3th IAEE Asian Conference

The Role of Coal in China

Ying Fan

Center for Energy and Environmental Policy research (CEEP)
Institute of Policy and Management (IPM)
Chinese Academy of Sciences (CAS)

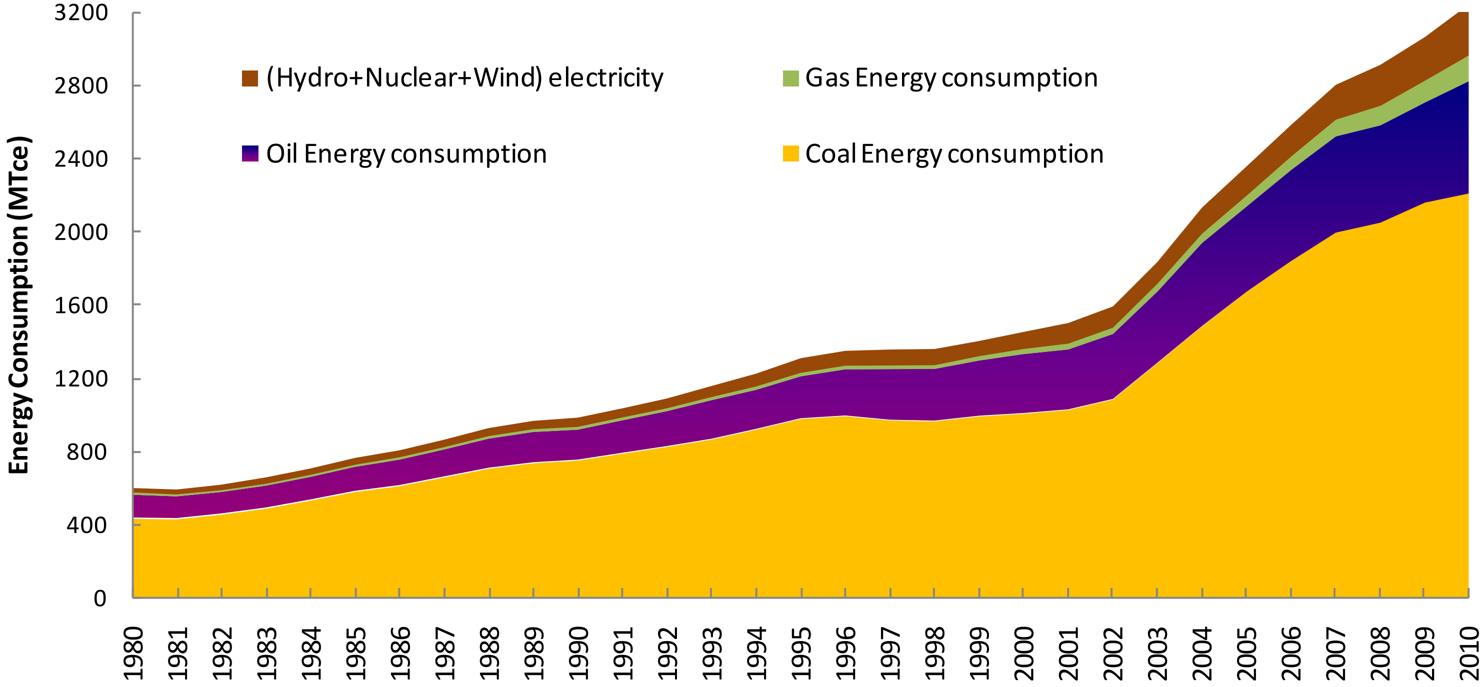
20-22 Feb, 2012, Kyoto

Contents

- Introduction
- Coal demand
- Challenges
- CCS investment

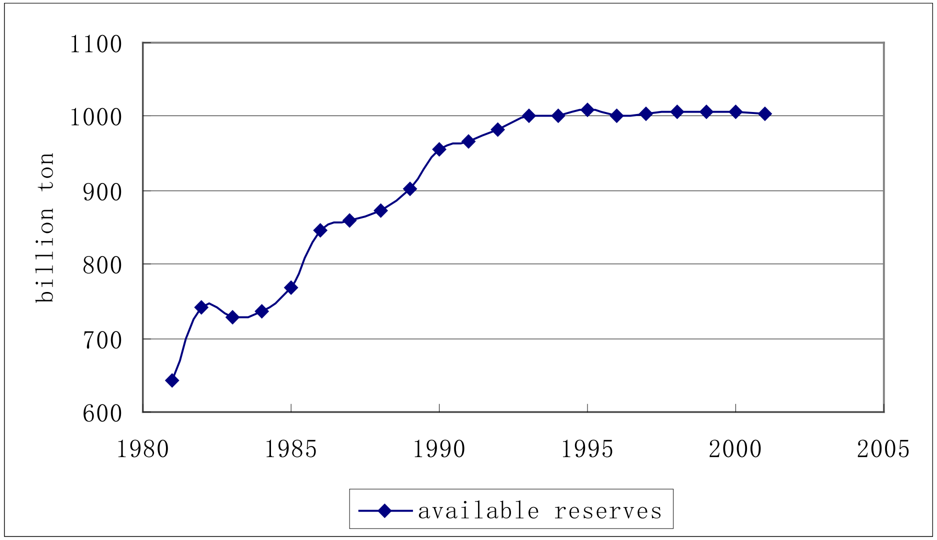
Economic growth and energy consumption

- China's rapid economic growth was accompanied with quick increase of energy consumption
- in 1978-2010, --Annual economic growth rate in average is more than 9%
  --Primary energy consumption growth rate is 5.6%
  --Energy production growth rate is 5.0%
- In 2010, China has consumed 3.25 BTce energy, in which coal, oil, gas, nuclear and renewable have accounted for 68.0%, 19.0%, 4.4%, and 8.6% (coal equivalent calculation), respectively.

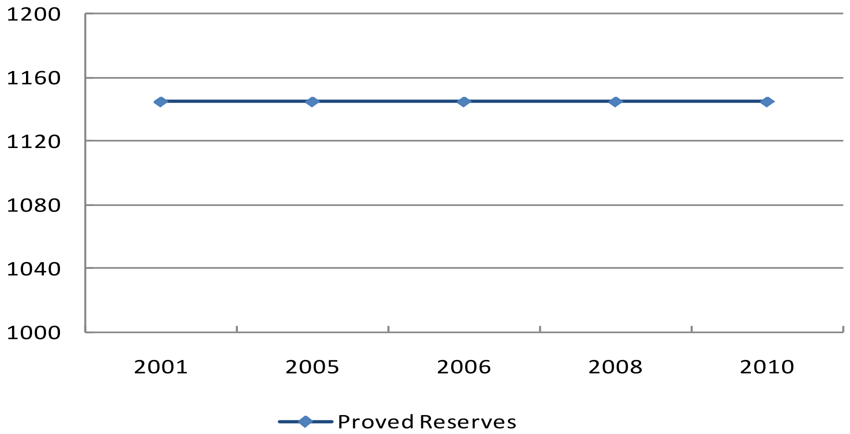


Coal reserves -1

- **The primary energy resources: rich coal, poor oil, little gas**
- There is relatively rich coal resource endowment: In 2010, the coal reserve-production ratio is 35, and oil and gas are 9.9 and 28.8.
- The R/P ratio has decreased very sharply from 105 years in 2001 to 35 years in 2010

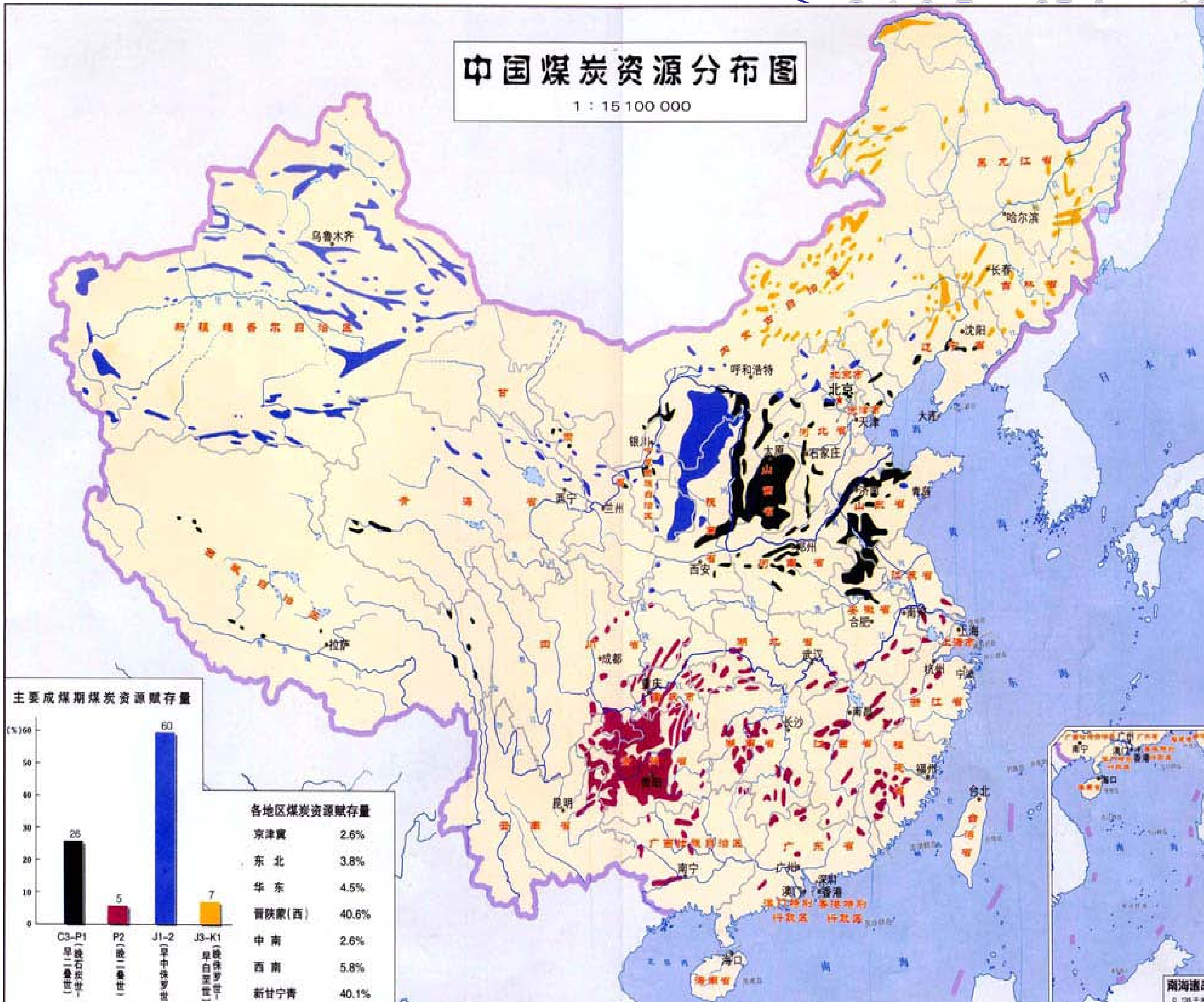


Source: China Statistics Yearbook 1981-2002



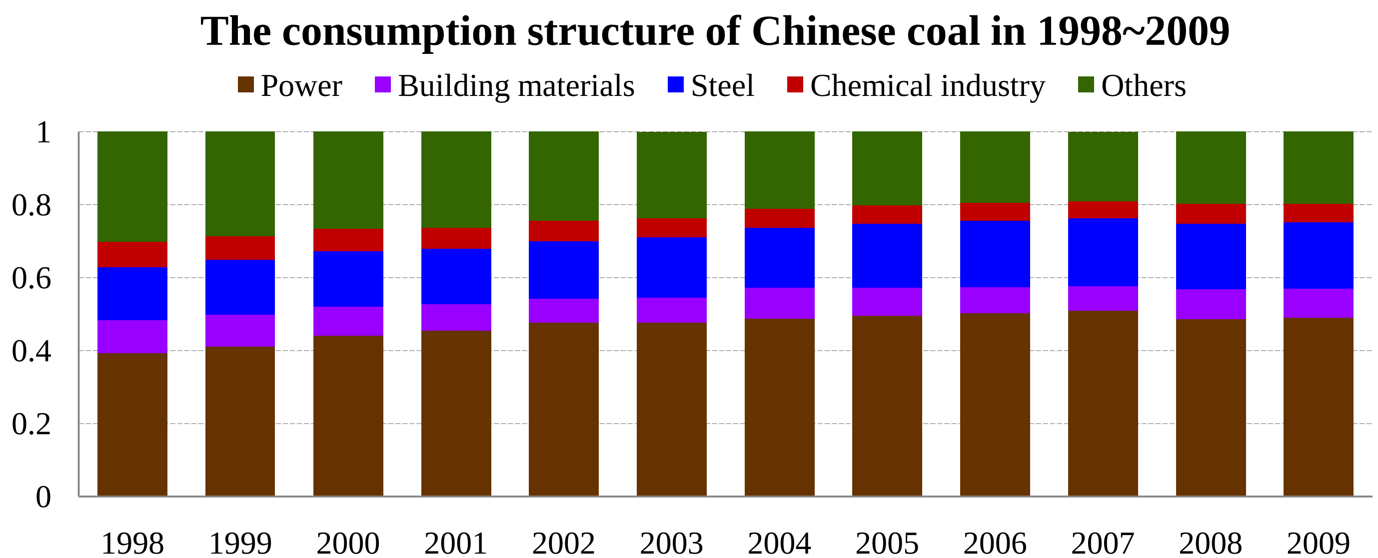
Source: BP Statitical Review, 2002, 2006, 2007, 2009, 2011

Coal reserves -2



Coal consumption

The main coal consumed industries are power, steel, building material, and chemical industry. Their coal consumption proportion increased gradually and reached 80% of the total coal consumption in 2009.



Date source：State statistics bureau

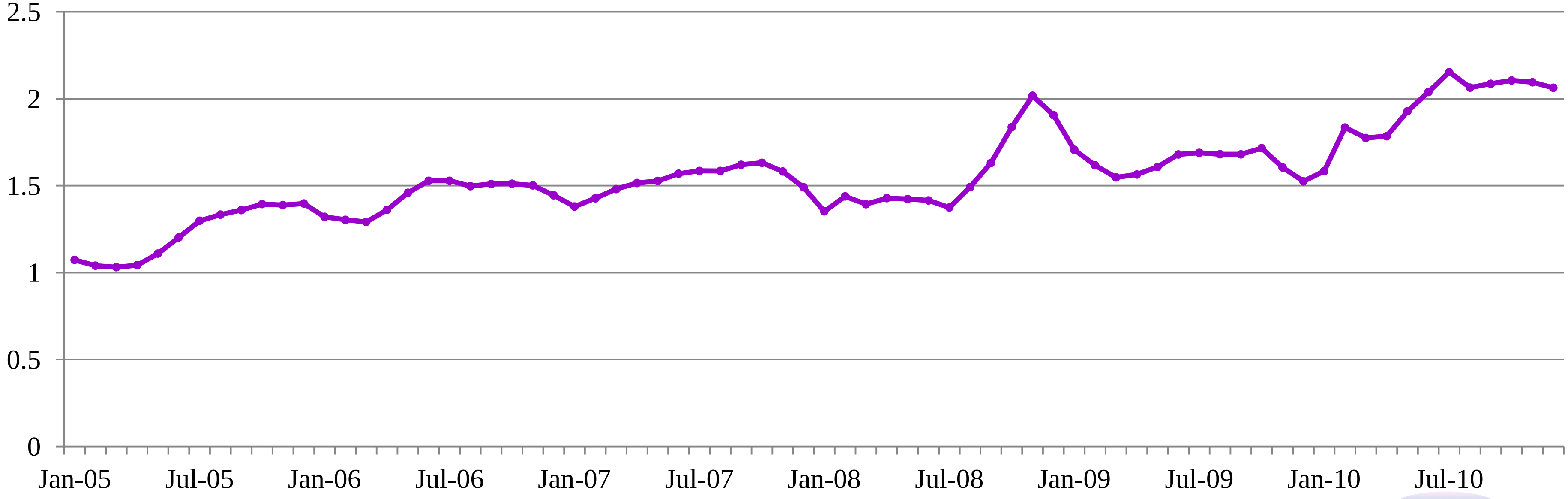
Coal production

The coal production increased fast.(2.4 billion tons in 2005 to 3.2 billion tons in 2010)

Production capacity reached 3.6 billion tons at the end of 2009. It is forecasted that the coal production capacity will be 3.8~4.0 billion tons in 2013.

coal inventory reached 200 million tons in 2010 with a rising trend.

The coal inventory in China in 2005 ~ 2010 (in 100million tons)



Environmental impact

Production side

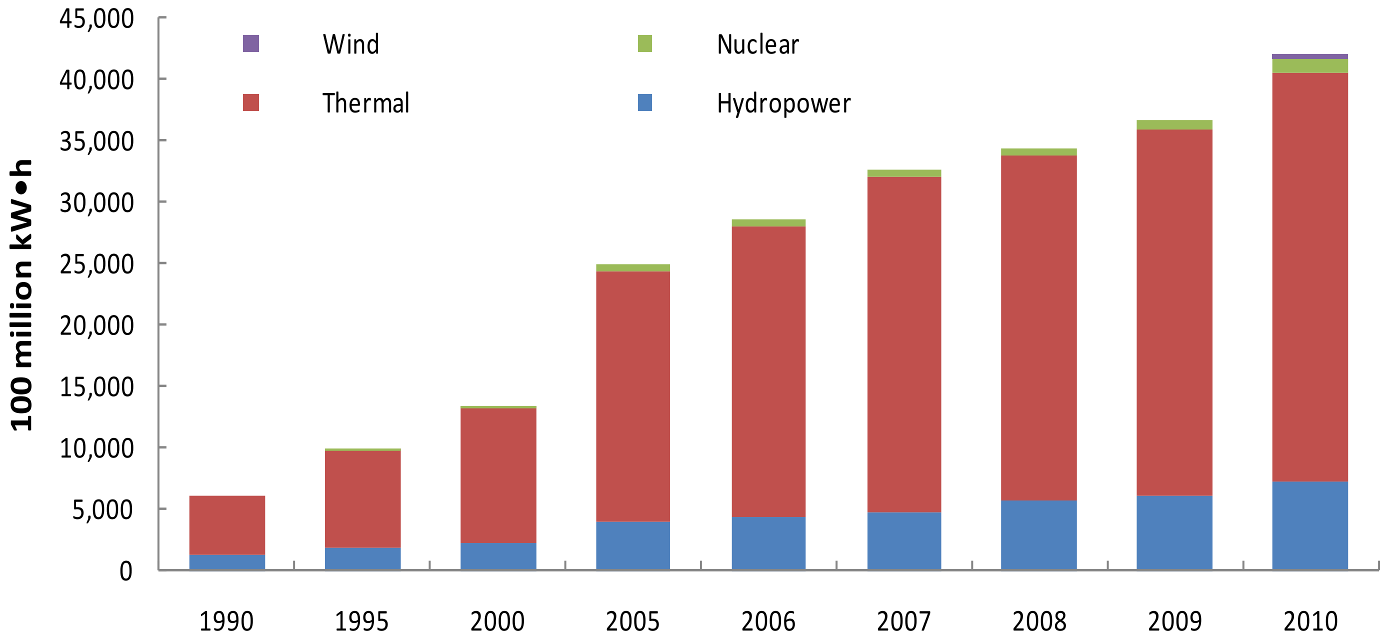
- Surface subsidence in coal mining
- Coal waste piling from coal mining and processing
- Underground water system destroyed.
- By the end of 1990, due to the coal mining and processing, the area of surface subsidence was 300 thousand ha, and increasing at the speed of 13~20 thousand ha/a. The coal waste was piling up at the speed of 130 billion tons.

Consumption side

- Come from four industries: Power generation, building materials, steel and chemical industry.
- Air pollution, water pollution, etc, because of emissions of SO2, CO2, NOx, VOC, PM10, solid waste, and so on.
- According to statistics, the SO2 emission proportion due to coal direct burning in national total emissions was 87%, CO2 was 71%, Nox was 67%, and PM10 was 60%.

Coal dominates China's energy consumption

Coal is mainly used to produce electricity. In 2009, China produced 4.21 trillion kilowatts hours of electricity, of which 79.2% was produced by thermal power



Power generation from 1990-2010

Source: China Statistics Yearbook 2011

China's GDP growth by scenario

	2005	2010-2015	2016-2020	2021-2025	2025-2030
Extensive Economic Scenario	11.3%	8.8%	7.3%	6.0%	5.0%
Reference Scenario	11.3%	7.5%	6.5%	5.9%	5.3%
Enhanced Low-carbon Scenario	11.3%	7.4%	6.4%	5.9%	5.3%

- In the Reference Scenario, China's GDP will grow at the economic 7% per annum from 2011 to 2020 and 5.6% per annum from 2021 to 2030.
- In the Extensive Economic Scenario, It will grow faster in the short term with an average rate of 8.8% per annum from 2011 to 2015.

China's primary energy demand and CO2 emissions

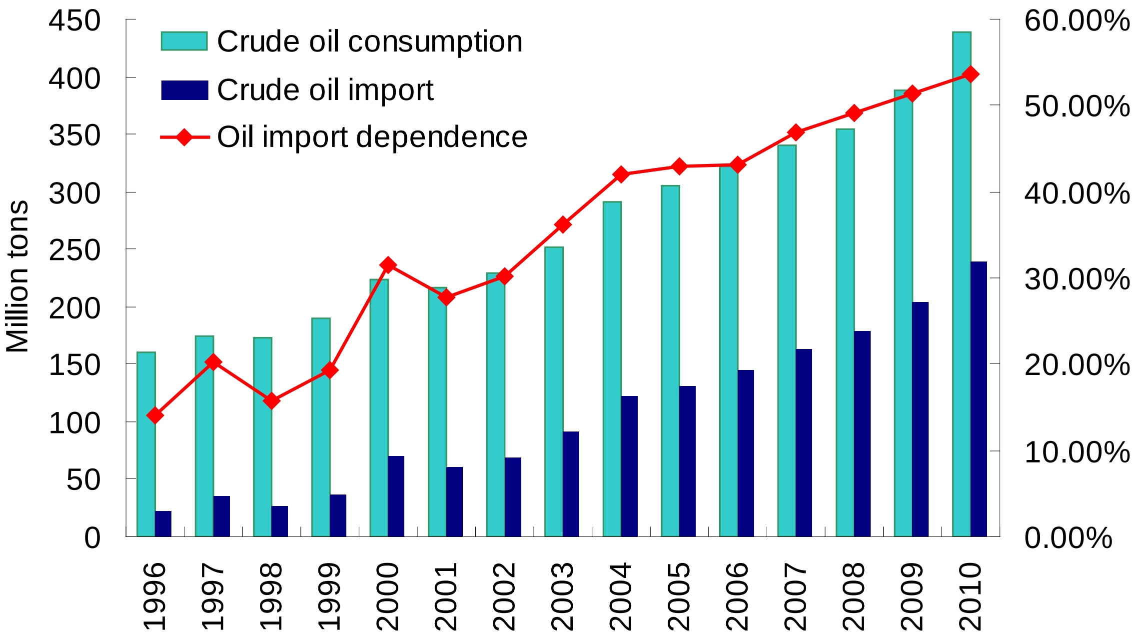
Center for Energy & Environmental Policy Research

			Extensive Economic Scenario		Reference Scenario		Enhanced Low-carbon Scenario	
		2005	2020	2030	2020	2030	2020	2030
Primary energy demand (Mtoe)	Coal	1142.1	2290.2	2345.3	1980.6	1993.1	1793.8	1738.6
	Oil	328.2	695.2	817.9	573.6	626.8	520.3	537.0
	Gas	42.2	318.4	430.3	272.4	355.9	248.8	294.8
	Non-fossil energy*	110.4	399.8	780.4	499.6	978.5	514.4	1052.9
	Total	1622.8	3703.6	4373.9	3326.3	3954.3	3077.3	3623.3
CO_2 emissions (Mt)		5630	13490	14360	11200	11740	10230	10460
CO_2 emissions per unit of GDP (t-CO_2/million constant 2000$)		2973.5	1936.6	1208.2	1782.4	1088.3	1636.7	968.3
The share of non-fossil energy (%)		6.8	10.8	17.8	15.0	24.7	16.7	29.1

Challenge -1

- **Energy Security**
- Energy demand will increase further, although the energy intensity will keep decrease
- Oil import dependence is keeping rising
- The share of Renewables and nuclear is limited in near future

China became a net oil importer since 1993. In 2011, China imported 253.7 million tons of crude oil, the import dependence is higher than 55%.

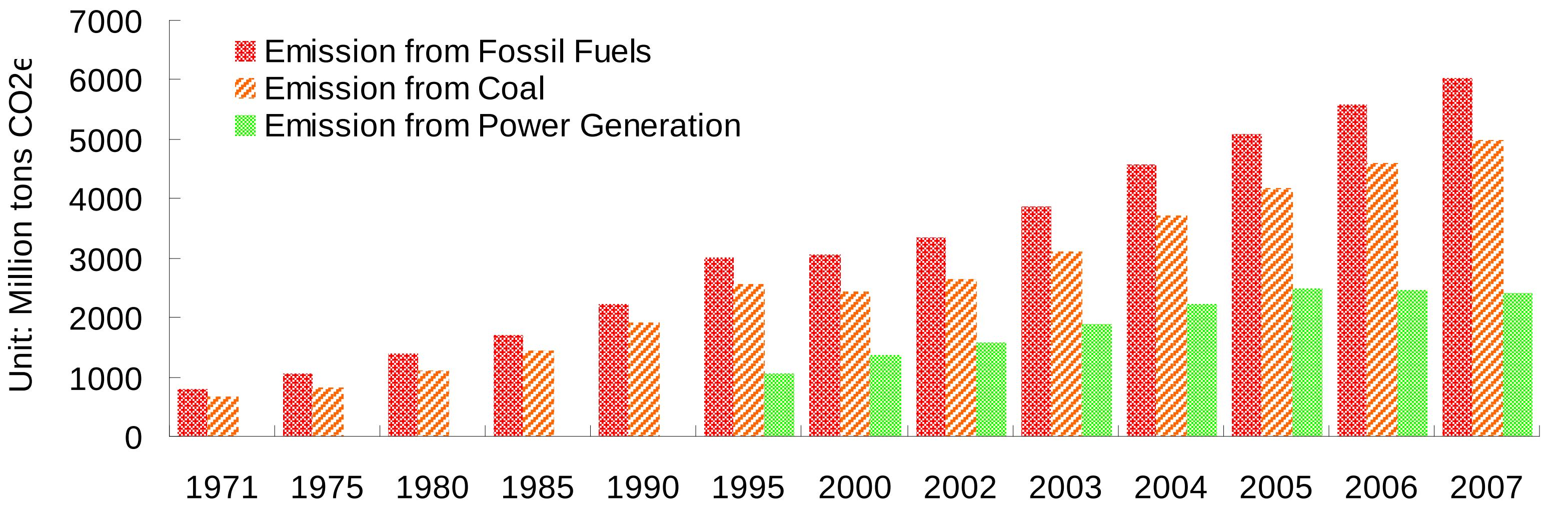


Challenge -2

- **Environment protection**
- Severe environmental pollution, ecological and underground water destruction
- In 2010,
- SO_2: 21.85 million tons
- NOX: 22.73 million tons

Challenge -3

- **Mitigating climate change**
- CO_2 emissions are highly correlated with coal combustion.



CO2 emissions from fossil energy use in China

In 2009 CO2 emissions (IEA, 2011)

- from fossil fuels: 6877.2 million tons
- from coal: 5750.8 million tons (83.6%);
- from power generation: 3324.3 millions tons (48.3%)

Challenge -4

- **Coal industry development and regulation**

- Inadequate coal exploration investment
- Including the cost of environment into coal production
- Enhancing safety production: although the coal mining mortality rate fell to 0.749 from 2.77. And the coal company also help to solve employment problem, and raise the staff's welfare.

Solutions to sustainable development

1 Energy conservation

- Improve the production efficiency
- Improve energy consumption efficiency
- Improve the efficiency of thermal power generation further
- Resource management, resource tax induced

Solutions to sustainable development

2 Coal production modernization

- Improve the resource utilization level
- Safety production
- Promoting the market reform
- Constructing 14 coal industry bases
- Coal clean utilization

Solutions to sustainable development

3 Managing environmental cost

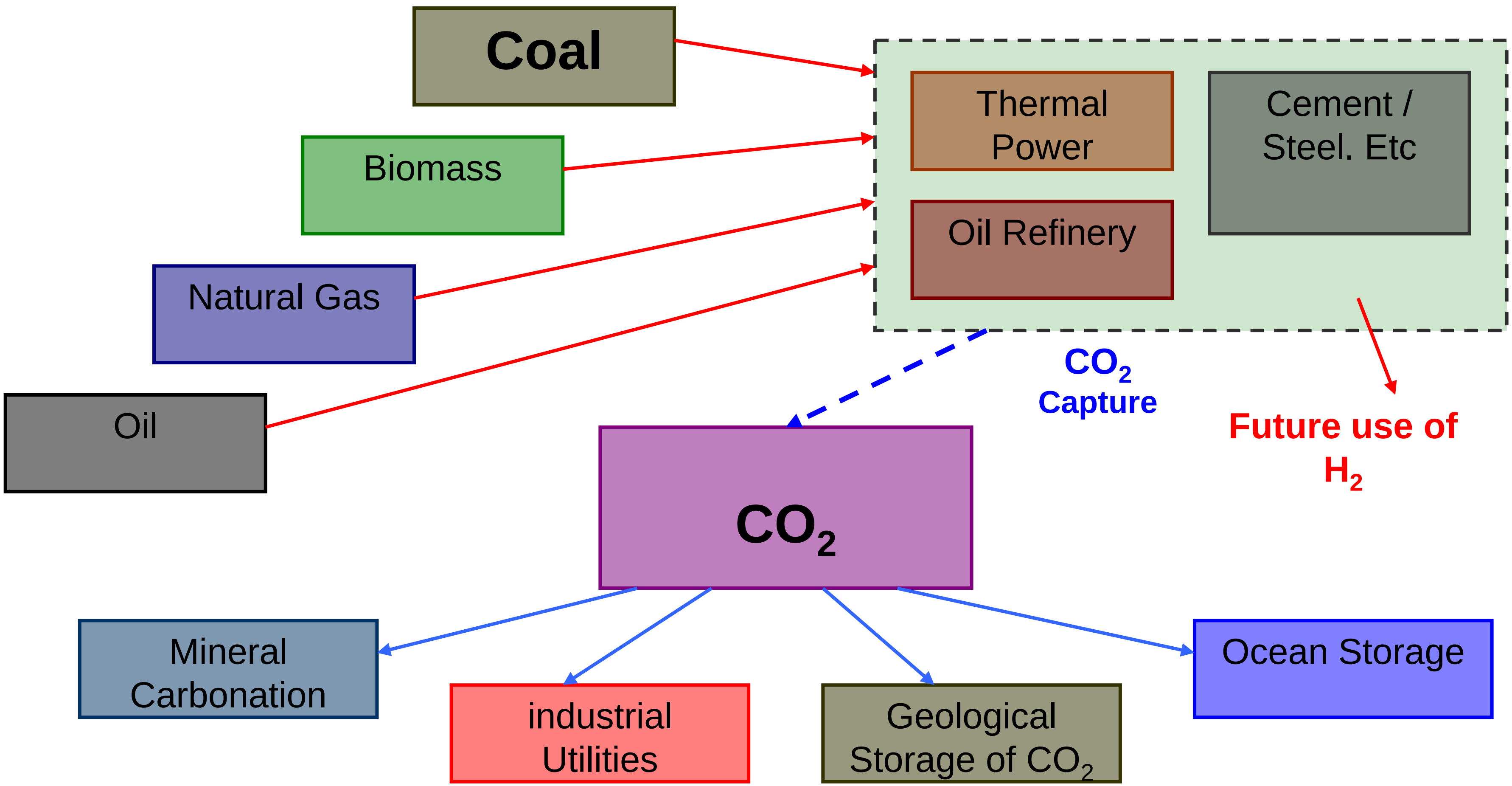
- Carbon tax
- Emission trading system
- Expenditure for improving environmental lost
- Ecological recovery

Solutions to sustainable development

4 Alternative Energy development

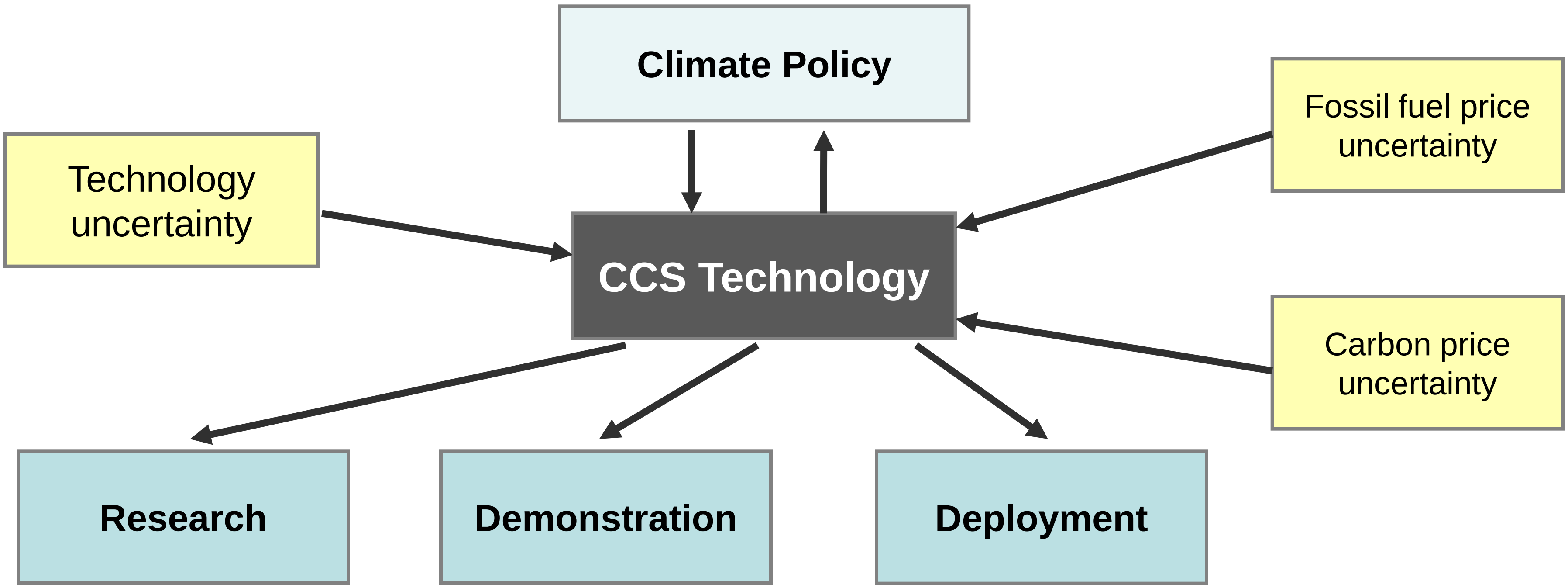
- Investment and financing
- R&D
- Policy support
- International cooperation

5 Carbon Capture and Storage ?



(IPCC, 2005)

Uncertainties



The research in progress of CCS technology will directly affect the future amount of emission reduction in fossil energy

The cost and applicability of CCS is one of the main factors that affect CCS development in developing countries which energy consumption is dominated by coal, such as China

CCS investment evaluation model

- **We establish a CCS investment evaluation model based on real options theory**
- The model considers uncertainties from the existing thermal power generating cost, carbon price, thermal power with CCS generating cost, and investment in CCS technology deployment
- **The model aims to evaluate the value of the cost saving effect and the amount of CO2 emission reduction through investing in thermal power with CCS to replace existing thermal power**
- The model could be used as a policy analysis tool to evaluate the effects of regulations on CCS investment through scenario analysis
- The **cost saving effect** in this paper is defined as: in a specific carbon tax, generating cost that can be saved from investing in thermal power with CCS technology to replace existing thermal power**. Cost saving is positive means the power corporate can avoid unnecessary expenses or receive extra income through selling VER. And cost saving is negative means the power corporate will have to pay the extra cost through investing in CCS**

Uncertainty factors

1) CCS Investment cost

– It will take time for a power plant to complete CCS investment and switch from existing thermal power to thermal power with CCS. To indicate the uncertainty of CCS technology, here assuming the **remaining total deployment investment *K* follow a stochastic process:**

$$dK = -iP_C dt + \beta [iP_C K]^{0.5} dx$$

2) Thermal power generating cost

– Thermal power generating cost consists of operational cost and fuel cost, and **the uncertainty of thermal power generating cost mainly come from its fuel price risk:**

$$dP_F = \alpha P_F dt + \sigma_F P_F dz_F$$

Uncertainty factors

3) Carbon tax

- **The carbon tax defined in this paper mainly refers to the carbon price, i.e., the price paid per unit emission.**
- **For fixed carbon price mechanism, the emission per unit is valued as a constant price**
- **For volatile carbon price mechanism, a stochastic process can better reflect the trend of price changes and volatility**

$$dP_C = \gamma P_C dt + \sigma_C P_C dz_C$$

4) CCS generating cost

- **Generating cost of thermal power with CCS is not only affected by fossil fuel price, but also affected by the capture technology. Therefore, a controlled diffusion process has been applied to represent the motion of generating cost of thermal power with CCS**

$$dP_S = \upsilon(M) P_S dt + \sigma_S(M) P_S dz_S \qquad K > 0$$ (During CCS deployment period)

$$dP_S = \theta P_S dt + o_S P_S dz_S \qquad K = 0$$ (After CCS deployment period)

$$P_S \geq P_C * 1.1$$

Model description

- The given period for the cost saving effect observation in this model can be divided into two stages
  - **stage I (**CCS deployment**) is the time needed to complete the deployment**
  - **stage II (**generating period**) is after the deployment and starts receiving cost saving cash flows to the end of the given period**
- In CCS operation period (stage II)
  - **the remaining expected value of cost saving through adopting CCS in the presence of carbon tax is:**

$$E[V(P_F,P_C,P_S,t)]=\frac{P_F}{(\hat{\alpha}-\alpha)}q\left[1-e^{-(\hat{\alpha}-\alpha)(T-t)}\right]+cr\frac{P_C}{(\gamma-\gamma)}q\left[1-e^{-(\gamma-\gamma)(T-t)}\right]-\frac{P_S}{(\hat{\theta}-\theta)}q\left[1-e^{-(\hat{\theta}-\theta)(T-t)}\right]$$

- In CCS deployment period (stage I)
  - **At the initial stage, the expected value of the CCS cost saving (value of CCS investment opportunity) is:**

$$E[F(P_F,P_C,P_S,K,0)]=\frac{P_{F_0}}{(\hat{\alpha}-\alpha)}e^{(\alpha-\hat{\alpha})T_{0\min}(K_0)}q\left[1-e^{-(\alpha-\alpha)(T-T_{0\min}(K_0))}\right]+cr\frac{P_{C_0}}{(\gamma-\gamma)}e^{(\gamma-\gamma)T_{0\min}(K_0)}q\left[1-e^{-(\gamma-\gamma)(T-T_{0\min}(K_0))}\right]$$

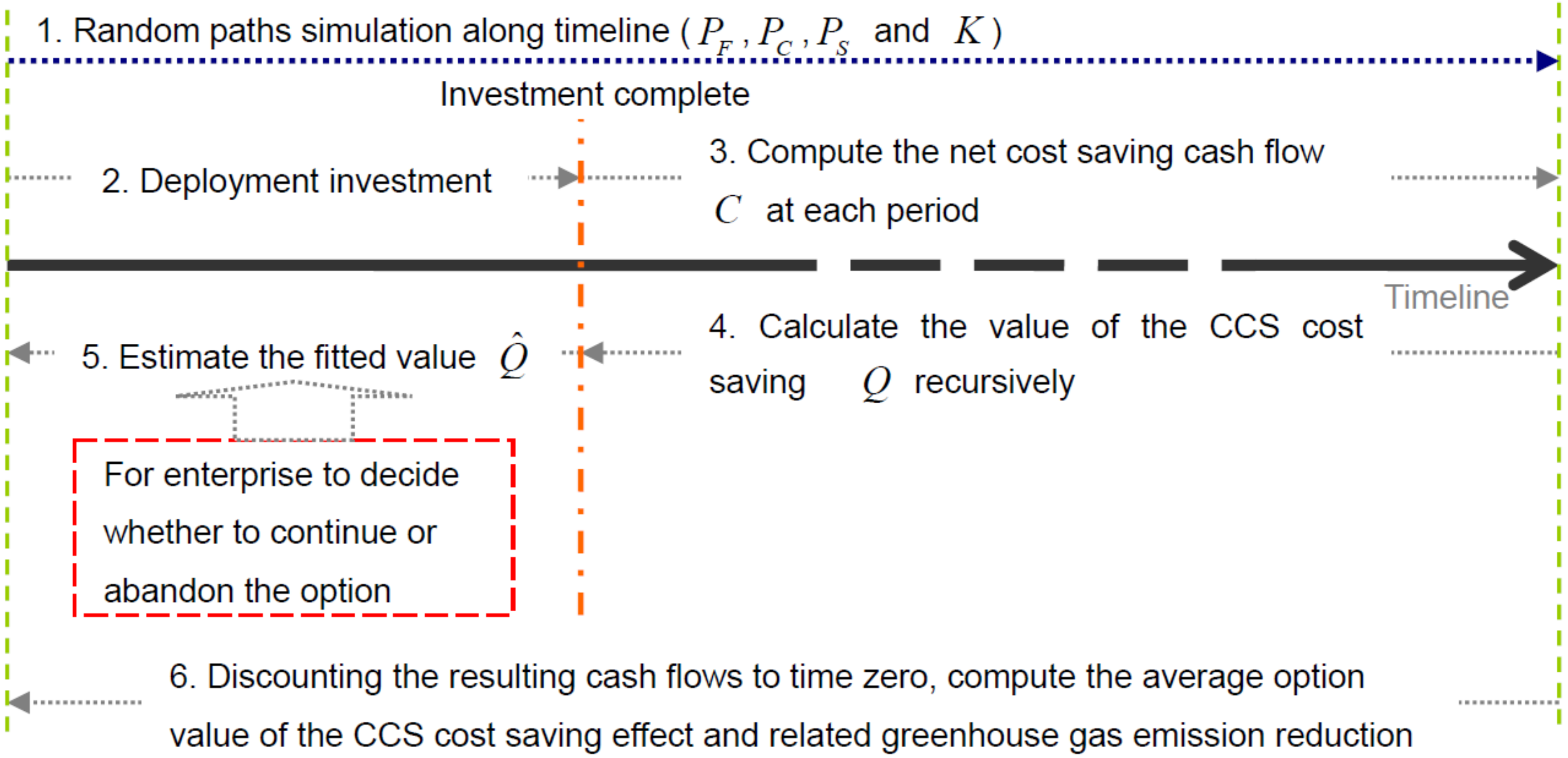
$$-\frac{P_{S_0}}{(\hat{\theta}-\theta)}e^{(\theta-\hat{\theta})T_{0\min}(K_0)}q\left[1-e^{-(\theta-\theta)(T-T_{0\min}(K_0))}\right]$$

$$-\int_0^{T_{0\min}(K_0)}P_{C_0}i_{\max}e^{-(\hat{\gamma}-\gamma)t}dt-\int_0^{T_{0\min}(K_0)}Me^{-rt}dt$$

Model description

• **In the period before the CCS deployment is completed, the corporate owns the abandon option**: if the investment needed is higher than expected cost saving value at a time step, the corporate will exercise the option to terminate the project to prevent from more losses

• The abandon option of the CCS investment is computed by the Least Squares Monte Carlo (LSM) method.



Model Parameters

Parameter	Model symbol	value	Notes
generation capacity of CCS	q	25000*10^6kwh	In 2007, China had produced 2722930*10^6 kwh of electricity. For one power generation enterprise, the generation capacity of CCS is set as 1% of total domestic electricity production.
thermal power generating cost	P_F	0.3 yuan/kwh	As coal-fired generation dominates China's thermal power generation, this paper takes the average generating cost of coal-fired power to represent thermal power generating cost. The data refers to the estimation from Zhu and Fan (2010).
thermal power generating cost drift rate	α	0.04/year	Set by this study. As the fuel cost of coal accounts large proportion of thermal power generating cost and the coal prices have showed a significant upward trend in recent years, we set the drift rate of thermal power generating cost as 0.04/year.
Thermal power generating cost standard deviation rate	σ_F	9.00%/year	The data refers to the estimation of coal generating fuel risk from Zhu and Fan (2010).
CO2 cost	P_C	0.12 yuan/kwh	It is a cost that power enterprises should pay for their GHG emissions form thermal power generation. Zhu and Fan (2010) have obtained the CO2 cost in China by converting the emission factor and CO2 price into per-kWh generating cost for thermal power. The data refers to the estimation of CO2 cost from Zhu and Fan (2010).
CO2 drift rate	γ	0.02/year	Set by this study.
CO2 standard deviation rate	σ_C	11.50%/year	The data refers to the estimation of carbon price risk from Zhu and Fan (2009).
thermal power with CCS generating cost	P_S	0.65 yuan/kwh	The data is a comprehensive assessment result which refers to technical assessment of China CCS applicability research in China-EU Straco2 project, IPCC report (2005), and Zhou et.al (2010).
thermal power with CCS drift rate (after deployment)	θ	-0.03/year	Set by this study.
thermal power with CCS standard deviation rate (after deployment)	σ_S	9.00%/year	CCS technology is based on fossil energy generation, here assuming it has the same cost volatility with existing thermal power. The data refers to the estimation of coal generating fuel risk from Zhu and Fan (2010).
thermal power with CCS drift rate (before deployment)	$\upsilon(M)$	-0.0325/year (when R&D input is 1000*10^6yuan/year), $\min\theta(M)$=-0.04/year	Set by this study.
thermal power with CCS standard deviation rate (before deployment)	$\sigma_S(M)$	8.33%/year (when R&D input is 1000*10^6yuan/year), $\max\sigma_S(M)$=7%/year	Set by this study.
Total investment cost of CCS deployment	K	10000*10^6yuan	The data is a comprehensive assessment result which refers to technical assessment of China CCS applicability research in China-EU Straco2 project, and Zhou et.al (2010).
Initial annual deployment expenditure	I	2000*10^6yuan/year	Set by this study which considers the assessment result from technical assessment of China CCS applicability research in China-EU Straco2 project, and Zhou et.al (2010)..
R&D expenditure	M	1000*10^6yuan/year	Set by this study.
Technology uncertainty	β	0.5	Here refers to the settings in the research of Schwartz (2003), Dixit and Pindyck (1994).
Riskfree rate	r	5.00%	China's long-term deposit interest rate is used as a risk-free rate to represent the discount rate
Capture rate	cr	90%	
Observation time	T	Year 2011-2030	According to the discussions about commercialization of CCS in China-EU Straco2 project, the authors believe that CCS can play a significant role in greenhouse gas emission reduction in the next 20 years.
Time Step Size in Simulations	Δt	1year	
Number of Simulations		5000	In general, the simulation results will start to convergence when paths more than 1000, so the number of paths simulated in different scenarios are set as 5000.
Emission Factor	e	893g CO2/kwh	Emission factor of coal-fired generation comes from IEA (2009). In 2007, CO2 emission per kwh from electricity and heat generation using coal/peat in China is 893g CO2/kwh.

Simulation

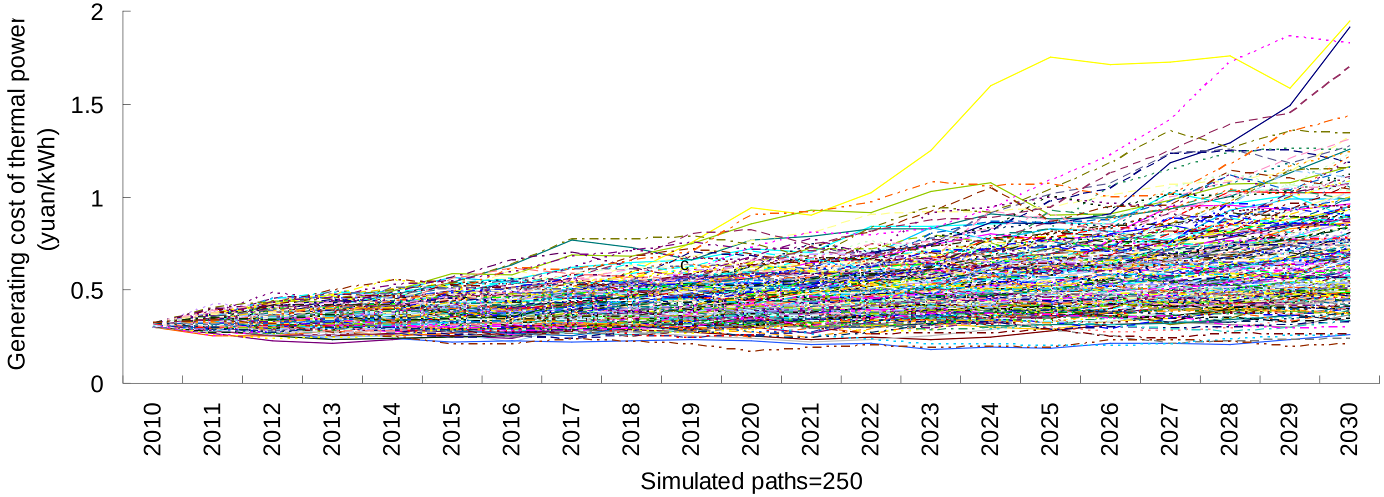


Figure 1: Thermal power generating cost simulation

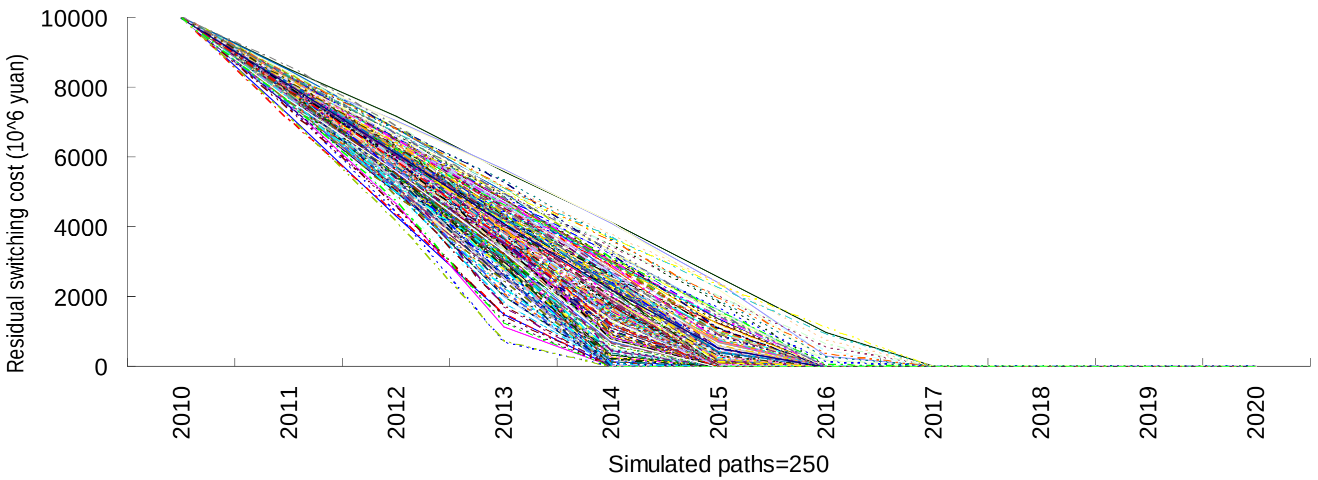


Figure 2: Residual switching cost simulation

Single simulation path

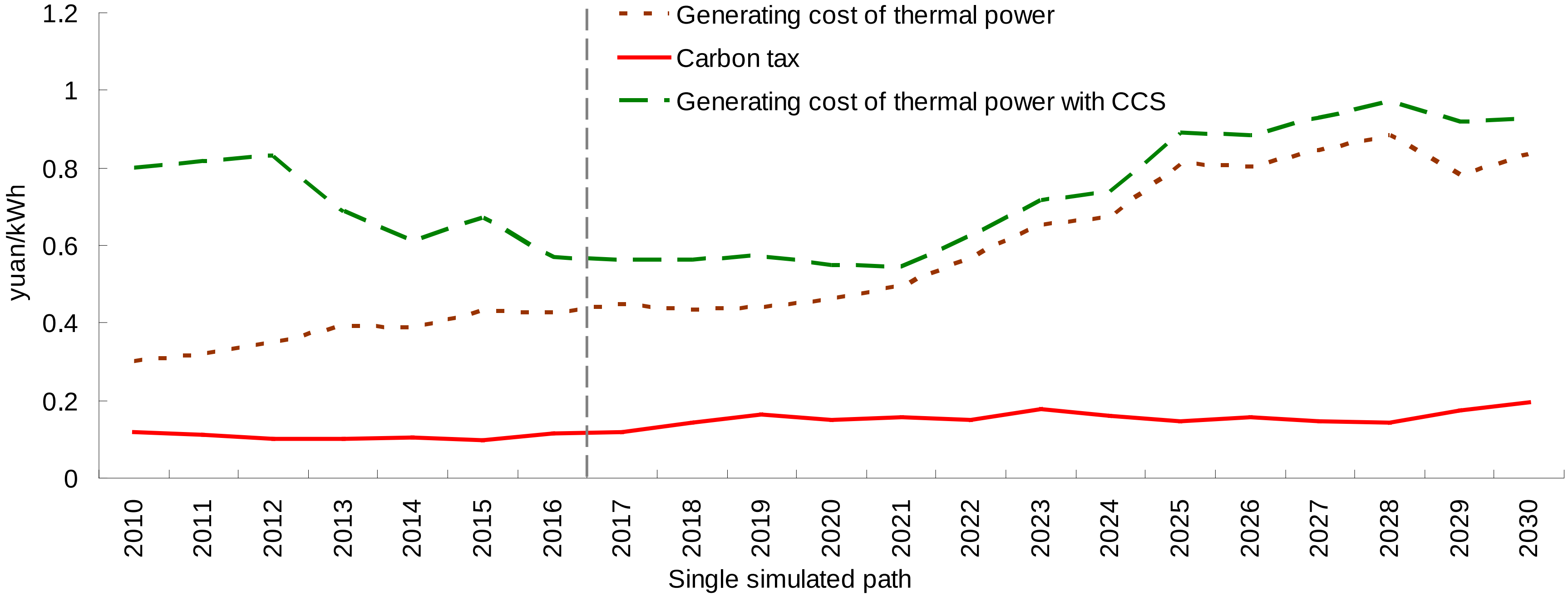


Figure 3: single simulated path for thermal power generating cost, carbon tax and thermal power with CCS generating cost

Single simulation path of cash flow

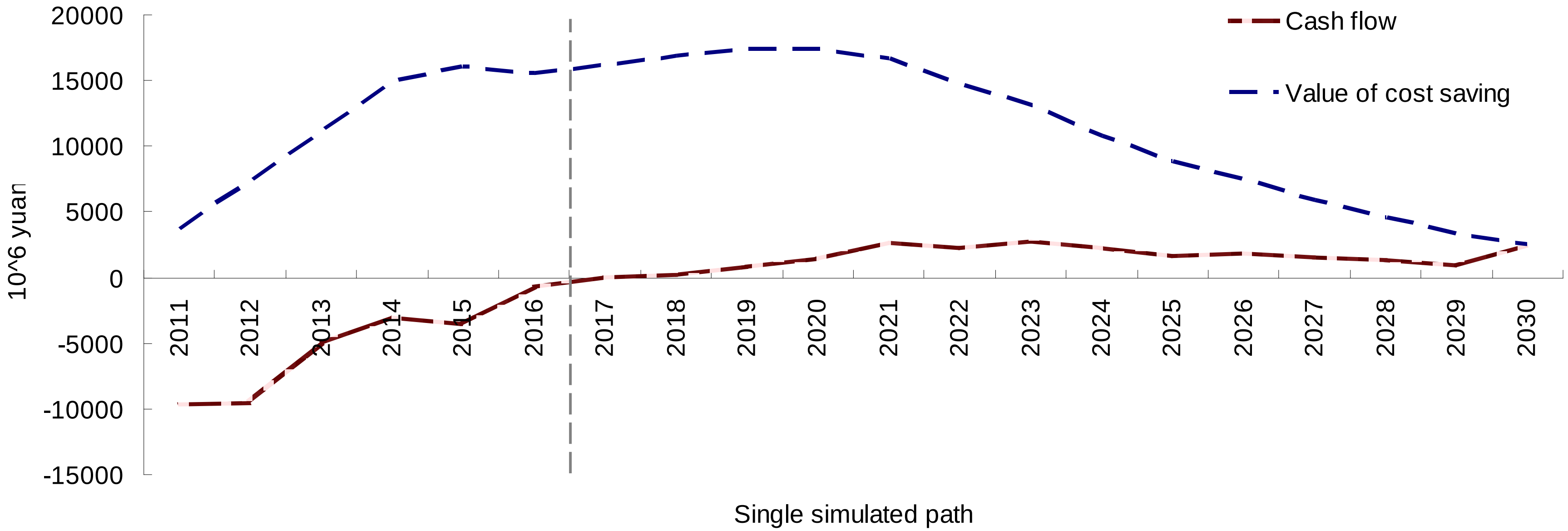


Figure 4: Single simulated path of CCS cash flow and value of cost saving

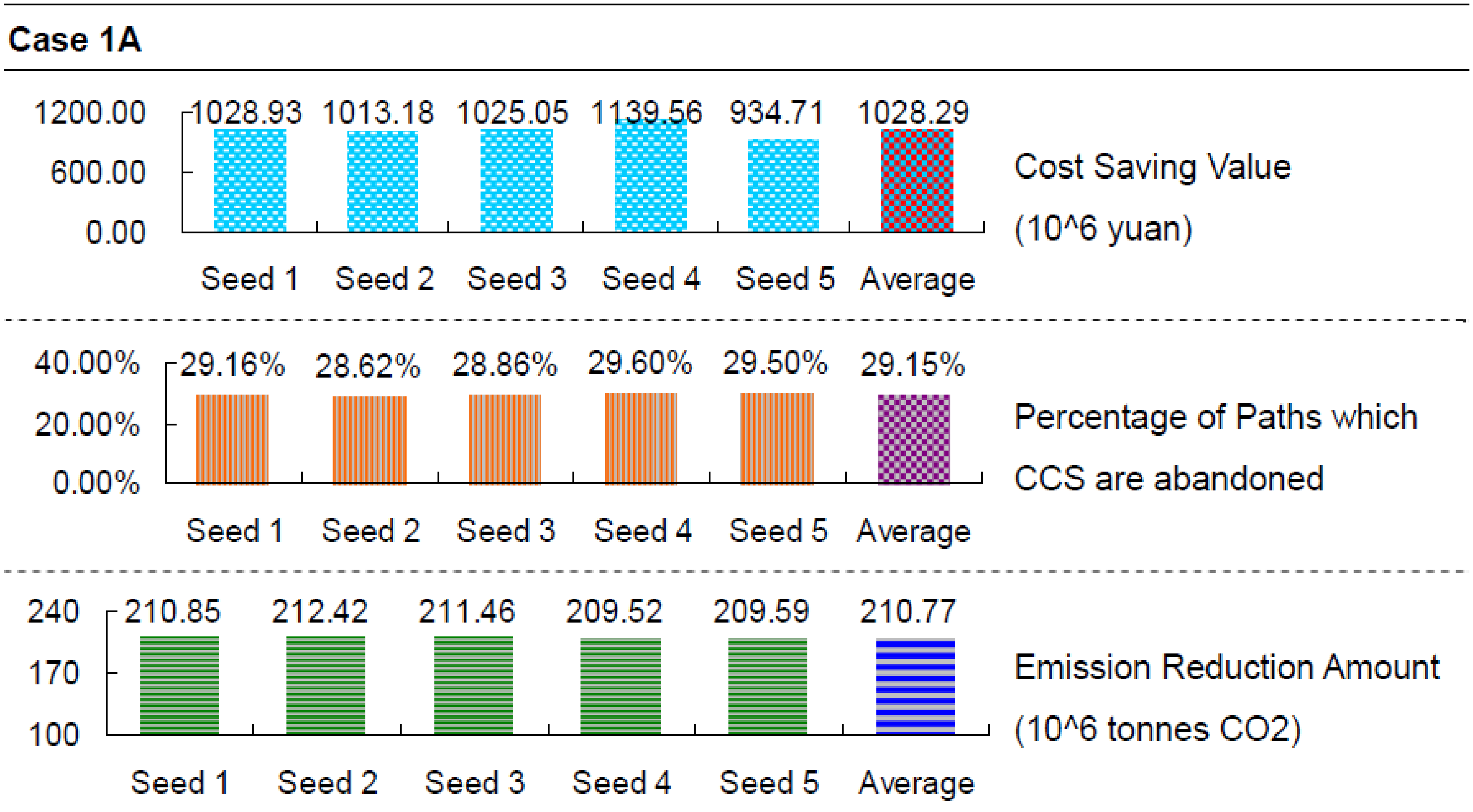
Scenarios and configuration setup

	Scenarios		CO2 cost	CO2 cost (fixed)	R&D expenditure	Gov Covered R&D	Generating subsidy
	Unit		yuan/kwh	yuan/kwh	10^6yuan/year	10^6yuan/year	yuan/kwh
1. Two carbon tax mechanisms (volatile or fixed)	Base Case+Carbon tax	Case 1A	0.12	-	1000	-	-
		Case 1B	0.15	-	1000	-	-
		Case 1C	0.18	-	1000	-	-
		Case 1D	-	0.12	1000	-	-
		Case 1E	-	0.15	1000	-	-
		Case 1F	-	0.18	1000	-	-
2. Adding R&D input & R&D subsidy	Carbon tax+Enhance R&D	Case 2A	0.12	-	1100	-	-
		Case 2B	0.12	-	1200	-	-
		Case 2C	0.12	-	1300	-	-
		Case 2D	0.12	-	1100	100	-
		Case 2E	0.12	-	1200	200	-
		Case 2F	0.12	-	1300	300	-
3. External generating subsidy	Carbon tax+Generating subsidy	Case 3A	0.12	-	1000	-	0.04
		Case 3B	0.12	-	1000	-	0.06
		Case 3C	0.12	-	1000	-	0.08
		Case 3D	0.12	-	1000	-	0.004

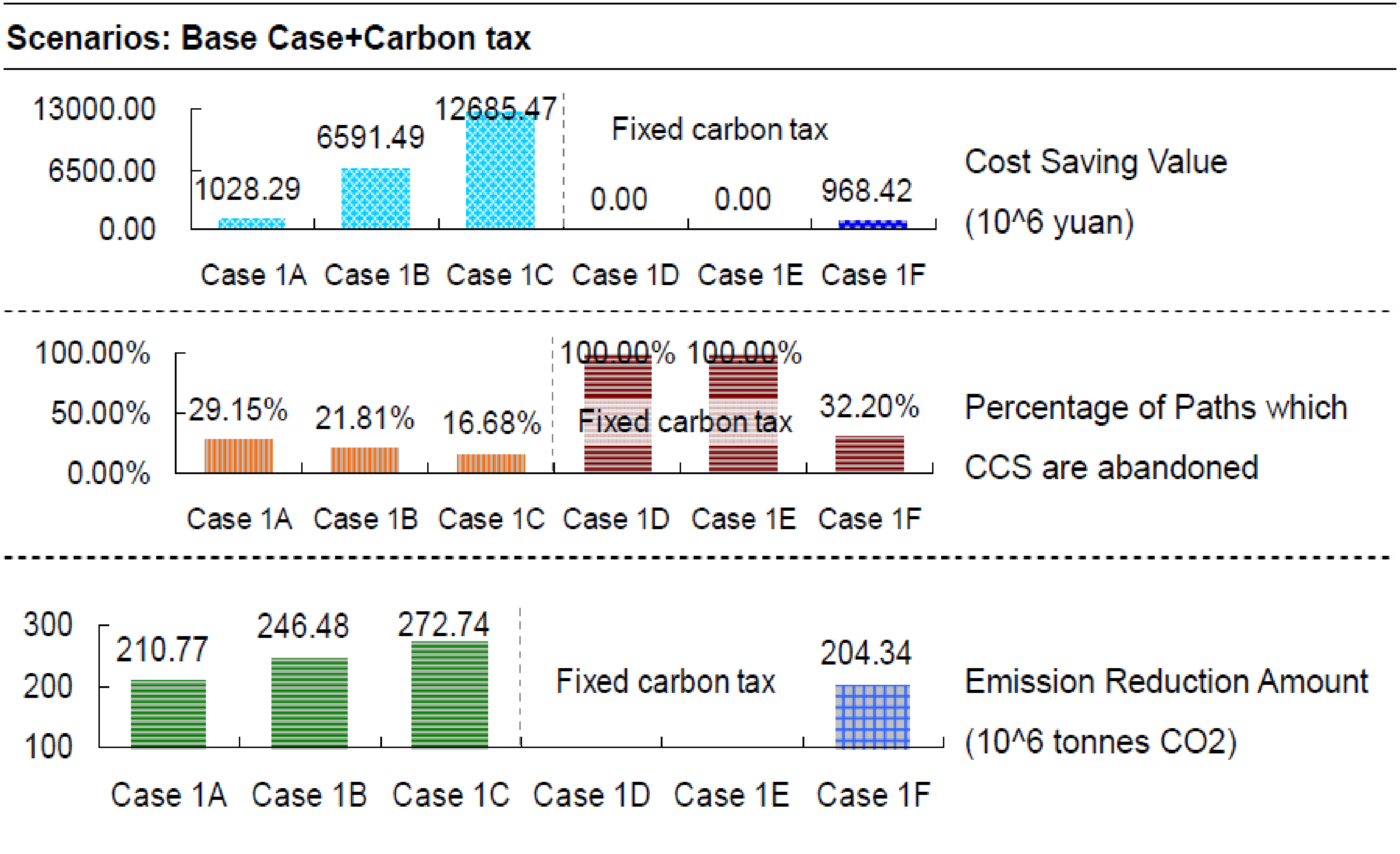
CCS Cost Saving Values

Center for Energy & Environmental Policy Research

In order to have more accurate results, we have calculated several seeds in each scenario. Each seed has a result based on 5000 paths simulation.

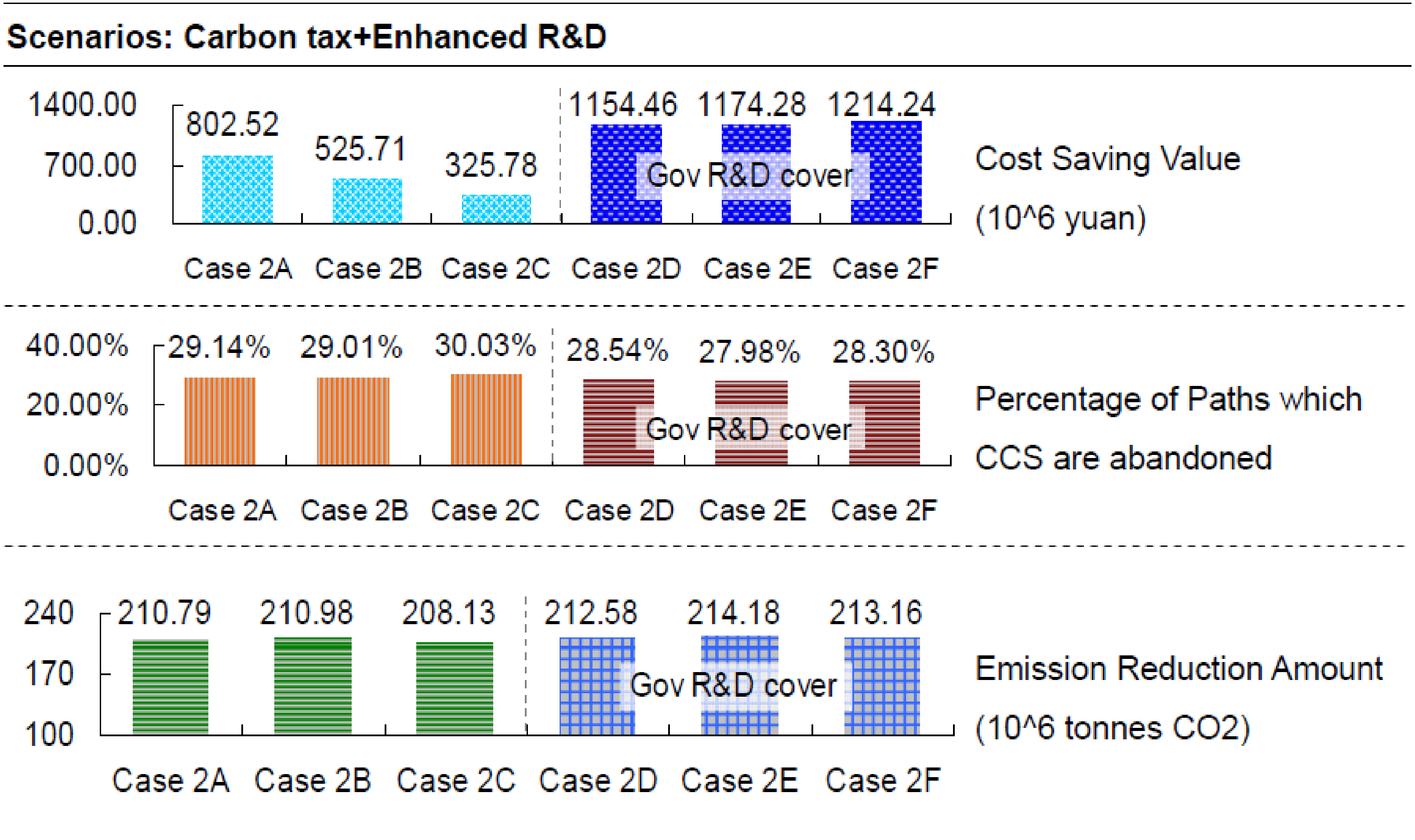


Two carbon tax mechanism



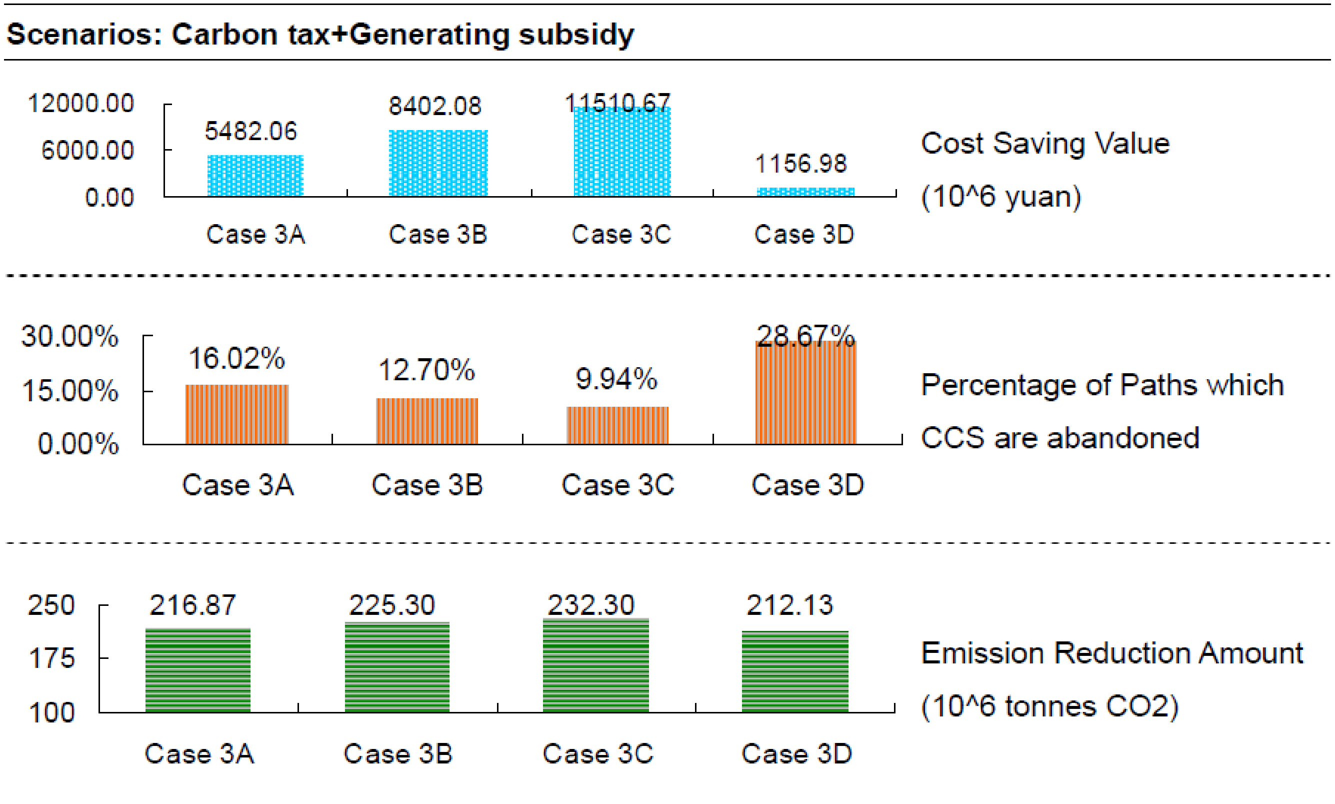
- Currently the investment risk of CCS is large
- Increasing the carbon price can reduce the CCS investment risk effectively
- Volatile carbon price mechanism can better promote investment in CCS technology

External R&D subsidy



- While R&D input has been increased, it may have a negative effect on CCS investment if all the R&D input need to be beard by the enterprise
- Some subsidies for CCS R&D are necessary to maintain interest of investment

Generating subsidy



- generating subsidies have direct impact on CCS investment
- But, given the same level of total financial input, **it will be a little better to promote R&D subsidy than generating subsidy**

Conclusions from simulations

- **The investment risk of CCS is quite high**.
- Among all the uncertainties, **climate policy (carbon price) has the most significant impact on CCS investment**. This point is directly supported by the model, which shows that increasing the carbon price can reduce the CCS investment risk effectively. It is necessary to tax or price the emissions from the power sector for CCS development.
- **R&D input increasing may have a negative effect on CCS investment** if all the input is taken by the enterprise.
- **Enhancing the CCS generating capacity can not reduce CCS investment risk effectively** as the value of the CCS cost saving varies a lot among different hybrid policies.
- **There is an important trade off between reducing greenhouse gas emissions and protecting the interests of investors.**

Policy implication

1) Carbon price (tax) mechanism. **Market based volatile carbon price mechanism is more attractive than fixed carbon tax mechanism for investment.**

2) Subsidies for enterprises R&D input. **External subsidies for CCS R&D is necessary to maintain the interest of CCS investment.** This could be implemented through transfer payments of carbon tax.

3) Generating subsidies. **It will be a little better to promote R&D subsidy than generating subsidy.** Particular policies need to be adopted on different CCS development scenarios.

Is CCS a solution?

Since the role of coal in future energy mix, CCS is one of important options.

Huge challenges:

- Technology
- Energy penalty
- Cost
- Storage sites
- Long term moniter
- Demonstration

Thanks for Your Attention!

Ying Fan
Center for Energy and Environmental Policy research (CEEP)
Institute of Policy and Management (IPM)
Chinese Academy of Sciences (CAS)
Emial: yfan@casipm.ac.cn