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GHG emission reductions and costs to achieve Kyoto target

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Abstract: Emission projection and marginal abatement cost curves (MACs) are the central components of any assessment of future carbon market, such as CDM (clean development mechanism) potentials, carbon quota price etc. However, they are products of very complex, dynamic systems driven by forces like population growth, economic development, resource endowments, technology progress and so on. The modeling approaches for emission projection and MACs evaluation were summarized, and some major models and their results were compared. Accordingly, reduction and cost requirements to achieve the Kyoto target were estimated. It is concluded that Annex I Parties' total reduction requirements range from 503—1304 MtC with USA participation and decrease significantly to 140—612 MtC after USA's withdrawal. Total costs vary from 21—77 BUSD with USA and from 5—36 BUSD without USA if only domestic reduction actions are taken. The costs would sharply reduce while considering the three flexible mechanisms defined in the Kyoto Protocol with domestic actions' share in the all mitigation strategies drops to only 0—16%.

Keywords: Kyoto Protocol; emission reduction; abatement cost; flexible mechanisms

Introduction

The Kyoto Protocol, agreed at the Third Conference of the Parties (COP 3), set binding quantified reduction commitments for a basket of six greenhouse gases, that is, CO_2, CH_4, N_2O, SF_6, PFCs, and HFCs, for the Annex I Parties during the period 2008 to 2012. Since the binding quantified reduction targets were set based on 1990 emission level, it is hard to know the real reduction requirements due to uncertain business as usual (BAU) emission projections for the first commitment period. This paper attempts to evaluate emission reduction and cost requirements to achieve the Kyoto target considering diverse GHG emission projection and marginal abatement cost curves (MACs) derived from various models.

1 Modeling approaches for BAU emission projection and MACs evaluation

The modeling approaches for GHG emission projection could be divided into bottom-up, top-down and hybrid. The bottom-up approaches consider technological options or project-specific climate change mitigation policies, whereas top-down approaches evaluate the system from aggregate economic variables. In the hybrid, bottom-up and top-down modeling approaches are integrated.

For the bottom-up modeling approaches, integrated energy system simulation models or dynamic energy optimization models are used. Integrated energy system simulation models include a detailed representation of energy demand and supply technologies. Demand and technology development are driven by exogenous scenarios. This allows development trends to be projected through technology development scenarios. Dynamic energy optimization models often have explicit, detailed description of the whole energy system to determine the mix of energy consumption and technology to meet exogenous energy service demands and to comply with emission limits with total system costs minimized. Both of these two kinds of models are suited for short- to medium-term studies (IPCC, 2001; Zhang, 1996).

Top-down modeling approaches apply either input-output models, macroeconomic models or computable general equilibrium (CGE) models. Input-output models describe the complex interrelationships among economic sectors with a far higher degree of sectoral detail than other models. They are limited to short-term studies due to the restrictions of fixed input-output coefficients etc. Like input-output models, macroeconomic models are demand-driven, but they go beyond input-output models by carefully modeling the role of prices and by incorporating the supply-side equilibrating mechanisms. Macroeconomic models are well suited for short- to medium -horizon. CGE models construct the behavior of economic agents based on microeconomic principles. The models often simulate the operating of markets for factors of production, products and foreign exchange, with equations specifying supply and demand behavior. CGE models are well suited for medium- to long- term studies(IPCC, 2001; Zhang, 1996).

Bottom-up models do not include feedback from and to other sectors of an economy, and lack of demand-price interactions. Top-down models are not able to indicate detail technology mix. In the hybrid approaches, top-down and bottom-up models are linked to complement each other.

The modeling approaches using either bottom-up or top-down or hybrid models are able to project future GHG emissions, as well as to evaluate MACs by introducing a constraint on allowed GHG emissions within the models. MACs could also be evaluated without formal modeling, with the application of bottom-up project-based approach.

2 Models and results comparison for BAU emission projection

Table 1 summarizes the finding from the comparison of some major models for GHG emission projection, including EPPA (Emissions Prediction and Policy Analysis) model, WEM (World Energy Model), WEPS (World Energy Projection System), GTEM (Global Trade and Environment Model), a model developed by CICERO (Center for International Climate and Environmental Research, Norway), and the six models to generate IPCC SRES scenarios, that is, Asian Pacific Integrated Model (AIM), Atmospheric Stabilization Framework Model (ASF), Integrated Model to Assess the Greenhouse Effect (IMAGE), Multi-regional Approach for Resource and Industry Allocation (MARIA), Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), and Mini Climate Assessment Model (MiniCAM).

Table 2 displays the emission projection for Annex I Parties in 2010 from EPPA, GTEM, CICERO, WEM, EPPA, national communication(NC), and RIIA(Royal Institute of International Affairs, England). In addition, results of the six IPCC marker scenarios from the six SRES models are given.

It could be seen that for all Annex I countries, when only CO_2 is considered, WEM and EPPA provide the highest projections, 24.5% and 21% higher than 1990 respectively, when all GHGs are considered, A1F1-MiniCAM, A1B-AIM, and EPPA are in the high end, around 20% higher than 1990 level.

Under the situation of CO_2 only, the projections for total Annex I emissions from national communications, CICERO, GTEM, RIIA, and B2-MESSAGE are very close, all around 9% higher than 1990 level, approaching the projections from WEPS and A1B-AIM (11.6% and 12.8% respectively). When all GHGs are covered, the projections from National Communications, CICERO, GETM, and RIIA are also similar, 3.7%, 2.1%, 2%, and 2.4% respectively, ranking the low end of all projections.

Although some models provide very close projection for the total Annex I Parties' emission, there are still large differences for individual region's projection from these models. Table 3 shows the ranges of emissions in 2010 from various models for six Annex I regions, that is, USA, Japan, European Union (EEC), other OECD (OOE), Former Soviet Union (FSU) and other economics in transition (EET).

The projections from the national communications for European Union is relatively low compared with other projections. This is basically due to the internal burden sharing of the Kyoto commitments among the member countries and the impact of energy policy like energy tax and carbon tax that are currently being implemented or negotiated in response to climate change are incorporated in the national communications (Gruetter, 2001a; 2001b). The relatively high projection for the Former Soviet Union from the national communications reflects the political expediency.

Table 1 Comparison of models for GHG emission projection

Model	Developer	Modeling approaches for emission projection	Subsystems	Starting and ending year	Regions	Types of GHGs
EPPA	MIT, USA	Top-down CGE (computable general equilibrium)		1985/1995 to 2100 in 5-year intervals	12	All GHGs
WEM	IEA (International Energy Agency), Paris	Bottom-up integrated energy system simulation model		1995 to 2020	13	Only CO_2
WEPS	Energy Information Administration, US Department of Energy	Bottom-up integrated energy system simulation model		1990 to 2020 in 5-year intervals	23	Only CO_2
CICERO model	CICERO, Norway	Top-down static partial equilibrium		From 1990	32	All GHGs
GTEM	ABARE (Australian Bureau of Agricultural and Resource Economics)	Top-down dynamic general equilibrium model		From 1995	45	CO_2, CH_4, N_2O
AIM	NIES (National Institute of Environmental Studies), Japan	Bottom-up integrated energy system simulation model (AIM) linked with top-down Edmonds-Reilly-Barns (ERB) model	AIM, ERB, land equilibrium model, global climate change model, and climate change impact model	From 1990 to 2100	17	All GHGs
ASF	ICF Consulting, USA	Bottom-up integrated simulation model	Energy, agricultural and deforestation GHG emissions and atmospheric model	From 1990 to 2100	9	All GHGs
IMAGE	RIVM (National Institute for Public Health and Environmental Hygiene), Netherlands	Based on bottom-up system dynamics simulation model TIMER (Targets Image Energy Regional)	Energy-industry system, terrestrial environment system, and atmosphere-ocean system	From 1990 to 2100	13	All GHGs
MESSAGE	IIASA (International Institute of Applied System Analysis), Austria	Bottom-up dynamic linear optimization energy model (MESSAGE) linked with top-down MACRO	Scenario generator (SG), MESSAGE, MACRO, MAGICC (model for assessment of greenhouse gas-induced climate change)	From 1990 to 2100	10	Only energy and industry related emissions
MARIA	Science University of Tokyo, Japan	Top-down non-linear optimization model	Energy, economy, resources, land use, climate change models	From 1990 to 2100	8	All GHGs
MiniCAM	PNNL (Pacific Northwest National Laboratory), USA	Top-down partial equilibrium model ERB	ERB model, agriculture, forestry and land-use model	From 1990 to 2100	11	All GHGs

Source: Ellerman, 1998; IEA, 2000; EIA/USDOE, 2001; ABARE, 2000; Holtsmark, 1998; IPCC, 2000

The reasons for the wide range of difference could also be traced to diverse model structures and assumptions about population growth, GDP growth, economic structure adjustment, technology development, resource endowments, the extent of no-regret options, the choice of policy instruments, the number of gases included, inclusion of emissions or removals from sinks or not, and so on.

Table 2 Emission projections from different models Unit: MtC

	CO_2 only			All GHG		
	Annex II	EITs	Annex I	Annex II	EITs	Annex I
1990	2786	1167	3953	3461	1490	4951
1998	3008	714	3722	3697	935	4632
NC	3223	1102	4315	3783	1350	5133
EPPA	3747	1041.5	4788.5	4534.6	1375	5909.6
WEM	3625	1298	4923	-	-	-
WEPS	3474	939	4413	-	-	-
CICERO	3266.6	1072.8	4339.4	3733.9	1321.6	5055.5
GTEM	3470.1	871.2	4341.3	4009.8	1040.1	5049.9
RIIA	3213	1080	4293	3797	1275	5072
A1B-AIM	3410	1050	4460	4326	1673	5999
A1FI-MiniCAM	3580	940	4520	4721	1365	6086
AIT-MESSAGE	3310	880	4190	4212	1401	5613
A2-ASF	3510	1030	4540	4461	1368	5829
B1-IMAGE	3300	810	4110	4311	1116	5427
B2-MESSAGE	3500	800	4300	4368	1098	5466

Source: Ellerman, 1998; IEA, 2000; EIA/USDOE, 2001; ABARE, 2000; Holtsmark, 1998; IPCC, 2000; UNFCCC, 1998; Grueter, 2001a; 2001b; Reily, 1998; 2000a

Table 3 Ranges of emissions in 2010 from various models, % change from 1990

	CO_2 only	All GHGs
USA	24% (NC, CICERO)—40% (EPPA, GTEM)	12.7%(CICERO)—34.9%(EPPA)
Japan	7.5% (WEPS)—24.4% (EPPA)	11% (GTEM)—27.9% (EPPA)
EEC	-2.0% (NC)—15.9% (EPPA)	-7.2% (NC)—14.6% (EPPA)
OOE	23% (NC, CICERO)—89% (EPPA)	12.1% (CICERO)—71.8% (EPPA)
FSU	-27% (GTEM)— -6.6% (NC)	-32% (GTEM)— -6.9% (NC)
EET	-24% (WEPS)—4.3% (RIIA)	-24.5% (GTEM)— -4.8% (RIIA)
Total	4% (B1-IMAGE)—25% (WEM)	2% (GTEM)—23% (A1F1-MiniCAM)

Source: author's calculation based on Table 2

3 Emission reduction and cost requirements to achieve Kyoto target

3.1 Emission reduction requirements

Table 4 displays reduction requirements to achieve the Kyoto target. Almost all models show that economies in transition would have surplus assigned amount in the first commitment period, but the range of it varies sharply, ranging from 85—420 MtC. Reductions of Annex I to meet the Kyoto target range from 503—1304 MtC with USA participation and from 140—612 MtC without USA. Considering hot air, the net reduction requirements would decrease to 358—1219 MtC with USA and from - 195 to 527 MtC without USA. The minus values indicate that the surplus assigned amount for the economies in transition, termed as "hot air", is larger than Annex II Parties' emission reduction requirements, and no emission reduction measures but only emission trading (ET) are needed to be undertaken to achieve the Kyoto target.

3.2 Sink credits and their costs

COP 7 (Seventh of Conference of Parties) define two categories of eligible activities for sinks under Article 3.3 and 3.4 of the Kyoto Protocol, that is, forest, including afforestation, reforestation and deforestation, and agriculture, covering revegetation, cropland management and grazing land management. A specific cap for each Annex I Party to use the credit from carbon sequestration resulting from forest activities is stipulated (UNFCCC, 2001). No cap is defined for the use of agriculture activities. Jotzo and Michaelowa(Jotzo, 2001) estimated possible credits from agriculture sinks based on cropland/grassland sequestration rates per hectare listed in IPCC report and the whole cropland/grassland for each country with the assumption that 10% of available land are managed by the first commitment period. Combining the credit cap for forest and Jotzo's and Michaelowa's estimation, credits from carbon sequestration for each regions are given as Table 5.

Table 4 Reductions required to achieve Kyoto target Unit: MtC

	NC	EPPA	CICERO	GTEM	RIIA
USA	412	691.8	325.4	554.3	412
Japan	78	112.4	61.9	56.3	50
EEC	9	259.1	73.4	95.4	39
OOE	53	240.3	42.2	72.8	65
FSU	-83	-74.4	-60.9[a]	-355	-194
EET	-27	-10.6	-77.5[b]	-64.9	9
Total reductions with USA	552	1303.6	502.9	778.8	575
Total reductions without USA	140	611.8	177.5	224.5	163
Hot air	110	85	138.4	419.9	194
Net reductions with USA	442	1218.6	364.5	358.9	381
Net reductions without USA	30	526.8	39.1	-195.4	-31

Source: author's calculation based on Table 2. a. Russia; b. all economics in transition except Russia

Table 5 Credits from carbon sequestration Unit: MtC

	USA	JPN	EEC	OOE	FSU	EET	All with USA	All without USA
Forest	28	13	5.17	13.11	34.83[a]	3.76	97.87	69.87
Agriculture	18.41	0.23	9.16	7.91	7.15[b]	1.87	44.73	26.32
Total	46.41	13.23	14.33	21.02	41.98	5.63	142.6	96.19

Source: UNFCCC, 2001; Jotzo, 2001. a. among with Russia 33 MtC; b. among with Russia 4.7 MtC

There is a sharp discrepancy on the estimation of marginal abatement cost for sink projects. And the cost in different regions could be quite various. Assuming average 1 USD/tC of abatement costs for sink credits, then totally 143 or 96 million USD needed to achieve the sink credits under with or without USA participation.

3.3 Costs to achieve Kyoto target for non-sink credits

Marginal abatement cost curves for different regions is the basic element to assess the Kyoto target costs. In this paper, the MACs are taken from MIT's and ABARE's studies. MIT gave the CO_2 marginal abatement cost curves in the form of $MC = aQ^2 + bQ$ derived from EPPA model (Reily, 1998), where MC is the marginal abatement cost; Q is the emission reduction; a and b are the coefficients. For the non-CO_2 gases, the marginal abatement curves were evaluated based on detailed technological assessments and resulted from more detailed models for individual gases and sources, presenting as $MC = a\exp(bx)$ (Reily, 2000b), where x is the abatement rate. ABARE provided the MACs based on GTEM modeling, and they were given as $MC = a(\exp(bQ) - 1)$ (ABARE, 2000; Gruetter, 2001).

Compared with EPPA, the projections from national communications, CICERO and RIIA are quite close to that from GTEM. Therefore ABARE's MACs are applied to national communications, CICERO and RIIA. For EPPA, with the individual projections as well as marginal abatement cost curves for the six GHGs,

Table 6 Marginal abatement costs for non-sink credits

Unit: USD/tC (2000 price)

MACs	ABARE				MIT
model	NC	CICERO	GTEM	RIIA	EPPA
USA	167.00	116.19	266.58	167.00	210.14
Japan	479.15	328.49	281.22	231.12	326.18
EEC	0	27.04	40.52	9.84	104.55
OOE	47.26	28.99	87.55	70.58	297.95
FSU	0	0	0	0	0
EET	0	0	0	1.93	0

Source: author's calculation

the marginal abatement cost and total reduction cost to achieve the Kyoto target could also be calculated. The principle to do the calculation is that the total abatement costs would be minimized when all gases are abated until their marginal abatement costs are equal. Table 6 and Table 7 give the results.

Table 7 Total abatement costs for non-sink credits

Billion USD (2000 price)

MACs model	ABARE				Model
	NC	CICERO	GTEM	RIIA	EPPA
USA	24.71	13.72	51.24	24.71	41.00
Japan	12.80	6.89	5.30	3.79	11.43
EEC	0	0.73	1.44	0.12	7.20
OOE	0.68	0.29	1.91	1.34	17.41
FSU	0	0	0	0	0
EET	0	0	0	0.0032	0
Total	38.19	21.62	59.90	29.97	77.04
Total without USA	13.48	7.90	8.66	5.25	36.04

Source: author's calculation

Table 8 Abatement rate of different GHGs to achieve the Kyoto target(%)

	CO_2	CH_4	N_2O	PFC	HFC	SF_6
USA	26.22	40.96	30.75	85.54	95.57	79.79
JPN	19.30	42.77	33.48	97.89	96.45	86.52
EEC	13.53	38.08	26.42	65.93	94.17	69.10
OOE	36.30	42.39	32.92	95.34	96.27	85.14

Source: author's calculation

It could be seen that different regions' marginal abatement costs are quite different. USA's and Japan's marginal abatement cost range from 116—267 USD/tC and 231—479 USD/tC respectively. For EEC and OOE, their marginal abatement costs are relatively low, ranging from 0—40 USD/tC and 29—88 USD/tC under the projections other than EPPA. But they would be much higher, reaching 105 and 298 USD/tC respectively under the EPPA projection due to the much larger reduction requirements. For FSU and EET, almost all models show that no abatement costs needed.

If only domestic actions are taken, total abatement costs for non-sink credits for all Annex I Parties would range from 21—77 billion USD. And it would shrink to around 5—36 billion USD after USA's withdrawal from the Kyoto Protocol.

With the individual projections and MACs for the six greenhouse gases, Table 8 shows the different gases' abatement rates for each region. The abatement rates of PFCs, CFCs and SF6 are quite high, larger than 80% for most of the regions, due to their relatively low marginal abatement costs. While their shares in the total abatement are quite low, all together less than 15% for all regions, owing to their relatively low emissions. Although the abatement rate of CO_2 ranges from only 13%—36% for all regions, the share of CO_2 in the total abatement reaches 58%—76% for most of the regions since CO_2 contributes the largest in the total emission.

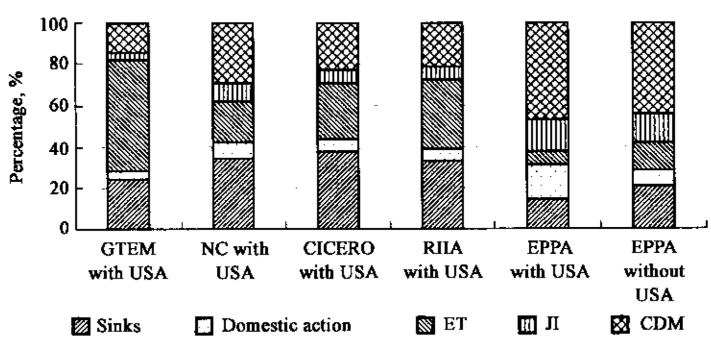

Fig.1 Share of sink credits, domestic action and the three mechanisms to achieve Kyoto target with global cost minimized
(Source: author's calculation)

With the MACs from GTEM for both Annex I and Non-Annex I Parties, the share of sink credits, and non-sink credits from domestic action, JI (joint implementation), CDM and ET could be evaluated with application of the Carbon Emission Reduction Trading (CERT) model developed by Gruetter etc. (Gruetter, 2001a; 2001b). Fig.1 displays the results. Please note that the sink credits cover the value shown in Table 5 and 1% of base year emission for each Annex I

Parties for CDM in accordance with COP7 decisions(UNFCCC, 2001). Moreover, for the cases of without USA, only results for EPPA are given in the figure since all projections other than EPPA show that only hot air and sink credits could achieve the Kyoto target.

The share of domestic action would sharply drop to 0—16% with contribution mainly comes from sink credits, hot air, and CDM due to very low cost for both sink credits and hot air, and relatively low marginal abatement cost in Non-Annex I Parties. The global reduction cost would substantially descend, for example, 90% fall under the case of GTEM projection with USA participation(Chen, 2001).

4 Conclusions

There is a great uncertainty for the reduction requirements for Annex I Parties to achieve the Kyoto target. Different models' comparison shows that the reduction requirements for Annex I Parties range from 503—1304 MtC under USA participation and from 140—612 MtC after USA's withdrawal with hot air varying from 85 to 420 MtC. With the six greenhouse gases rather than CO_2 only and sink credits, the costs to achieve the Kyoto target would be largely saved, but still range from 21—77 BUSD with USA and from 5—36 BUSD without USA if only domestic actions are taken. The three flexible mechanisms, that is, CDM, JI and ET, would further sharply decrease the total costs with domestic actions sharing only 0—16% in the all mitigation strategies. However, costs might not be the only consideration, other factors like environment protection, technology renovation etc. might promote domestic actions due to the great uncertainty in sink credits and no real reductions for use of hot air.

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