The costs of mitigating carbon emissions in China: Findings from China MARKAL-MACRO modeling

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Topics of discussion

- MARKAL-MACRO
- Simplified RES for China MARKAL-MACRO
- Basic assumptions for the modeling
- Reference scenario
- Marginal abatement cost analysis
- Potentials impacts of carbon reduction
  - Shadow price of fuels
  - Energy service demand
  - GDP losses
- Concluding remarks

MARKAL

- Dynamic linear programming model built on the concept of a Reference Energy System, RES.
- Incorporates full range of energy processes, e.g. exploitation, conversion, transmission, distribution and end-use.
- Searches for a least-cost combination of technologies and fuels dynamically over the planning period to meet user-specified energy service demands.

MACRO

- A macroeconomic model with an aggregated view of long-term economic growth
- The basic input factors of production are capital, labor and energy service demands. The economy's outputs are used for investment, consumption and inter-industry payments for the cost of energy.

$$Y_t = \left[akl(K_t)^{\rho\alpha}(L_t)^{\rho(1-\alpha)} + \sum_{dm} b_{dm}(D_{dm,t})^{\rho} \right]^{1/\rho}$$

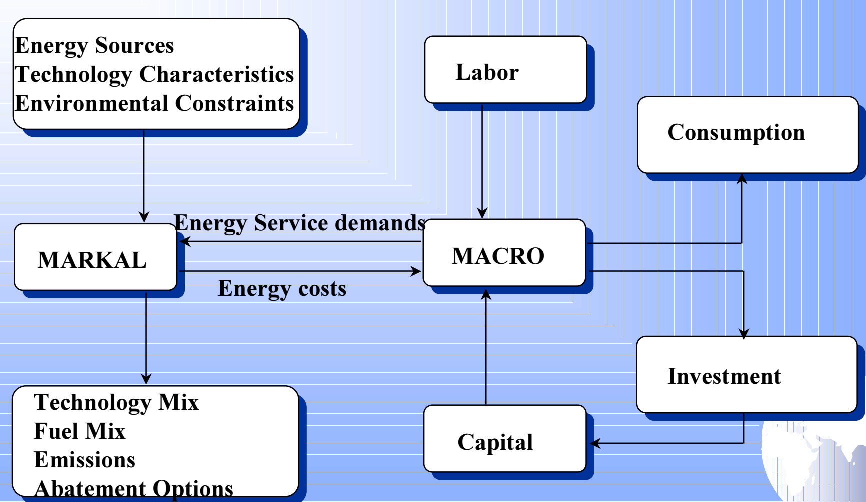
MARKAL-MACRO

- **Objective function**

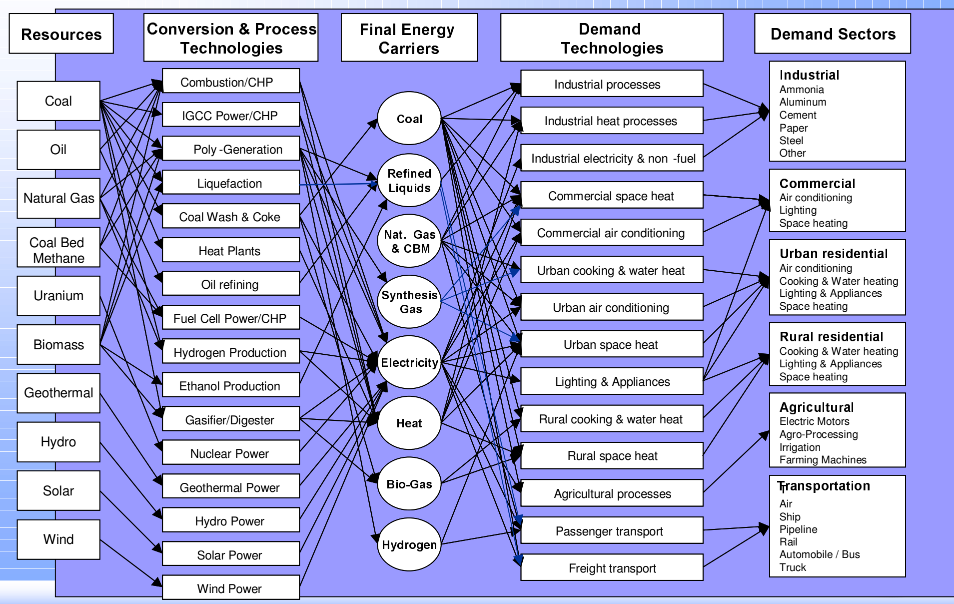
$$UTILITY = \sum_{t=1}^{T-1} (udf_t)(\log C_t) + (udf_T)(\log C_T) / \left[1 - (1 - udf_T)^{ny}\right]$$

- **MARKAL-MACRO, merging the bottom-up engineering to top-down macroeconomic approaches, adds price elasticity on energy service demands and links changes in the energy system to the level of economic activity while maintaining the technological richness and flexibility of MARKAL.**

MARKAL and MACRO Interactions



Simplified RES for China MARKAL-MACRO

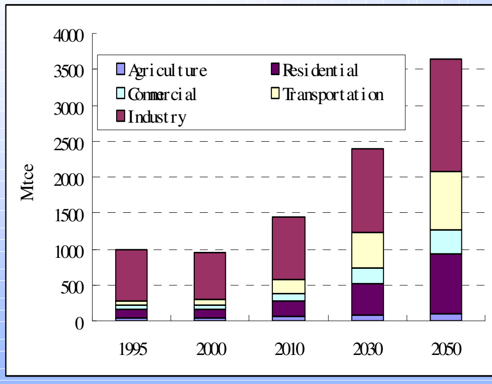


Basic Assumption for Social and Economic growth

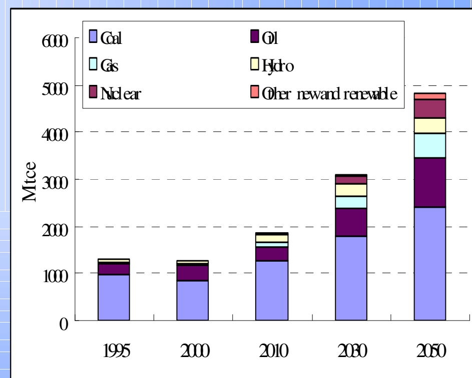
	1995	2010	2030	2050
GDP growth rate(%)		7.5	6.0	4.5
Population(Billion)	1.21	1.386	1.56	1.575
Urbanisation (%)	29.1	42.4	58.4	70
Industrial Structure				
Primary(%)	20.5	15.0	10.0	6.0
Secondary(%)	48.8	45.0	42.0	39.0
Tertiary(%)	30.7	40.0	48.0	55.0

Reference scenario for energy consumption

Final energy



Primary energy



	Industry	transportation
1995	72.2	5.3
2050	42.8	22.6

	coal	new and renewable
1995	74.6	5.6
2050	50.2	17.3

Reference scenario for carbon emission

	1995	2000	2010	2030	2050
Carbon emission (MtC)	819	792	1077	1655	2394
Per capita carbon emission (tC/capita)	0.676	0.625	0.777	1.061	1.520
Energy intensity per GDP (Kgce/US$)	1.819	1.229	0.859	0.489	0.347
Carbon intensity per energy consumption (Kg-C/Kgce)	0.635	0.618	0.577	0.533	0.497
Carbon intensity per GDP (Kg-C/US$)	1.156	0.76	0.496	0.261	0.172

Breakdown of the contribution to CO_2 growth

$$C=\left(\frac{C}{FEC}\right)\times\left(\frac{FEC}{TEC}\right)\times\left(\frac{TEC}{GDP}\right)\times\left(\frac{GDP}{POP}\right)\times POP$$

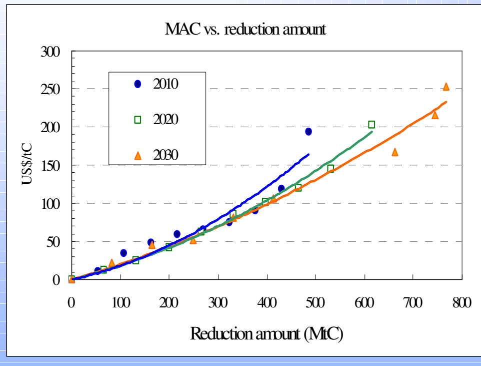
$$\Delta C=\frac{C}{(C/FEC)}\times\Delta\left(\frac{C}{FEC}\right)+\frac{C}{(FEC/TEC)}\times\Delta\left(\frac{FEC}{TEC}\right)+\frac{C}{(TEC/GDP)}\times\Delta\left(\frac{TEC}{GDP}\right)+\frac{C}{(GDP/POP)}\times\Delta\left(\frac{GDP}{POP}\right)+\frac{C}{POP}\times\Delta POP$$

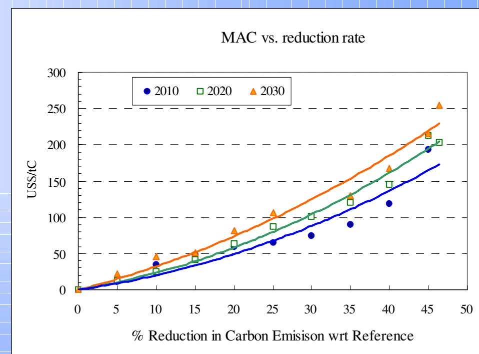
	Due to change in fossil fuel carbon intensity	Due to penetration of carbon free fuel	Due to change in energy intensity	Due to per capita GDP growth	Due to population growth	Total change in CO_2 emissions
1980-2000	-8	-19	-782	1042	147	380
2000-2050	-151	-161	-1850	3512	251	1601

Scenarios designed

- **M2010, M2020, M2030: a same percentage of carbon reduction wrt reference is set from the year 2010, 2020 and 2030 respectively and lasting to 2050**
- **M2030N1: same as M2030, nuclear by 2050 240GW**
- **M2030N2: same as M2030, nuclear by 2050 160GW**

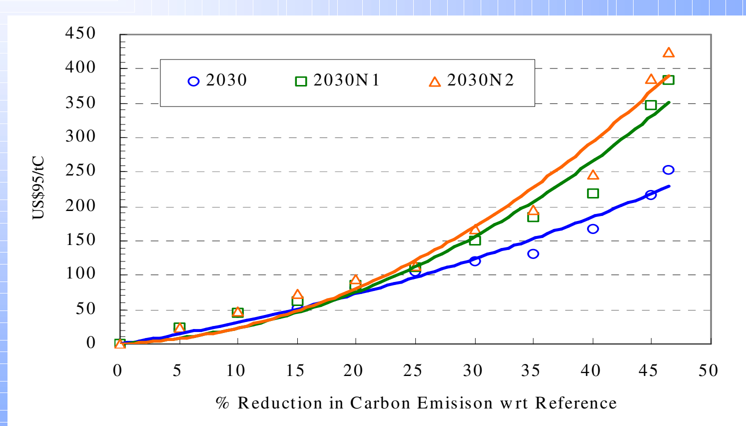
Marginal abatement cost curves



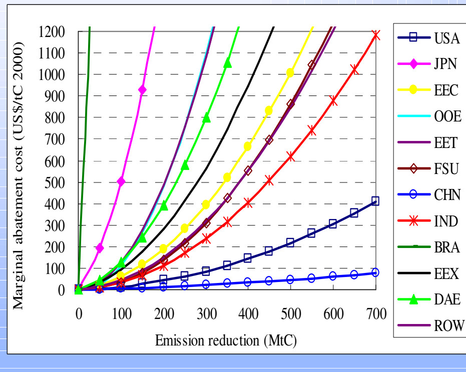


Varying the emission reduction rate from 5% to 45%, the marginal abatement costs would be in the range of 12-216US$95/tC

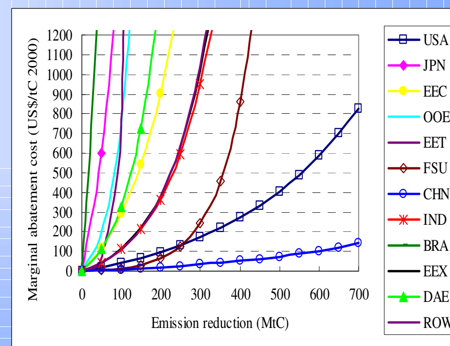
Marginal abatement cost curves with nuclear power development constraints



MAC curves for different regions in 2010

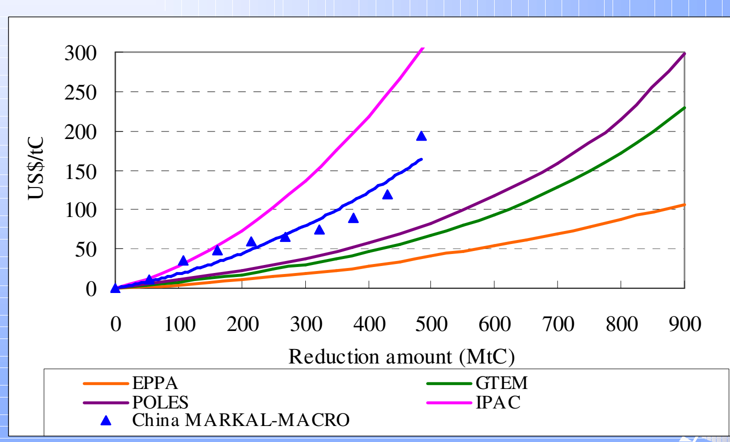


EPPA



GTEM

Comparisons of MAC curves for China from different sources



Possible reasons for the disparity

- Modeling approach and model structure
- Distinct abatement opportunities as represented by the estimated MAC curves
- Different energy substitution possibility assumed
- Dissimilar cost assumptions for technologies etc.
- Different basic assumptions for GDP growth, population growth, GDP structure etc.
- Diverse "no-regret", low cost and even some high cost mitigation measures considered in the reference scenario

Impacts of carbon emission reduction on the shadow prices of fuels

	Coal US$/t	Gas US$/$m^3$	Oil US$/t	Electricity US$/KWh
Reference	24.5	0.105	189.8	0.022
11% reduction	45.8	0.133	230.7	0.026
23% reduction	69.5	0.159	267.4	0.031
27.4% reduction	81.9	0.173	287.1	0.033
46.4% reduction	156.3	0.282	402.4	0.031

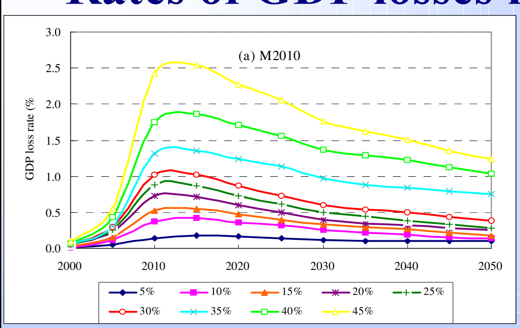
For the year 2030 in M2030

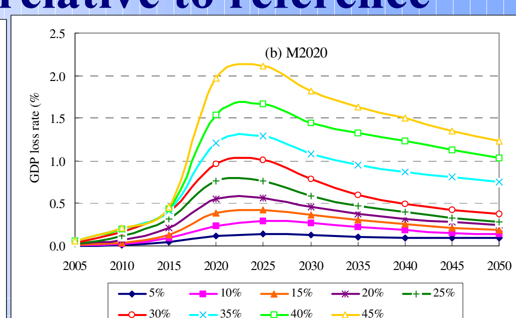
Impacts of carbon emission reduction on energy service demands

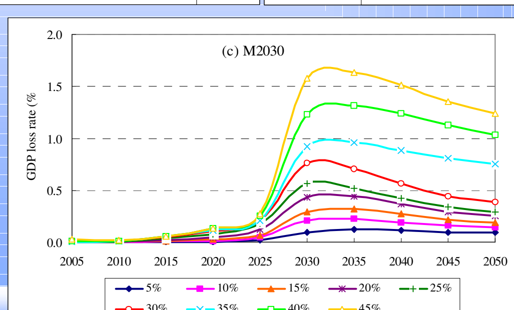
Sector	% reduction	Sector	% reduction	Sector	% reduction
Industry		Commercial		Transportation	
Aluminum	2~3	Space heating and water heating	9.5~27.6	Freight	
Ammonia	0.1~3.9	Cooling	1.6~4.2	Railway	2.3~3.3
Cement	2~7	Lighting and electric appliances	2~2.8	Highway	2.4~10.1
Paper	1.1~5.4	Urban residential		Waterway	0.6~2.7
Steel	3.4~12.9	Space heating	5.3~23.6	Pipeline	3.3~11.8
Other industry electricity	3~4	Cooking and water heating	3.8~15.8	Passenger	
Other industry heat	9~27	Air conditioning	0.5~1.5	Air	1.9~6.9
Non-energy use	0.7~7.2	Lighting and electric appliances	3~4	Railway	1.1~2.3
		Rural residential		Bus	0.9~4
		Space heating	9~20	Car	0.5~2.3
		Cooking and water heating	6~18	Waterway	0.4~1.7
		Lighting and electric appliances	0.9~2.5		

For the year 2030 in M2030

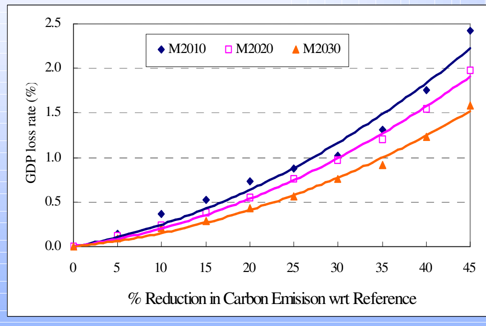
Rates of GDP losses relative to reference

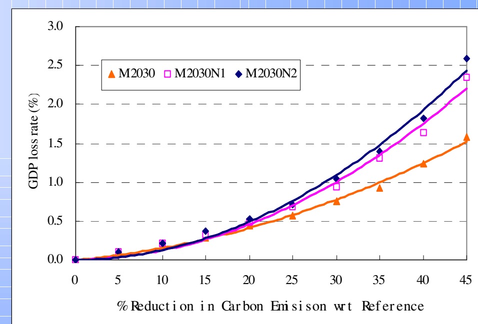




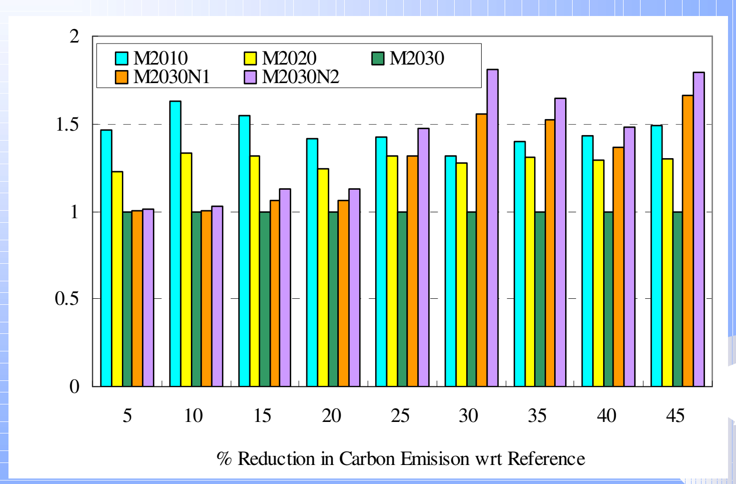


Comparisons of GDP loss rates





Comparisons of accumulative GDP losses



A comparison of GDP loss rates for China across models in 2010

Model	Abatement rate (%)	Marginal carbon abatement cost (US$/tC)	Rate of GDP (GNP) loss relative to reference (%)
GLOBAL 2100	20.1	84	0.976
	30.1	167	1.893
GREEN	20.1	14	0.253
	30.1	25	0.458
Zhang's CGE model	20.1	23	1.521
	30.1	45	2.763
China MARKAL-MACRO	20(27)	59(69)	0.732(0.938)
	30(40)	75(119)	1.026(1.749)

A comparison with US MARKAL-MACRO modeling result

- **US MARKAL-MACRO**

  stabilization USA' carbon emission in 2010 at its 1990 levels (24% reduction wrt reference in 2010)

  GDP loss rate: 0.59%

- **China MARKAL-MACRO**

  24% reduction wrt reference in 2010

  GDP loss rate: 0.85%

Concluding remarks

- The carbon emission is expected to be 2394MtC and the carbon intensity per GDP 0.172Kg-C/US$ by 2050 with annual decrease rate of 3% during 2000to 2050.
- Varying carbon reduction rates from 5% to 45%, the marginal abatement costs would be in the range of 12-216US$95/tC, and the rates of GDP losses relative to reference 0.1-2.54%.
- Future carbon emission reduction especially high percentage reduction will heavily depend on the development of nuclear power. Setting constrains on the maximum capacity of nuclear power will further heighten both the marginal abatement costs and the GDP losses.
- The earlier to start to set limits on carbon emission, the higher GDP loss rates (relative to reference) and the more accumulative GDP losses in the whole planning horizon would be.

Concluding remarks (continued)

- China MARKAL-MACRO considers a lot of advanced technologies both in the energy supply and demand sides. The availability of these technologies significantly reduces the reference carbon emission as well as the carbon emission abatement costs. Policies and programs that encourage the development, demonstration and commercialization of the advance energy technologies are needed.
- It will be more realistic for China to make continuous contributions to combating global climate change by implementing sustainable development strategy rather than accepting a carbon emission ceiling.
- To take the road of sustainable development, China is still faced with considerable restrains and difficulties. It is highly necessary for the developed countries to achieve their commitments defined in the UNFCCC to provide new and additional financial as well as technical transfers to developing countries including China.