Co-control of CO_2 and Local Air Pollutants in the Electric Power Industry of China:

Application of Co-control Methodology

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Background on Power Industry

- Coal-dominated primary energy structure lead to a power structure dominated by coal-fired thermal power in China.

- From 2001 to 2010, the proportion of coal-fired thermal power capacity out of the national total was kept above **70%**, while power generation accounted for more than **80%**.

- 2001 – 2010, power industry accounted for more than **50%** of the total Coal consumption data .

- In 2009, **SO_2**, **NO_x**, and **CO_2** emissions from coal-fired power plants amounted to **9.48 million tonnes**, **8.65 million tonnes**, and **2.787 billion tonnes**, respectively, accounting for **42.81%**, **51.10%**, and **36.15%** of the national total.

Background on Power Industry

- Emission-reduction measures were implemented by the power industry during the 11th Five-Year Plan period (2006–2010).

- By the end of 2010, thermal power capacity with flue-gas desulfurization (**FGD**) installation surpassed **560 GW** or **86%** of the national total coal-fired power generation capacity.

- SO_2 emissions per unit power generation decreased by 14.67% compared with 2005.

- **But what about CO_2 and NOx and other pollutants?**

Counter Benefits of FGD

- FGD consumes electric power at 3.67 kWh/kg SO_2, indicating that when it decreases the emission of 1 kg of SO_2, it consumes 1.182 kg more SCE and emits more CO_2 (5.43 kg) and NO_x (0.016 kg).

- For 2010, it is estimated that, if all the FGD capacity worked well, then, when 8.46-23.8 million tons of SO_2 was reduced, it lead to annually increasing
  - ✓ $3.11*10^4$ - $8.73*10^4$ GWh of electricity,
  - ✓ 10.0 – 28.1 million tce of coal；
  - ✓ 45.9 – 129 million ton of CO_2 emission;
  - ✓ 0.135 – 0.381 million ton of NOx emission.

Counter Benefits of CCS and SCR

- If Carbon Capture and Storage/Sequestration (CCS) is implemented， how much extra SO_2 and NOx will be emitted ?
- If Selective Catalytic Reduction (SCR) for denitrification is implemented, how much extra SO_2 and CO_2 will be emitted ?
- Based on the data of 2009, if the reduction for NOx and CO_2 are,
  - ✓ Q_{NOx} = 1.2975 million ton (15% reduction)
  - ✓ Q_{CO2} = 557.00 million ton (20%reduction)
- Then, annual increase of,

Reduction technologies	Electricity use (billion kWh)	Coal use (SCE, million ton)	Emission (thousand ton)		
			SO_2	NOx	CO_2
(SCR)	2.579	0.8304	7.8	—	2,458.8
CCS	138.484	44.5920	724.6	613.1	—

With the methodology framework, there is a possibility of co-control in the power industry…..

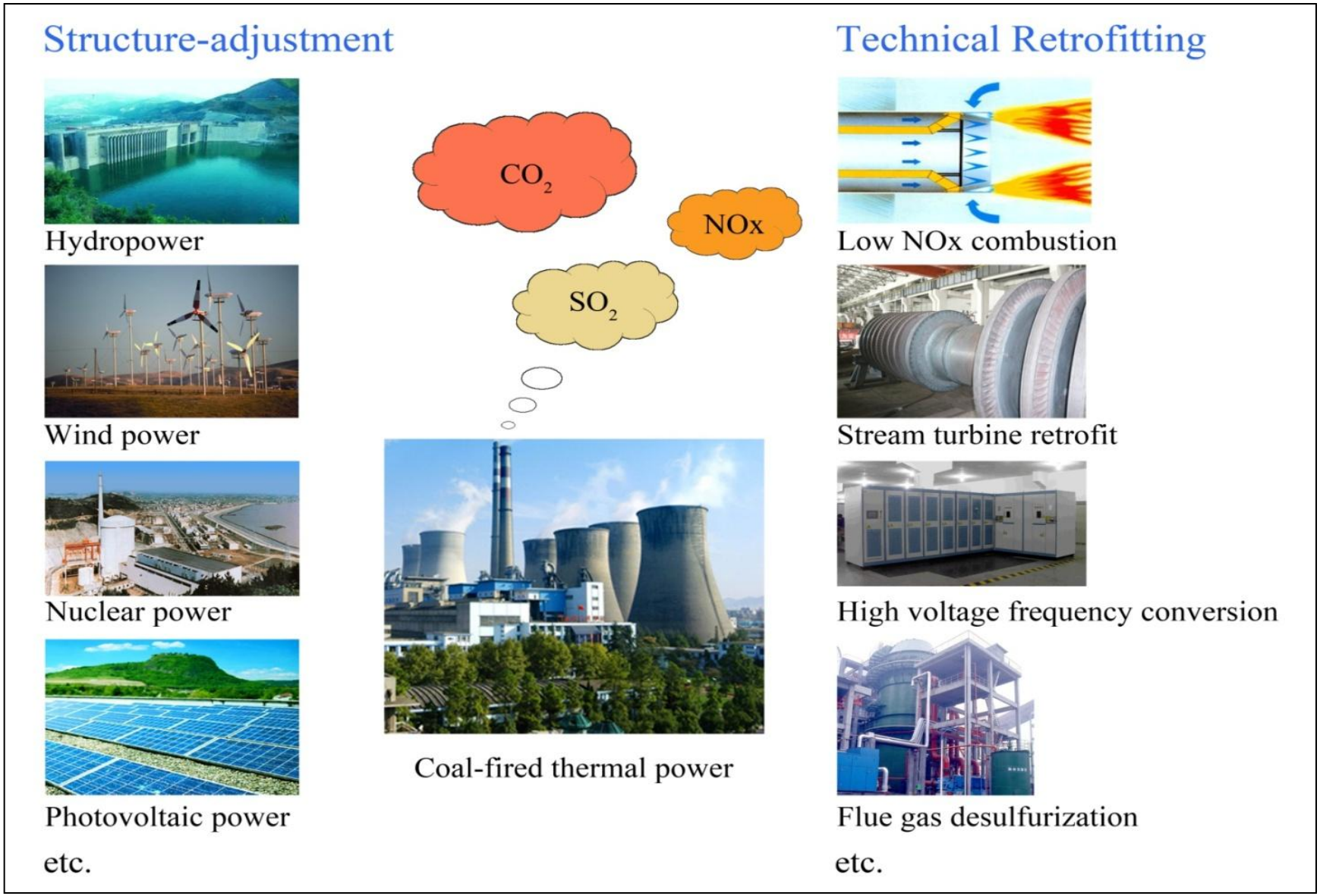

Table 1 Selected emission-reduction measures in the power industry of China

Classification of measures		Technical measures for emission reduction	
		Names of the measures	Abbreviation
Technical emission-reduction measures in coal-fired thermal power industry	front-end control measures	Coal washing	CW
	in-the-process control measures	Low NO_x combustion technique	LNC
		Retrofit of power station boiler air preheater for flexible contact seal	Air preheater retrofit (APR)
		Retrofitting condensing steam turbine unit into heat and power cogeneration	Combined heat and power (CHP)
		Retrofit of flow passage of stream turbine	Retrofit of flow passage (RFP)
		Retrofit of steam seal for stream turbine	Retrofit of steam seal (RSS)
		Pulverized coal low-power igniting technique	Low-power igniting(LPI)
		High voltage frequency conversion	HVC
		Intelligent boiler soot-blowing optimization & coking on-line early-alarm system	Coking alarm(CA)
	end-of-pipe control measures	Flue gas desulfurization	FGD
		Flue gas denitrification	FGDN
		Carbon Capture and Storage/Sequestration	CCS
Structure-adjustment emission-reduction measures in power industry	Thermal power industry restructuring	Substituting large sized units for small sized ones	SLFS
	New technology selection in new power plant	Circulating fluidized bed power generation technology	CFB
		Supercritical power generation (including desulfurization and denitrification)	SC
		Ultra-supercritical power generation (including desulfurization and denitrification)	USC
		Integrated gasification and combined cycle power generation technology	IGCC
		Natural gas power generation	GPG
		Hydropower	HPG
		Nuclear power generation	NPG
		Wind power generation	WPG
		Biomass power generation	BPG
		Photovoltaic power generation	PVG

Elasticity of technological reduction measures in thermal power industry

Type	Name	$Els_{c/s}$	$Els_{s/c}$	$Els_{c/n}$	$Els_{n/c}$	$Els_{n/s}$	$Els_{s/n}$
front-end control measures	CW	0.16	—	—	—	0.17	—
in-the-process control measures	LNC	—	—	0.02	—	—	0.02
	Air preheater retrofit (APR)	1.00	1.00	1.00	1.00	1.00	1.00
	Combined heat and power (CHP)	1.00	1.00	1.00	1.00	1.00	1.00
	Retrofit of flow passage (RFP)	1.00	1.00	1.00	1.00	1.00	1.00
	Retrofit of steam seal (RSS)	1.00	1.00	1.00	1.00	1.00	1.00
	Low-power igniting(LPI)	1.00	1.00	1.00	1.00	1.00	1.00
	HVC	1.00	1.00	1.00	1.00	1.00	1.00
	Coking alarm(CA)	1.00	1.00	1.00	1.00	1.00	1.00
end-of-pipe control measures	FGD	-0.02	—	—	—	-0.02	—
	FGDN	—	—	-0.01	—	—	-0.005
	CCS	—	-0.33	—	-0.34	—	—

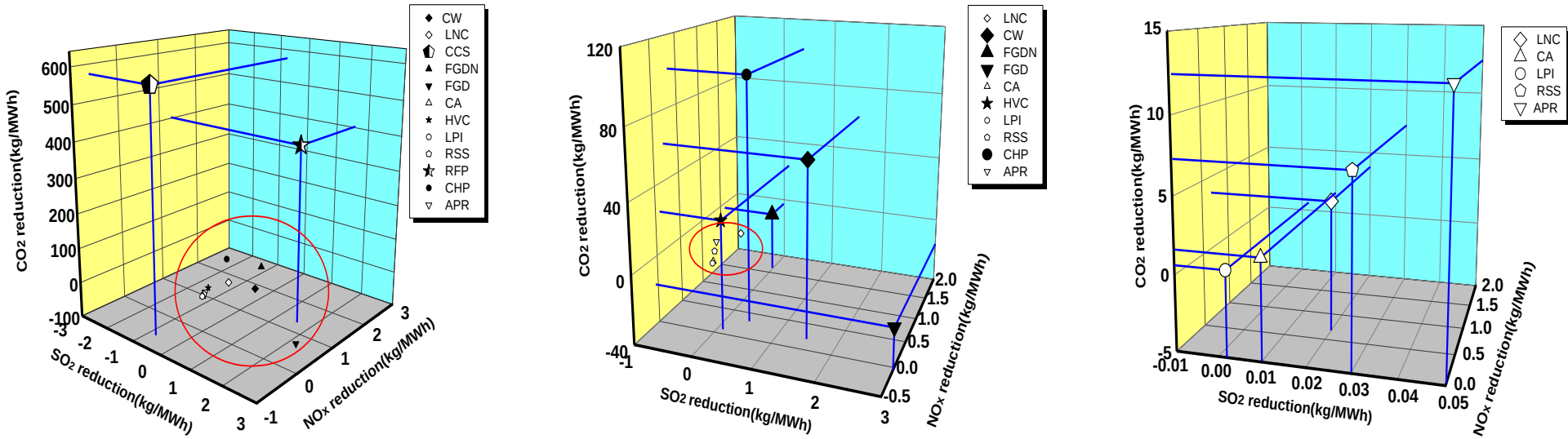

Figure 1. Three-dimensional coordinate system for SO_2, NO_x and CO_2 (Sector Average within China)

Co-control effects of technical emission-reduction measures in coal-fired thermal power industry

Implication from the co-control coordinate system analysis

- End-of-pipe measures reduce the emission of a specific pollutant but simultaneously increase that of the other two.
- For instance, carbon capture and storage/sequestration (CCS)

- Front-of-pipe control measures and in-the-process control measures often simultaneously reduce air pollutants and GHG emissions
- For example, coal washing (CW) ,Low NO_x combustion (LNC), Air preheater retrofitting (APR), combined heat and power (CHP), and retrofitting of steam seals for steam turbines (RSS).

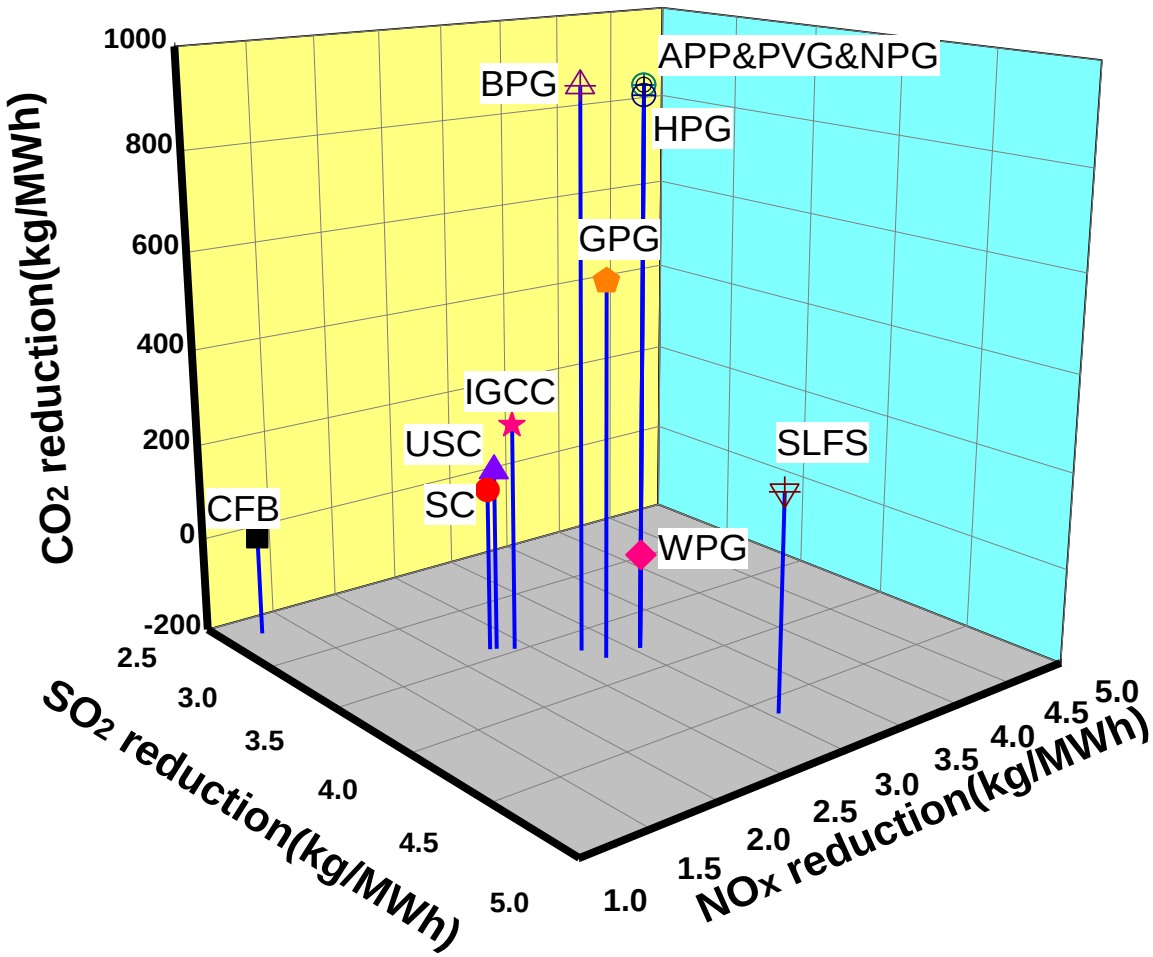

Figure 2. Three-dimensional coordinate system for SO_2, NO_x and CO_2 co-control effects of structure-adjustment emission-reduction measures in power industry

Implication from the co-control coordinate system analysis

- Structure-adjustment measures for the power industry or options for clean power generation technologies are diverse.
- New energy power generation technologies, such as hydropower (HPG), nuclear power (NPG), wind power (WPG), and photovoltaic power (PVG), present very low local air pollutant and CO_2 emission.
- Advanced coal-fired thermal power technologies, such as SC and USC power generation, improve power generation efficiency and reduce emissions
- VPP has excellent co-control effectiveness.

Design of multi-pollutant co-control routes based on Unit Pollutant Reduction Cost

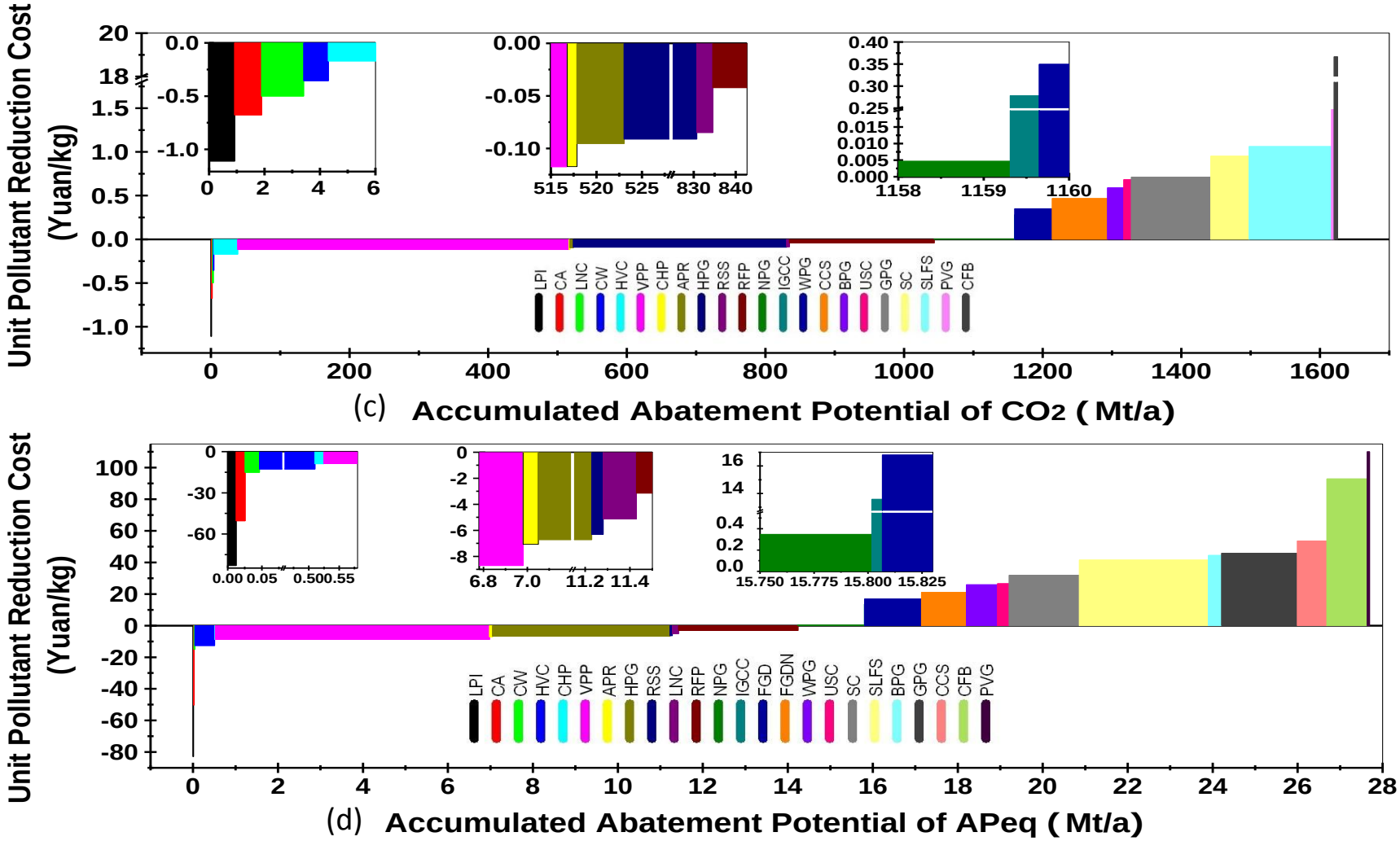

Figure 3. Potential and the routes of SO_2, NO_x, CO_2 and AP_{eq} emission reduction in China's power industry

Design of multi-pollutant co-control routes based on Unit Pollutant Reduction Cost

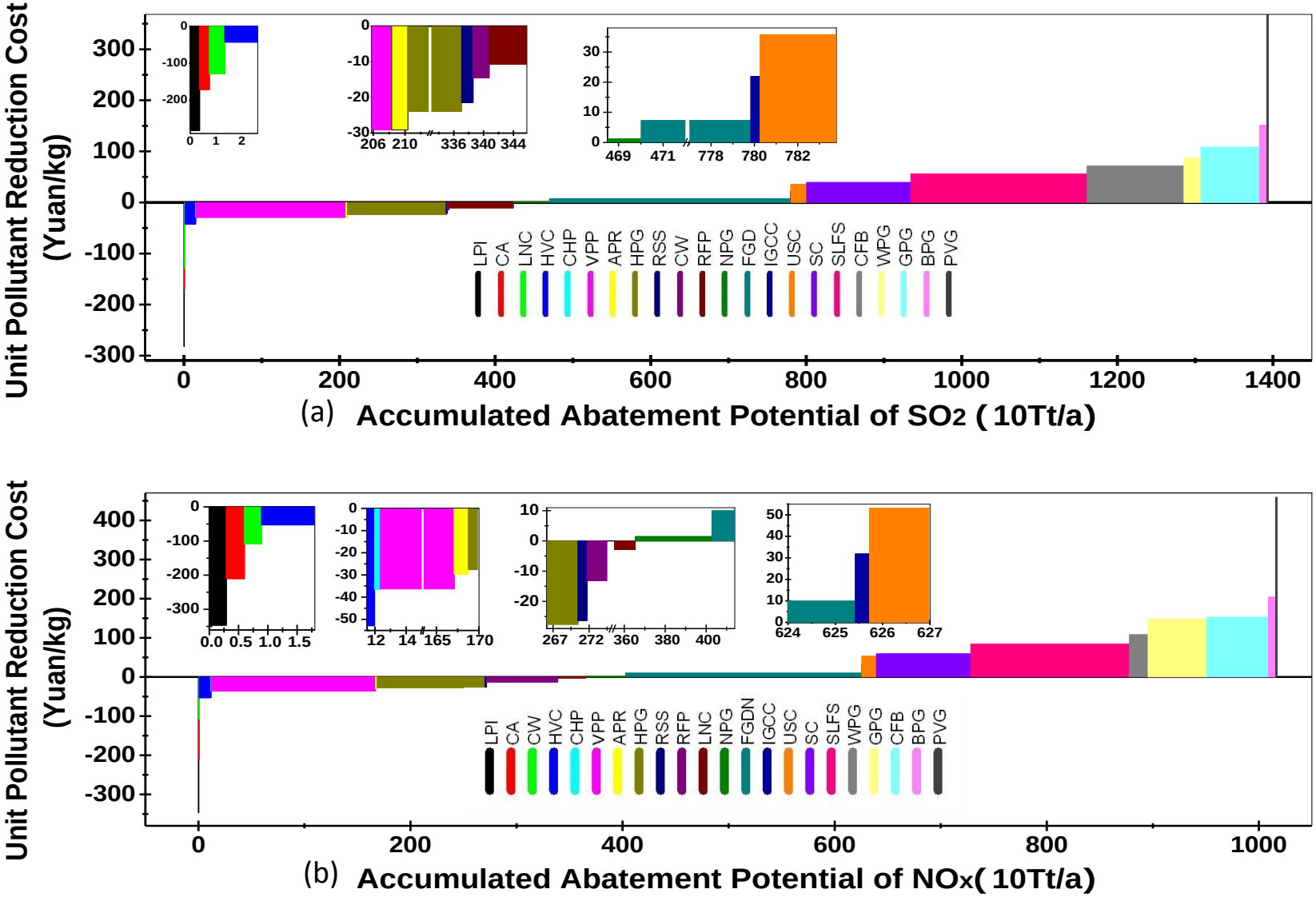

Figure 3. Potential and the routes of SO_2, NO_x, CO_2 and AP_{eq} emission reduction in China's power industry

Design of multi-pollutant co-control routes based on Unit Pollutant Reduction Cost (UPRC)

- When implementing an abatement plan, the technologies with lower UPRCs should be adopted before those with higher UPRCs.
- planners should choose the appropriate route according to:
  - the target of total abatement quantity (the width between the origin and the intersecting point on the abscissa axis) or,
  - the MAC constraints (the height of the vertical ordinate) or,
  - total abatement cost constraint (the region surrounded by the MAC curves and abscissa axis)

An Implementation Mock Case: Co-control reduction Plan for the Power Industry of China (2008-2015)

- total reduction is combined of two parts:
  - emission reduction from the existing generation capacity;
  - reduction from the increased generation capacity.

- the target rates for SO_2 and NO_x reduction are set at 40% and 15%, respectively.
- a 17% reduction in terms of CO_2 intensity reduction (CO_2 emission reduction per unit GDP) is set.
- These translated to 12.3877 million tonnes, 7.9014 million tonnes, and 1.150 billion tonnes per year for SO_2 , NO_x and CO_2

Table 2 Electric power industry reduction route analysis (2008-2015)

Reduction route	Route 1	Route 2	Route 3
Single pollutant reduction target set	**12.3877 million tonnes of SO_2**	**7.9014 million tonnes of NOx**	**1.150 billion tonnes of CO_2**
Route description	LPI-CA-LNC-HVC-CHP-VPP-APR-HPG-RSS-CW-RFP-NPG-FGD-IGCC-USC-SC-SLFS-CFB(62.35% of the potential used)	LPI-CA-CW-HVC-CHP-VPP-APR-HPG-RSS-RFP-LNC-NPG-FGDN-IGCC-USC-SC-SLFS(41.18% of the potential used)	LPI-CA-LNC-CW-HVC-VPP-CHP-APR-HPG-RSS-RFP-NPG(91.98% of the potential used)
SO_2 reduction (million tonnes)	**12.3877**	7.1665 (Co-control effect)	4.6626 (Co-control effect)
NOx reduction (million tonnes)	6.8668 (Co-control effect)	**7.9014**	3.9982 (Co-control effect)
CO_2 reduction (billion tonnes)	1.33062 (Co-control effect)	1.27037 (Co-control effect)	**1.150**
Equivalent to AP_{eq} (million tonnes)	**22.71**	**20.04**	**15.67**
Reduction cost without energy saving benefit being deducted (billion Yuan)	799.407	442.433	155.293

An Implementation Mock Case: Co-control Reduction Plan for the Power Industry of China (2008-2015)

- Along reduction routes 1, 2, and 3, when a single reduction target for SO_2, NOx, and CO_2 is fulfilled, tremendous co-control or co-reduction for the other two pollutants.

- the financial costs are **799.407**, **442.433**, and **155.293 billion Yuan**, respectively.

Reduction Route 4:

Air Polluiton Equivalent (AP_{eq})

with the cost limitation for single pollutant reduction

(2008-2015)

AP_{eq} reduction routes	AP_{eq} reduction under cost limitation of route 1	AP_{eq} reduction under cost limitation of route 2	AP_{eq} reduction under cost limitation of route 3
Reduction route description	LPI-CA-CW-HVC-CHP-VPP-APR-HPG-RSS-LNC-RFP-NPG-IGCC-FGD-FGDN-WPG-USC-SC-SLFS-BPG-GPG (0.29% of the potential used)	LPI-CA-CW-HVC-CHP-VPP-APR-HPG-RSS-LNC-RFP-NPG-IGCC-FGD-FGDN-WPG-USC-SC-SLFS (8.26% of the potential used)	LPI-CA-CW-HVC-CHP-VPP-APR-HPG-RSS-LNC-RFP-NPG (91.98% of the potential used)
AP_{eq} (million tonnes)	**24.22 (>22.71)**	**21.11 (>20.04)**	**15.67(=15.67)**

Reduction route 4: AP_{eq} with the cost limitation for single pollutant reduction (2008-2015)

- with the same reduction cost, the effects of a reduction scheme aimed at multi-pollutant reduction measured by AP_{eq} are **better or at least equal** to those of the reduction schemes aimed at single pollutant reduction.

Conclusion

- Co-control evolved from the term “co-benefits,” and is foreseen as an important strategic option, rather than relying on end-of-pipe measures for single pollutant reduction.

- co-control elasticity and coordinate system provide visual reflection of the pollutant reduction effectiveness of different technologies. The UPRC index evaluates the effect over cost of reduction measures.

- Combined with the targets of total pollutant control and cost limitations, single pollutant or multi-pollutant abatement routes can be drawn to formulate appropriate emission reduction plans.

- Large co-control potential for technical and structure-adjustment measures characterizes the power industry.

Discussion: next phase work

- More pollutants could be included in, PM2.5, Hg, etc.;

- Resource consumption could be included in, especially **water consuming**, b/c 1kWh= 2.2 litter of water!

Many thanks for your attention!