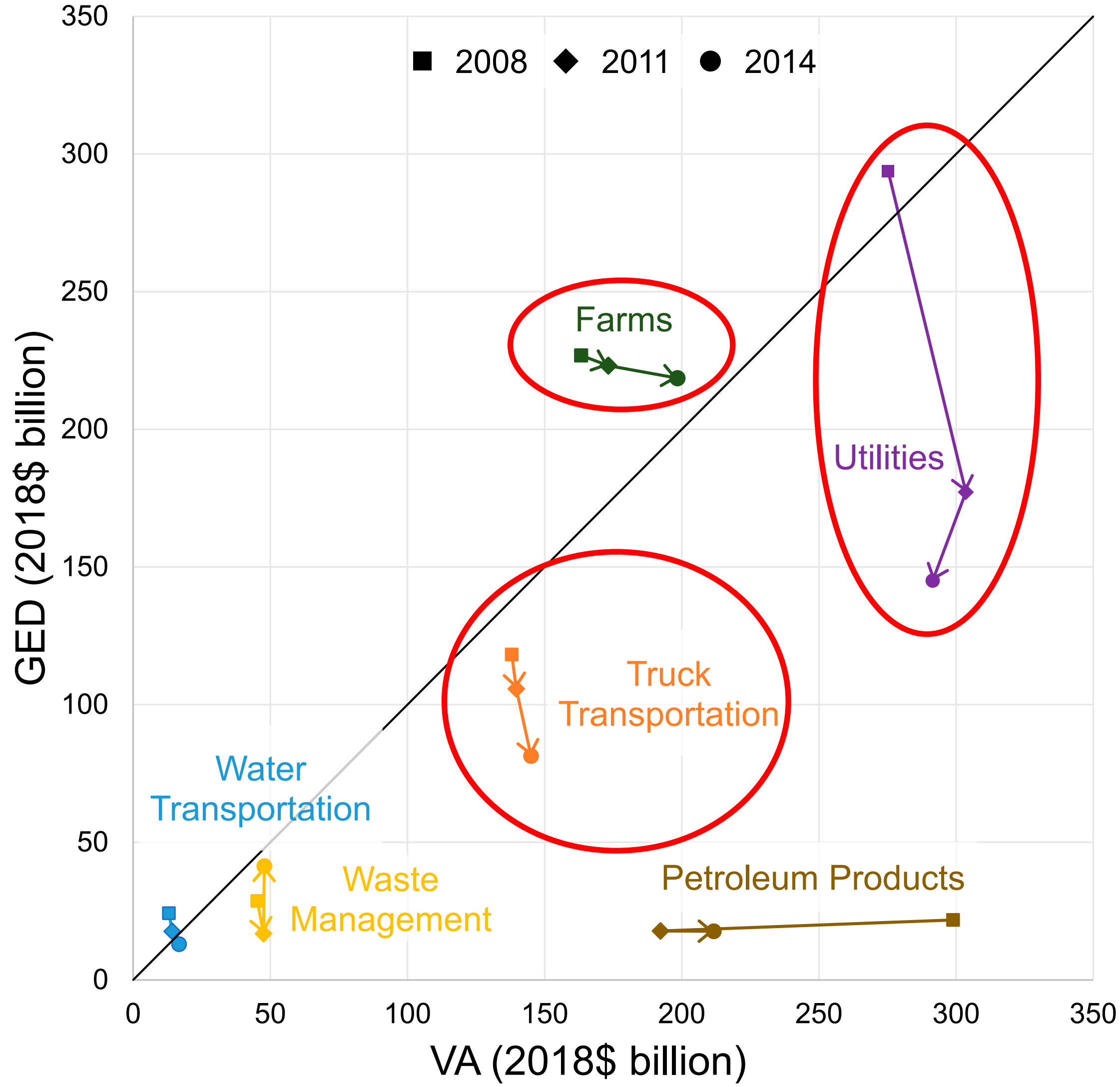


Fig. 3. GED versus VA for 2008, 2011, and 2014 for select subsectors in $2018 billion. The dividing line signifies a ratio of 1 between damages and VA.

https://www.cnn.com/2020/06/23/politics/black-lives-matter-support-impact/index.html

What are the distributional effects from air pollution from electricity?

Environmental Science & Technology

Article

pubs.acs.org/est

Fine Particulate Air Pollution from Electricity Generation in the US: Health Impacts by Race, Income, and Geography

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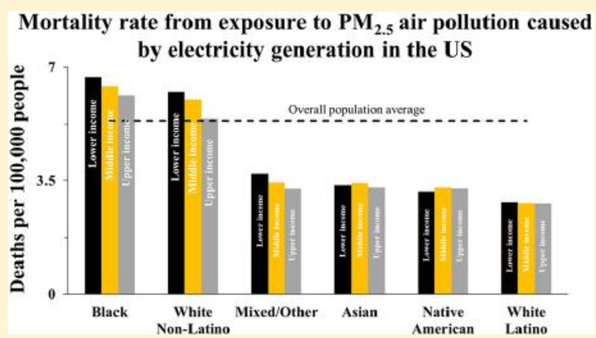
Supporting Information

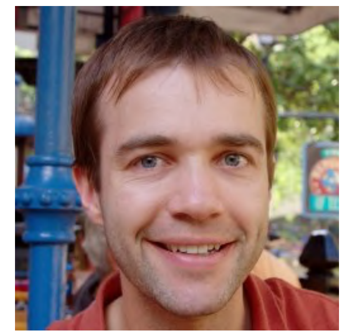
ABSTRACT: Electricity generation is a large contributor to fine particulate matter ($PM_{2.5}$) air pollution. However, the demographic distribution of its resulting exposure is largely unknown. We estimate exposures to and health impacts of $PM_{2.5}$ from electricity generation in the US, for each of the seven Regional Transmission Organizations (RTOs), for each US state, by income and by race. We find that average exposures are the highest for the Blacks, followed by Non-Latino Whites. Exposures for remaining groups (e.g., Asians, Native Americans, and Latinos) are somewhat lower. Disparities by race/ethnicity are observed for each income category, indicating that the racial/ethnic differences hold even after accounting for differences in income. Levels of disparity differ by state and RTO. Exposures are higher for lower-income than for higher-income, but disparities are larger by race than by income. Geographically, we observe large differences between where electricity is generated and where people experience the resulting $PM_{2.5}$ health consequences; some states are net exporters of health impacts, other are net importers. For 36 US states, most of the health impacts are attributable to emissions in other states. Most of the total impacts are attributable to coal rather than other fuels.

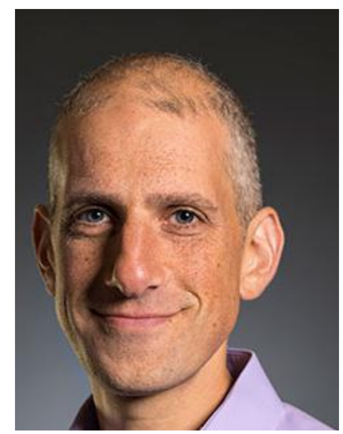


1. INTRODUCTION

Fine particulate matter ($PM_{2.5}$) is the largest environmental health risk in the United States (US) and globally.[1,2] $PM_{2.5}$ is associated with increased mortality rates from cardiovascular

year 2016 projected emissions: 17 000 (Fann et al. 2013).[14] Levy et al. (2009)[17] modeled the monetized damages associated with 407 coal-fired power plants in the United States. Buonocore et al. (2014)[18] estimated monetized health





Results: Premature mortality by race.

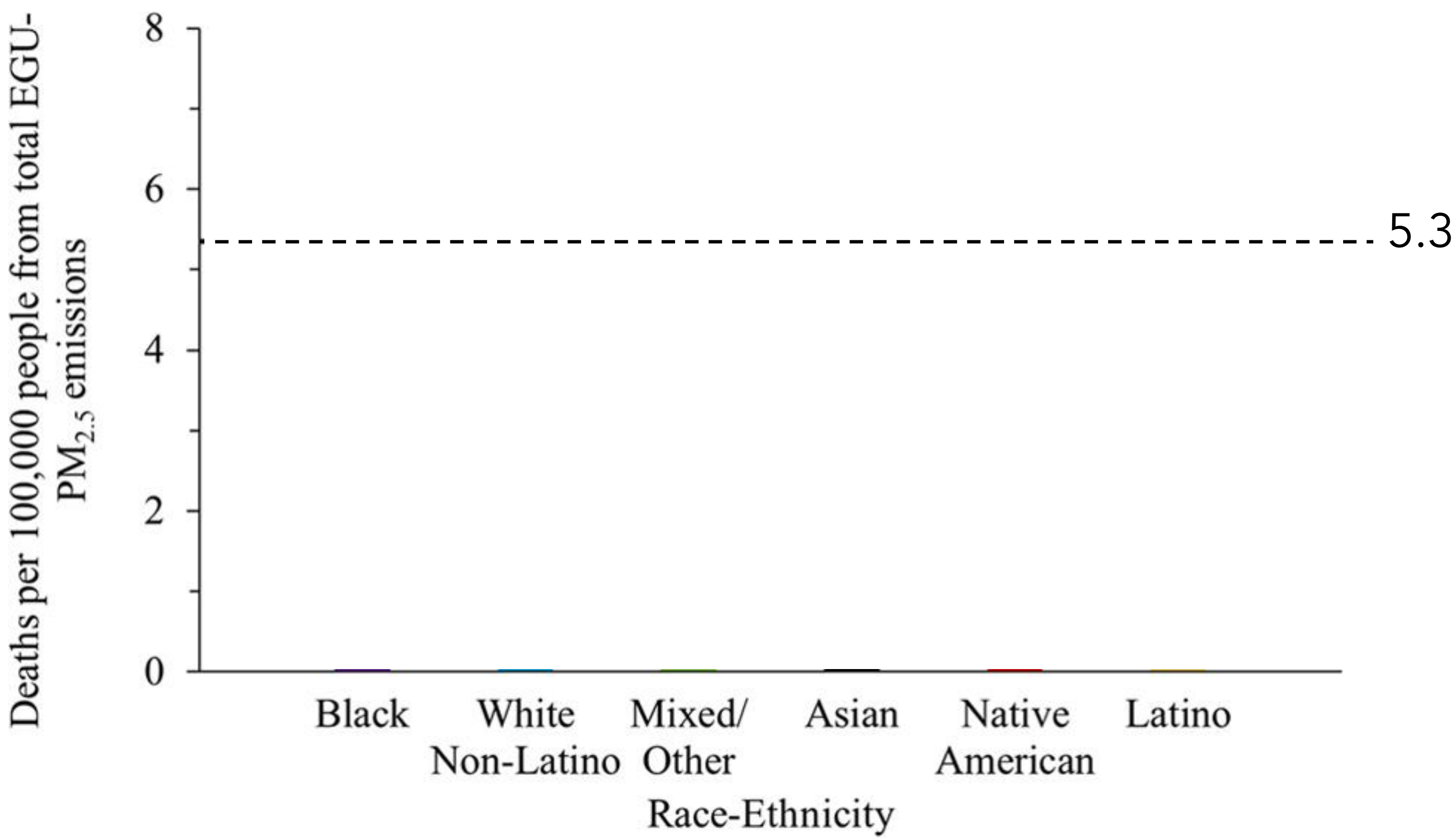
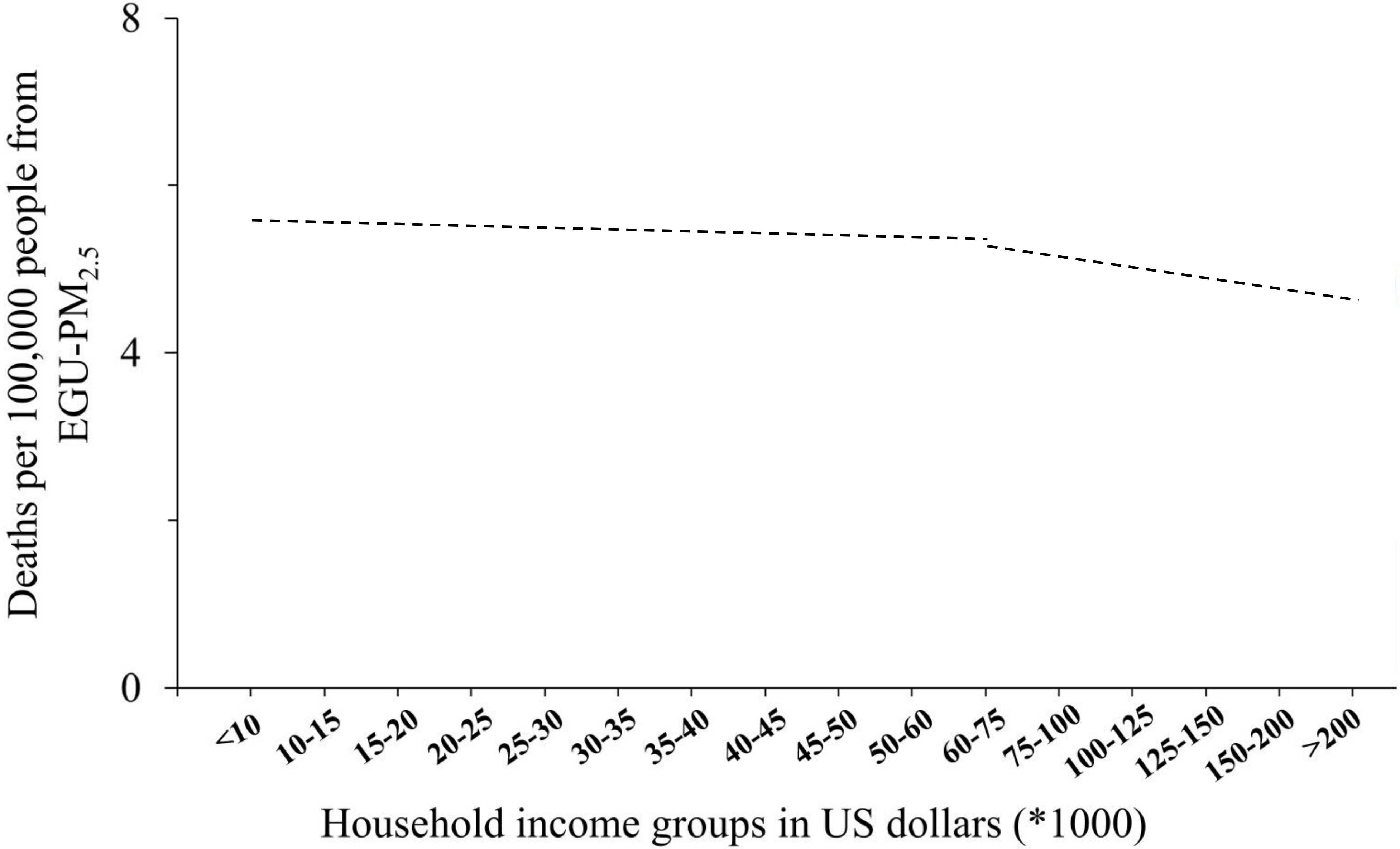
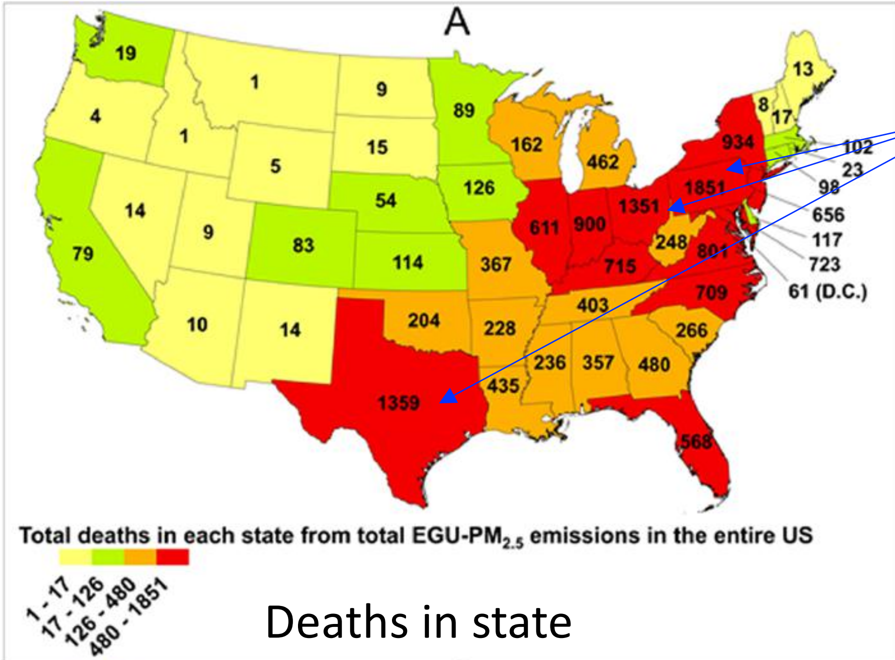


Figure 1. Deaths per 100 000 people attributable to $PM_{2.5}$ from electricity generation in the US in 2014.

Results: Premature mortality by race and income.

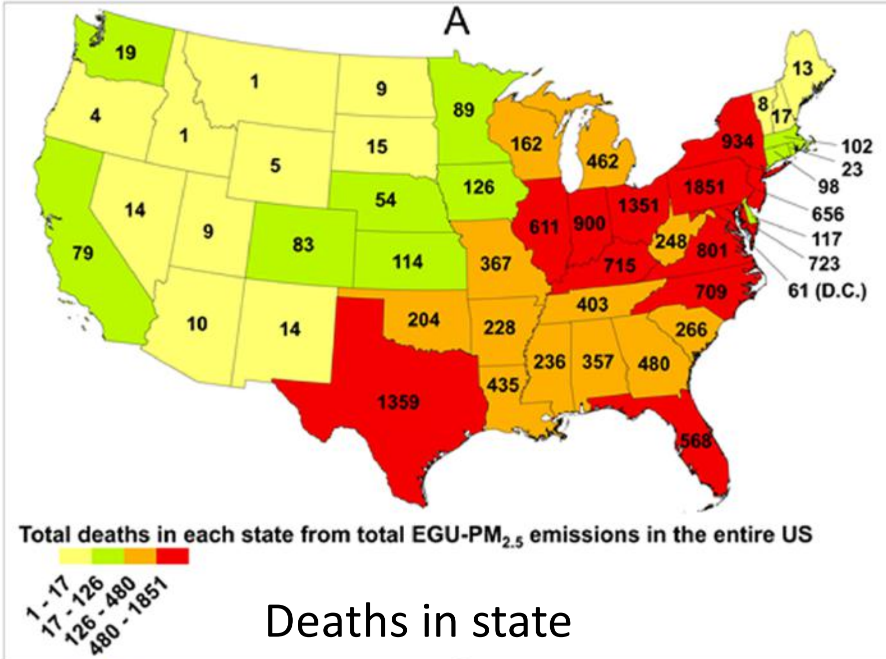


Results: Total, self-, imported and exported damages

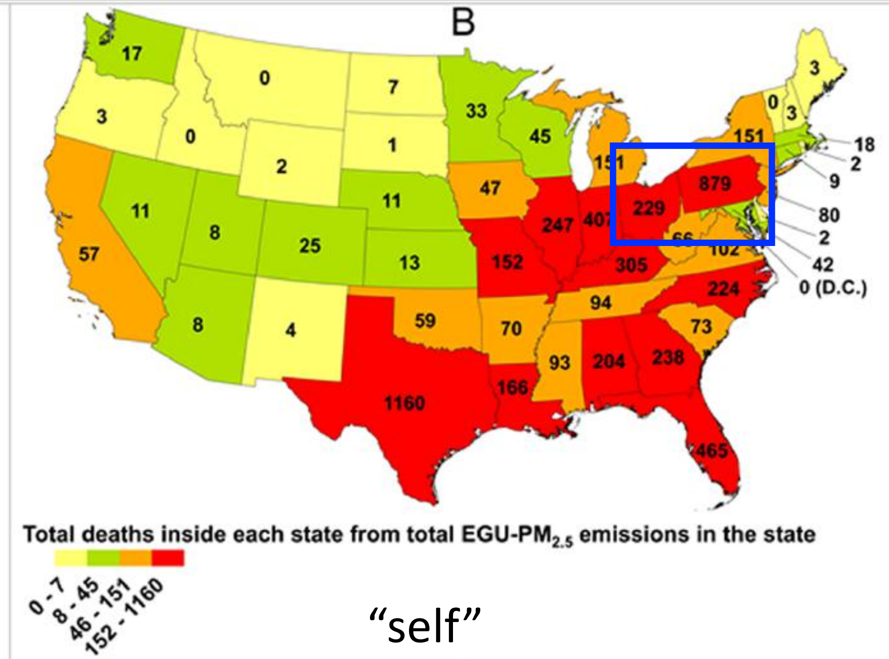


Pennsylvania, Texas, Ohio

Results: Total, self-, imported and exported damages

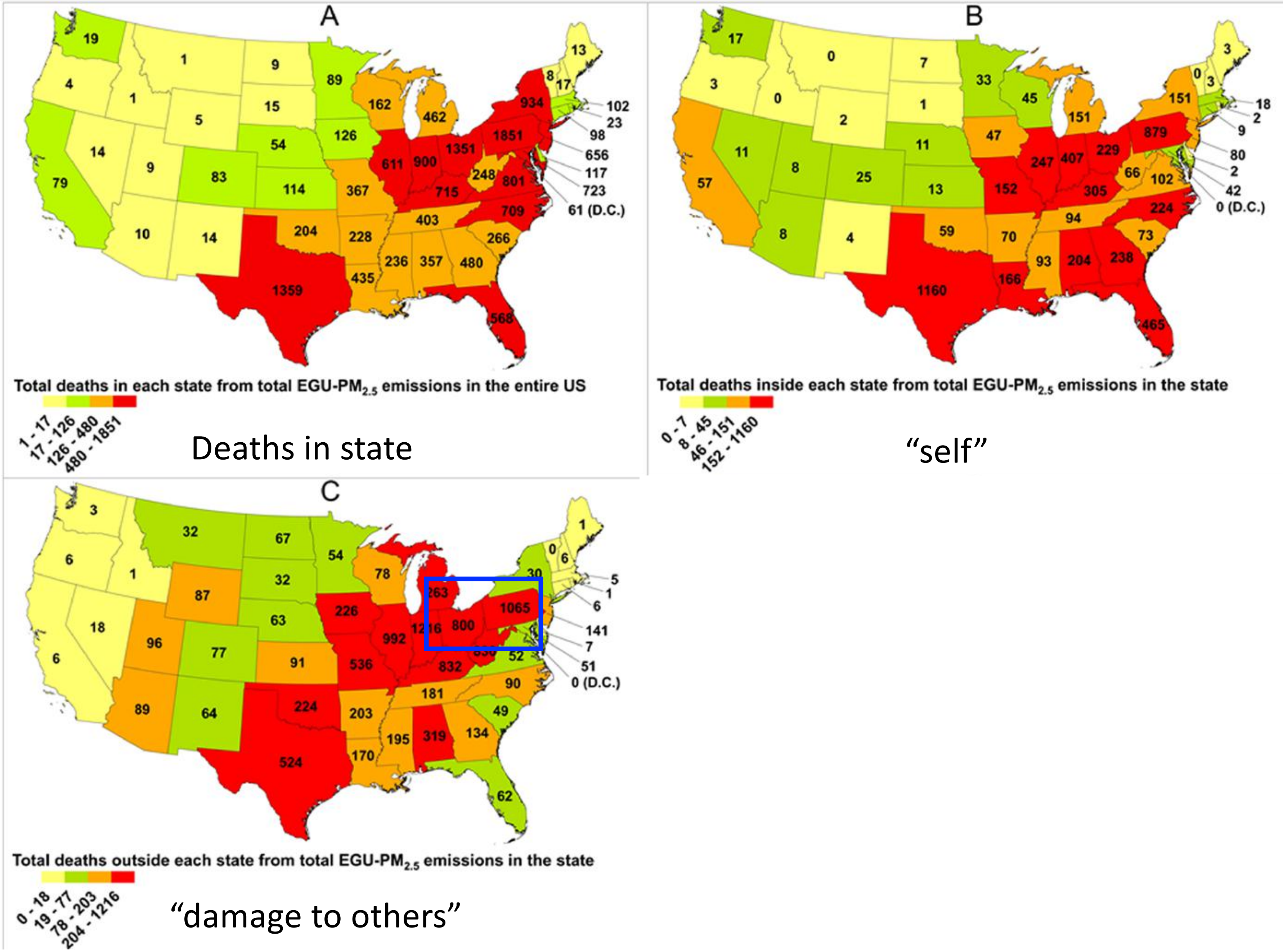


Deaths in state



"self"

Results: Total, self-, imported and exported damages



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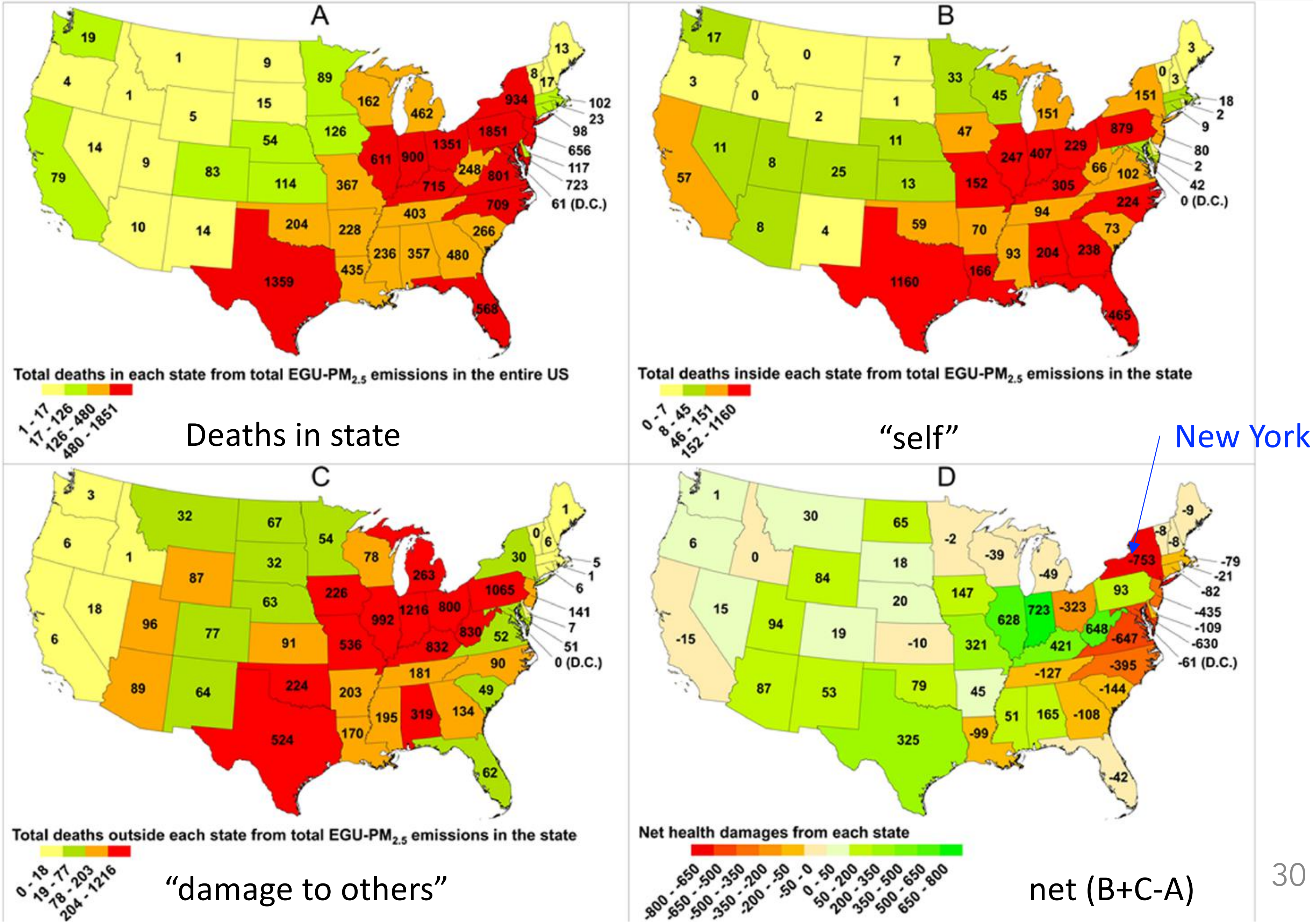

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