EPIC | ENERGY POLICY INSTITUTE AT THE UNIVERSITY OF CHICAGO

The Global Energy Challenge

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The Global Energy Challenge

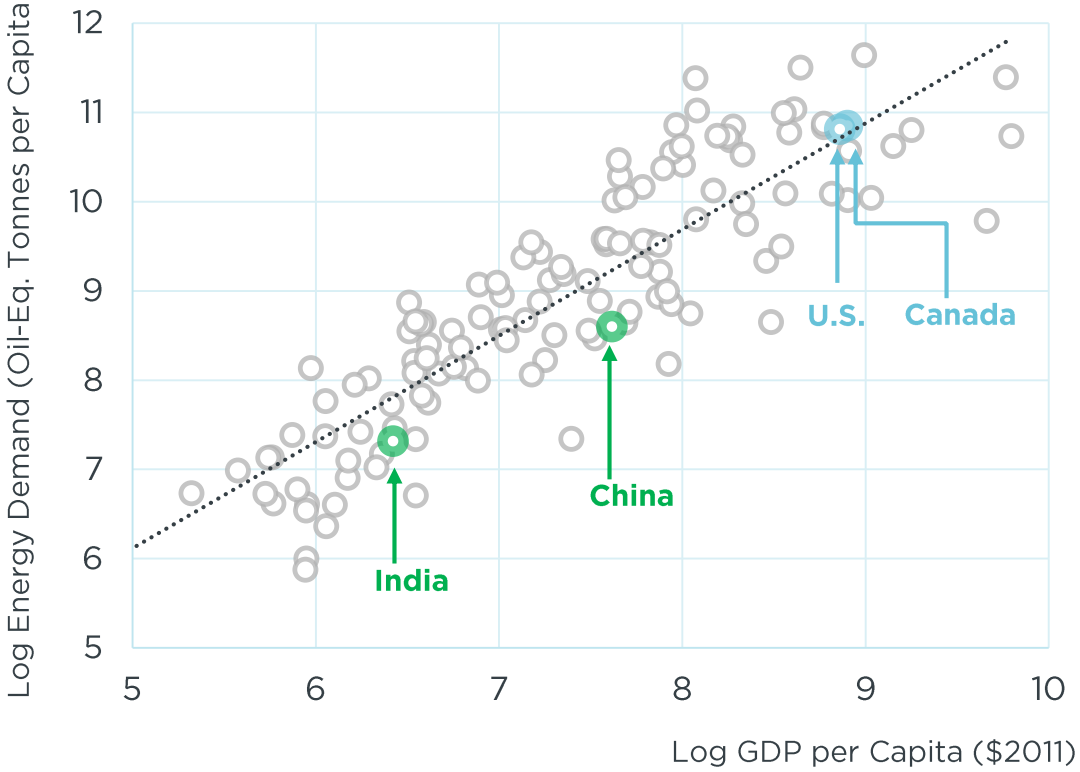
How can we ensure that people around the world have access to the reliable, affordable, energy needed for economic growth and human development without putting the environment, climate or security at risk?

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 (2011)



- 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

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2. Energy Access is a Major Problem

Energy Access is a Major Problem

Per Capita Electricity Consumption and Population

Country	Population (Millions)	kWh per Capita
U.S.	321	12,985
Germany	81	7,019
Chile	18	3,879
China	1,364	3,762
Argentina	43	3,093
Brazil	206	2,529
Mexico	125	2,057
India	1,295	765
Bihar	104	122

- Per capita energy consumption in developing economies remains significantly lower than developed world levels.
- According to the International Energy Agency, nearly 1.2 billion people globally lack access to reliable electricity—300 million in India alone.
- It takes 131 kWh to use a 60 watt light bulb for 6 hours per day for a full year.

Source: World Bank

Seven Facts that Explain the Difficult Balance between Energy and Growth

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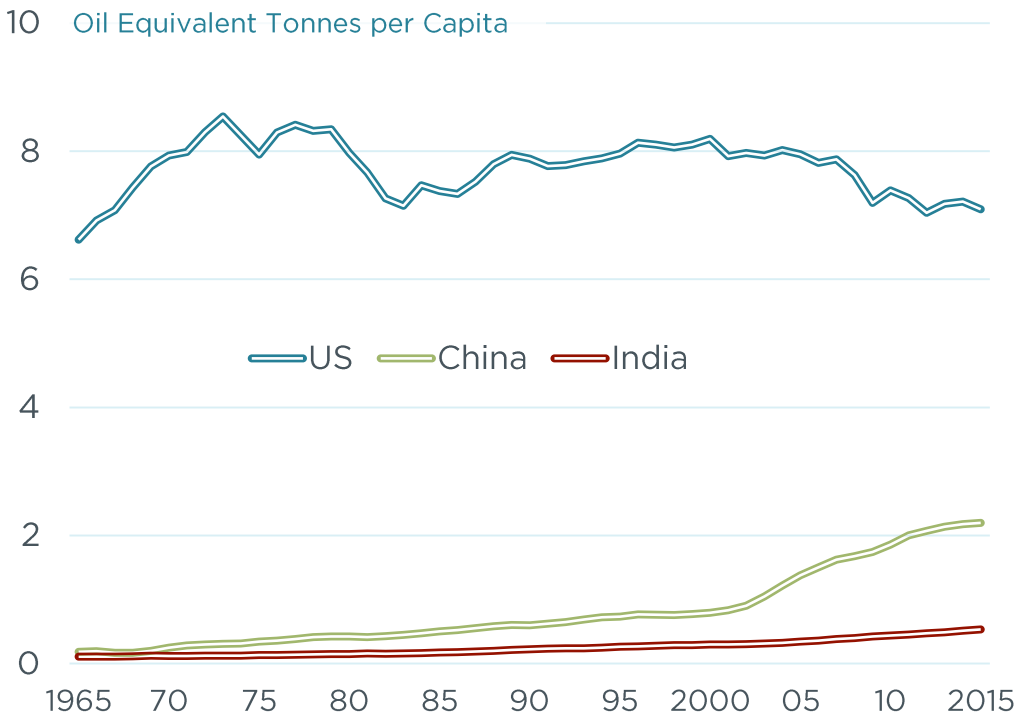
3. Demand will Grow Rapidly in Developing Countries

Demand will grow Rapidly in non-OECD

Primary Energy Demand per Capita

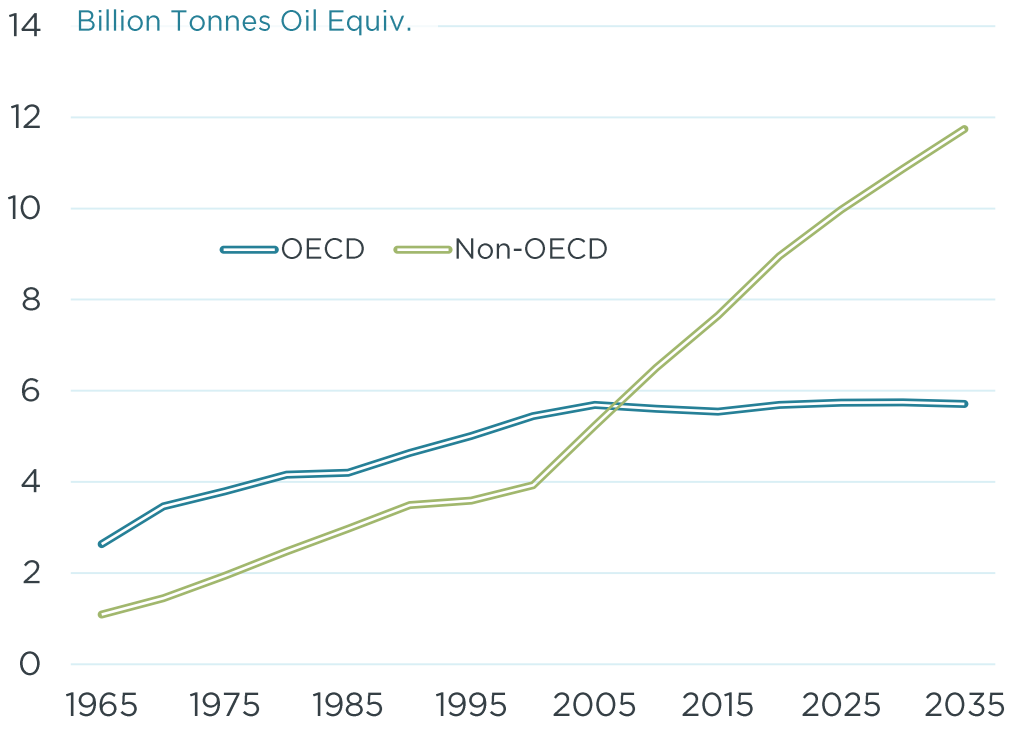


- Though China is now the world's largest energy consumer, its per capita consumption is less than one-third the U.S. level.
- Hundreds of millions of people will move into the middle class in these economies before 2035, with profound implications for energy demand.

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

Demand will grow Rapidly in non-OECD

Global Energy Demand, 1965-2035



- Global energy demand is set to grow by one-third between now and 2035.
- Fully 100 percent of expected growth will occur in emerging market economies, especially in Asia.
- China and India are expected to account for more than half of global energy demand growth between today and 2035 based on business as usual.

Source: EPIC analysis based on data from BP Statistical Review 2015 and BP Energy Outlook

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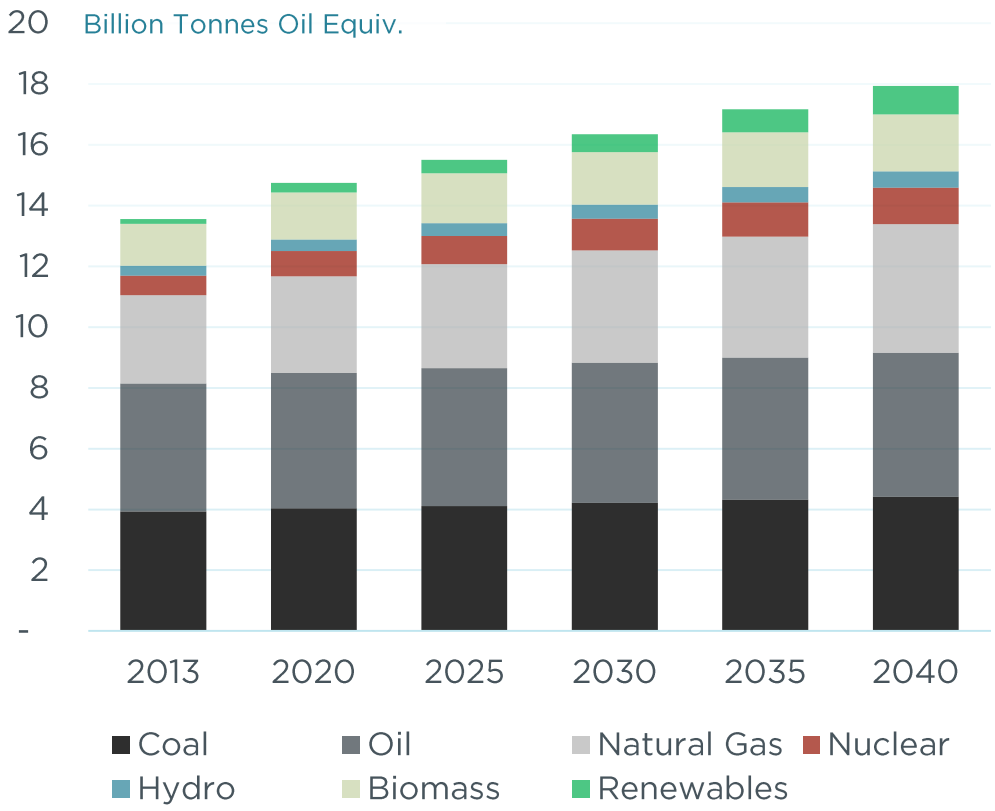
Fossil Fuels will meet Much of this Growth

World Primary Energy Demand, 2013 - 2040

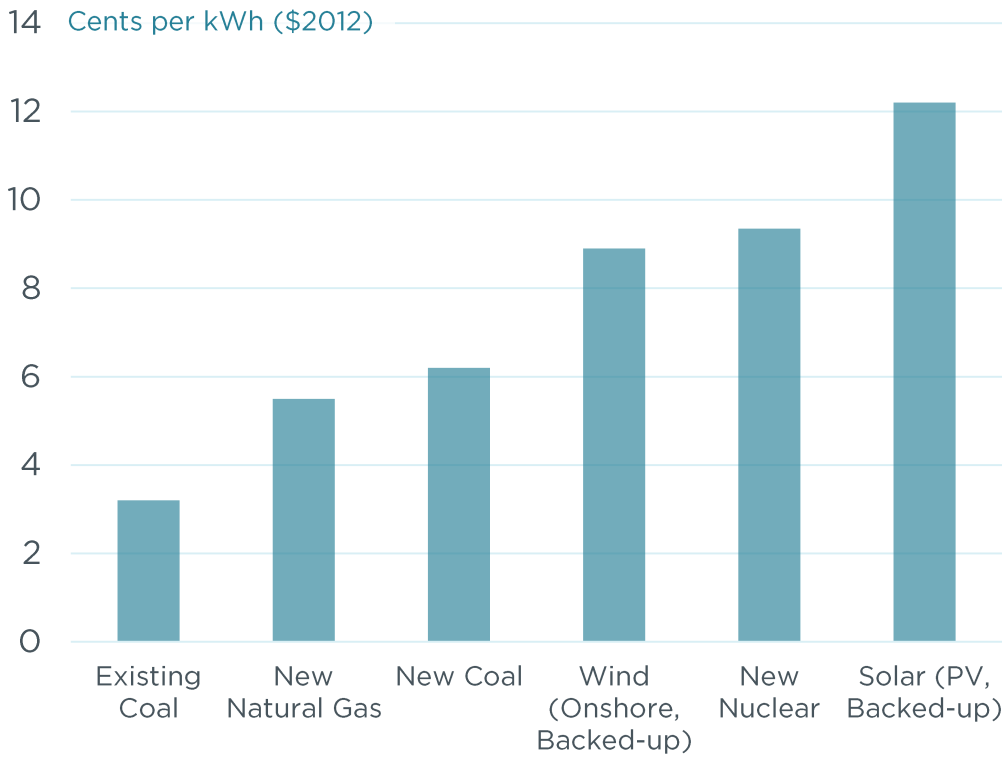


- Based on policies in place and committed at the end of 2015, the International Energy Agency expects fossil fuels to supply 75 percent of world primary energy in 2040, compared to 81 percent in 2013.
- While renewables are the fastest growing resource, coal, oil, and natural gas together account for more than half of all growth through 2040.

Source: International Energy Agency, 2015

Fossil Fuels are Inexpensive in Power...

Levelized Cost of Energy, United States

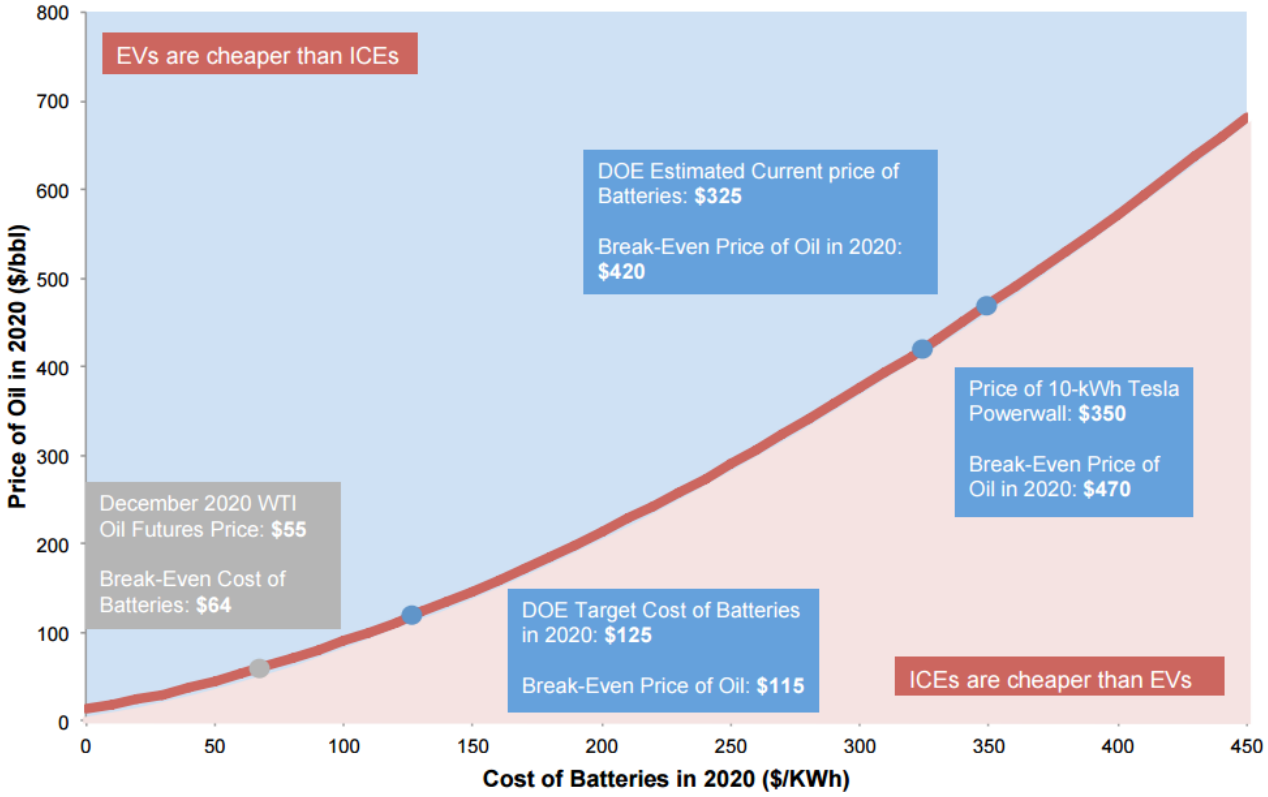


- Conventional fuels and technologies are the most cost-effective sources of energy today and continue to attract significant investment as a result.
- Challenges in transportation are even greater, where the combination of the combustion engine and oil have no competition.

EPIC analysis based on data from the Department of Energy.

...and in other Sectors like Transportation

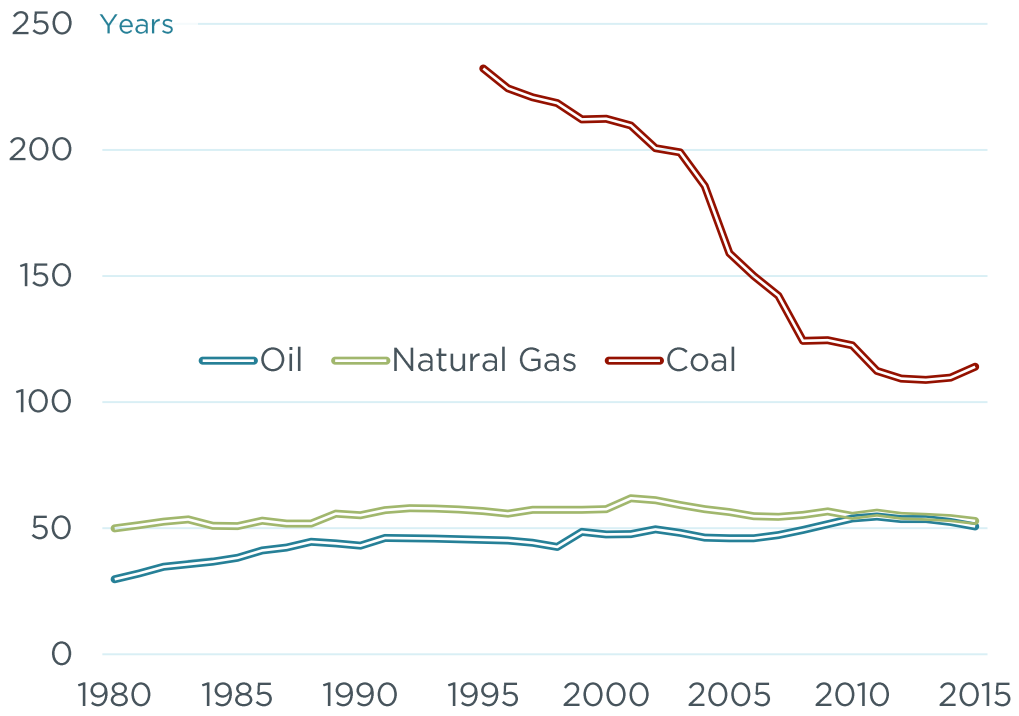
Breakeven NPV of Owning an ICE versus an EV with 250 Miles of Range



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

...And Fossil Fuels Remain Abundant

Fossil Fuel Reserves-to-Production Ratios



- The world has consistently held approximately 50 years worth of natural gas reserves for the past 30 years, meaning annual reserve additions have roughly equaled production.
- Oil reserves have grown significantly over the same period, and are also now equal to 50 years of current production.
- Coal reserves are currently equal to 110 years of consumption—down significantly from 1995, but still ample.

EPIC analysis based on data from BP

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

Ebenstein, Fan, Greenstone, He, and Zhou (2016)

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China's Huai River Winter Heating Policy

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

2) **Provides free coal to run small boilers from November 15 to March 15 to keep households warm**

3) **Due to budget limitations, the heating system only exists North of the line formed by the Huai River and Qinling Mountains**

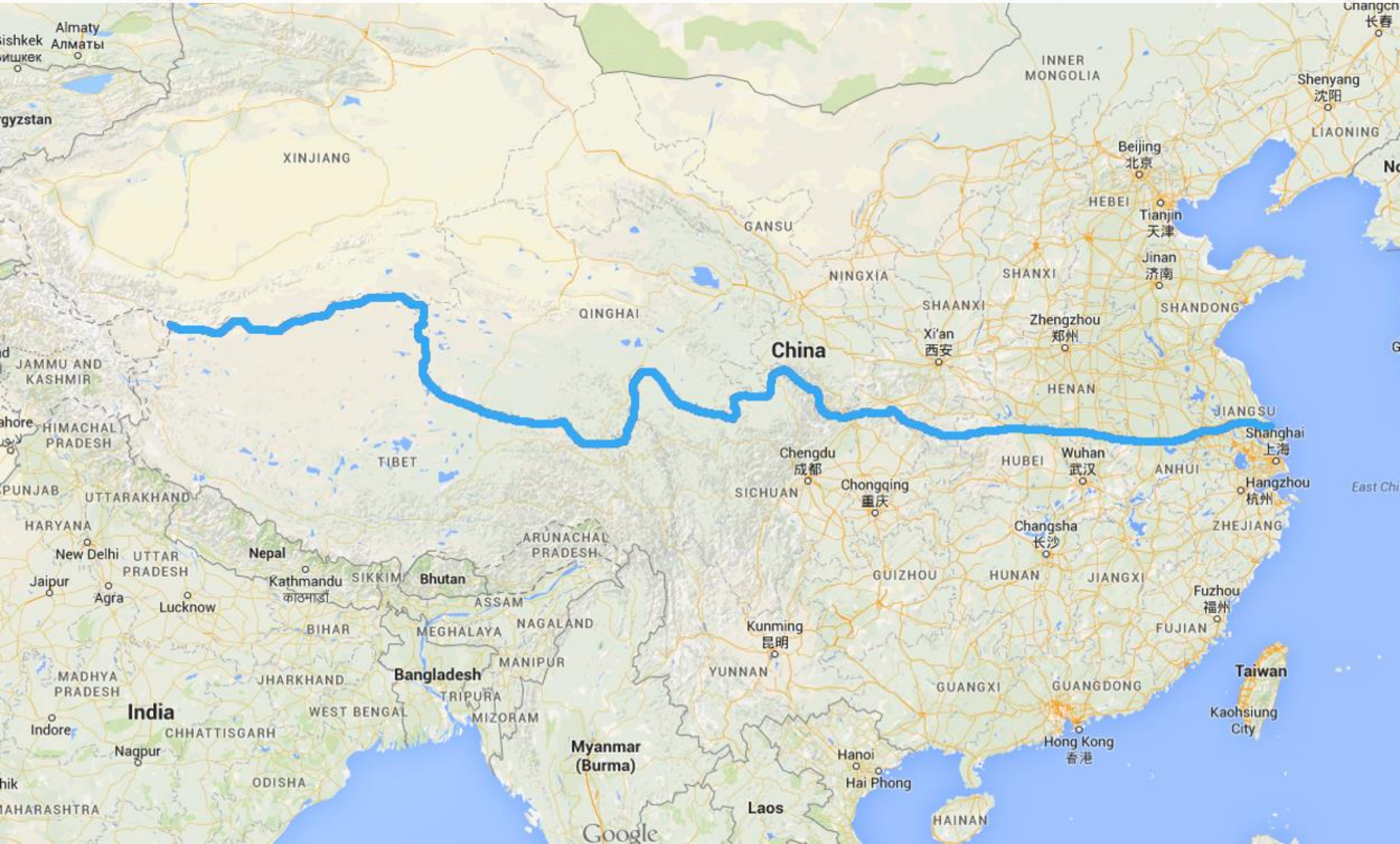
   - » Heating forbidden to the South
   - » In recent years as the market economy has taken hold, heating has started to emerge in the South

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.

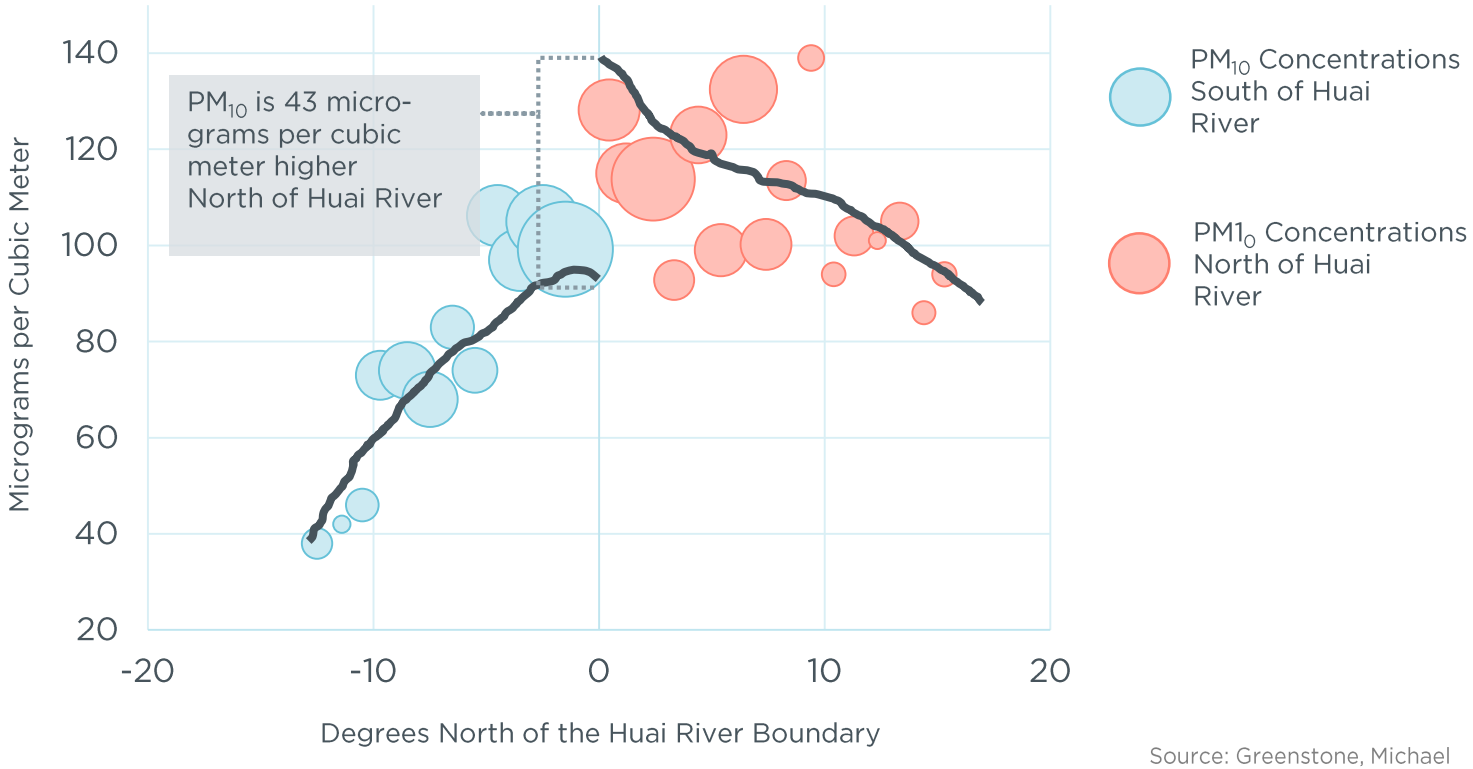
The Dividing Line

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.



Pollution is 50% Higher North of the River

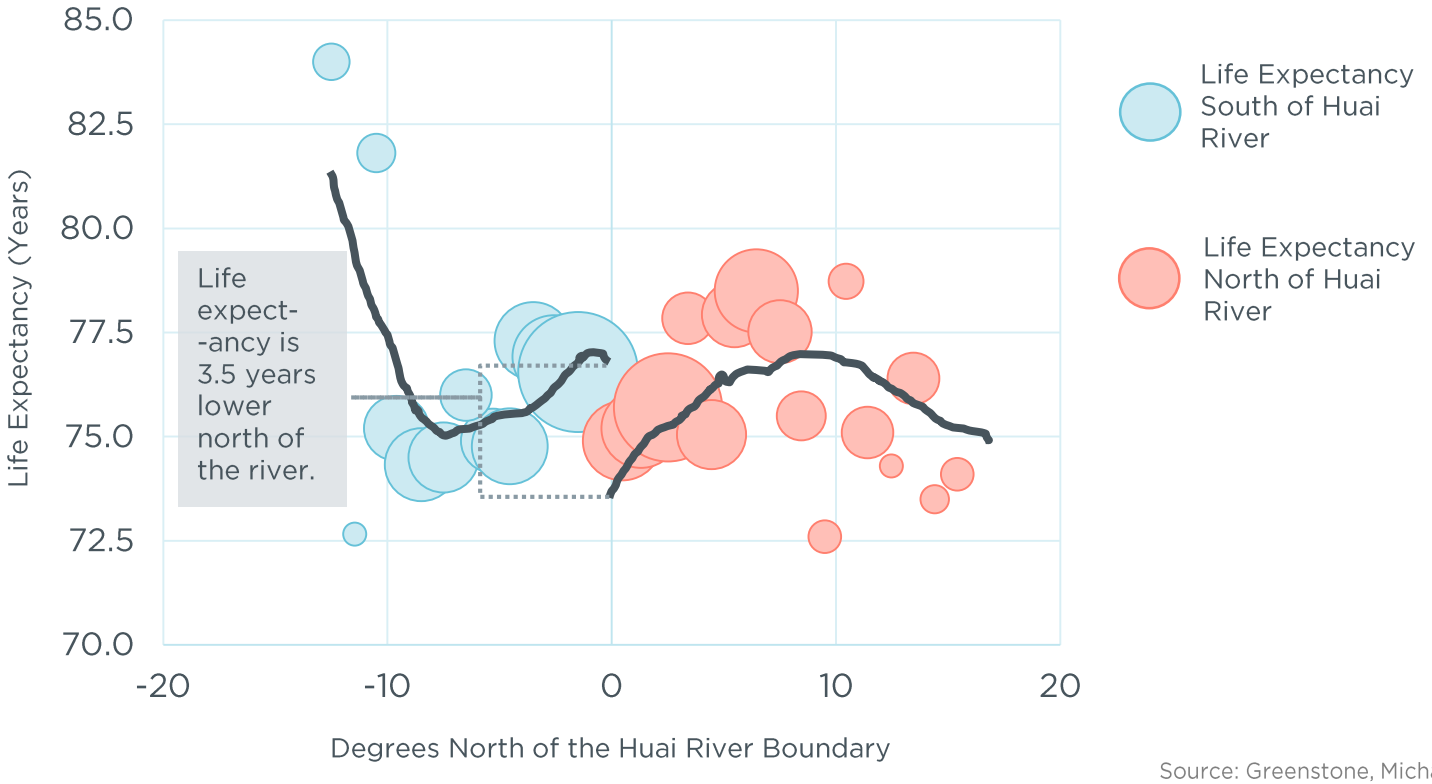
PM_{10} Emissions North and South of the Huai River



Source: Greenstone, Michael

And Life Expectancy is about 4 Years Lower

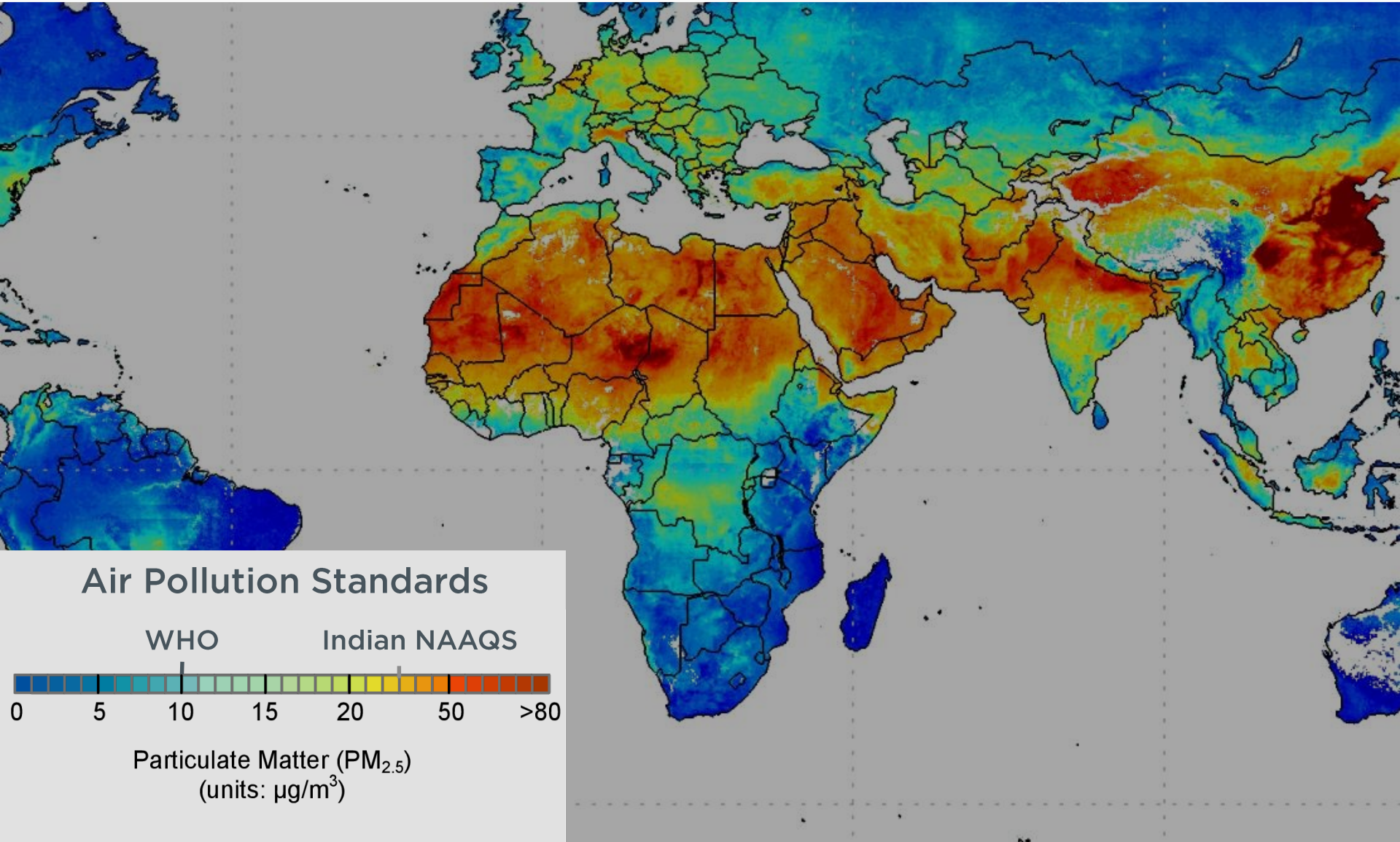
Life Expectancy North and South of the Huai River



Source: Greenstone, Michael

Global Concentrations of PM 2.5

High concentrations of fine particulate matter have caused the loss of 2.1 billion life years in India and 2.5 billion in N. China.



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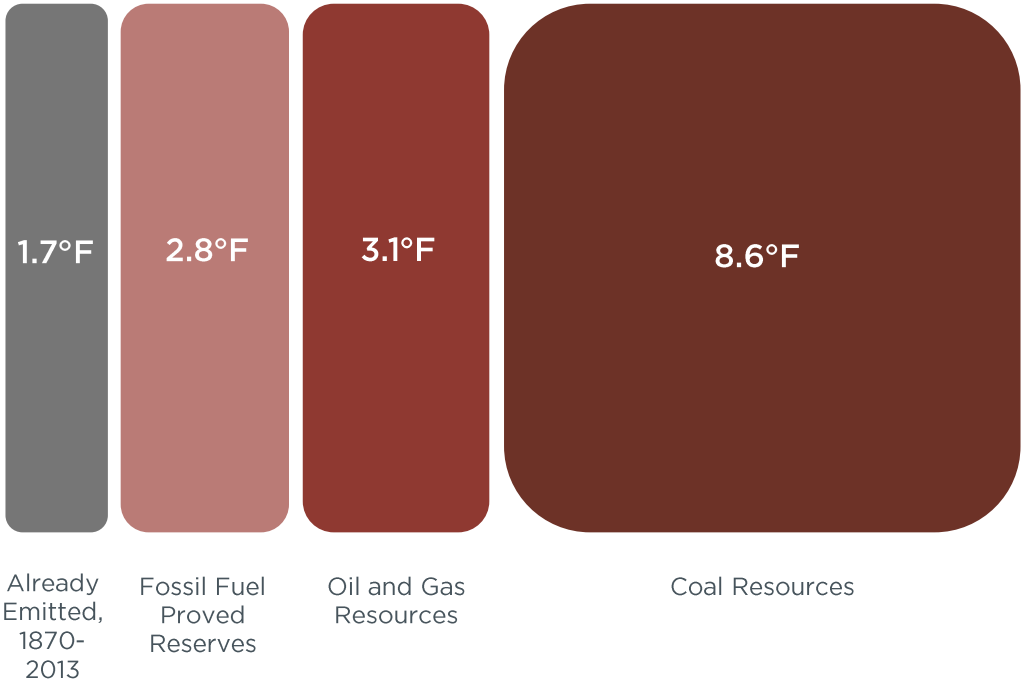
How Much Warming is Possible?

Estimated Temperature Impact of Combustion

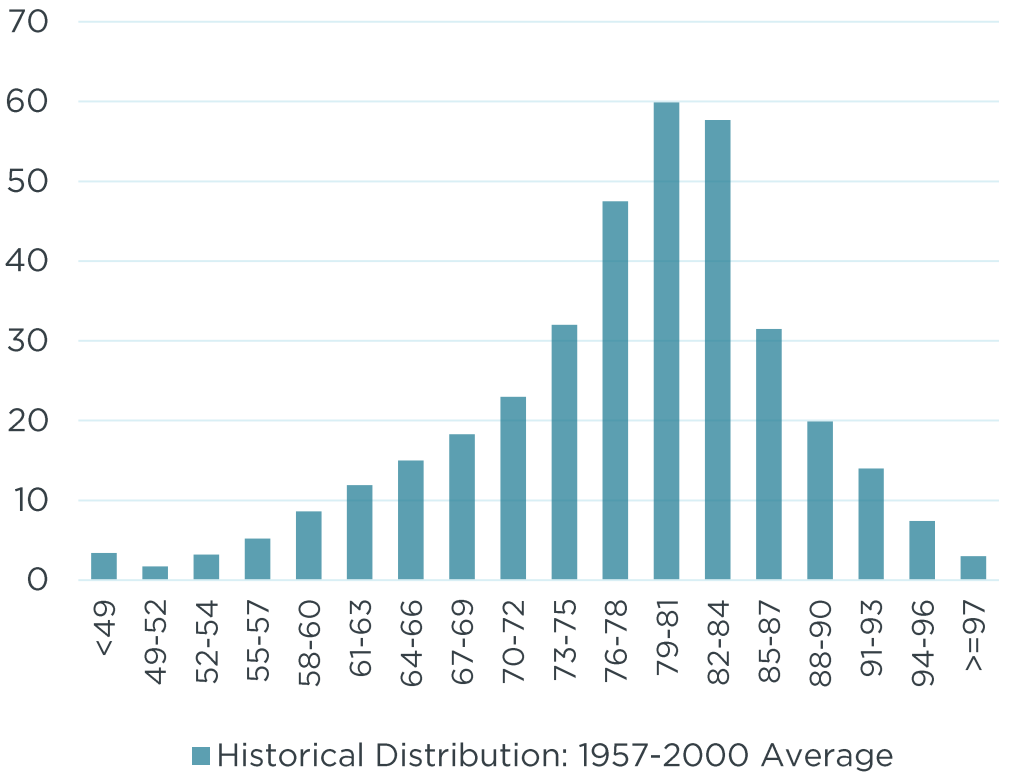


- The world possesses practically unlimited fossil fuel resources.
- Advancements in technology will make the majority of this resource base accessible over the coming decades.
- The global warming potential of combusting and emitting the full resource base is significant.

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

The Climate is Expected to Change

Distribution of Average Temperatures in India



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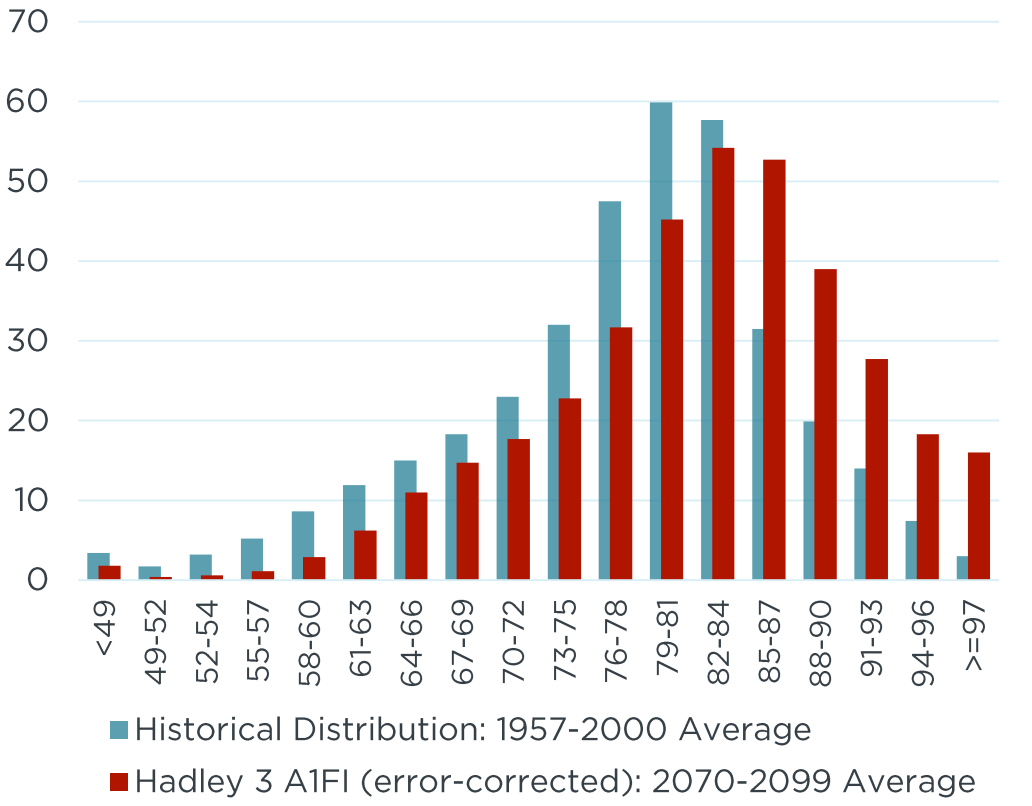

The Unequal Effects of Weather and Climate Change: Evidence from Mortality in India

Burgess, Deschenes, Donaldson, and Greenstone (2016)

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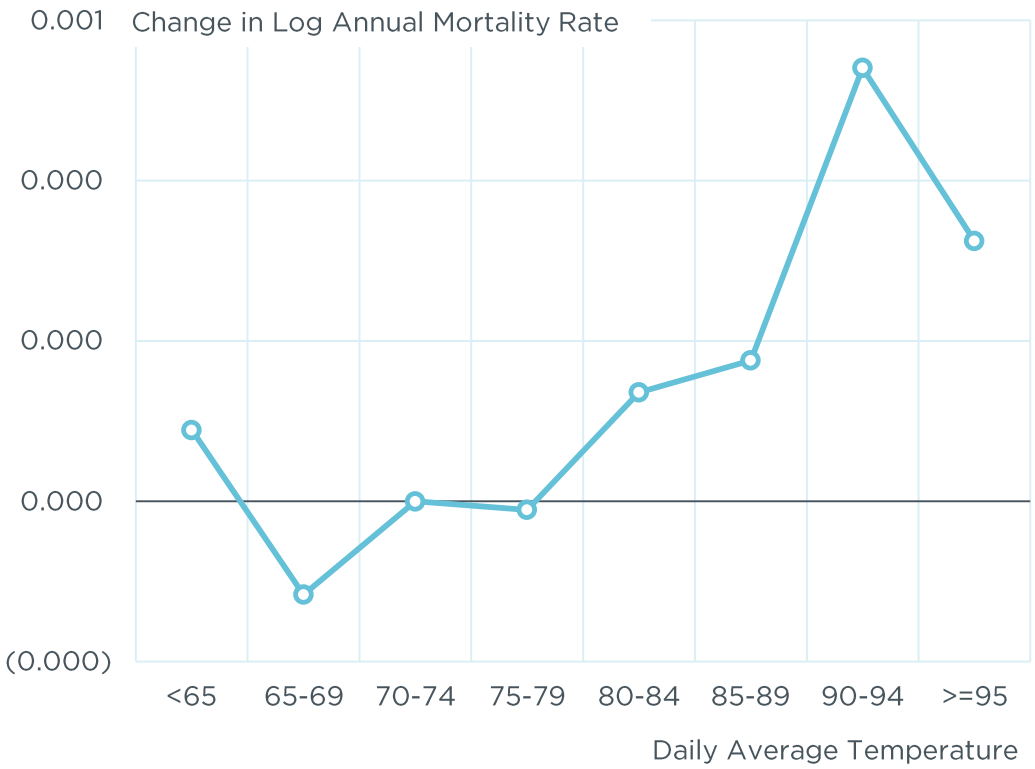
Impacts to the US are Minimal

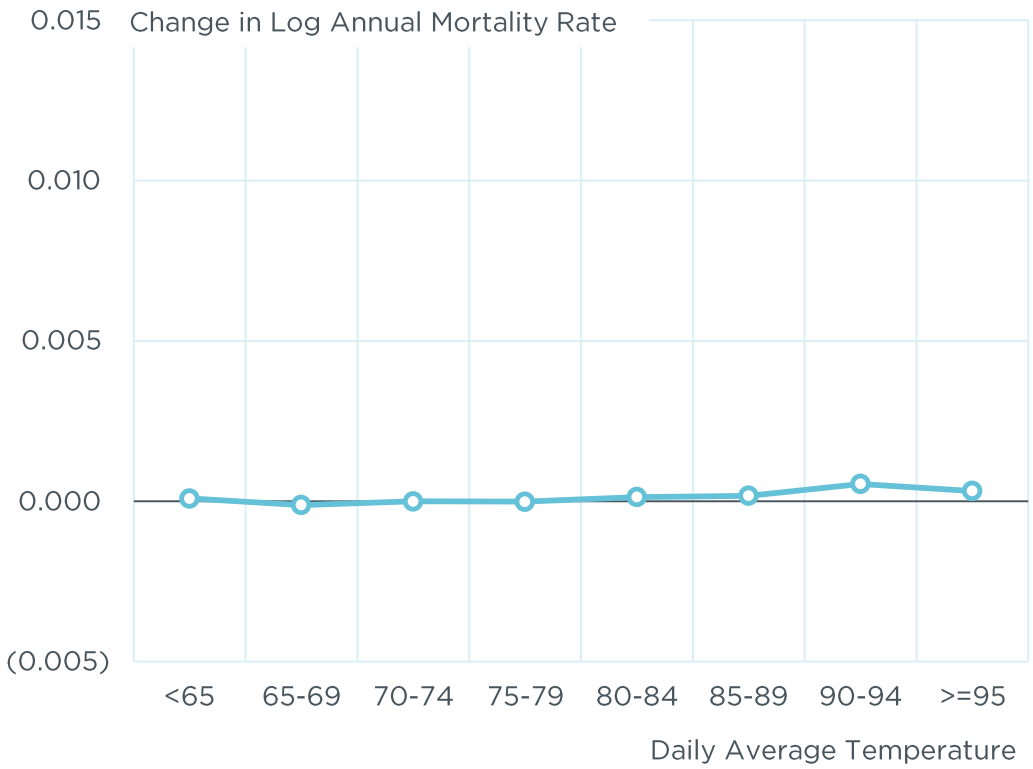
Estimated Impact of Temperature on Mortality



- 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

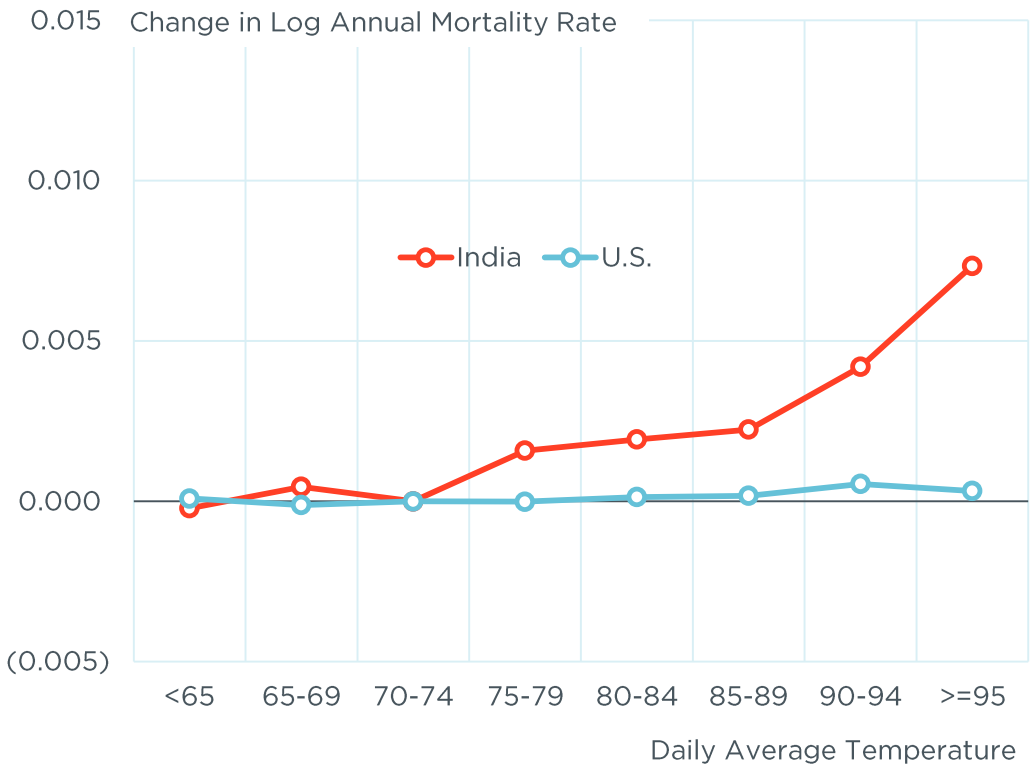
Estimated Impact of Temperature on Mortality



› 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 Relatively Large

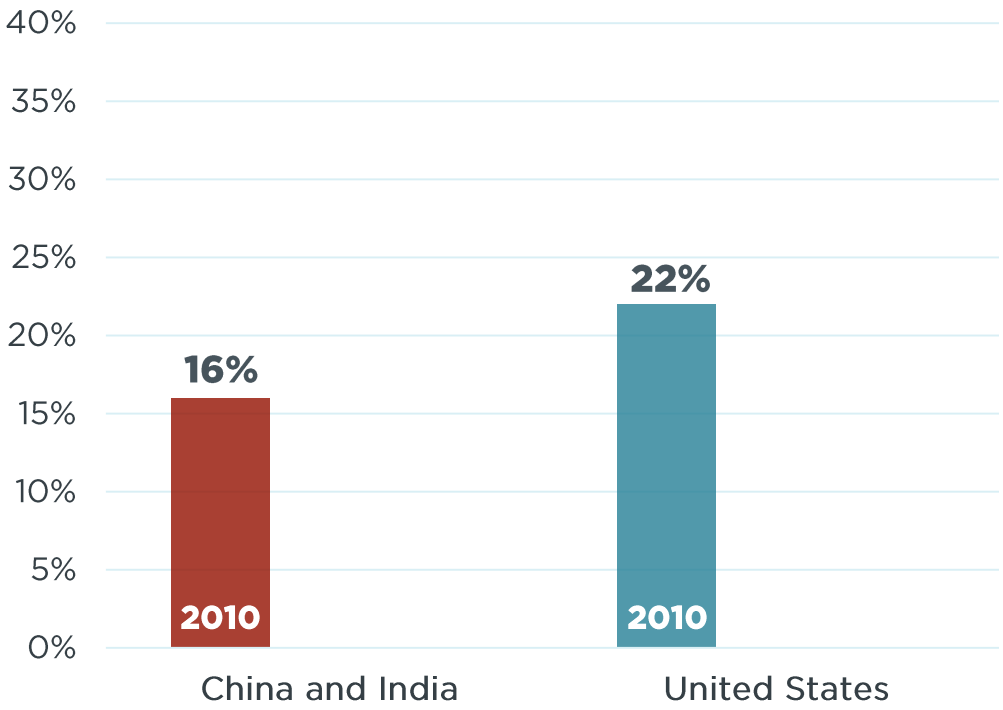
Estimated Impact of Temperature on Mortality



- 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

Share of World Cumulative GHG Emissions



› The United States accounted for 22 percent of cumulative global greenhouse gas emissions through 2010, share that significantly exceeded China and India combined.

The Politically Challenging GHG Accounting

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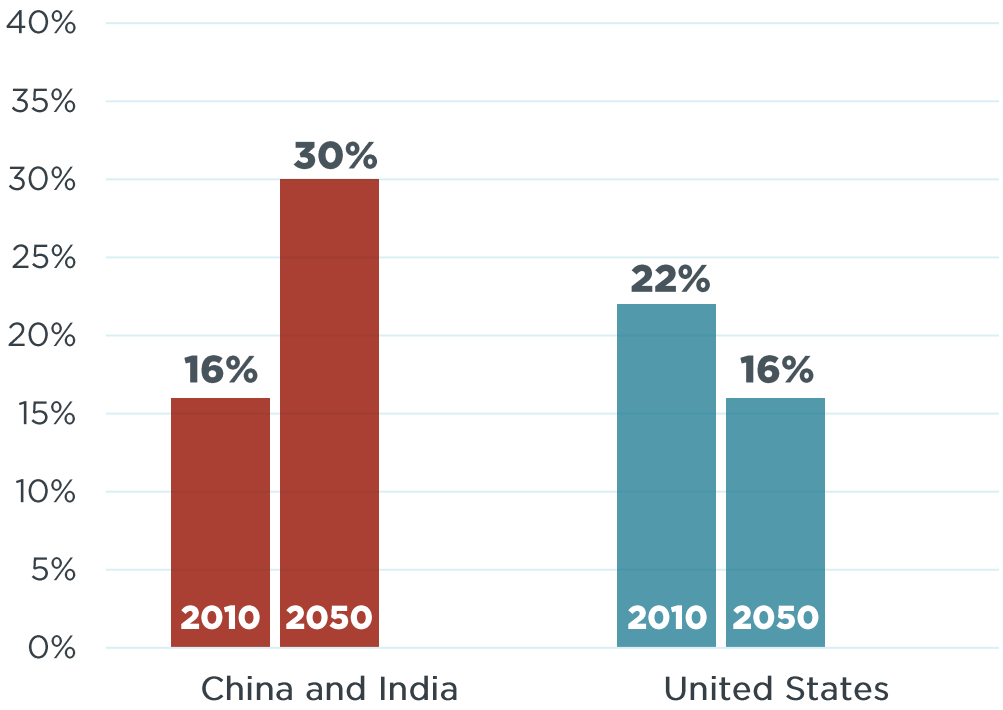

› By 2050, however, cumulative emissions from China and India will account for nearly double the U.S. share.

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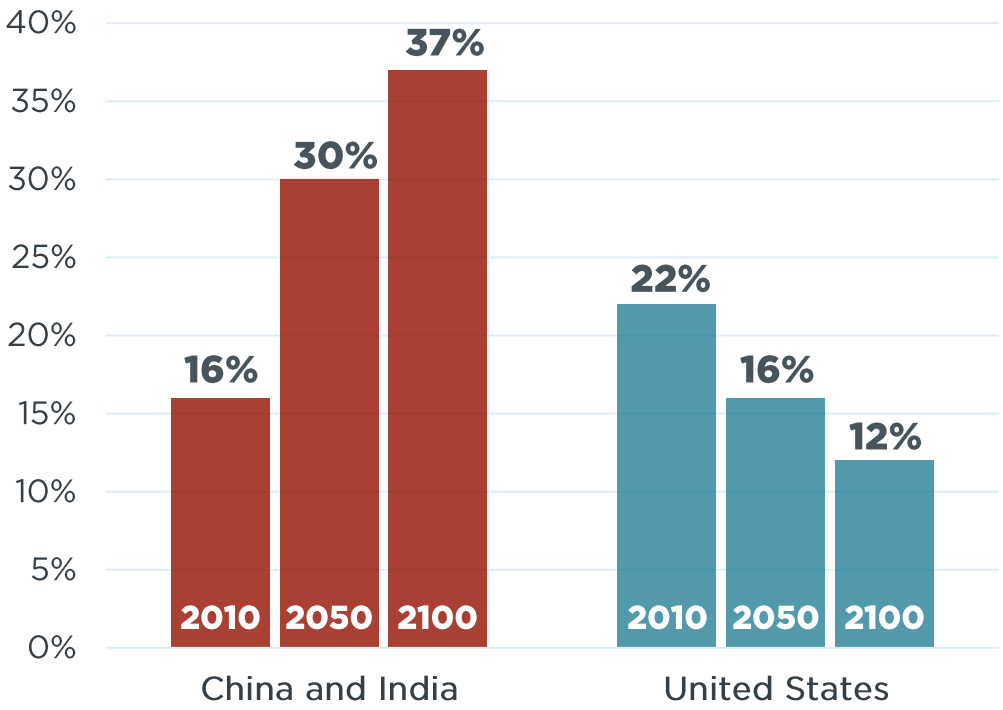

› By 2100, cumulative emissions from China and India will account for more than a third of the world total, compared to just 12 percent for the United States.

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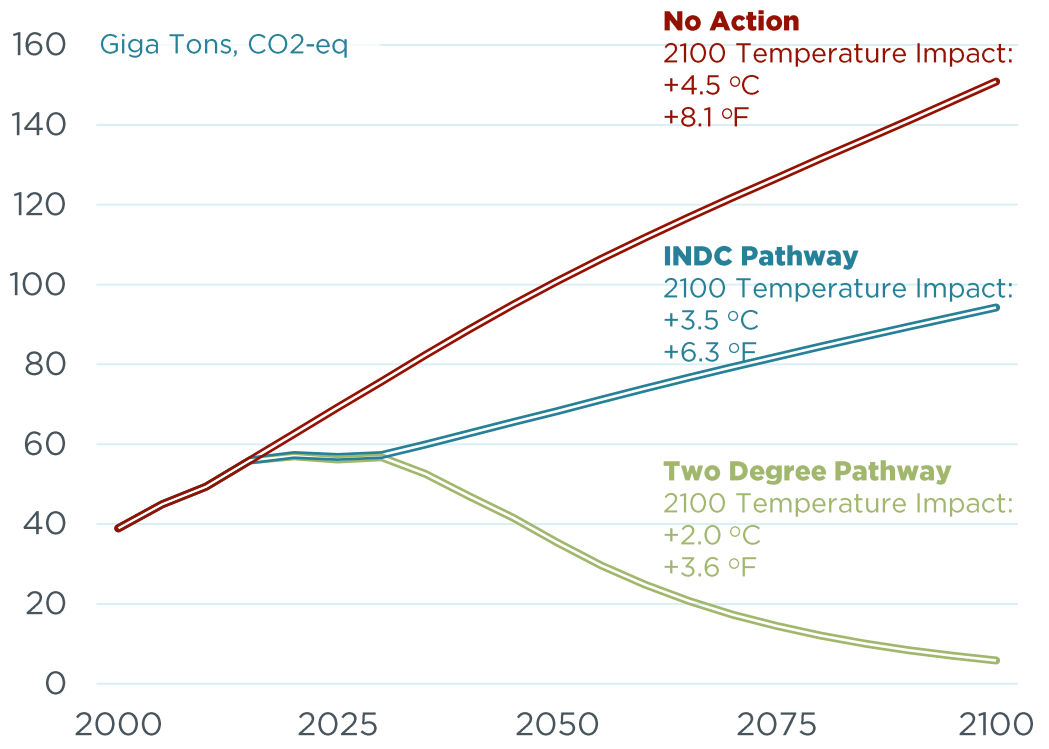
6. Fossil Fuels are Causing the Complicated Climate Challenge
7. The Paris Agreement is Expected to Help…Some

Meeting Paris Climate Commitments Would Help Some

Global GHG Emissions



- Policymakers around the world made ambitious commitments to reduce greenhouse gas emissions as part of the Paris Climate Agreement
- These commitments, however, are not adequate to avoid serious climate damages over the coming century.

Source: Climate Interactive

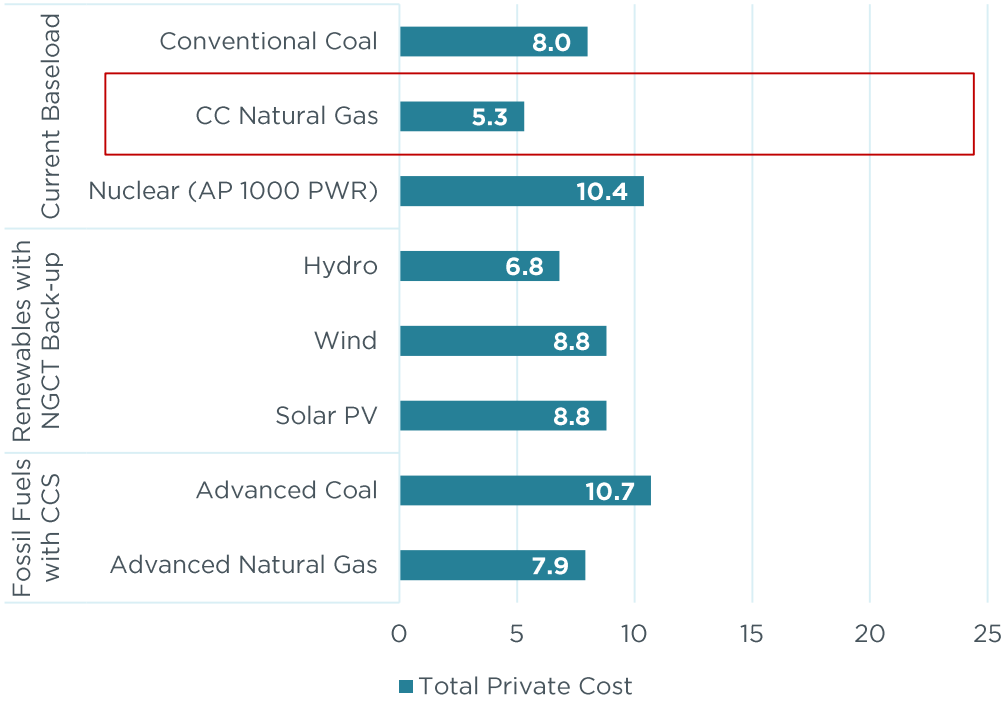
Section 2

Three Key Solutions

1. Price Energy at its Full Social Cost

Fossil Fuels are Mispriced

Levelized Cost of Energy for New Plants, 2023

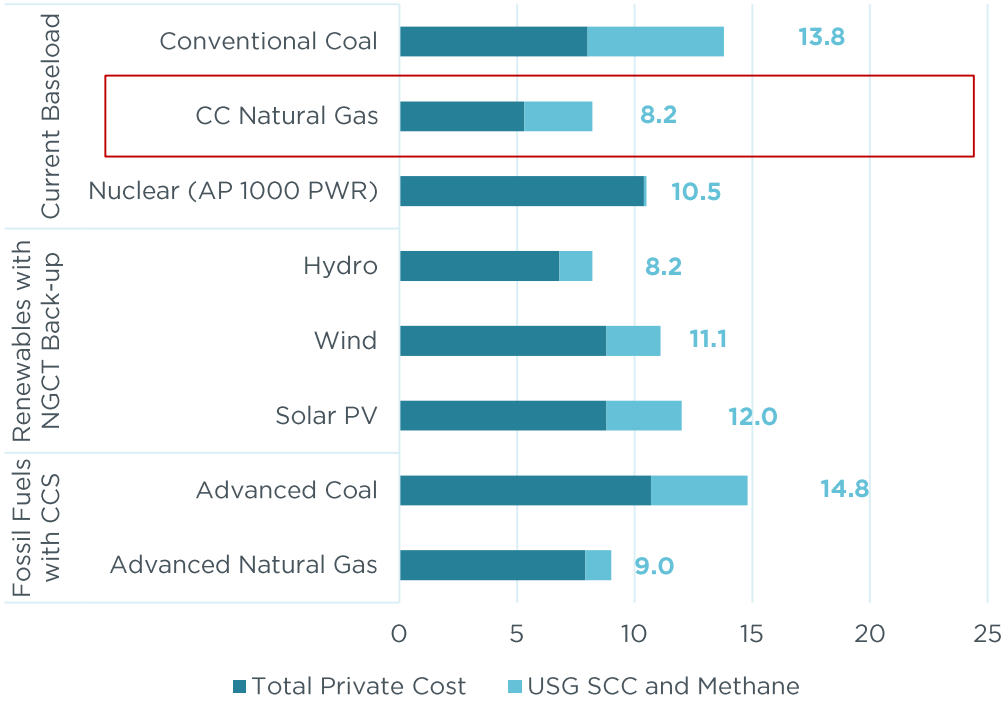


- Presenting energy costs in strictly private terms heavily favors conventional fossil generation.
- This is especially true if we limit our analysis to system configurations capable of providing baseload power.

Source: EIA

Fossil Fuels are Mispriced

Levelized Cost of Energy for New Plants, 2023



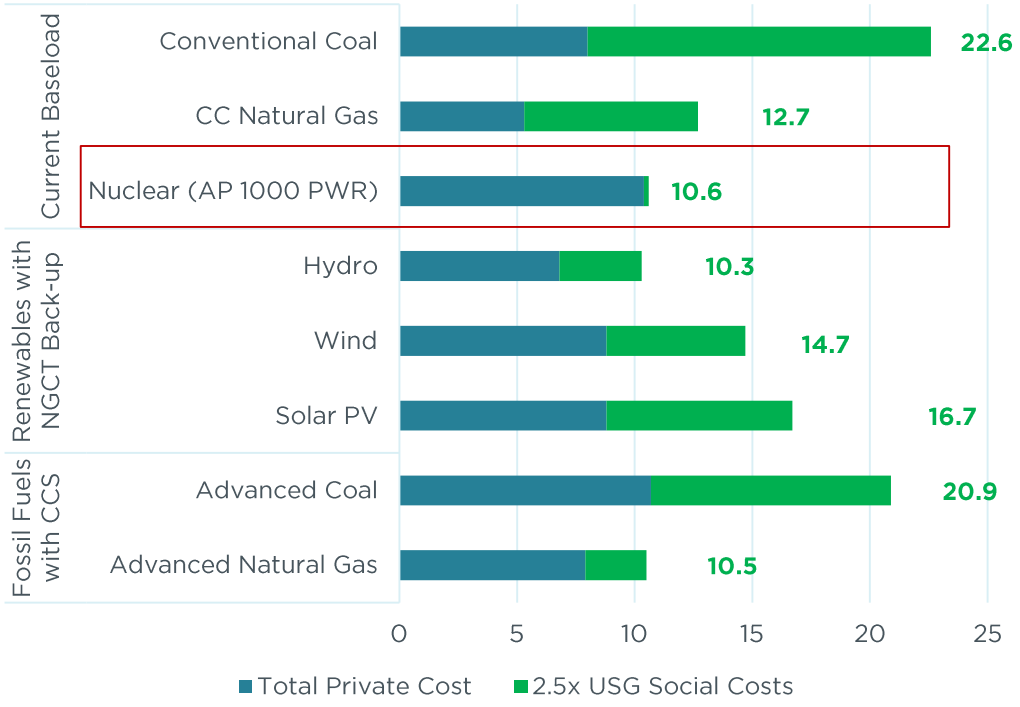
2015 ¢ per kWh

Source: EIA

- By adding the U.S. government's estimate of the social cost of carbon—currently about $40 per tonne— and social cost of methane, the economics shift significantly.
- In this case, combined cycle natural gas and hydro power are the most economically competitive, and natural gas with CCS is a close second.
- Coal with CCS is the most expensive source of power supply, followed by conventional coal.

Fossil Fuels are Mispriced

Levelized Cost of Energy for New Plants, 2023



2015 ¢ per kWh

Source: EIA

- Higher levels of carbon pricing alter the economics further.
- Increasing the estimated social costs by a factor of 2.5 results in hydropower becoming the most economically-competitive form of new power generation, though its scalability is limited by geography.
- Natural gas with CCS and nuclear power are both competitive with hydropower and also benefit from greater scalability.

What is the Social Cost of Carbon?

The Most Important Number You Have Never Heard

Definition

The social cost of carbon (SCC) is the monetary value of the damages from emitting an incremental ton of CO_2 into the atmosphere. In principle, it should reflect the full cost to society of the range of impacts we know will be associated with a warming world, including the costs of adaptation.

Why is it important?

The SCC is a critical input for developing effective and efficient climate policies.

- By providing a robust monetary estimate of the cost of emitting a ton of carbon, the SCC can facilitate efficient carbon pricing, particularly a carbon tax.
- The SCC can also be fed directly into the cost-benefit analysis of major regulatory actions to limit carbon emissions, facilitating the development of efficient, appropriately stringent limits.
- In short, it eliminates the guesswork for policymakers.

The Social Cost of Carbon

The SCC is Already Being Deployed

U.S. Federal Action on Climate

The U.S. EPA currently uses an SCC figure of $37/ton for CO_2 emitted in 2015. This figure was used in the cost-benefit analysis of recent vehicle emissions and power plant standards. Its use allowed lawmakers to appropriately capture the social benefits of reduced emissions.

Going forward, SCC could inform a wide range of federal decisions, such as:

- Mineral leasing on public lands;
- Vehicle and services acquisition; or
- The development of a national carbon price.

Locally

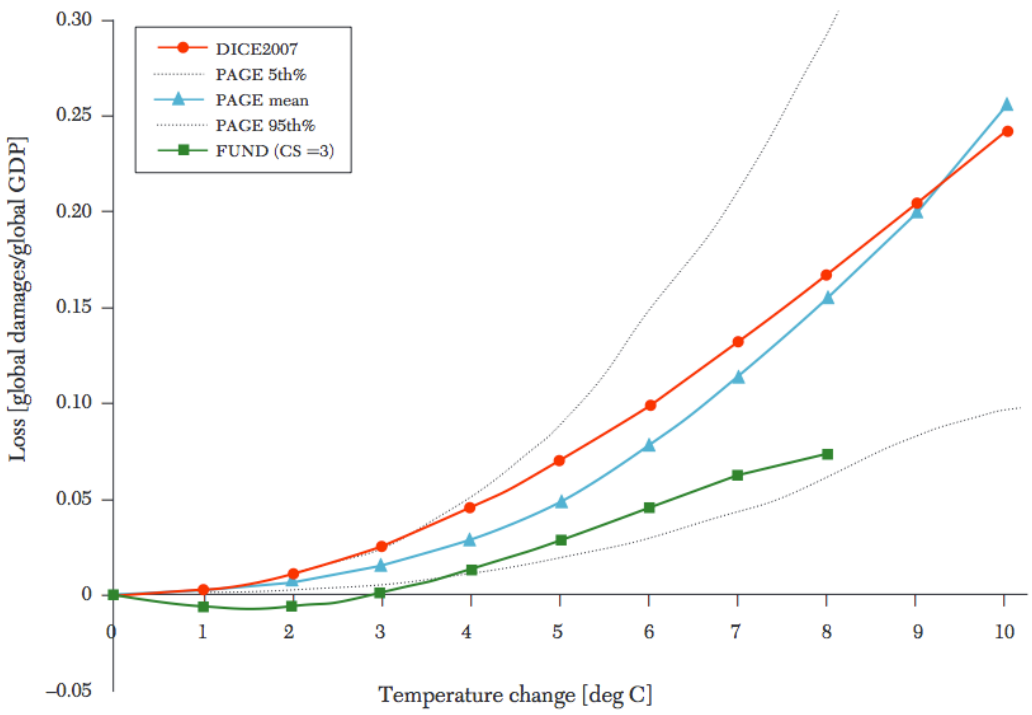
The state of Minnesota recently used the U.S. federal estimate for the SCC to set a state-level utility feed-in tariff for solar power.

Globally

Canada recently adopted the current U.S. estimate as its own for use in energy and climate regulation. France, Germany, Mexico, Norway, and the United Kingdom have all recently used their own SCC estimates in regulatory action.

Damage Functions

Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature



- Using three models that are combined to produce USG SCC
  - DICE (Nordhaus 2008)
  - FUND (Hope 2008)
  - PAGE (Tol 2009)

Source: EPA

"The bottom line here is that the damage functions used in most [climate models] are completely made up, with no theoretical or empirical foundation."

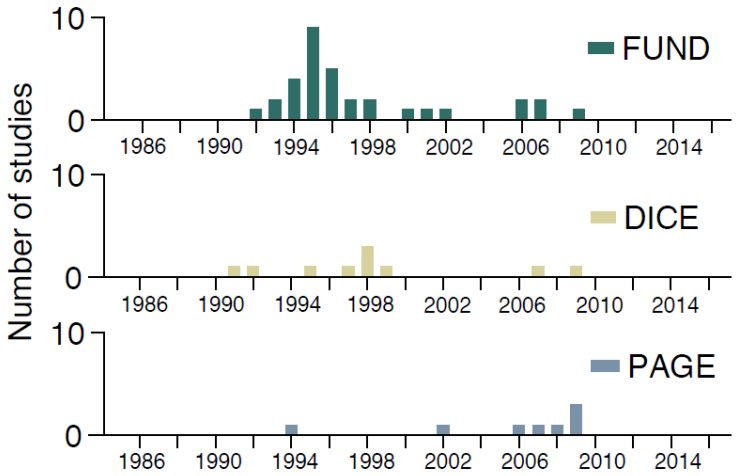
Robert Pindyck
Professor of Economics and Finance
Massachusetts Institute of Technology

The Social Cost of Carbon

Current SCC Estimates Rely on Outdated Information and Analysis

The Current SCC

The federal government's SCC estimate is based on inputs from three models: FUND, DICE, and PAGE. The studies that informed these models were primarily done in the mid-1990s.

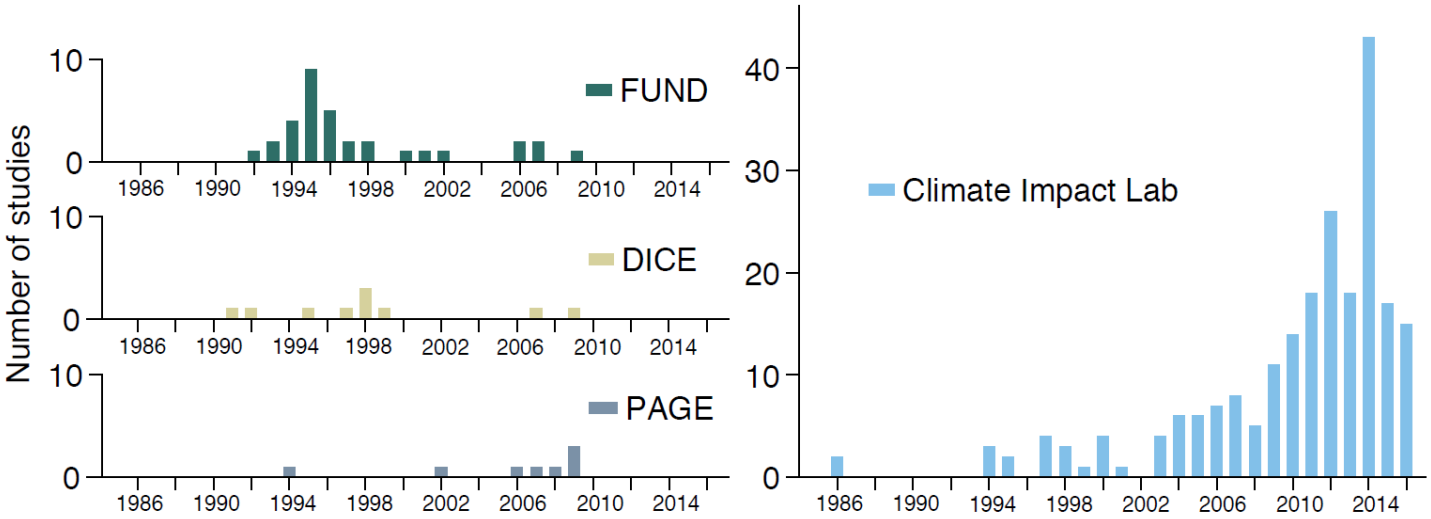


The Social Cost of Carbon

Updating and Improving the SCC could Drive a Generation of Climate Policy

The Opportunity

In 2015, the White House Office of Management and Budget and the Council of Economic Advisors commissioned the National Academy of Sciences to recommend a process for updating the SCC. Climate Impact Lab is gearing up with a step-change in analytical capacity and a transformative approach that could become the government's preferred approach. We are now fully engaged with the NAS panel.



The Social Cost of Carbon

The Impact Lab Methodology

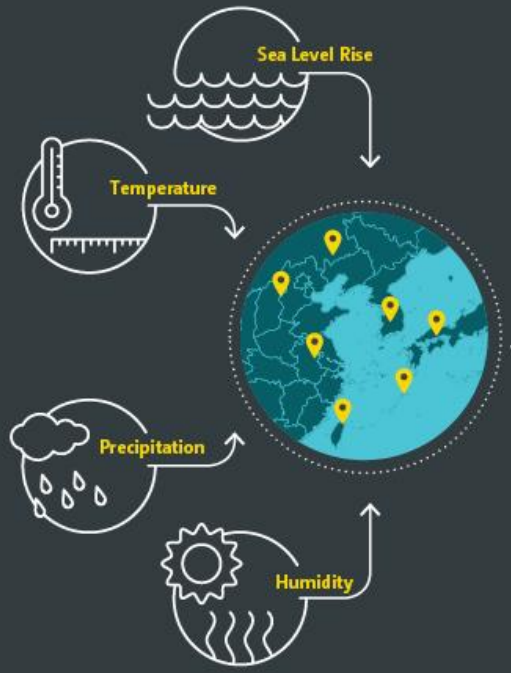
A Novel Approach

The Impact Lab's analytical work consists of three primary functions:

- First, the project will develop a range of climate projection scenarios across four key variables: temperature, precipitation, sea-level rise, and humidity.
- Second, the Lab will use historical, real-world data to develop rigorous projections of climate impacts across key outcomes, including: health, agriculture, labor productivity, energy demand, conflict, and coastal inundation. We will develop these for every global region and at the local level for most countries.
- Finally, the climate-driven impacts are monetized and aggregated to produce an empirically derived estimate of the social cost of carbon.

Measuring the Costs of Climate Change

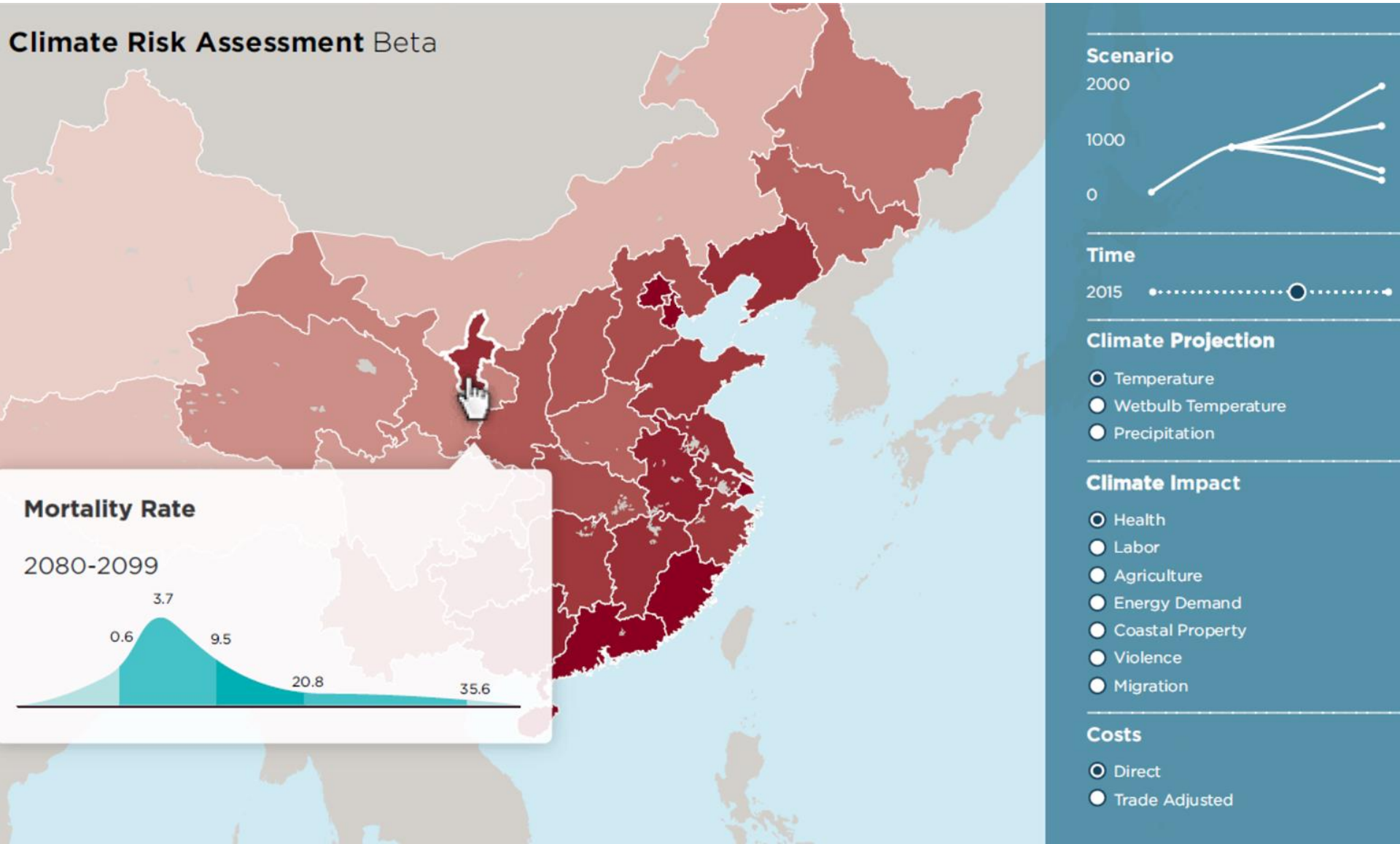
The Climate Impact Lab has developed a ground-breaking approach that uses detailed historical climate data to derive actionable information about the future.



Global Mitigation
Policymakers around the world can feed the social cost of carbon into regulations designed to mitigate emissions, driving investment in clean energy.

Local Adaptation
City planners, CEOs, insurance agents, and farmers can manage risks and make local decisions using an online climate impact assessment tool.

Climate Impact Assessment Tool



Three Key Solutions

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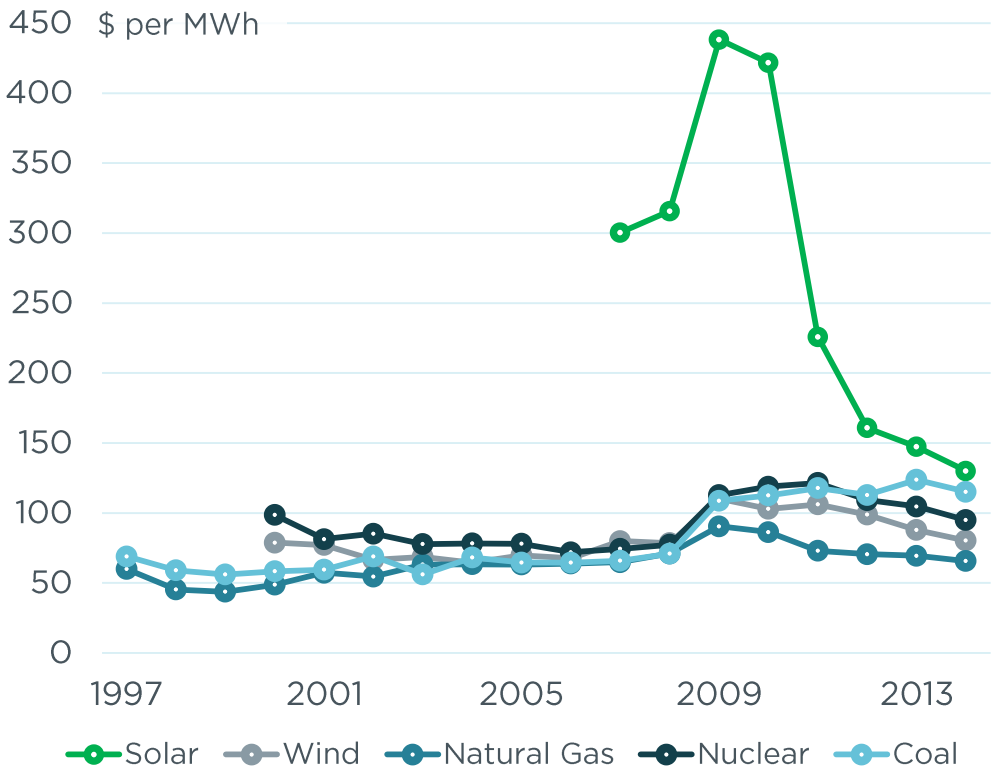
2. Invest in Innovation

Innovation is Causing Rapid Change in Energy

Levelized Cost of Energy

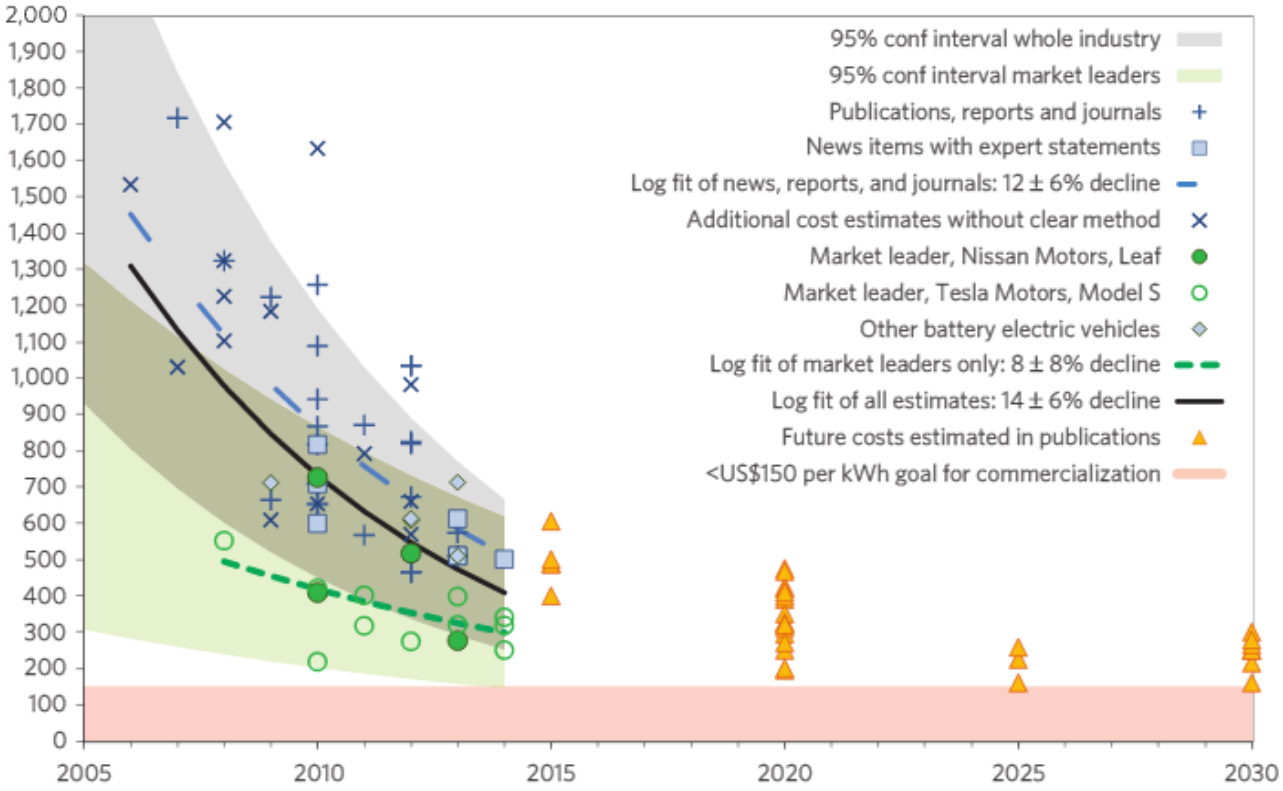


› The cost of solar PV has plummeted in recent years, from $438 per MWh in 2009 to $130 per MWh in 2014.

Source: DOE, EIA

Innovation is Causing Rapid Change in Energy

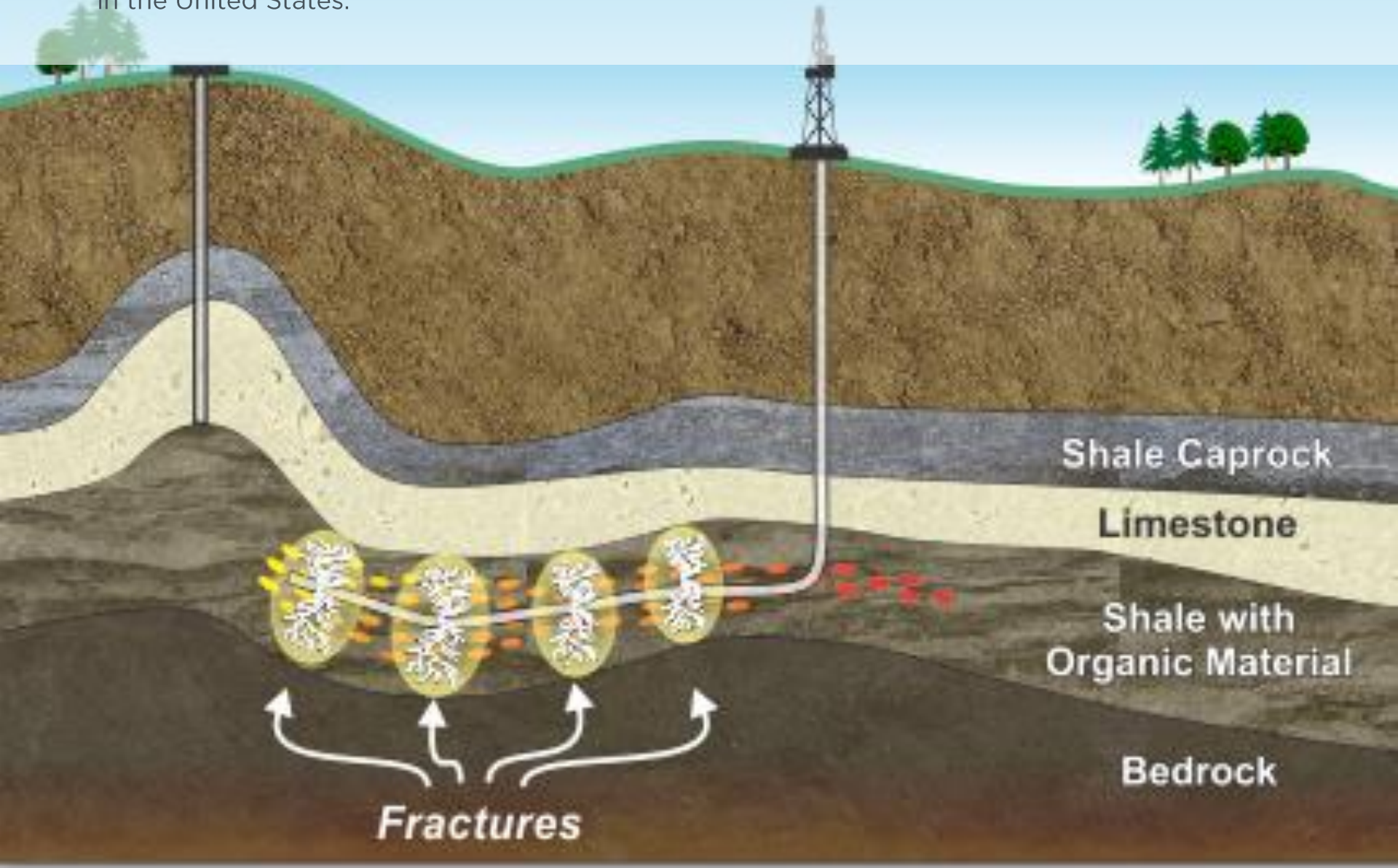
Lithium-ion Battery Pack Cost for BEV ($ per kWh)



Source: Nature Climate Change

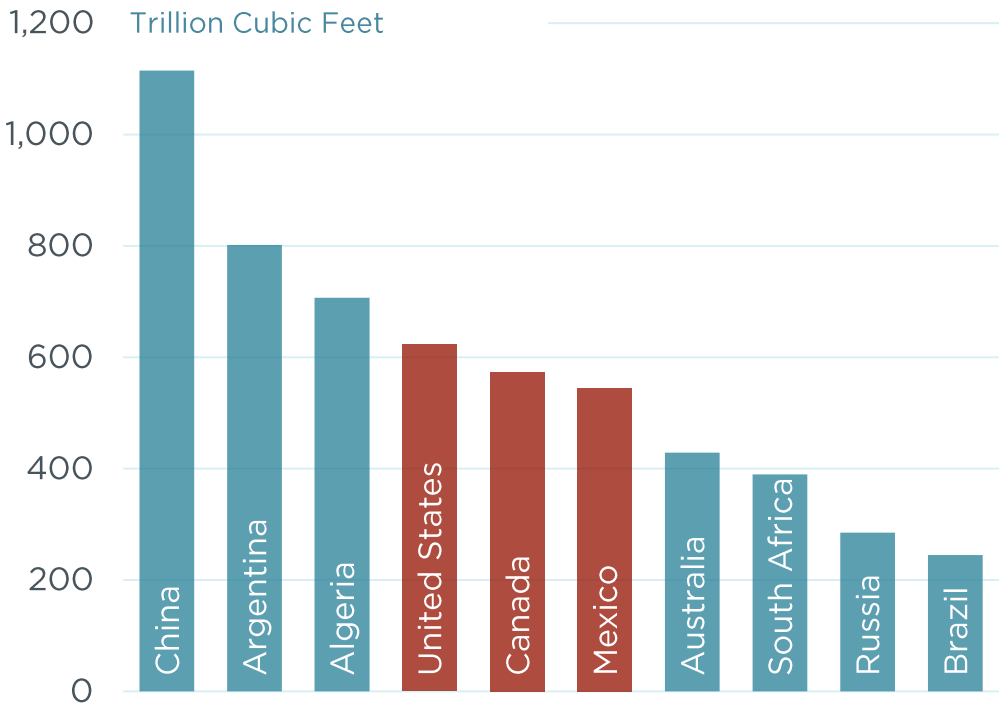
There has also been Innovation in Fossil Fuel Recovery

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



Innovation in Fossil Fuel Resource Recovery

Shale Gas Resources by Country

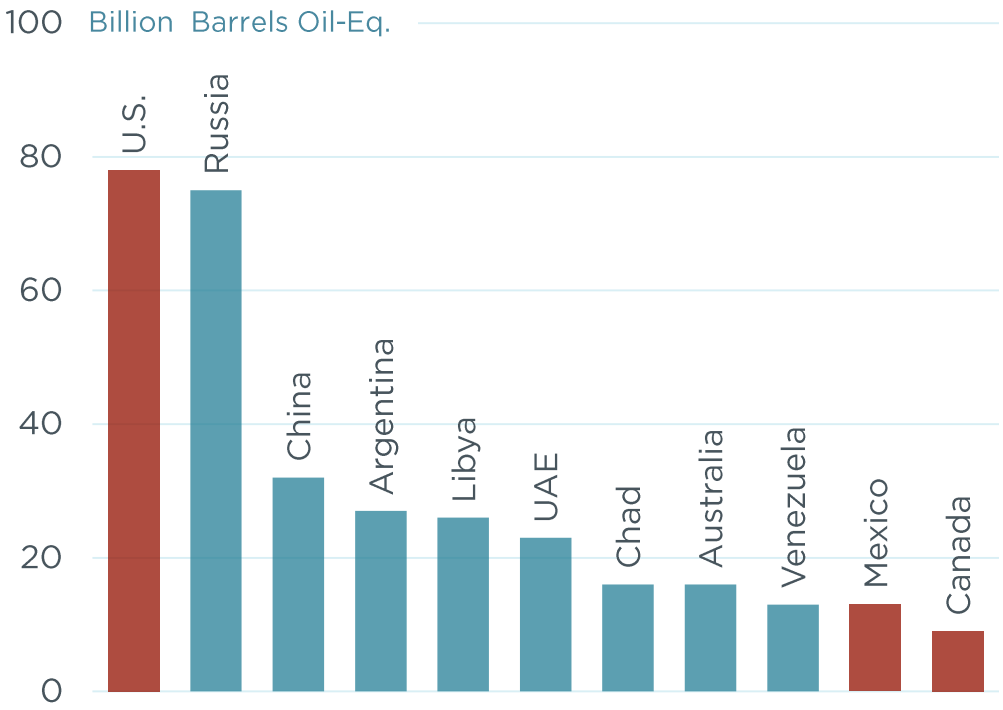


- Innovation in drilling and well-completion has unlocked massive supplies of natural gas globally.
- The U.S. Department of Energy recently estimated global shale gas resources to be more than 7,500 trillion cubic feet (TCF)—equal to **120 years of global gas consumption**.

Source: DOE, EIA

Innovation in Fossil Fuel Resource Recovery

Shale Oil Resources by Country

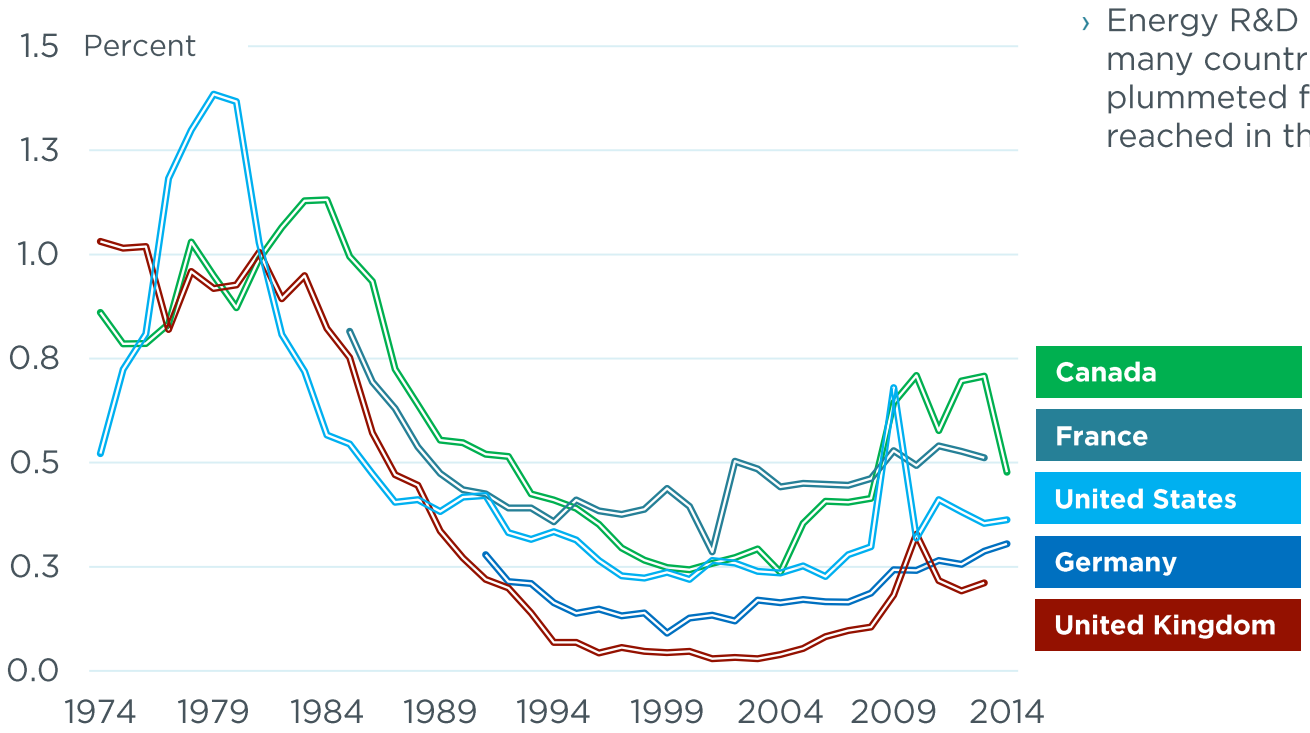


- Estimates of shale oil are also significant.
- The U.S. Department of Energy recently estimated global shale oil resources to be 420 billion barrels of oil equivalent—equal to **34 years of global oil consumption**.
- For comparison, total proved reserves in Saudi Arabia are currently **260 billion barrels.**

Source: DOE, EIA

Investment in Energy R&D is still too Low

Energy R&D Share of GDP



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

Source: IEA

Geoengineering

1) **Goal: reduce climate change through large-scale human interventions**

2) **Some Proposed Methods**
   - » Solar Radiation Management
   - » Carbon Dioxide Air Capture (e.g., artificial trees)
   - » Ocean Iron Fertilization and Artificial Ocean Upwelling
   - » Ocean Alkalinization (to reverse ocean acidification)

Mount Pinatubo, 1991

The eruption ejected 17 megatons of SO_2 into the atmosphere, forming a large sulfate aerosol cloud that caused dramatic decreases in the net radiation reaching the Earth's surface. The result: a temporary decrease in Northern Hemisphere temperatures of up to 0.6° Celsius.

A Substitute for Mitigation?

1) **Unproven at Scale**
   - » Possibly modest effect on warming

2) **Potential Side Effects**
   - » Jellyfish explosions?

3) **Legal and Political Challenges**
   - » Who gets to set the global temperature?

4) **Some Methods would require Continuous Investment, because GHG Problem would be continuing in the Background**

Three Key Solutions

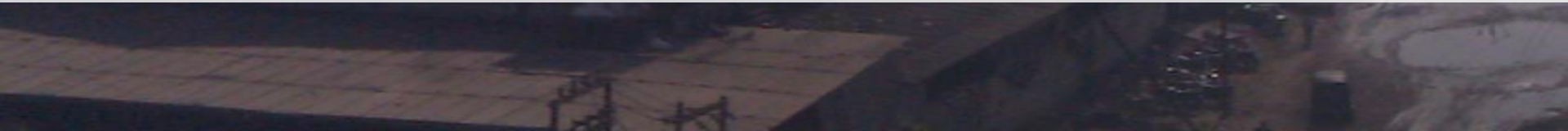
1. Price Energy at its Full Social Cost
2. Invest in Innovation
3. Identify Effective Policy Tools

Section 3

Case Study: Reducing Pollution in Gujarat

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.

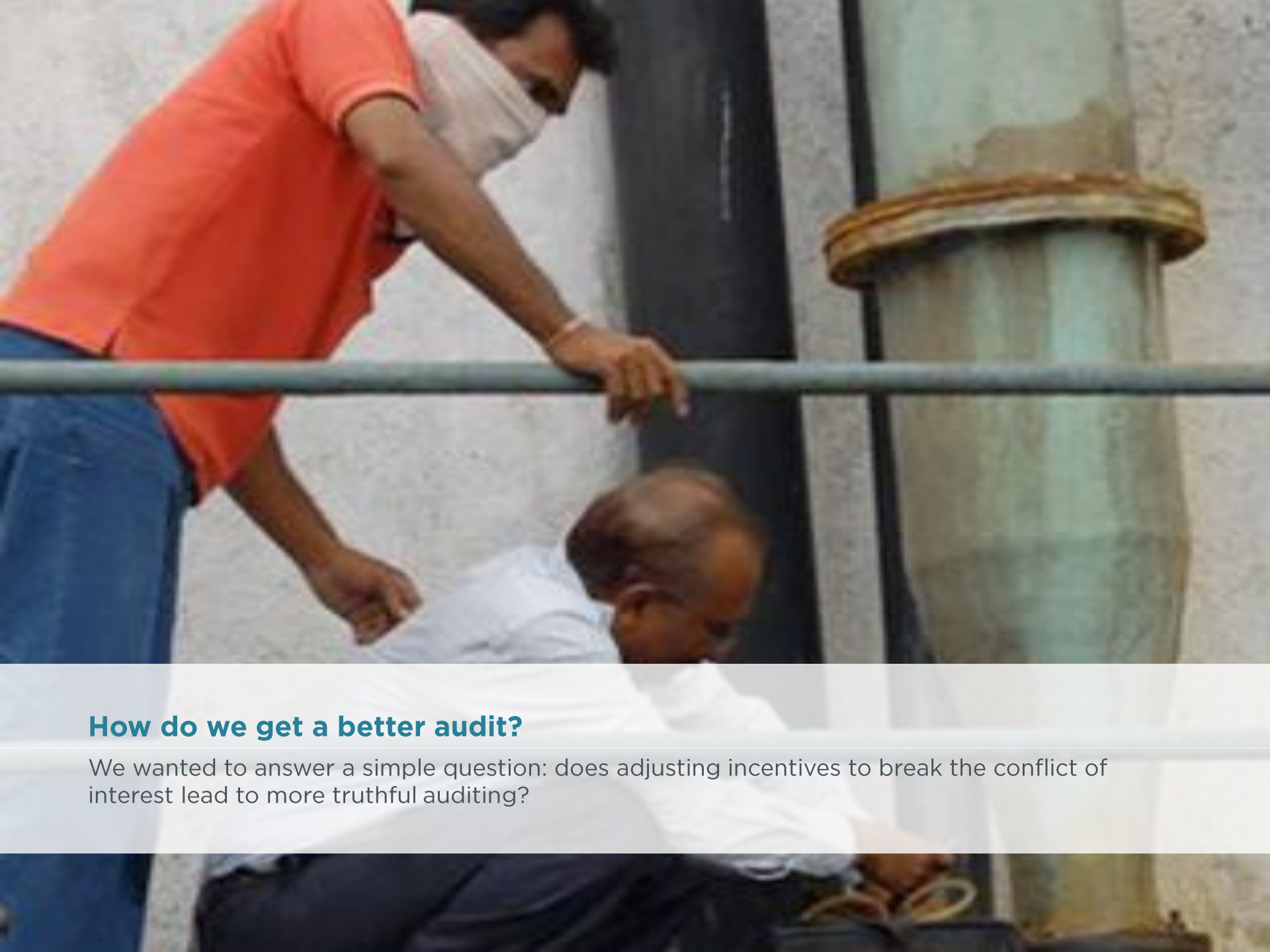


The Policy Status Quo

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

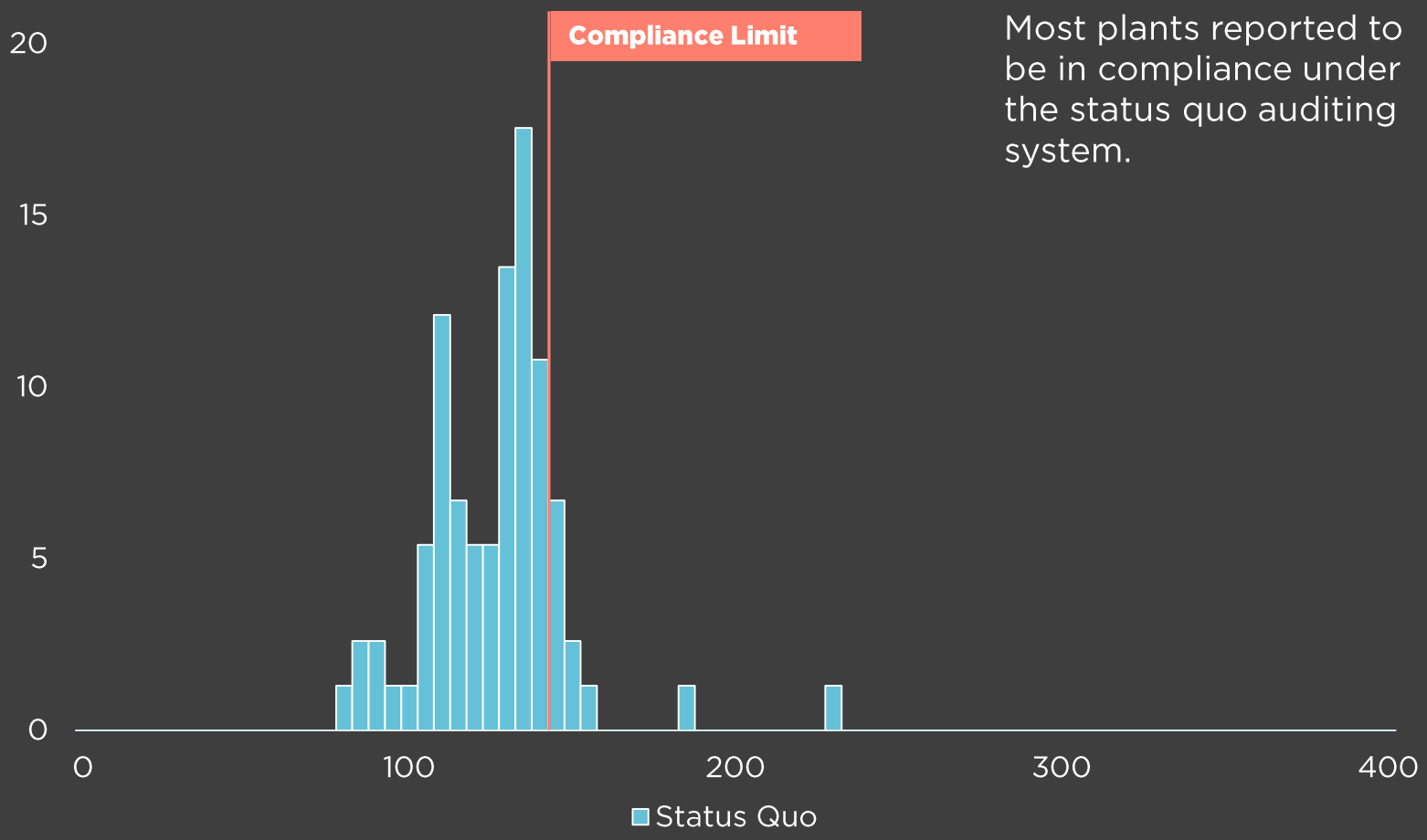


How do we get a better audit?

We wanted to answer a simple question: does adjusting incentives to break the conflict of interest lead to more truthful auditing?

Getting a Better Pollution Audit

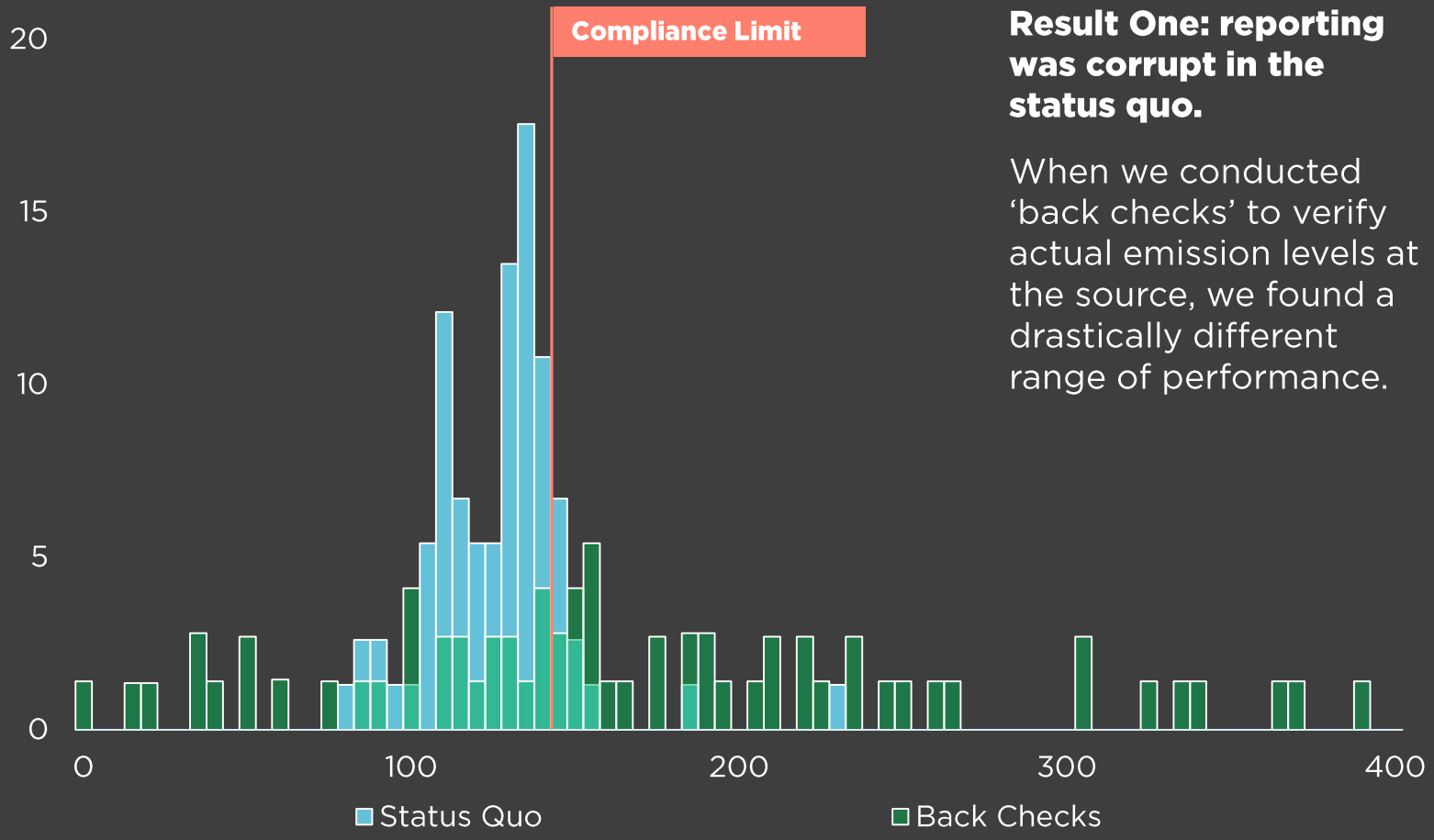
Audit Readings for Suspended Particulate Matter



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

Getting a Better Pollution Audit

Audit Readings for Suspended Particulate Matter

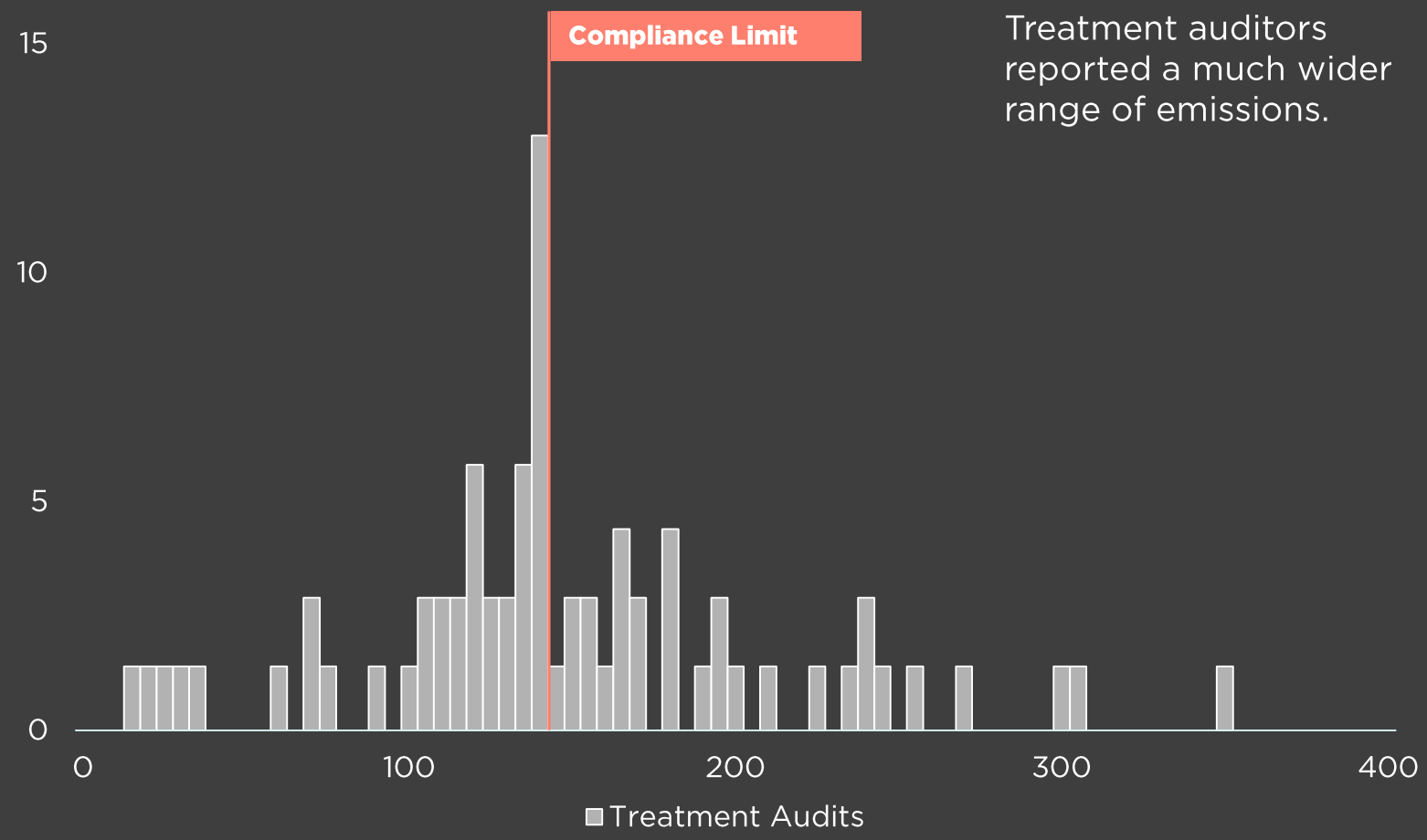


Result One: reporting was corrupt in the status quo.

When we conducted 'back checks' to verify actual emission levels at the source, we found a drastically different range of performance.

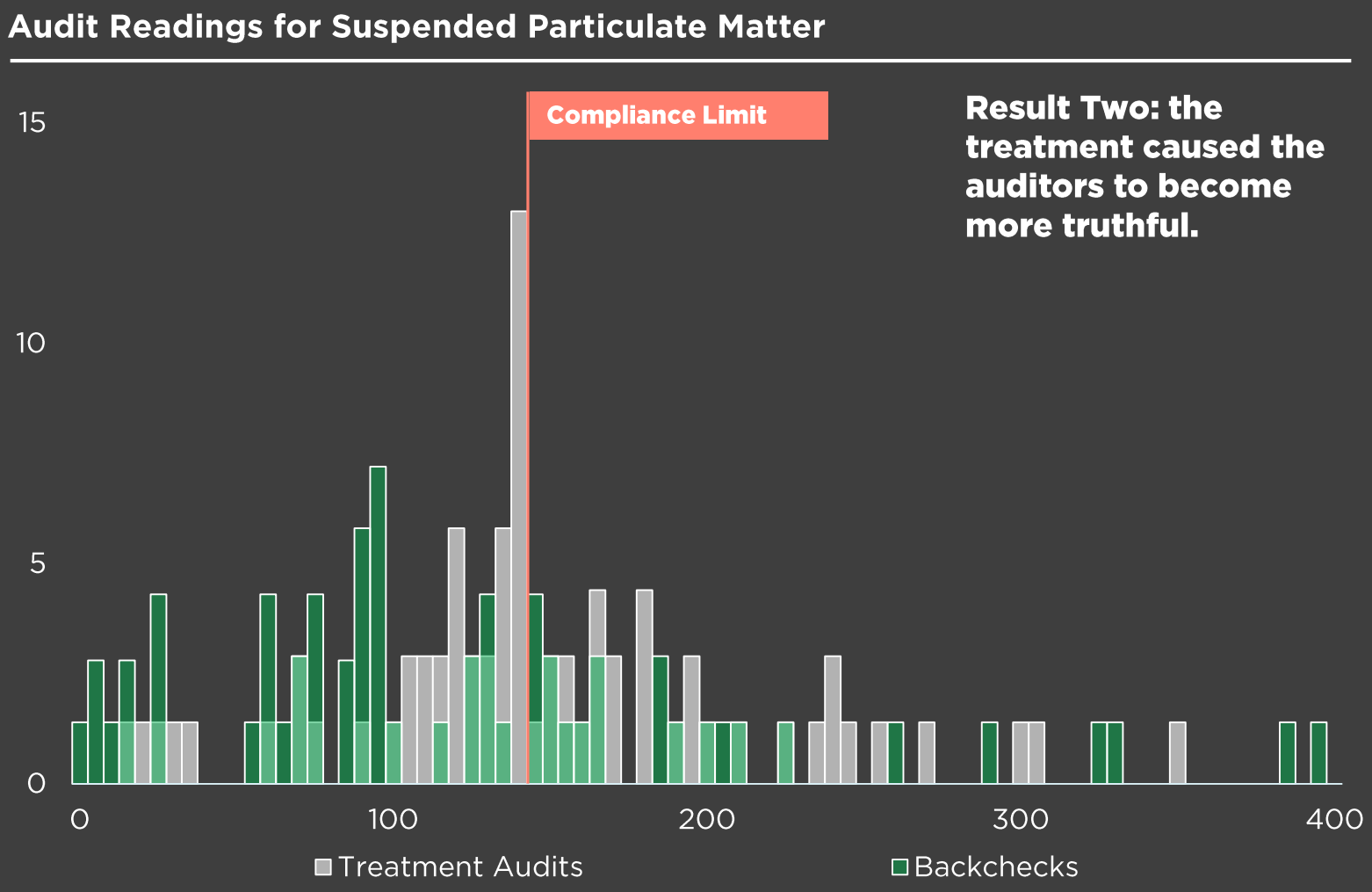
Getting a Better Pollution Audit

Audit Readings for Suspended Particulate Matter



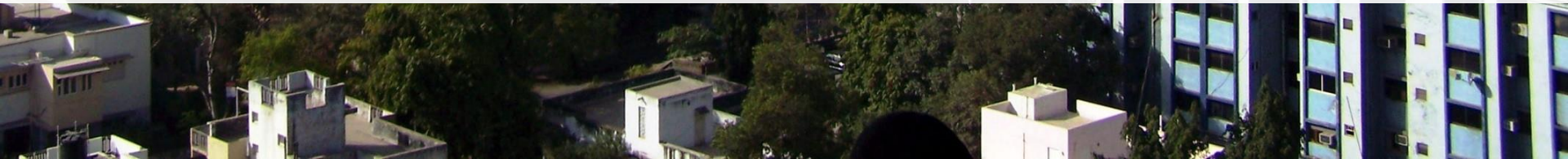
Treatment auditors reported a much wider range of emissions.

Getting a Better Pollution Audit



What happened to pollution?

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



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

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?