Current Work on Integrated Assessment Modeling in China and Future Collaborations

Shuxiao Wang

School of Environment, Tsinghua University

December 8, 2016

Outline

- Recent control measures and emission trends
- Projection of air pollutants emissions
- Quantification of health effects
- Perspectives on future IAM collaborations

Evolution of emission standards

Tightened emission standards: coal-fired power plants

1996

)$_2$:400-1200 mg/m^3
)x:450-1000 mg/m^3
/I: 50 mg/m^3

)-2100 mg/m^3
)-1000 mg/m^3
mg/m^3

2003

SO_2:200 mg/m^3
NOx:100-200 mg/m^3
PM: 30 mg/m^3
Hg: 0.03 mg/m^3

2011

SO_2:50 mg/m^3
NOx:100 mg/m^3
PM: 20 mg/m^3
Hg: 0.03 mg/m^3

2014
Key regions

2015(2020)

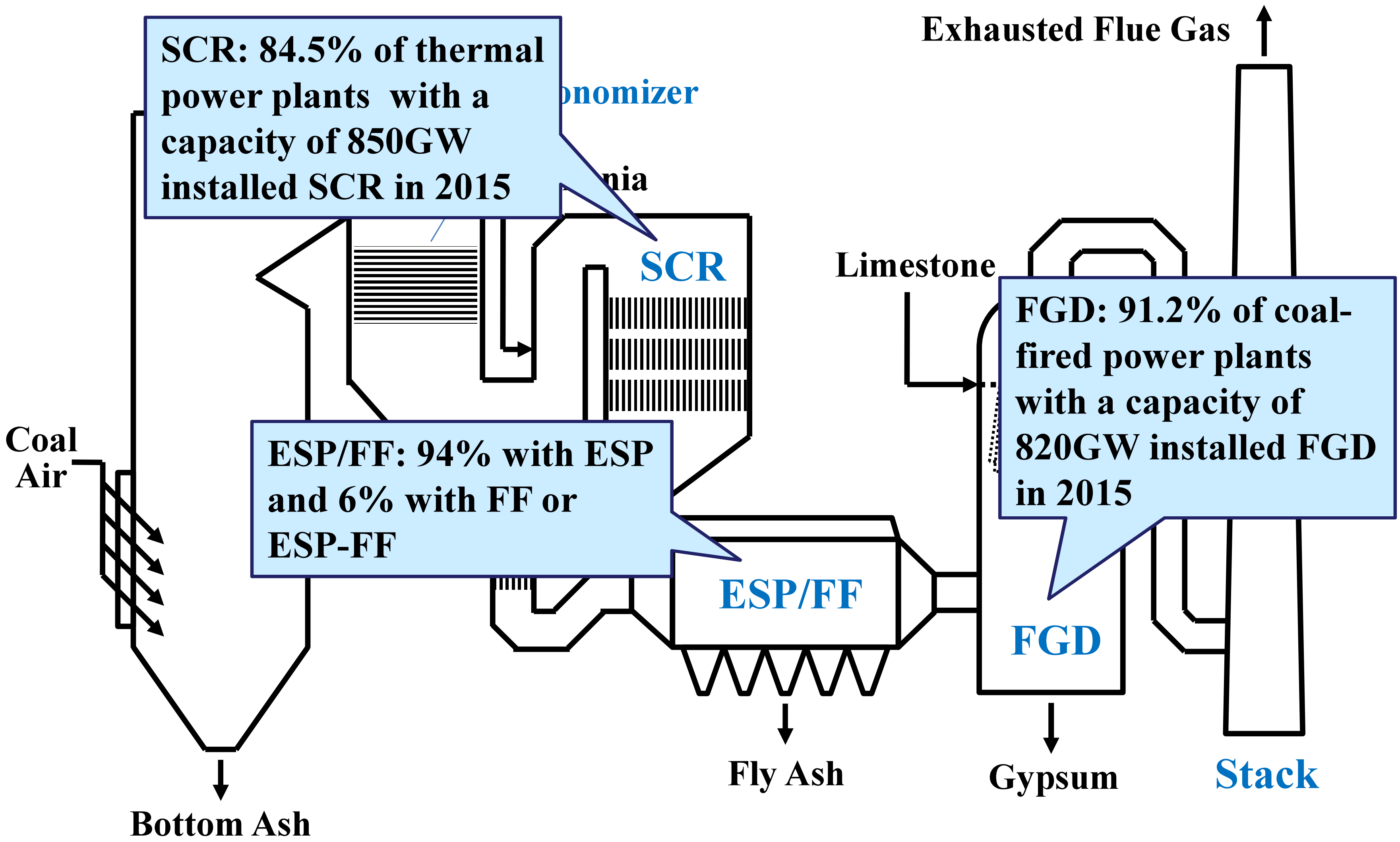
Ultra-low emission standard(2015)

SO_2 :35 mg/m^3
NOx: 50 mg/m^3
PM: 10 mg/m^3
Hg: 0.03 mg/m^3

Emission standard of air pollutants for boilers

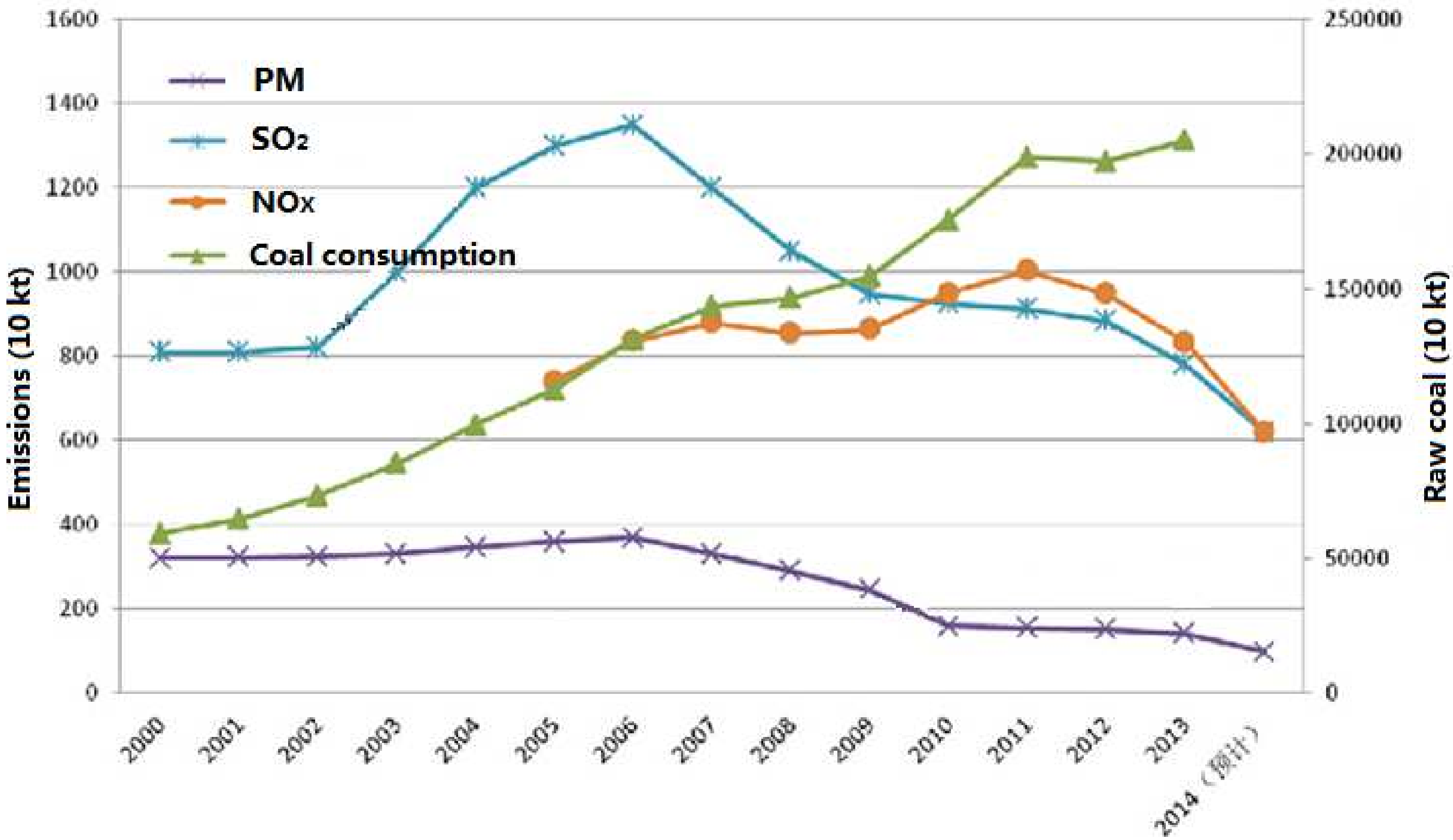
2001	2014
SO_2:900 mg/m^3	SO_2:400 mg/m^3
NOx: No limit	NOx: 400 mg/m^3
PM: 80-250 mg/m^3	PM: 80 mg/m^3
Hg: No limit	Hg: 0.05 mg/m^3

Application of air pollution control devices



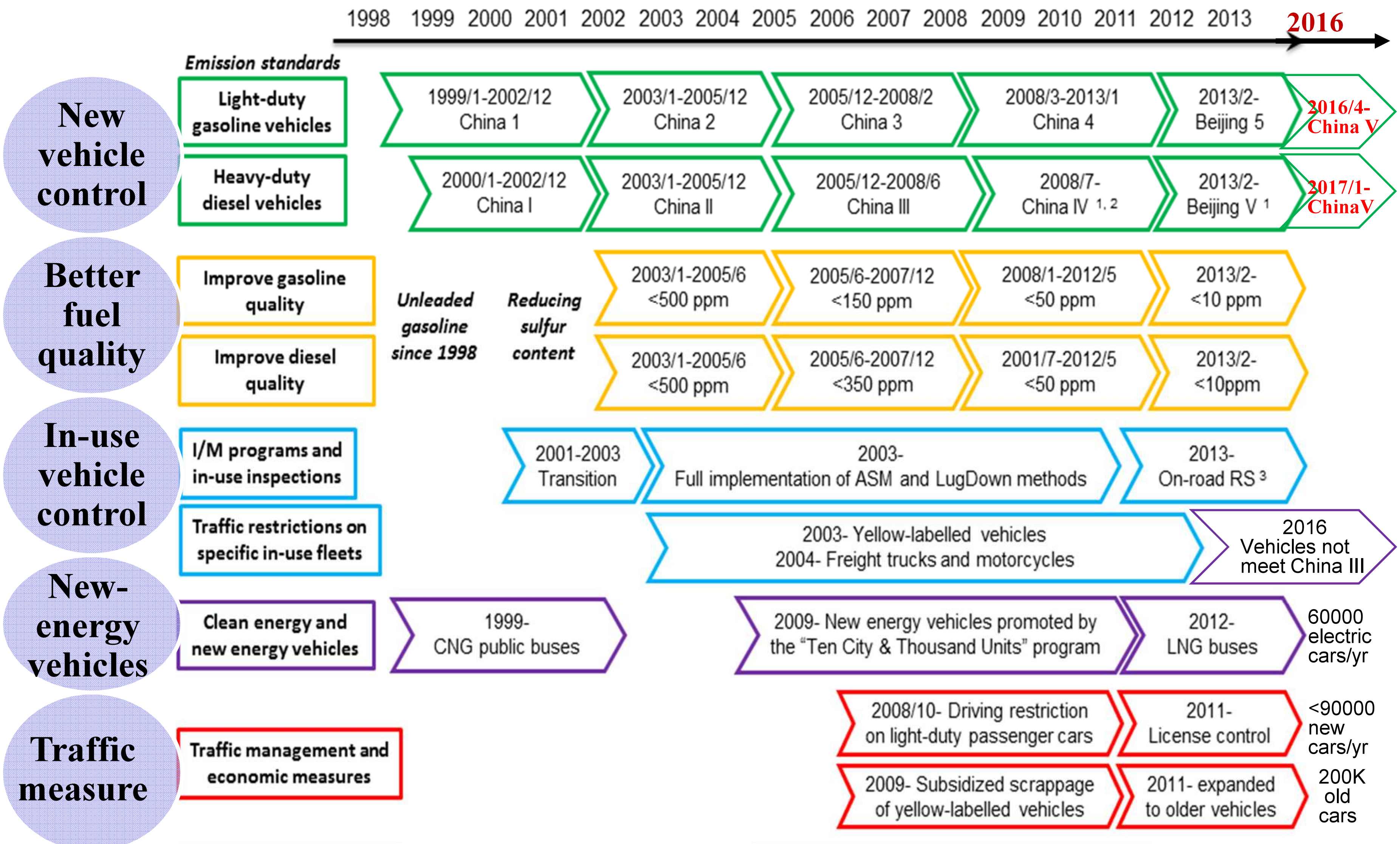
Reduction of emissions from power plants

Although coal consumption increased 60%, the emissions of PM, SO_2, and NOx in 2015 were 9%, 15%, and 22% of that in 2006.



Coal consumption and air pollutant emissions from thermal power plants

Evolution of vehicle emission control



[1] only implemented for public fleets; [2] for freight trucks and long-distance coaches, they complied with the China IV emission standard from July 2013 as required by the Ministry of Environmental Protection; [3] remote sensing test

Trends of air pollutant emissions from vehicles

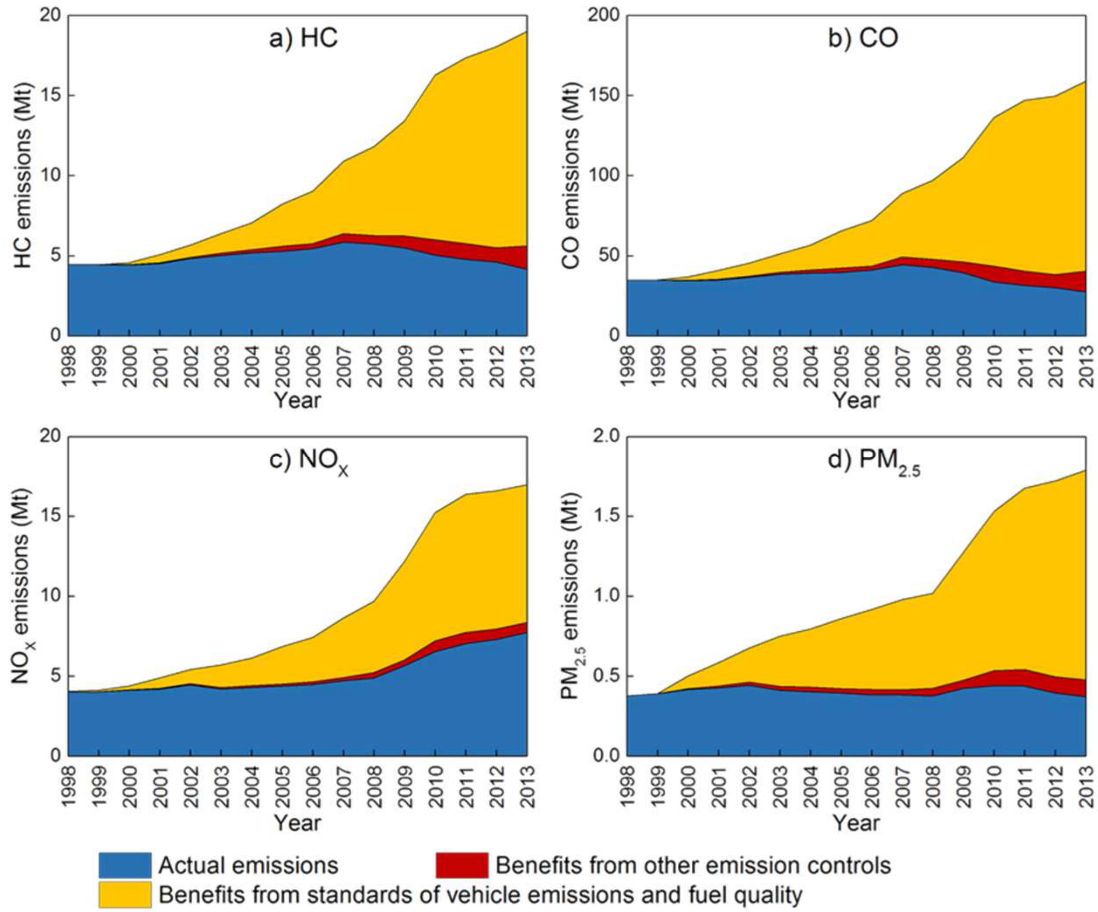
Although vehicle population increased by over 5 times in the past 15 years, the national vehicle emissions started to decline:

HC and CO: peak in 2007

$PM_{2.5}$: peak in 2010-2011

NO_X: peak in 2013

Vehicle-related emissions in Beijing started to decline much earlier than the national level: peak in 2000-2002.

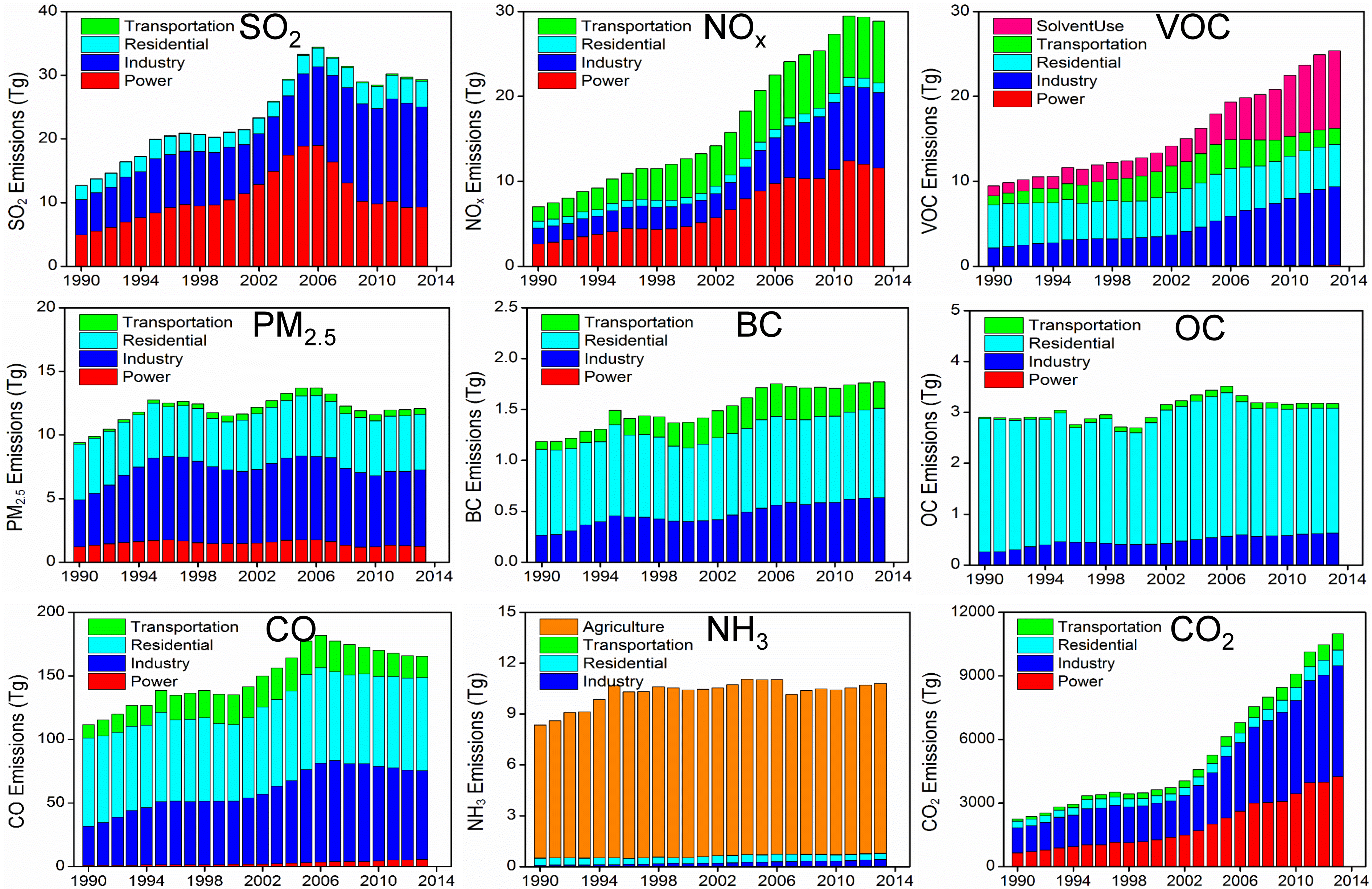


National/regional air pollution control policies

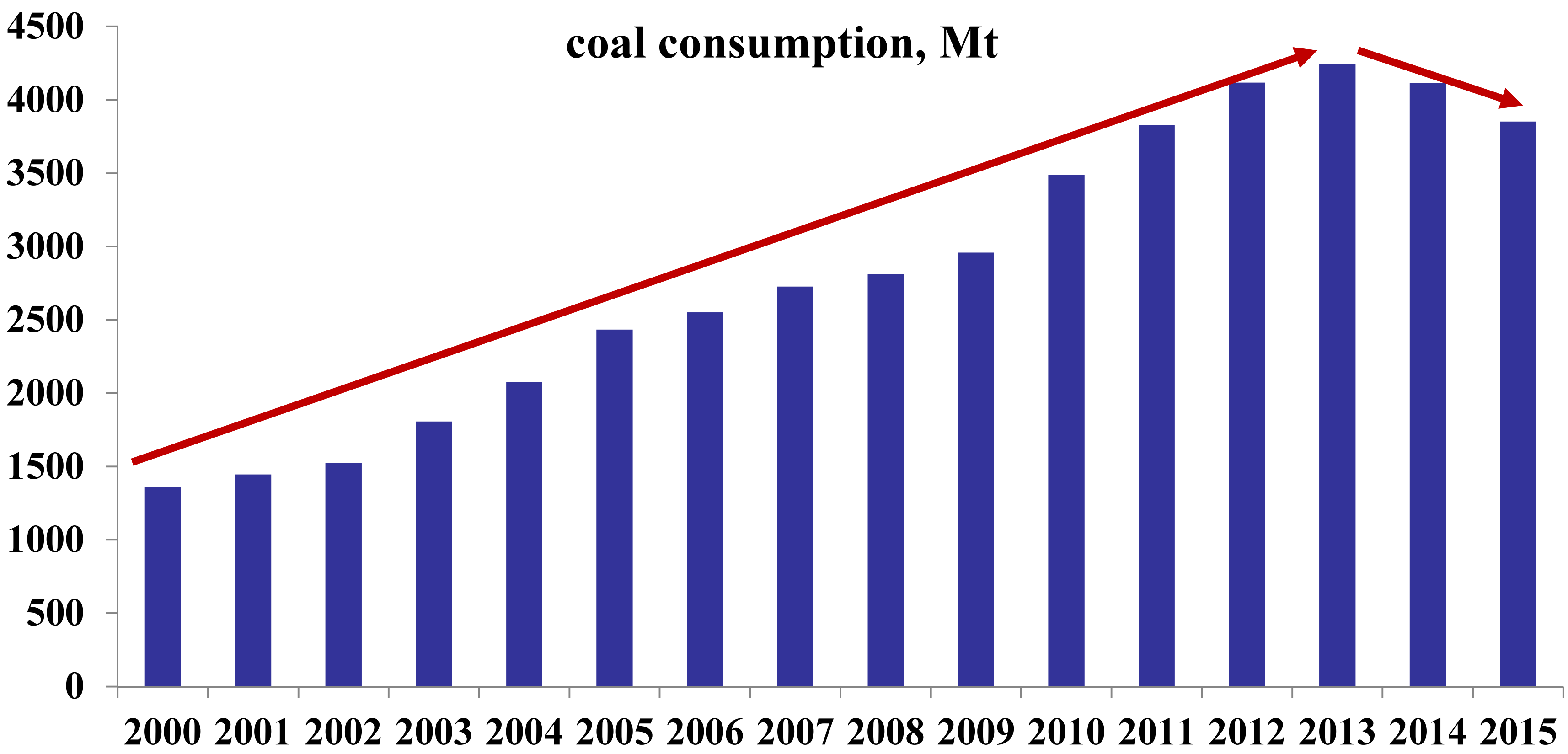
- **Recent policies:**
  - **2011, national emission control target for both SO_2 and NOx**
  - **2012, the *12^{th} FYP on air pollution control for key regions***
  - **2012, amendment of NAQQS, including $PM_{2.5}$**
  - **2013, Air Pollution Prevention and Control Action Plan**
  - **2015, new Air Pollution Prevention and Control Law**

Objective	Pollutants	Focus	Scale
emissions	Single pollutant	industry	local
↓	↓	↓	↓
Air quality	Multiple pollutants	Multiple sources	Regional & national

Emissions trends of air pollutants, 1990-2013

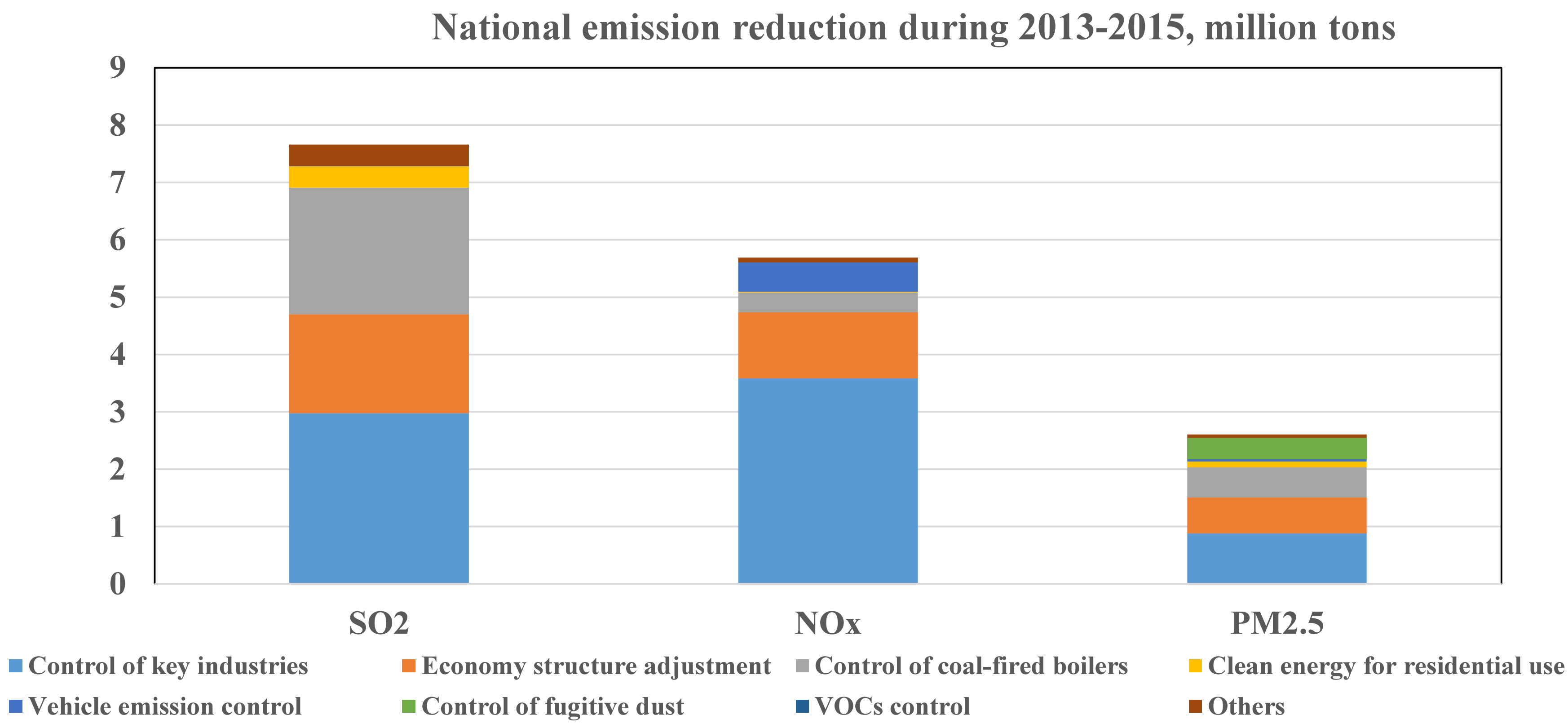


Trends of coal consumption, 2000-2015



- China's coal consumption grew from 1.36 billion tons in 2000 to 4.24 billion tons in 2013, an annual growth rate of 12%.
- National coal consumption in 2015 decreased 6.5% compared with 2013.
- The contribution of coal to total energy decreased to 64% in 2015.

Emission reductions by the Action Plan

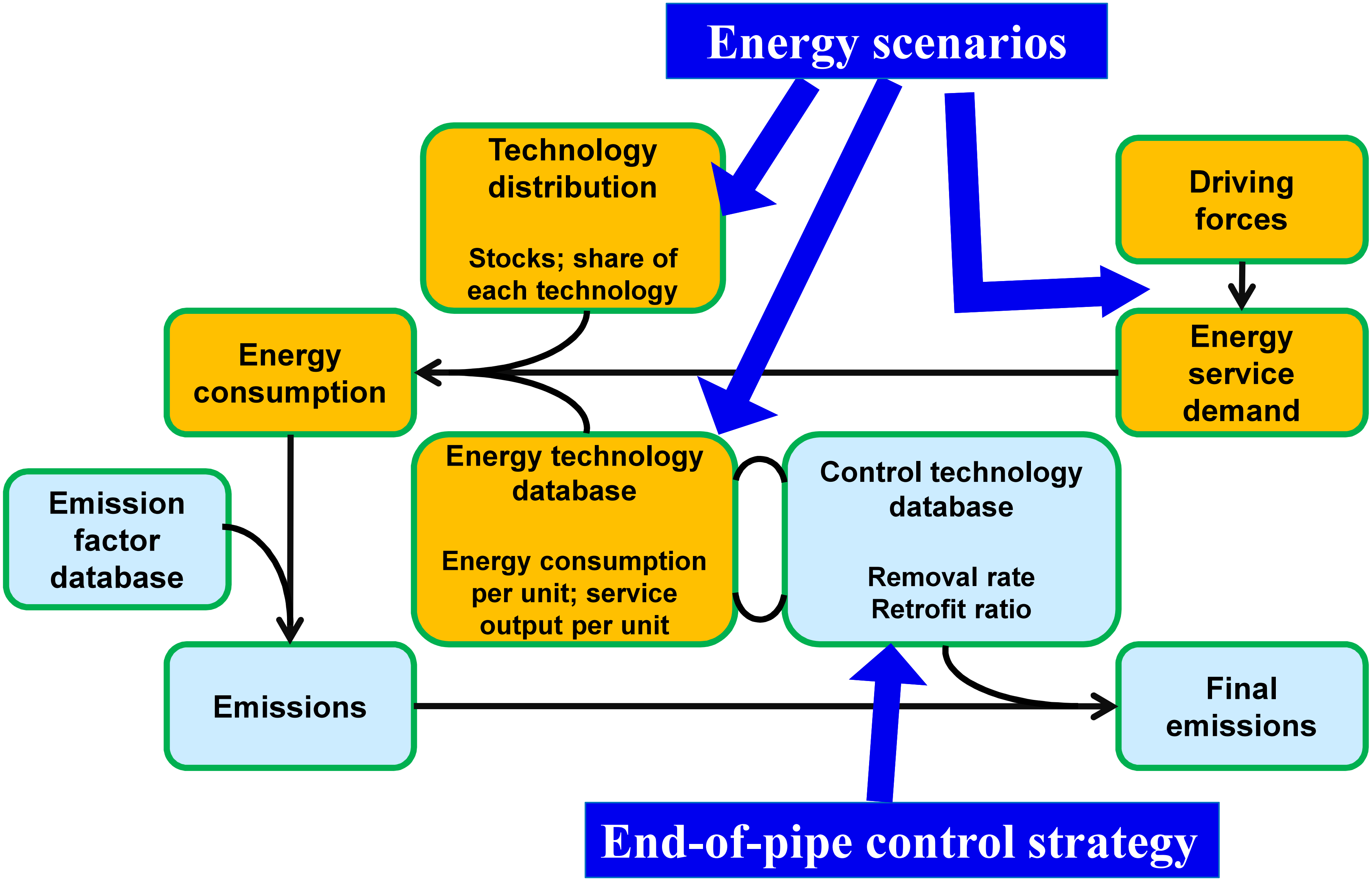


- **During 2013-2015, national SO_2, NO_x and $PM_{2.5}$ emissions were reduced by 7.6, 5.7 and 2.6 million tons**
- **Control of key industries and boilers, shutdown of outdated factories contributed 39%, 29% and 22% of the SO_2 emission reductions.**
- **Control of key industries, shutdown of outdated factories and vehicle emission control contributed 63%, 20% and 9% of the NOx emission reductions.**

Outline

- Recent control measures and emission trends
- Projection of air pollutants emissions
- Quantification of health effects
- Perspectives on future IAM collaborations

Framework for policy scenario development



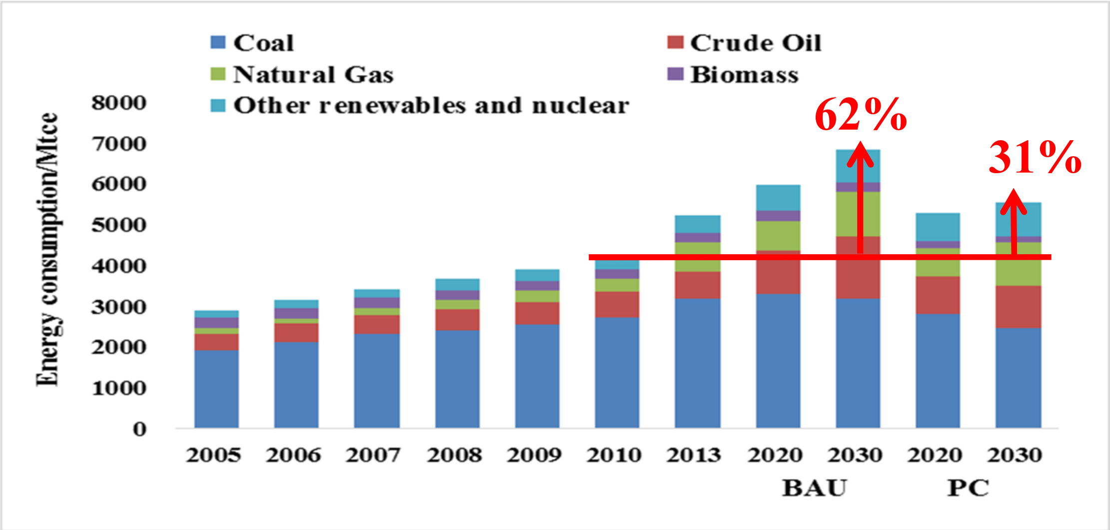
Definition of emission scenarios

Base year: 2013, Future emissions: 2015, 2020, 2025, 2030

Energy Policy	End-of-Pipe Emission Control Policy	
	[1] the 12th FYP and the 2013 Action Plan	[2] Maximum Feasible Emission Controls
BAU: Current Legislation and Implementation Status as of end of 2012.	BAU[1]	BAU[2]
PC: Additional energy saving policies will be implemented, including life style changes, structural adjustments and energy efficiency improvements.	PC[1]	PC[2]

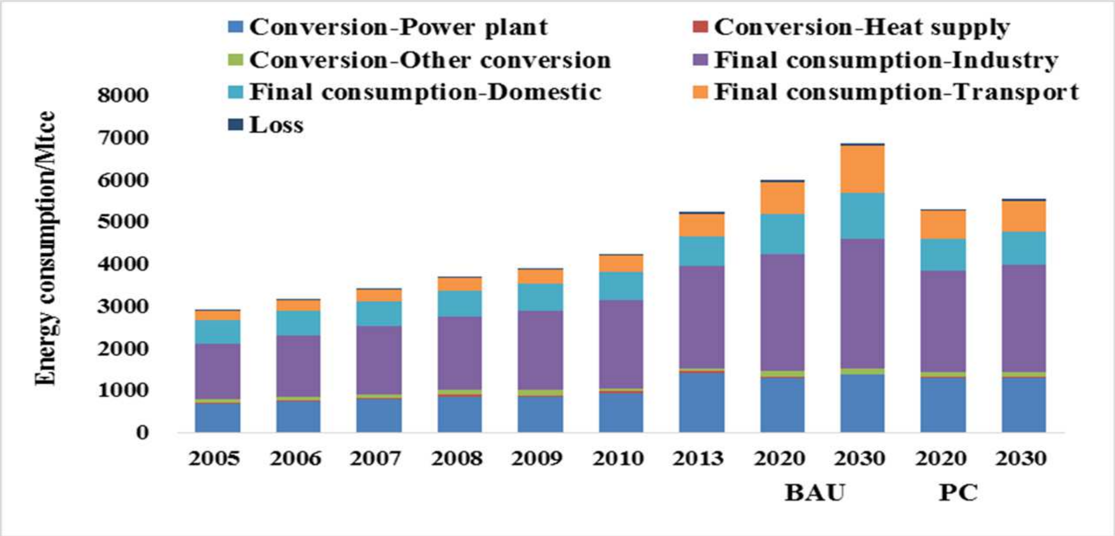
Projected energy consumption

Energy consumption by fuel



	Coal	Other renewable and nuclear
2010	68%	7.5%
2013	61%	8.3%
2030_BAU	47%	11.8%
2030_PC	44%	15.1%

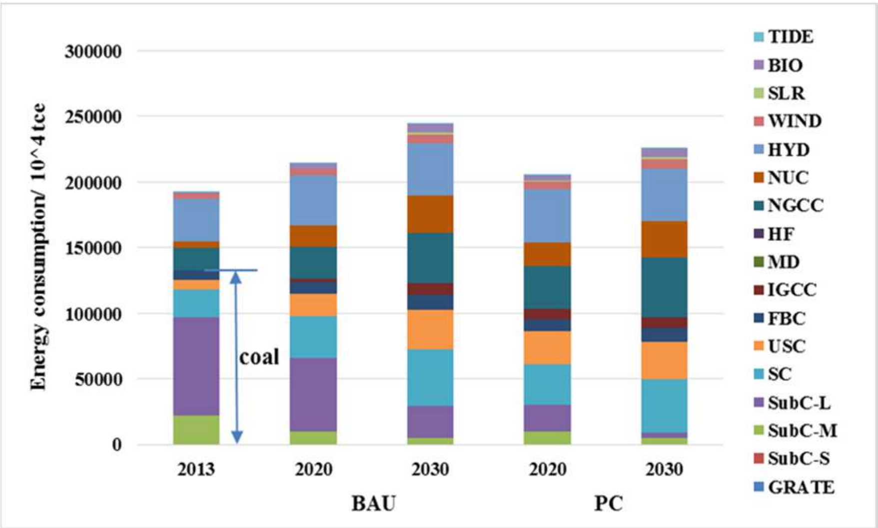
Energy consumption by sector



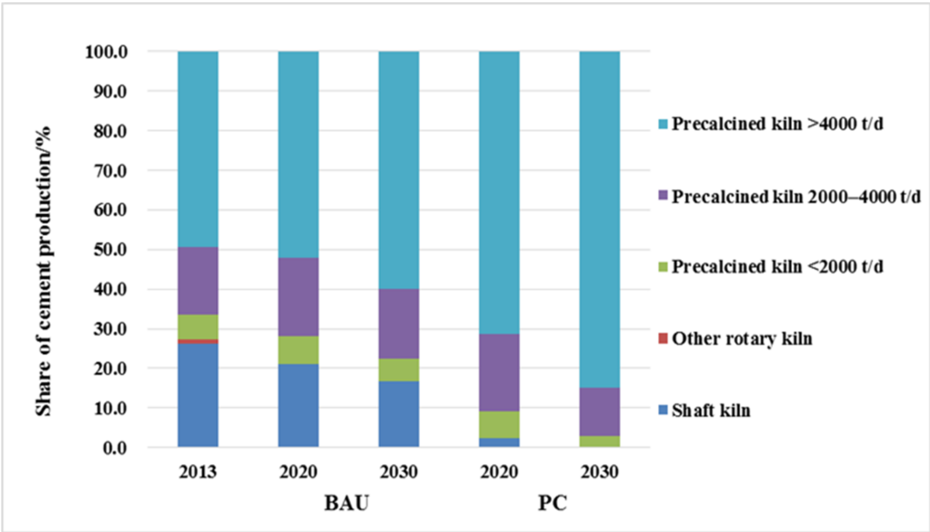
	Industry	Transportation
2010	48%	9.0%
2013	46%	10.1%
2030_BAU	45%	16.1%
2030_PC	45%	13.1%

Projected technology shift

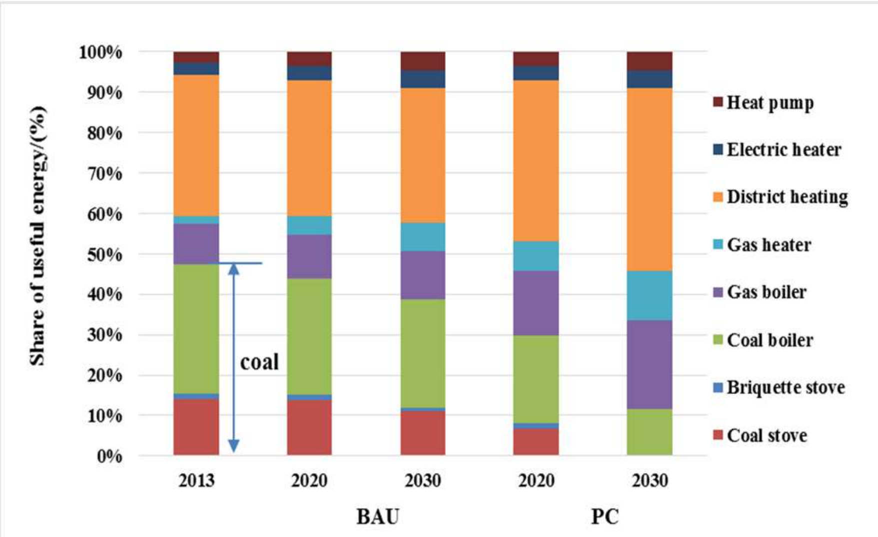
Power plants



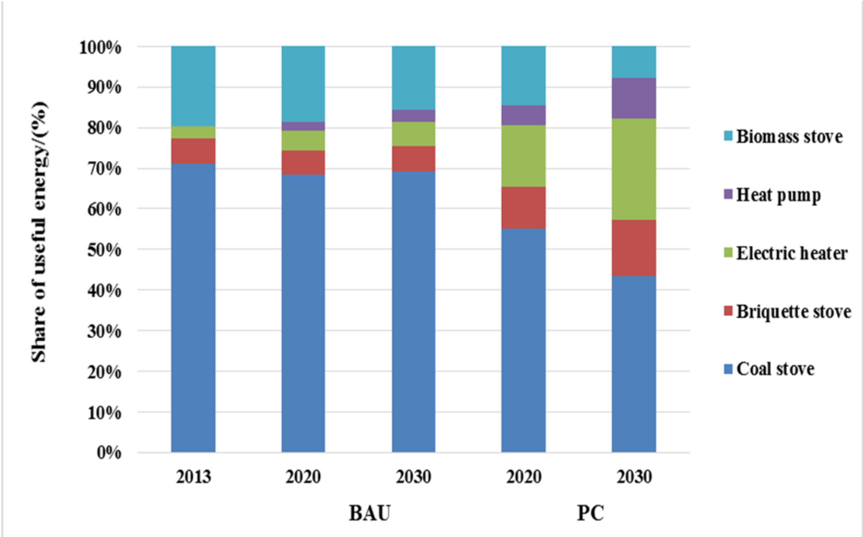
Cement industry



Domestic heating (north urban)



Domestic heating (north rural)



NOx control technologies for key sectors

Penetration of Major NOx Removal Equipment in Chinese Industrial Sectors (%)

process	Removal equipment	2010	2013	[1] 2020	[1] 2030	[2] 2020	[2] 2030
Coal-fired industrial grate boiler	NOC	100	77	76	76	70	0
	LNB	0	18	18	18	20	0
	LNB+SNCR	0	0	0	0	0	0
	LNB+SCR	0	5	6	6	10	100
Precalcined cement kiln ≥4000 tons/day	NOC	60	47	24	12	0	0
	LNB	40	52	26	13	0	0
	LNB+SNCR	0	1	30	45	60	0
	LNB+SCR	0	0	20	30	40	100
Glass production – float process	NOC	100	76	52	26	0	0
	OXFL	0	16	24	56	50	0
	SCR	0	8	24	18	50	100
Sintering	NOC	100	93	92	92	40	0
	SNCR	0	0	0	0	0	0
	SCR	0	7	8	8	60	100

NMVOC control technologies for key sectors

Solvent use type	Control technology	2010	2013	[1] 2020	[1] 2030	[2] 2020	[2] 2030
Paint use in interior wall of buildings	No control (GB18582-2001)	0	0	0	0	0	0
	Decrease of solvent content--GB18582-2008	100	97	80	45	35	0
	Decrease of solvent content--2004/42/EC stage 1	0	3	20	45	55	0
	Decrease of solvent content--2004/42/EC stage 2	0	0	0	10	10	100
Paint use in vehicle refinishing	No control (solvent-based paint)	93	90	84	61	60	0
	Sustitution with high solids or water-based paint	8	10	16	39	40	100
Paint use in wood coating	No control (solvent-based paint)	89	84	65	42	33	0
	Incineration	0	1	8	15	20	20
	Substitution with high solids paint	4	6	12	19	20	20
	Substitution with water-based or UV paint	7	9	15	25	28	60
Offset printing	No control (solvent-based ink)	90	88	73	48	38	0
	Substitution with water-based or UV ink	10	13	18	25	25	10
	Add-on control technology	0	0	10	28	38	90
Flexography and rotogravure printing (for packaging)	No control (solvent-based ink)	64	60	43	23	15	0
	Substitution with low solvent or water-based ink	35	38	40	38	35	0
	Add-on control technology	1	3	8	20	20	0
	Substitution + add-on control technology	0	0	10	20	30	100
Screen printing	No control (solvent-based ink)	85	83	71	40	34	0
	Substitution with low solvent or water-based ink	15	18	21	33	31	0
	Add-on control technology	0	0	8	25	33	0
	Substitution + add-on control technology	0	0	0	3	3	100
Adhesive use in wood processing	No control	98	95	91	74	75	0
	Add-on control technology	3	5	9	26	25	100
Adhesive use in manufacturing of shoes	No control (solvent-based adhesive)	87	85	76	65	60	10
	Substitution with low solvent adhesive	13	15	24	35	40	90
	Add-on control technology	0	0	0	0	0	0

Vehicle emission control

Further development of the public transportation system and improvement in vehicle emission control system

- **Development of green transportation: public transportation, non-motorized traffic modes, intelligent traffic system**
- **Accelerating the scrappage of older vehicles (high emitters)**
- **Promoting clean energy vehicles and clean transportation fuels**
- **More stringent standards for vehicle emissions and fuel quality**

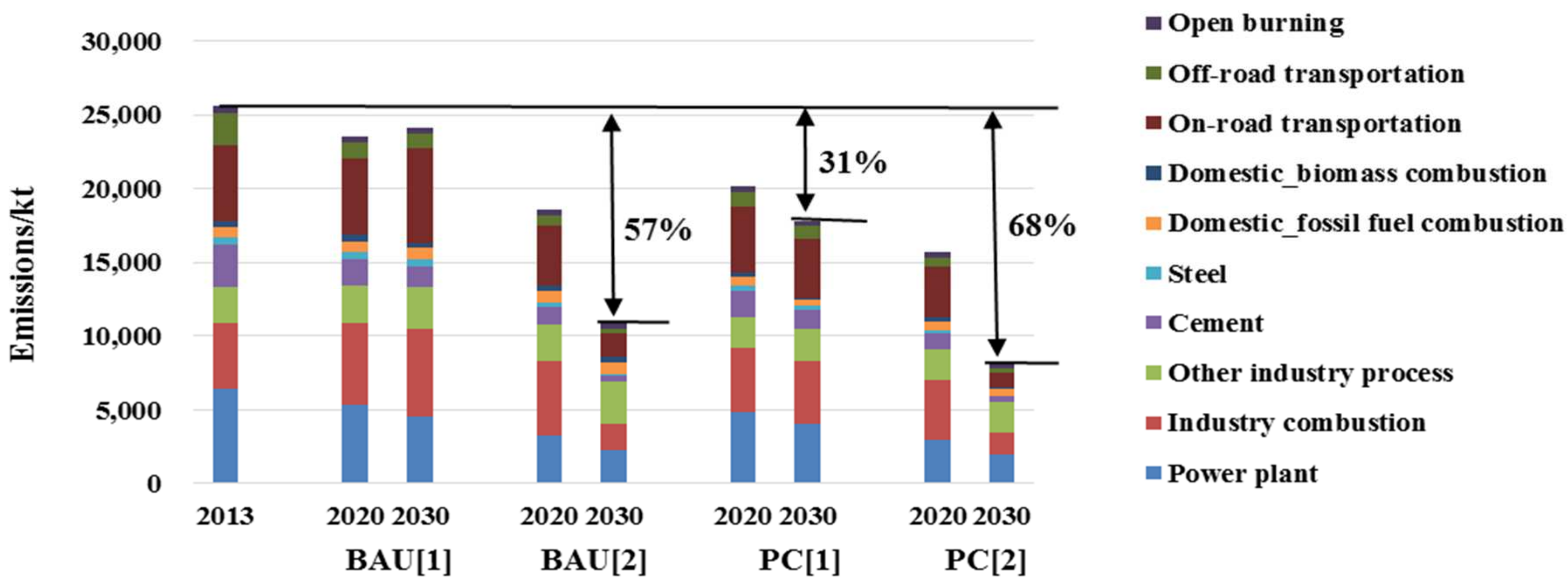
Type	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Light duty vehicle	1	1	1	1	1	2	2	2	3	3	3	4	4	4	4	4	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6
Heavy duty diesel vehicle		1	1	1	2	2	2	3	3	3	3	3	3	4	4	4	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6
Heavy duty gasoline vehicle				1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Motorcycle (2&4 strokes)				1	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Rural Vehicle							1	2	2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6	6	6	6	6	6	6	6
Tractors, machines									1	1	2	2	2	2	3A	3A	3A	3A	3B	3B	3B	4	4	4	4	4	4	4	4	4	4
Train, inland water															3A	3A	3A	3A	3B	3B	3B	4	4	4	4	4	4	4	4	4	4

Numbers 1–6 represent the Euro I to Euro VI vehicle emission standards.

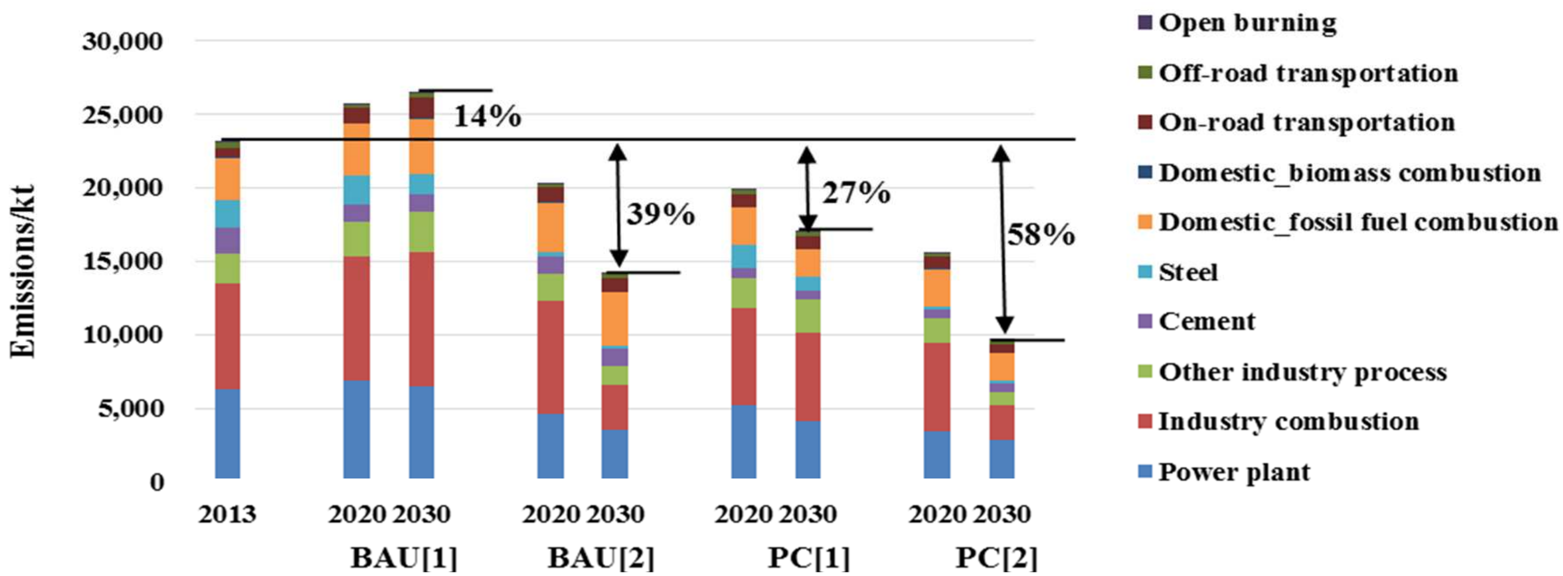
Numbers in black represent standards released, and numbers in red represent standards to be released in the future.

Future trends of NO_X and SO_2 emissions

NO_X

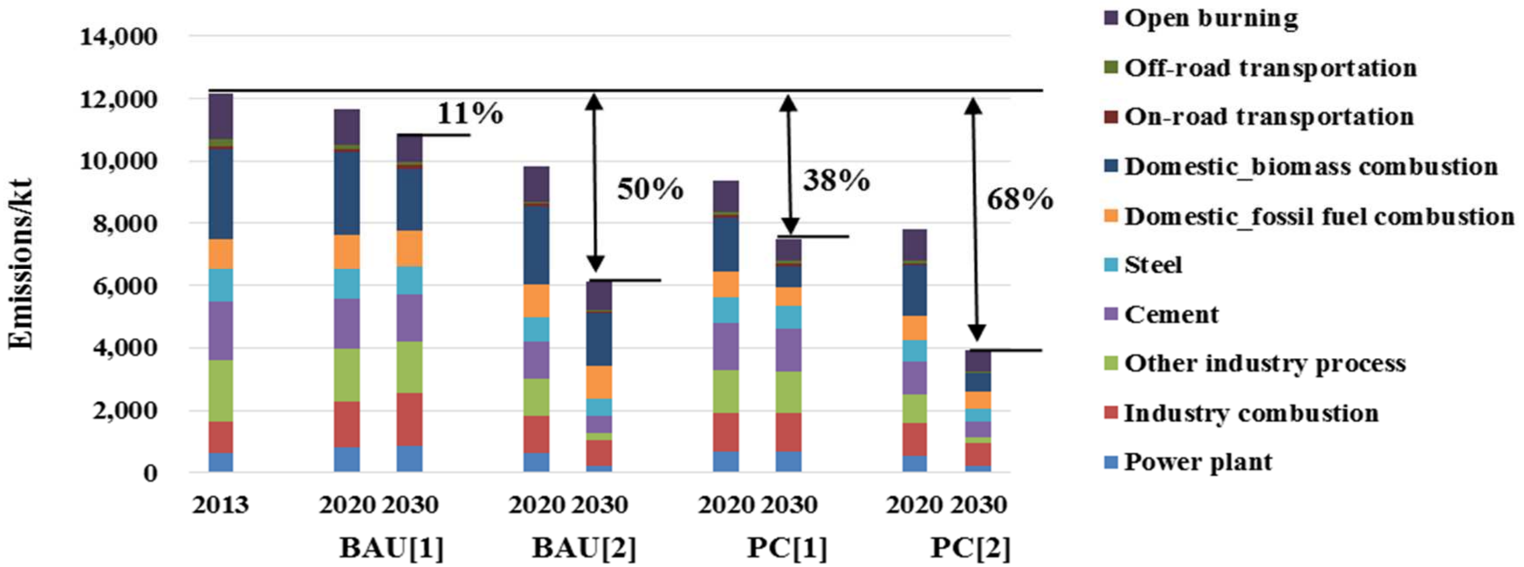


SO_2

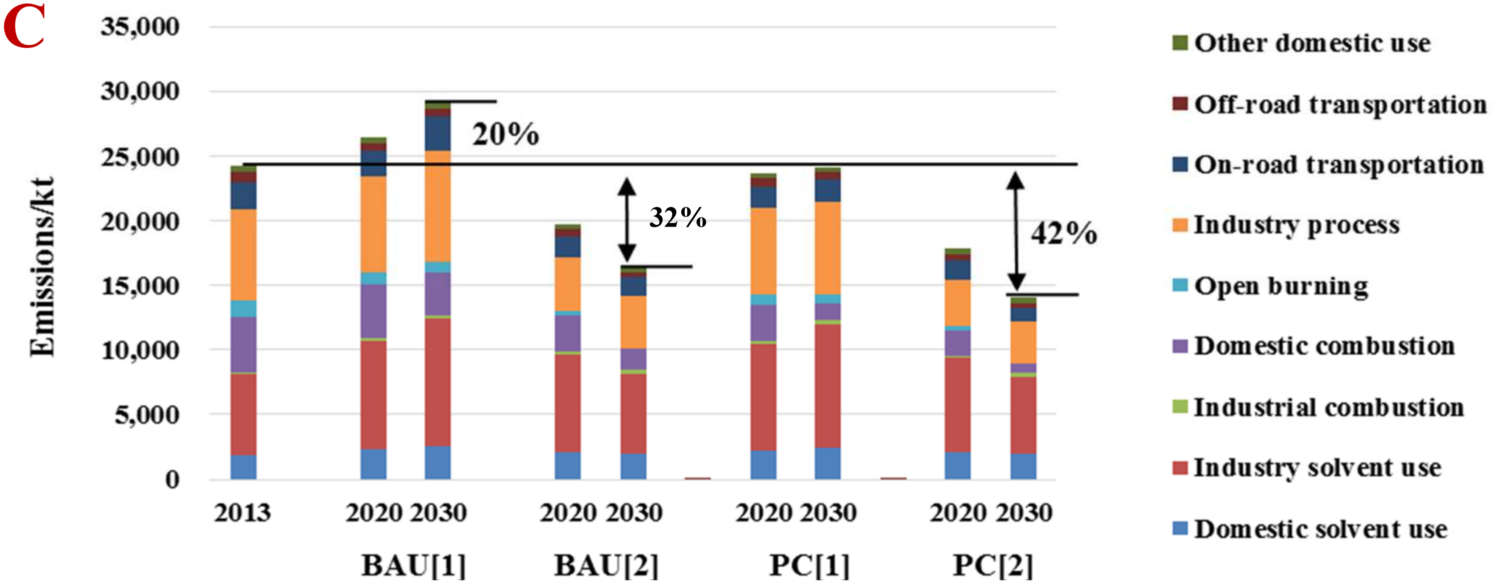


Future trends of $PM_{2.5}$ and NMVOC emissions

$PM_{2.5}$



NMVOC

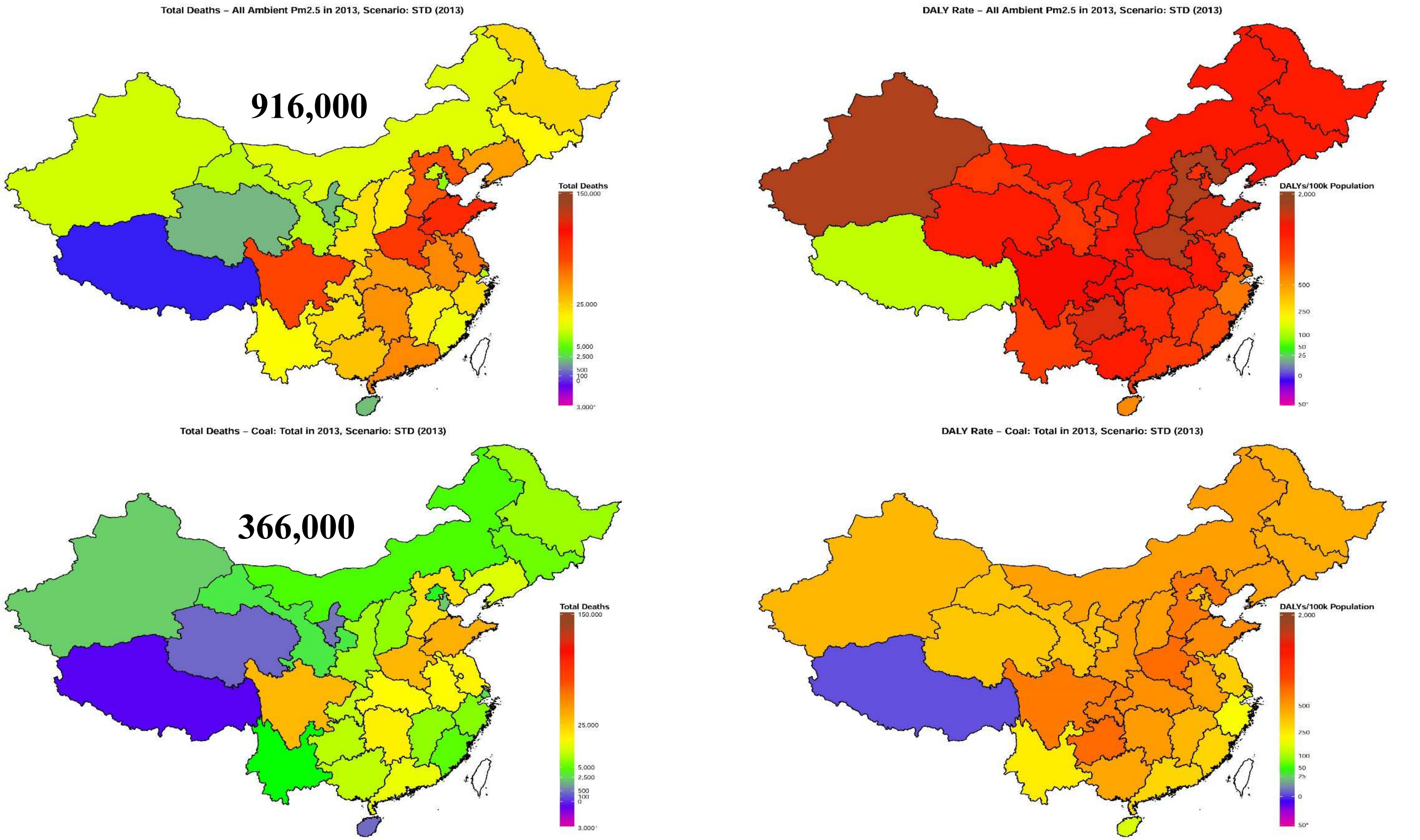


Outline

- Recent control measures and emission trends
- Projection of air pollutants emissions
- Quantification of health effects
- Perspectives on future IAM collaborations

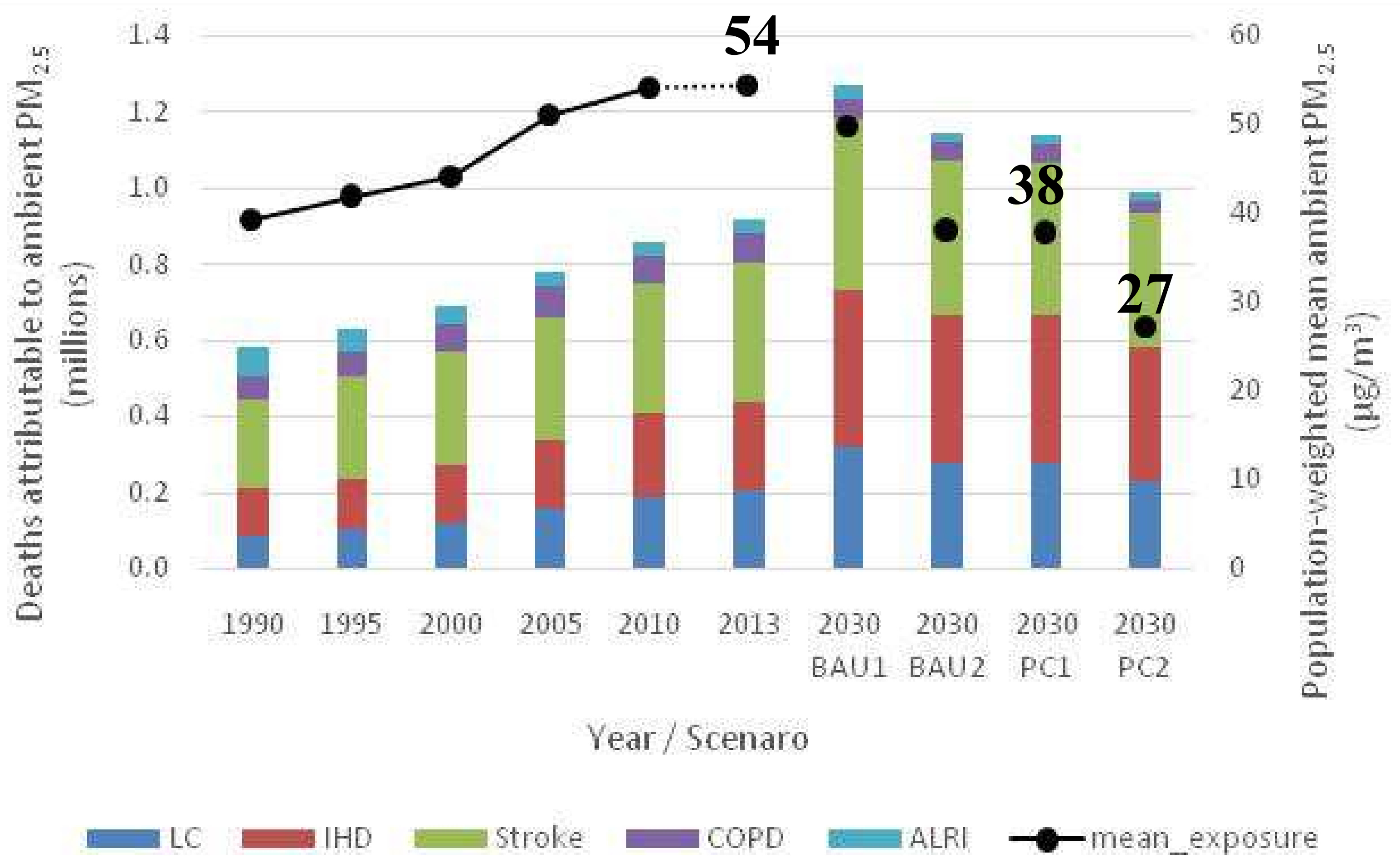
PM$_{2.5}$ attributable deaths in China, 2013

- **Evaluate the current and future burden of disease from major air pollution sources in China (GBD MAPS)**



GBD MAPS China Report, 2016

Future trends of $PM_{2.5}$ attributable deaths



- Despite reductions in $PM_{2.5}$ levels, all of the future scenarios are predicted to lead to increases in future deaths attributable to ambient $PM_{2.5}$, compared to 2013.
- Strict control of PM levels is critical to stabilize or reduce burden in the face of changing demographics.

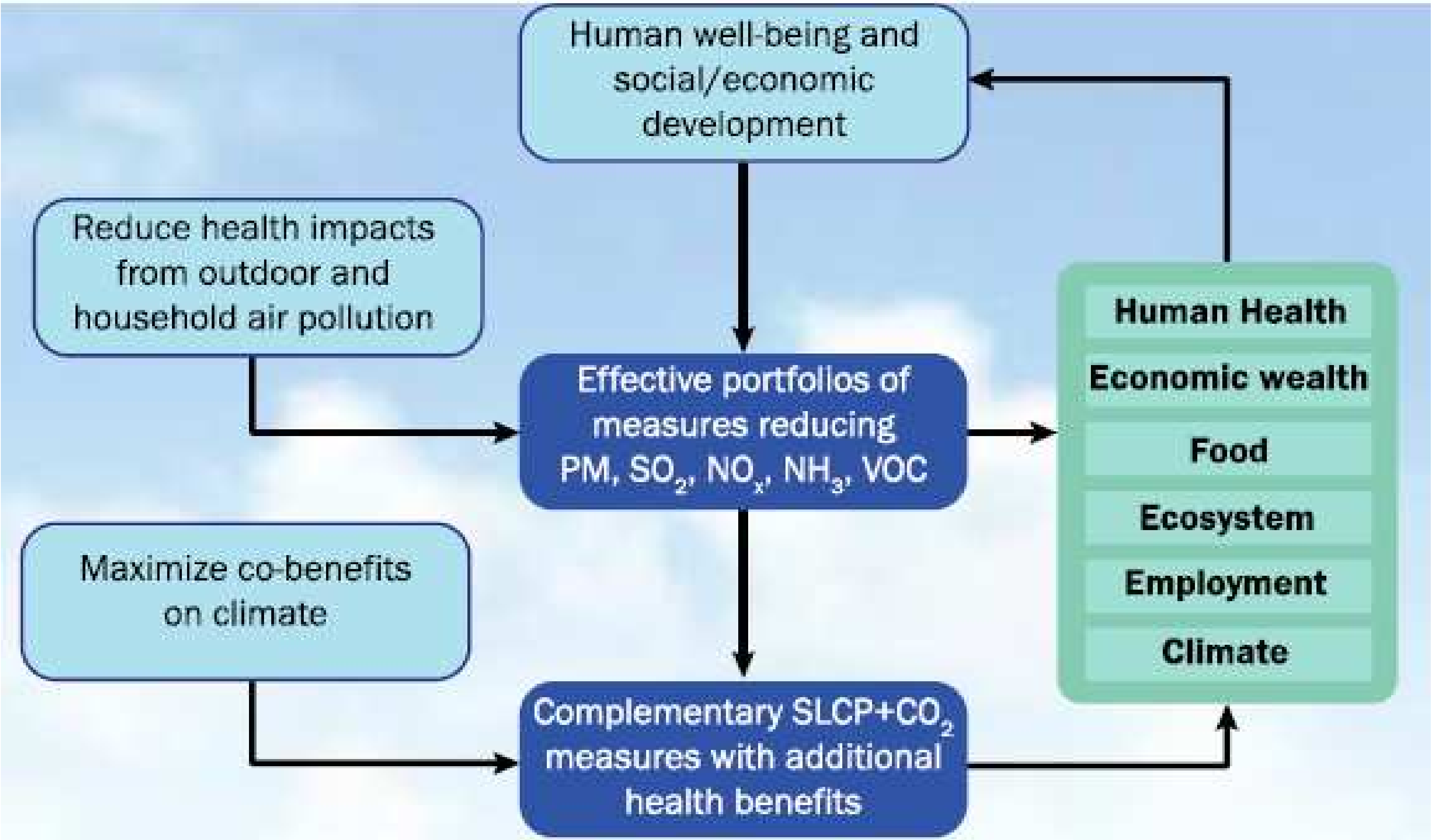
Outline

- Recent control measures and emission trends
- Projection of air pollutants emissions
- Quantification of health effects
- Perspectives on future IAM collaborations

Perspectives on future IAM collaborations

- **To build a green economy and safe future, our collaboration and partnership to address air pollution and climate issues are needed now more than ever.**
- **Emission and modeling studies conducted at each country as well as East-Asia region, i.e. MICS-Asia, provide a good basis for further IAM collaborations in North-east Asia (NEA).**
- **The NEA IAM framework shall aim to provide cost-effective emission control strategies and to support national efforts addressing both air pollution and climate issues in future.**
- **The target pollutants may include $PM_{2.5}$, O_3, GHGs and Hg.**
- **The core elements of the IAM framework may include but not limited to policy scenarios, impact assessment, cost evaluation, etc.**

Perspectives on future IAM collaborations



Some initial thoughts on the IAM framework

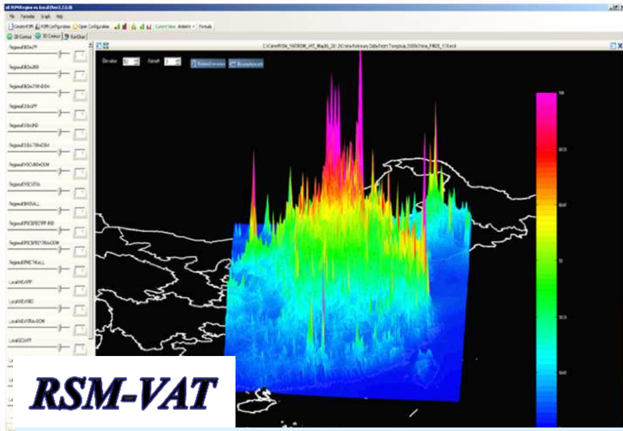
- To establish a NEA science center or an expert group to facilitate the IAM collaborations.
- To develop one set of policy scenarios for NEA sub-region as well as assessment tool to enable the analysis under a same baseline.
- To build up a platform to enhance the scientific exchange and information share.

Synergies with existing efforts (MICS-Asia, CMAS-Asia, etc.)

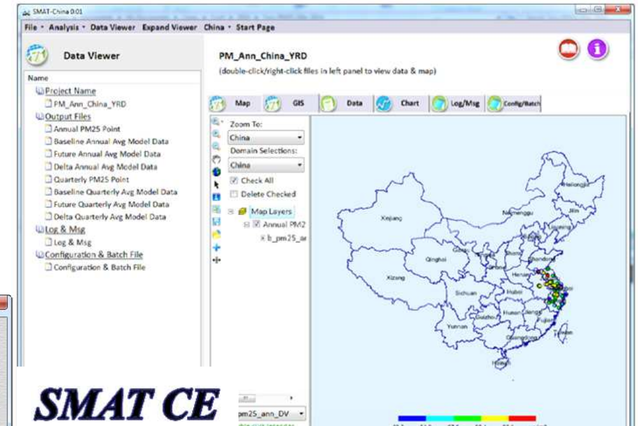
Linkage to policies (periodic reporting and governmental consultation)

Tools under the IAM framework: an example

Air Benefit and Cost and Attainment Assessment System



Provide Source-Receptor Relationships

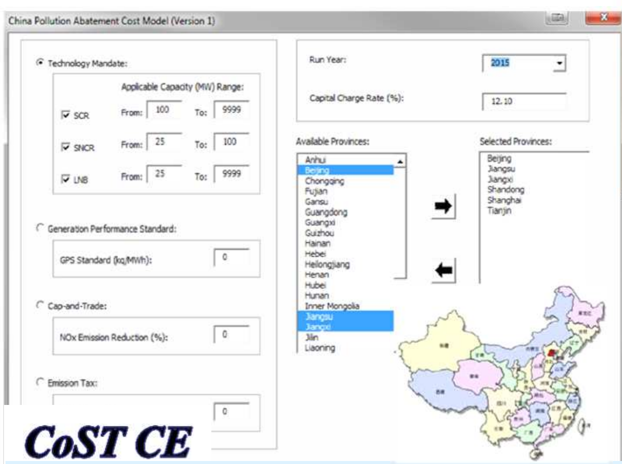


Provide Attainment Test for $PM_{2.5}/O_3$ Non-attainment Areas

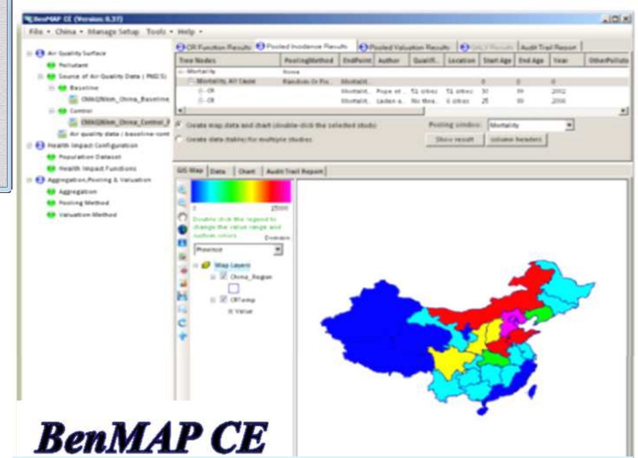
ABaCAS system

Available at:

http://www.abacas-dss.com/



Provide Cost Analysis of Emissions Control



Provide Health Impacts and Economic Benefits Estimate

Thanks for your attention!

Definition of emission scenarios

Energy scenarios	Energy scenario definition	Emission scenarios	Emission scenario definition
BAU	The BAU scenario is based on current legislations and implementations status (until the end of 2012)	BAU[1]	For end-of-pipe control strategy, it is designed based on the "Twelfth Five-Year Plan for Environmental Protection" and the "Air Pollution Prevention and Control Action Plan".
		BAU[2]	For end-of-pipe control strategy, it assumes that the technically feasible control technologies would almost be fully applied by 2030, regardless of the economic cost.
PC	assumes new energy-saving policies will be released and enforced, including life style changes, structural adjustment and energy efficiency improvement.	PC[1]	The PC[1] scenario assumes the same energy saving policy as PC scenario and the same end-of-pipe control strategy as BAU[1].
		PC[2]	The PC[2] scenario is an aggressive scenario using the same energy saving policy as PC scenario with nearly maximum feasible reductions of emissions.

Driving forces and service demand

	Current		BAU		PC	
	2010	2013	2020	2030	2020	2030
GDP (2005 price)/billion CHY [a]	31165	39486	65741	117718	65741	117718
Population/billion	1.34	1.36	1.44	1.47	1.44	1.47
Urbanization rate/%	49.7	53.7	58	63	58	63
Power generation/TWh	4205	5398	6931	8506	6733	8000
Share of coal-fired power generation/%	75.3	66.4	56.7	48.3	48.9	41.3
Crude steel yield/Mt	627	779	710	680	610	570
Cement yield/Mt	1880	2417	2001	2050	1751	1751
Urban domestic building area per capita/m^2	23	23	29	33	27	29
Rural domestic building area per capita/m^2	34.1	37	39	42	37	39
Vehicle population per 1000 persons	58.2	93.6	191.2	380.2	178.5	325.2
Share of new and renewable energy/% [b]	7.5	8.3	10.5	11.8	13.1	15.1

Disease burden of $PM_{2.5}$ pollution in China

Sector contributions to population-weighted ambient $PM_{2.5}$ and deaths, 2013

Subsector	Mean $PM_{2.5}$	Deaths
All ambient $PM_{2.5}$	54.3	916,000
Total Coal	21.9	366,000
Power plant coal	5.2	86,500
Industrial coal	9.4	155,500
Domestic coal	2.4	41,000
Non-Coal Industry	5.6	95,000
Domestic biofuel	8.0	136,500
Traffic	8.2	137,500
Open burning	4.1	70,000

- Coal combustion contributes 40% of $PM_{2.5}$ exposure and 366,000 deaths.
- Traffic (vehicles) results in 137,500 deaths.
- Domestic biofuel burning results n 136,500 deaths.

Ma et al, 2016, ACPD, doi:10.5194/acp-2016-601

Emission trends and mitigation options

Atmos. Chem. Phys., 14, 6571–6603, 2014
www.atmos-chem-phys.net/14/6571/2014/
doi:10.5194/acp-14-6571-2014

Atmospheric Chemistry and Physics
Open Access

Emission trends and mitigation options for air pollutants in East Asia

S. X. Wang[1,2], B. Zhao[1], S. Y. Cai[1], Z. Klimont[3], C. P. Nielsen[4], T. Morikawa[5], J. H. Woo[6], Y. Kim[6], X. Fu[1], J. Y. Xu[1], J. M. Hao[1,2], and K. B. He[1,2]

[1]State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China
[2]State Environmental Protection Key Laboratory of Sources and Control of Air Pollution Complex, Beijing 100084, China
[3]International Institute for Applied System Analysis, Laxenburg, Austria
[4]Harvard China Project, School of Engineering and Applied Sciences, Harvard University, 29 Oxford St, Cambridge, MA 02138, USA
[5]Japan Automobile Research Institute, Tsukuba, Japan
[6]Department of Advanced Technology Fusion, Konkuk University, Seoul, South Korea

Correspondence to: S. X. Wang (shxwang@tsinghua.edu.cn)

Received: 18 December 2013 – Published in Atmos. Chem. Phys. Discuss.: 27 January 2014
Revised: 17 May 2014 – Accepted: 19 May 2014 – Published: 1 July 2014

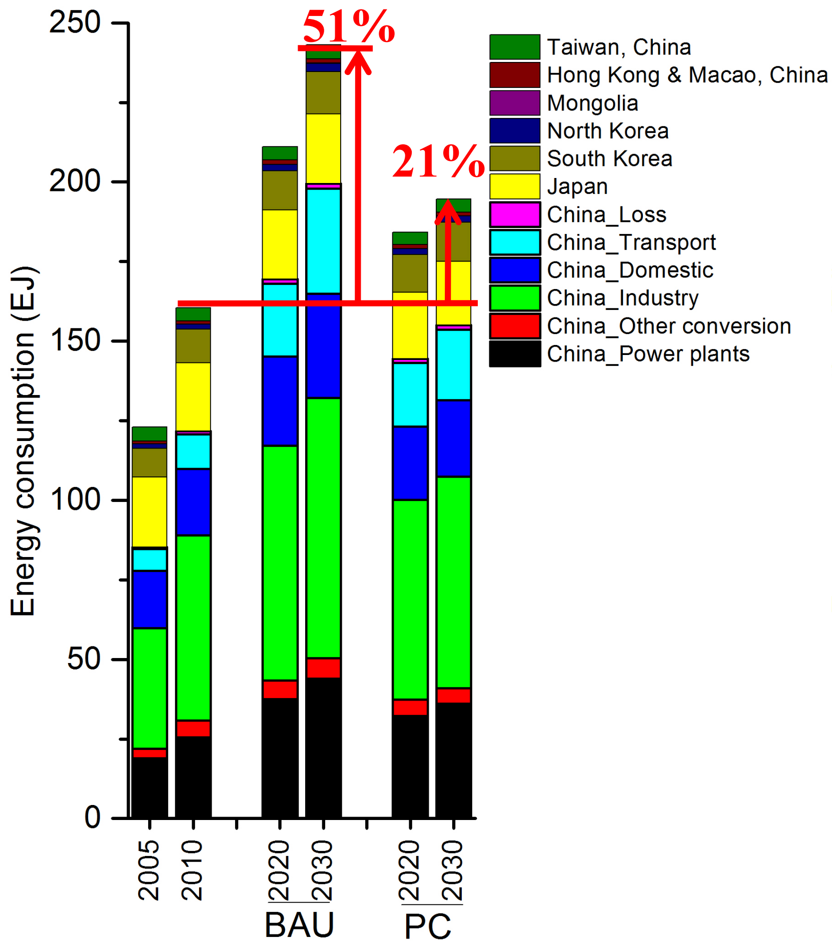
Definition of energy scenarios and emission scenarios

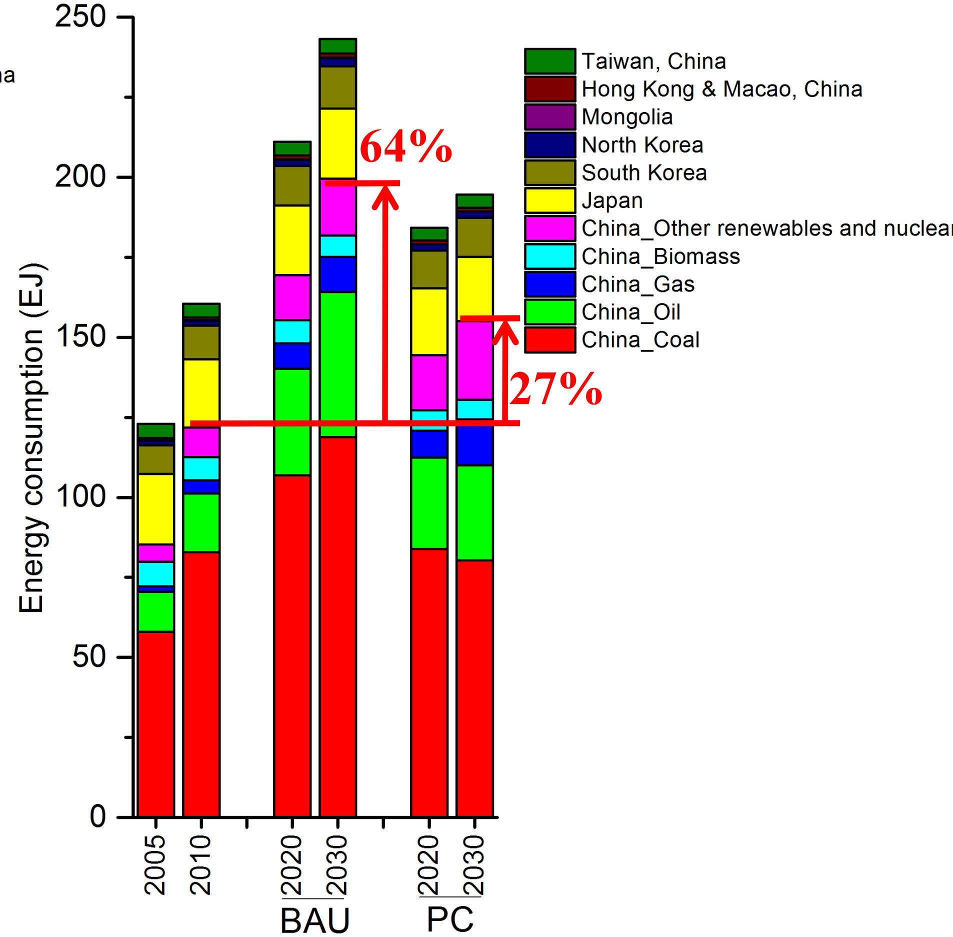
Energy Scenario	Energy Scenario Definition	End-of-pipe Control Strategy	End-of-pipe Control Strategy Definition	Emission scenario
Business as Usual (BAU)	Current policies and compliance (as of the end of 2010) are assumed.	**Baseline ([0])**	Current policies and current implementation status (as of the end of 2010).	**BAU[0]**
		Progressive ([1])	New pollution control policies are implemented in China, representing progressive approach towards future environmental policies. For the other countries in East Asia, the assumptions of the strategy [1] are exactly the same as strategy [0].	**BAU[1]**
		Maximum Feasible Reduction ([2])	Technically feasible control technologies would be fully applied by 2030.	**BAU[2]**
Alternative Policy Scenario (PC)	New energy-saving policies are released and enforced more stringently, including life style changes, structural adjustment and energy efficiency improvement.	**Baseline ([0])**	See the descriptions above.	**PC[0]**
		Progressive ([1])	See the descriptions above.	**PC[1]**
		Maximum Feasible Reduction ([2])	See the descriptions above.	**PC[2]**

Scenarios for countries other than China

- Our BAU and PC scenarios are consistent with the energy pathways of the reference and 450-ppm scenarios in Shindell et al. (2012), and UNEP and WMO (2011).
- The reference scenario is based on current energy and climate-related policies, the 450-ppm scenario explores the global energy consumption if countries take coordinated action to restrict the global temperature increase to 2ºC.
- Our control strategies [0] and [2] are consistent with the control strategies of the reference scenario and the maximum feasible reduction scenario in UNEP and WMO (2011), respectively. The control strategy [1] has the same assumptions as control strategy [0].

Projected energy consumption





	Industry	Transportation
2010	48%	9.0%
2030_BAU	41%	16.5%
2030_PC	41%	14.3%

	Coal	Other renewable and nuclear
2010	68%	7.5%
2030_BAU	60%	8.9%
2030_PC	52%	15.8%

End-of-pipe control techniques: power sector

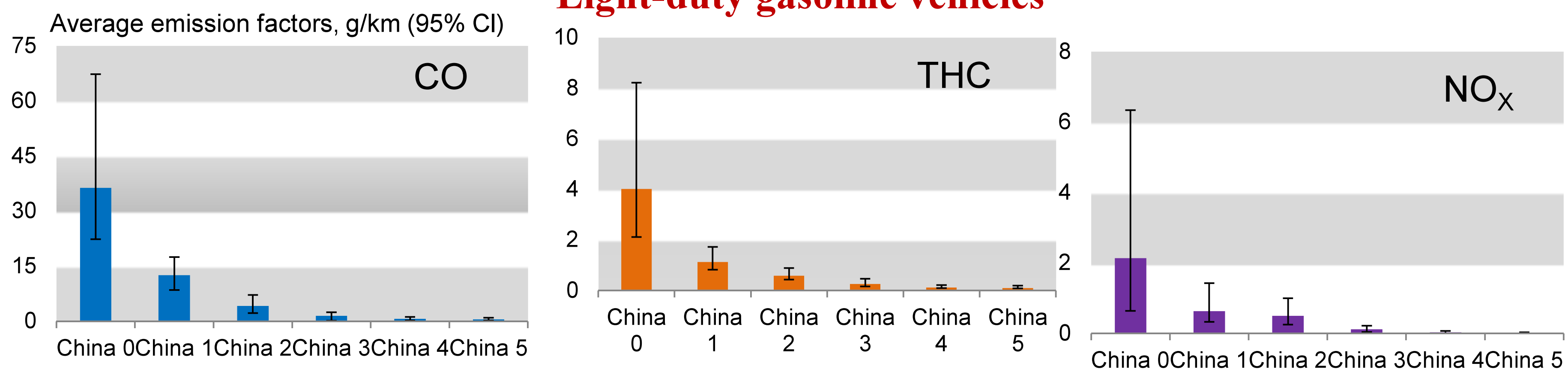
Penetrations of major control techniques in power sector in China (%)

Energy technology	Control technology	2010	2013	[1] 2020	[1] 2030	[2] 2020	[2] 2030
Grate boilers	CYC (PM)	12	10	0	0	0	0
	WET (PM)	88	90	100	100	100	100
Pulverized coal combustion	WET (PM)	0	0	0	0	0	0
	ESP (PM)	93	85	90	80	80	0
	HED (PM)	7	15	10	20	20	100
	FGD (SO_2)	88	93	95	97	100	100
	LNB (NO_X)	75	38	19	10	8	0
	LNB+SNCR (NO_X)	1	2	4	5	6	0
	LNB+SCR (NO_X)	12	54	74	84	86	100
Fluidized bed combustion	WET (PM)	0	0	0	0	0	0
	ESP (PM)	100	85	90	80	80	0
	HED (PM)	0	15	10	20	20	100
	CFB-FGD (SO_2)	53	53	66	80	100	100
	SNCR (NO_X)	0	0	3	8	0	0
	SCR (NO_X)	0	0	15	51	100	100
Natural gas power	LNB (NO_X)	74	70	60	35	50	0
	LNB+SNCR (NO_X)	1	0	3	6	5	0
	LNB+SCR (NO_X)	5	15	30	55	45	100

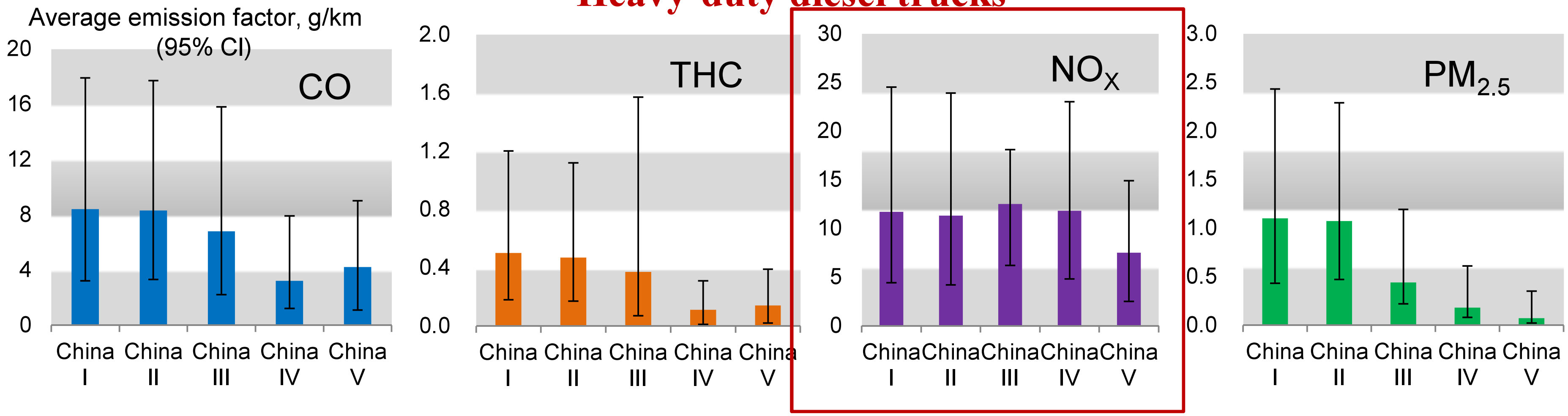
Vehicle emission factors significantly reduced

Increasingly stringent emission standards have substantially reduced vehicle emission factors, expect for NO_X emissions from heavy-duty diesel trucks.

Light-duty gasoline vehicles



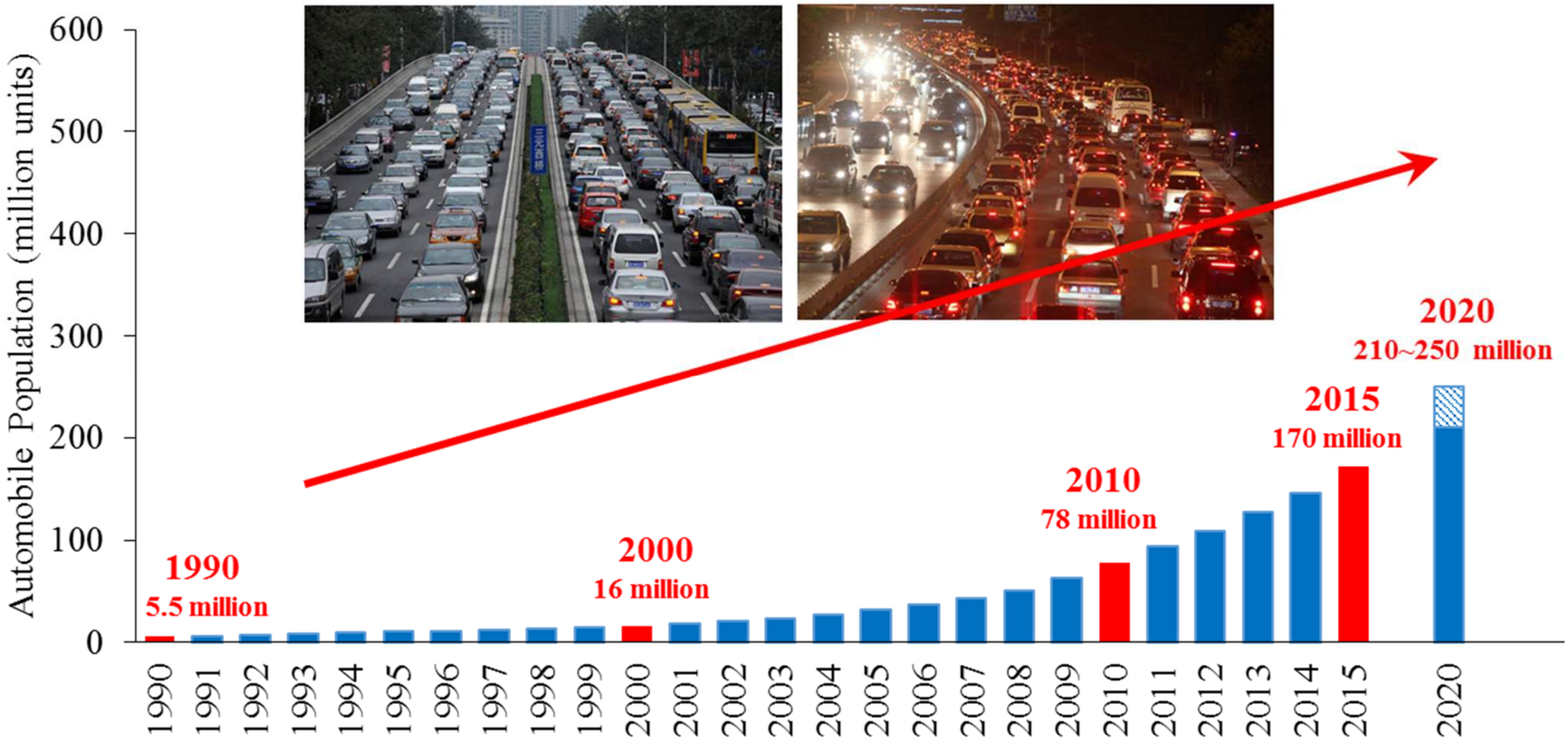
Heavy-duty diesel trucks



Note: Assessed by the EMBEV 2.0 model developed by Tsinghua University.

Source: Zhang et al., Atmos. Environ., 2014, 89. 216-229.

Growth of vehicle population in China



- **In 2009, China became the largest market with the vehicle sales worldwide.**
- **In 2013, China became the only country with sales of more than 20 million.**

Challenges and pathways: vehicle pollution

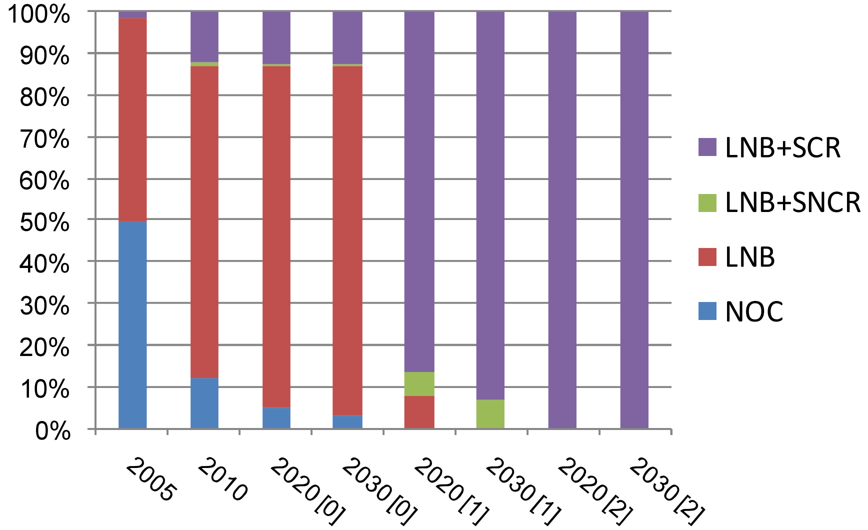
➢ **Enhance the emission control of non-road mobile sources (NRMS)**

NRMS emission standards

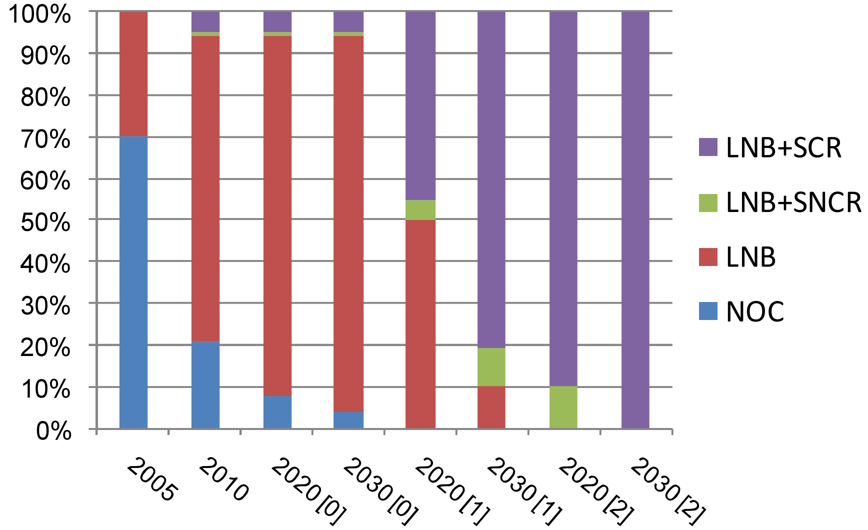
地区	车型	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
美国 U.S.	非道路柴油机 Non-road diesel engine	Tier 3						Tier 3 interim		Tier 4	
欧盟 EU	非道路柴油机 Non-road diesel engine	Stage 3A						Stage 3B		Stage 4	
中国 China	重型柴油机 Heavy-duty diesel engine	国2 China 2			国3 China 3					国4 China 4	
	非道路柴油机 Non-road diesel engine	无控制要求 No emission control regulation			国1 China 1		国2 China 2				
	船用柴油机 Marine diesel engine	无控制要求 No emission control regulation									

Application of NOX control technologies

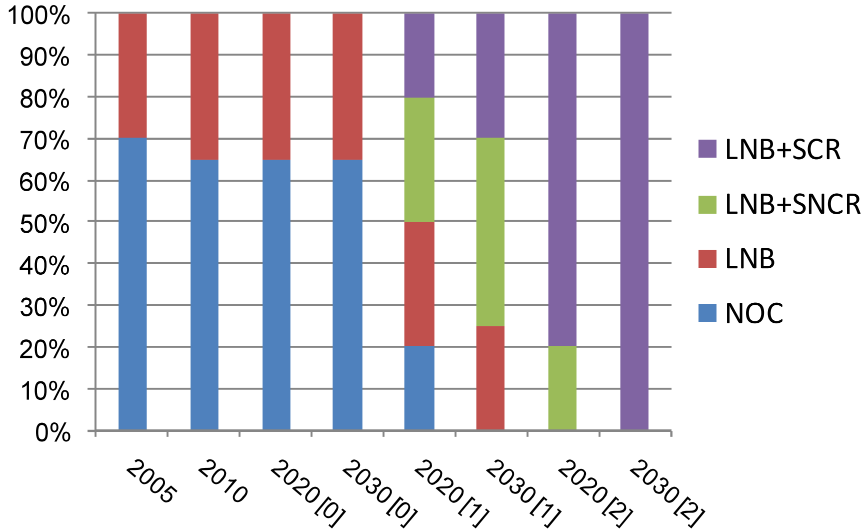
Coal-fired power plants



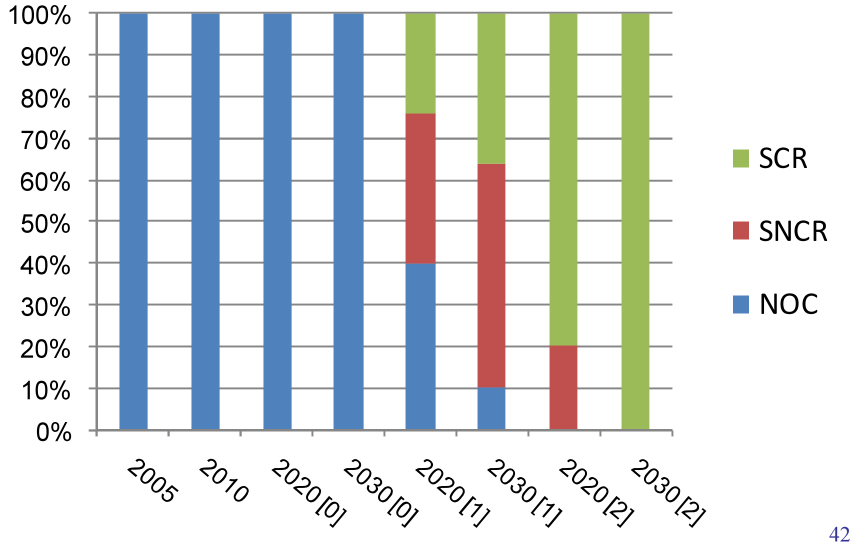
Natural gas power plants



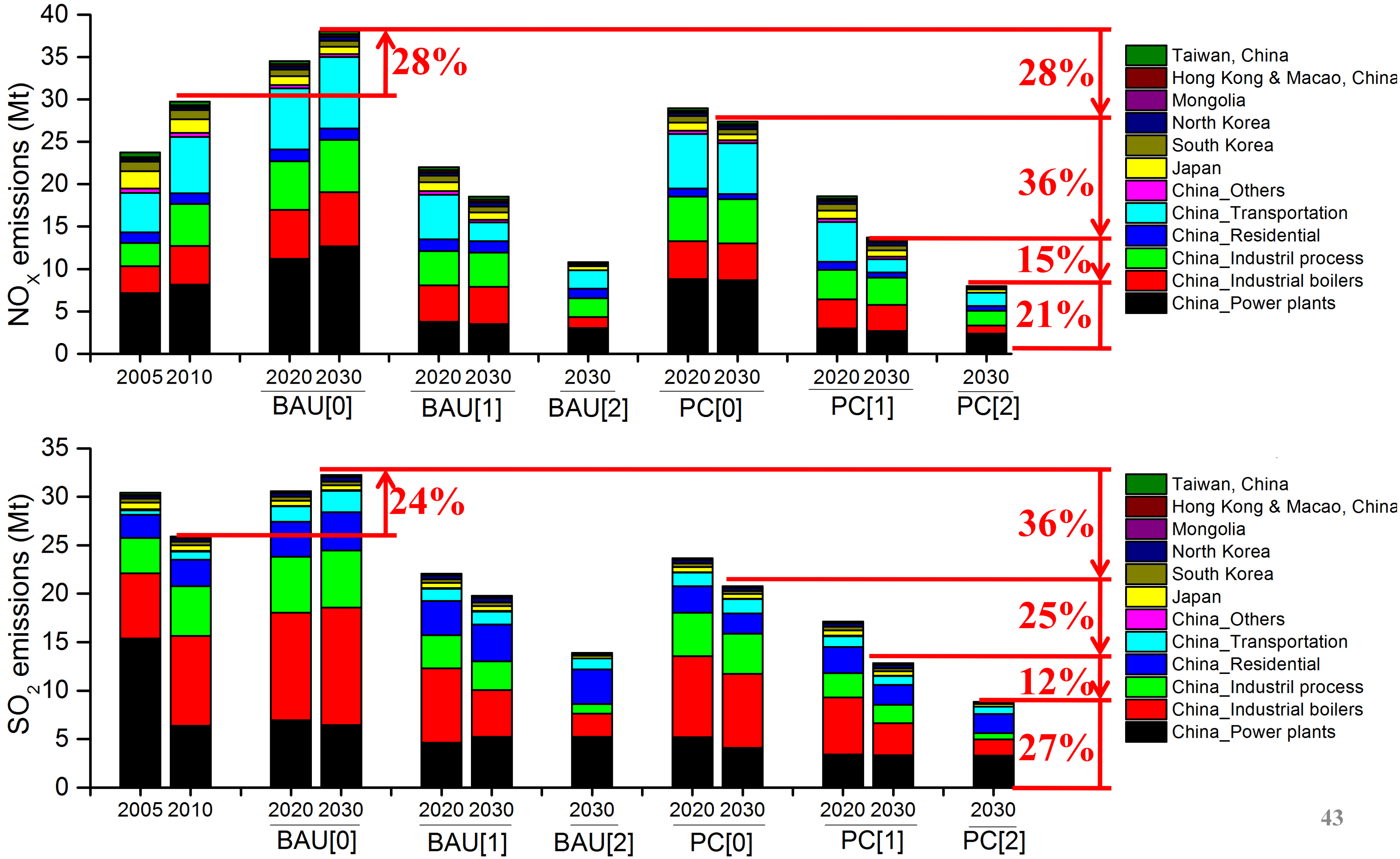
Precalcined cement kiln



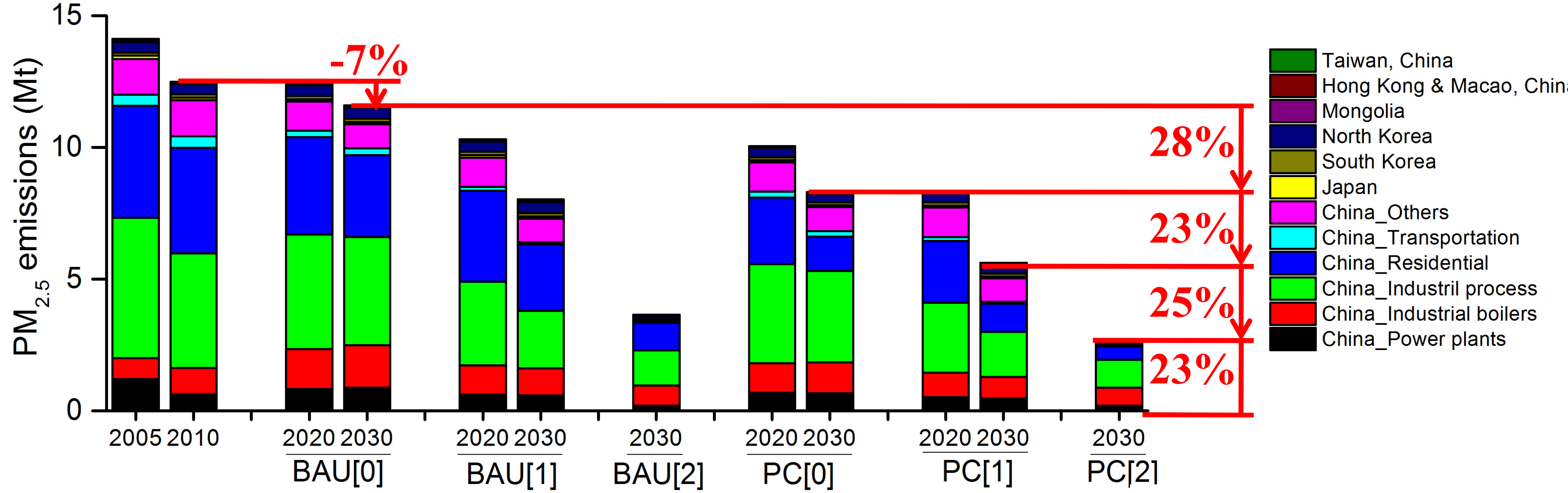
Sintering

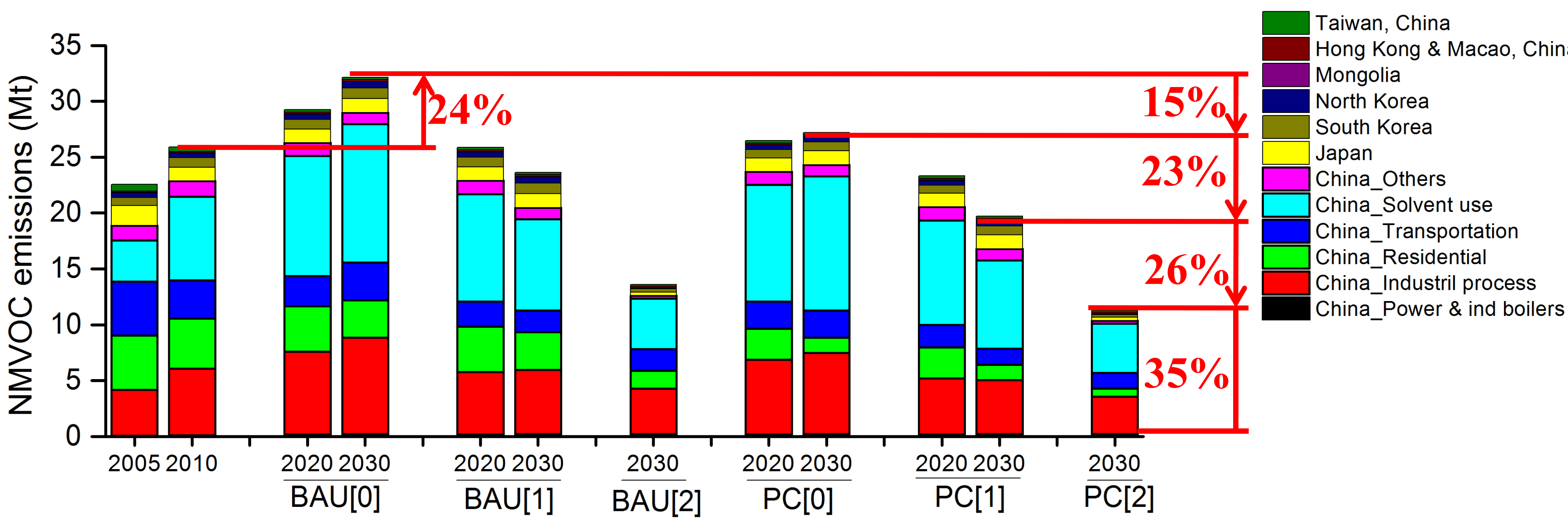


Future trends of NOx and SO2 emissions

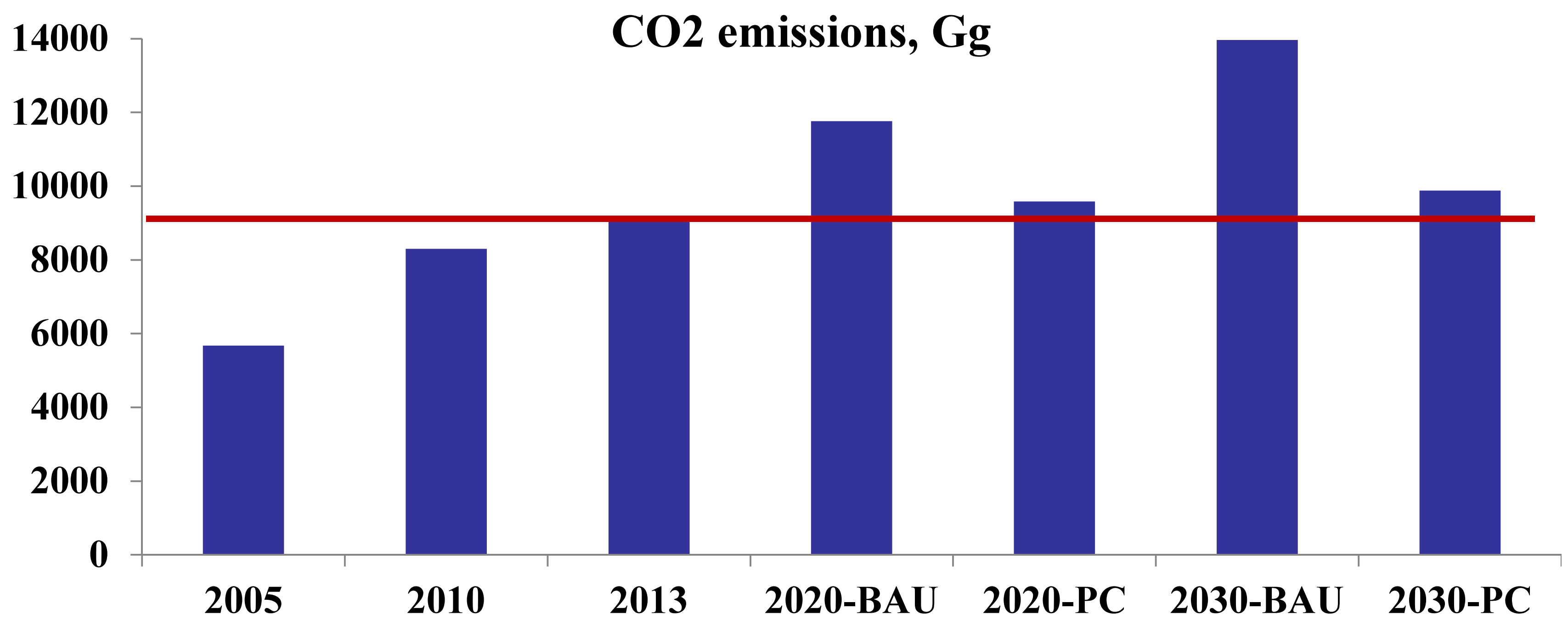


Future trends of PM2.5 and NMVOC emissions



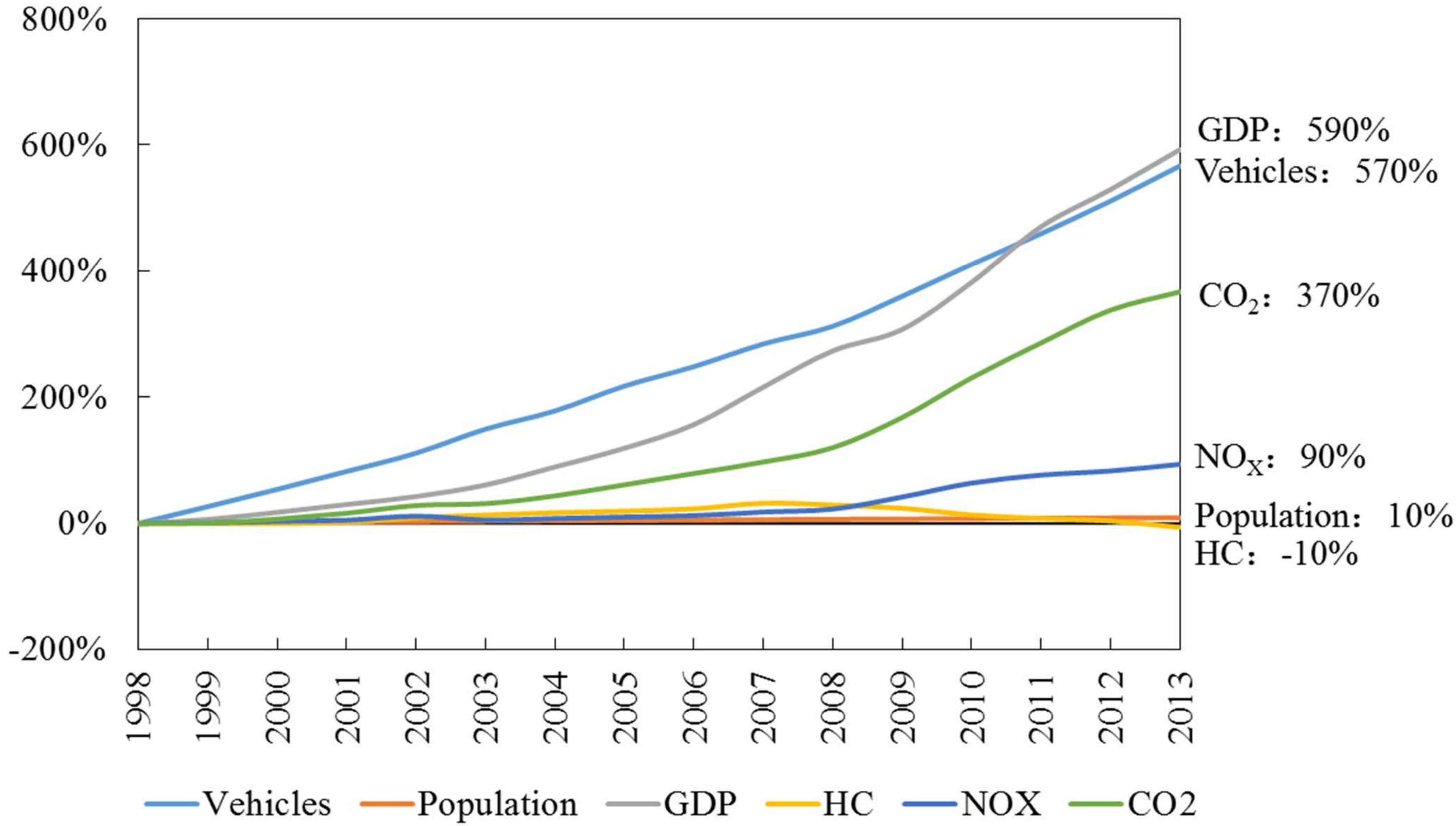


Challenges: multiple pollutants vs multiple effects



- **In the next 20 years, China needs to push hard to mitigate emissions of both CO_2 and multiple air pollutants.**
- **Addressing multi-pollutants multi-effects provides opportunities for innovation and to build the clean energy economy of the future—a future that's safer and healthier for our children.**

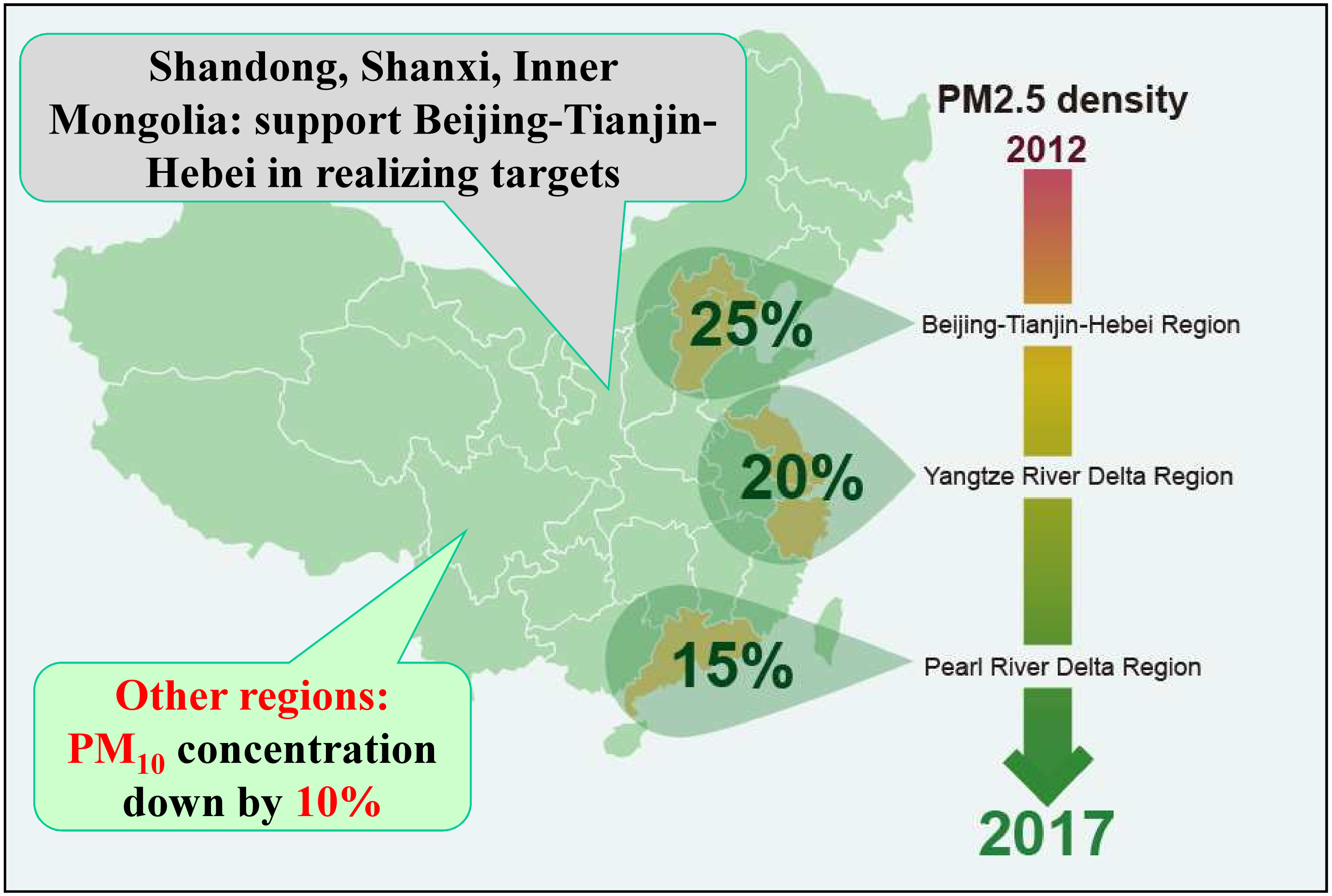
Economic growth in China, 1998-2013



Multi-pollutant emission inventory for China

- **Years:** 1990-2014
- **Spatial domain:** Mainland China
- **Categories/Sectors:** ~800 anthropogenic sources, aggregated to four sectors (Power, Industry, Residential, Transportation)
- **Species:** SO_2, NO_x, NMVOC, NH_3, BC, OC, $PM_{2.5}$, PM_{10}, CO and CO_2
- **VOC speciation:** ~600 individual species, lumped to various mechanisms (SAPRC99, SAPRC07, CB05, etc.)
- **Spatial resolution:** user defined

Air Pollution Prevention and Control Action Plan



China's air quality management has shifted from targeting "Emissions Reduction" (Technology-based) to targeting "Air Quality" (Risk-based)