生產力與效率分析
Productivity and Efficiency Analysis

邊際減排成本與排放權配置
(Marginal Abatement Costs & Allocation of Emission Permits)

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國立成功大學製造資訊與系統研究所
IMIS
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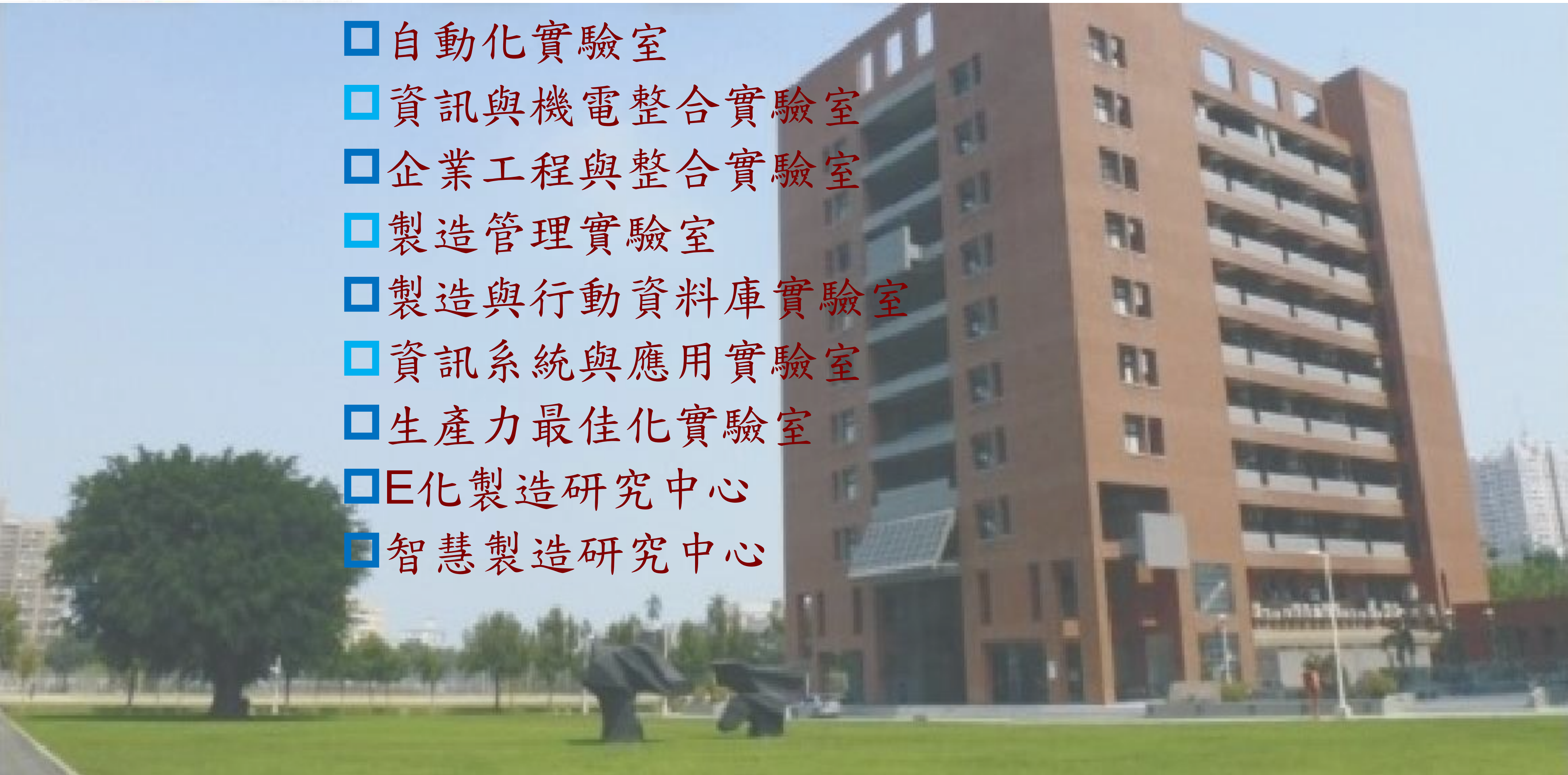
成功大學製造資訊與系統研究所(前稱製造工程研究所)，成立於民國八十三年八月，任務在於配合我國高科技產業發展及傳統工業升級之需要，培養具E化製造、製造技術、製造系統、製造知識管理與應用及製造管理之製造資訊與系統整合人才，並以執行產學合作計畫之方式，提昇產業競爭力之製造資訊系統研究。



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Outline

- Marginal Abatement Costs (MAC)
- Allocation of Emission Permits (AEP)

Introduction

- Energy Market with Undesirable Output (Dakpo et al., 2016)
  - (1) treating the pollution as a free disposable input (Atakelty Hailu & Veeman, 2001), but challenged as it violates the physical laws (Färe & Grosskopf, 2003)
  - (2) data transformation applied to treat the bad outputs as good outputs equivalently (Seiford & Zhu, 2002), but challenged due to undesirable output reduction without any cost (Färe & Grosskopf, 2004)
  - (3) assuming the weak disposability and nulljointness of good outputs and bad outputs (Färe, Grosskopf, Lovell, & Pasurka, 1989) (Färe & Grosskopf, 2009), but violating the law of thermodynamics (Coelli, Lauwers, & Van Huylenbroeck, 2007)
  - (4) the material balance principles requiring knowledge of the technical coefficients between desirable outputs, undesirable outputs and inputs (Hampf & Rødseth, 2014)
  - (5) the use of two sub-technologies (i.e., by-production) (Murty, Robert Russell, & Levkoff, 2012).

Marginal Abatement Costs (MAC)

Lee, Chia-Yen and Peng Zhou, 2015. Directional Shadow Price Estimation of CO_2, SO_2 and NO_x in the United States Coal Power Industry 1990-2010. Energy Economics, 51, 493–502.

Cap-and-Trade

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Marginal Abatement Cost (MAC)

How to estimate the marginal effects of multiple good and bad outputs when increasing one extra unit of input?

Marginal Abatement Cost (MAC)

- Introduction
  - Total U.S. energy-related emissions of carbon dioxide (CO_2) by the electric power sector in 2012 were 2,039 million metric tons, or about 77% of total U.S. CO_2 emissions.
  - CO2 emissions from U.S. electricity generation by source, 2012

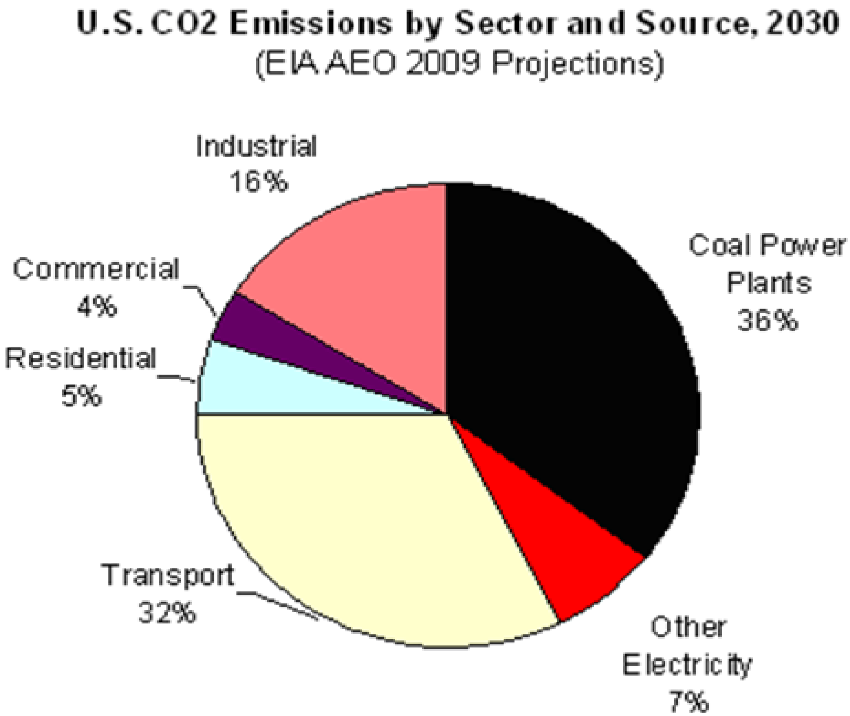
Source	Million Metric Tons	Share of Total
Coal	1,514	74%
Natural gas	494	24%
Petroleum	19	1%
Other[2]	12	1%
Total	2,039	

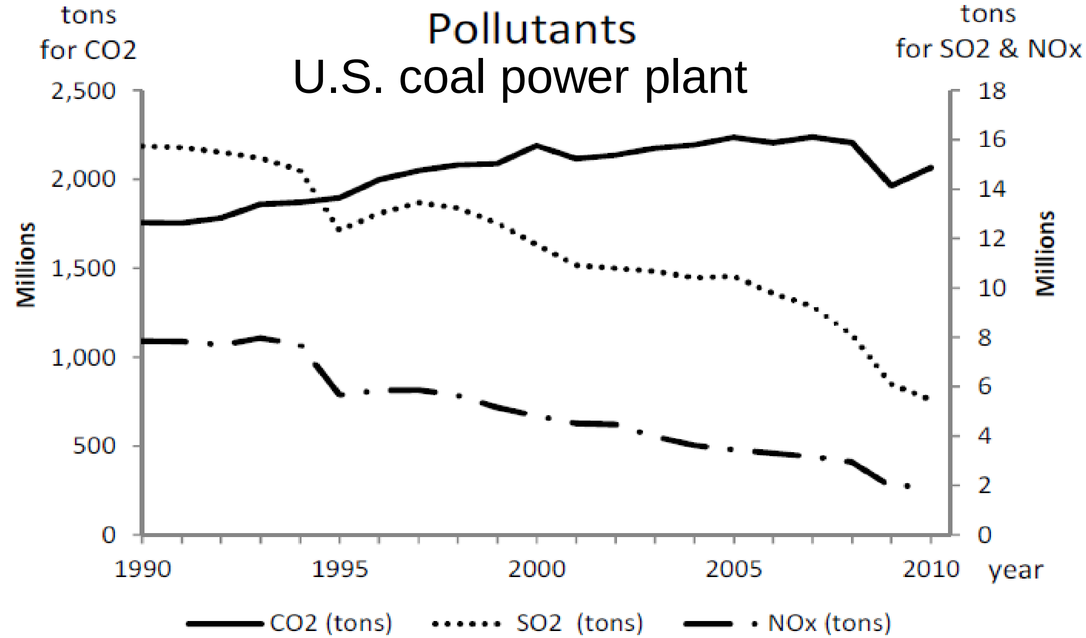
[2]Miscellaneous wastes and from geothermal power generation.

EIA, 2013. http://www.eia.gov/tools/faqs/faq.cfm?id=77&t=11
EIA, 2013. International Energy Statistics. http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=90&pid=44&aid=8

Marginal Abatement Cost (MAC)

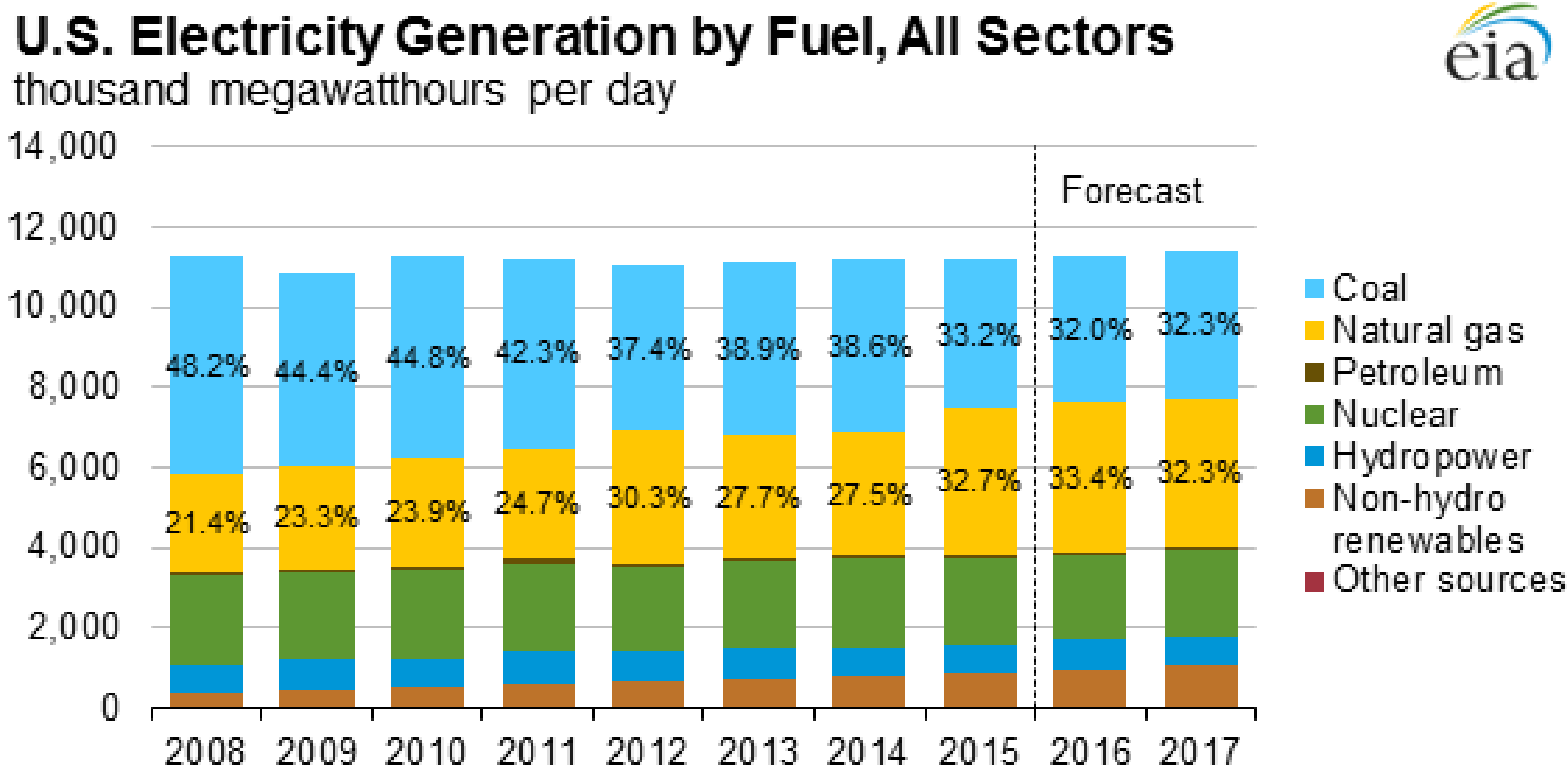
- U.S. Coal-fired Power Plant
  - Source of Air Pollution





77% (2012)→ 43% (2030)

Coal Power Plant



Note: Labels show percentage share of total generation provided by coal and natural gas.

Source: Short-Term Energy Outlook, March 2016.

Marginal Abatement Cost (MAC)

Air Pollution in China

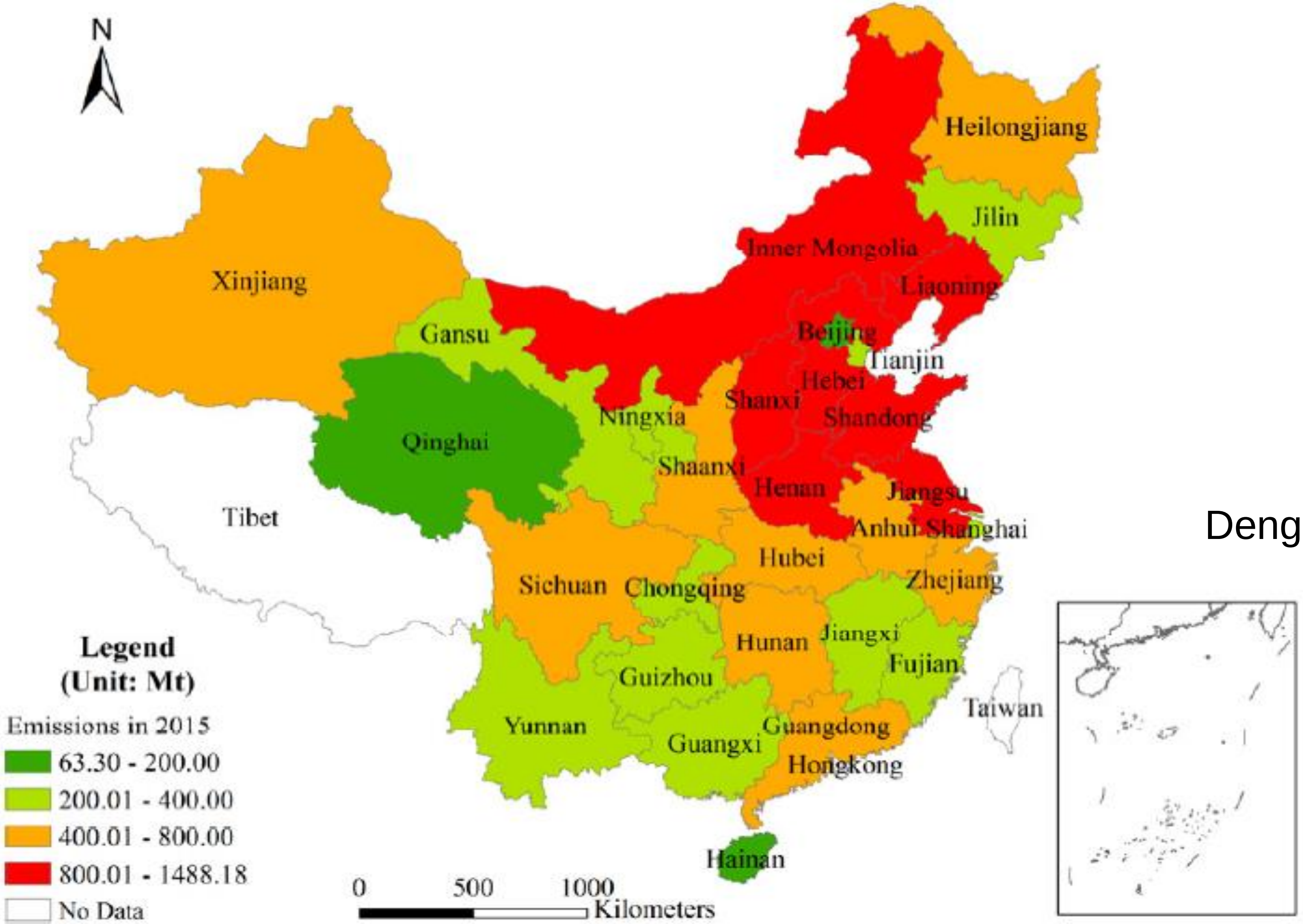
- In 2012 China was the largest contributor to carbon emissions from fossil fuel burning and cement production, and responsible for 25 percent of global carbon emissions.

- manufacturing and power generation are the major sectors contributing to China's carbon emissions, together these sectors accounted for 85 percent of China's total carbon emissions in 2012 (Liu, 2015).

- In 2013-2015, China also struggled from the hazardous smog with the high concentration of PM 2.5.

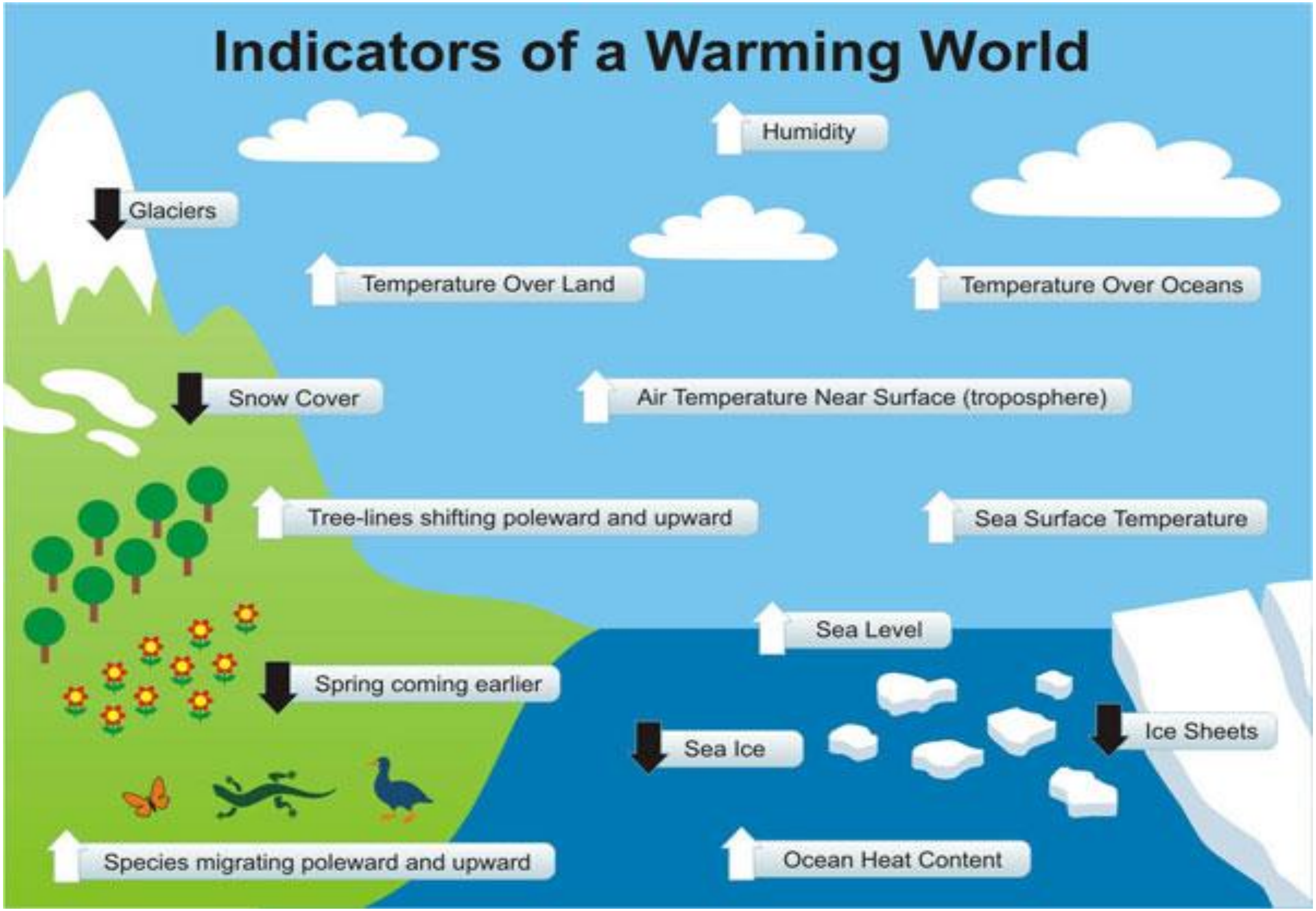
- In fact, the two key components of urban smog and acid rain are emissions of SO_2 and NO_x (Zhang and Samet, 2015).

- Emission intensity distribution of CO2 in 2015;



Deng et al. (2015)

Story…



Indicators of a Warming World
Humidity
Glaciers
Temperature Over Land
Temperature Over Oceans
Snow Cover
Air Temperature Near Surface (troposphere)
Tree-lines shifting poleward and upward
Sea Surface Temperature
Sea Level
Spring coming earlier
Sea Ice
Ice Sheets
Species migrating poleward and upward
Ocean Heat Content

Climate Change

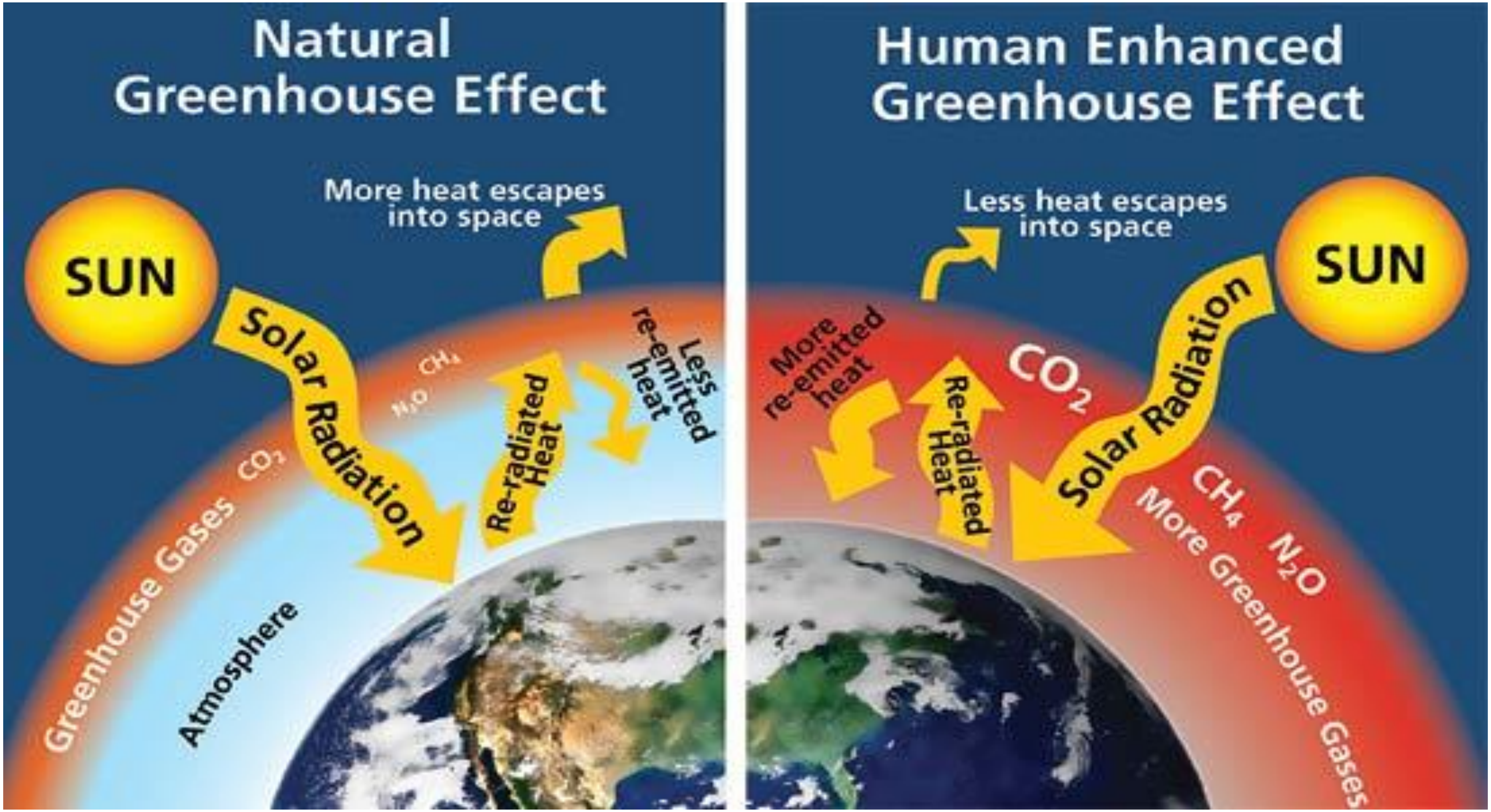
- is a more general term that refers to changes in many climatic factors (such as temperature and precipitation) from the global to the local scale.

Global Warming

- is the rise in global mean temperature due to an increase of heat-trapping greenhouse gases such as carbon dioxide and methane in the atmosphere.

- Based on surface and atmospheric temperatures from thousands of locations, and from satellites worldwide, scientists have determined that the global mean temperature has risen 0.8 degrees C, since 1880.

Greenhouse Effect



http://www.nps.gov/goga/naturescience/climate-change-causes.htm

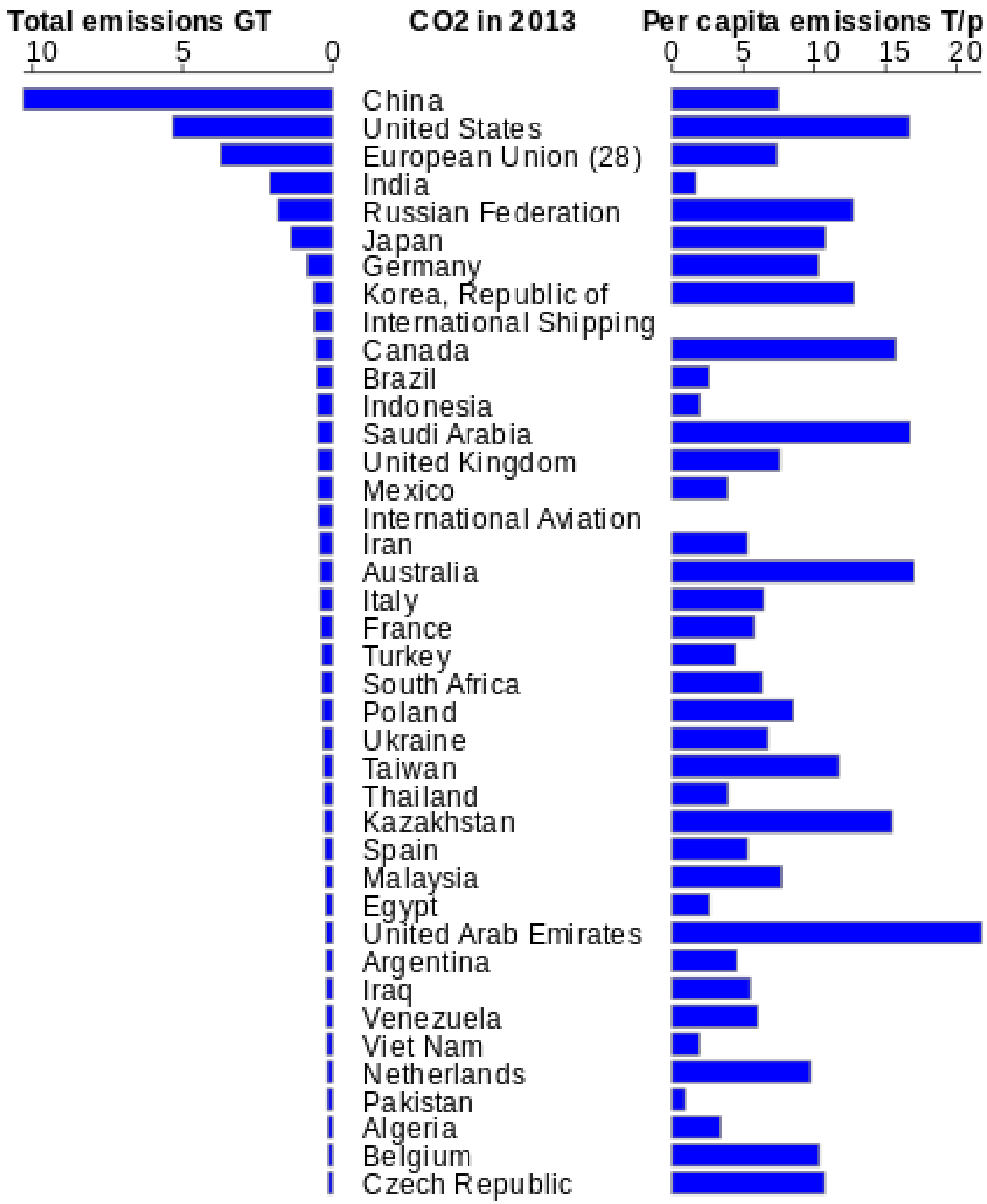
Kyoto Protocol (1997)

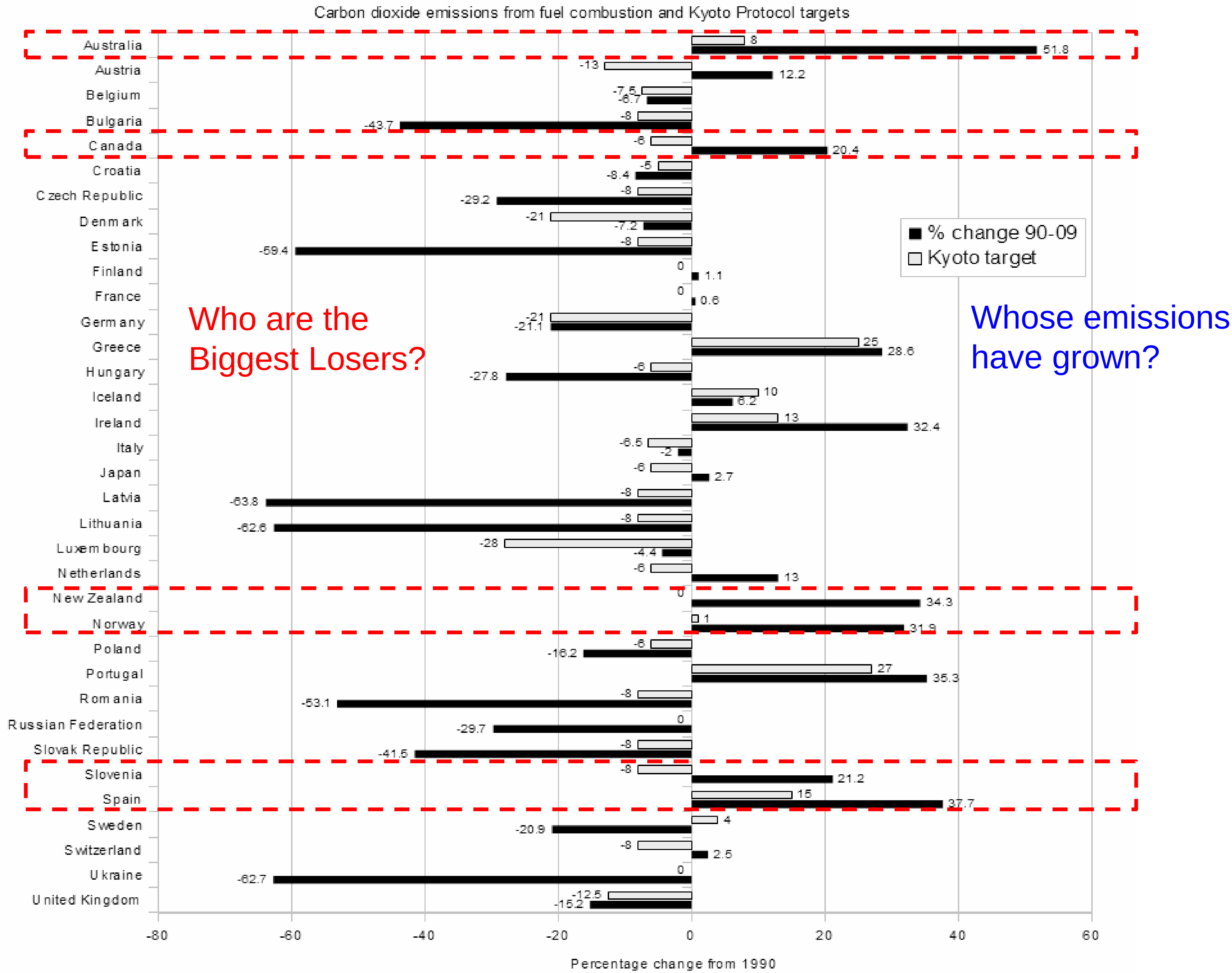
- Dec 1-11, 1997: representatives from 160 countries agreed to enter into binding limits on emissions of greenhouse gases (United States, the number 1 emitter of CO2 gases has not joined)

TARGETS:

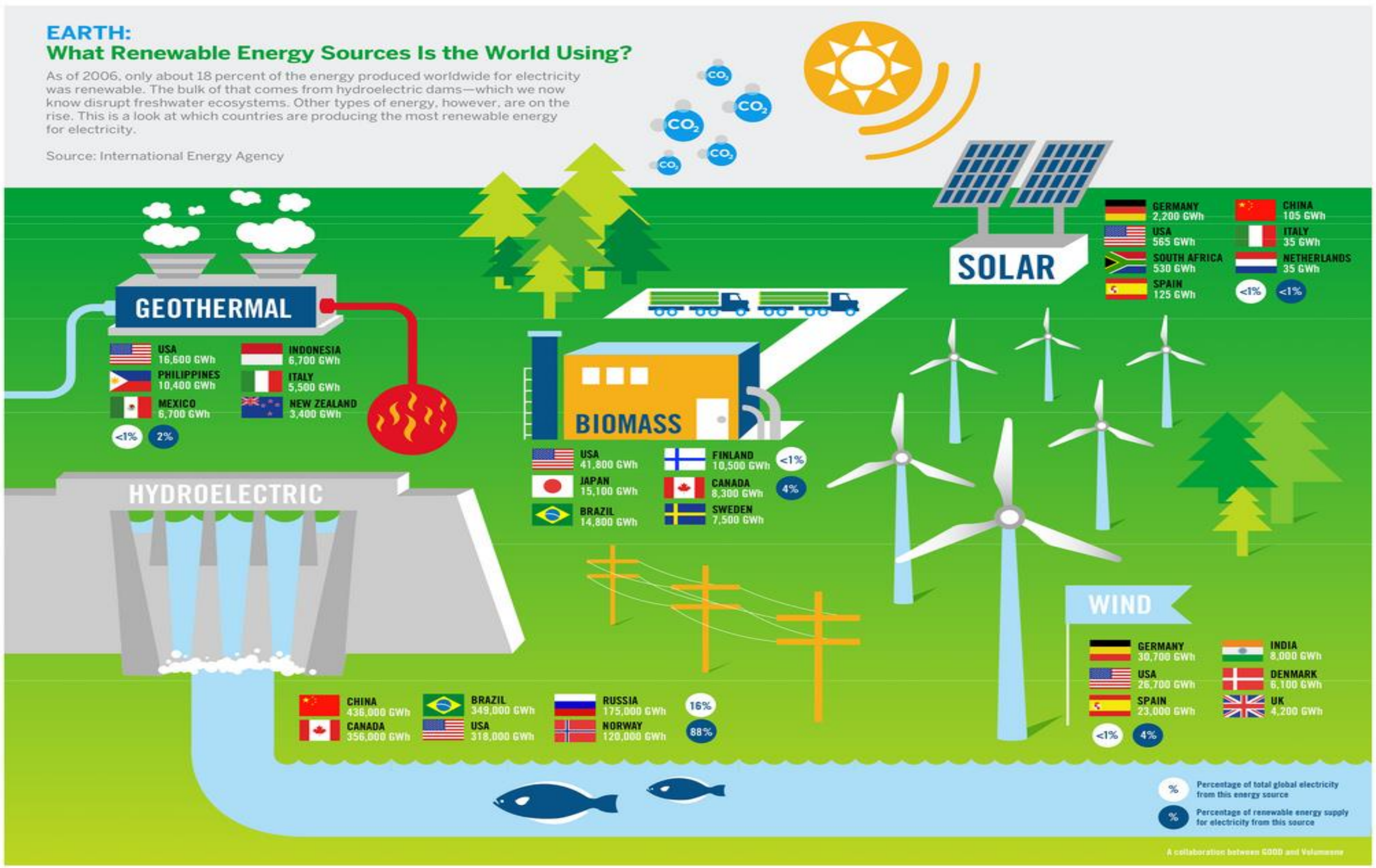
- Total: reduce developed nation emissions to 5% below 1990 levels during "commitment period" 2008-2012 (most countries need -18% reduction in BAU by 2008)
- 37 industrialized nations and the EU subject to binding emissions targets
- Greenhouse gases: CO2, CH4, N2O, HFCs, PFCs, and SF6

Kyoto Protocol




Carbon dioxide emissions from fuel combustion and Kyoto Protocol targets
% change 90-09
Kyoto target
Who are the Biggest Losers?
Whose emissions have grown?
Australia 8 51.8
Austria -13 12.2
Belgium -7.5 -6.7
Bulgaria -8 -43.7
Canada -6 20.4
Croatia -5 -8.4
Czech Republic -8 -29.2
Denmark -21 -7.2
Estonia -8 -59.4
Finland 0 1.1
France 0 0.6
Germany -21 -21.1
Greece 25 28.6
Hungary -6 -27.8
Iceland 10 6.2
Ireland 13 32.4
Italy -6.5 -2
Japan -6 2.7
Latvia -8 -63.8
Lithuania -8 -62.6
Luxembourg -28 -4.4
Netherlands -6 13
New Zealand 0 34.3
Norway 1 31.9
Poland -6 -16.2
Portugal 27 35.3
Romania -8 -53.1
Russian Federation 0 -29.7
Slovak Republic -8 -41.5
Slovenia -8 21.2
Spain 15 37.7
Sweden 4 -20.9
Switzerland -8 2.5
Ukraine 0 -62.7
United Kingdom -12.5 -15.2
-80 -60 -40 -20 0 20 40 60
Percentage change from 1990

- Options to reduce emissions include:
  - Improved abatement technologies
  - Renewable energy
  - Tradable Permits for Emissions



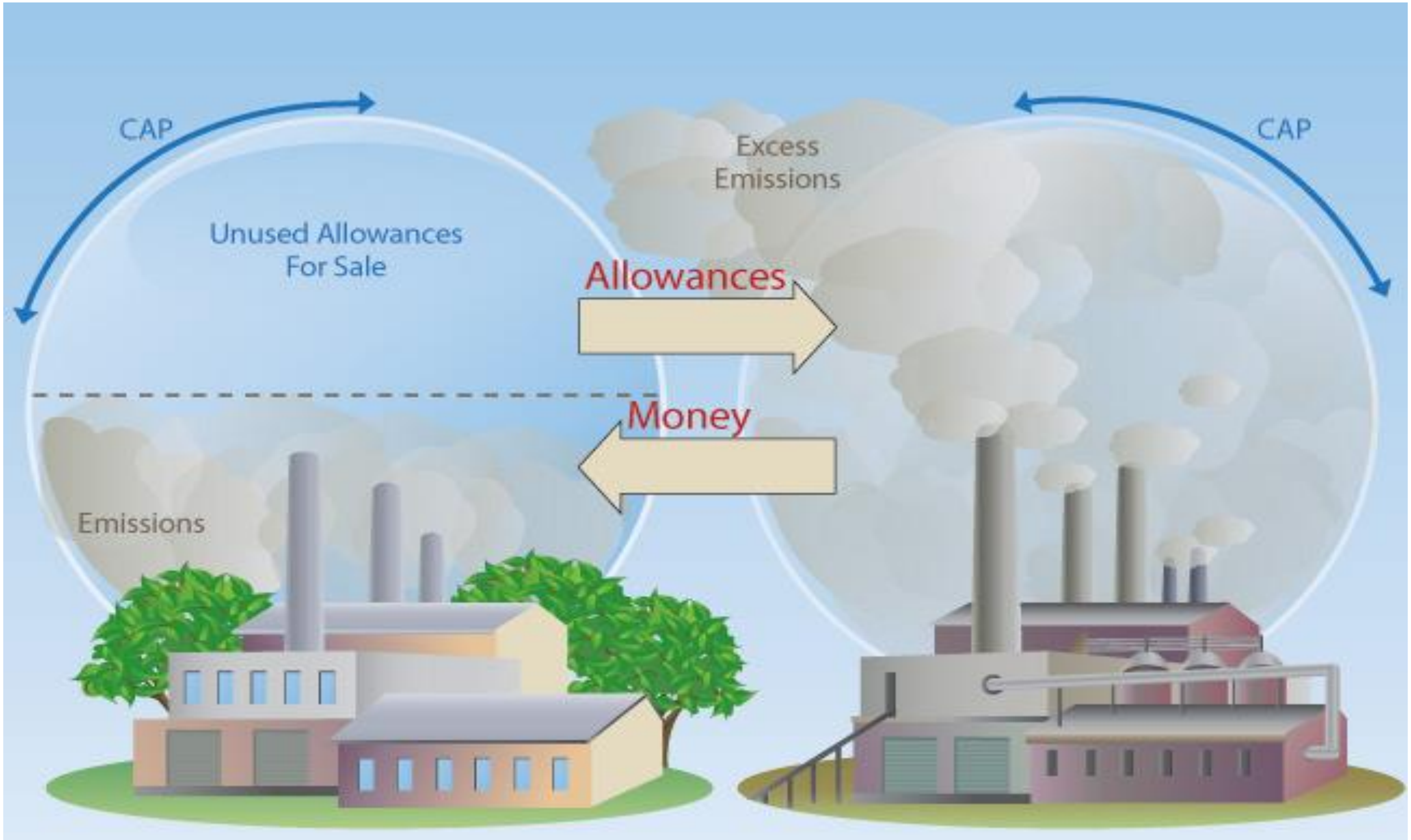
Carbon Policy

- Carbon Policy: carbon tax and cap-and-trade.

- 1) Carbon Tax is more about 'Price'.
  - The carbon tax puts a direct price on each tonne of carbon (or GHG emitted) thereby sending a price signal that will, over time, elicit a market response across the economy to reduce carbon emissions.

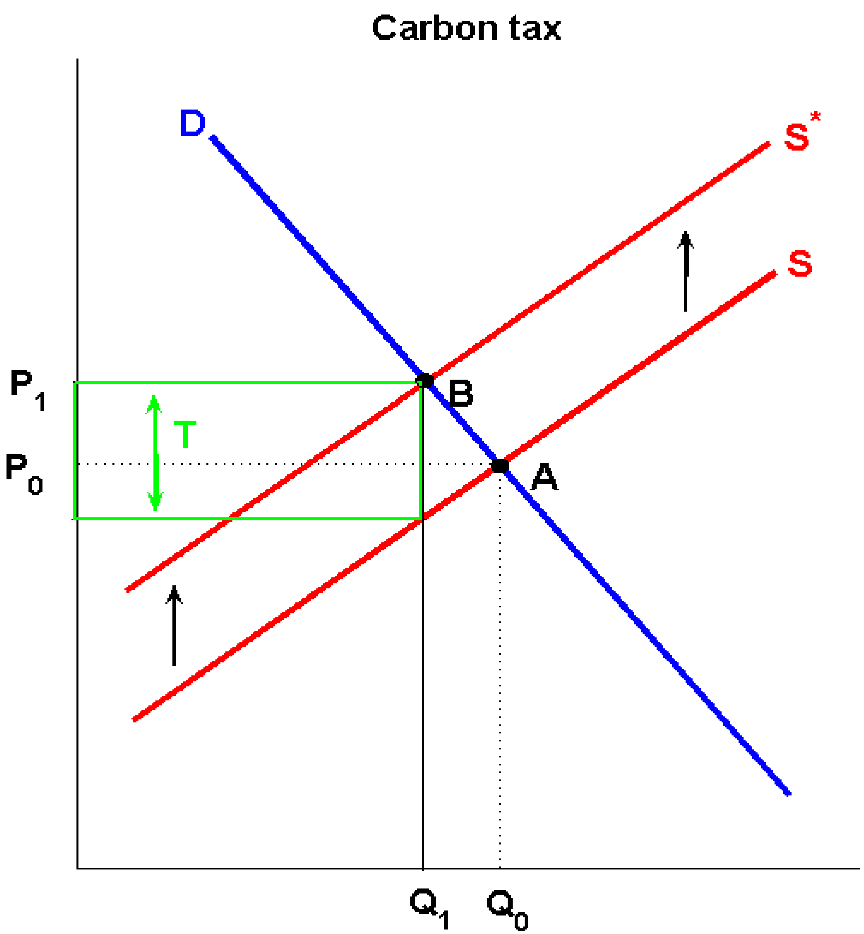
- 2) Carbon Cap and Trade is more about 'Quantity'.
  - The carbon cap system sets an absolute limit on the quantity of carbon emissions across specified industrial sectors. At the same time, the permits for each tonne of carbon emissions that specified industrial sectors get can be sold and transferred within the system.

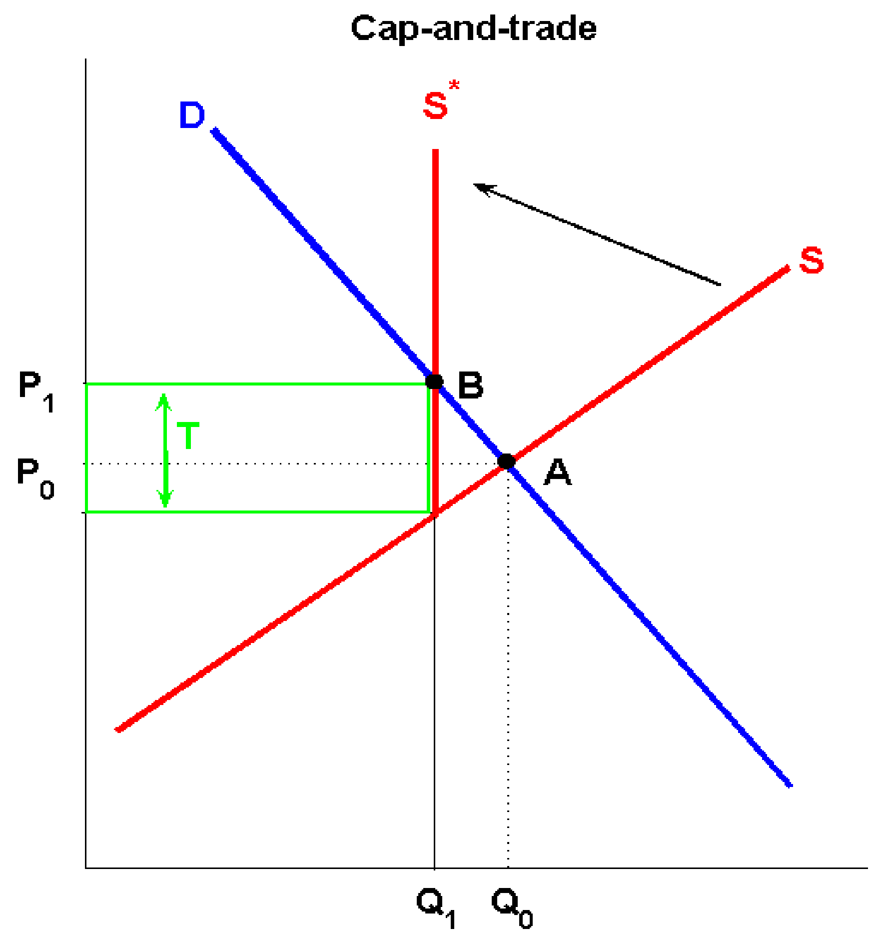
Idea is …



Calwatchdog.com (2013)

Tax vs. Cap-and-Trade





Cap-and-Trade

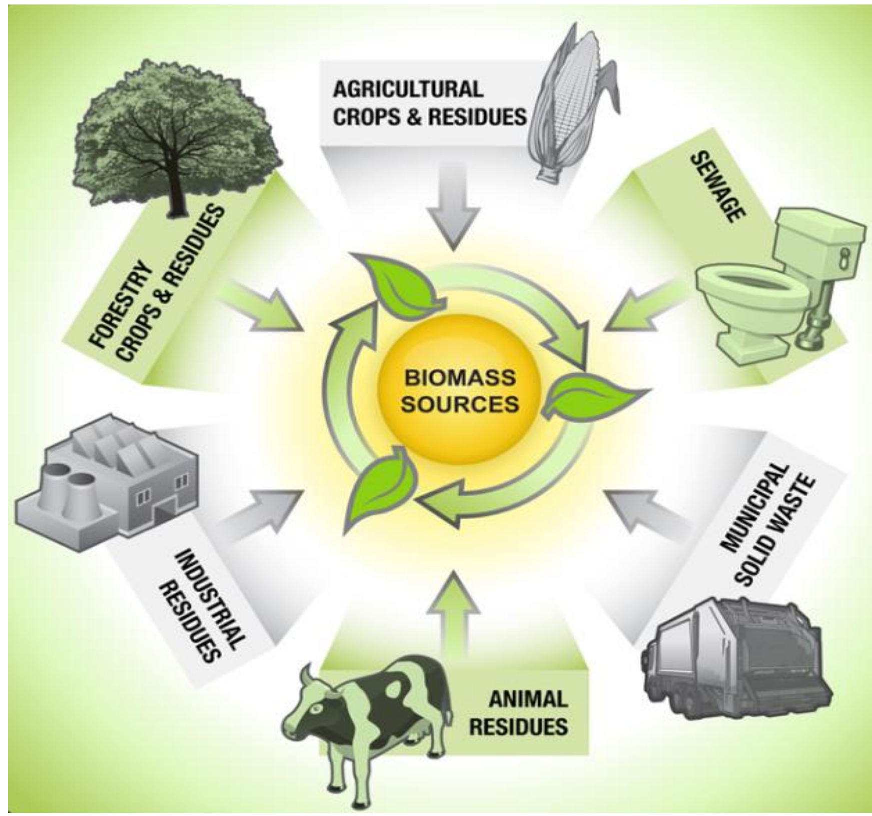
- Goal:
  - Reduce carbon dioxide and other greenhouse gas emissions economy-wide in a cost-effective manner.
- Cap (碳總量管制)
  - Each large-scale emitter (company)
  - A limit on the amount of greenhouse gas that it can emit.
    - Emission Permits
    - Over time more restrictive
- Trade (碳交易)
  - Some companies will reduce their emissions below their required limit more quickly and efficiently than others.
  - They can sell their extra permits to other companies.

Agriculture Example

- Create an incentive for carbon-emitting industries to buy less carbon intensive forms of energy.

- Biofuels grown on America's farms and ranches

- An incentive to pay farmers to employ conservation practices that actually take carbon dioxide out of the air and store it in the soil.



Agriculture Example

- Create a market for how farmers grow in addition to what they grow.

- Through conservation practices like no-till farming and the use of buffer strips that fix carbon in the soil and keep it there, farmers can offset carbon emissions in a more cost-efficient way than many companies.

- As a result, farmers could provide the low-cost means of meeting the greenhouse gas cap for private companies.

Video Time

International Trade

- Unless all the big carbon-intensive economies reduce their emissions – there is little chance for reducing global warming.

- If the U.S. implements a carbon reduction policy – what about countries that don't?
  - US Energy Secretary Steven Chu :

    Place tariffs on countries that don't comply (carbon duties).

    China has threatened a trade war if faced with carbon duties.

- Critics say that the U.S. cap and trade will reduce our competitive advantage and hurt our economy (issue!?).

Trading Economic Analysis

- Quantity regulation
  - Total allowable emissions capped.
  - Price determined by the market (i.e., auction)
- Total number of allowances created to match cap
- Allowances may be traded on a market
- Individual firms abate until $MAC = P_{permit}$, where MAC is marginal abatement cost
- The way you allocate the allowances does not affect the market price

Marginal Abatement Cost (MAC)

Environmental Externalities

- Economic solutions to environmental externalities, such as the air pollution, often include emissions taxes and permit trading systems.

- Policy-makers need to determine the marginal abatement costs (MAC) or shadow prices (SP) of pollutants to represent the costs of reducing one extra unit of pollutant.

- The emission trading mechanism is based on Coase's assertion (Coase, 1960) that if trading in an externality and absent a transaction cost, bargaining will lead to an efficient outcome regardless of the initial allocation of property rights trading.

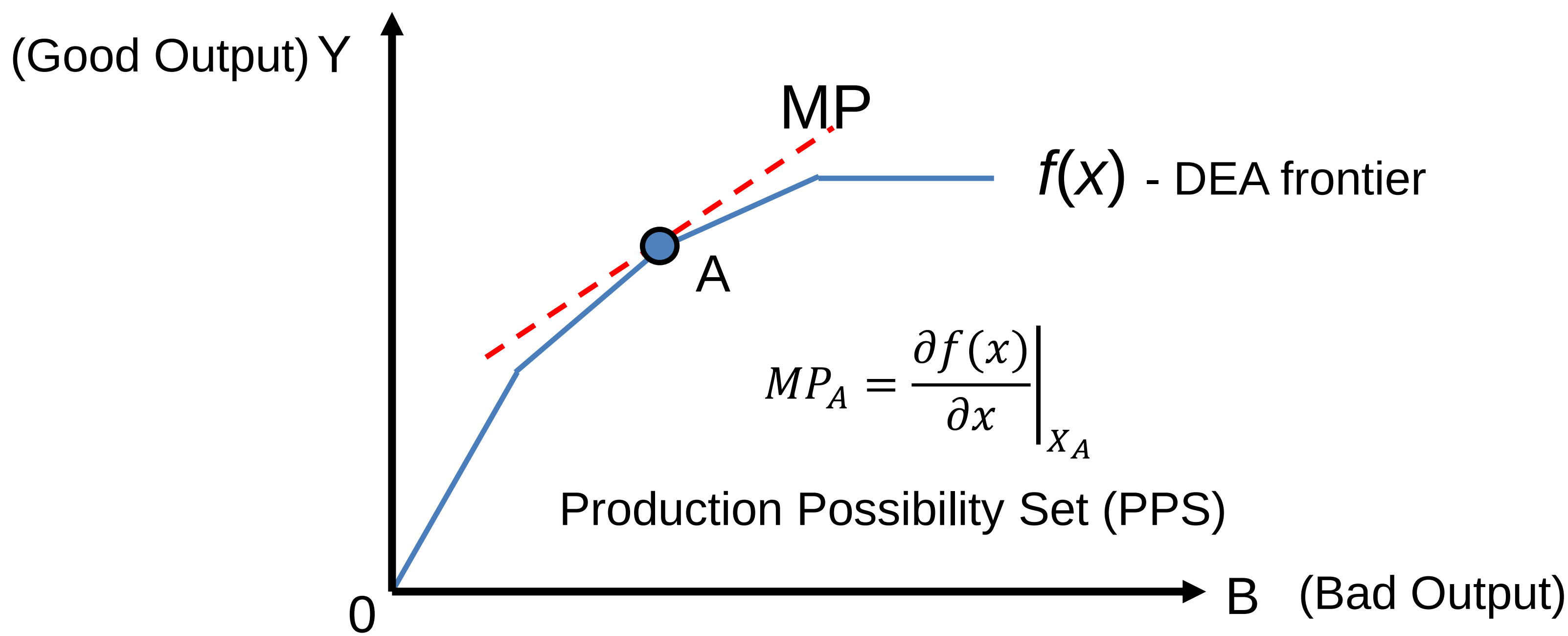
- Since 2013, seven pilot provinces and provincial cities, i.e. Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Chongqing and Hubei, have successively launched their emission trading scheme.

How much does it cost to abate one extra tone of pollution emission?

Directional Marginal Productivity

- The shadow prices (SP) of pollutants are used as a reference value to the allowance price in the trading market (Lee et al., 2002).

- Estimate the marginal product (MP) with respect to one efficient benchmark to derive the SP (Keilback, 1995), which is a differentiable characteristic of the production function.
  - Dual variables in data envelopment analysis (DEA)



Literatures for MAC estimation

POLab

- Profit Maximization

Good Output ↗ $p'_y y$, Bad Output ↗ $p'_b b$, Input ↗ $p'_x x$

$$\pi(p_y, p_b, p_x) = \max_{y,b,x} p'_y y - p'_b b - p'_x x$$

$$\text{s.t. } F(x, y, b) = 0$$ (Production Transformation Function)

- Lagrange function: $\max_{y,b,x} p'_y y - p'_b b - p'_x x + \varphi F(x, y, b)$

- First-order conditions (FOCs):
  - $p_{y_j} + \varphi \frac{\partial F(x,y,b)}{\partial y_j} = 0$
  - $-p_{b_q} + \varphi \frac{\partial F(x,y,b)}{\partial b_q} = 0$
  - $-p_{x_i} + \varphi \frac{\partial F(x,y,b)}{\partial x_i} = 0$
  - $F(x, y, b) = 0$

- Marginal Abatement Cost

$$p_{b_q} = p_{y_j} \left(\frac{\partial F(x,y,b)}{\partial b_q} / \frac{\partial F(x,y,b)}{\partial y_j} \right)$$

How to calculate the derivative of a production function?

Literatures for MAC estimation

- Stochastic Frontier Analysis (SFA) (Färe et al., 2005)
  - Parametric method
  - Translog functional form
  - Directional distance function

$$\text{Min} \sum_n \left[\vec{D}_o(x^n, y^n, b^n; g_y, -g_b) - 0\right]$$

$$\text{s.t. } \vec{D}_o(x^n, y^n, b^n; g_y, -g_b) \geqslant 0;$$

$$\partial\vec{D}_o(x^n, y^n, b^n; g_y, -g_b)/\partial y^n \leqslant 0;$$

$$\partial\vec{D}_o(x^n, y^n, b^n; g_y, -g_b)/\partial b^n \geqslant 0;$$

$$\partial\vec{D}_o(x^n, y^n, b^n; g_y, -g_b)/\partial x^n \geqslant 0;$$

$$g_y \sum_j \alpha_j - g_b \sum_k \alpha_k = -1;$$

$$g_y \sum_j \sum_{j'} \gamma_{jj'} - g_b \sum_j \sum_k \gamma_{jk} = 0;$$

$$g_y \sum_j \sum_k \gamma_{jk} - g_b \sum_k \sum_{k'} \gamma_{kk'} = 0;$$

$$g_y \sum_i \sum_j \beta_{ij} - g_b \sum_i \sum_k \beta_{ik} = 0;$$

$$g_y^2 \sum_j \sum_{j'} \gamma_{jj'} + g_b^2 \sum_k \sum_{k'} \gamma_{kk'} - g_y g_b \sum_j \sum_k \gamma_{jk} = 0;$$

$$\gamma_{ii'} = \gamma_{i'i},\ i \neq i';\ \gamma_{jj'} = \gamma_{j'j},\ j \neq j',\ \gamma_{kk'} = \gamma_{k'k},\ k \neq k'$$

$$\begin{aligned}
\ln D(x, y, b) = {} & \alpha_0 + \sum_i \alpha_i \ln x_i + \sum_j \alpha_j \ln y_j + \sum_k \alpha_k \ln b_k \\
& + \frac{1}{2} \sum_i \sum_{i'} \gamma_{ii'} \ln x_i \ln x_{i'} + \frac{1}{2} \sum_j \sum_{j'} \gamma_{jj'} \ln y_j \ln y_{j'} \\
& + \frac{1}{2} \sum_k \sum_{k'} \gamma_{kk'} \ln b_k \ln b_{k'} + \sum_j \sum_k \gamma_{jk} \ln y_j \ln b_k \\
& + \sum_i \sum_j \beta_{ij} \ln x_i \ln y_j + \sum_i \sum_k \beta_{ik} \ln x_i \ln b_k \gamma_{ii'} \\
& = \gamma_{i'i},\ i \neq i';\ \gamma_{jj'} = \gamma_{j'j},\ j \neq j';\ \gamma_{kk'} = \gamma_{k'k}, k \neq k
\end{aligned}$$

Literatures for MAC estimation

- Data Envelopment Analysis (Lee et al. 2002)
  - Nonparametric method
  - Directional distance function
  - Dual variables

$$\vec{D}_o(x, y, b; g_y, g_b) = \max_{\lambda\beta} \beta$$

$$\text{s.t. } Y\lambda \geqslant (1 + \beta g_y) y^n;$$

$$B\lambda = (1 - \beta g_b) b^n;$$

$$X\lambda \leqslant x^n;$$

$$\beta, \lambda \geqslant 0$$

However…

Previous studies have estimated the shadow prices of individual undesirable outputs separately.

Marginal Abatement Cost (MAC)

- This equation $p_b = p_y \left(\frac{\partial \vec{D}_O(x,y,b;g^y,g^b)}{\partial b} \Big/ \frac{\partial \vec{D}_O(x,y,b;g^y,g^b)}{\partial y} \right)$, which takes derivatives with respect to one specific undesirable output to estimate its shadow price, implicitly assumes that a firm can generate only one type of pollutant at a time when increasing one extra unit of input.

- That is, estimating the shadow price of SO_2 is independent of estimating the shadow price of NO_x.

- In reality, the production process generates multiple undesirable outputs simultaneously when producing desirable outputs. Thus, estimating shadow prices separately may lead to an overestimation of marginal productivity and an underestimation of shadow price.

How to estimate the marginal effects of multiple bad outputs simultaneously when burning one extra unit of coal?

Directional Marginal Productivity (DMP)

DMP with Bad Outputs

- Kuosmanen and Podinovski (2009) introduce the weak disposability property which forms a convex technology with undesirable outputs.

MP for multiple outputs given a pre-determined direction (g^{Y_j}, g^{B_q})

$$\text{Min } v_{i^*}$$

$$\text{s.t. } \sum_i v_i \frac{X_{ir}}{X_i^{Max}} - \sum_j u_j \frac{Y_{jr}}{Y_j^{Max}} + \sum_q w_q \frac{B_{qr}}{B_q^{Max}} + u_0 = 0$$

$$\sum_i v_i \frac{X_{ik}}{X_i^{Max}} - \sum_j u_j \frac{Y_{jk}}{Y_j^{Max}} + \sum_q w_q \frac{B_{qr}}{B_q^{Max}} + u_0 \geq 0, \forall k$$

$$\sum_i v_i \frac{X_{ik}}{X_i^{Max}} + u_0 \geq 0, \forall k$$

$$\sum_{j \in J^*} u_j g^{Y_j} + \sum_{q \in Q^*} w_q g^{B_q} = 1$$

$$v_i, u_j \geq 0, \; w_q, u_0 \text{ are free}$$

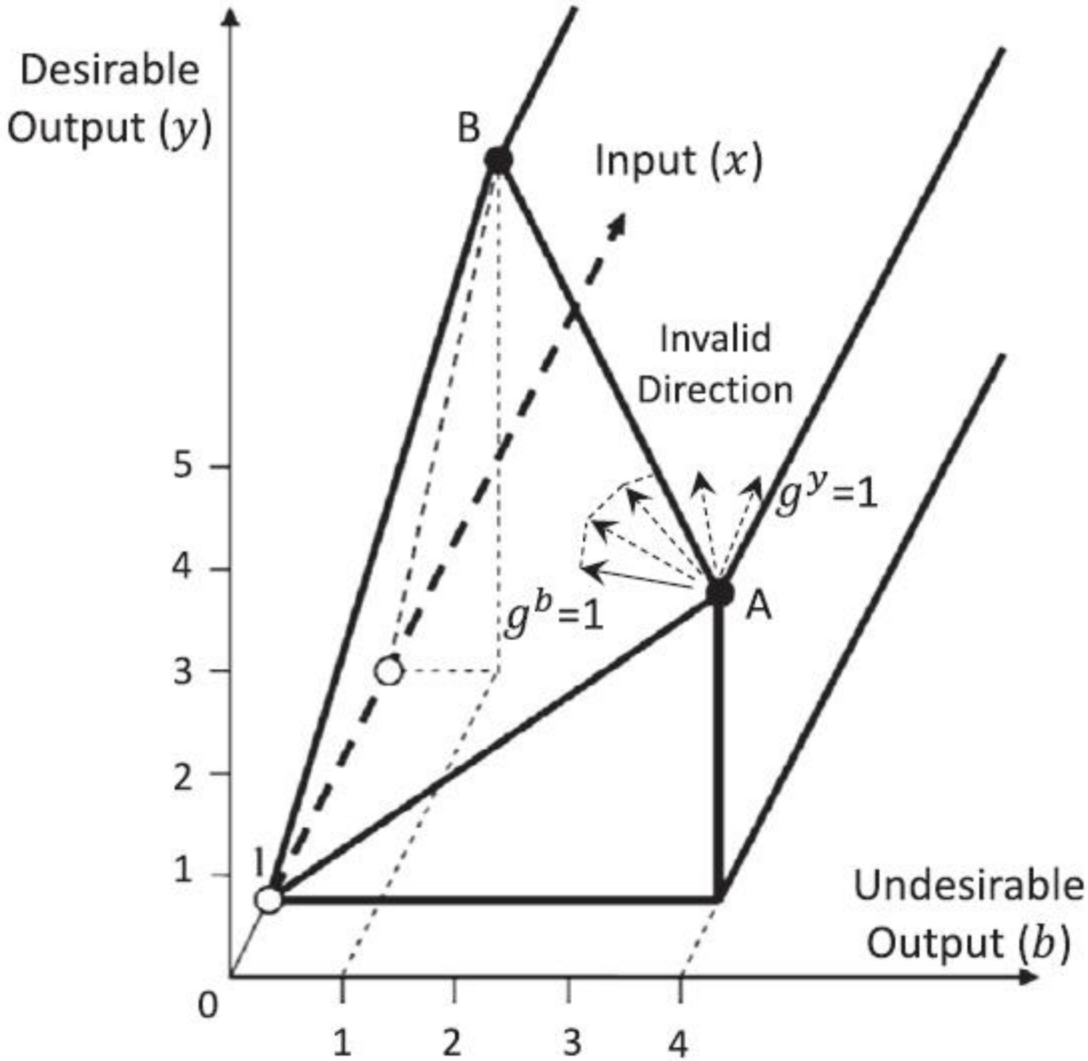
$$\frac{\partial(Y_{jr}, B_{qr})}{\partial X_{i^*r}} = v_{i^*}\left(g^{Y_j} Y_j^{Max}, -g^{B_q} B_q^{Max}\right) / X_{i^*}^{Max}$$

Directional Marginal Productivity (DMP)

Note: $\sum_{j \in J^*} g^{Y_j} + \sum_{q \in Q^*} g^{B_q} = 1$ for unit simplex (Färe et al., 2013)

Marginal Abatement Cost (MAC)

- DMP with Bad Output



Lee (2014)

Marginal Abatement Cost (MAC)

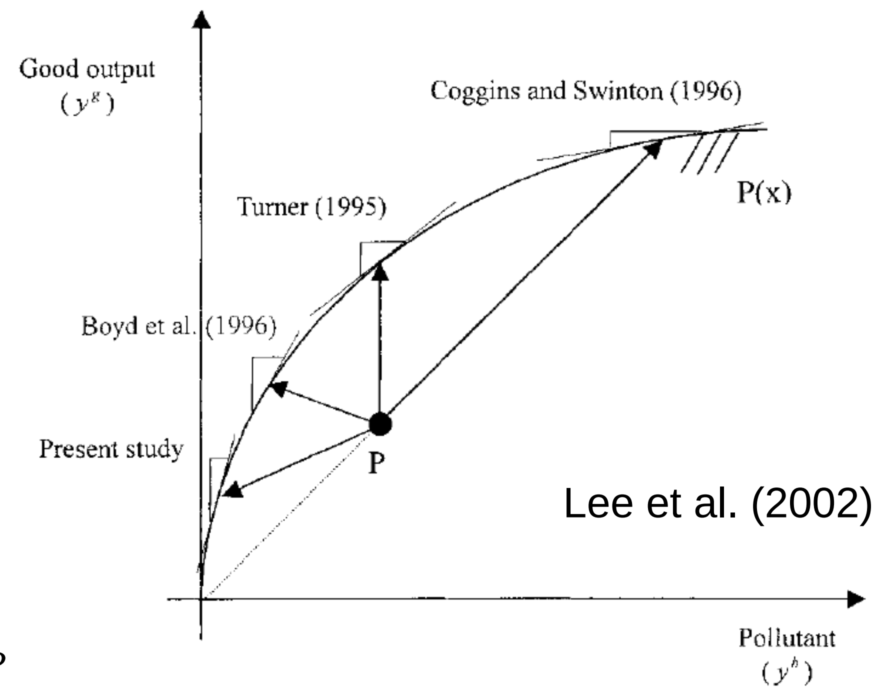
- Directional Shadow Prices of Pollutants p_{b_q} (Lee and Zhou, 2015)
- $p_{b_q} = p_{y_j}\left(\frac{\partial F(x,y,b)}{\partial b_q} / \frac{\partial F(x,y,b)}{\partial y_j}\right) = p_{y_j}\left(\frac{\partial y_j}{\partial b_q}\right) = p_{y_j}\left(\frac{\partial y_j}{\partial x_i} / \frac{\partial b_q}{\partial x_i}\right)$

- Given direction vector (g^{Y_j}, g^{B_q})
- $\left(\frac{\partial y_j}{\partial x_i}, \frac{\partial b_q}{\partial x_i}\right)$: DMP of good output and bad output

$$\frac{\partial(Y_{jr}, B_{qr})}{\partial X_{i^*r}} = v_{i^*}\left(g^{Y_j} Y_j^{Max}, -g^{B_q} B_q^{Max}\right) / X_{i^*}^{Max}$$

Directional Marginal Productivity (DMP)

Directional Shadow Price (DSP)



Lee et al. (2002)

Empirical Study of Coal-Fired Power Plant in U.S.

Empirical Study

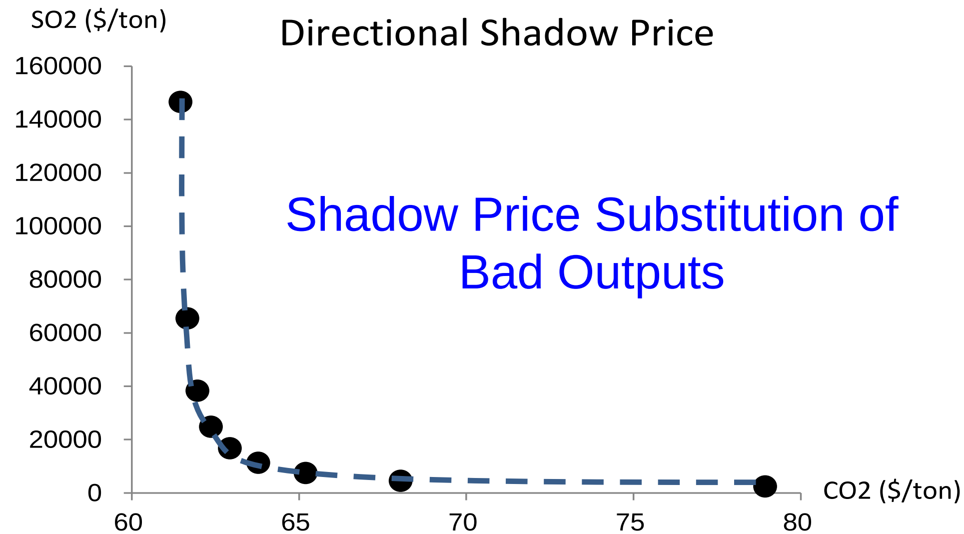
- Empirical Study: 2010 U.S. Coal Power Plants
- 48 observations of state-level dataset
- Inputs and Outputs
  - One desirable output: the annual amount of electricity generated by coal in Megawatt-hours (MWh).
  - Three undesirable outputs: the annual amount in tons of CO_2, SO_2 and NO_x.
  - One input: the annual amount in tons of coal consumption.
  - The average electricity price (p_y) is a weighted calculation among residential, commercial and industrial prices measured in dollars per MWh.

Empirical Study

DMP and DSP of CO_2 and SO_2

Direction	DMP	DSP
$(g^{B_{CO_2}}, g^{B_{SO_2}}, g^{B_{NOx}})$	$\frac{\partial(B_{CO_2}, B_{SO_2}, B_{NOx})}{\partial X}$	$(p_{b_{CO_2}}, p_{b_{SO_2}}, p_{b_{NOx}})$
(1, 0, 0)	(2.0273, 0, 0)	(61.41, N/A, N/A)
(0.9, 0.1, 0)	(2.0060, 0.0008, 0)	(61.47, 146485, N/A)
(0.8, 0.2, 0)	(1.9755, 0.0019, 0)	(61.67, 65317, N/A)
(0.7, 0.3, 0)	(1.9615, 0.0032, 0)	(61.97, 38288, N/A)
(0.6, 0.4, 0)	(1.9545, 0.0049, 0)	(62.37, 24774, N/A)
(0.5, 0.5, 0)	(1.9502, 0.0074, 0)	(62.94, 16666, N/A)
(0.4, 0.6, 0)	(1.9472, 0.0110, 0)	(63.79, 11261, N/A)
(0.3, 0.7, 0)	(1.9450, 0.0171, 0)	(65.21, 7400, N/A)
(0.2, 0.8, 0)	(1.6151, 0.0244, 0)	(68.04, 4504, N/A)
(0.1, 0.9, 0)	(1.0208, 0.0294, 0)	(78.94, 2322, N/A)
(0, 1, 0)	(0, 0.0718, 0)	(N/A, 1167, N/A)

Individual Shadow Price (ISP)



Direction Generation $(g^{B_{CO2}}, g^{B_{SO2}}, g^{B_{NOx}})$

- Two different two-stage benchmarking techniques: a literature-based method and an individual-SP method
- Stage 1 narrows down the infinite possible vectors into two alternatives and Stage 2 derives the better one.
- In Stage 1 we can find the direction so that the DSP shows equally proportional to the SP estimates of the three pollutants generated from these two techniques.

Method	Literature-based			Method	Individual-SP		
Direction $(g^{B_{CO2}}, g^{B_{SO2}}, g^{B_{NOx}})$	0.048	0.508	0.444	Direction $(g^{B_{CO2}}, g^{B_{SO2}}, g^{B_{NOx}})$	0.045	0.631	0.324
DSP	136	3403	19049	DSP	137	2585	24629
Maximal SP in Literature (MSPL)	124	3107	17393	Individual SP (ISP)	61	1167	11149
Benchmarking Ratio (DSP/MSPL)	1.10	1.10	1.10	Benchmarking Ratio (DSP/ISP)	2.23	2.22	2.21

Empirical Study

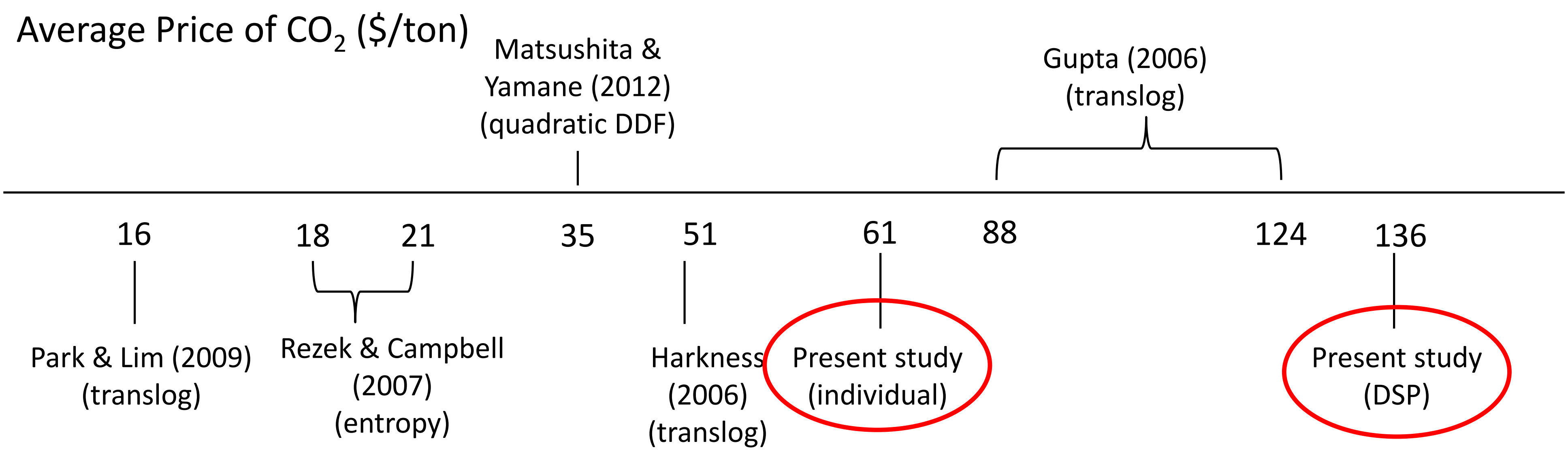
Direction Generation ($g^{B_{CO_2}}$, $g^{B_{SO_2}}$, $g^{B_{NO_x}}$)

- In Stage 2 we decide the best direction by testing the robustness of the directions generated from Stage 1 via a comparison with Boyd et al. (1996) and Turner (1995).
- Through a literature-based method, we found that the direction ($g^{B_{CO_2}}$, $g^{B_{SO_2}}$, $g^{B_{NO_x}}$)=(0.048, 0.508, 0.444).

	Method	Literature-based			Method	Individual-SP		
	Direction ($g^{B_{CO_2}}$, $g^{B_{SO_2}}$, $g^{B_{NO_x}}$)	0.048	0.508	0.444	Direction ($g^{B_{CO_2}}$, $g^{B_{SO_2}}$, $g^{B_{NO_x}}$)	0.045	0.631	0.324
Boyd et al. (1996)	DSP	128	3212	17983	DSP	131	2478	23615
	Benchmarking Ratio (DSP/MSPL)	1.03	1.03	1.03	Benchmarking Ratio (DSP/ISP)	1.85	1.838	2.16
Turner (1995)	DSP	125	3121	17470	DSP	128	2410	22965
	Benchmarking Ratio (DSP/MSPL)	1.01	1.01	1.01	Benchmarking Ratio (DSP/ISP)	2.06	1.82	3.04

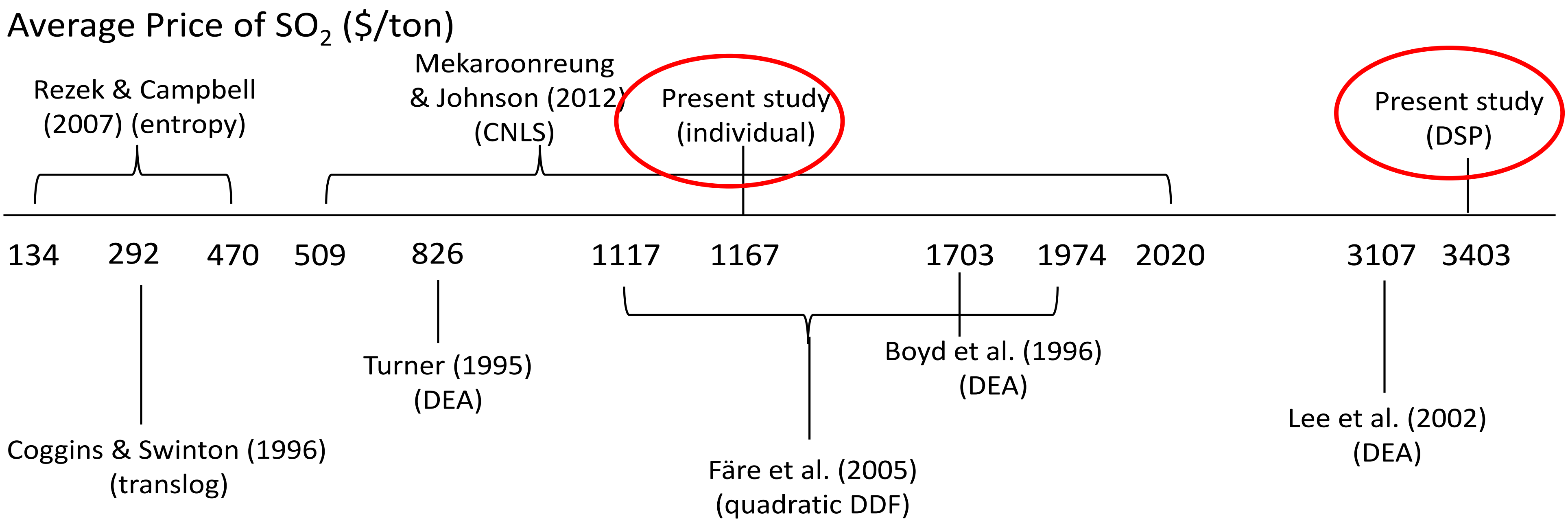
Note that both Boyd et al. (1996) and Turner (1995) project inefficient firms to the frontier according to the different directions (g^Y, g^B).

- Comparison of studies for shadow price estimations in electric power sectors



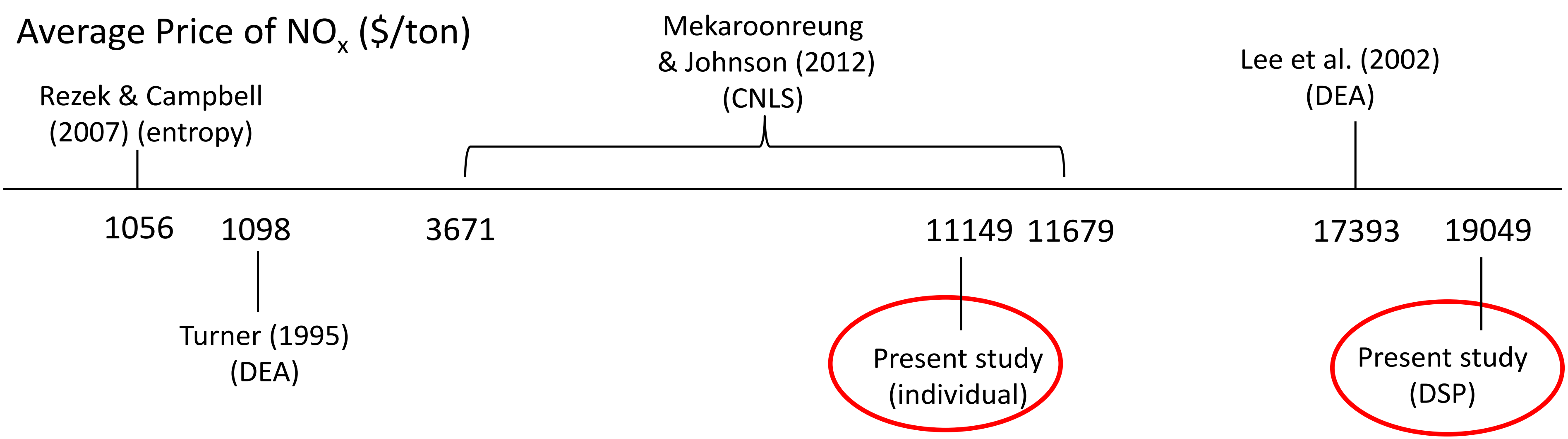
PO Lab

- Comparison of studies for shadow price estimations in electric power sectors

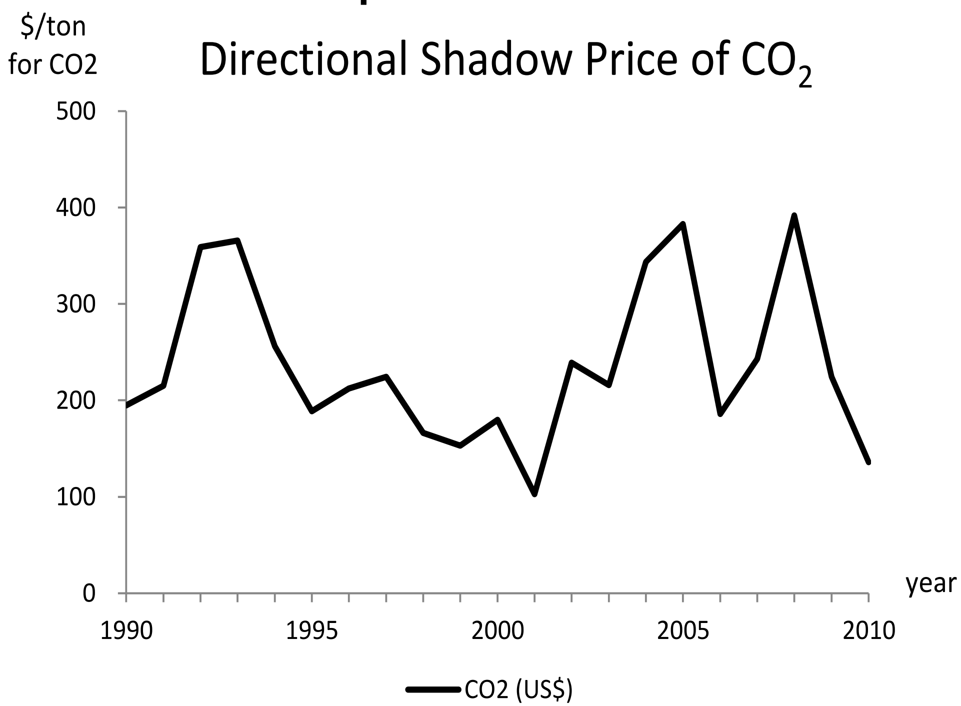


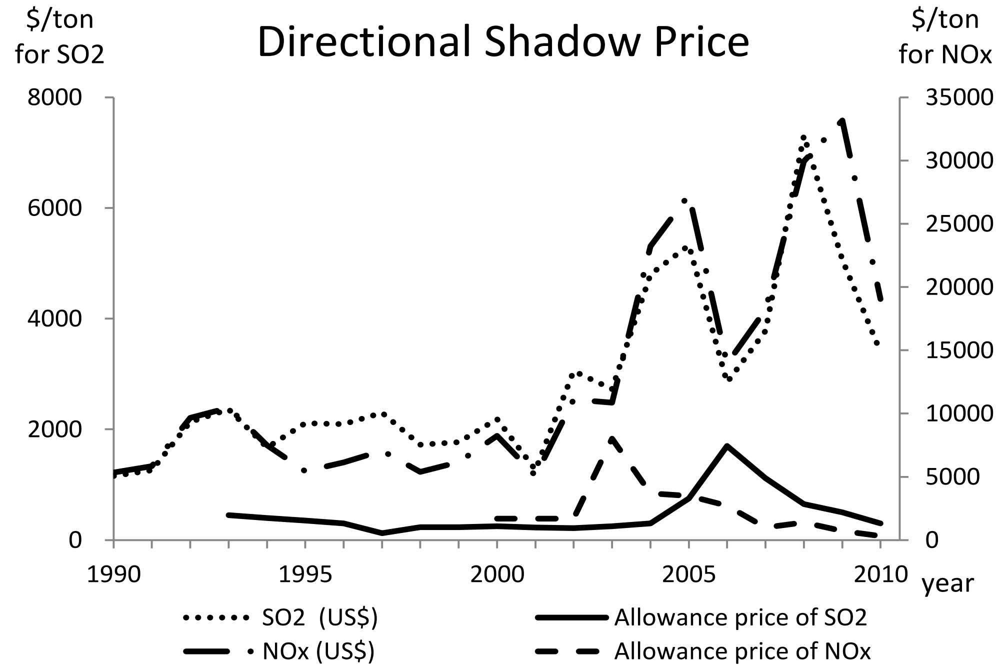
Empirical Study

- Comparison of studies for shadow price estimations in electric power sectors



DSP of pollutants in 1990-2010

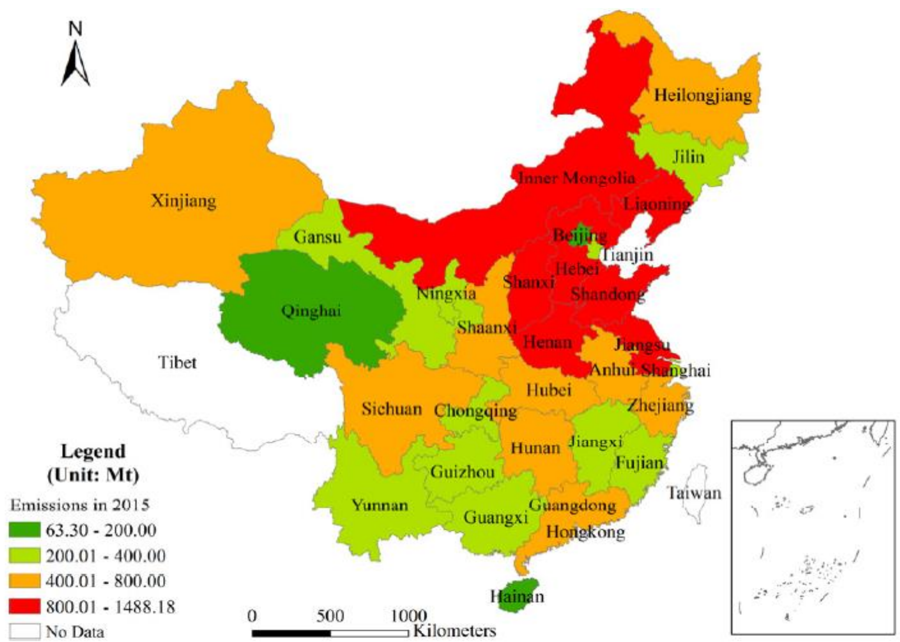




- The DSPs of SO_2 and NO_x rise gradually due to a successful emission reduction and Clean Air Interstate Rule (CAIR) beginning in 2010.
- Allowance prices rose in 2003 & 2006 since CAIR provided incentives for utilities to purchase allowances and bank them for future use.
- After 2005, emission levels fell because of the increased use of gas-fired boilers and pollution control equipment. Thus, an excess supply of allowances in the market caused allowance market prices to fall.

Empirical Study of Coal-Fired Power Plant in China

2013 China Coal Power Plants in North and Northeast regions



Deng et al. (2015)

Empirical Study

Managerial Insights (Engineering Perspective)

- The higher MACs of SO_2 implies that the abatement technology of SO_2 in coal-fired power industry is urgent.
  - In fact, the key components of urban smog and acid rain are emissions of SO2 (Zhang and Samet, 2015).

- Nevertheless, it also implies the development of abatement technology on reducing SO_2 is not affordable. Thus, in the short run, the province should tend to purchase emission allowances of SO_2 from the market if the allowance price is much lower than MAC (in 2013 the average allowance price of carbon in Beijing is US$8.78 per tonne and US$5.18 in Tianjin, respectively).

- The lower MAC of NO_x implies that the plant is encouraged to invest the development of the NO_x abatement techniques at the present stage. Though the allowance price is lower than MAC, in the long run, when carbon regulation becomes more and more stringent, the MAC and allowance price is likely to rise.

Empirical Study

Managerial Insights (Market Perspective)

- MAC should reflect the market prices for Environmental Protection Agency (EPA)'s pollutant allowances. However, allowance price significantly reflects the investors' expectations regarding the environmental policy in the future.

- In 2013, China issued an <Air Pollution Prevention and Control Action Plan> to control PM2.5 and reduce the number of smoggy days.
  - limits the emissions, energy use, and technology migration.

- The sharp increase in SO_2 and NO_x prices resulting from environmental policy (eg. Acid Rain Program (ARP) and the Clean Air Interstate Rule (CAIR)), which required further SO2 and NOx reductions from power plants beginning in 2010 and caused an increase in the expected pollutant control costs in the future and provided incentives for utilities to purchase allowances and bank them for future use. (so…someone really in need cannot get it…)

Empirical Study

Managerial Insights (Market Perspective)

- In 2015, just before the Paris conference (Dec. 12), China submitted its INDC (Intended Nationally Determined Contributions)
  - (i) peak CO_2 emissions no later than 2030
  - (ii) increase the share of non-fossil fuels in the total energy supply to 20% by 2030
  - (iii) reduce the carbon intensity of GDP by 60-65% compared to 2005 levels by 2030

Concluding Remarks

Theoretical Benefits

- Directional marginal productivity (DMP)
- Marginal abatement cost (MAC) of bad outputs
- Shadow price substitution of bad outputs
- Comparison of previous studies: addressing the issue
  - estimating shadow prices separately may lead to an overestimation of marginal productivity and an underestimation of shadow price

Practical Benefits

- Provide environmental policy guidelines and support Cap-and-Trade
  - the allowance price in emission trading markets
  - the penalty rates for pollutant emission
- Bidding or Auction → Reasonable marginal abatement cost (MAC)
  - Reduce the **fluctuation** of the market price caused by the “**expectation**”

Conclusions

Summary

- Support Cap-and-Trade regulation in Asia regions
  - In 2014 China established 7 environment exchange.
  - Beijing, Tianjin, Shanghai, Shenzhen, Guangzhou, Hubei, Chongqing for carbon trading (by bidding or auction)

Date	Trading Volume (tonne)	Average Price (CNY$/tonne)	Total (CNY$)
Nov. 14, 2014	800	52	41,600

  - http://www.bjets.com.cn/

Final Goal: Pollution Emission Reduction!

Marginal Abatement Cost (MAC)

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Directional shadow price estimation of CO_2, SO_2 and NO_x in the United States coal power industry 1990–2010

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ABSTRACT

Shadow prices, also termed marginal abatement costs, provide valuable guidelines to support environmental regulatory policies for CO_2, SO_2 and NO_x, the key contributors to climate change. This paper complements the existing models and describes a directional marginal productivity (DMP) approach to estimate directional shadow prices (DSPs) which present substitutability among three emissions and are jointly estimated. We apply the method to a case study of CO_2, SO_2 and NO_x produced by coal power plants operating between 1990 and 2010 in the United States. We find that DSP shows 1.1 times the maximal shadow prices estimated in the current literature. We conclude that estimating the shadow prices of each by-product separately may lead to an overestimation of the marginal productivity and an underestimation of the shadow prices.

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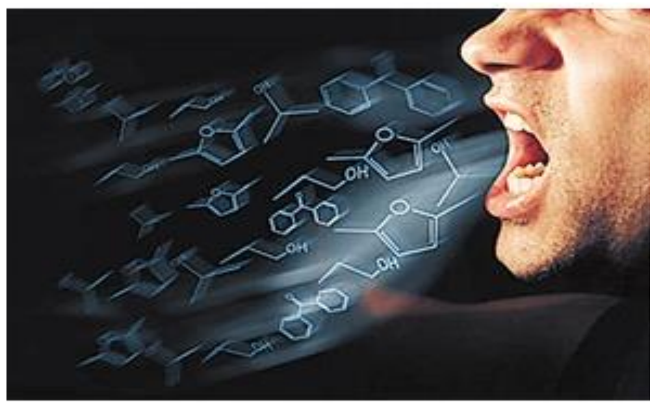
How about CO_2 emitted from your body?



Cost for One Breath

- Assumption: human body is Coal-fired power plant…
- If you emit CO_2 over the “CAP”…
  - Human may get 25920~28800 breaths a day
  - For example, the 28801th breath will cost you…

- One Breath: 500cc and 4% CO_2
- MAC of one metric ton
  - US$61 / 0.90718474 = 67.24098997
- Exchange rate to NTD
  - 67.24098997*30 = NTD$2017.229699
- MAC of one extra breath
  - NTD$2017.229699 * 0.5 * 0.04 =

40.34

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Allocation of Emission Permits (AEP)

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Thanks for your attention!

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