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# Markets Can Solve the Global Energy Challenge...if We Let Them

How prices, market design, and information can transform the global energy system

## Aspen Ideas Festival

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### Michael Greenstone

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University of Chicago

Director  
Becker-Friedman Institute

Director  
Energy Policy Institute at 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 human health at risk?

## Section 1

# Markets Can Solve the Global Energy Challenge... if We Let Them

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## 1. Increasing Energy Access

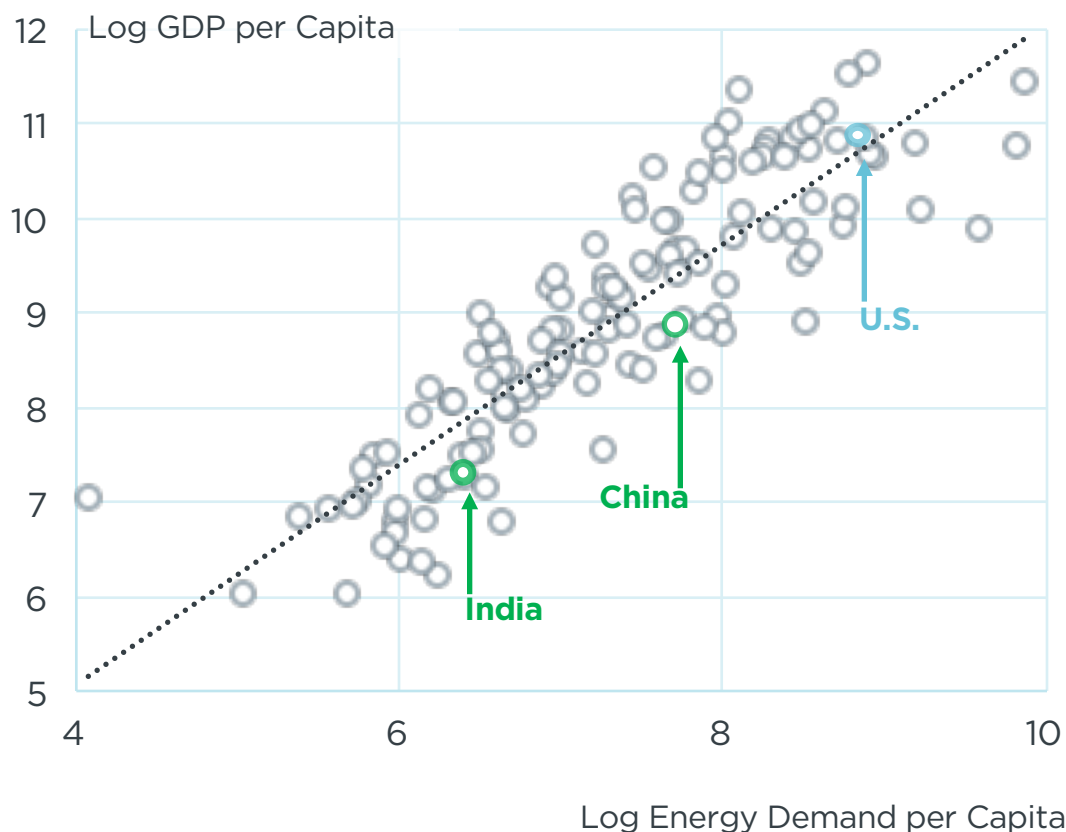


## **1 in 6 People Worldwide Lack Access to Reliable Electricity**

According to the International Energy Agency, nearly 1.2 billion people globally lack access to reliable electricity—300 million in India alone. As access to electricity grows, fossil fuels are expected to meet much of the increase in energy demand.

# Energy is Critical for Growth

## Primary Energy Demand & GDP per Capita (2013)



- › 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.

# Energy Access is a Major Problem

## Per Capita Electricity Consumption and Population

Country	Population (Millions)	kWh per Capita
U.S.	316	12,988
Germany	82	7,019
China	1,357	3,762
World	7,176	3,104
Brazil	204	2,529
India	1,279	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.

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# Investment is Flowing to Off-Grid Solutions

THE  
NEW YORKER

A REPORTER AT LARGE  
JUNE 26, 2017 ISSUE

## THE RACE TO SOLAR- POWER AFRICA

*American startups are  
competing to bring  
electricity to communities  
that remain off the grid.*

By Bill McKibben



- › Cumulative investments in off-grid solar technologies through the end of 2015 totaled \$511 million.
- › Between 2012 and 2015 investments grew by 15-fold, to \$276 million in 2015.
- › Over \$36 million of investments have come from grant funding.

*“Developing countries can leapfrog conventional options in favor of cleaner energy solutions, just as they leapfrogged land-line based phone technologies in favor of mobile networks.”*

**Ban Ki-Moon, then United Nations  
Secretary General, 2012**

Source: Investment totals from “Off-Grid Solar Market Trends Report 2016”, Lighting Global and Bloomberg New Energy Finance, February 2016.

## A Variety of Retail Sources Already Exist

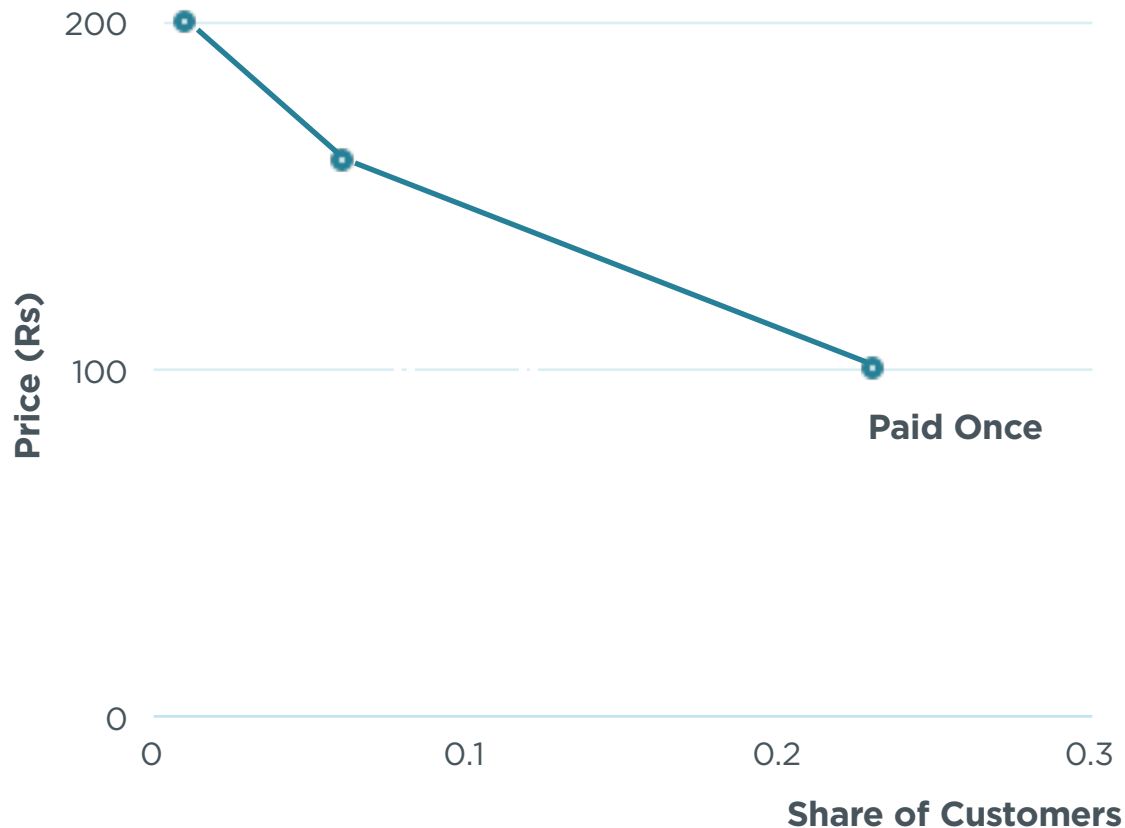
### Summary of Electricity Sources in Bihar



- › Off-grid options usually do not enter in a vacuum.
- › In Bihar, diesel is the big off-grid electricity source and the government is continually expanding grid access.

# Off-Grid Uptake Will Likely Be Limited

Mini-Grid Solar Demand Curve

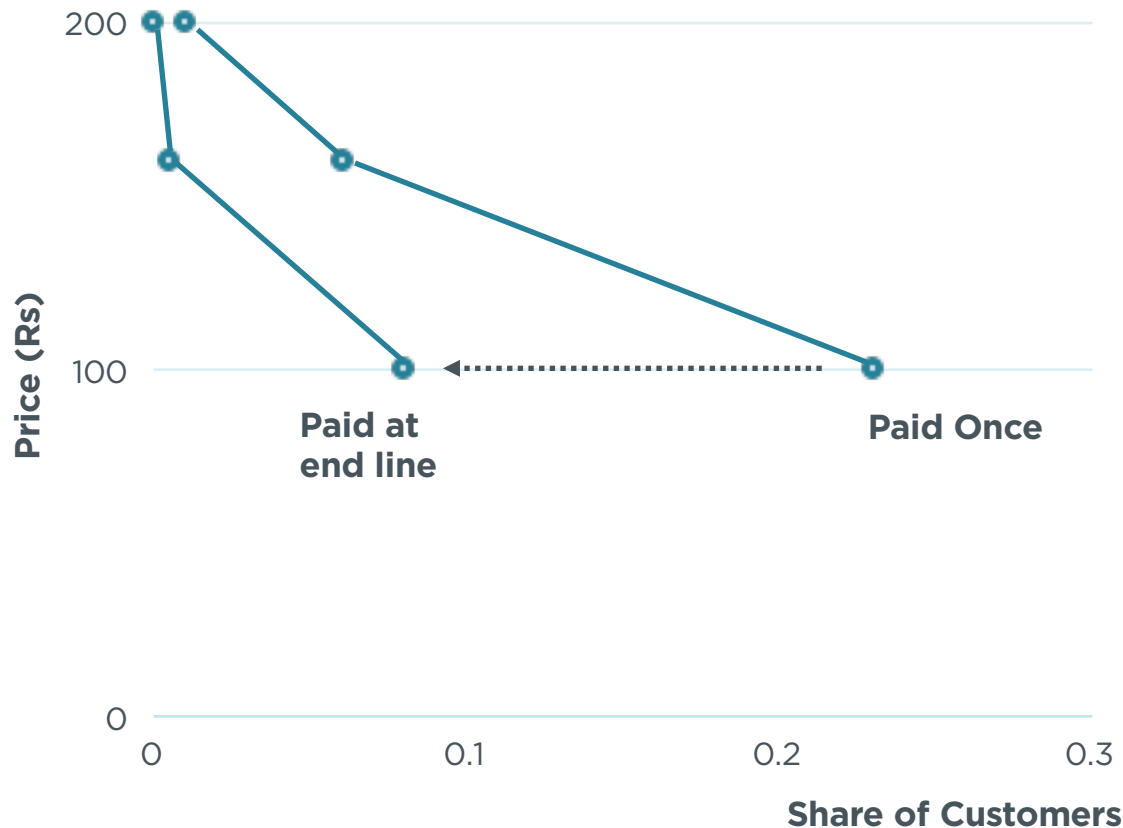


- › Results are from a randomized experiment in India, where villages were given access to mini-grid solar energy at various prices.
- › No evidence of significant effects on health and educational outcomes.
- › Even at subsidized prices, take-up fell dramatically over the 28 month time period.
- › Demand fell most in areas where grid was made available.

Source: Ryan et al. (2017)

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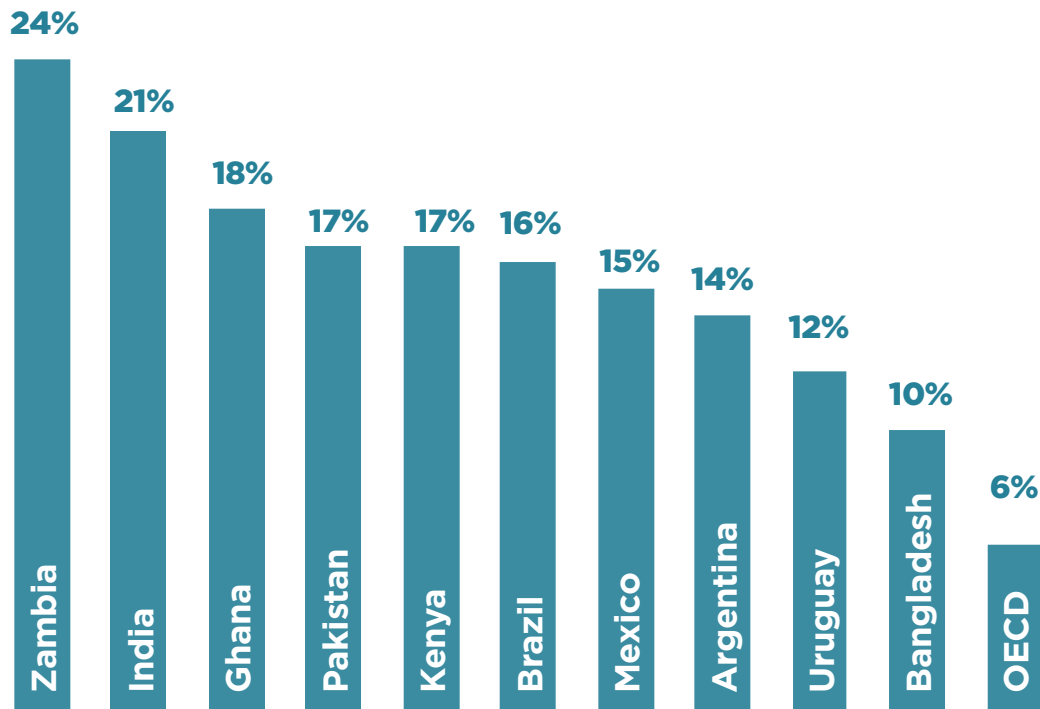
Source: Ryan et al. (2017)

# Should Energy be a Right?



# Many Countries Suffer High Line Loss Rates

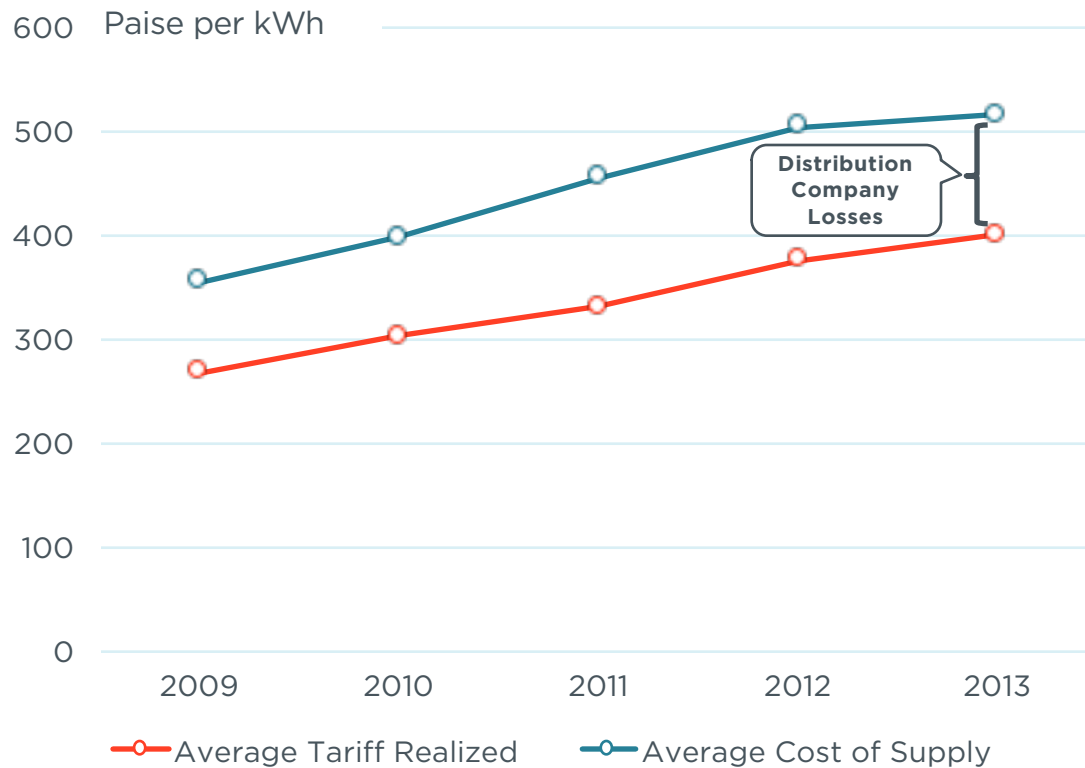
## Transmission and Distribution Losses by Country



- › Electricity is treated as a right in many countries.
- › Research suggests that about two-thirds of India's losses are non-technical or commercial losses.
- › Loss rate in Bihar is 46%.

# Challenging Economics

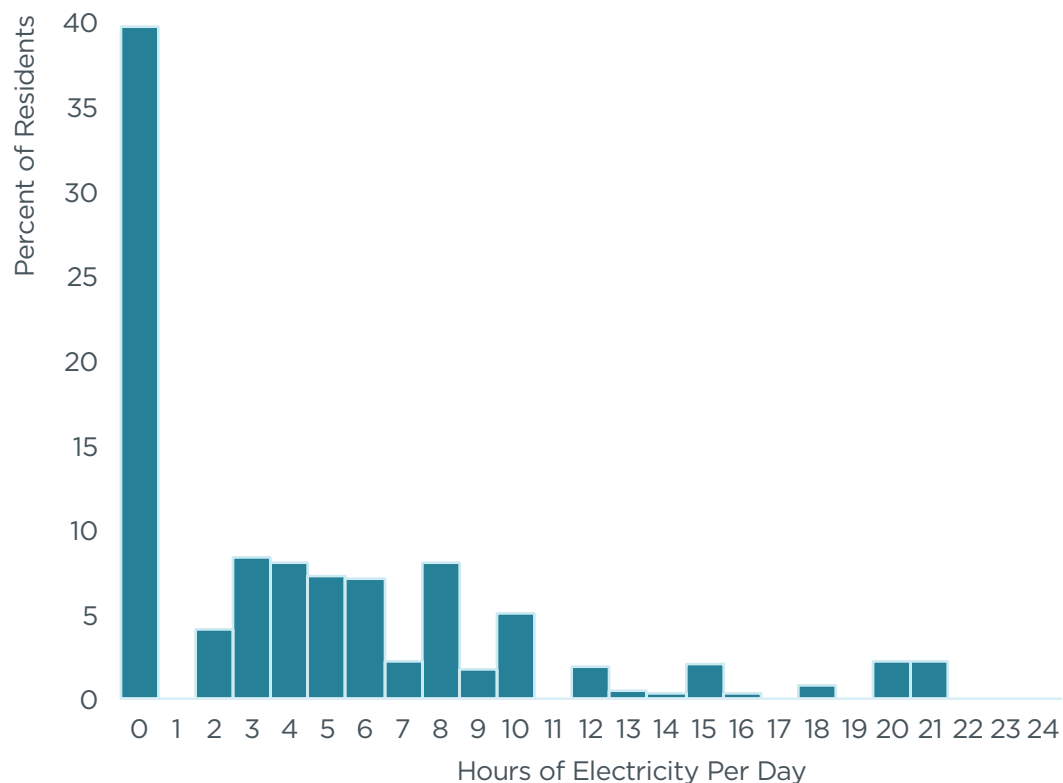
## Cost of Supply versus Revenue in India



- › Utilities in India make a loss on every unit of electricity sold.
- › **This results in financially distressed distribution utilities.**

# DISCOMs Ration Power to Stay Solvent

## Distribution of Daily Electricity Supply in Bihar



- › Only 26% of rural Bihar households used electricity as a primary source of lighting in 2012.
- › Rationing means feeders are turned off and electricity isn't available at any price; not necessarily a shortage of generation.

## An Experiment to Change the Social Norm that Electricity is a Right

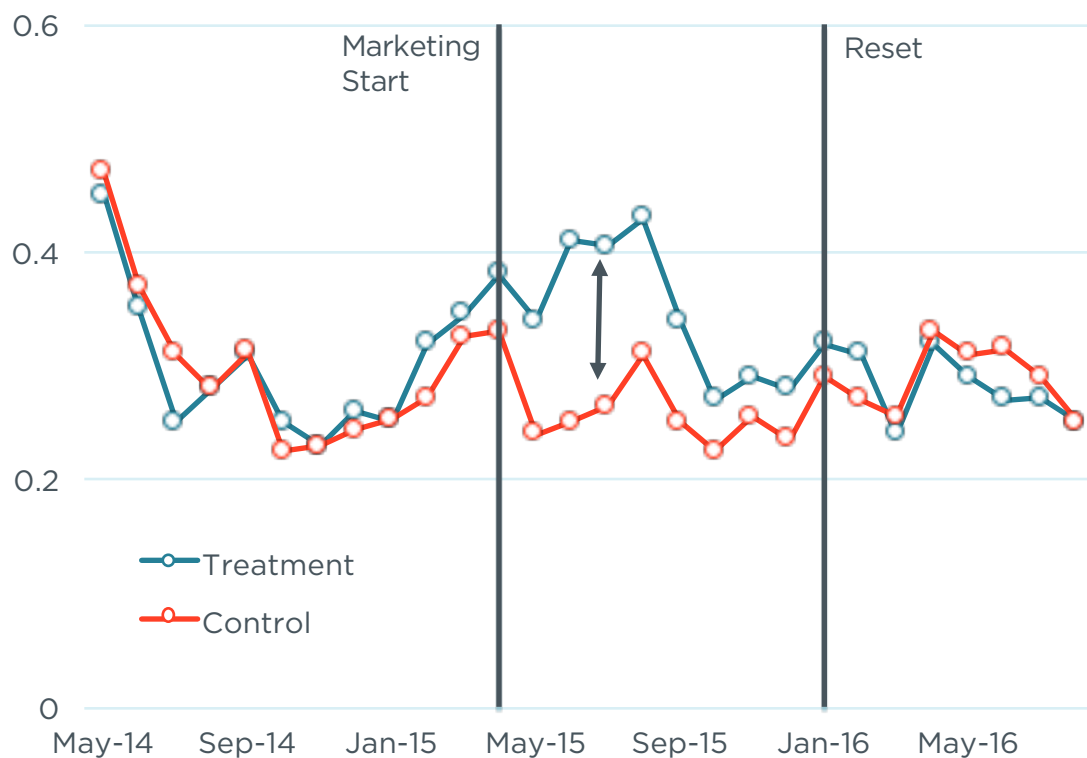
- 1) **Project to rapidly and cost-effectively increase electricity access in one of India's poorest states**
  - > 100 million people with enough electricity on average to use one light bulb for six hours per day
- 2) **Our sample includes a total of 400 electricity system feeders, covers a population of 28 million people**
  - > Experimental design focuses on breaking the expectation that electricity is a right
  - > Bill inserts to 570,000 consumers
  - > 30,000 SMS messages sent every month



*“Pay bills on time, get high electricity supply. People of my area paid their electricity bills on time, leading to more supply here and helped me gain profits in my business.”*

# Revenue Rate Increased by 40% per Feeder

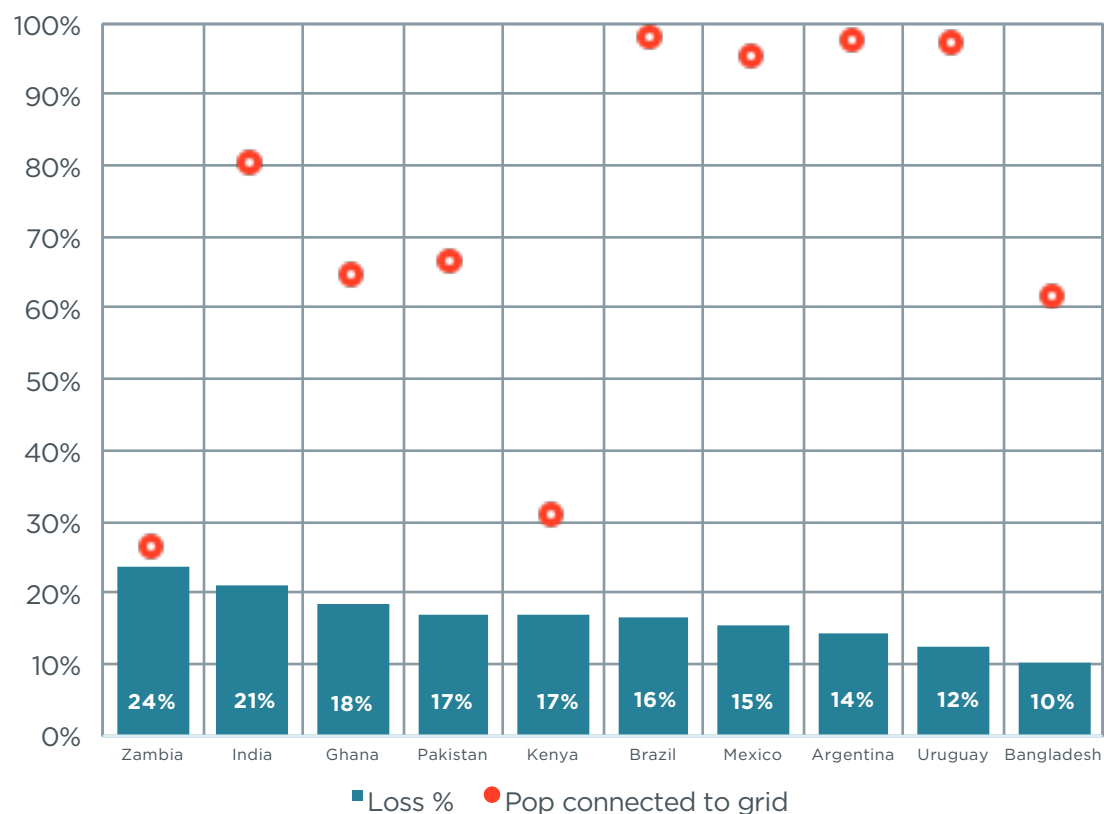
## Treatment and Control Feeder Revenue Rate



- › Revenue per feeder increased by Rs 400,000 (approx. \$6,250 USD).
- › This allows utilities to purchase up to an additional 67,000 kWh per feeder.
- › **Scaling up throughout all of Bihar would lead to additional revenue to purchase 300 GW, or 10% of current supply.**

## Major Opportunities Beyond Bihar

Percent of Population Connected to the Grid  
In Countries With High Transmission Losses



› More than 1.7 billion people are connected to the grid in countries with transmission and distribution losses greater than 10%.

## Section 2

# Markets Can Solve the Global Energy Challenge... if We Let Them

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1. Increasing Energy Access
2. Protecting Health from Pollution Related to Energy Consumption

A photograph of two young boys in a heavily polluted urban environment. They are both wearing white cloth masks over their mouths and noses. The boy on the left is wearing a colorful, patterned shirt, while the boy on the right is wearing a striped shirt. The background is a hazy, smoggy street with blurred traffic lights and buildings, suggesting a city like Delhi. The overall tone is somber and highlights the health impacts of air pollution.

## **What are the health and pollution consequences of continued reliance on fossil fuels?**

The International Energy Agency expects fossil fuels to supply 74 percent of the world's primary energy demand in 2040, compared to 81 percent in 2014.

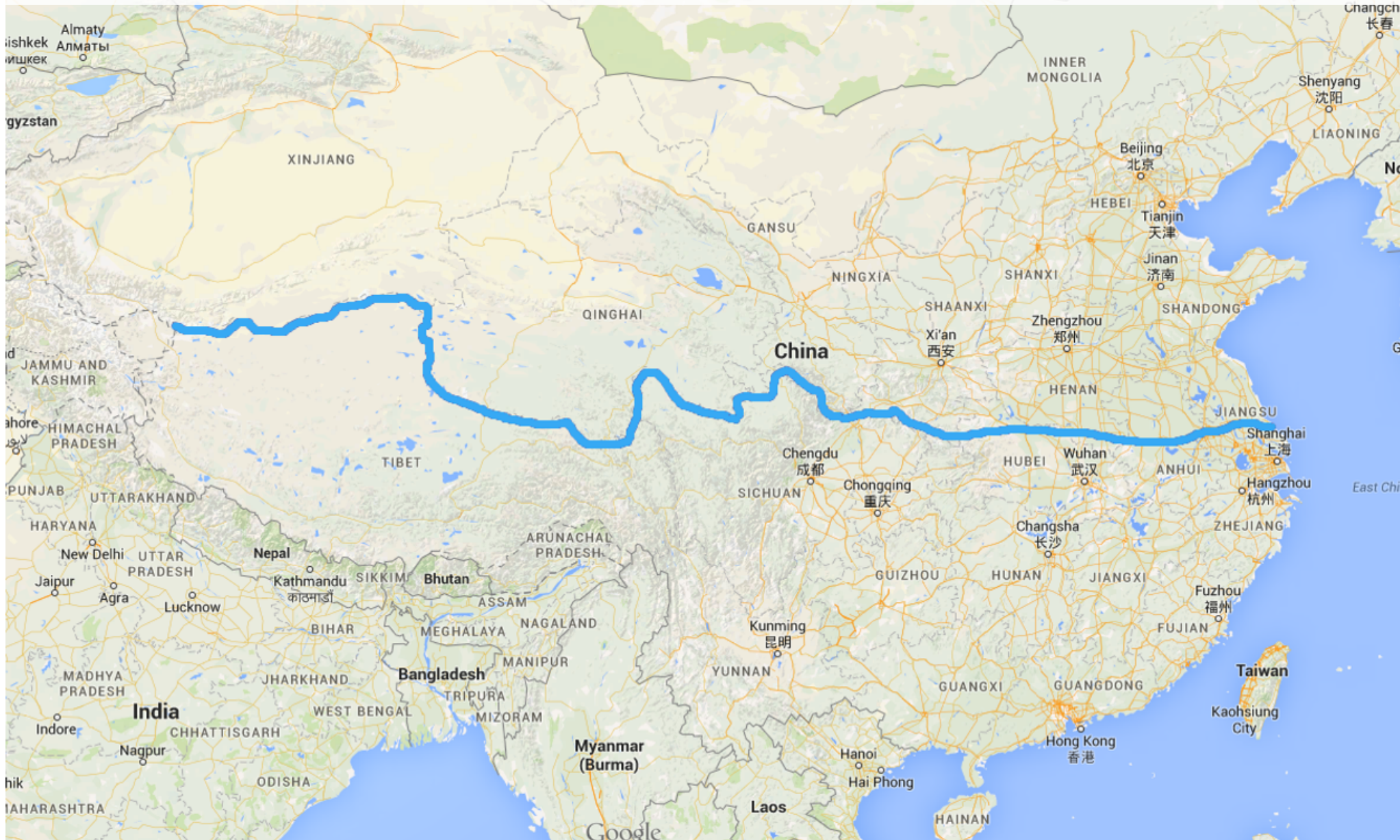
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# China's Huai River Winter Heating Policy

- 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

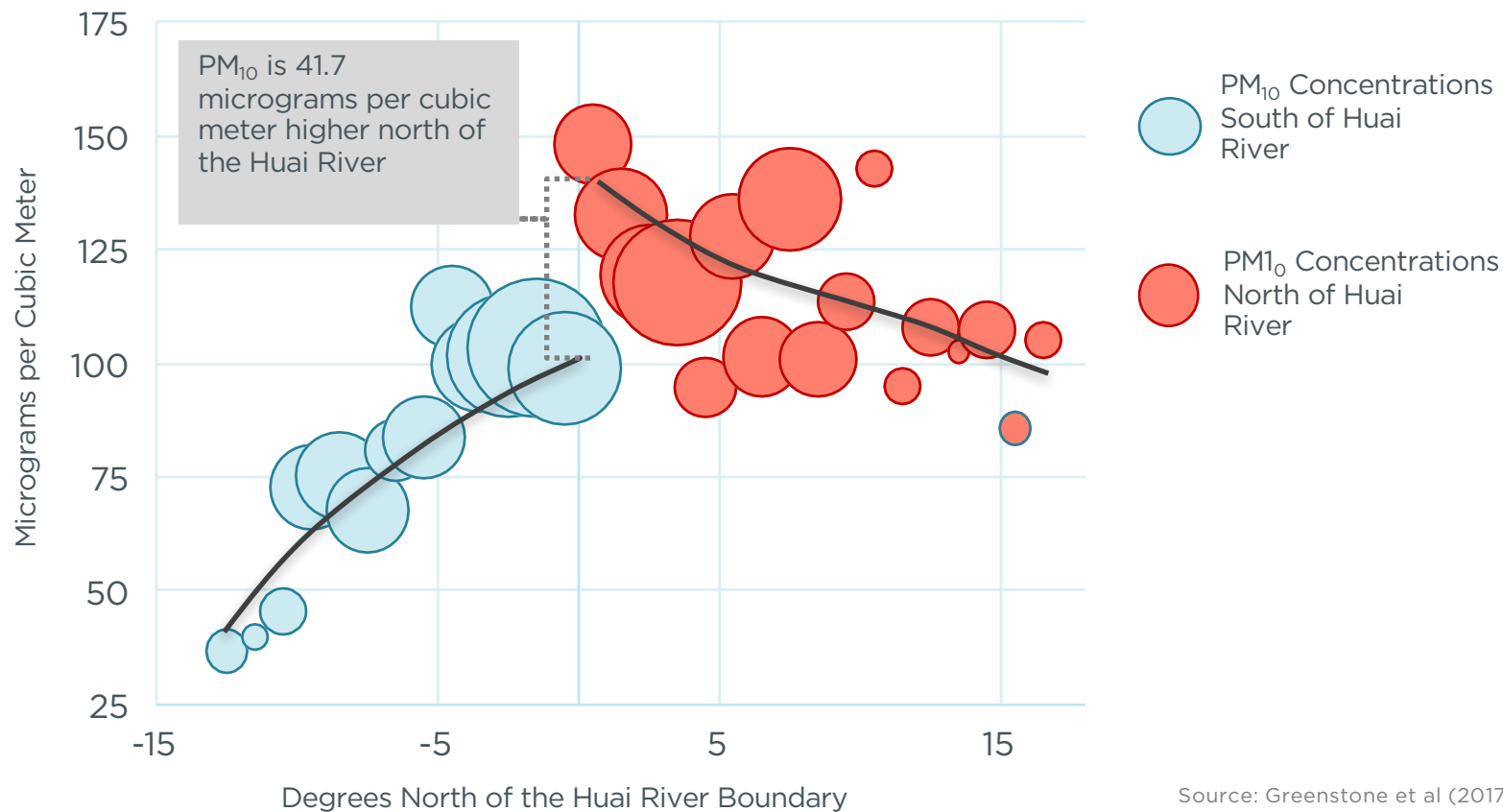
## The Dividing Line

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.



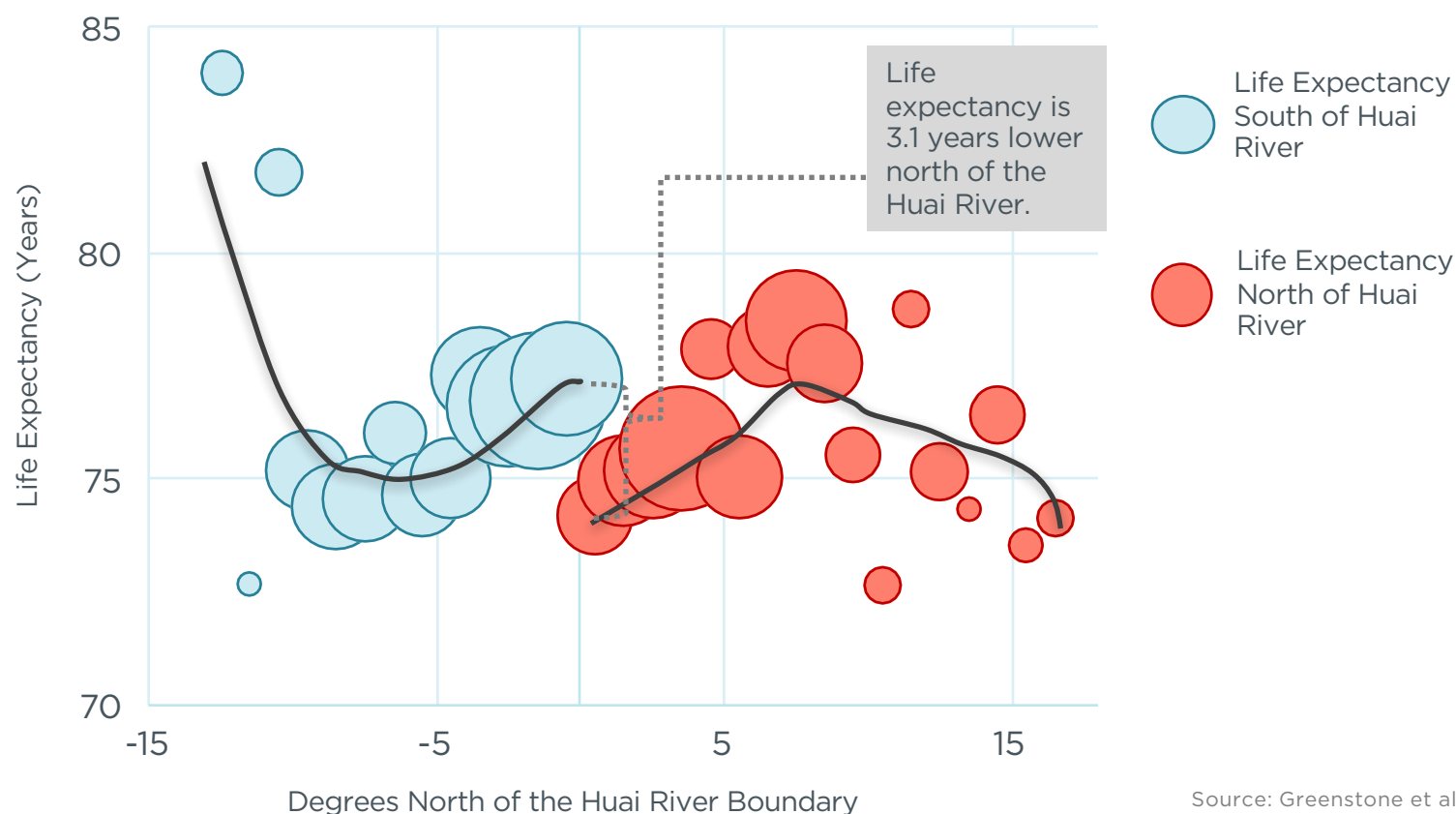
# Pollution is 50% Higher North of the River

## PM<sub>10</sub> Emissions North and South of the Huai River



# Life Expectancy is about 3 Years Lower

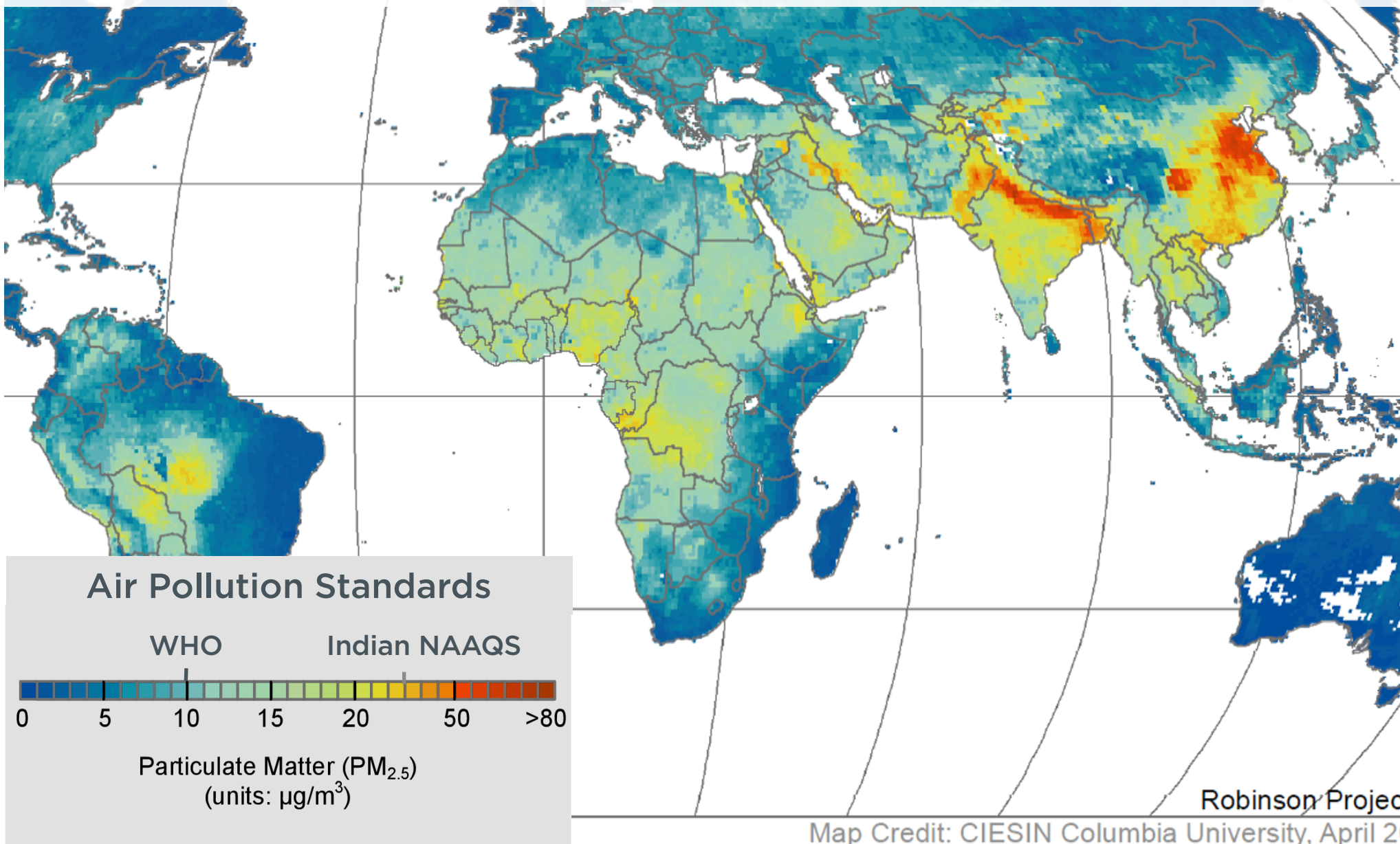
## Life Expectancy North and South of the Huai River



Source: Greenstone et al (2017)

## Global Concentrations of PM<sub>2.5</sub>

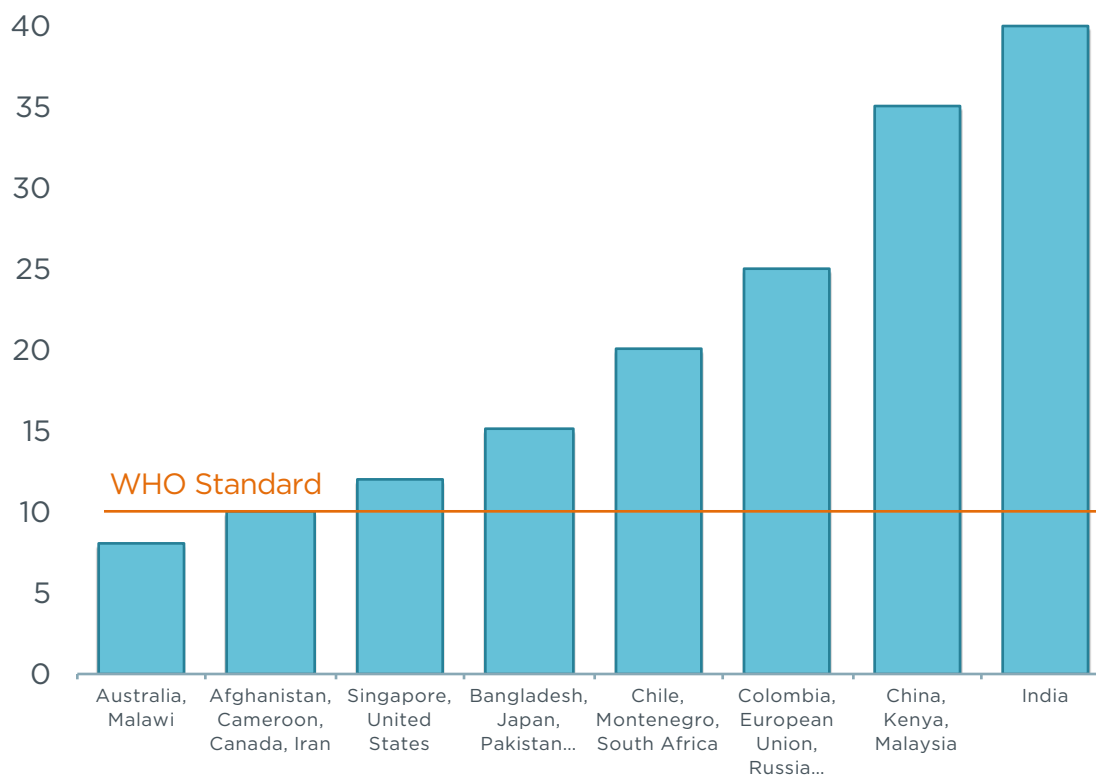
High concentrations of fine particulate matter have caused the loss of 2.1 billion life years in India and 2.5 billion in N. China.



# Nations Implement Standards in Response

## Annual PM<sub>2.5</sub> Standards for Select Countries

45 Micrograms per Cubic Meter

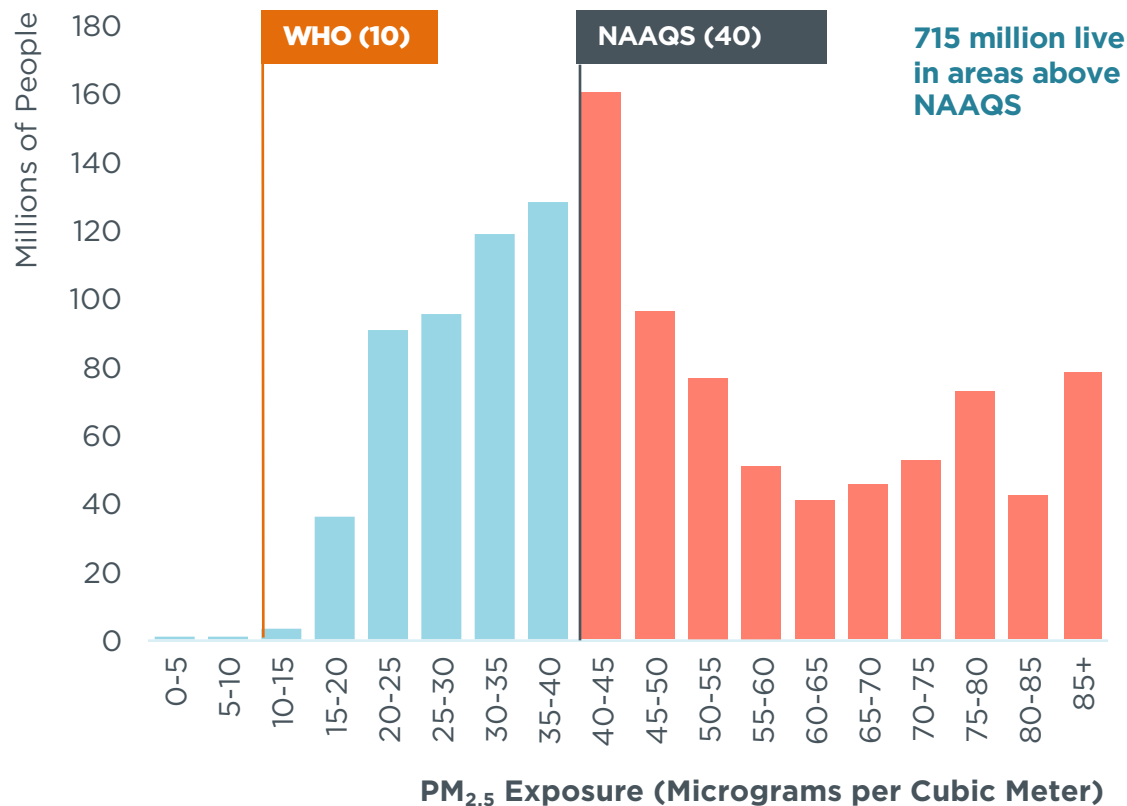


- › The conventional solution is to establish National Air Quality Standards.
- › 80+ countries have PM<sub>2.5</sub> standards. These standards are inconsistent around the world and determined arbitrarily.
- › Only 6 countries have a PM<sub>2.5</sub> standard at or below the WHO standard.

Source: National standards from Joss et al (2017)

## But Often Lack Enforcement Tools

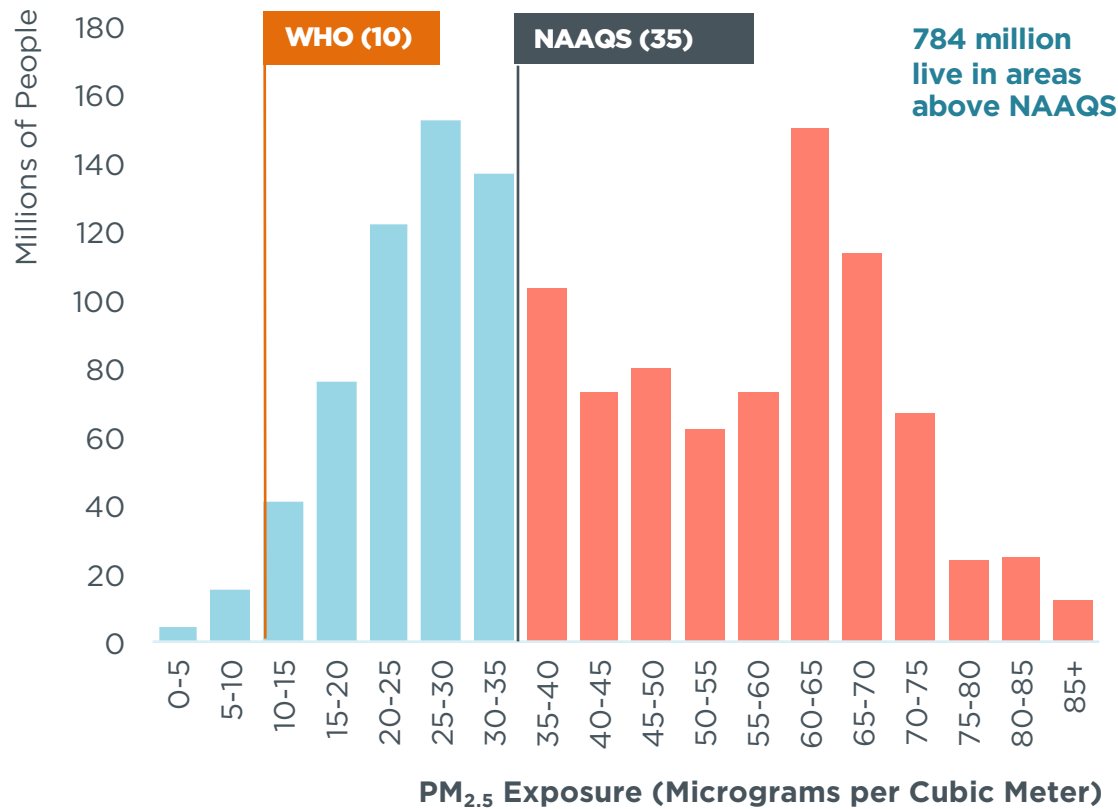
### India: Population by Ambient PM<sub>2.5</sub> Exposure



Source: EPIC analysis using LandScan Global Population Database and PM<sub>2.5</sub> Data from the Atmospheric Composition Analysis Group

## But Often Lack Enforcement Tools

### China: Population by Ambient PM<sub>2.5</sub> Exposure



Source: EPIC analysis using LandScan Global Population Database and PM<sub>2.5</sub> Data from the Atmospheric Composition Analysis Group

## Non-Compliance With Environmental Standards Is Common Practice



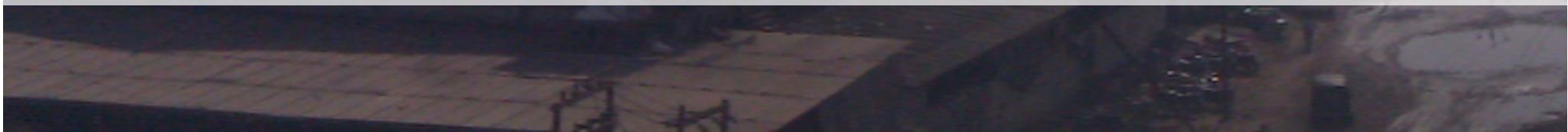
- 1) **In early 2017, China's Ministry of Environmental Protection examined whether businesses were meeting environmental standards for controlling pollution**
  - > Inspected 20,000 businesses across 28 cities in northern China
  
- 2) **Inspectors found that nearly 70% of these businesses failed to 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.



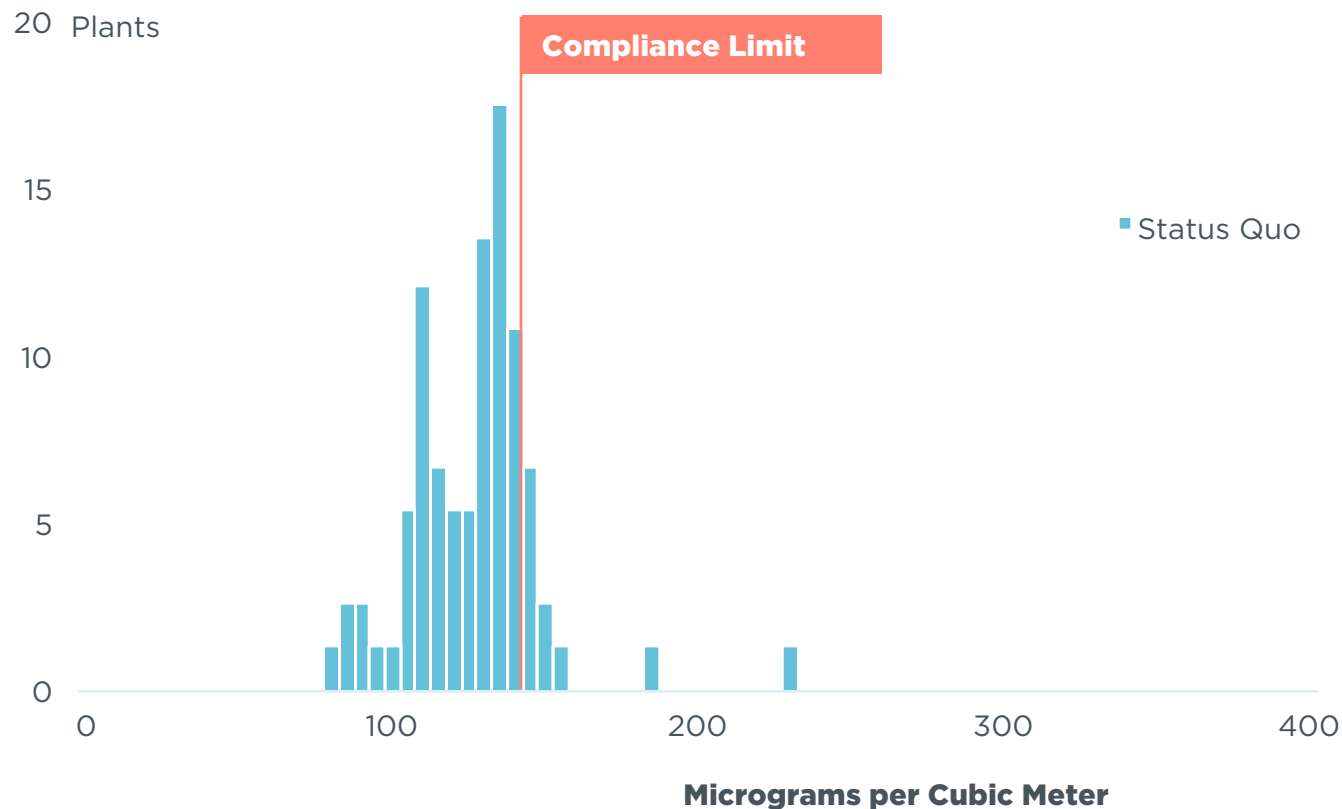
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## The Policy Status Quo

- 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

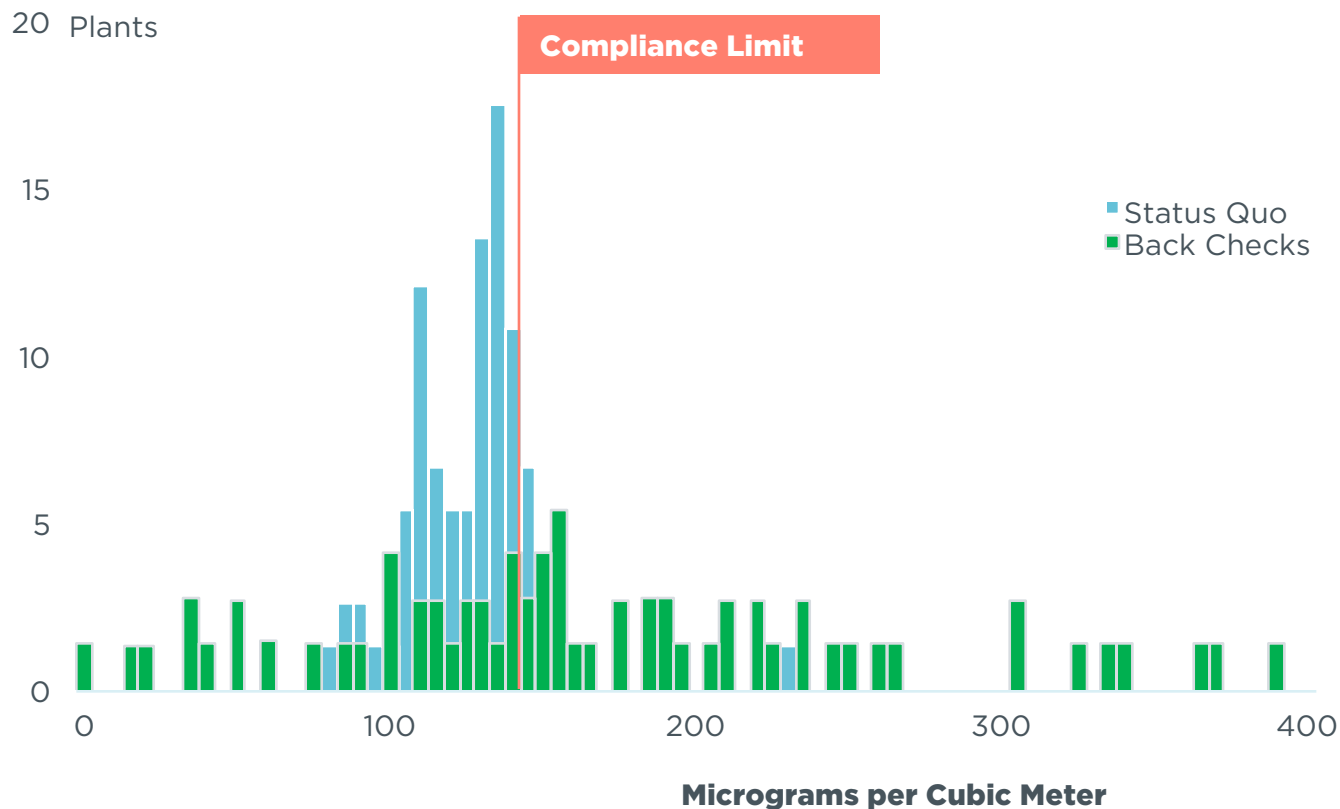
## Audit Readings for Suspended Particulate Matter



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

# Getting a Better Pollution Audit

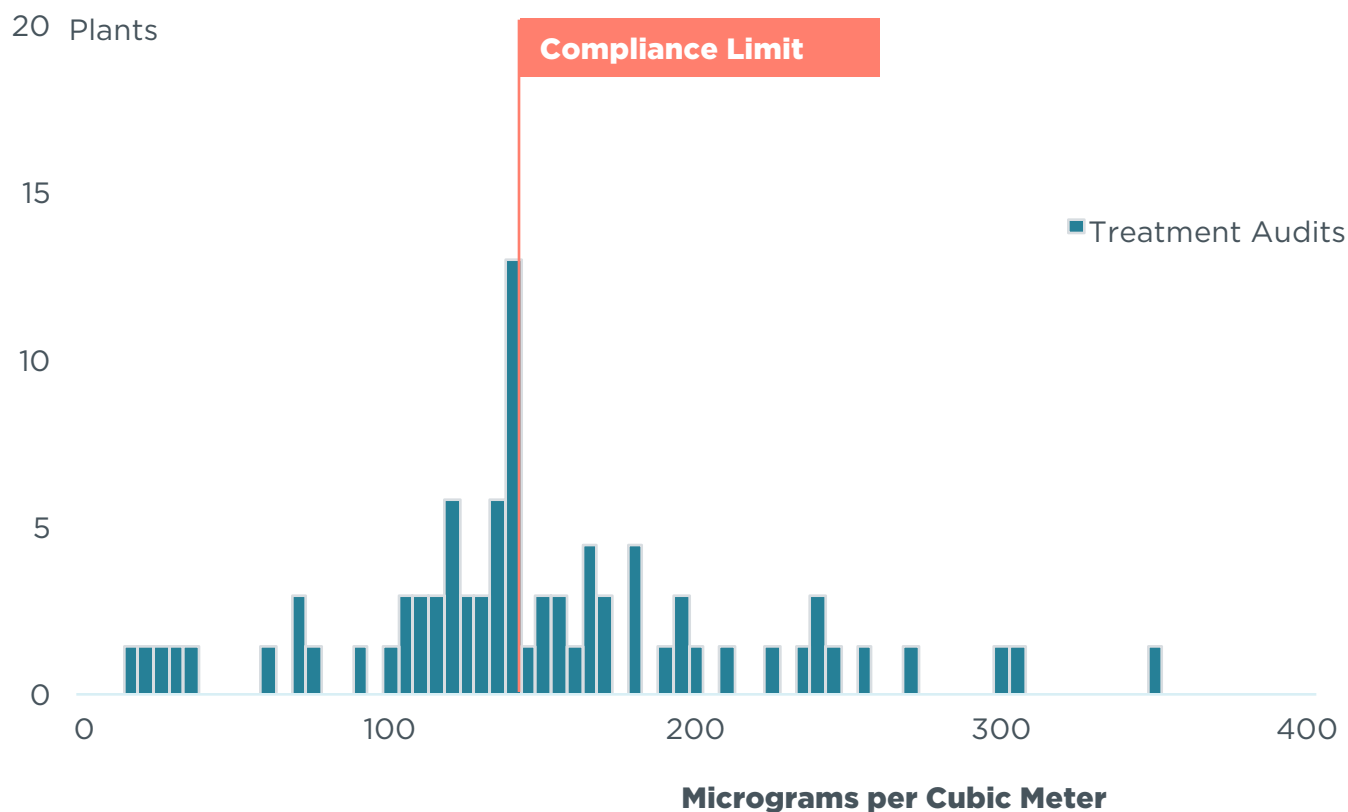
## Audit Readings for Suspended Particulate Matter



- › **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

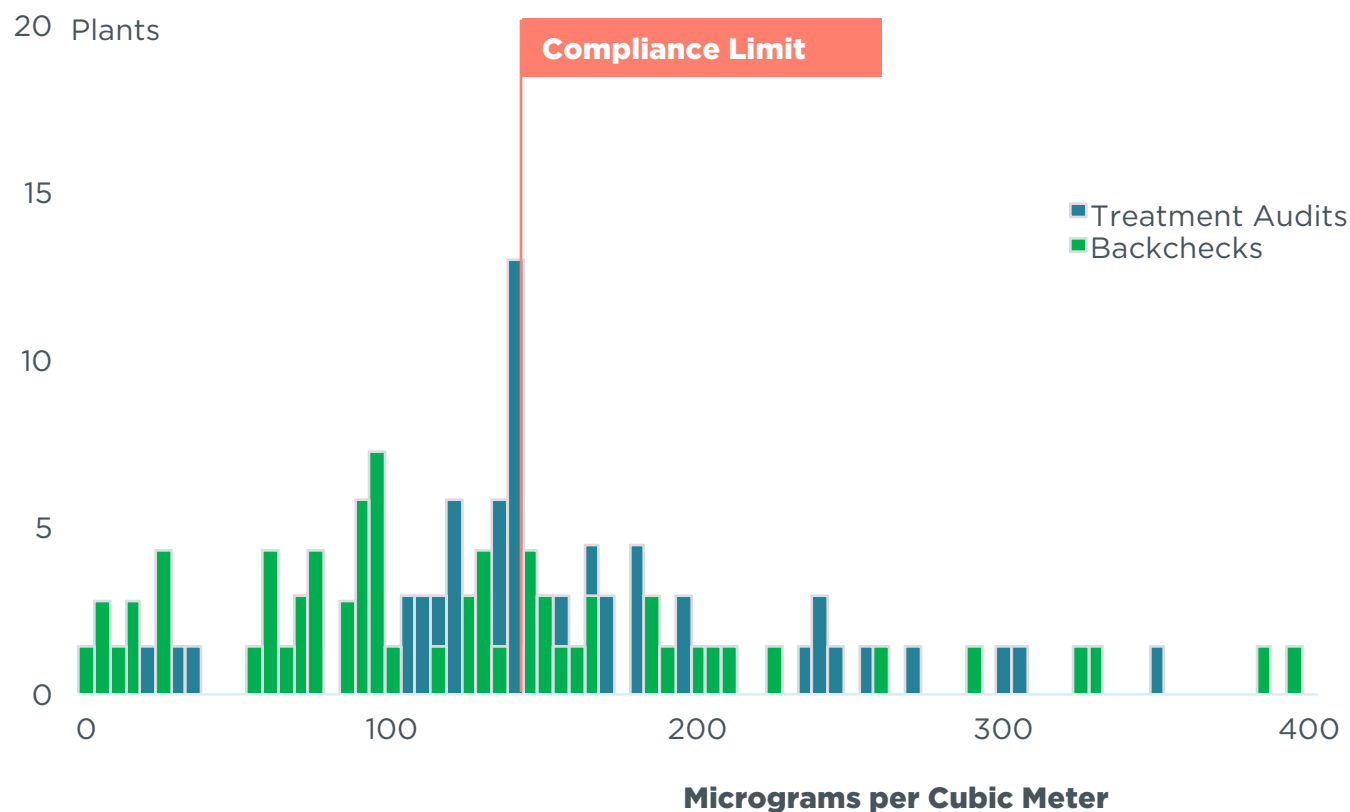
## Audit Readings for Suspended Particulate Matter



- › Treatment auditors reported a much wider range of emissions.

# Getting a Better Pollution Audit

## Audit Readings for Suspended Particulate Matter

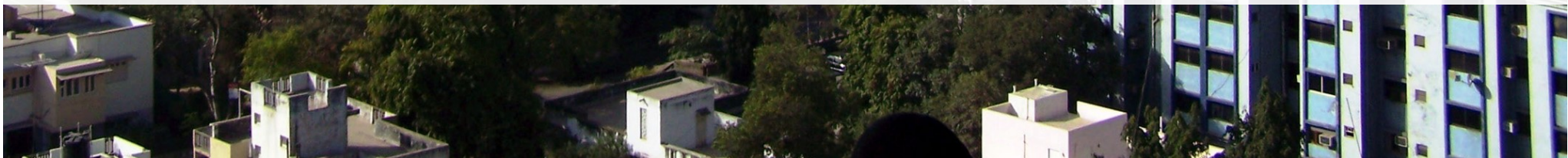


› **Result Two: the treatment caused the auditors to become more truthful.**



## **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**

### Section 3

## **Markets Can Solve the Global Energy Challenge... if We Let Them**

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1. Increasing Energy Access
2. Protecting Health from Pollution Related to Energy Consumption
3. Preventing Disruptive Climate Change



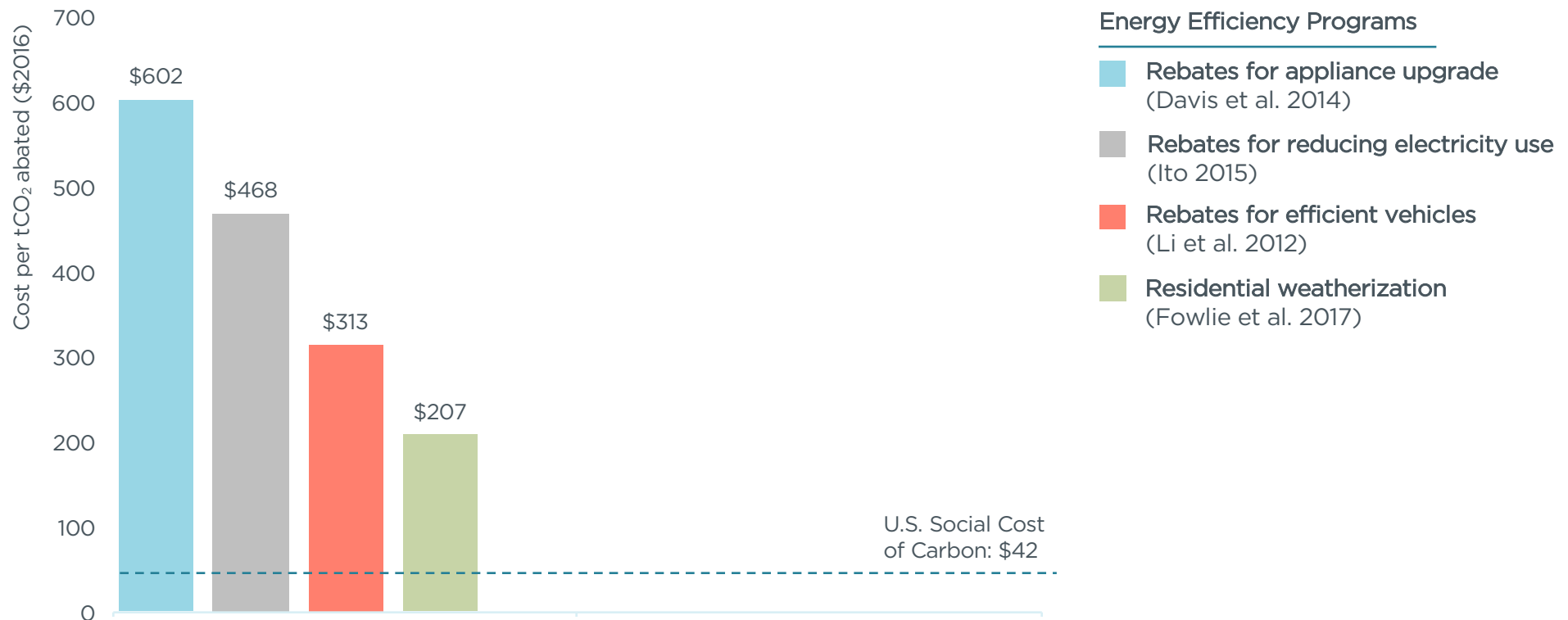
## **What are the costs of this? And how should policy reflect them?**

Climate policy faces a key challenges today: lawmakers do not know how to value the vast amounts of carbon pollution being pumped into the atmosphere, leaving policy around the world inconsistent and ineffective.



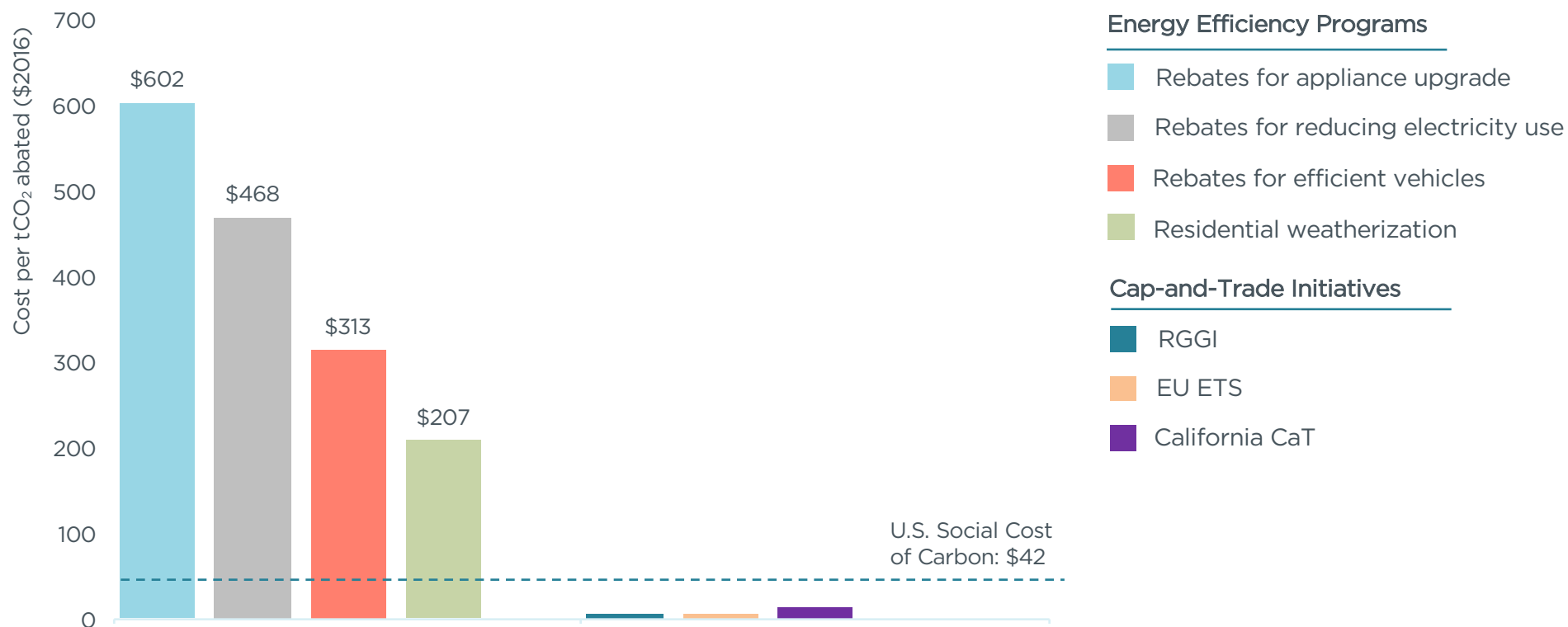
# Large Variation in Cost Effectiveness of Energy Efficiency Programs

Cost Effectiveness of Programs that Abated Carbon Emissions



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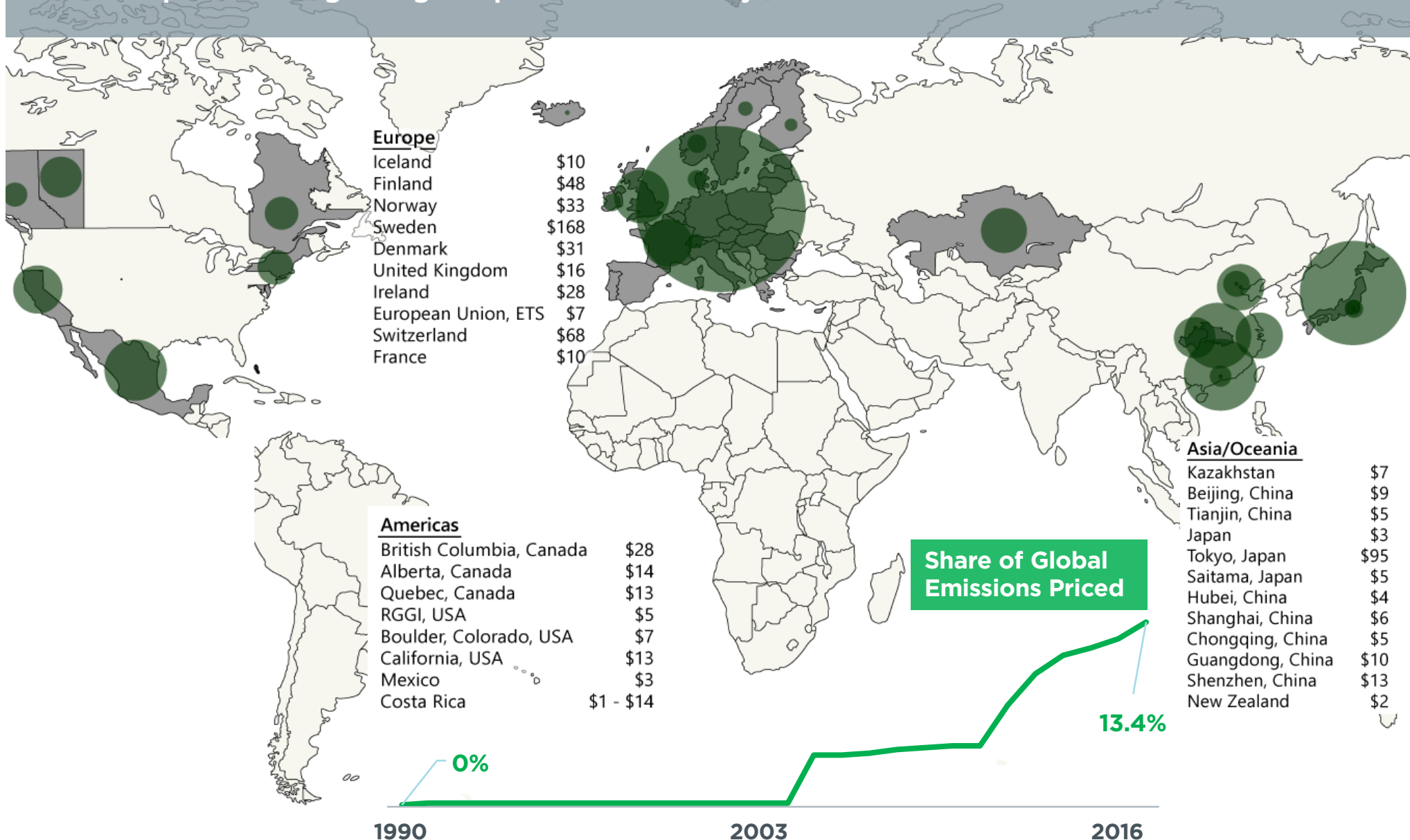
## Cost Effectiveness of Programs that Abated Carbon Emissions



Source: Cap-and-trade prices from World Bank as of August 1, 2016.

## Global Carbon Pricing is Expanding but Highly Inconsistent

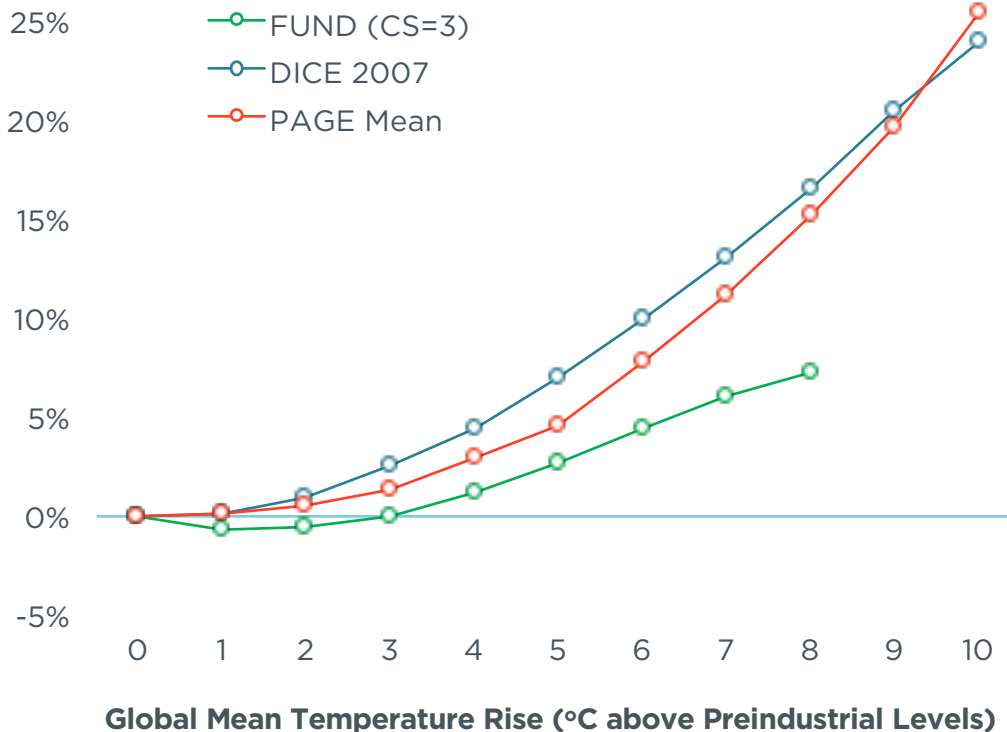
The number of countries that have implemented some form of carbon pricing has grown rapidly in recent years. In 2003, almost no global emissions were priced. Today, the share is 13.4 percent and growing. Yet prices are extremely inconsistent.



# How We Measure Damages Today

## Climate Damages

30% Share of Global GDP



- › “The assumptions built into the economic modeling on growth, damages and risks, come close to assuming directly that the impacts and costs will be modest.”
- › “A new generation of models is needed in all three of climate science, impact and economics.”

-N. Stern, JEL 2013

## A Better Approach to Measurement



**Climate  
Impact Lab**

### **A New Way of Thinking about Measuring Climate Damages**

1. Based on observations of real world relationships between climate and human well-being
2. Highly localized to capture nonlinearities

### **Measurements of Climate Impacts**

<b>Mortality:</b>	Heat and cold deaths
<b>Agriculture:</b>	Crop yields for seven major crops
<b>Energy:</b>	Energy and electricity demand
<b>Labor:</b>	Labor supply effects
<b>Conflict:</b>	Large-scale violent conflict
<b>Crime:</b>	Interpersonal violent crime
<b>Migration:</b>	International and within-country
<b>Coastal:</b>	Sea level rise and storm damages

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# A More Realistic View of the World

DICE (1992): One Global Region

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# A More Realistic View of the World

FUND (1996): 16 Global Regions

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# A More Realistic View of the World

Climate Impact Lab (2017): 25,000 Global Regions

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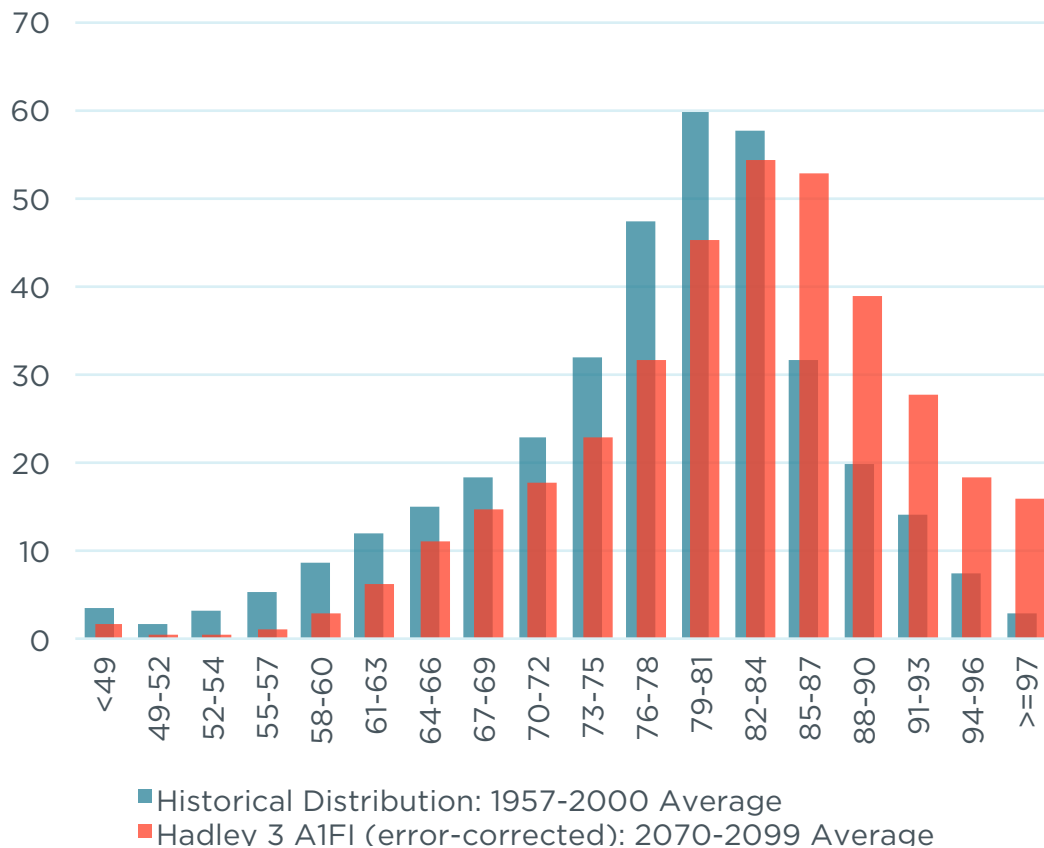
## Case Study: Mortality

Health costs will undoubtedly be one of the largest impacts of a warming world. In particular, mortality due to an increase in hot days will likely increase. But how much will costs increase and where? And what is the role of adaptation?



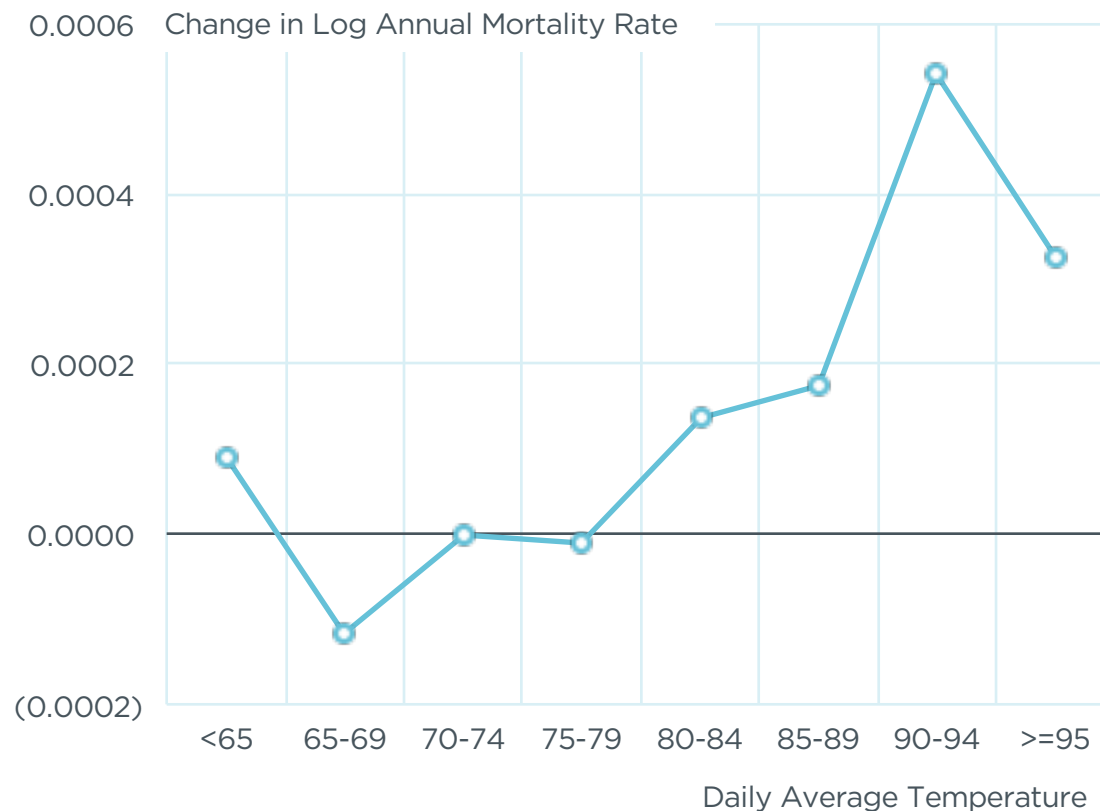
# The World is Expected to Get Hotter

Distribution of Average Temperatures in India



# Impacts to the US are Minimal

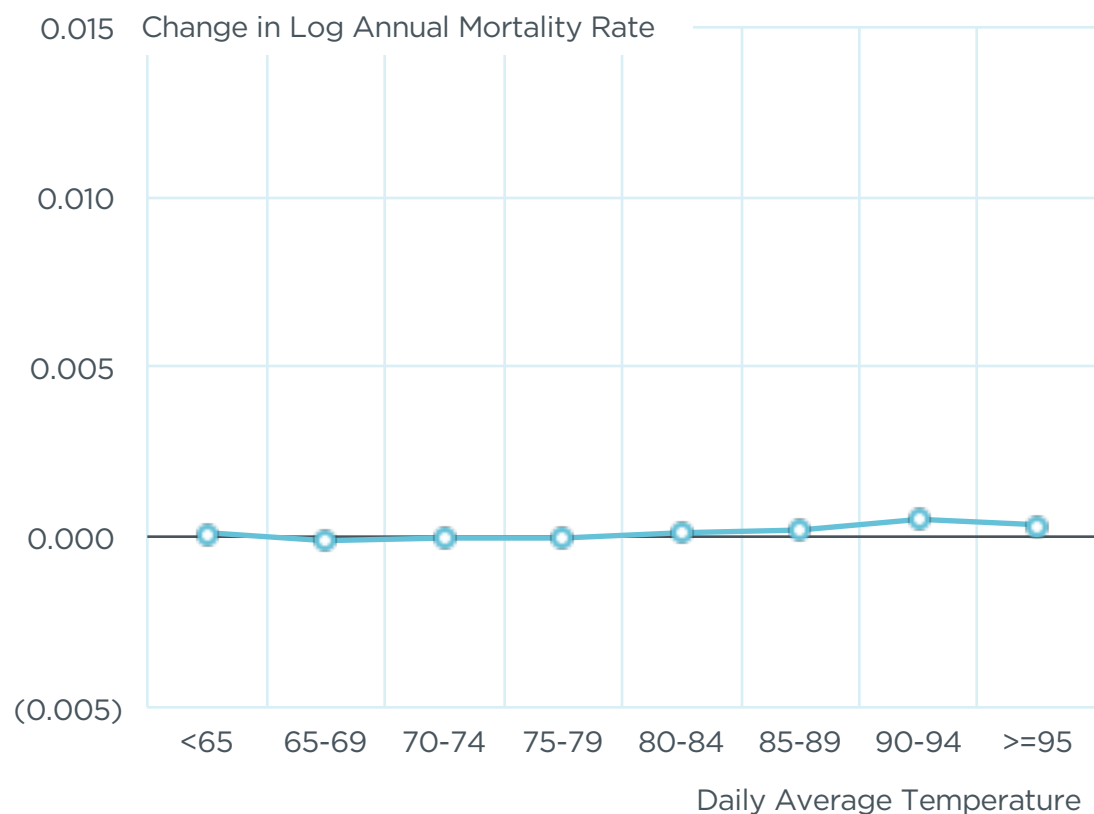
## Estimated Impact of Temperature on Mortality



- › 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

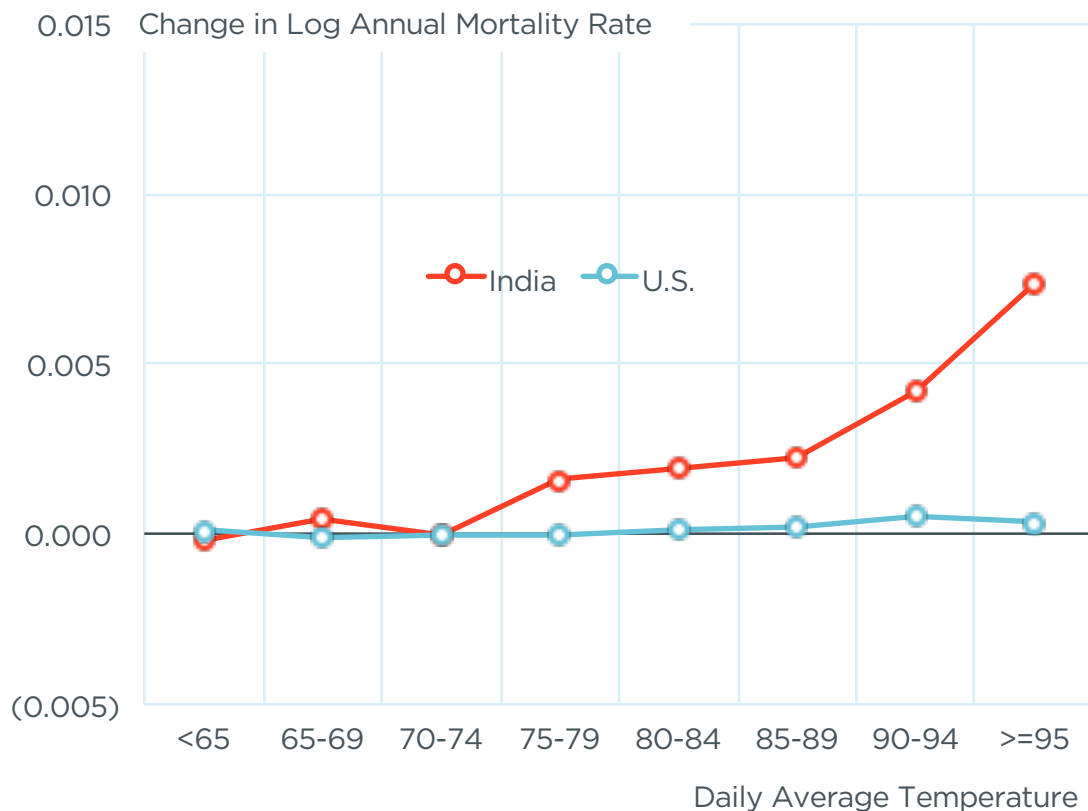
## Estimated Impact of Temperature on Mortality



- › 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 the US are Minimal

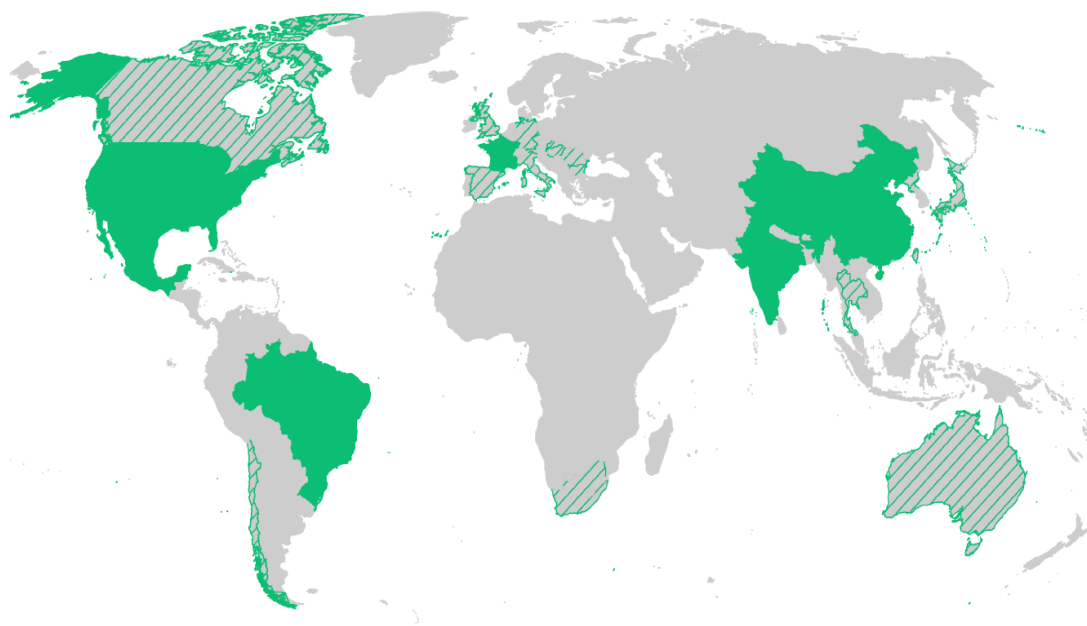
## Estimated Impact of Temperature on Mortality





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

# Global Mortality

## Impact Lab Data Coverage: Mortality



 Data in current case study

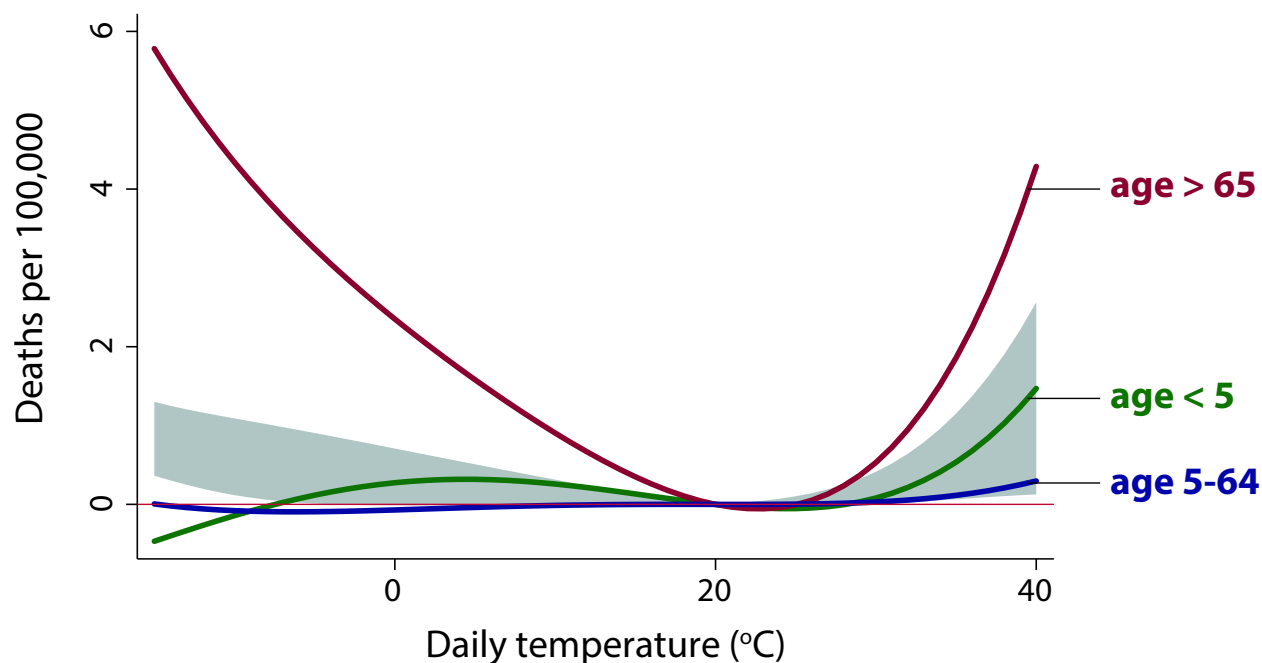
 Data in progress (reanalysis and new projects)

- › Universe of mortality data from multiple countries equal to 57 percent of global population.
- › Daily historical county temperature and precipitation.
- › High-resolution projections of roughly 20 GCMs to 2100.
- › RCPs 4.5, 8.5 provide approximately 100 datasets of daily future weather.

## Estimating the Mortality Temperature Relationship

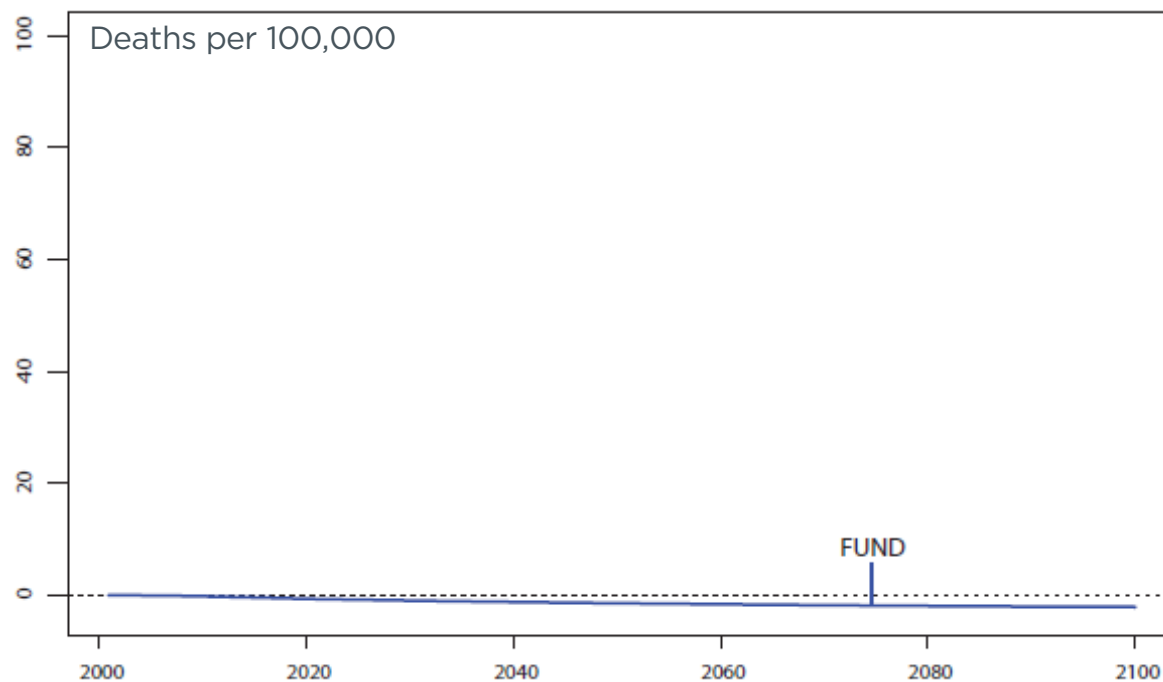
$$M_{aict} = \underbrace{f_a(T_{it})}_{\text{mortality rate}} + \underbrace{\left[ \theta_{a,1}^c P_{it} + \theta_{a,2}^c P_{it}^2 \right]}_{\text{temperature and rainfall}} + \underbrace{\alpha_{ai} + \delta_{act}}_{\text{fixed effects}} + \varepsilon_{iat}$$

$a$  = age group,  $i$  = county,  $c$  = country,  $t$  = year



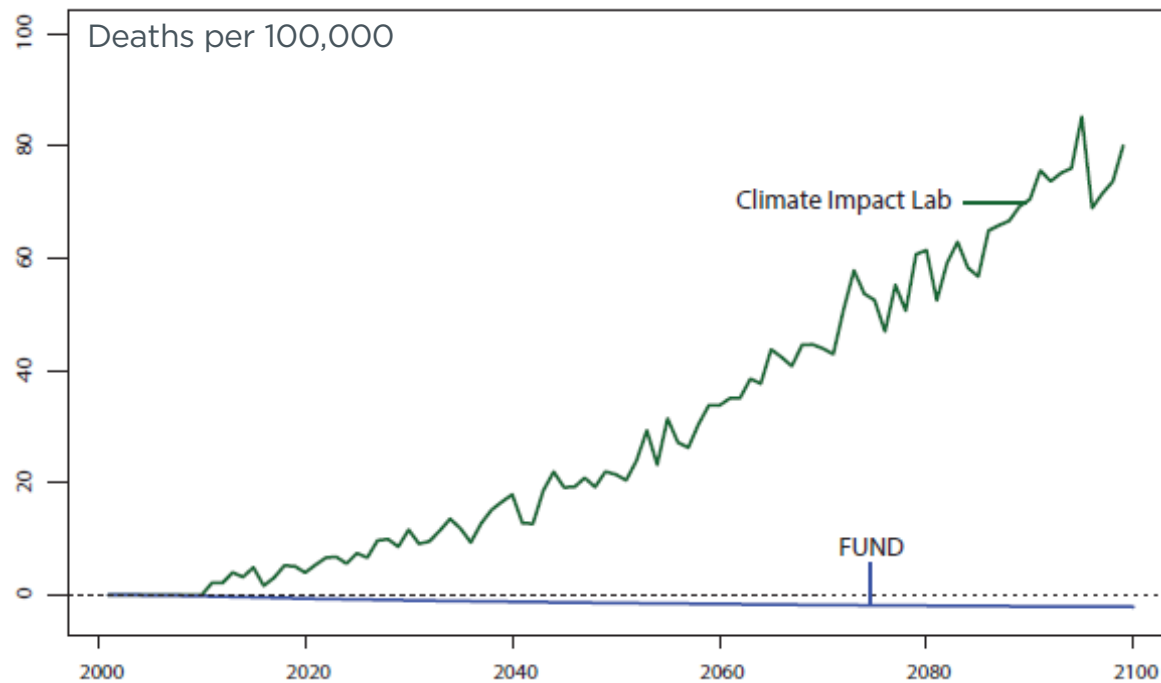
# Empirics and Granularity Matter

## Heat Induced Mortality in Climate Models



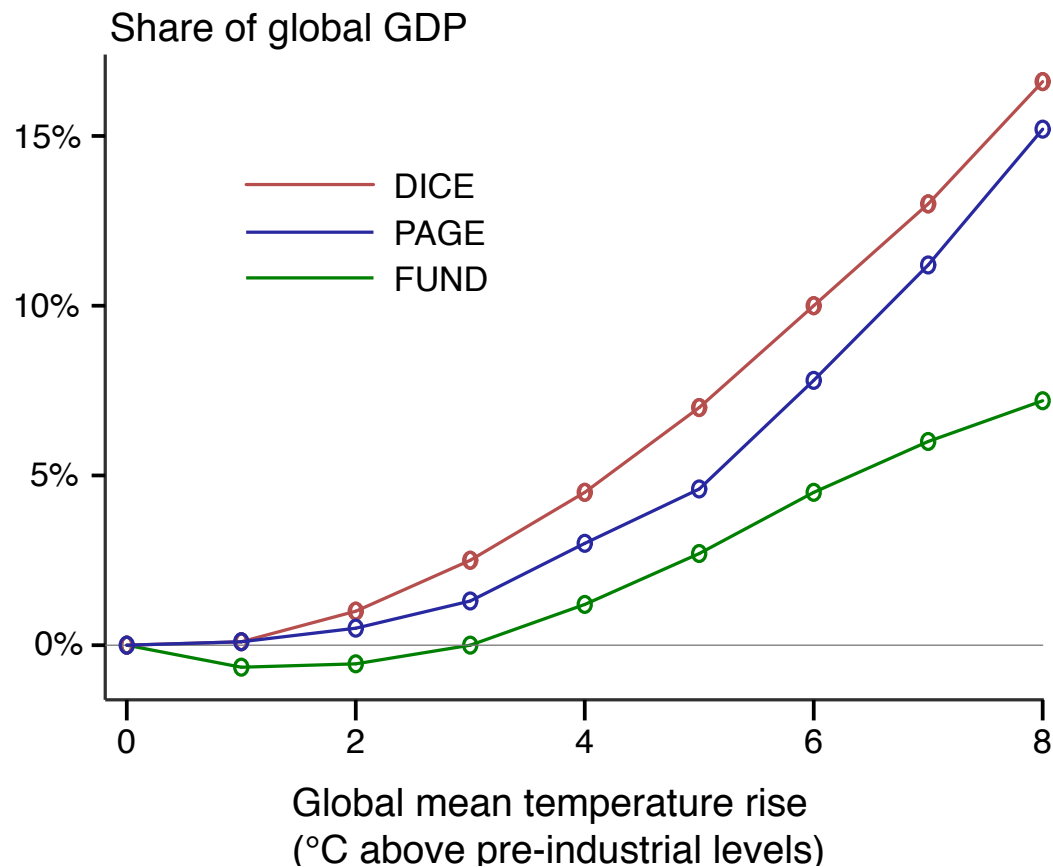
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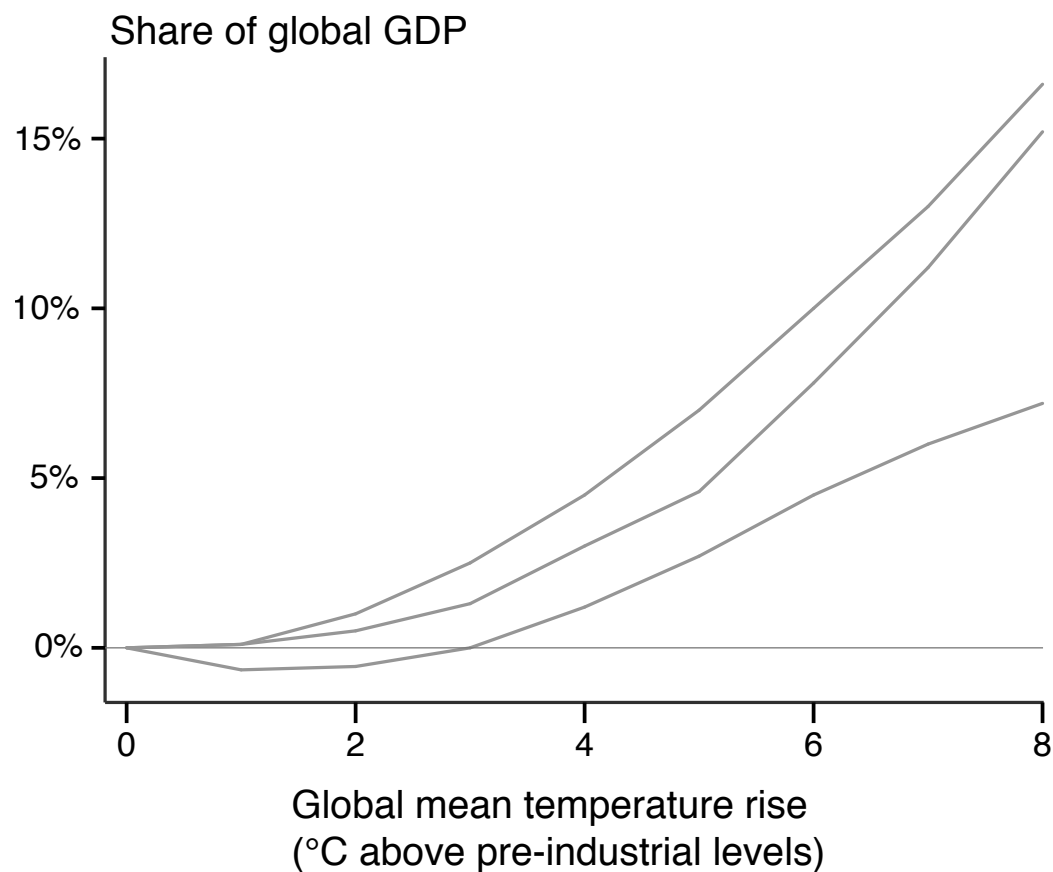
# Reconsidering Climate Damages

## Climate Damages



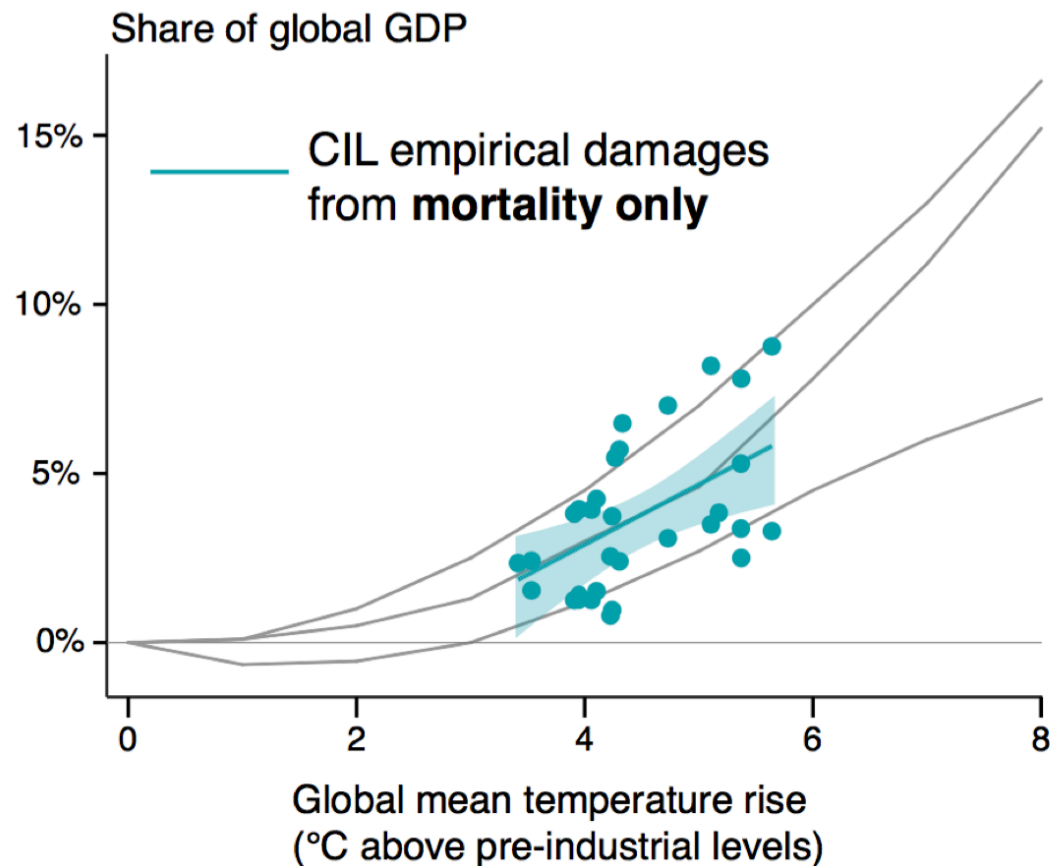
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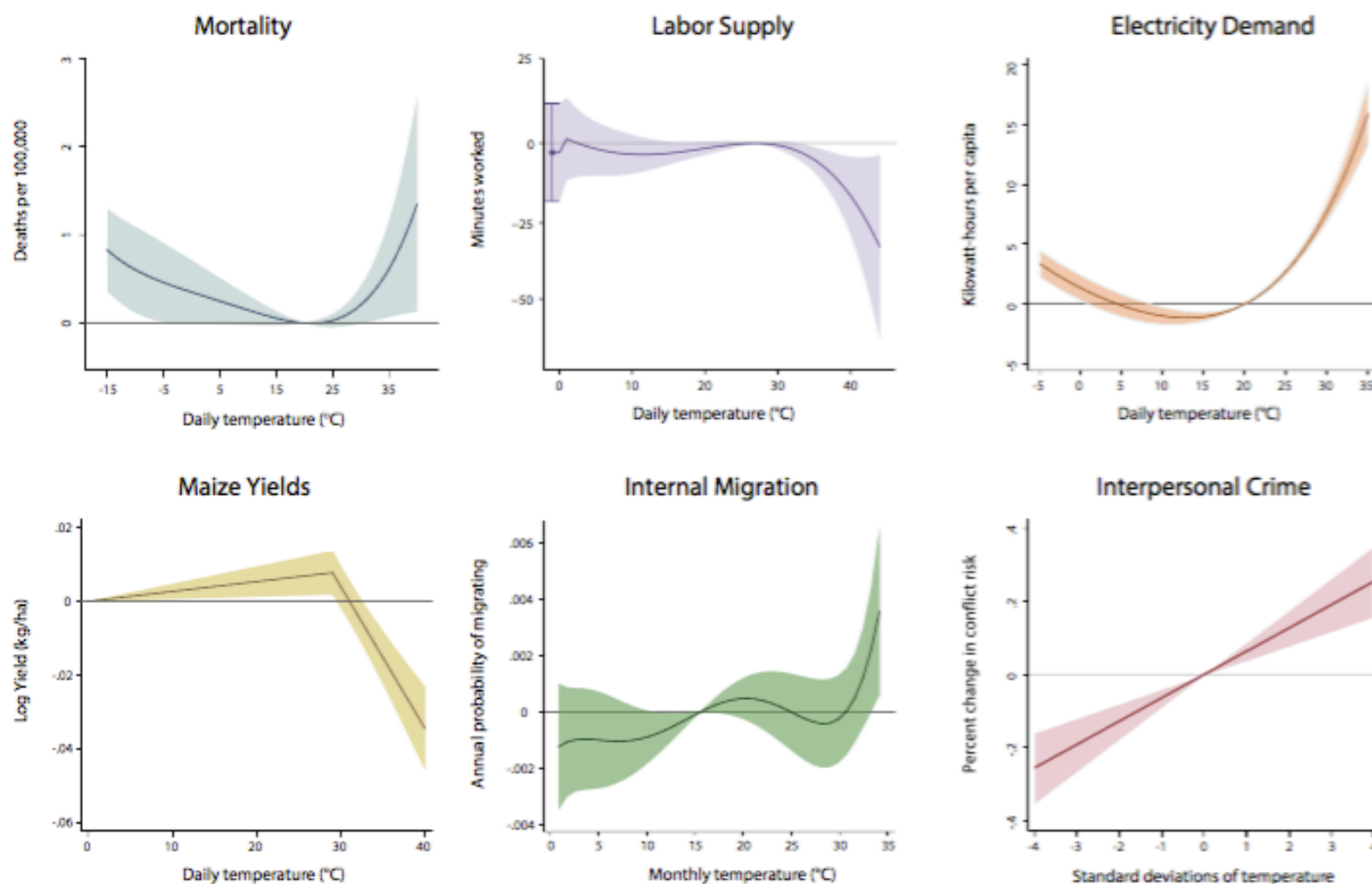


# Reconsidering Climate Damages

## Climate Damages

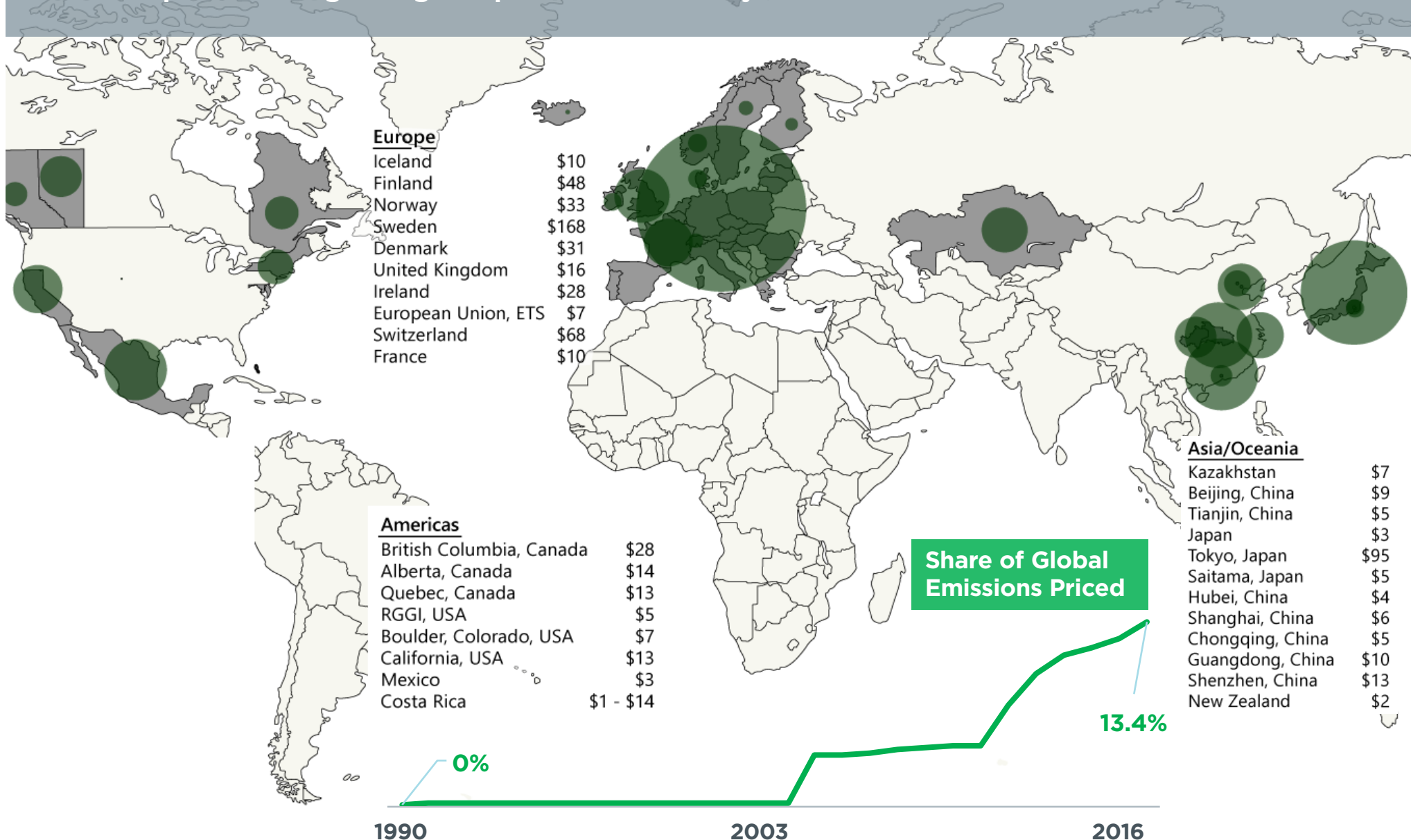


# A Multi-Sector Approach



## 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.





## 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 human health at risk?