AMERICAN ECONOMIC ASSOCIATION

Climate Change Economics

AEA Continuing Education Program

January 5-7, 2020
San Diego, CA

Instructors

Prof. Lint Barrage
UC Santa Barbara Department of Economics

Prof. Michael Greenstone
University of Chicago Department of Economics

Prof. Gilbert Metcalf
Tufts University Department of Economics

Agenda and Schedule

Topic	Leader(s)
Day 1	
Global Energy Systems and Markets	Greenstone
Climate Science Basics	Metcalf
Day 2	
Basic Climate Change Economics	Greenstone, Barrage
Integrated Assessment and Macro Models of Climate Change	Barrage
What do we know about Climate Change's Impacts?	Greenstone
Climate-Economy Models: Challenges and New Frontiers	Barrage
Policy Overview	Metcalf, Greenstone
Day 3	
Climate Policy Options I	Metcalf
Climate Policy Options II	Metcalf
Wrap up	Metcalf, Barrage

EPIC | ENERGY POLICY INSTITUTE AT THE UNIVERSITY OF CHICAGO

The Global Energy Challenge

AEA Continuing Education
January 5, 2020

Michael Greenstone

Milton Friedman Distinguished Professor in Economics and the College
University of Chicago

Director
Becker Friedman Institute at the University of Chicago

Director
Energy Policy Institute at the University of Chicago



The Global Energy Challenge

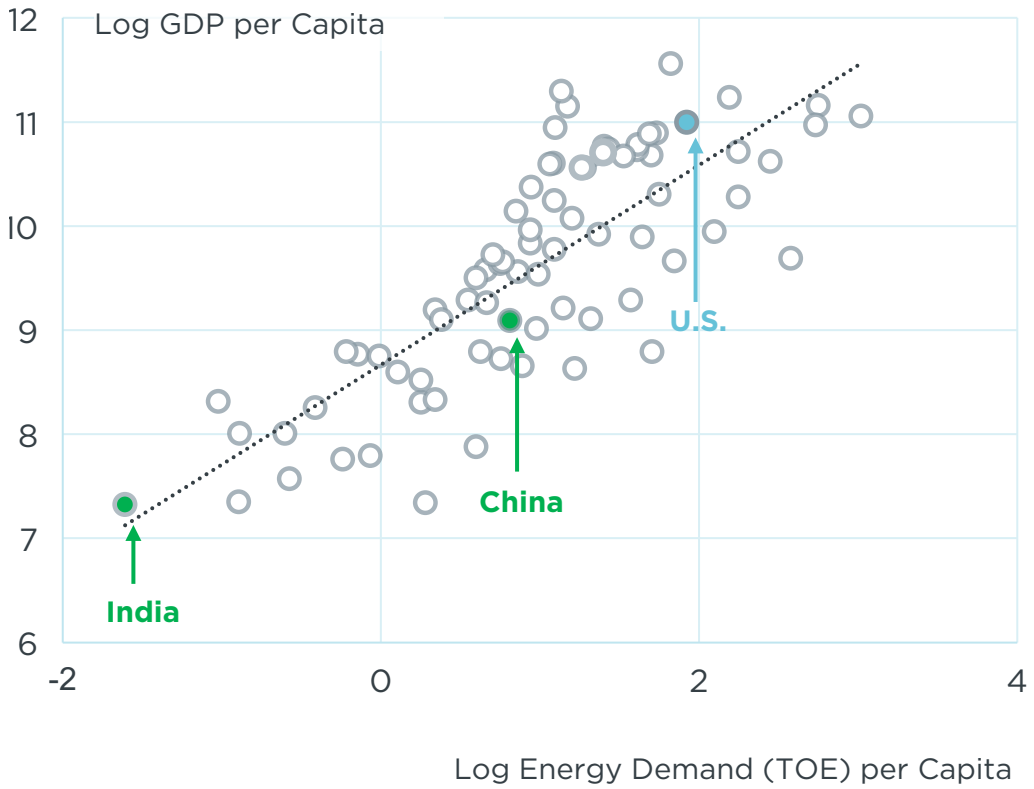
How can we ensure that people around the world have access to the reliable, affordable, energy needed for economic growth and human development without putting the environment, climate or security at risk?

Seven Facts that Explain the Difficult Balance between Energy and Growth

1. Energy is Critical for Growth

Energy is Critical for Growth

Primary Energy Demand & GDP per Capita (2017)



- There is no economic growth without energy.
- Continued growth in energy demand per capita is critical for improving quality of life in emerging economies.
- In this sense, expanded energy access is not only desirable, it is fundamentally imperative and inevitable.

Source: EPIC analysis based on World Bank data.

Seven Facts that Explain the Difficult Balance between Energy and Growth

1. Energy is Critical for Growth
2. Energy Access is a Major Problem

Energy Access is a Major Problem

Per Capita Electricity Consumption and Population, 2016

Country	Population (Millions)	kWh per Capita
Canada	36	14800
U.S.	323	12800
China	1,379	4300
Mexico	128	2300
India	1,324	900
Bihar	104	272

Sources: IEA Atlas of Energy for country consumption statistics, World Bank for country population statistics, Indian Census 2011 and Bihar Economic Survey for Bihar statistics.

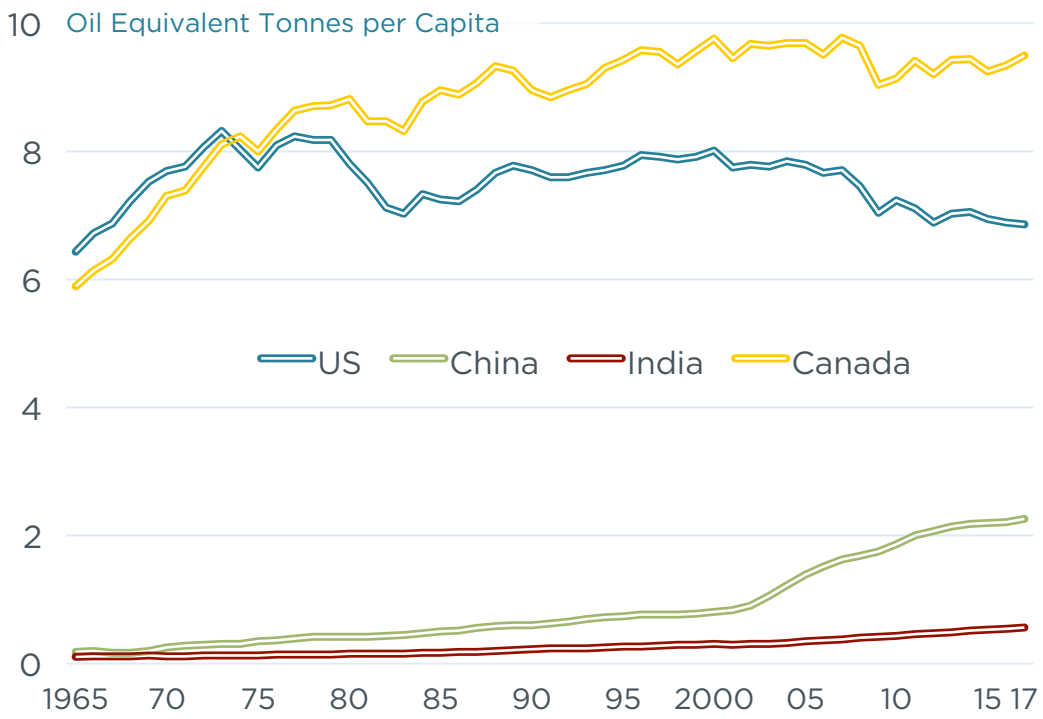
- Per capita energy consumption in developing economies remains significantly lower than developed world levels.
- According to the International Energy Agency (2017), nearly 1.1 billion people globally lack access to reliable electricity—239 million in India alone.
- It takes 131 kWh to use a 60 watt light bulb for 6 hours per day for a full year.

Seven Facts that Explain the Difficult Balance between Energy and Growth

1. Energy is Critical for Growth
2. Energy Access is a Major Problem
3. Demand will Grow Rapidly in Developing Countries

Demand will grow Rapidly in non-OECD

Primary Energy Demand per Capita

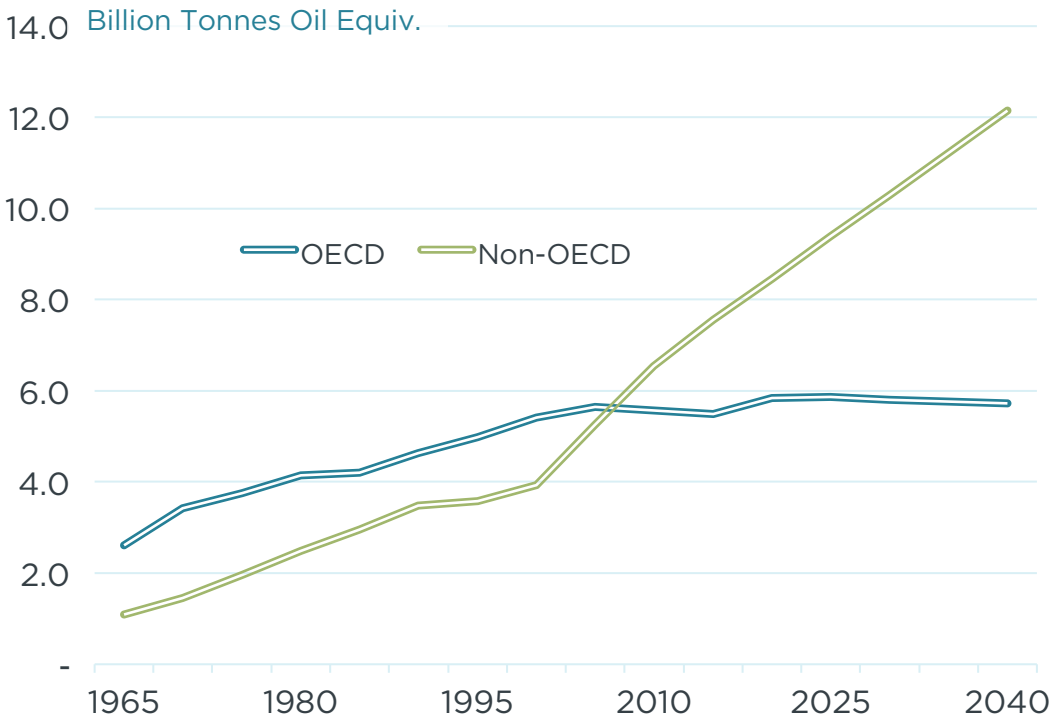


- Though China is now the world's largest energy consumer, its per capita consumption is less than one-third the U.S. level.
- Hundreds of millions of people will move into the middle class in these economies before 2035, with profound implications for energy demand.

Source: EPIC analysis based on data from BP Statistical Review and World Bank.

Demand will grow Rapidly in non-OECD

Global Energy Demand, 1965-2040



- Global energy demand is set to grow by one-third between now and 2040.
- Fully 100 percent of expected growth will occur in emerging market economies, especially in Asia.
- China and India are expected to account for about half of global energy demand growth between today and 2040 based on business as usual.

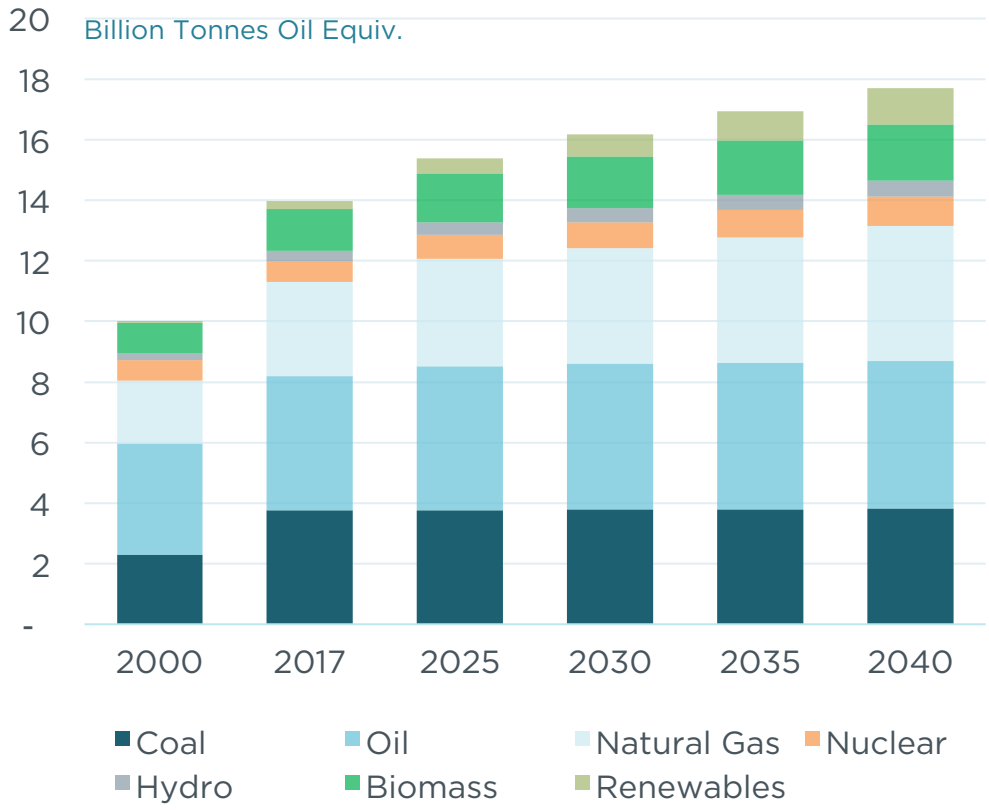
Source: EPIC analysis based on data from BP Statistical Review 2018 and BP Energy Outlook 2019

Seven Facts that Explain the Difficult Balance between Energy and Growth

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Fossil Fuels will meet Much of this Growth

World Primary Energy Demand, 2013 - 2040

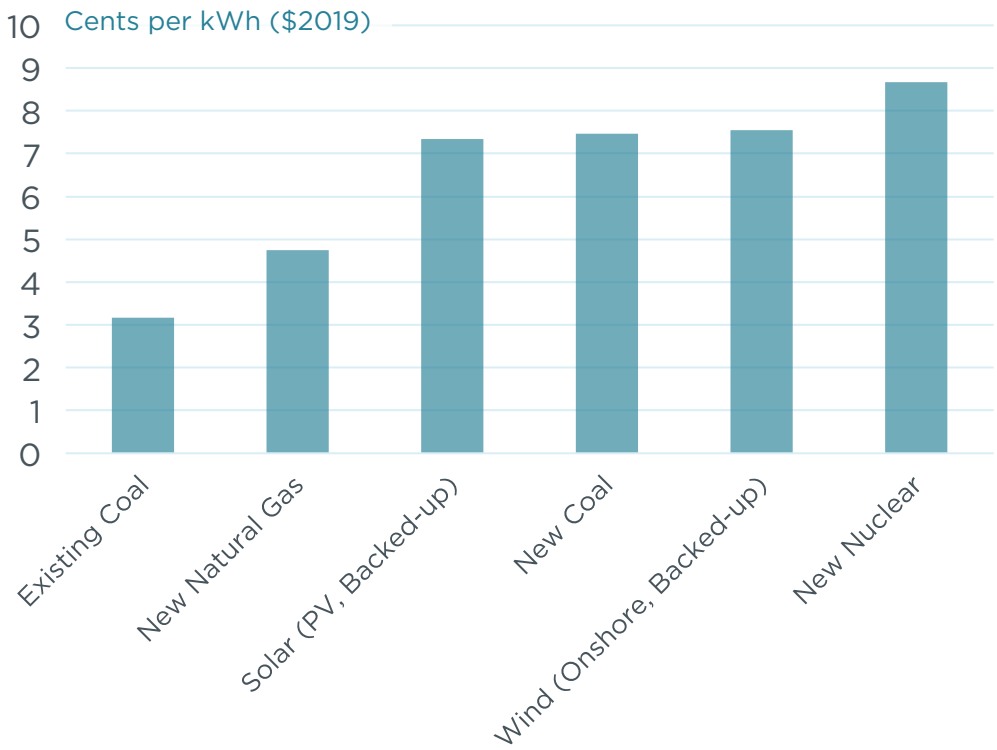


- Based on policies in place and committed at the end of 2016, the International Energy Agency expects fossil fuels to supply 74 percent of world primary energy in 2040, compared to 81 percent in 2017.
- While renewables are the fastest growing resource, coal, oil, and natural gas together account for about half of all growth through 2040.

Source: International Energy Agency, 2018

Fossil Fuels are Inexpensive in Power...

Levelized Cost of Energy, United States



- Conventional fuels and technologies are the most cost-effective sources of energy today and continue to attract significant investment as a result.
- Challenges in transportation are even greater, where the combination of the combustion engine and oil have no competition.

EPIC analysis based on data from the EIA Annual Energy Outlook 2019. Existing coal excludes capital cost. Wind and solar are backed up by natural gas combustion turbine.

...and in other Sectors like Transportation

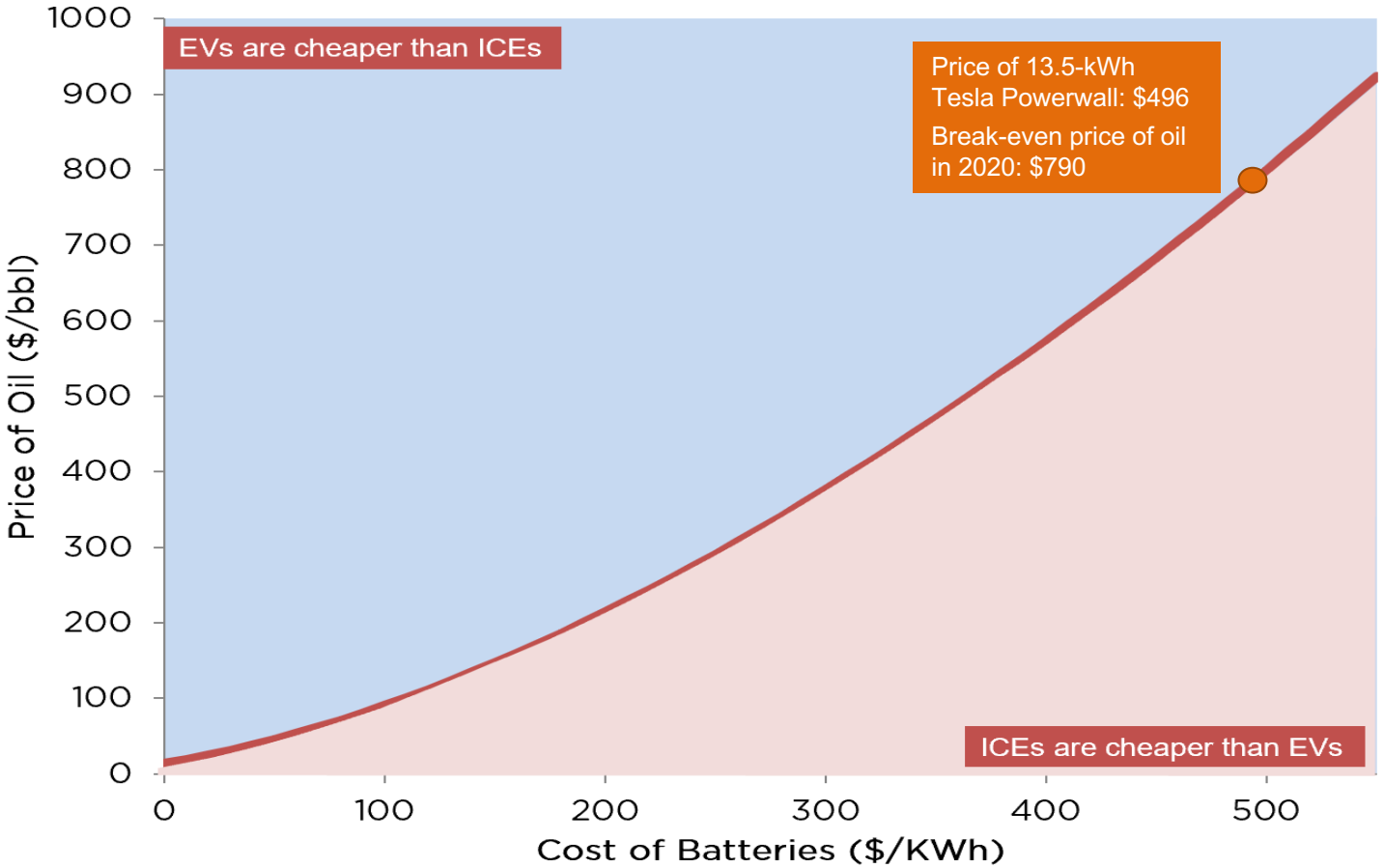
Breakeven NPV of Owning an ICE versus an EV with 250 Miles of Range



Source: Greenstone et. al., "Will We Ever Stop Using Fossil Fuels?"

…and in other Sectors like Transportation

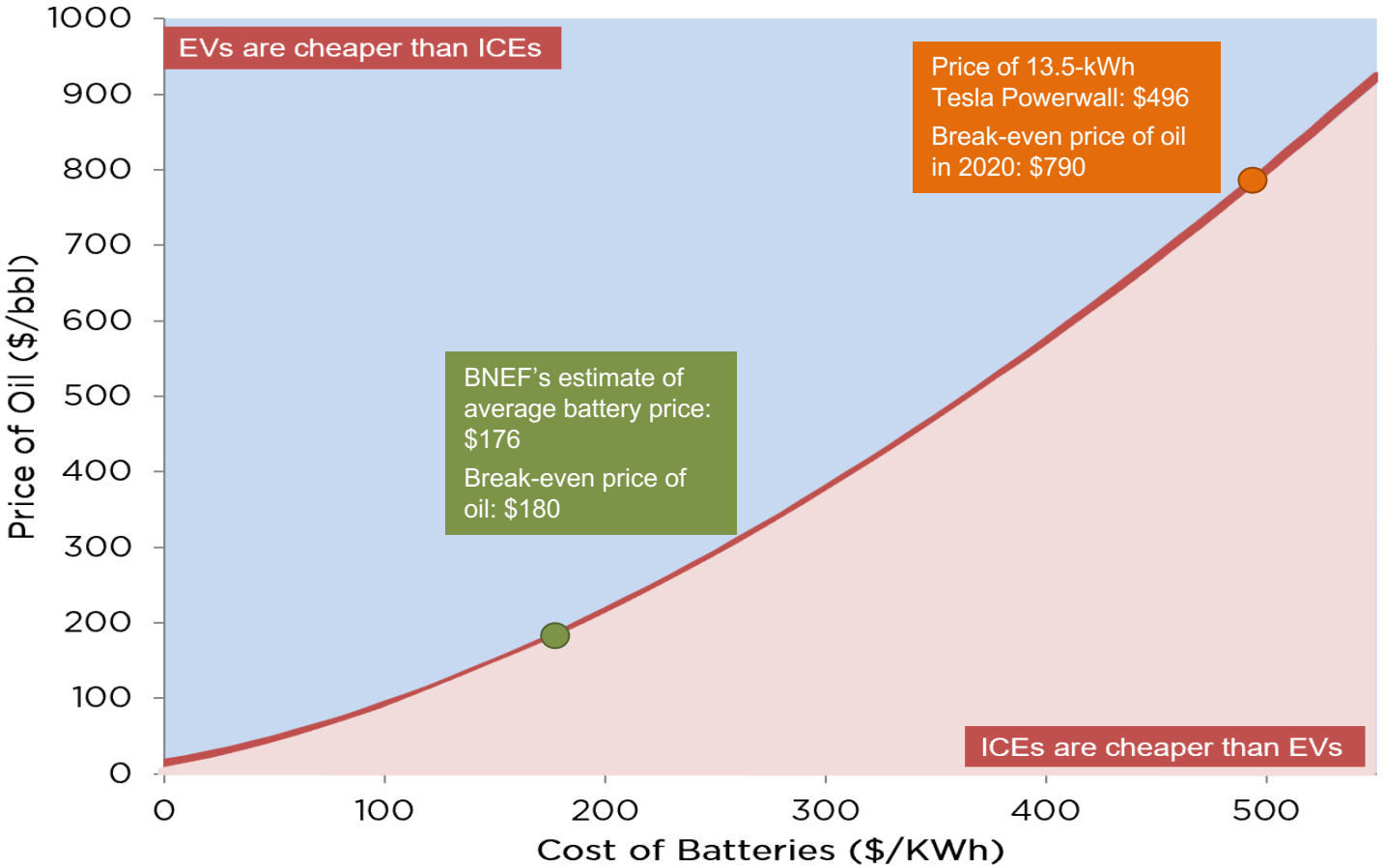
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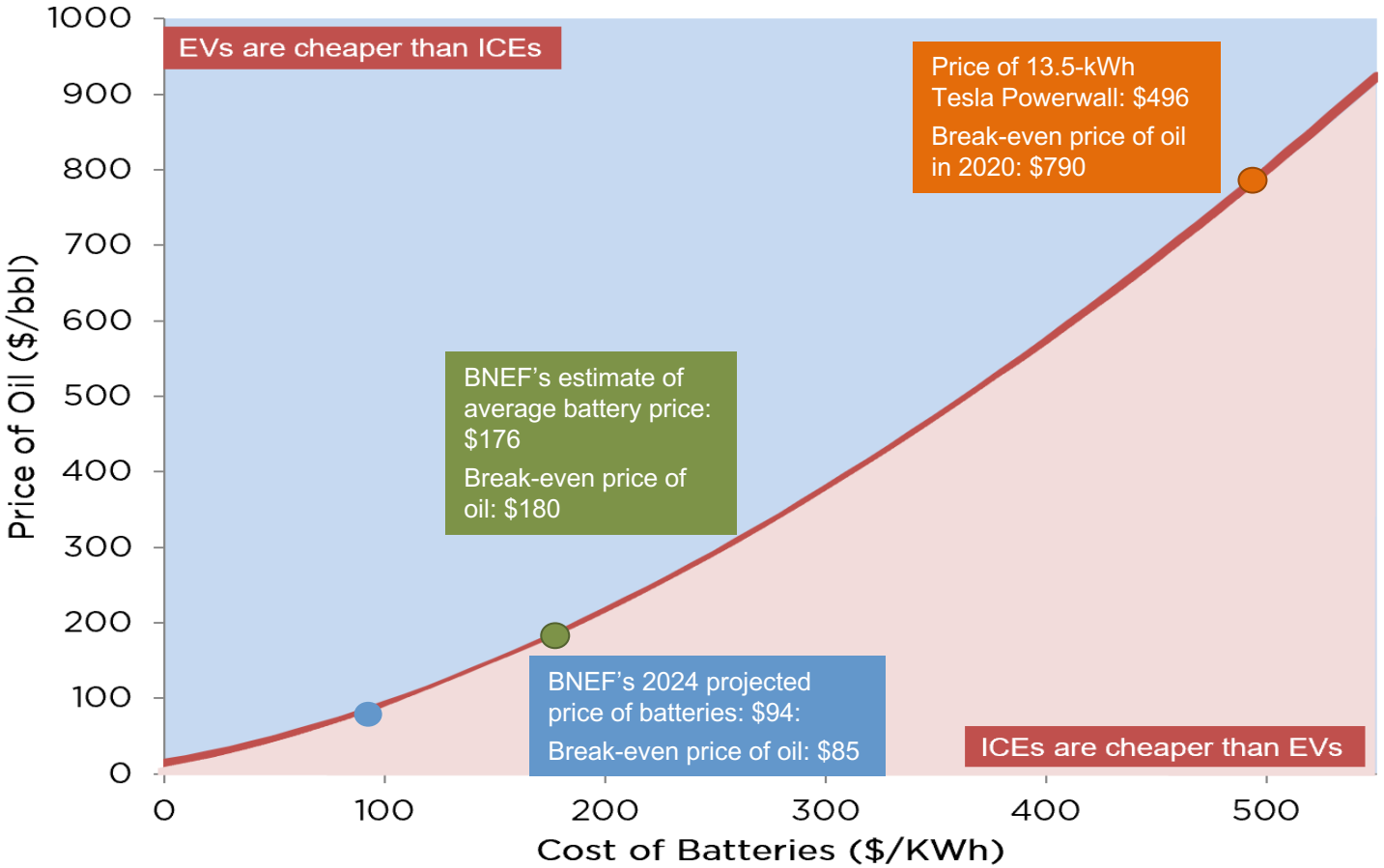
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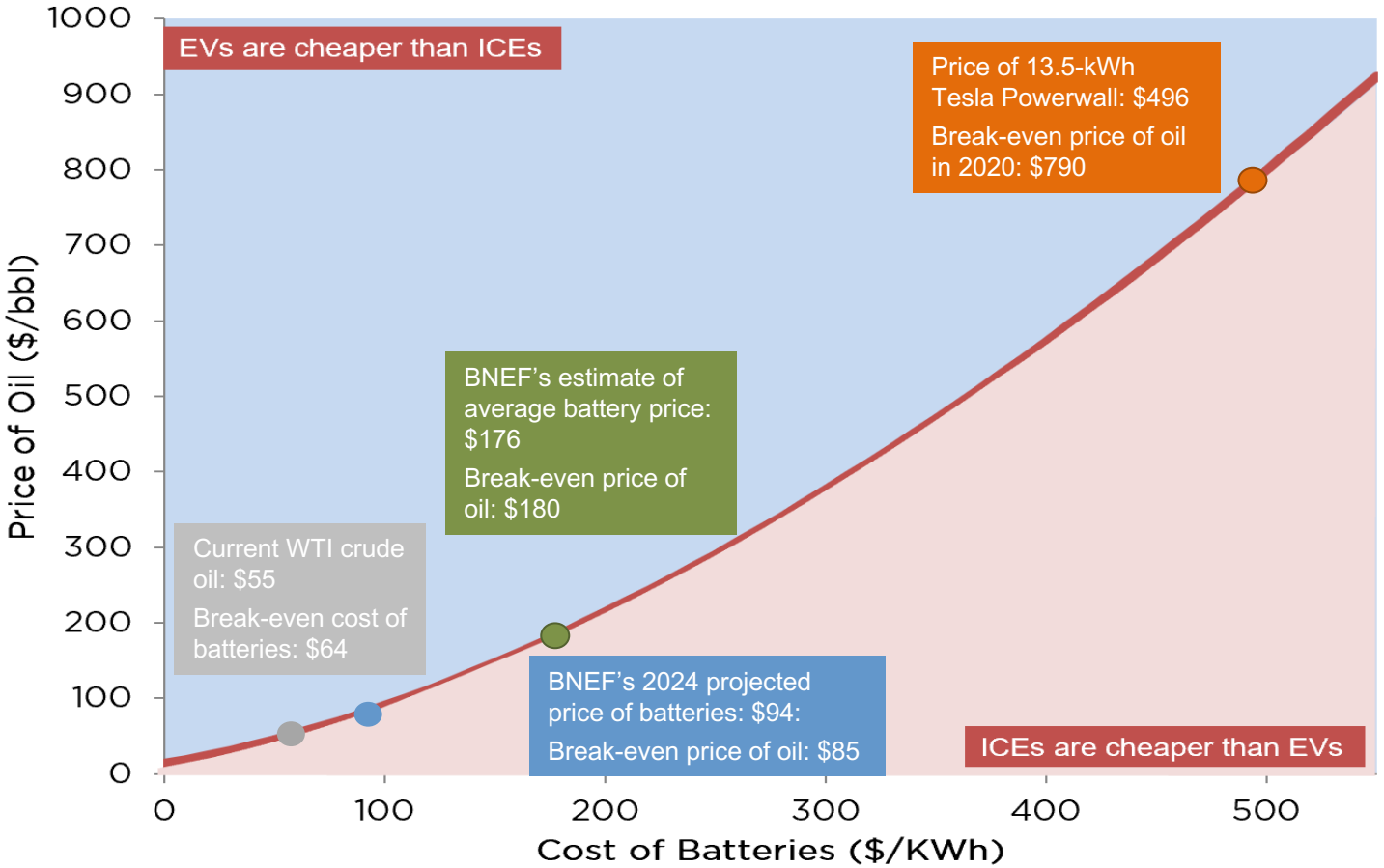
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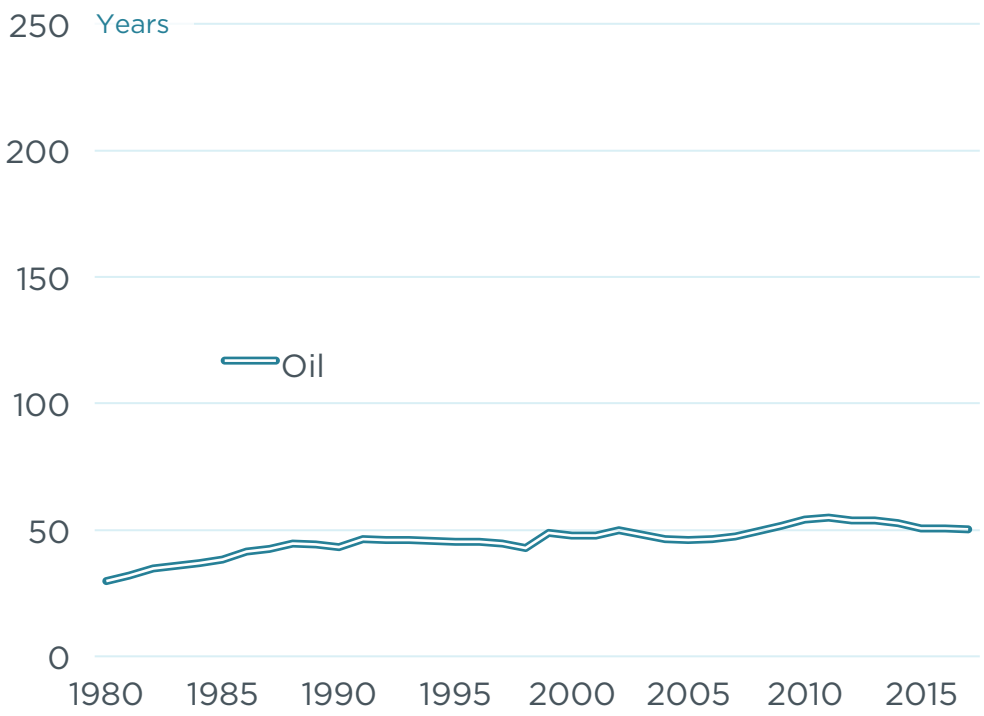
Breakeven NPV of Owning an ICE versus an EV with 250 Miles of Range



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...And Fossil Fuels Remain Abundant

Fossil Fuel Reserves-to-Production Ratios

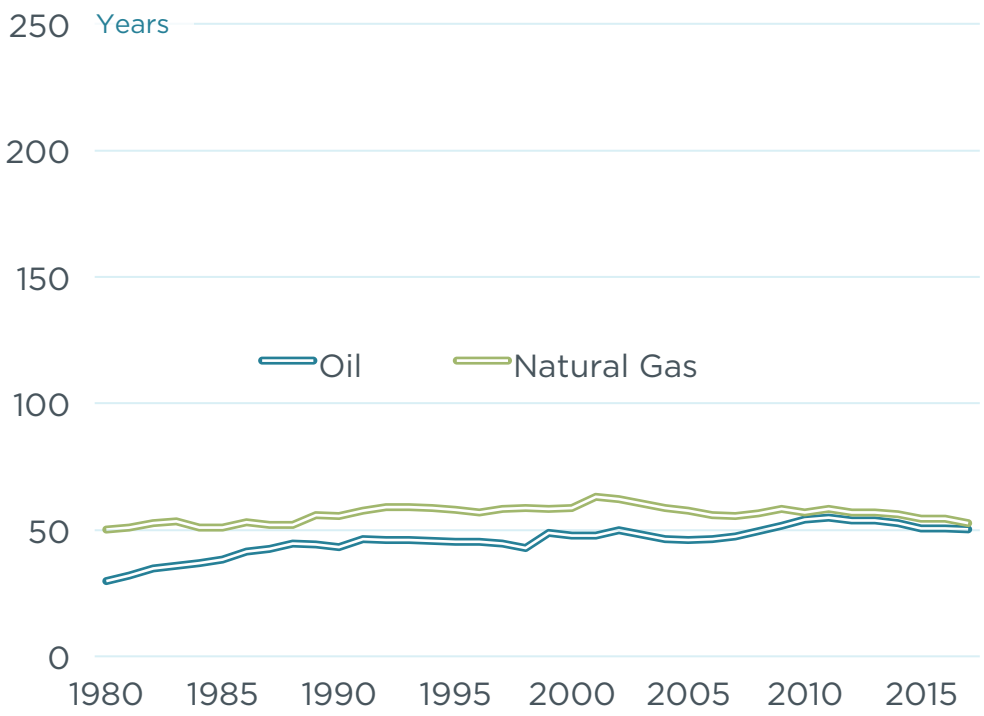


› Oil reserves have grown significantly over the past 30 years, and are now equal to 50 years of current production.

EPIC analysis based on data from BP

...And Fossil Fuels Remain Abundant

Fossil Fuel Reserves-to-Production Ratios

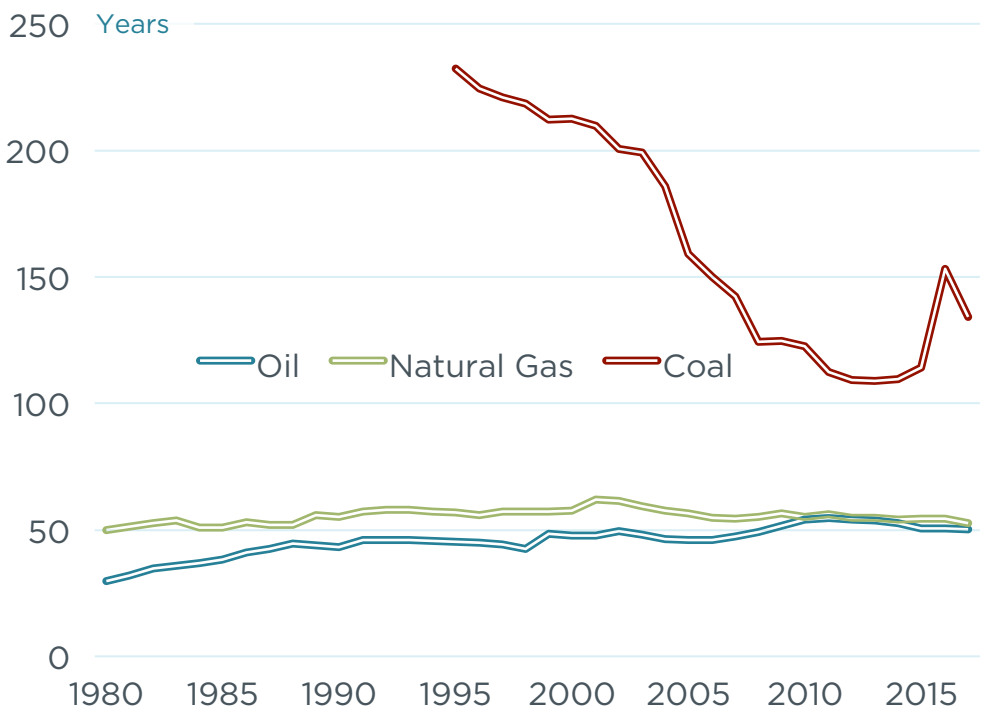


- Oil reserves have grown significantly over the past 30 years, and are now equal to 50 years of current production.
- The world has consistently held approximately 50 years worth of natural gas reserves for over the same time period, meaning annual reserve additions have roughly equaled production.

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Fossil Fuel Reserves-to-Production Ratios



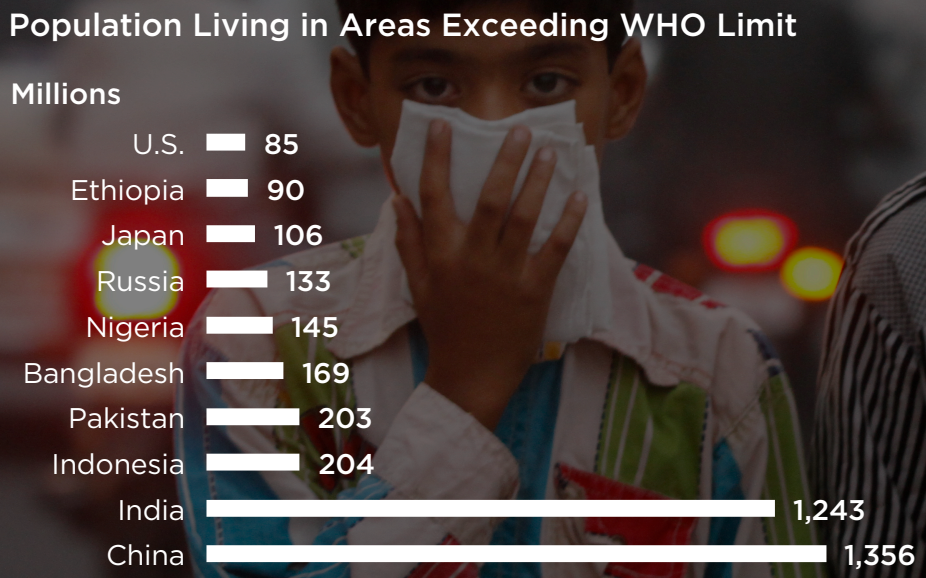
- Oil reserves have grown significantly over the past 30 years, and are now equal to 50 years of current production.
- The world has consistently held approximately 50 years worth of natural gas reserves for over the same time period, meaning annual reserve additions have roughly equaled production.
- Coal reserves are currently equal to 134 years of consumption—down significantly from 1995, but still ample.

EPIC analysis based on data from BP

Seven Facts that Explain the Difficult Balance between Energy and Growth

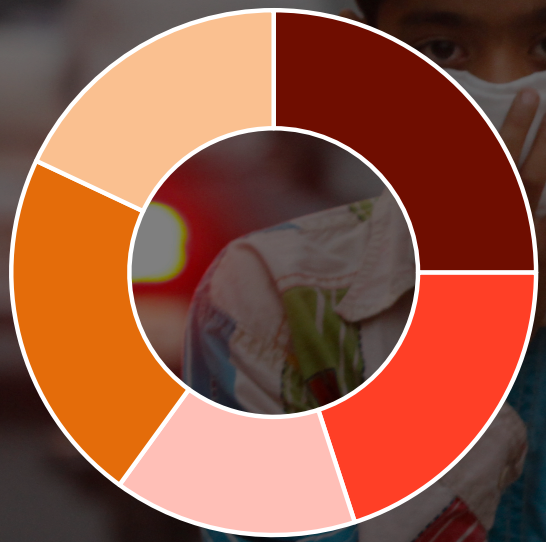
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5.5 billion people currently live in areas that exceed the WHO safe guideline for small particulate pollution.



Particulate pollution overwhelmingly comes from energy use.

Where does PM Pollution Come From?



- 25% Vehicles
- 20% Household Wood and Coal Burning
- 15% Power Plants and Industry
- 22% Other Human Activity
- 18% Natural Sources

Revisiting the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River Policy

Ebenstein, Fan, Greenstone, He, and Zhou (2017)

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China's Huai River Winter Heating Policy

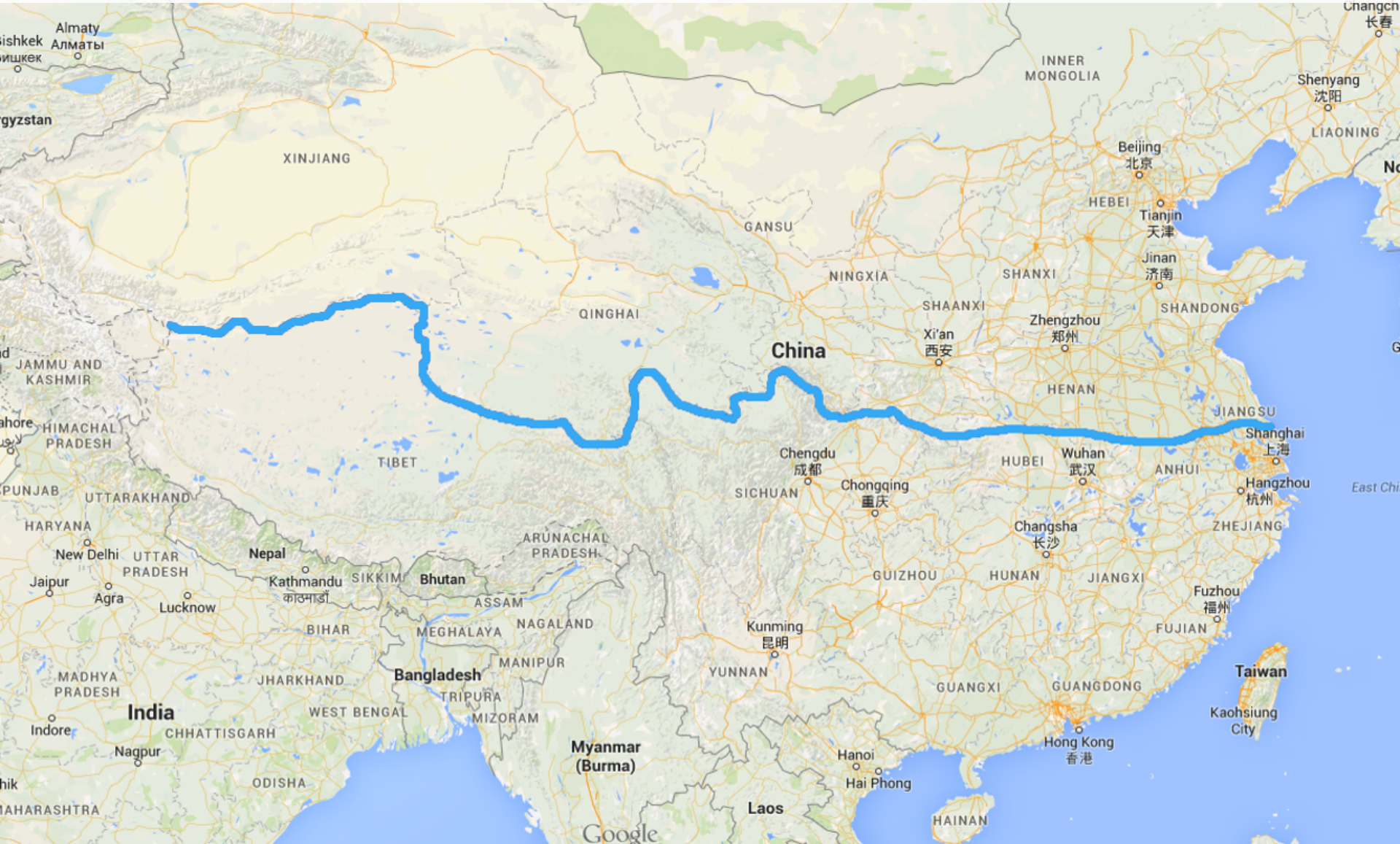
1) **Established during the planning period, 1950-80.**

2) **Municipal heating systems built in cities to provide subsidized heating to homes each winter (e.g. Nov 15 to Mar 15 in Beijing). Heat generated by coal boilers.**

3) **Due to budget limitations, only built municipal heating systems in cities north of Huai River-Qinling Mountains line.**
   - » Only in recent years has municipal heating started to emerge in southern cities

The Dividing Line

The Huai River forms the dividing line between regions with heavy coal-fired home heating and regions with little to no use of such boilers.



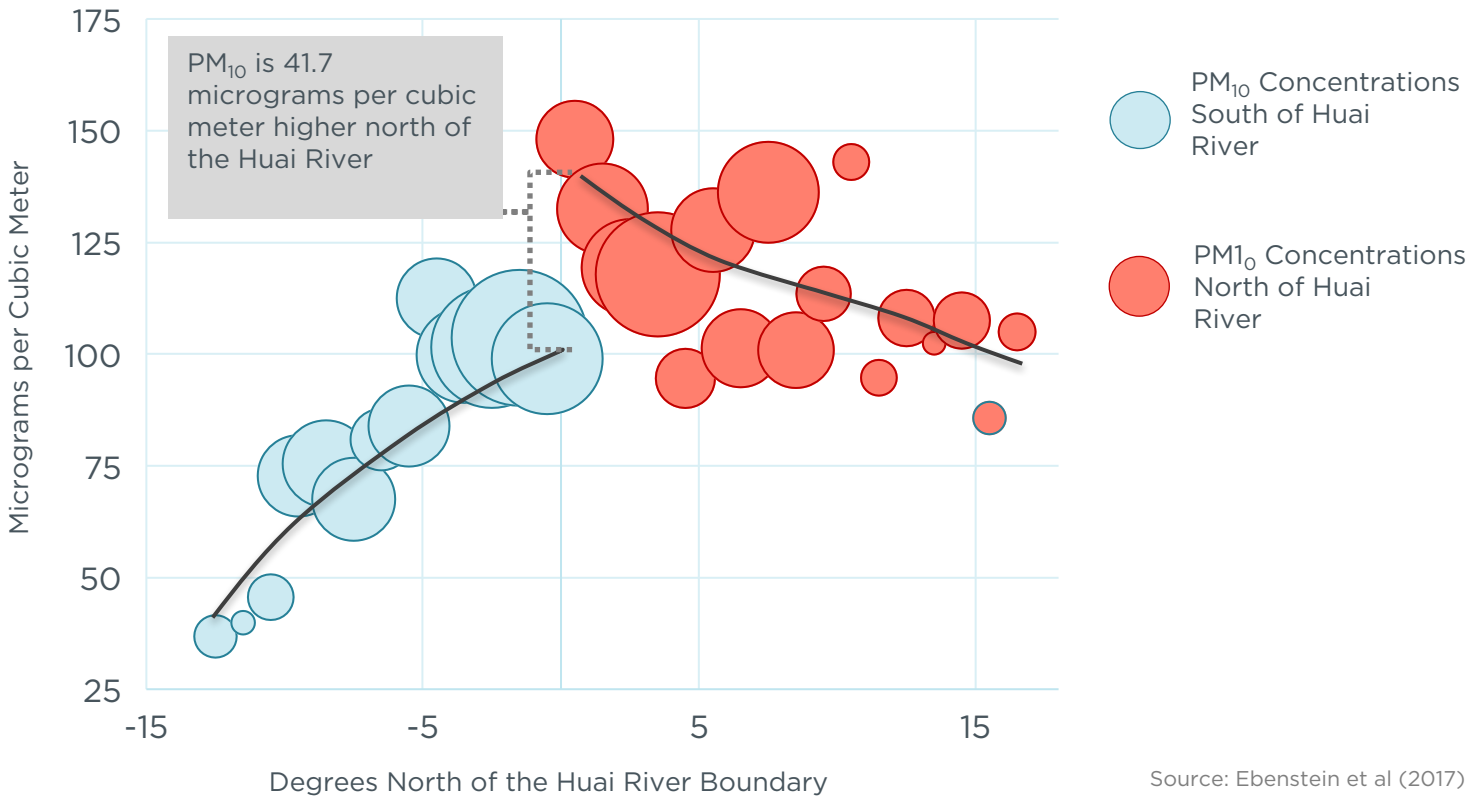
The Boiler Heating System

Subsidized coal is burned to heat water, often in a boiler housed in a building. The combusted coal emits high levels of soot and particulate matter.



Pollution is 40% Higher North of the River

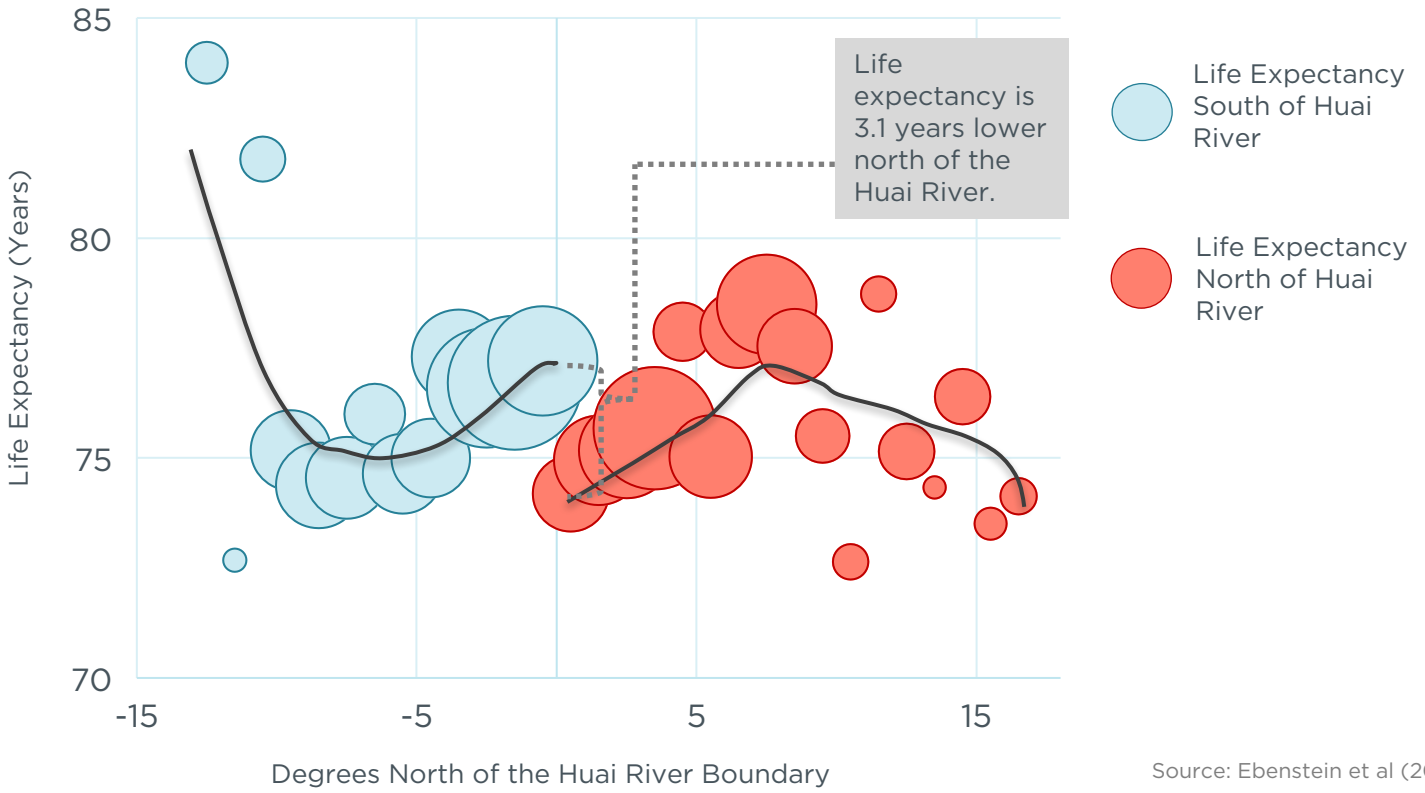
PM_{10} Emissions North and South of the Huai River



Source: Ebenstein et al (2017)

Life Expectancy is about 3 Years Lower

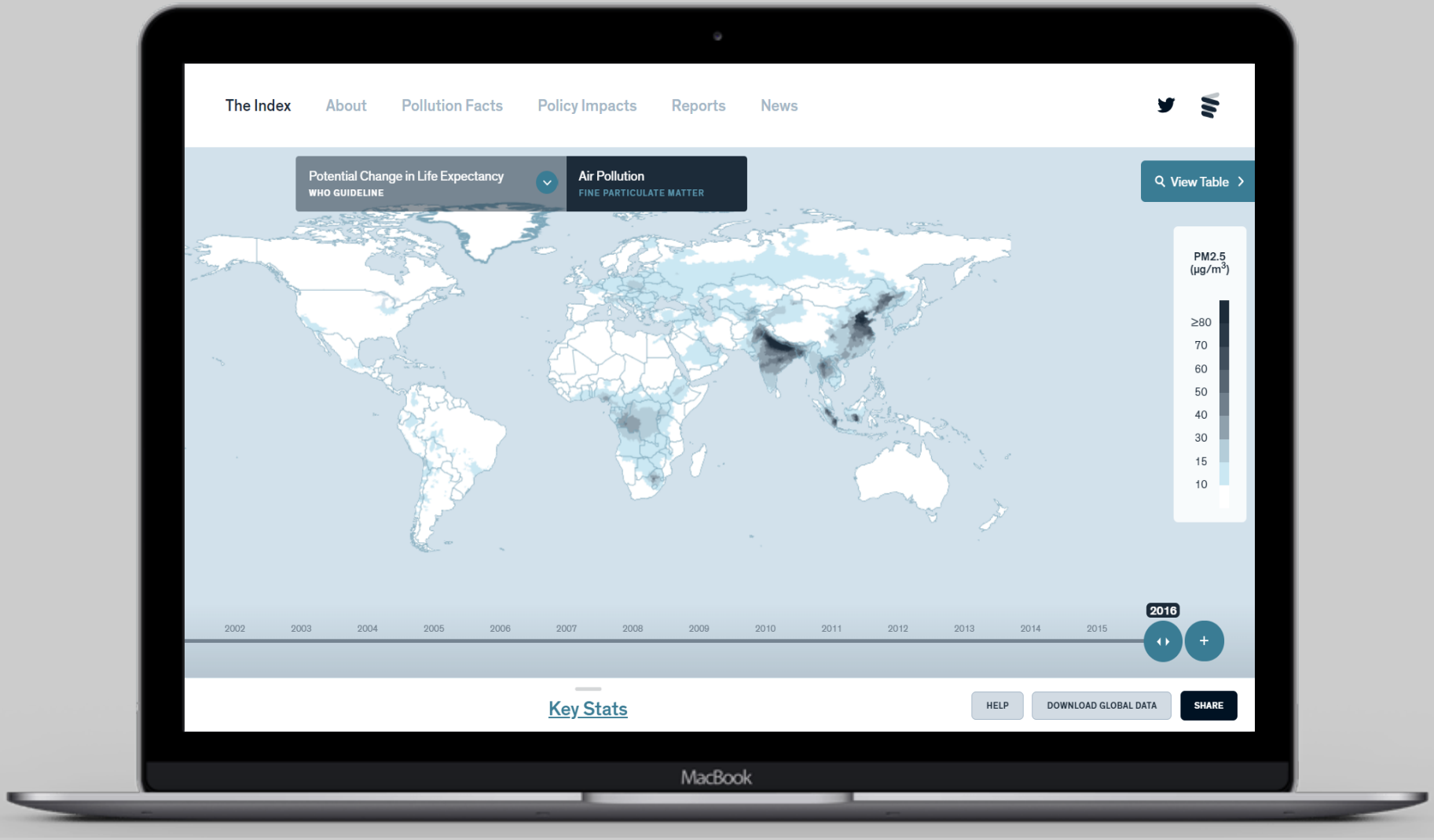
Life Expectancy North and South of the Huai River



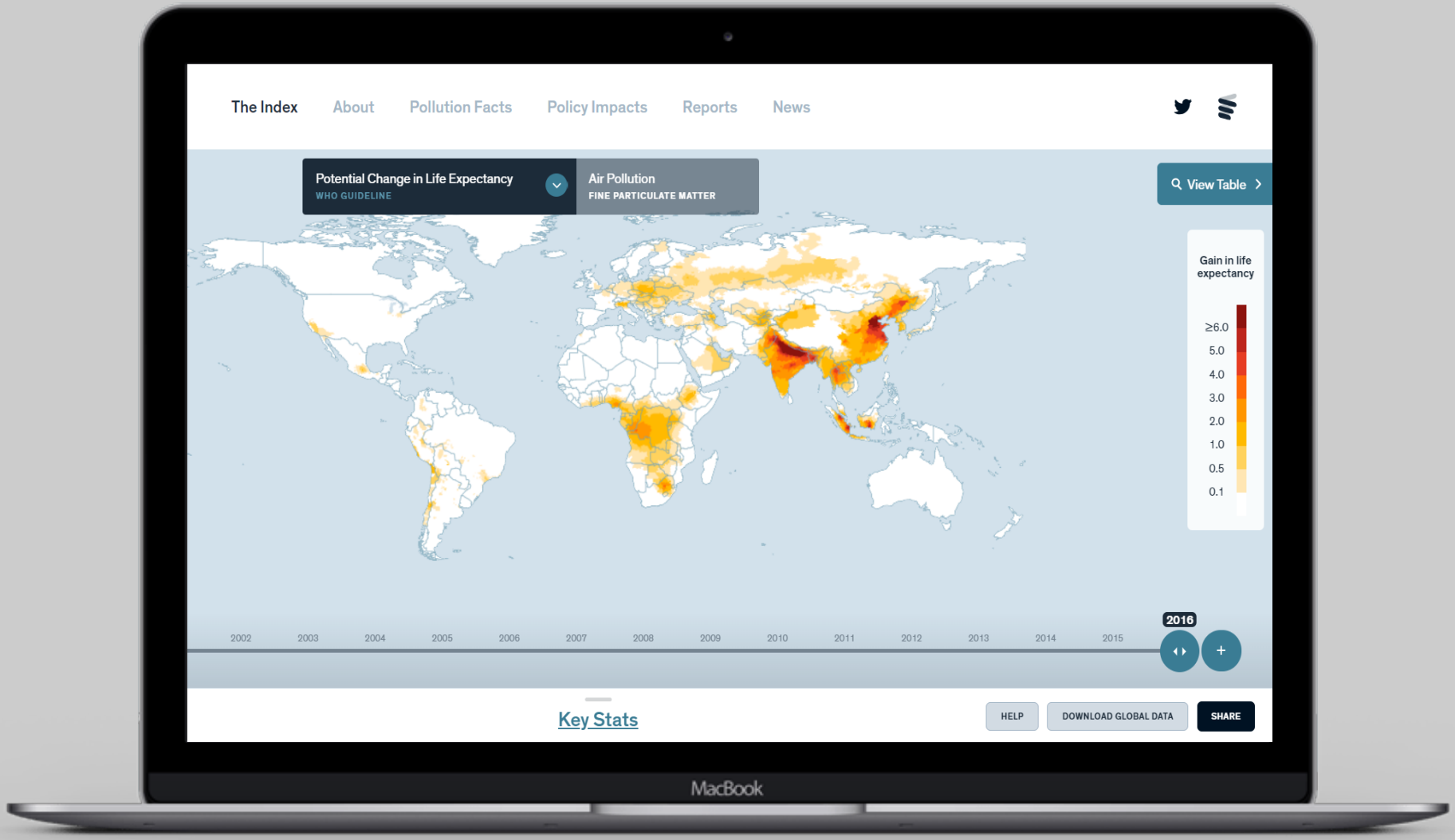
Source: Ebenstein et al (2017)

PM pollution concentrations around the globe...

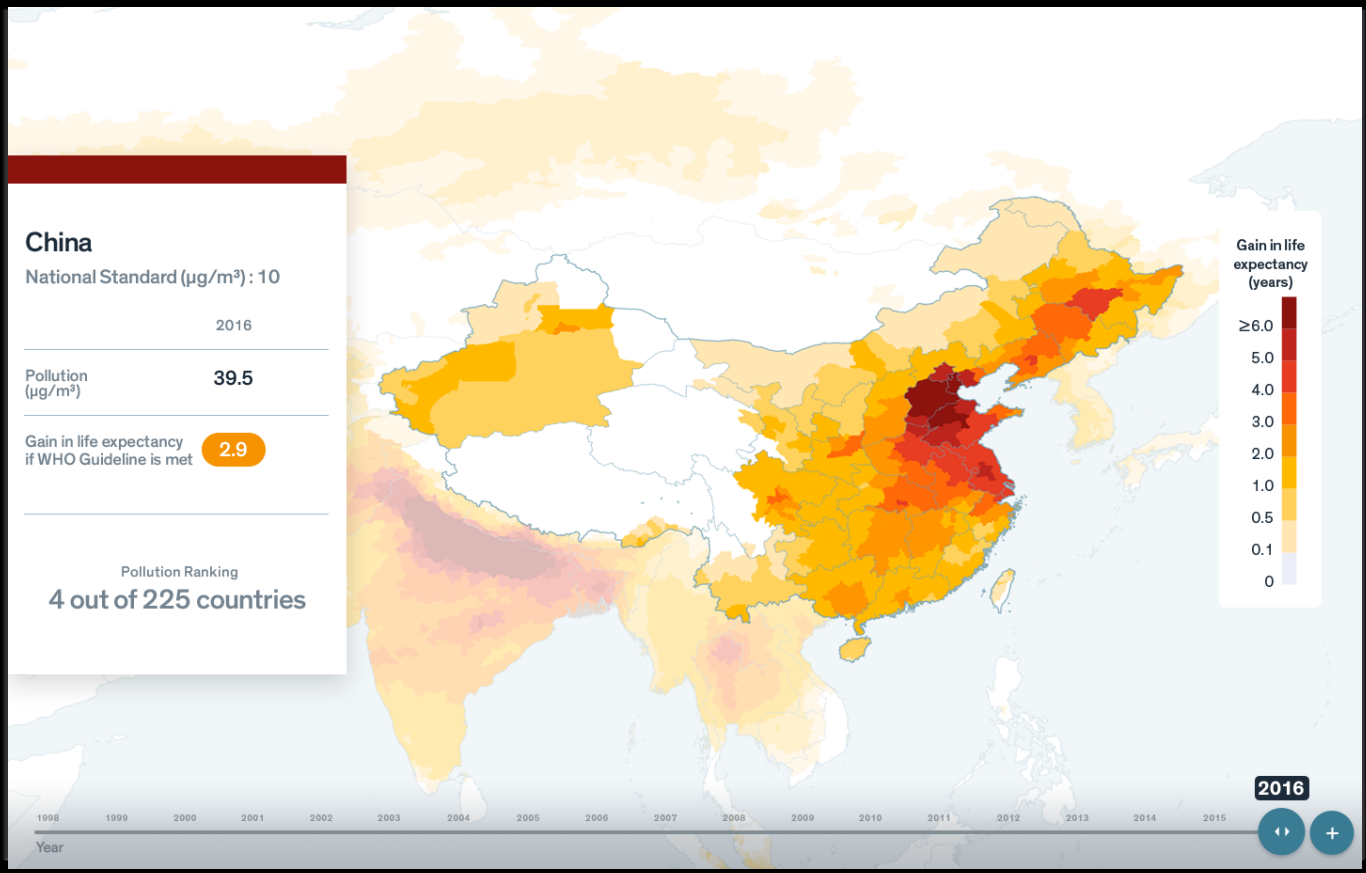
With high-resolution, satellite-derived global dataset of $PM_{2.5}$ concentrations



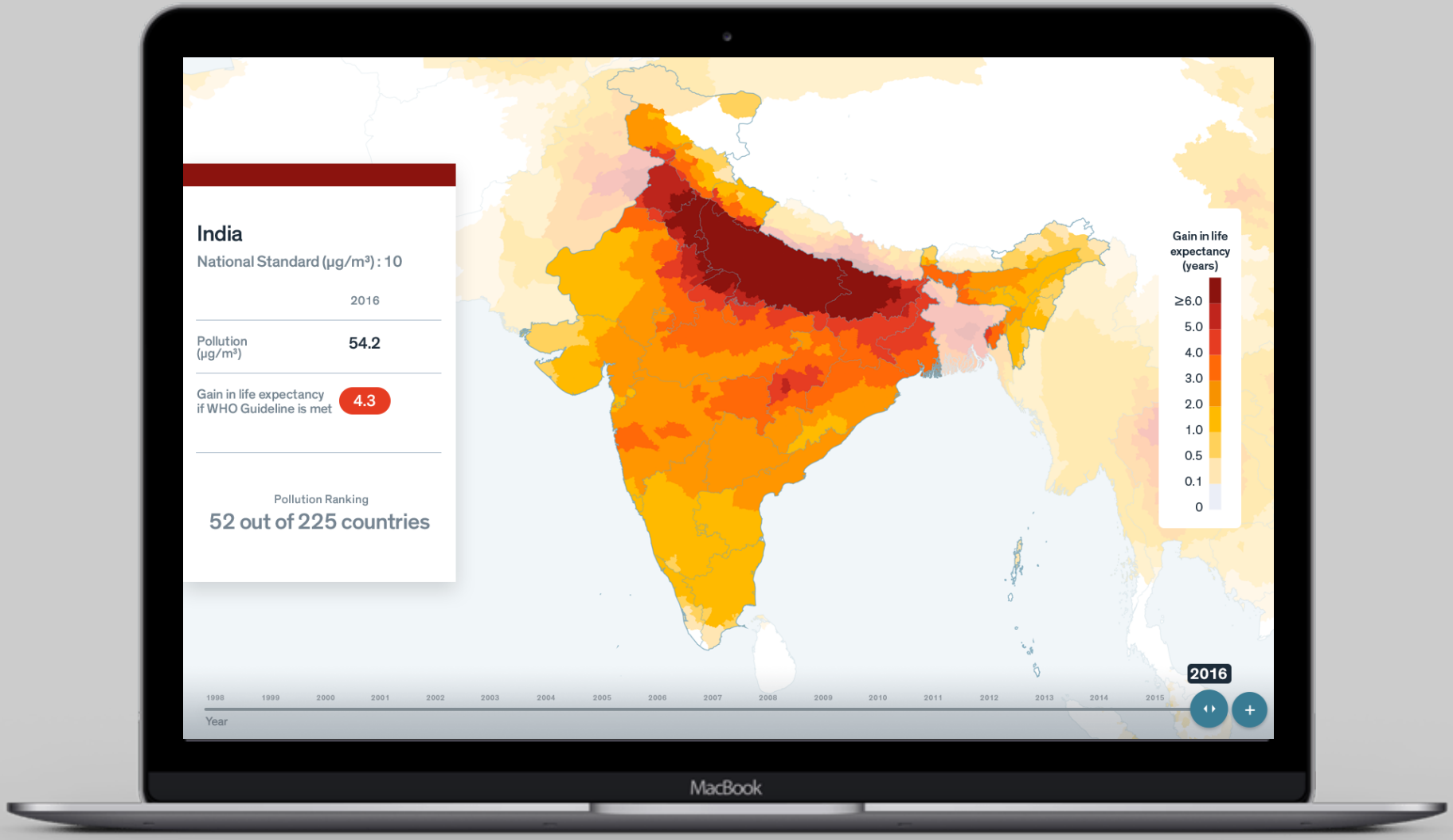
… and finds PM Pollution Cuts Average Global Life Expectancy by 1.8 Years



In China, reducing $PM_{2.5}$ to the WHO guideline could increase life expectancy by 2.9 years.



In India, reducing $PM_{2.5}$ to the WHO guideline could increase life expectancy by 4.3 years.



Particulate matter air pollution is thus the single greatest threat to human health globally.



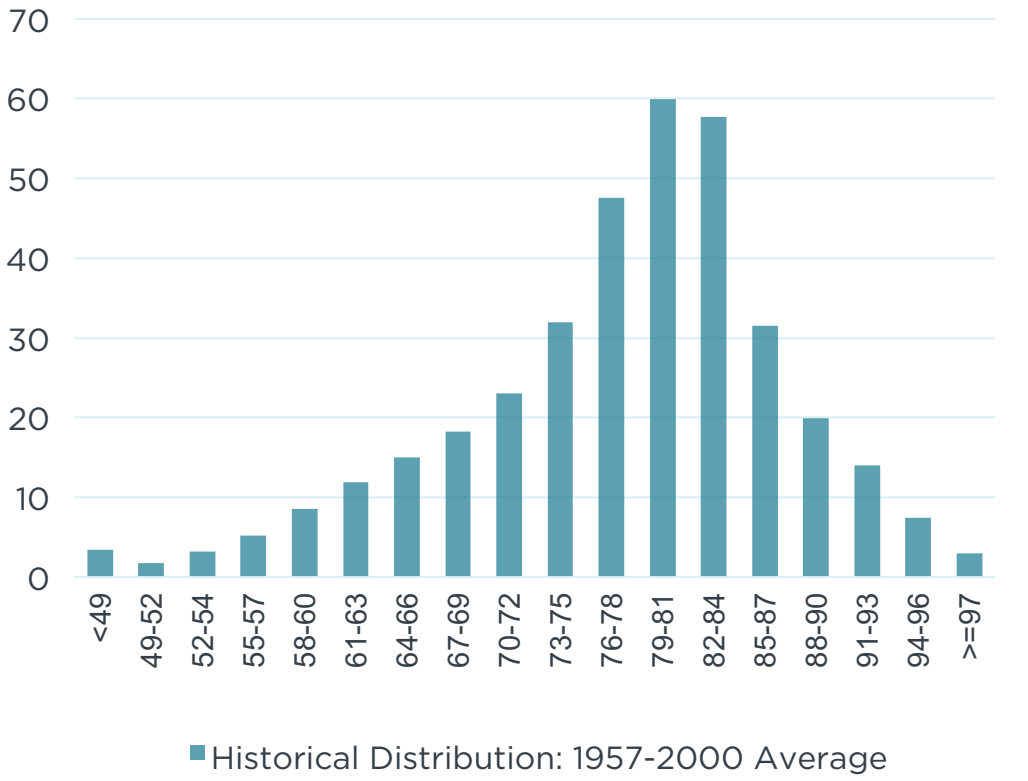
Data on other causes and risks of mortality are from the Global Burden of Disease (2016).

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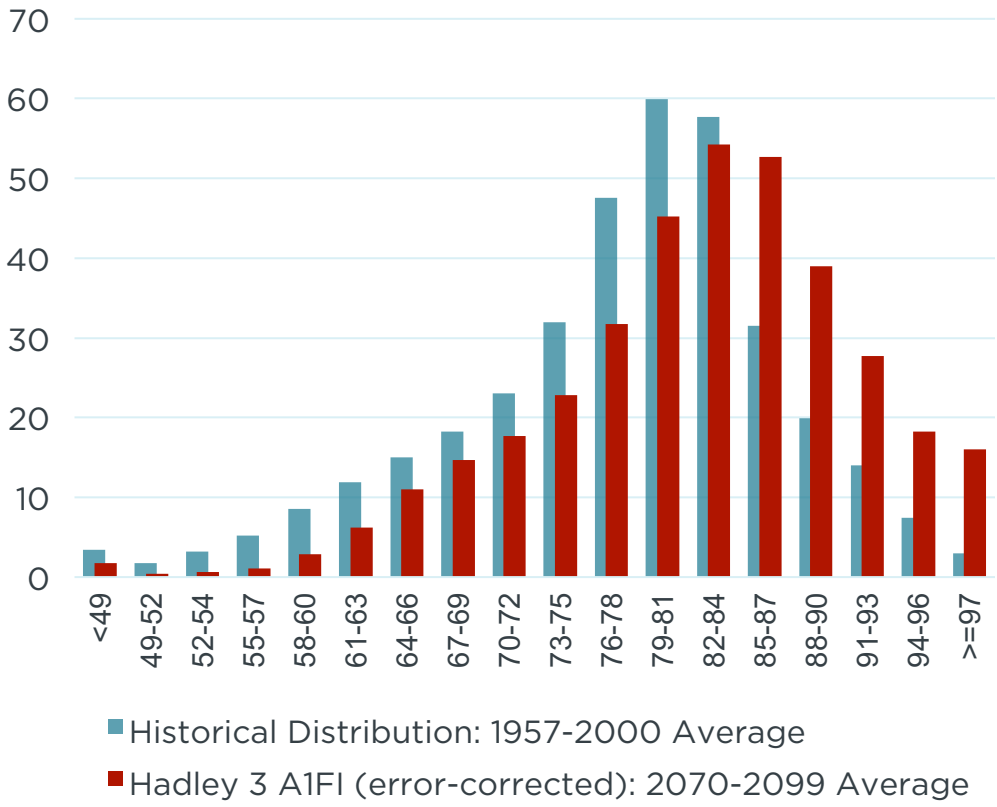
The Climate is Expected to Change

Distribution of Average Temperatures in India



The Climate is Expected to Change

Distribution of Average Temperatures in India



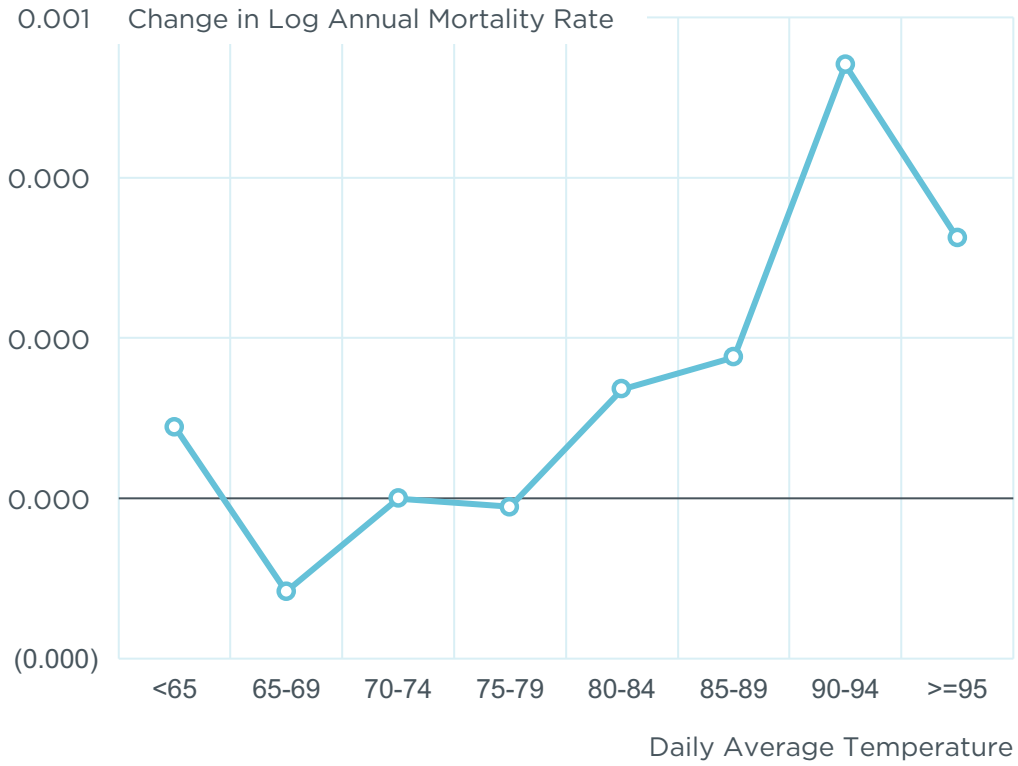
The Unequal Effects of Weather and Climate Change: Evidence from Mortality in India

Burgess, Deschenes, Donaldson, and Greenstone (2019)

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Impacts to the US are Minimal

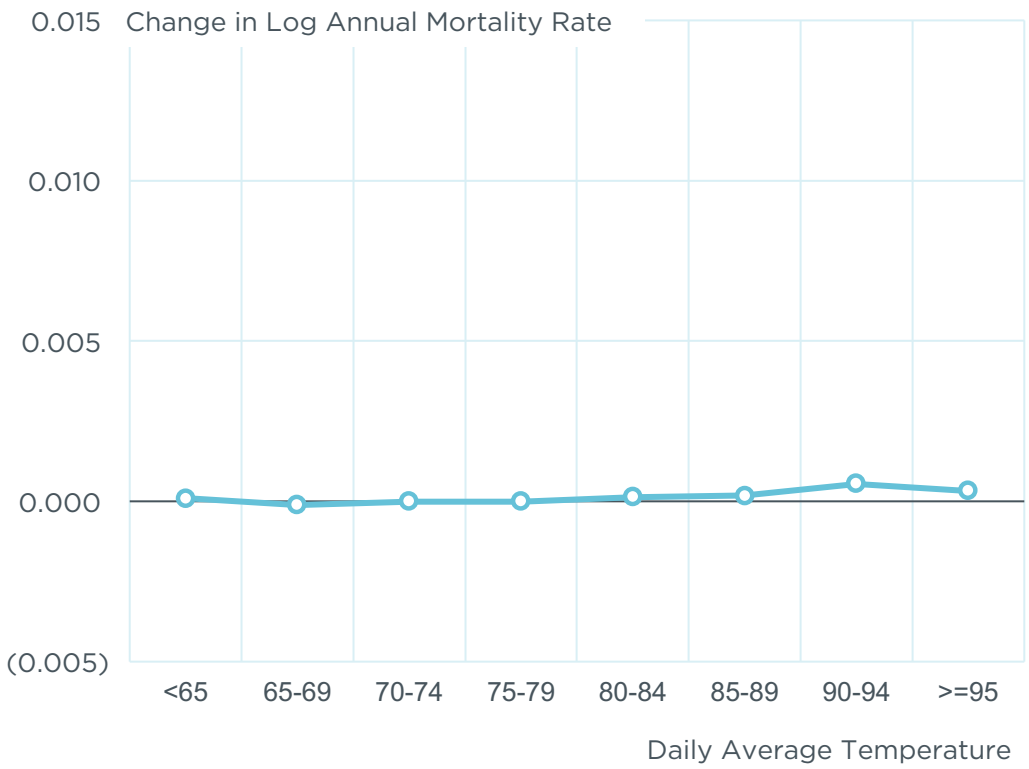
Estimated Impact of Temperature on Mortality



- This figure presents the estimated mortality impact of a day in one of seven daily temperate bins relative to a day in the 70-74 °F bin.
- There is a clear relationship between increased temperature and mortality, though the actual impacts are minimal for Americans.

Impacts to the US are Minimal

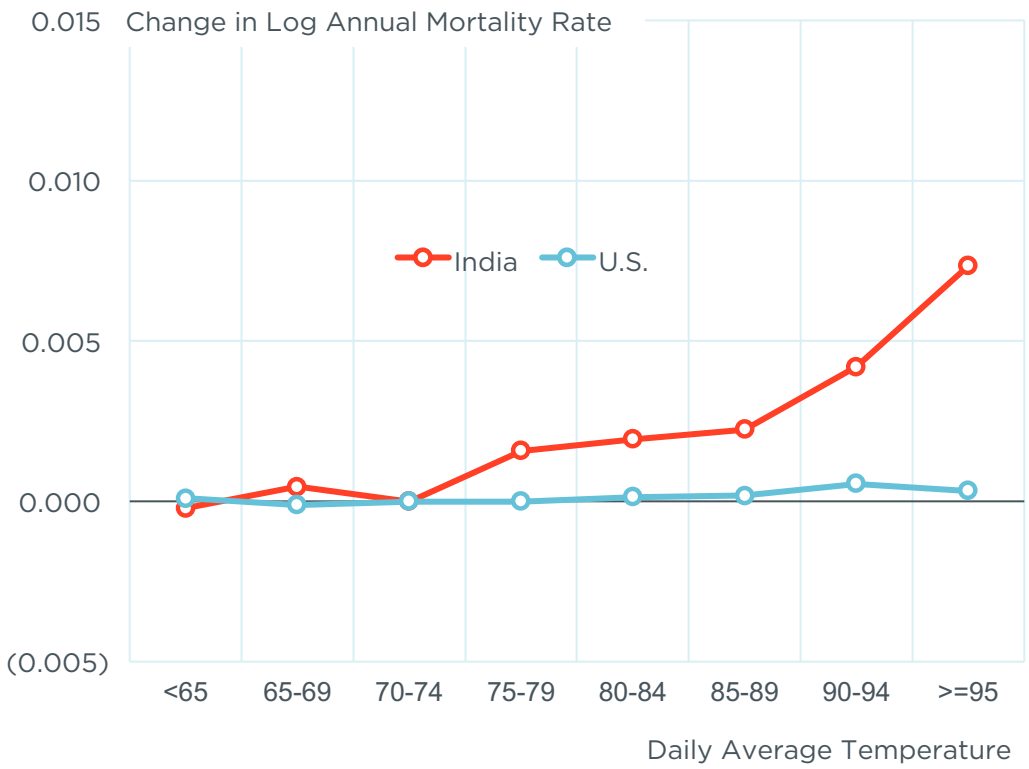
Estimated Impact of Temperature on Mortality



› The relationship in the United States is negligible if we zoom out to a scale where large changes would indicate much more dramatic impacts.

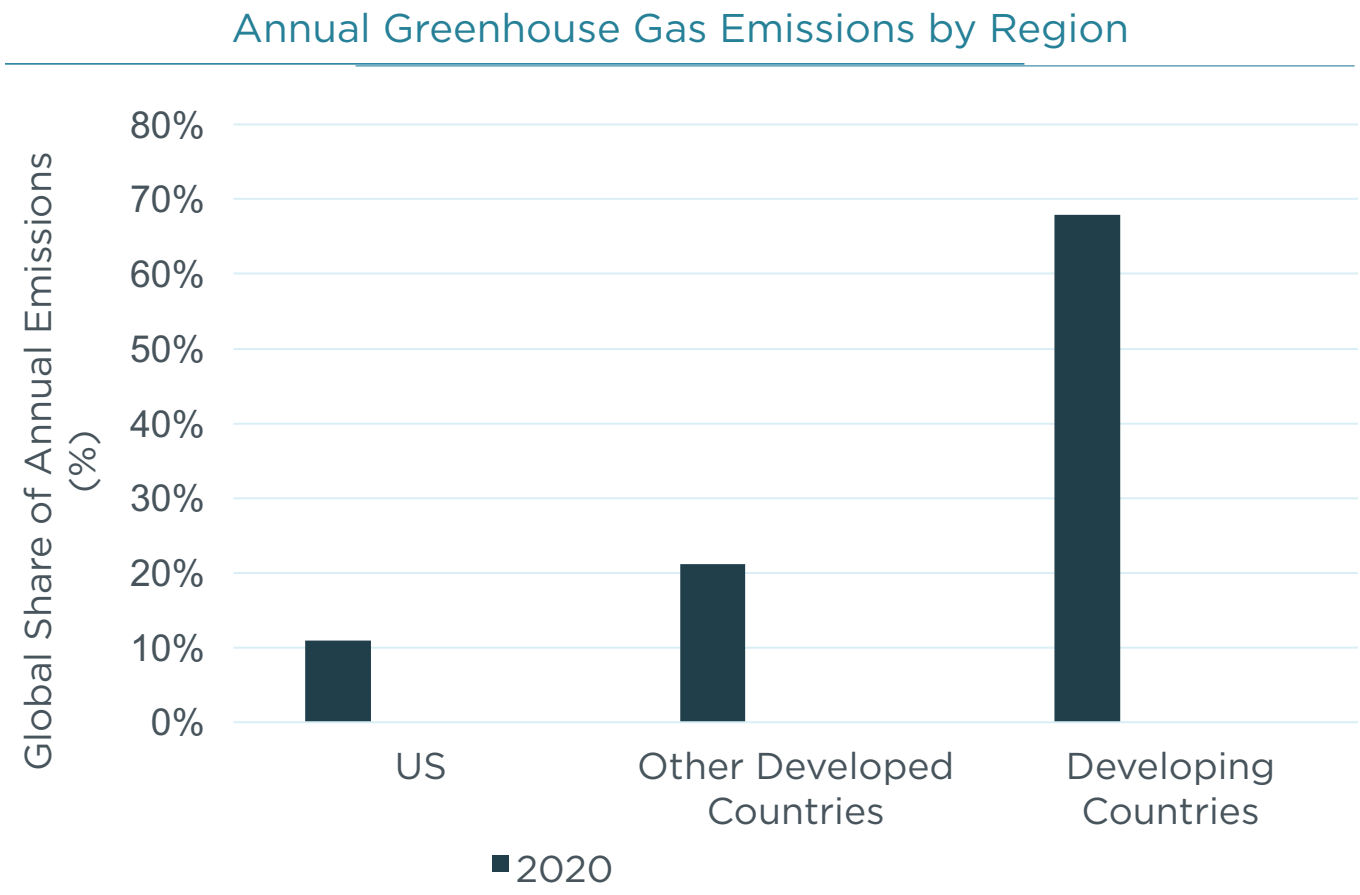
Impacts to India are Large

Estimated Impact of Temperature on Mortality



- The relationship in the United States is negligible if we zoom out to a scale where large changes would indicate much more dramatic impacts.
- However, even at this scale, the relationship in India is today quite substantial, indicating that the population there is highly vulnerable to shifts in temperature.

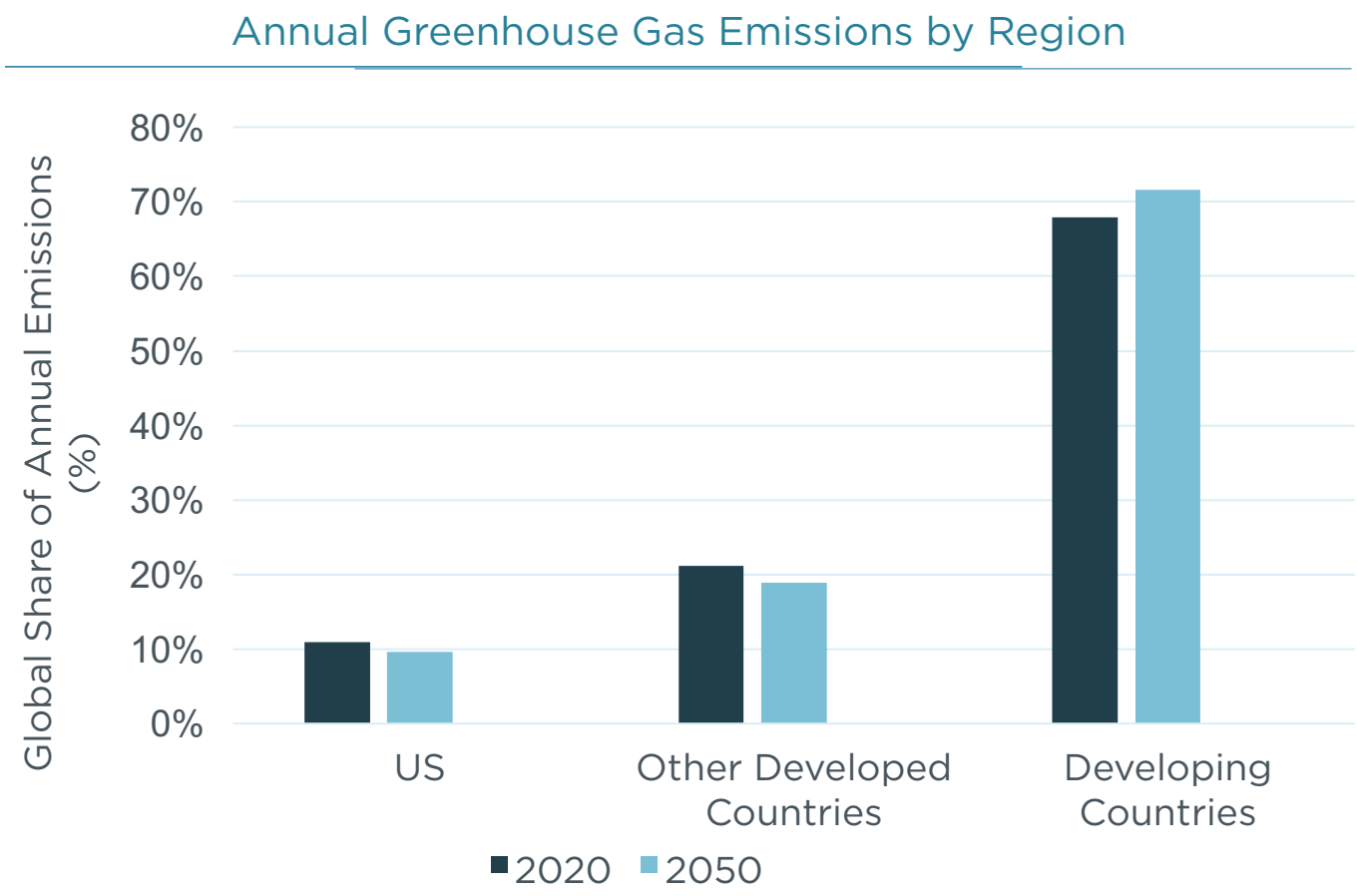
The Politically Challenging GHG Accounting



- Through the end of the 21st century, 70% of annual emissions are projected to come from developing countries

Source: Climate Interactive C-Roads Model

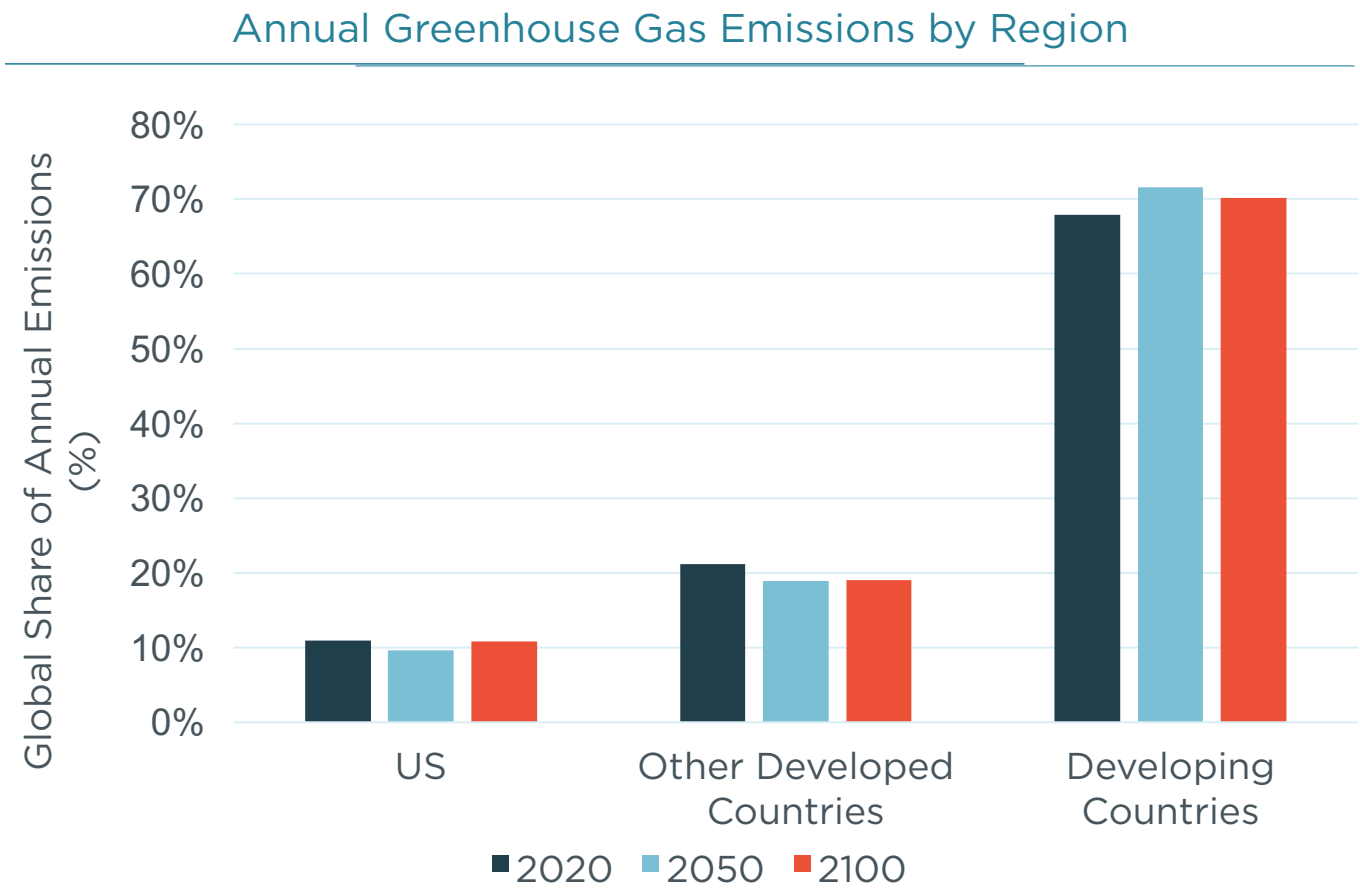
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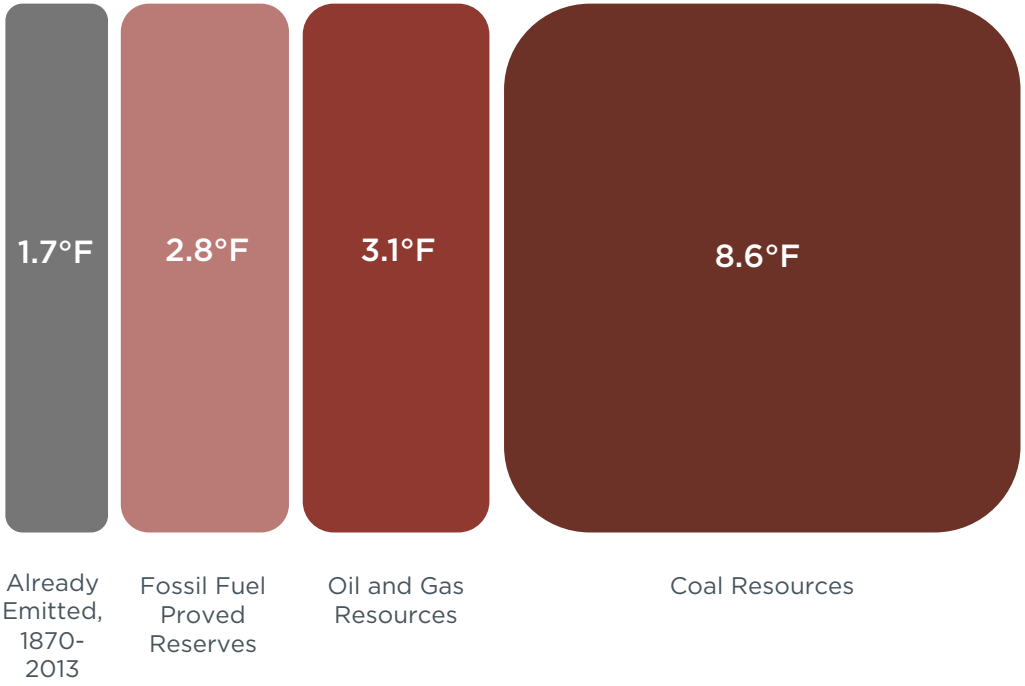


› Through the end of the 21st century, 70% of annual emissions are projected to come from developing countries

Source: Climate Interactive C-Roads Model

How Much Warming is Possible?

Estimated Temperature Impact of Combustion



- The world possesses practically unlimited fossil fuel resources.
- Advancements in technology will make the majority of this resource base accessible over the coming decades.
- The global warming potential of combusting and emitting the full resource base is significant.

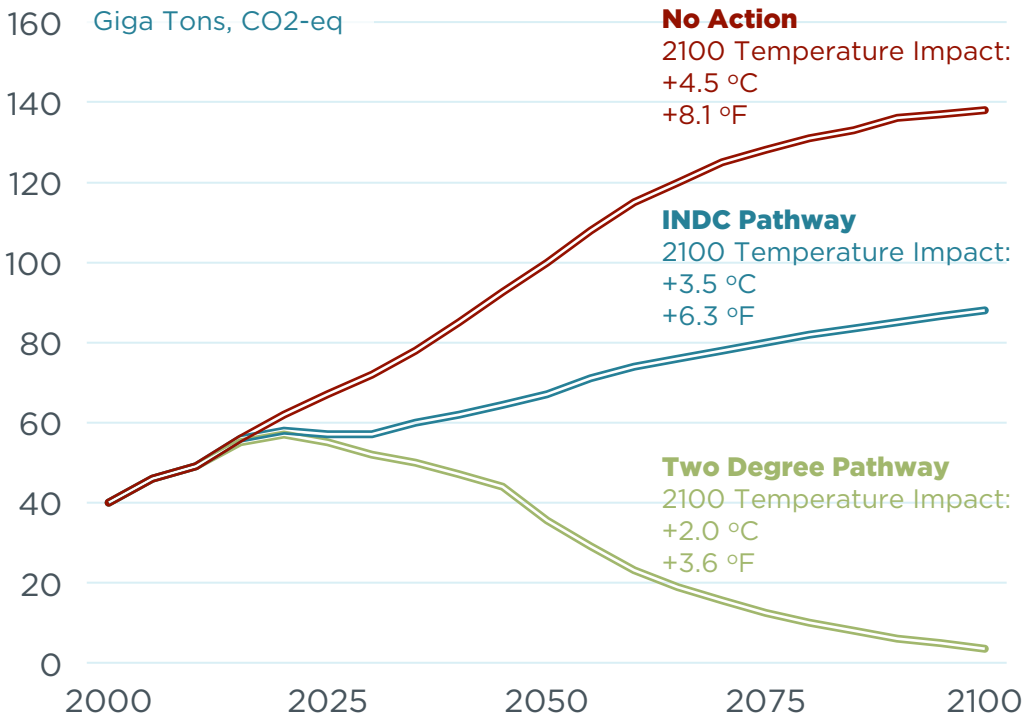
Source: Michael Greenstone, "If We Dig Out All Our Fossil Fuels, Here's How Hot We Can Expect It to Get," **New York Times**, April 8, 2015

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7. The Paris Agreement is Expected to Help…Some

Paris Talks are projected to help somewhat

Global GHG Emissions



- Policymakers around the world have made ambitious commitments to reduce greenhouse gas emissions in advance of the December 2015 Paris Climate Negotiations.
- These commitments, however, are not adequate to avoid serious climate damages over the coming century.

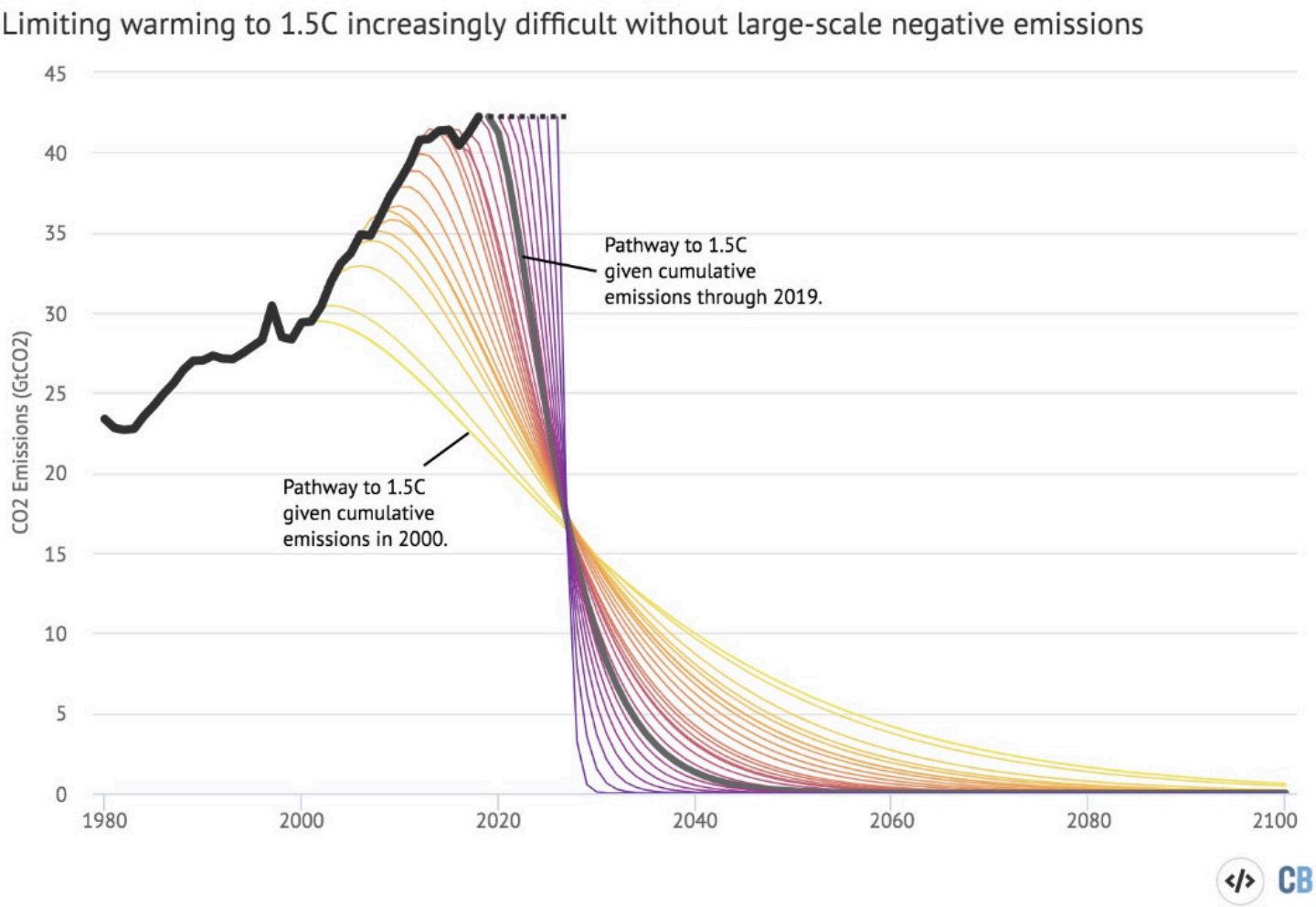
Source: EPIC analysis

…though perhaps less so than originally believed



› President Trump announcing on June 1st, 2017 that the U.S. will withdraw from the Paris climate accord

Either way, we are unlikely to stay below 1.5°C of warming



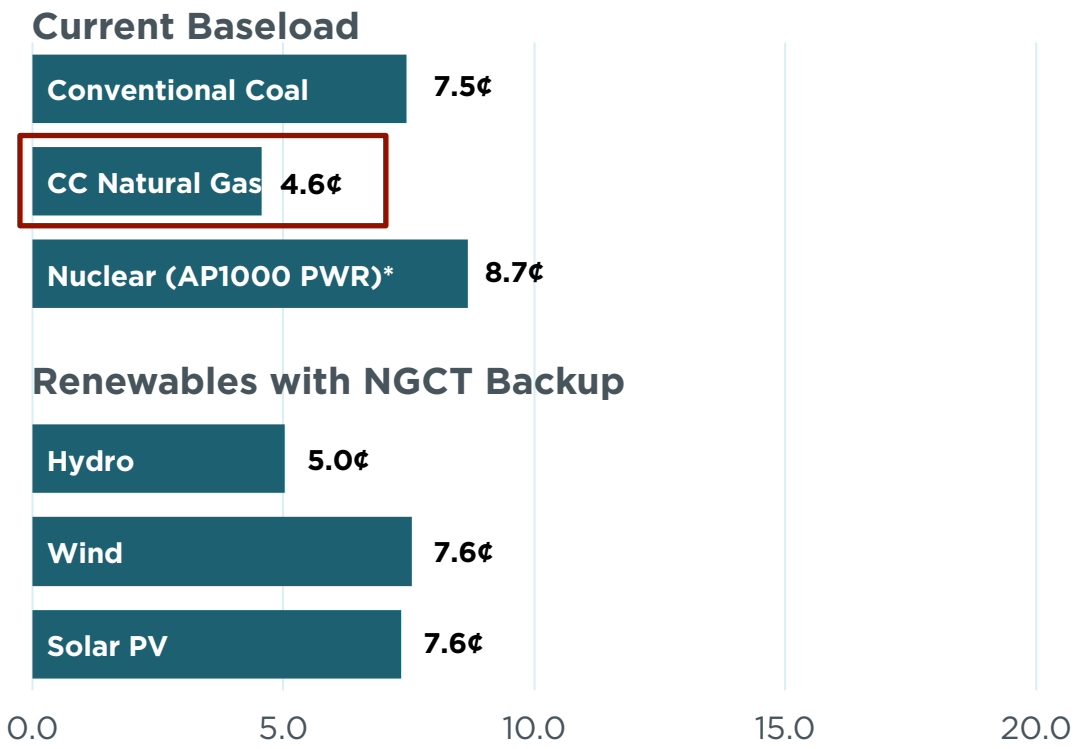
Section 2

Two Key Solutions

1. Price Energy at its Full Social Cost

Incorporating externalities into the price of electricity

Levelized Cost of Energy for New Plants in 2023

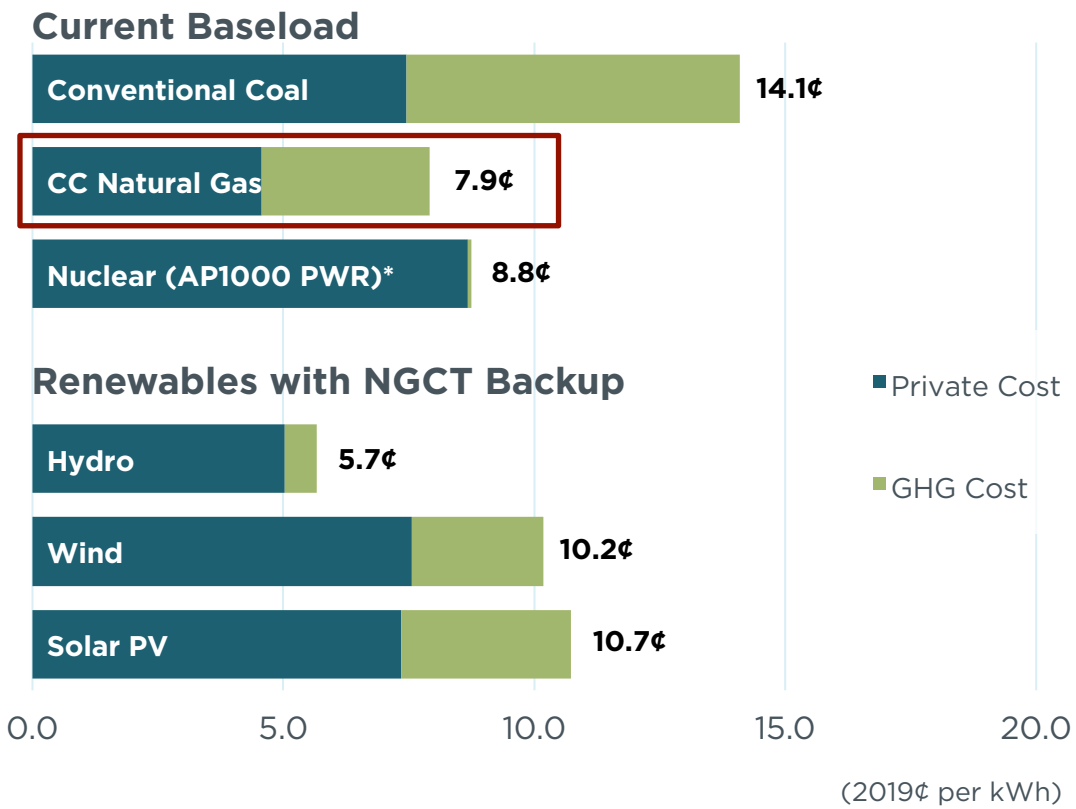


- Presenting energy costs in strictly private terms heavily favors conventional fossil generation.
- This is especially true if we limit our analysis to system configurations capable of providing baseload power.

Source: DOE, EIA, EPA, NREL, NAS, EPIC

Incorporating externalities into the price of electricity

Levelized Cost of Energy for New Plants in 2023

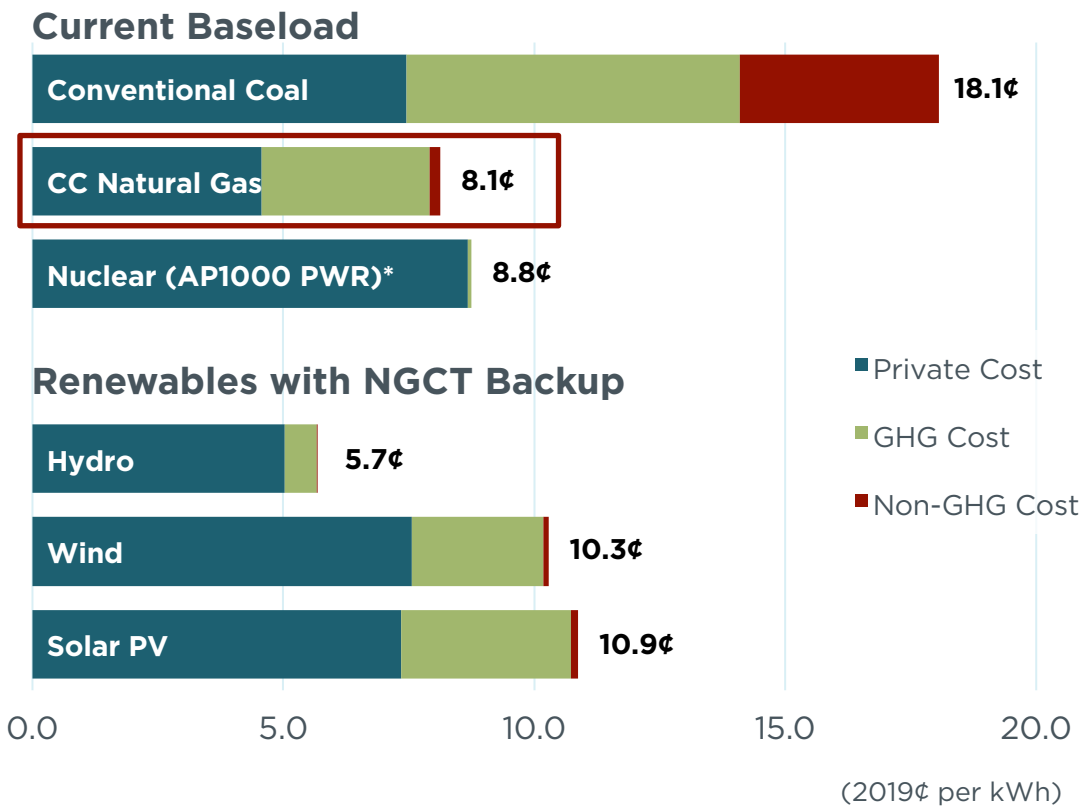


- Presenting energy costs in strictly private terms heavily favors conventional fossil generation.
- This is especially true if we limit our analysis to system configurations capable of providing baseload power.
- The story gets more interesting if we begin to include external costs, such as the climate impacts of fossil fuels.

Source: DOE, EIA, EPA, NREL, NAS, EPIC

Incorporating externalities into the price of electricity

Levelized Cost of Energy for New Plants in 2023

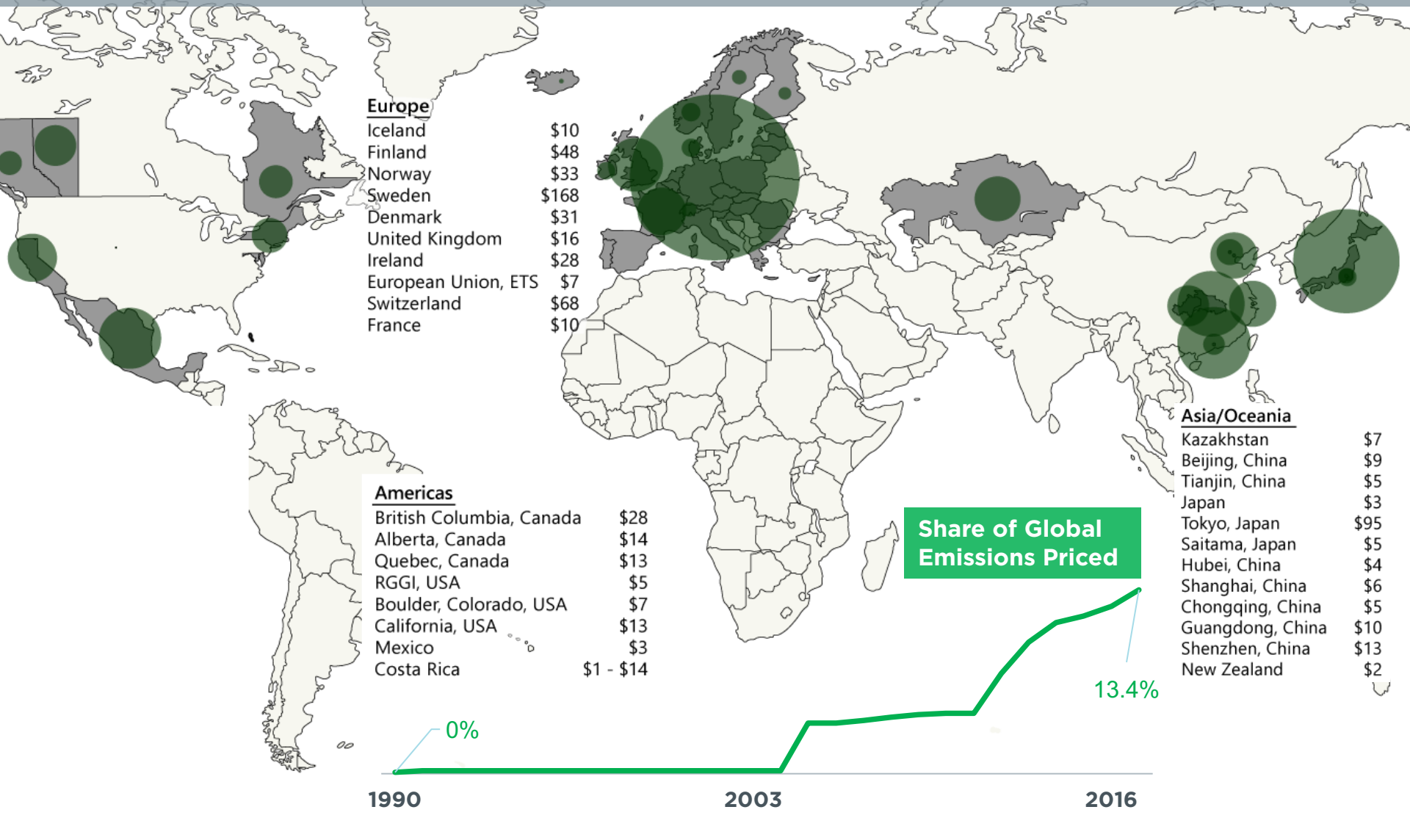


- Presenting energy costs in strictly private terms heavily favors conventional fossil generation.
- This is especially true if we limit our analysis to system configurations capable of providing baseload power.
- The story gets more interesting if we begin to include external costs, such as the climate impacts of fossil fuels as well as the non-climate impacts of fuel combustion.

Source: DOE, EIA, EPA, NREL, NAS, EPIC
Note: *Unable to quantify non-GHG costs

Global Carbon Pricing is Expanding but Highly Inconsistent

The number of countries that have implemented some form of carbon pricing has grown rapidly in recent years. In 2003, almost no global emissions were priced. Today, the share is 13.4 percent and growing. Yet prices are extremely inconsistent.



Two Key Solutions

1. Price Energy at its Full Social Cost
2. Invest in Innovation

Two Key Solutions

1. Price Energy at its Full Social Cost

2. Invest in Innovation
   a) Policy Innovation

Non-Compliance With Environmental Standards Is Common Practice



1) **In early 2017, China's Ministry of Environmental Protection examined whether businesses were meeting environmental standards for controlling pollution**
   - > Inspected 20,000 businesses across 28 cities in northern China

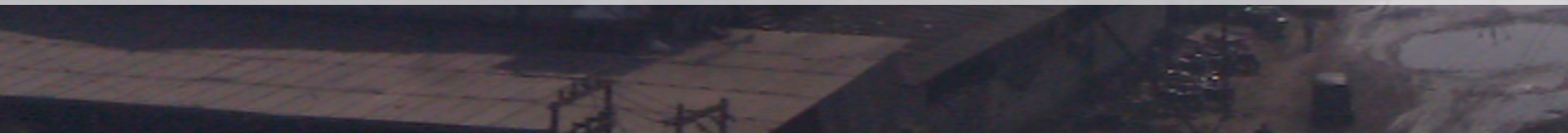
2) **Inspectors found that nearly 70% of these businesses failed to meet standards**
   - > Violations included lack of pollution control equipment, excessive emissions, and lack of relevant certifications

Source: The New York Times, June 13, 2017



Case Study: An Experiment to Improve Environmental Regulation in Gujarat

Gujarat is the most industrialized state in India and among its most heavily polluted. The Gujarat Pollution Control Board regulates more than 20,000 industrial plants using third-party audits.



The Policy Status Quo

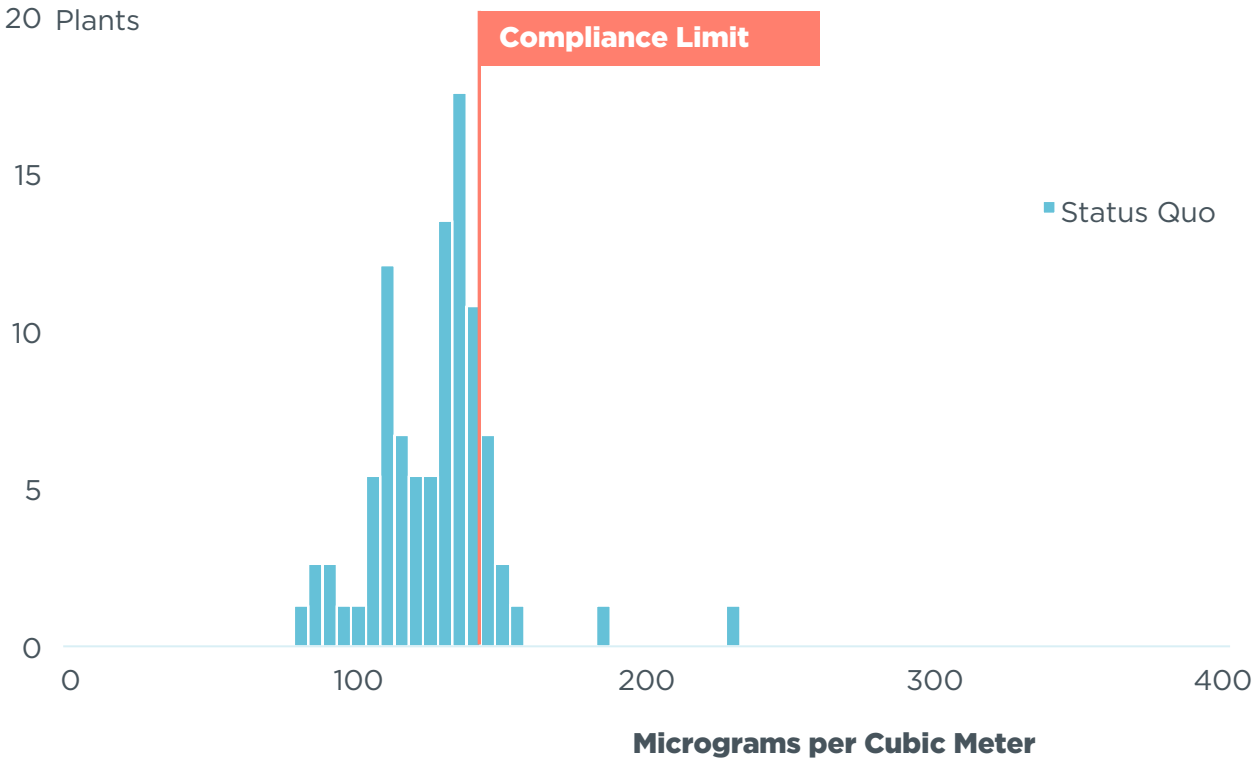
1) **India has strict environmental laws on the books**
   - » Yet, pollution levels are high

2) **Gujarat uses third-party audits to enforce environmental regulations**
   - » Polluters select and pay their auditors

3) **Working with the Gujarat Pollution Control Board, we designed an intervention to break this conflict of interest**
   - » We divided plants into a control group and a treatment group
   - » The control group continued the status quo approach to audits
   - » In the treatment group, polluters paid into a central fund, which randomly assigned auditors to the plants

Getting a Better Pollution Audit

Audit Readings for Suspended Particulate Matter

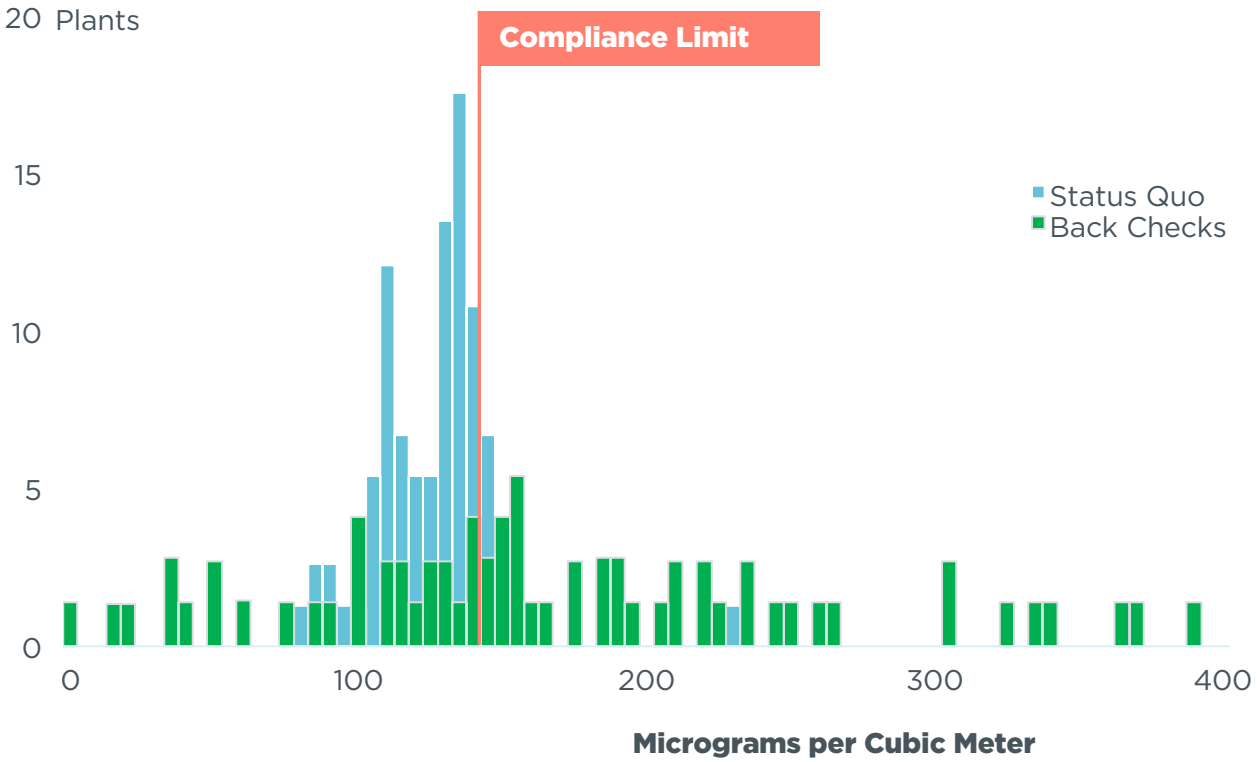


› Most plants reported to be in compliance under the status quo auditing system.

Source: Duflo et al (2013)

Getting a Better Pollution Audit

Audit Readings for Suspended Particulate Matter

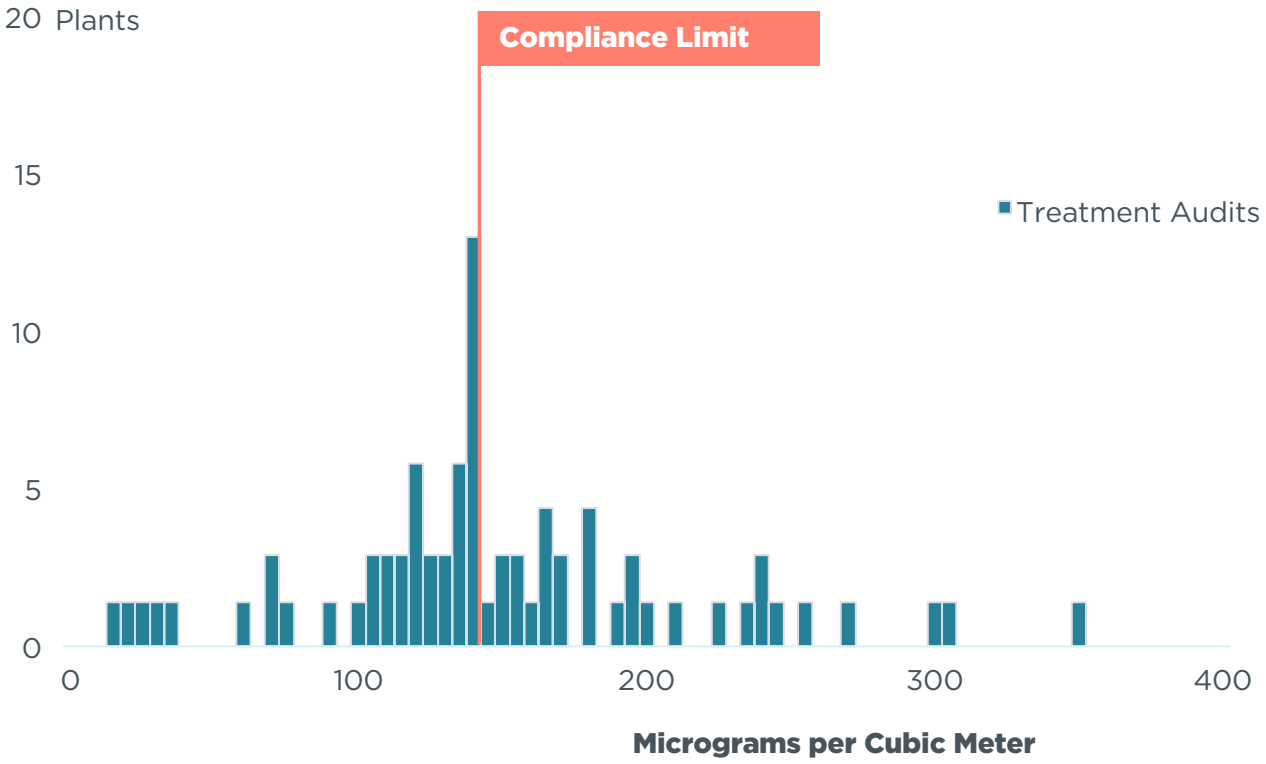


- **Result One: reporting was corrupt in the status quo.**
- When we conducted 'back checks' to verify actual emission levels at the source, we found a drastically different range of performance.

Source: Duflo et al (2013)

Getting a Better Pollution Audit

Audit Readings for Suspended Particulate Matter

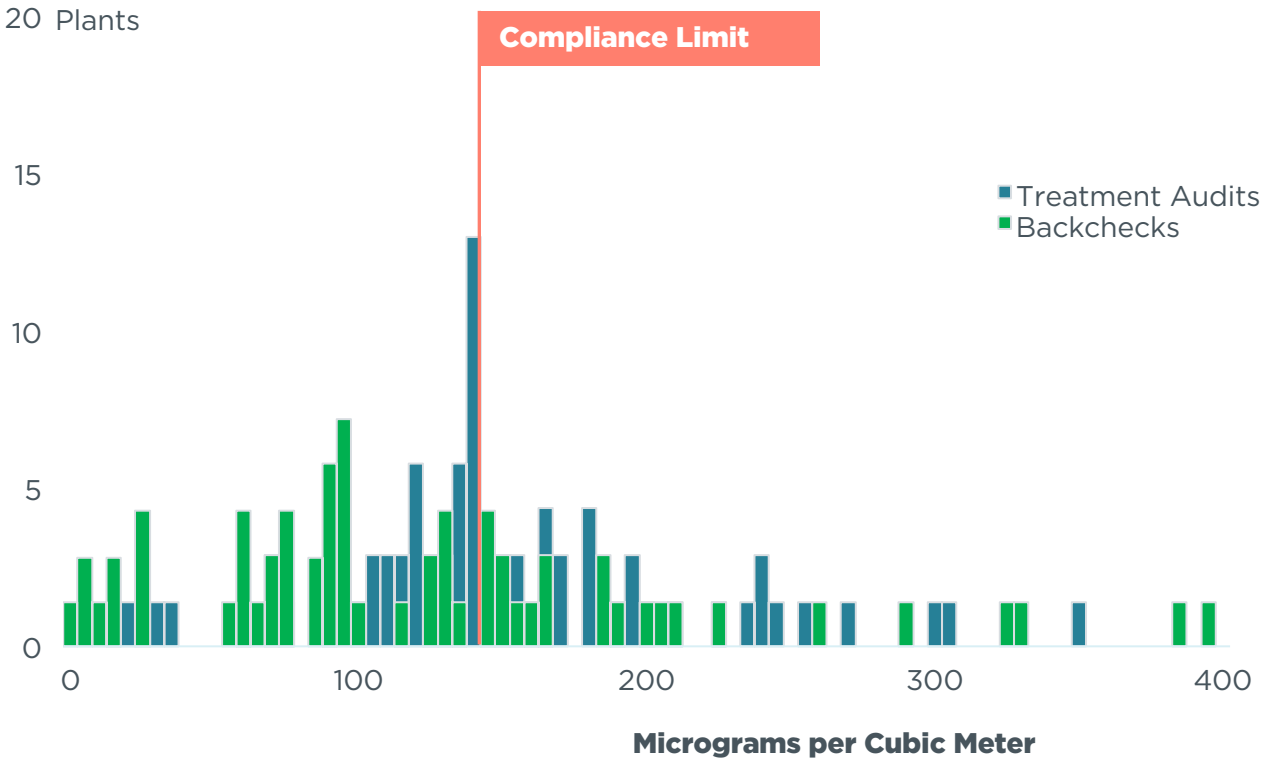


› Treatment auditors reported a much wider range of emissions.

Source: Duflo et al (2013)

Getting a Better Pollution Audit

Audit Readings for Suspended Particulate Matter



› **Result Two: the treatment caused the auditors to become more truthful.**

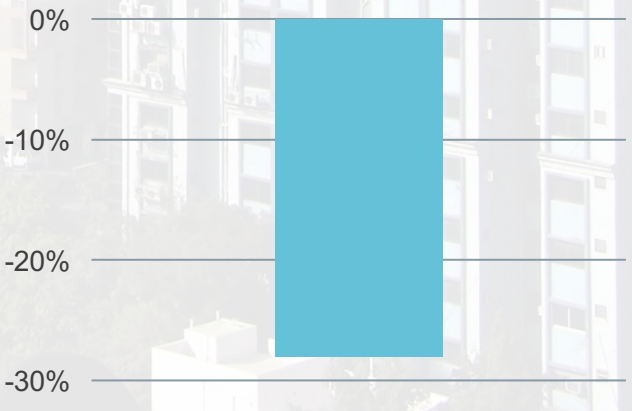
Source: Duflo et al (2013)



What happened to pollution?

The reformed auditing program caused plants to reduce their pollution emissions by 28 percent.

Percent Change in Pollution Emissions Among Audited Firms





Research and Policy Partnership

"Our partnership proves the success of innovative, evidence-based approaches to policymaking and is a model for how researchers and policymakers can make a big difference by working together."

Hardik Shah, Member Secretary of the Gujarat Pollution Control Board

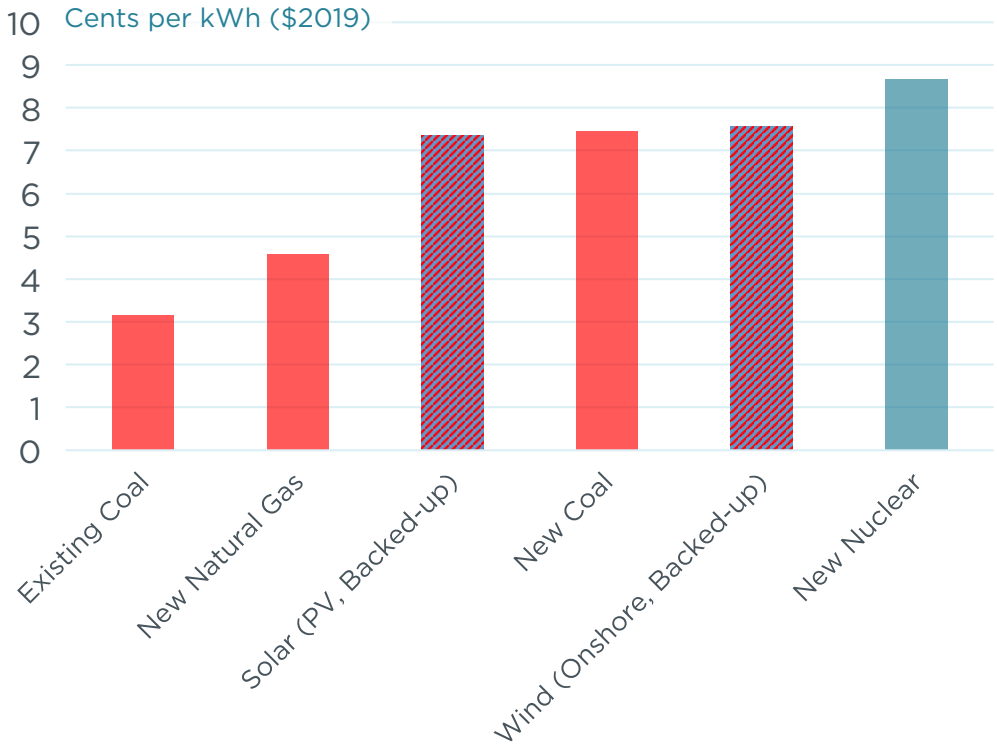
Two Key Solutions

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2. Invest in Innovation
   a) Policy Innovation
   b) Technical Innovation

The Private Cost of Fossil Fuels Remains Low

Levelized Cost of Energy, United States

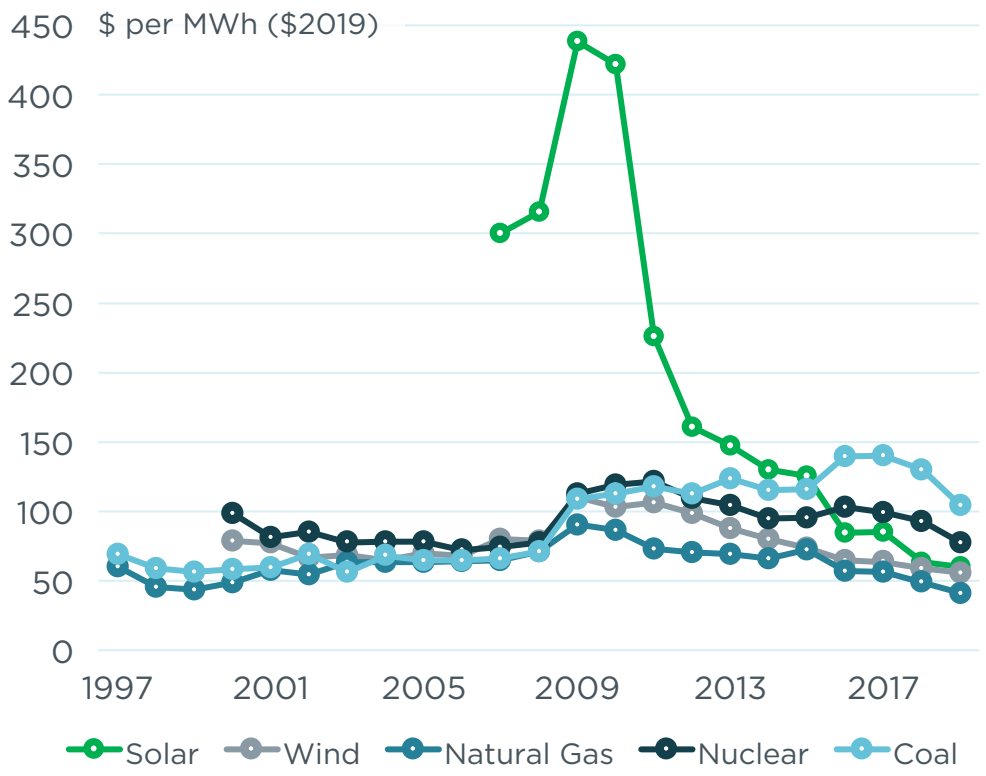


- Conventional fuels and technologies are the most cost-effective sources of energy today and continue to attract significant investment as a result.
- Challenges in transportation are even greater, where the combination of the combustion engine and oil have little competition.

EPIC analysis based on data from the EIA Annual Energy Outlook 2019. Existing coal excludes capital cost. Wind and solar are backed up by natural gas combustion turbine.

Innovation is Causing Rapid Change in Energy

Levelized Cost of Energy

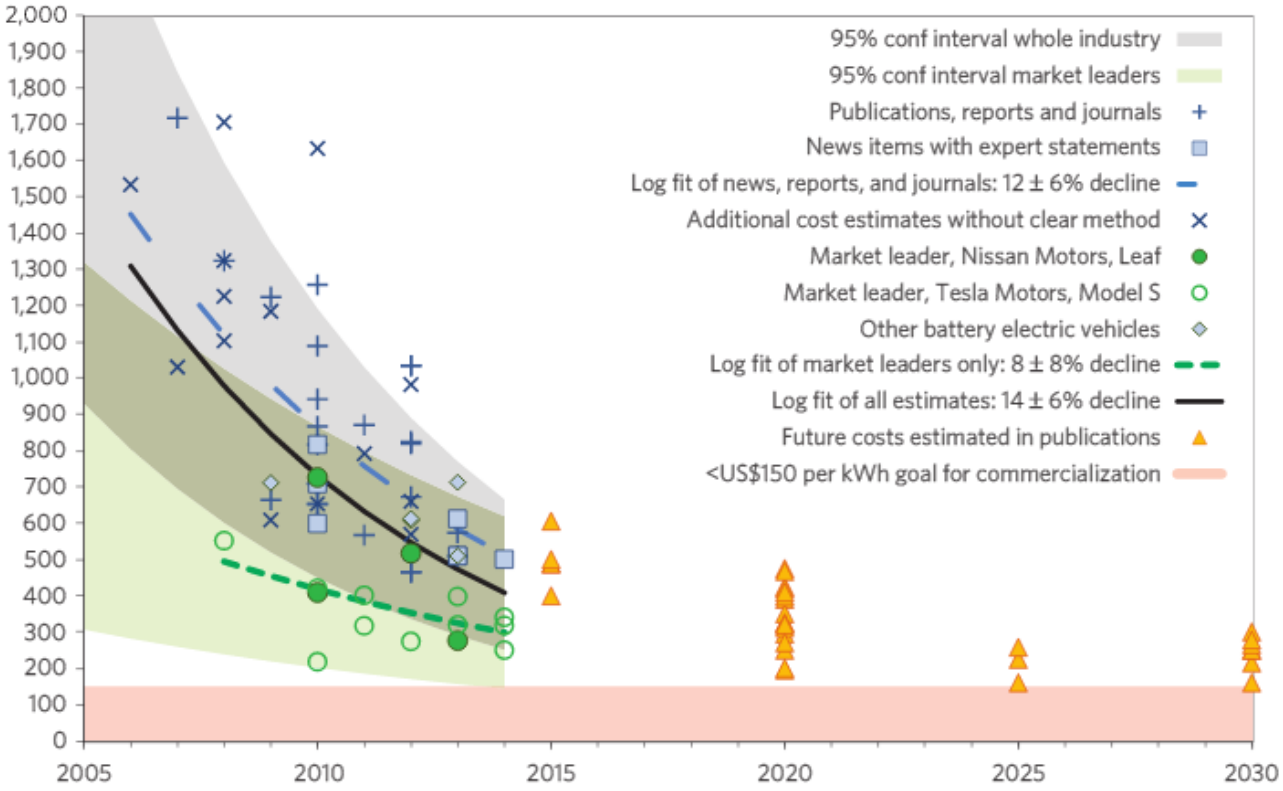


› The cost of solar PV has plummeted in recent years, from $438 per MWh in 2009 to $60 per MWh in 2019.

Source: DOE, EIA Annual Energy Outlook

Innovation is Causing Rapid Change in Energy

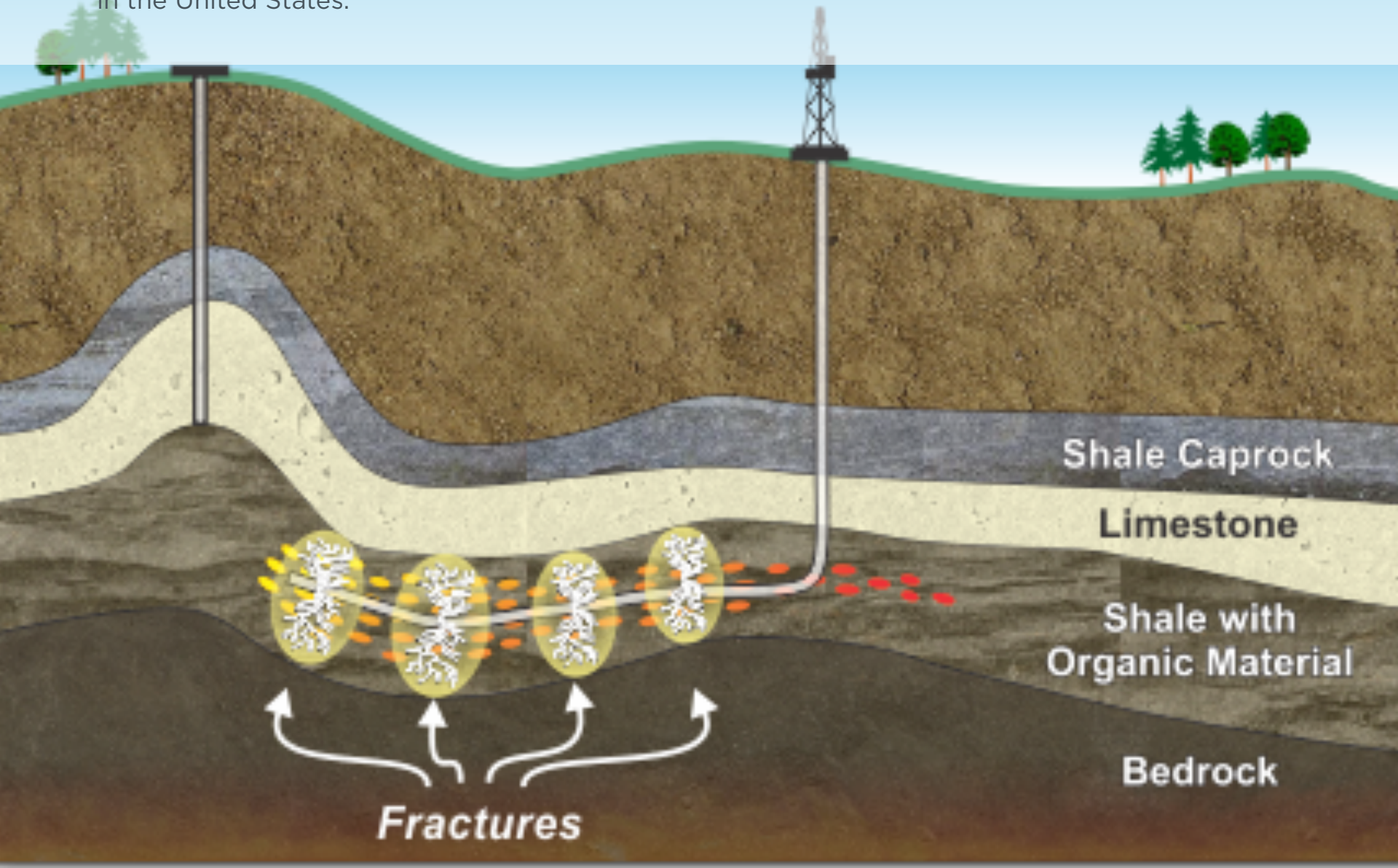
Lithium-ion Battery Pack Cost for BEV ($ per kWh)



Source: Nature Climate Change

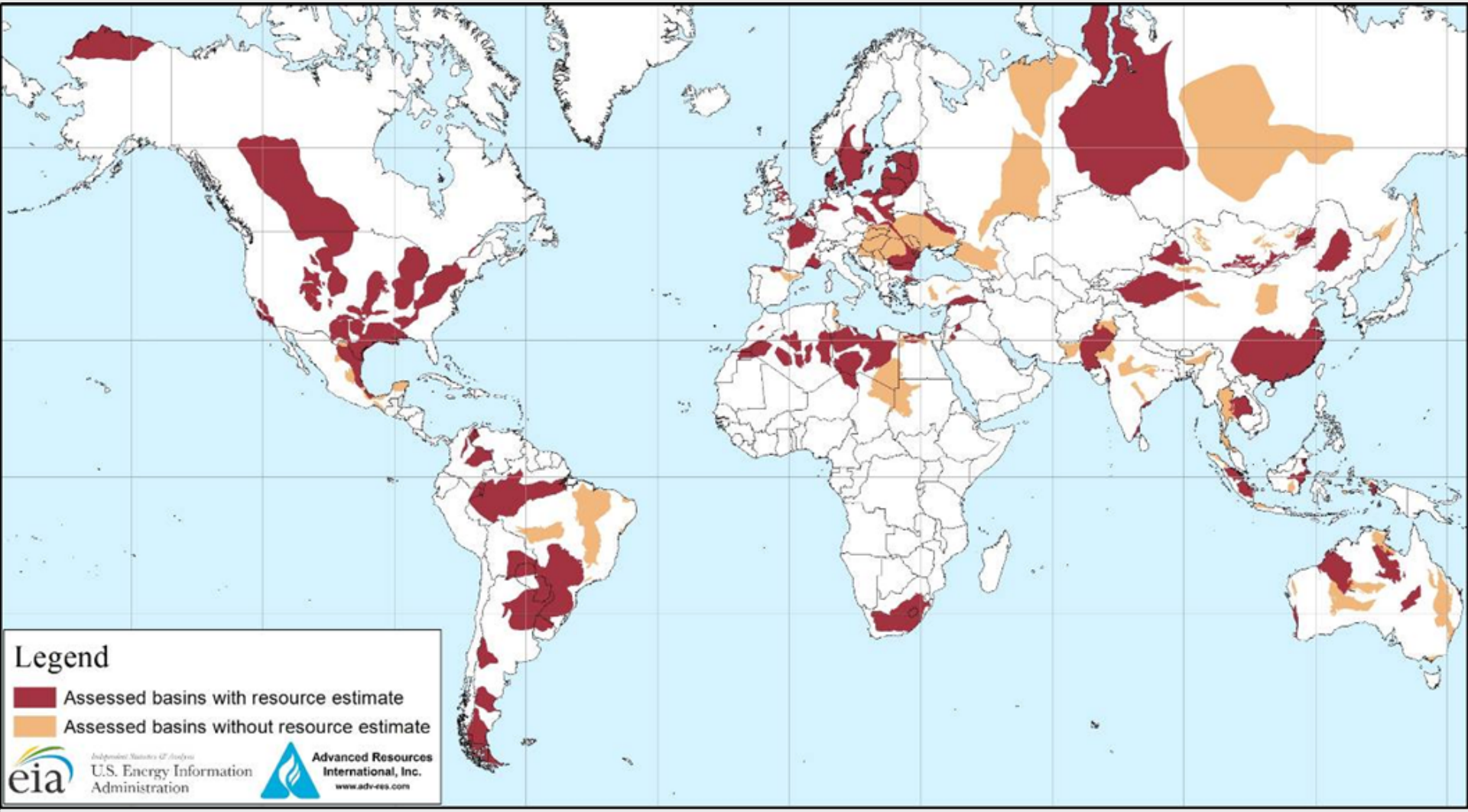
There has also been Innovation in Fossil Fuel Recovery

Hydraulic fracturing and horizontal drilling have unlocked massive oil and natural gas resources in the United States.



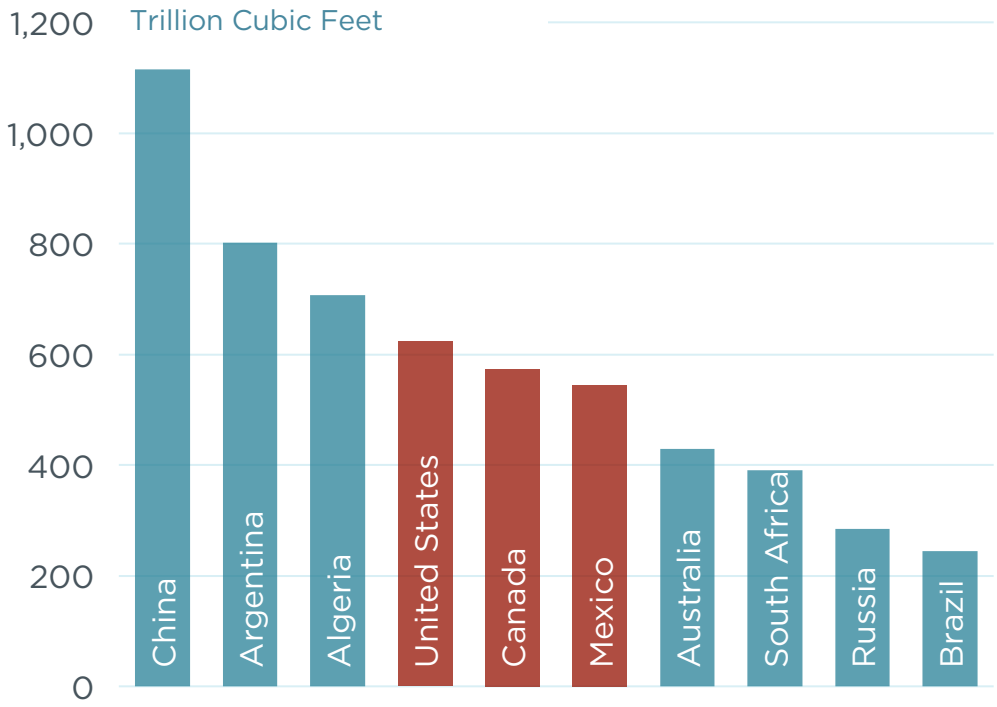
Untapped Shale Resources Exist Around the World

Outside North America, China and Argentina have tapped shale deposits, and many other countries have the potential to do so.



Innovation in Fossil Fuel Resource Recovery

Shale Gas Resources by Country

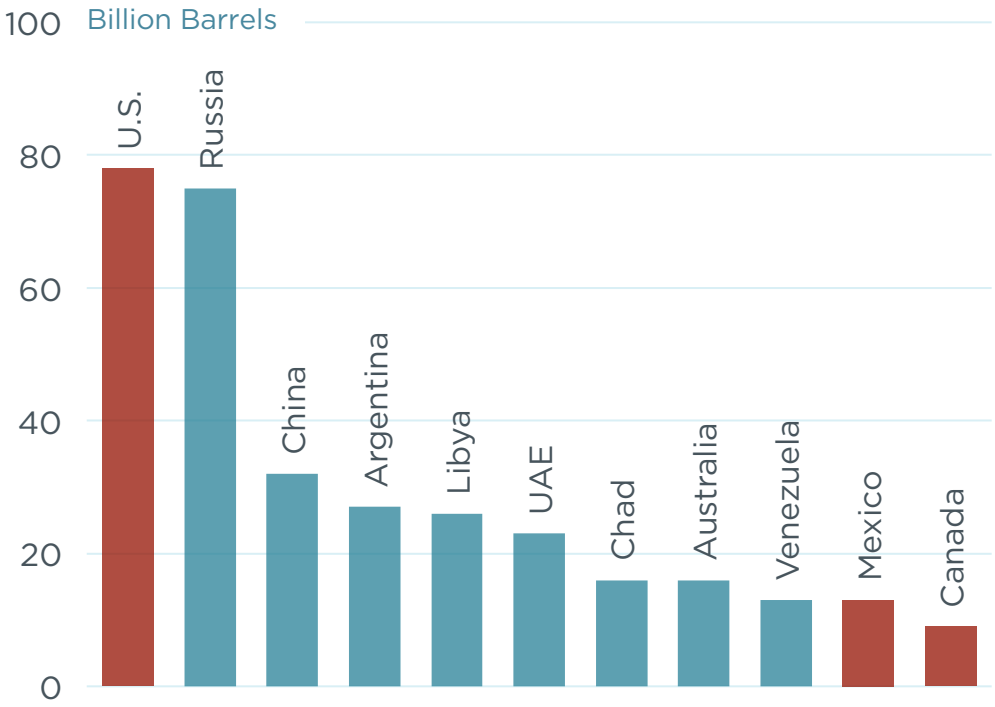


- Innovation in drilling and well-completion has unlocked massive supplies of natural gas globally.
- The U.S. Energy Information Administration estimated global shale gas resources to be more than 7,500 trillion cubic feet in 2015 — equal to **58 years of global natural gas consumption** at the 2017 consumption level.

Sources: Country-level statistics from EIA. The latest available statistics are from 2013, except for the US statistic, which was updated by EIA in 2015. Global natural gas consumption from BP Statistical Review 2018.

Innovation in Fossil Fuel Resource Recovery

Shale Oil Resources by Country

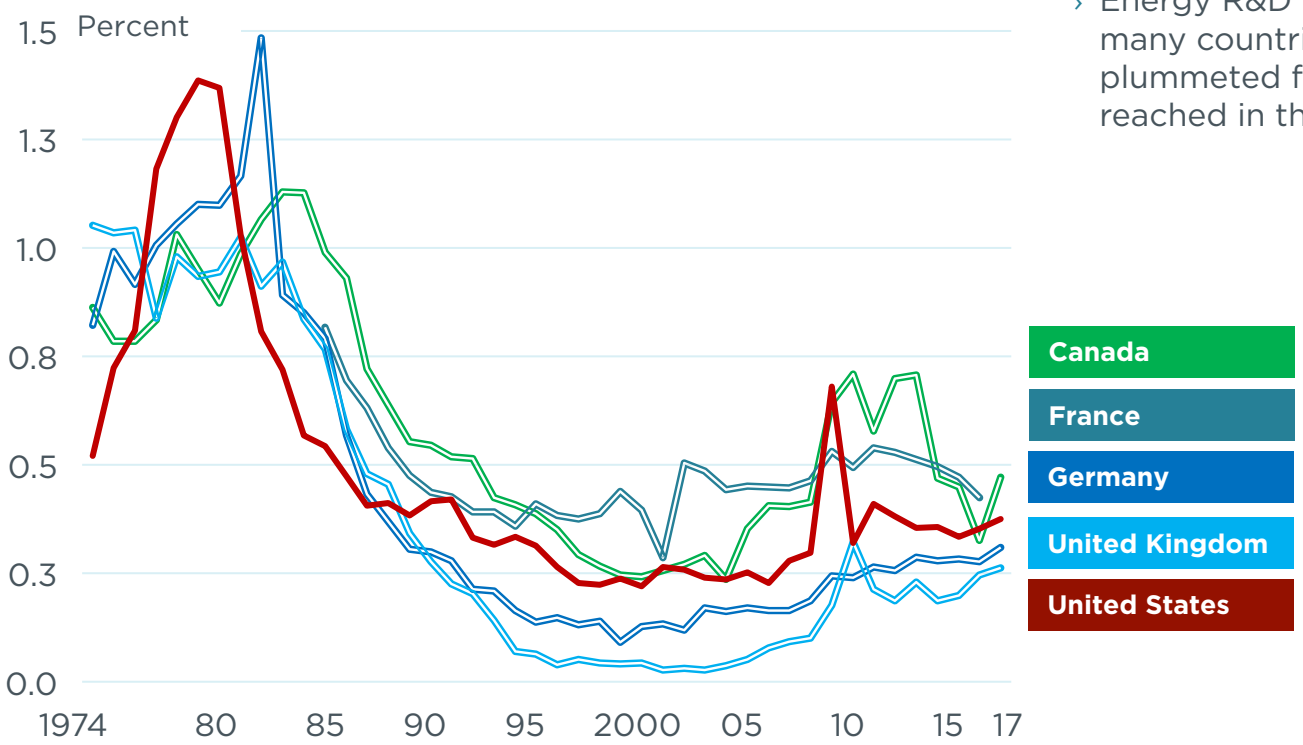


- Estimates of shale oil are also significant.
- The U.S. Energy Information Administration estimated global shale oil resources to be 420 billion barrels in 2015—equal to **12 years of global oil consumption** at the 2017 consumption level.
- For comparison, total proved reserves in Saudi Arabia were **266 billion barrels** at the end of 2017.

Sources: Country-level statistics from EIA. The latest available statistics are from 2013, except for US statistic, which was updated by EIA in 2015. Global oil consumption and Saudi Arabia reserves from BP Statistical Review 2018.

Energy R&D is a small share of GDP

Energy R&D Share of GDP



› Energy R&D investment in many countries has plummeted from levels reached in the mid-1970s.

Source: IEA



The Global Energy Challenge

How can we ensure that people around the world have access to the reliable, affordable, energy needed for economic growth and human development without putting the environment, climate or security at risk?