Urban Air Pollution and Carbon Emissions in China

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MIT JOINT PROGRAM
SCIENCE POLICY
GLOBAL CHANGE

Beijing Skyline on Jan 14, 2013

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Refer to: Image 5 in "China's Toxic Sky," *The Atlantic*, Jan. 30, 2013.

Source: Photographs by Ed Jones (AFP).

Beijing Skyline on Feb 4, 2012

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Refer to: Image 5 in "China's Toxic Sky," *The Atlantic*, Jan. 30, 2013.

Source: Photographs by Ed Jones (AFP).

Conventional Air Pollutants

Pollutants	Primary Emission Sources
Ozone (O_3)	Produced through chemical reaction between NO_x (see below) and VOC (mobile, solvent, industrial processes)
Particulate matter (PM_{10} or $PM_{2.5}$)	Dust, fuel combustion, and mobile
Nitrogen oxides (NO_x)	Mobile and fuel combustion
Sulfur dioxide (SO_2)	Fuel combustion
Carbon monoxide (CO)	Mobile

- All strongly associated with cardiopulmonary, cardiovascular, and respiratory diseases.

Air Pollution in China

- Byproduct of miraculous economic growth

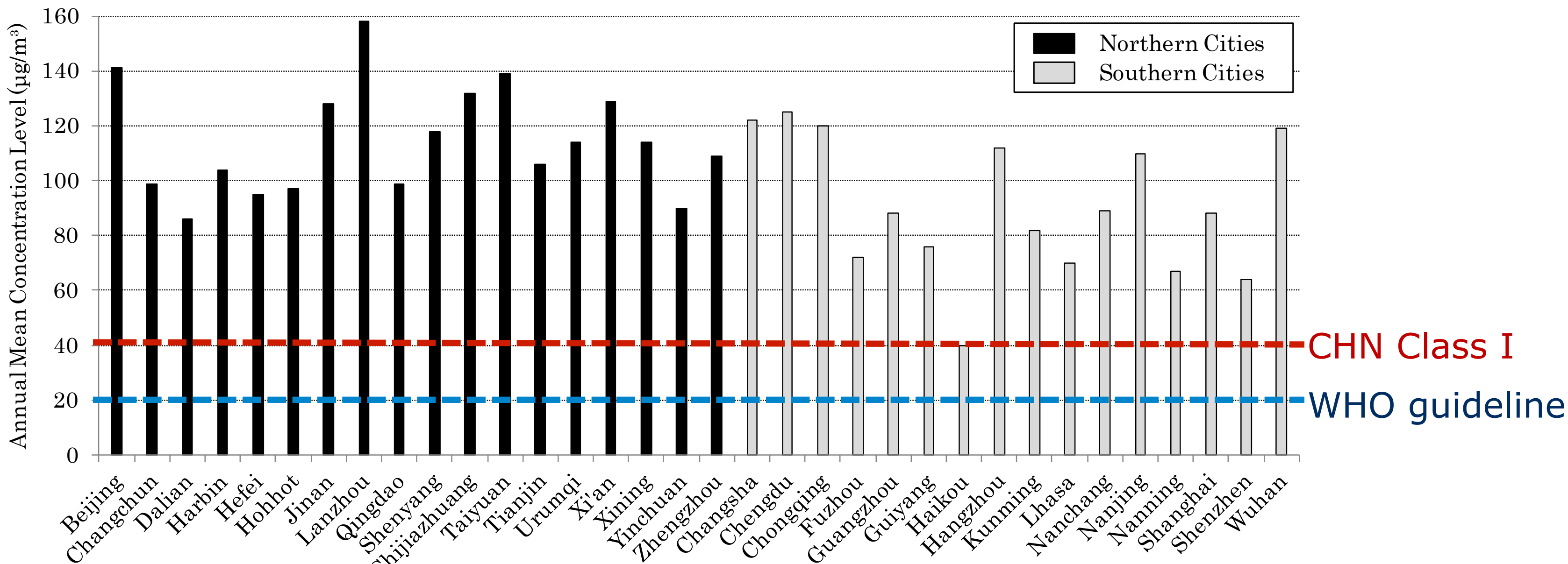

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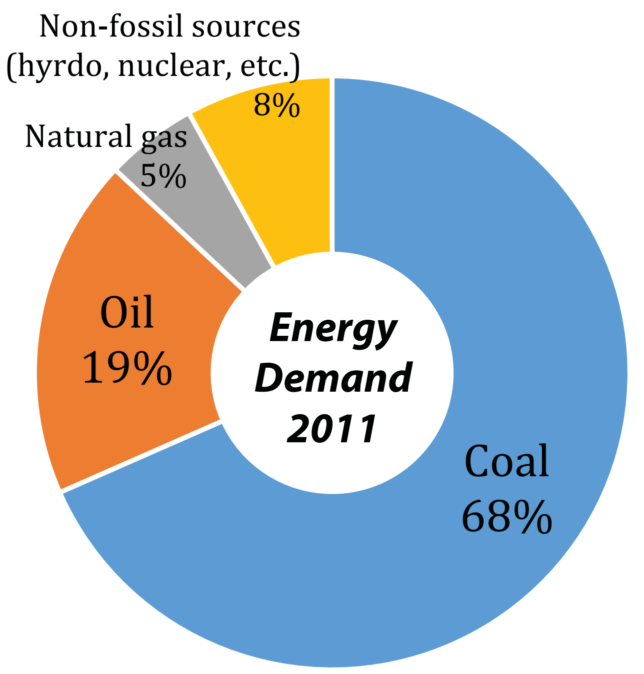
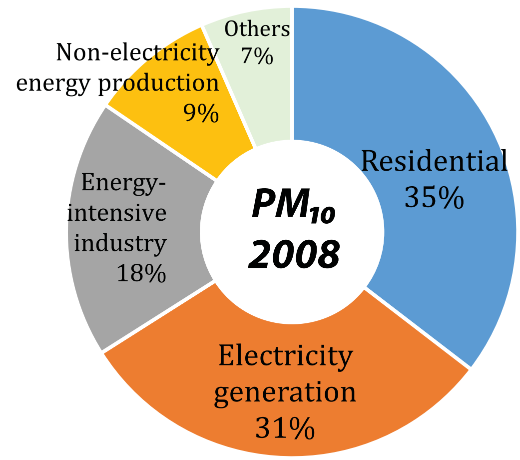
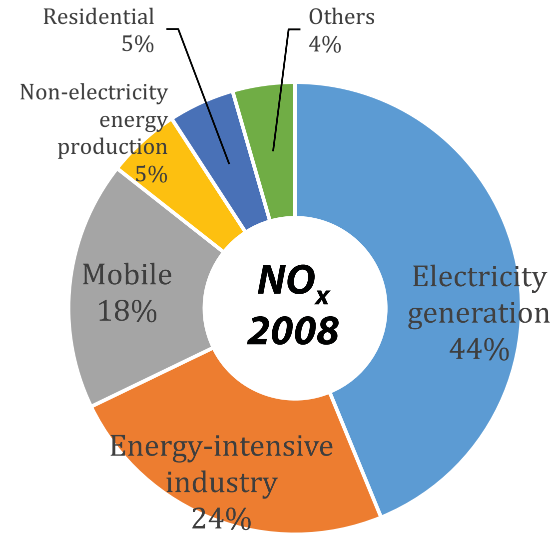
Figure: Annual Mean PM_{10} concentration levels in China's major cities, 2005.

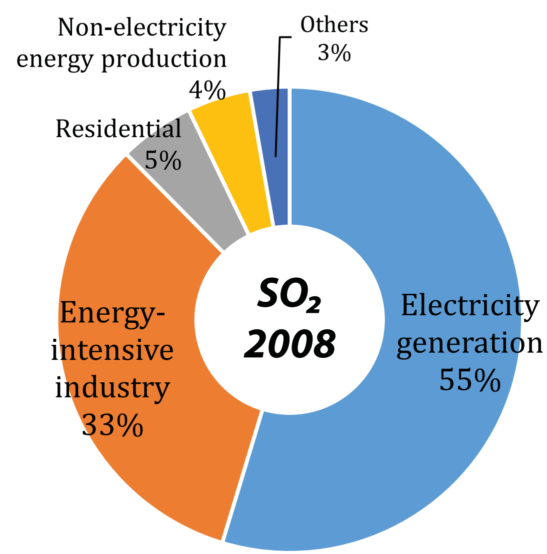
Source: Matus *et al*. (2012), p. 57.

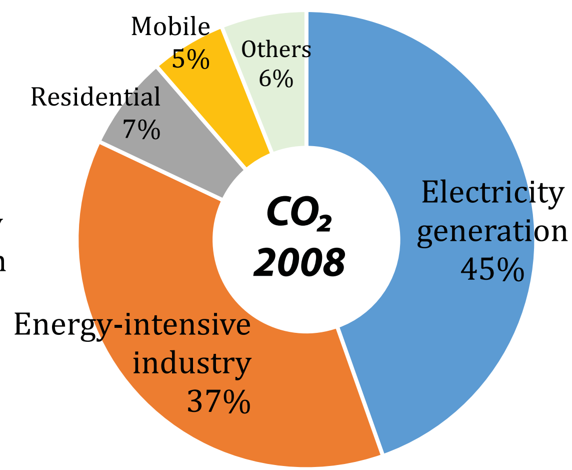
Decomposition: China's Energy and Emissions











Source: Created from IEA and EDGAR.

Research Question (for Analysis 1)

- How big is the cost of air pollution in China?

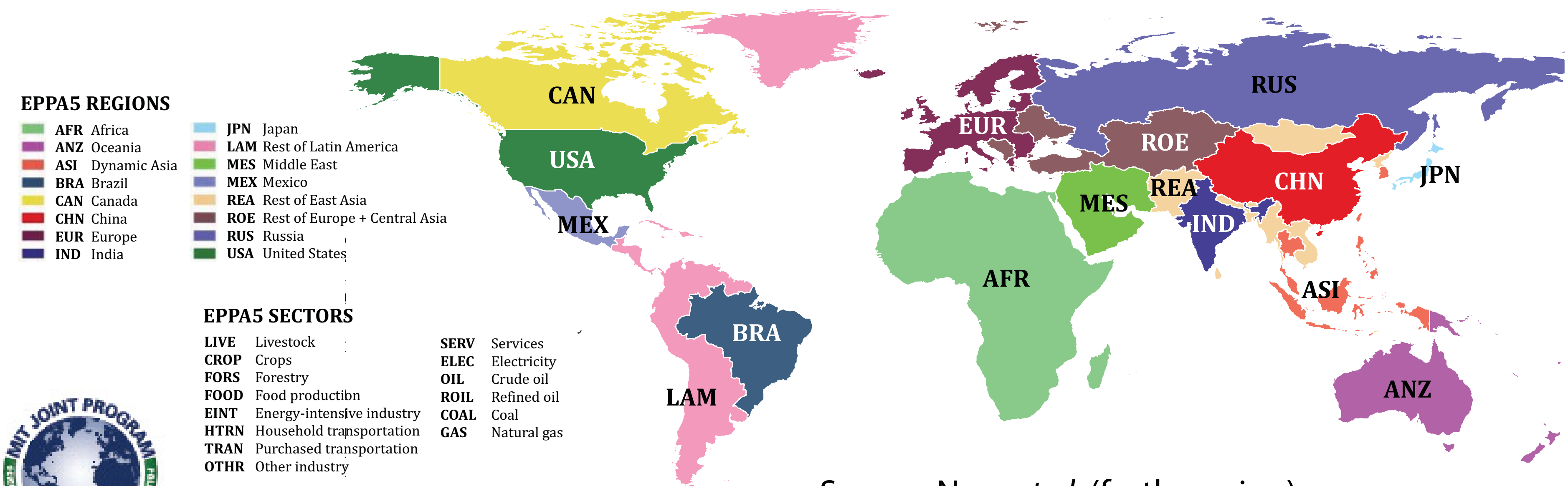
Preliminary answers from other studies

Study	Year of Interest	Cost Estimates
World Bank (1997)	1995	US$34 billion (4.6% of GDP)
World Bank and SEPA (2007)	2003	US$55 billion (3.8% of GDP)

Possibility of substantial underestimation: sole focus on PM + static method

Method: EPPA

- A modified version of the MIT Emissions Prediction and Policy Analysis (EPPA) model
- EPPA is a recursive dynamic computable general equilibrium (CGE) model, where China represents one of the 16 global regions.



Source: Nam *et al.* (forthcoming).

Method in Brief

- Extend the conventional social accounting matrix (SAM) to include air pollution's impacts on human health.
- Construct exposure-response (ER) and valuation tables.
- Compute historical air quality levels.
- Construct reference and counterfactual scenarios.
- Simulate the model.
- Estimate economic damage from air pollution.

Modeling Strategy

Human health as a receptor of air pollution
Main components of the cost:
- Labor loss (market), medical expenditure (market), leisure loss (non-market)

Extended Social Accounting Matrix

		INTERMEDIATE USE						*HOUSEHOLD SERVICES*		FINAL USE				OUTPUT
		1	2	…	*j*	…	*n*	*Mitigation of Pollution Health Effects*	*Labor-Leisure Choice*	Consumption	Investment	Government Purchase	Net-export	
DOMESTIC PRODUCTION	1													
	2													
	:													
	i													
	:													
	Medical Services for Health Pollution							*Medical Services*		*Health Services*				
	n													
IMPORTS	1													
	2													
	:													
	i													
	:													
	n													
LEISURE									*Leisure*	*Leisure*				
VALUE-ADDED	Labor							*Labor*	*Labor*					
	Capital													
	Indirect Taxes													
	Resources													
INPUT														

Source: Nam *et al*. (2010), p. 5061.

Exposure-Response (ER) Functions

Receptor	Impact category		ER function[a]	C.I. (95%)		Computed or adapted from[b]
				Low	High	
Entire age groups	Respiratory hospital admissions	PM_{10}	7.03E−06	3.83E−06	1.03E−05	ExternE (2005)
		O_3	3.54E−06	6.12E−07	6.47E−06	ExternE (1999)
	Cerebrovascular hospital admissions	PM_{10}	5.04E−06	3.88E−07	9.69E−06	ExternE (2005)
	Cardiovascular hospital admissions	PM_{10}	4.34E−06	2.17E−06	6.51E−06	ExternE (2005)
	Respiratory symptoms days	O_3	3.30E−02	5.71E−03	6.03E−02	ExternE (1999)
	Asthma attacks	O_3	4.29E−03	3.30E−04	8.25E−03	ExternE (1999)
	Mortality from Acute Exposure	O_3	0.03%	0.01%	0.04%	ExternE (2005)
		PM_{10}	0.06%	0.04%	0.08%	ExternE (2005)
	Mortality from Chronic Exposure	PM_{10}	0.25%	0.02%	0.48%	Pope et al. (2002)
Children	Chronic Bronchitis	PM_{10}	1.61E−03	1.24E−04	3.10E−03	ExternE (1999)
	Chronic Cough	PM_{10}	2.07E−03	1.59E−04	3.98E−03	ExternE (1999)
	Respiratory symptoms days	PM_{10}	1.86E−01	9.20E−02	2.77E−01	ExternE (2005)
	Bronchodilator usage	PM_{10}	1.80E−02[c]	−6.90E−02	1.06E−01	ExternE (2005)
	Cough	O_3	9.30E−02[d]	−1.90E−02	2.22E−01	ExternE (2005)
	Lower respiratory symptoms (wheeze)	PM_{10}	1.86E−01[e]	9.20E−02	2.77E−01	ExternE (2005)
		O_3	1.60E−02[f]	−4.30E−02	8.10E−02	ExternE (2005)
Adults	Restricted activity day	PM_{10}	5.41E−02[g]	4.75E−02	6.08E−02	ExternE (2005)
	Minor restricted activity day	O_3	1.15E−02[h]	4.40E−03	1.86E−02	ExternE (2005)
		PM_{10}	3.46E−02[h]	2.81E−02	4.12E−02	ExternE (2005)
	Work loss day	PM_{10}	1.24E−02[h]	1.06E−02	1.42E−02	ExternE (2005)
	Respiratory symptoms days	PM_{10}	1.30E−01[i]	1.50E−02	2.43E−01	ExternE (2005)
	Chronic bronchitis	PM_{10}	2.65E−05	−1.90E−06	5.41E−05	ExternE (2005)
	Bronchodilator usage	PM_{10}	9.12E−02[j]	−9.12E−02	2.77E−01	ExternE (2005)
		O_3	7.30E−02[j]	−2.55E−02	1.57E−01	ExternE (2005)
	Lower respiratory symptoms (wheeze)	PM_{10}	1.30E−01[k]	1.50E−02	2.43E−01	ExternE (2005)
Elderly 65+	Respiratory hospital admissions	O_3	1.25E−05	−5.00E−06	3.00E−05	ExternE (2005)
	Congestive heart failure	PM_{10}	1.85E−05	1.42E−06	3.56E−05	ExternE (1999)

Source: Modified from Nam et al. (2010).

[a] E–R functions for mortality from acute and chronic exposure have the unit of % increase in annual mortality rate/($\mu g/m^3$), while the other E–R functions are measured in cases/(yr-person-$\mu g/m^3$).
[b] ExternE (1999) and ExternE (2005) refer to Holland et al. (1999) and Bickel and Friedrich (2005), respectively.
[c] Defined on children aged 5–14 years meeting certain criteria (around 15–25% of child population).
[d] ER functions on cough for O_3 are defined on general population of ages 5–14.
[e] LRS values for PM_{10} include impacts on cough.
[f] LRS ER functions for O_3 are defined on general population of ages 5–14.
[g] Restricted activity days include both minor restricted days and work loss days.
[h] Part of restricted activity days.
[i] Defined on adults population with chronic respiratory symptoms (around 30% of adult population).
[j] Defined on population of >20 with well-established asthma (around 4.5% of total adult population).
[k] LRS ER functions for PM are defined on adult population with chronic respiratory symptoms (around 30% of total adult population); ExternE (2005) LRS values for PM include impacts on cough.

Valuation Table

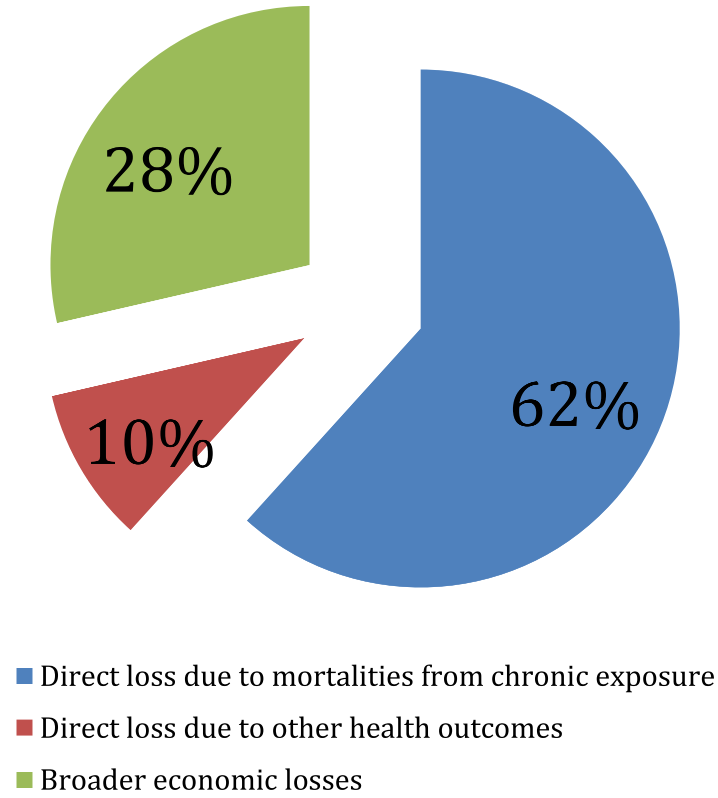
Outcome	Unit	Cost (1997 US$)
Hospital admission[a]	per admission	284
Emergency room visits for respiratory illness[a]	per visit	23
General practitioner visits		
Asthma[a]	per consultation	4
Lower respiratory symptoms[a]	per consultation	13
Respiratory symptoms in asthmatics[a]	per event	0.60
Respiratory medication use	per day	0
Restricted activity day	per day	2.32
Cough day	per day	0.60
Symptom day	per day	0.60
Work loss day	per day	1.43
Minor restricted activity day	per day	0.60
Chronic bronchitis[a]	per case	8,000
Mortality from acute exposure	per case	662

Note: All values displayed in this table are estimated by willingness-to-pay surveys and market data.

Source: [a]As estimated for China by World Bank and SEPA (1997: 25); For other endpoints, we adjusted the European valuation table presented in Bickel and Friedrich (2005: 156) by using the average cost difference between the valuation table for China estimated by World Bank and SEPA (1997: 25) and that for Europe estimated by Bickel and Friedrich (2005: 156).

Results

- Total pollution-health costs for China was estimated at **US$69 bn (7%)** of consumption loss or **US$112 bn (5%)** of welfare loss.
- PM_{10} and O_3 account for **87%** and **13%** of the 2005 pollution-health costs, respectively.
- **Chronic exposure to PM** as primary contributor (**62%**)
- **Broader Economic Losses** category account for **28%** of the welfare loss in 2005.
  - Includes impacts of distorted resource allocation and cumulative loss.
  - Larger in fast-growing economies (e.g., 12% for Western Europe)



Source: Created from Matus *et al*. (2012).

Comparison with World Bank Studies

World Bank Studies:

Year of Interest	Cost Estimates	Note
1995	US$34 bn (4.6% of GDP)	PM_{10} only, no threshold
2003	US$55 bn (3.8% of GDP)	PM_{10} only, threshold

vs.

Year of Interest	Cost Estimates	Note
1995	US$64 bn (8.7% of GDP)	PM_{10} only, no threshold
2005	US$104 bn (5.9% of GDP)	PM_{10} only, no threshold

Source: Matus *et al*. (2012), p. 63.

Research Question (for Analysis 2)

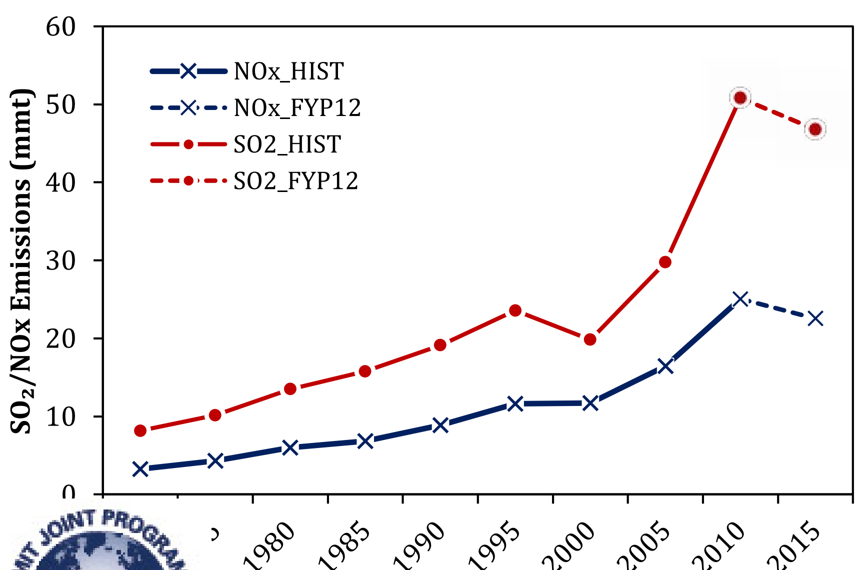
- How will China's pollution regulations interact with carbon mitigation policies?

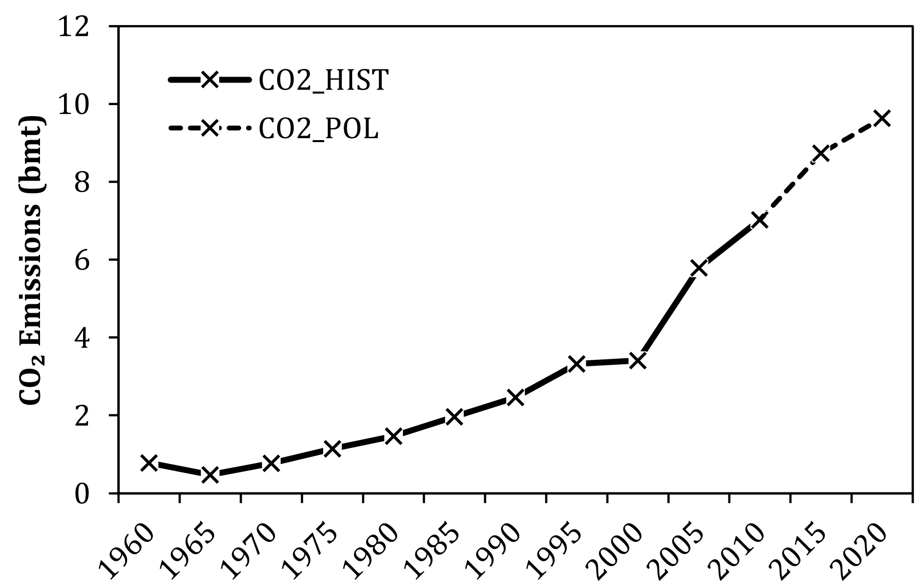
Motivations

- Linkage between conventional air pollutants (e.g., NO_x and SO_2) and CO_2
  - Common source of emissions: fossil fuel combustion
- Challenge in reaching global consensus on national carbon mitigation targets
  - Leakage across countries
- Major GHG emitters are more interested in regulating pollution than mitigating carbon emissions.

China's Latest Policy Targets

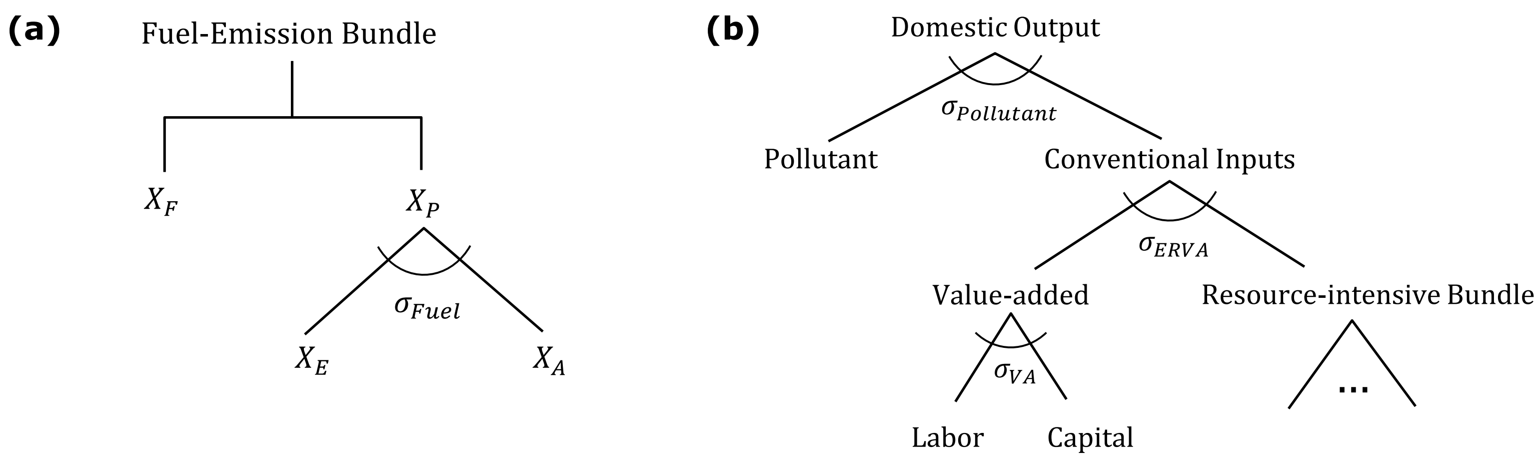
	NO_x	SO_2	CO_2
FYP12	10% **emissions** reduction from the 2010 level by 2015	8% **emissions** reduction from the 2010 level by 2015	17% **intensity** reduction from the 2010 level by 2015
Copenhagen Accord			40-45% **intensity** reduction from the 2005 level by 2020





Source: Modified from Nam *et al*. (forthcoming).

Pollution-Abatement Structure in EPPA



X_F: Fuel consumption	X_P: Pollution generated from fuel combustion
X_E: Pollution emitted	X_A: Pollution abated

Figure: **(a)** Fuel-related pollution, **(b)** Non-fuel-related pollution.
Source: Adopted from Nam *et al*. (2012), pp. 6-7.

**** Main responses to a policy shock ****

Fuel-switching, output reduction (less consumption of energy), adoption of non-fossil power-generation technologies, and **adoption of pollution-abatement technologies**

Example: Flue-gas Desulfurization

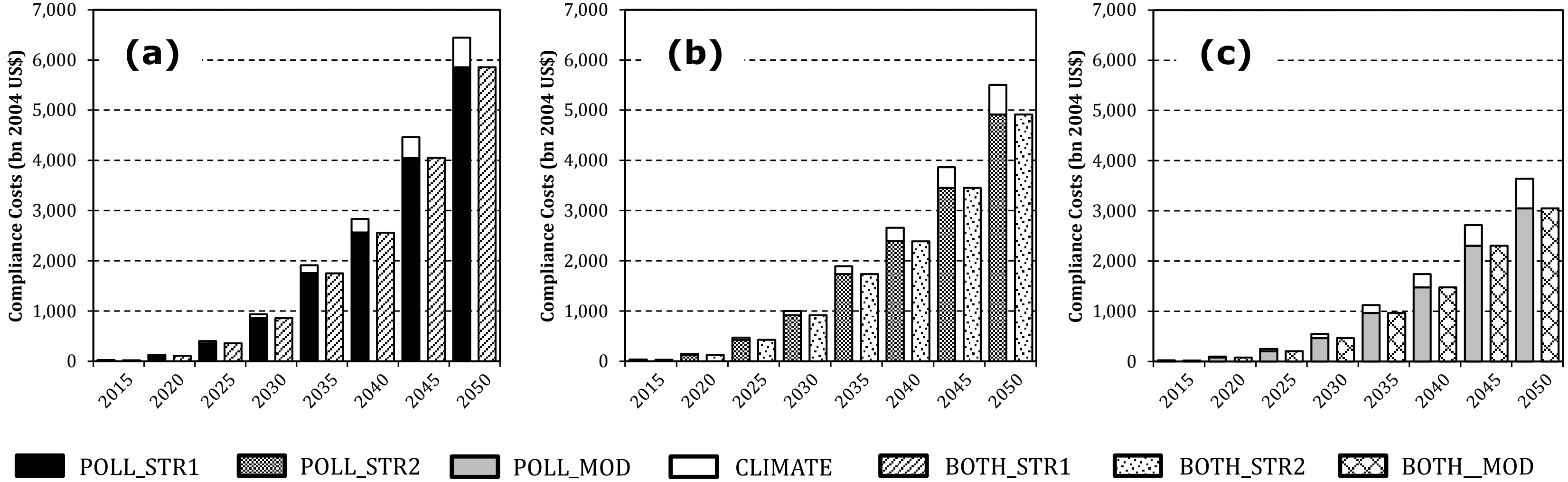
A power plant before installation of flue-gas desulfurization equipment.

Source: Wikipedia.
http://en.wikipedia.org/wiki/Flue-gas_desulfurization

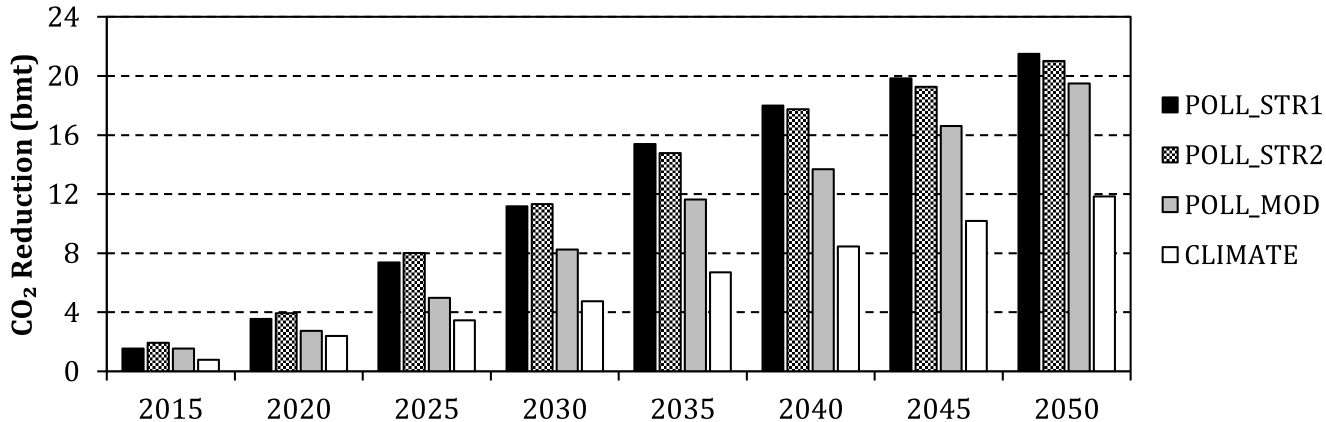
Schematic design of the absorber of an FGD and Scrubber removed due to copyright restrictions.

Results

Policy Compliance Costs



Carbon Emissions Reductions



Source:
Nam *et al.*
(forthcoming).

Conclusions (from Analysis 1)

- In China, welfare loss from air pollution has been substantial.
  - In 2005, US$69 billion of consumption loss (7% of historical level) or US$112 billion of welfare loss (5% of historical level).
  - Pollution health costs have increased with time in $ terms, but have declined in % terms.
- A dynamic approach is necessary.
  - Around 28% of the total welfare loss belongs to the "broader economic loss" category whose effect remains the economy beyond one period of time.
  - Crucial for fast-growing economies like China.

Conclusions (from Analysis 2)

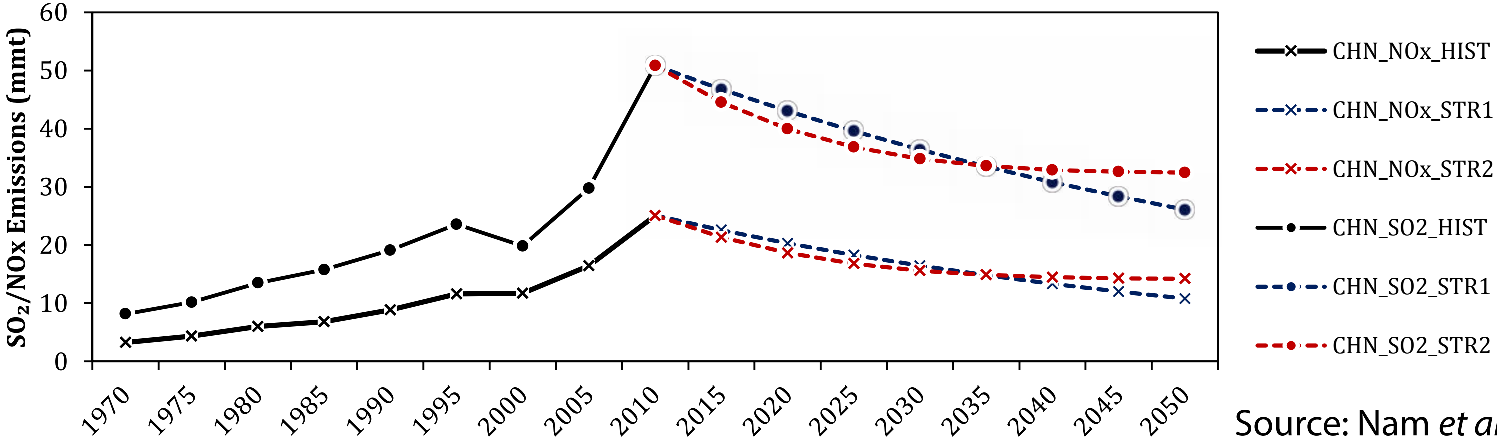
- Substantial synergy between pollution and climate abatement policies.
  - US$3 bn-586 bn (0.1-5.1% of baseline consumption) in any given year between 2015-2050, in terms of saved compliance costs
  - 1.5-21.5 bmt of ancillary CO_2 emissions reduction in any given year between 2015-2050
- China's proposed CO_2 intensity targets are not likely to bind.
  - Need to pay more attention to the synergy.
  - But still good news for the global community from a GHG mitigation perspective.

Recap and Discussion

- Does pollution regulation hurt economic growth?
  - Cost of NOT regulating pollution may be even greater in fast-growing economies.
- Key lessons learned from a policy perspective
  - More attention to coordination among policies
  - Need for a forward-looking approach that encourages earlier actions toward cleaner technologies
- Local actions for global impacts
  - Reversed policy logic would be more realistic.
  - Local air pollution control, not climate policy, should be placed at the center of global carbon mitigation strategy.

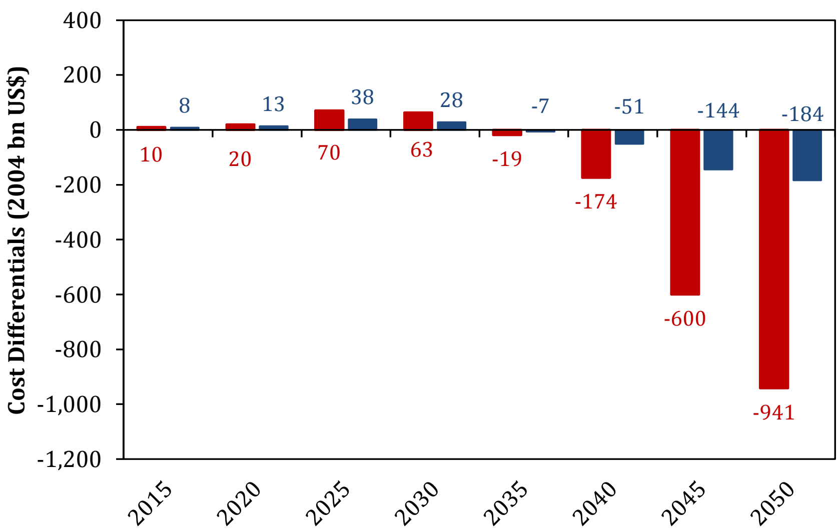
Need for Policies Requiring Earlier Actions

Policy Targets: STR1 and STR2 set to ensure same cumulative reduction



Source: Nam *et al*. (forthcoming).

Simulation Results: Policy Compliance Costs



When compared with STR1, STR2 will bring a net cost saving of **US$298 billion** to the Chinese economy by 2050.

Source: Nam *et al*. (forthcoming).

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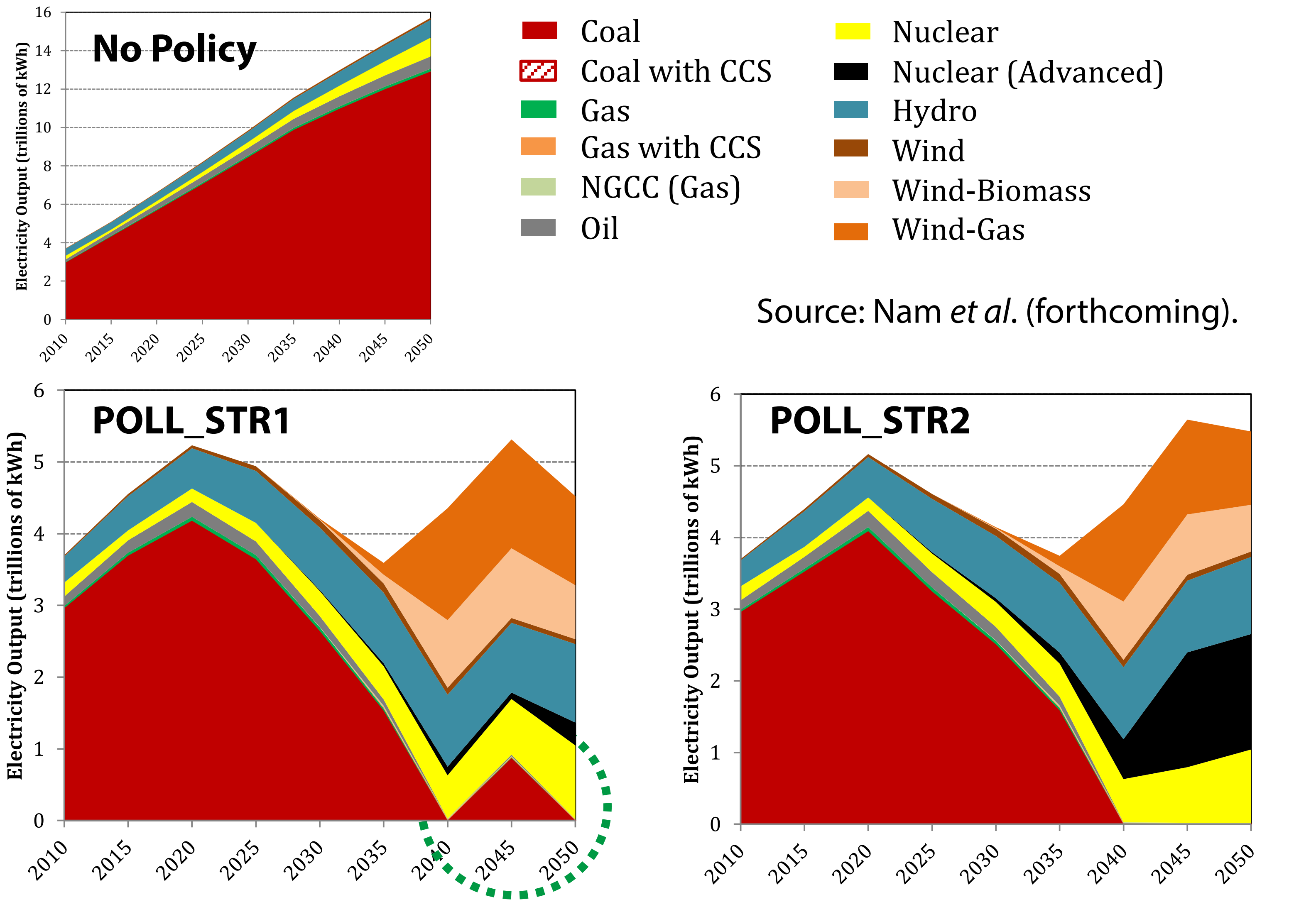
Why the difference?

Early Lock-in vs. Forward-looking Investment



Source: Nam *et al*. (forthcoming).

Thank you!

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