TABLES, BOXES AND FIGURES

NOT INCLUDED YET: **Tables 11.2.1** and **11.2.2** (to be developed from Chapters 4 to 10 results, to be completed by December 9, 2005 and to be reviewed before January 20, 2006)

Box 11.2.1*: Potential wedges: Strategies available to reduce the carbon emission rate in 2054 by 1 GtC/year or to reduce carbon emissions from 2004 to 2054 by 25 GtC.*
Source: Pacala and Socolow (2004)

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Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
	Energy efficiency and conservation	
Economy-wide carbon-intensity reduction (emissions/$GDP)	Increase reduction by additional 0.15% per year (e.g., increase U.S. goal of 1.96% reduction per year to 2.11% per year)	Can be tuned by carbon policy
1. Efficient vehicles	Increase fuel economy for 2 billion cars from 30 to 60 mpg	Car size, power
2. Reduced use of vehicles	Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5000 miles per year	Urban design, mass transit, telecommuting
3. Efficient buildings	Cut carbon emissions by one-fourth in buildings and appliances projected for 2054	Weak incentives
4. Efficient baseload coal plants	Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	Advanced high-temperature materials
	Fuel shift	
5. Gas baseload power for coal baseload power	Replace 1400 GW 50%-efficient coal plants with gas plants (four times the current production of gas-based power)	Competing demands for natural gas
	CO_2 Capture and Storage (CCS)	
6. Capture CO_2 at baseload power plant	Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1060 GW coal in 1999)	Technology already in use for H_2 production
7. Capture CO_2 at H_2 plant	Introduce CCS at plants producing 250 MtH_2/year from coal or 500 MtH_2/year from natural gas (compared with 40 MtH_2/year today from all sources)	H_2 safety, infrastructure
8. Capture CO_2 at coal-to-synfuels plant	Introduce CCS at synfuels plants producing 30 million barrels a day from coal (200 times Sasol), if half of feedstock carbon is available for capture	Increased CO_2 emissions, if synfuels are produced without CCS
Geological storage	Create 3500 Sleipners	Durable storage, successful permitting
	Nuclear fission	
9. Nuclear power for coal power	Add 700 GW (twice the current capacity)	Nuclear proliferation, terrorism, waste
	Renewable electricity and fuels	
10. Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" 30×10^6 ha, on land or offshore	Multiple uses of land because windmills are widely spaced
11. PV power for coal power	Add 2000 GW-peak PV (700 times the current capacity) on 2×10^6 ha	PV production cost
12. Wind H_2 in fuel-cell car for gasoline in hybrid car	Add 4 million 1-MW-peak windmills (100 times the current capacity)	H_2 safety, infrastructure
13. Biomass fuel for fossil fuel	Add 100 times the current Brazil or U.S. ethanol production, with the use of 250×10^6 ha (one-sixth of world cropland)	Biodiversity, competing land use
	Forests and agricultural soils	
14. Reduced deforestation, plus reforestation, afforestation, and new plantations.	Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)	Land demands of agriculture, benefits to biodiversity from reduced deforestation
15. Conservation tillage	Apply to all cropland (10 times the current usage)	Reversibility, verification

Table 11.2.3: Some learning rates, grouped by sector technology

Technology	Learning rate	Reference/ data source
Oil extraction (NRTH SEA 1984-97) (1)	25	Blackwood 1997
Gas pipelines, onshore (US 1984-97) (2)	3.7	Zhao 1999
Gas pipelines, offshore (WORLD 1976-94) (2)	24	Zhao 1999
Retail gasoline processing (US 1919-69) (3)	20	Fisher (1974)
Crude oil at Well (US 1869-1971) (3)	5	Fisher (1974)
Ethanol (BRA 1978-95) (4)	22	IEA (2000)
Ethanol (BRA 1979-95) (5)	20	Goldemberg (1996)
Compact fluorescent lamps, integral electronic types (US 1992-98) (1)	16	Iwafune (2000)
Air conditioners (JAP 1972-97) (2)	10	Akisawa (2000)
SONY laser diodes (1982-94) (3)	23	Lipman and Sperling (1999)
DC converters (WORLD 1958-63) (4)	37	Rabitsch (1999)
Coal for Electric Utilities (US 1948-69) (1)	25	Fisher (1974)
Supercitical coal (US time period n/a) (2&3)	3	IEA (2000); Joskcow and Rose (1985)
Nuclear power plants (OECD 1975-93) (4)	5.8	Kouvaritakis et al. (2000)
Hydropower plants (OECD 1975-93) (4)	1.4	Kouvaritakis et al. (2000)
Coal power plants (OECD 1975-93) (4)	7.6	Kouvaritakis et al. (2000)
Lignite power plants (OECD 1975-92) (4)	8.6	Kouvaritakis et al. (2000)
Coal power plants (US 1960-80) (2)	3.7	Joskcow & Rose (1985)
Gas turbines (WORLD 1963-80) (5)	22	MacGregor et al. (1991)
Gas turbines (WORLD 1958-80) (5)	9.9	MacGregor et al. (1991)
Gas turbines (WORLD 1975-93) (5&6)	13	Nakicenovic et al. (1998); MacGregor et al. (1991)
GTCC (EU time period n/a) (3&7)	4	IEA (2000); Claeson (1999)
GTCC power plants (OECD 1984-94) (4)	34	Kouvaritakis et al. (2000)
Electric power production (US 1926-70) (1)	25	Fisher (1974)
Electicity from biomass (EU 1980-95) (3)	15	IEA (2000)
Wind power plants (OECD 1981-91) (4)	17	Kouvaritakis et al. (2000)
Wind power (electricity) (CALIF 1991-97) (8&9)	18	CEC (1997); Loiter and Norberg-Bohm (1999)
Wind (GER 1981-95) (10)	8	Durstewitz (1999)
Wind Turbines (DEN 1982-97) (11)	8	Neij (1999)
Wind power (US 1985-94) (3)	32	IEA (2000)
Wind power (EU 1980-95) (3)	18	IEA (2000)
Wind power (GER 1990-98) (3)	8	IEA (2000)
Wind power (DEN 1982-97) (3)	4	IEA (2000)
Solar PV Modules (WORLD 1968-98) (12)	20	Harmon (2000)
Solar PV panels (US 1959-74) (13)	22	Maycock and Wakefield (1975)
Solar PV (EU 1985-94) (3)	35	IEA (2000)
Solar PV modules (WORLD 1976-92) (3)	18	IEA (2000)

Solar PV Modules (EU 1976-96) (3)	21	IEA (2000)
GTCC power plants (WORLD 1981-91)	-11	Claeson (1999)
GTCC power plants (WORLD 1991-97	26	Claeson (1999)

Table 11.2.4 (to be developed)

High-level classification of barrier	*Example*	*Potential for measures to reduce barrier*
Institutional failures in economic systems	• Split incentives between different actors • Subsidies • Contractual obstacles to energy efficiency markets • .. tbc	tbc
Hidden costs and benefits	• Cost of getting adequate information • Transaction costs • Inferior (or better) performance or higher risk (or lower risk) of new technologies • .. tbc	Tbc
Behavioural and internal organisational obstacles	• 'Satisficing' behaviour including inertia • Split incentives within organisations	tbc
Any other category of high level classification not covered in above? **Tbc**	•	tbc

Tbc = to be developed after seeing Chapters 4-11

Table 11.3.1*: Implications of modelling autonomous and induced technological change*

Note: (1) The table represents a stylised contrast of how opposite conceptions of innovation could influence policy choices; real innovation is some combination of both. In modelling terms, differences are generally greatest for models with learning-by-doing based upon empirical experience curves, but many other models with induced technological change show at least some of the characteristics indicated.

Source: Adapted from Grubb, Kohler and Anderson (2002).

	Autonomous / R&D-led technical change ('push')	**Market-induced technical change[1] ('pull')**
Process:	Technical change depends mostly on autonomous trends and government R&D	Technical change depends mostly upon corporate investment (private R&D, and learning-by-doing) in response to market conditions
Modelling implications:		
Modelling term	Exogenous / R&D	Endogenous / induced
Typical main parameter	AEEI / projected costs / targeted R&D investment	Macroeconomic knowledge investment function / price response / Learning rate
Mathematical implications	Usually linear	Non-linear, complex
Optimisation implications	Single optimum with standard techniques	Potential for multiple equilibria, perhaps very diverse, complex techniques required
Economic / policy implications:		
Implications for long-run economics of climate change	Atmospheric stabilisation below c.550ppm likely to be very costly without major R&D breakthrough	Atmospheric stabilisation in range around 500ppm may not be very costly if observed learning rates extend into the future
Policy instruments and cost distribution	Efficient instrument is uniform Pigouvian tax + government R&D	Efficient response may involve wide mix of instruments, targeted to reoriented industrial R&D and spur market-based innovation in relevant sectors. Potentially with diverse marginal costs
Timing implications for mitigation	Defer abatement to await cost reductions	Accelerate abatement to induce cost reductions
'First mover' economics	Costs with little benefits	Investment with potential benefits of technological leadership
International spillover / leakage implications	Spillovers generally negative (positive leakage: abatement in one region leads eg. to industrial migration that increases emissions elsewhere)	Positive spillovers may dominate (international diffusion of cleaner technologies induced by abatement help to reduce emissions in other regions)

Table 11.3.2: *A classification of economies from technological change*

Economies from R&D-Based Technological Change	**Economies from Learning-by-Doing-Based Technological Change**	**Economies from technological specialization and scale**
Internal R&D Effect Private cost reductions from policy-induced *net* increases in R&D *less* social cost of this R&D *Net R&D Spillover Effect* Private cost reductions from net spillovers associated with policy-induced net increases in R&D	*Net Internal Learning-by-Doing Effect* Private cost reductions from policy-induced *net* increases in experience and associated learning-by-doing *Net Learning-by-Doing Spillover Effect* Private cost reductions from net spillovers associated with policy-induced net increases in experience	*Net Internal Specialization Effect* Cost reductions from policy-induced *net* increases in specialization and scale *Net Specialization and Scale Spillover Effect* Cost reductions from net spillovers associated with policy-induced net increases in specialization and scale

Table 11.3.3*: Overview of top-down modelling approaches on the impact of induced technological change and spillovers on climate policy performance.*
Source: Sijm (2004)

Study	Model	ITC channel	Spillovers	Policy instrument	Focus of analysis	Major results (impact of ITC)	Comments
Goulder and Mathai (2000)	Partial cost-function model with central planner	R&D LBD	No	Carbon tax	Optimal carbon tax profile Optimal abatement profile	Lower time profile of optimal carbon taxes Impact on optimal abatement varies depending on ITC channel Impact on overall costs and cumulative abatement varies, but may be quite large	Deterministic One instrument High aggregation Weak database
Goulder and Schneider (1999)	General equilibrium multi-sectoral model	R&D	Yes (sectoral)	Carbon tax	Abatement costs and benefits	Gross costs increase due to R&D crowding-out effect Net benefits decrease	Lack of empirical calibration Focus on U.S. Full 'crowding out' effect
Nordhaus (2002)	R&DICE (global IAM, Top-down, neoclassical)	R&D	Implicit (social > private rate of return)	Carbon tax	Factor substitution versus ITC Carbon intensity Optimal carbon tax	ITC impact is lower than substitution impact and quite modest in early decades	Deterministic Full 'crowding out' of R&D High aggregation (global, one sector)
Buonanno et al (various)[a]	FEEM-RICE (6-8 regions, single sector) Top-down	R&D (and occasionally LBD)	Yes	Rate of carbon control Emissions Trading (plus ceilings)	Compliance costs of Kyoto protocol Impact of ET (+ restrictions)	Direct abatement costs are lower, but total costs are higher ET ceilings have adverse effects on equity and efficiency	Includes international spillovers No crowding-out effect
Gerlagh and Van der Zwaan (various)[b]	DEMETER One-sector Two technologies	LBD	No	Carbon tax	Optimal tax profile Optimal abatement profile Abatement costs	Costs are significantly lower Transition to carbon-free energy Lower tax profile Early abatement	Results are sensitive to elasticity of substitution between technologies as well as to the learning rate on non-carbon energy
Study	Model	ITC channel	Spillovers	Policy instrument	Focus of analysis	Major results (impact of ITC)	Comments
Popp (2004c)	ENTICE (based on Nordhaus' DICE)	R&D	Implicit	Carbon tax	Welfare costs Sensitivity analysis of R&D parameters	Impact on cost is significant Impact on emissions and global temperature is small	Partial crowding out effect
Rosendahl (2002)	Builds on Goulder and Mathai (2000)	LBD	Yes (industrial and regional)	Carbon tax Emissions trading	Optimal carbon tax (or permit price) over time in two regions Optimal ET + restrictions	ET restrictions are cost-effective Optimal carbon tax in Annex I region is increased with external spillovers	Outcomes are sensitive to learning rate, discount rate and slope of abatement curve
Kverndokk et al. (2001 and 2003)	Applied Computable General Equilibrium (CGE) model for small open economy	LBD	Yes (sectoral)	Carbon tax Technology Subsidy	Optimal timing and mixture of policy instruments Welfare effects of technology subsidies	Innovation subsidy is more important in the short term than a carbon tax Innovation subsidy may lead to 'picking a winner' and 'lock in'	
Sue Wing (2003)	Multi-sector CGE (U.S.)	R&D	No	Carbon tax	Macroeconomic costs Allocation of R&D resources	ITC impact is positive and large in reducing social costs	Outcome is due to the substitution effect of homogenous knowledge factor
Bollen (2004)	WorldScan (12 regions, 12 sectors)	R&D	Yes (sectoral, regional)	Carbon tax (+ recycling)	Income and production losses	ITC magnifies income losses	Sectoral R&D intensities stay constant overtime

a) See, for instance, Buonanno et al. (2000 and 2003); Galeotti et al. (2002 and 2003); Buchner et al. (2003); and Carraro, (2003).

b) See, for instance, Gerlagh and Van der Zwaan (2003); Gerlagh et al. (2003); Van der Zwaan et al. (2002) and Van der Zwaan and Gerlagh (2003).

Table 11.3.4: *Treatment of endogenous technological change(ETC) in the IMCP models.*
Source: (Edenhofer et al., 2006)
Note: See source for details of models.

Model	Model type	ETC related to energy intensity	ETC related to carbon intensity	Other ETC	Exogenous TC
IMACLIM-R	dynamic recursive growth model	• Cumulative investments drive energy efficiency • Fuel prices drive energy efficiency in transportation and residential sector	• Learning curves for energy technologies (electricity generation)	• Endogenous labor productivity, capital deepening	
DEMETER-1CCS	GE market model	• Factor substitution in CES production	• Carbon-free energy from renewables and CCS • Learning-by-Doing for both	• Learning-by-Doing for fossil fuels	• Overall productivity
AIM/Dynamic -Global	growth mode	• Factor substitution in CES production • Investments in energy saving capital raises energy efficiency for coal, oil, gas, and electricity (in addition to AEEI)	• Carbon-free energy from backstop technology (nuclear/renewables)		• AEEI for energy from coal, oil, gas, and for electricity
ENTICE-BR	endogenous growth IAM	• Factor substitution in Cobb-Douglas production • R&D investments in energy efficiency knowledge stock	• Carbon-free energy from generic backstop technology • R&D investments lower price of energy from backstop technology		• Total factor productivity • Decarbonization accounting for e.g. changing fuel mix
FEEM-RICE	endogenous growth IAM	• Factor substitution in Cobb-Douglas production • Energy technological change index (ETCI) increases elasticity of substitution • Learning-by-Doing in abatement raises ETCI • R&D investments raise ETCI	• ETCI explicitly decreases carbon intensity • see ETCI in the energy intensity column		• Total factor productivity • Decarbonization accounting for e.g. changing fuel mix

Model	Model type	ETC related to energy intensity	ETC related to carbon intensity	Other ETC	Exogenous TC
MIND	hybrid	• R&D investments improve energy efficiency • Factor substitution in CES production	• Carbon-free energy from backstop technologies (renewables and CCS) • Learning-by-Doing for renewable energy	• R&D investments in labor productivity • Learning-by-Doing in resource extraction	• Technological progress in resource extraction
DNE21+	ESM	• Energy savings in end-use sectors modelled using the long-term price elasticity.	• Carbon-free energy from backstop technologies (renewables, CCS, and nuclear) • Learning curves for energy technologies (wind, photovoltaic and fuel cell vehicle)		• Technological progress energy technologies (other than wind, photovoltaics, fuel cell vehicle)
GET-LFL	ESM	• Learning-by-Doing in energy conversion	• Carbon-free energy from backstop technologies (renewables and CCS) • Learning curves for investment costs • Spillovers in technology clusters		
MESSAGE/ MACRO	ESM	• Factor substitution in CES production in MACRO	• Carbon-free energy from backstop technologies (renewables, carbon scrubbing and sequestration) • Learning curves for energy technologies (electricity generation, renewable hydrogen production)		• Declining costs in extraction, production • Demand

Model	Model type	ETC related to energy intensity	ETC related to carbon intensity	Other ETC	Exogenous TC
E3MG	econometric	• Cumulative investments and R&D spending determine energy demand via a technology index	• Learning curves for energy technologies (electricity generation)	• Cumulative investments and R&D spending determine exports via a technology index • Investments beyond baseline levels trigger a Keynesian multiplier effect	
IMAGE-TIMER	simulation IAM	• price elastic energy demand via substitution possibilities for energy by energy savings capital	• Carbon-free energy from backstop technology (nuclear/renewables, CCS) • Learning-by-Doing for energy technologies (oil, gas, coal, nuclear, solar/wind, biomass)	• Capital accumulation and depreciation	• Efficiency of power plants, partly energy efficiency, transport and refining losses of fossil fuels and electricity

Table 11.4.3: *Sectoral results from a meta-analysis of top-down energy modelling (PRIMES for energy-related CO2 and bottom-up modeling of non-CO2 GHGs).*

The table shows the distribution of direct and total (direct and indirect) emissions of greenhouse gases in 1990/1995, in the 2010 baseline and in the most cost-effective solution for 2010 where emissions are reduced by 8% compared to the 1990/1995 level. Results of the ***meta-analysis*** *incorporating the PRIMES top-down approach for energy related CO2 emissions and the bottom-up information on non-CO2 greenhouse gases and process emissions of CO2. The top table gives the breakdown into sectors and the bottom table the breakdown into gases.*

Notes:

1/ The direct CO2 emissions of energy supply are allocated to the energy demand sectors in the right part of the table representing direct and indirect

2/ Industrial boilers are allocated to industrial sectors.

3/ Non-CO2 greenhouse gas emissions from fossil fuel extraction, transport and distribution.

4/ Due to data inavailability, emission data for aviation include international aviation, which is excluded in the IPCC inventory methodology.

emissions. Refineries are included in the energy supply sector.

Source: (EU DG Environment, 2001)

http://europa.eu.int/comm/environment/enveco/climate_change/summary_report_policy_makers.pdf

EU-15 Emission breakdown per sector (*top-down*)	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990/95	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990/95*	*Change from 2010 baseline*	*Emissions in 1990/95*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990/95*	*Change from 2010 baseline*
Energy supply[1/2/]	**1190**	**1206**	**1054**	**-11%**	**-13%**	**58**	**45**	**42**	**-27%**	**-6%**
CO_2 (energy related)	1132	1161	1011	-11%	-13%					
autoproducers	*124*	*278*	*229*	*85%*	*-18%*					
utilities	*836*	*772*	*667*	*-20%*	*-14%*					
other	*172*	*111*	*115*	*-33%*	*4%*					
Non-CO_2	58	45	42	-27%	-6%	58	45	42	-27%	-6%
Non-CO_2 fossil fuel[3/]	**95**	**61**	**51**	**-46%**	**-16%**	**95**	**61**	**51**	**-46%**	**-16%**
Industry[2/]	**894**	**759**	**665**	**-26%**	**-12%**	**1383**	**1282**	**1125**	**-19%**	**-12%**
Iron and steel	196	158	145	-26%	-9%	253	200	183	-28%	-9%
Non-ferrous metals	24	22	13	-47%	-40%	66	42	30	-54%	-28%
Chemicals	243	121	81	-66%	-33%	362	257	201	-44%	-22%
Building Materials	201	212	208	3%	-2%	237	240	232	-2%	-3%
Paper and Pulp	29	22	20	-32%	-9%	69	106	92	34%	-13%
Food, drink, tobacco	46	35	26	-42%	-24%	89	107	91	2%	-15%
Other industries	155	189	172	11%	-9%	308	331	295	-4%	-11%
Transport	**753**	**984**	**946**	**26%**	**-4%**	**778**	**1019**	**975**	**25%**	**-4%**
CO_2 (energy related)	735	919	887	21%	-4%	760	953	916	21%	-4%
road	*624*	*741*	*724*	*16%*	*-2%*	*624*	*741*	*724*	*16%*	*-2%*
train	*9*	*2*	*2*	*-83%*	*-8%*	*34*	*36*	*31*	*-10%*	*-14%*
aviation[4/]	*82*	*150*	*135*	*65%*	*-10%*	*82*	*150*	*135*	*65%*	*-10%*
inl. navigation	*21*	*27*	*26*	*26%*	*-2%*	*21*	*27*	*26*	*26%*	*-2%*
Non-CO_2 (road)	18	65	59	222%	-10%	18	84	143	681%	70%
Households	**447**	**445**	**420**	**-6%**	**-6%**	**792**	**748**	**684**	**-14%**	**-9%**
Services	**176**	**200**	**170**	**-3%**	**-15%**	**448**	**500**	**428**	**-4%**	**-14%**
Agriculture	**417**	**398**	**382**	**-8%**	**-4%**	**417**	**398**	**382**	**-8%**	**-4%**
Waste	**166**	**137**	**119**	**-28%**	**-13%**	**166**	**137**	**119**	**-28%**	**-13%**
Total	**4138**	**4190**	**3807**	**-8%**	**-9%**	**4138**	**4190**	**3807**	**-8%**	**-9%**

Breakdown per gas	*Emissions in 1990/95*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990/95*	*Change from 2010 baseline*
CO_2 - energy related	3068	3193	2922	-5%	-8%
CO_2 - other	164	183	182	11%	-1%
Methane	462	380	345	-25%	-9%
Nitrous oxide	376	317	282	-25%	-11%
HFCs	52	84	54	3%	-36%
PFCs	10	25	19	87%	-27%
SF_6	5	7	3	-41%	-53%
Total	**4138**	**4190**	**3807**	**-8%**	**-9%**

Table 11.4.4: *Percentage Differences against the business-as-usual in 2010.*
Source: Meyer and Lutz (2002)

	USA	Japan	Germany	France	Italy	Great Britain	Canada
GDP	-1.72	-0.23	-0.35	-0.31	-0.34	-0.75	-1.61
Labour	0.08	0.27	0.89	0.90	0.93	0.56	0.19

Table 11.4.5: *Output effects of carbon taxes on different sectors in the G7 in 2010 (% difference from business-as-usual)*
Source: (Meyer and Lutz, 2002)

	USA	Japan	Germany	France	Italy	Great Britain	Canada
Food processing	-2.02	-0.27	-0.32	-0.36	-0.29	-0.69	-1.83
Petroleum and Coal Products	-2.87	-0.33	-0.82	-0.50	-0.47	-2.42	-3.67
Iron and steel	-1.35	-0.28	-0.33	-0.45	-0.48	-0.82	-1.60
Machinery	-1.06	-0.22	-0.26	-0.29	-0.48	-0.72	-1.11
Motor vehicles	-1.41	-0.42	-0.33	-0.47	-0.40	-0.74	-1.92
Construction	-1.01	-0.02	-0.13	-0.21	-0.39	-0.78	-1.06
All industries	-1.74	-0.18	-0.32	-0.33	-0.35	-0.75	-1.71

Table 11.4.6: *Carbon tax rate and required additional investments for reducing CO_2 emissions in Japan.*
Source: Kainuma (2004)

sector	Subsidized measures and devices	Additional investment (bil. JPY / year)
Industrial sector	Boiler conversion control, High performance motor, High performance industrial furnace, Waste plastic injection blast furnace, LDF with closed LDG recovery, High efficiency continuous annealing, Diffuser bleaching device, High efficiency clinker cooler, Biomass power generation	101.3
Residential sector	High efficiency air conditioner, High efficiency gas stove, Solar water heater, High efficiency gas cooking device, High efficiency television, High efficiency VTR, Latent heat recovery type water heater, High efficiency illuminator, High efficiency refrigerator, Standby electricity saving, Insulation	353.9
Commercial sector	High efficiency electric refrigerator, High efficiency air conditioner, High efficiency gas absorption heat pump, High efficiency gas boiler, Latent heat recovery type boiler, Solar water heater, High efficiency gas cooking device, High frequency inverter lighting with timer, High efficiency vending machine, Amorphous transformer, Standby electricity saving, Heat pump, Insulation	194.5

Transportation sector	High efficiency gasoline private car, High efficiency diesel car, Hybrid commercial car, High efficiency diesel bus, High efficiency small-sized truck, High efficiency standard-sized track	106.6
Forest management	Plantation, Weeding, tree thinning, multilayered thinning, Improvement of natural forest	195.7
Total		952.0
Tax rate to appropriate required subsidiary payments (JPY/tC)		3,433

Table 11.4.7: *The effects of EU-wide and Annex B trading on compliance cost, savings and marginal abatement costs in 2010.*
Notes: The reference case assumes that the Kyoto commitment is implemented separately by domestic action in each EU Member State. The alternative reference case assumes that within a Member State the overall emission reduction target of the burden-sharing agreement applies equally to each individual sector in the economy, illustrating an allocation evidently more expensive than the least-cost one of the reference case.
Source: Capros and Mantzos (2000, p.8)

	Compliance cost	Savings against **Reference case**		Savings against **Alternative Reference case**		Marginal abatement cost €/tCO_2	
	€ million	€ million	%	€ million	%	For sectors participating in EU-wide trading	For other sectors
No EU-wide trading							
Reference case: Burden sharing target implemented least cost across sectors within a Member State	9026	n.a.	n.a.	11482	56.0	n.a.	54.3
Alternative Reference case: Burden Sharing target allocated uniformly to all sectors within a Member State	20508	-11482	-127.2	n.a.	n.a.	n.a.	125.8
EU-wide trading							
Energy suppliers	7158	1868	20.7	13350	65.1	32.3	45.3
Energy suppliers and energy intensive industries	6863	2163	24.0	13645	66.5	33.3	43.3
All sectors	5957	3069	34.0	14551	71.0	32.6	32.6
Annex B trading: All sectors	4639	4387	48.6	15869	77.4	17.7	17.7

Notes: A negative sign means a cost increase. A positive sign means a cost saving.It is assumed that the international allowance price would be €17.7/tCO_2. Compliance cost and savings are on an annual basis. *Source*: Primes

Table 11.5.1: *Models discussed in this section.*

R&DICE	Nordhaus (2002)	Models R&D investment
	Goulder and Matthai (2000)	Models R&D investment or LBD
MIND	Edenhofer et al (2005)	Endogenous growth; backstop technology
FEEM-RICE	Buonanno, P. et al (2003)	Endogenous growth; backstop technology
ENTICE	Popp (2004)	Endogenous growth
AIM	Masui et al (2005)	Bottom up
SGM	Edmonds et al (2004)	
Worldscan	Riahi et al (2004); Bollen et al (2004)	CGE
MARIA	Mori and Saito (2004)	
MERGE	Manne and Richels (2004)	
IMAGE2.2	Van Vuuren et al (2004)	IAM linked to CGE
DNE21	Akimoto et al (2004)	
MARKAL	Smenkens-Ramierz Morales (2004)	Detailed energy demand model
EPPA	McFarland et al (2004), Paltsev et al (2003)	
NEMS	Energy Information Administration (various years)	Detailed energy demand model
PRIMES	Capros and Mantzos (2000)	Detailed energy model; partial equilibrium
POLES	IPTS (2000); Criqui and Kitous (2003)	Detailed energy model; partial equilibrium
GTEM	Viguier et al (2003)	CGE
EDGE	Burniaux (2000)	
E3MG	Barker et al (2006)	Econometric; demand-led

Table 11.5.2*: The effects on abatement costs of different policy criteria and approaches to technology modeling.*
Notes: (1) The value of extra discounted consumption is US$(1990) 238; this is likely to be very small in relation to total discounted consumption.

Study	Policy criterion	Channel for ITC	abatement 2000	range	abatement 2050	range	Cumulated Abatement	range
			% relative to no ITC base (range from sensitivity tests)					
Nordhaus (2002)	B-C	R&D	1	..	6	..	..	..
Goulder and Matthai (2000)	C-E 550ppmv	R&D	-18	-39 to 0	-12	-51 to -4	-0.9	-1.5 to -0
	C-E 550ppmv	LBD	20	-9 to 15K	-6	-11 to 3K	-0.5	-1 to -0
	B-C	R&D	0	-0 to 0	2	1 to 8	3.7	2 to 26
	B-C	LBD	1	0 to 4	6	3 to 23	14.5	7.5 to 93

Study	Policy criterion	Channel for ITC	tax 2000	range	tax 2050	range	cost/unit abatement	range	Net benefits	range
Nordhaus (2002)	B-C	R&D	0	..	0	..	..	..	(1)	
Goulder and Matthai (2000)	C-E 550ppmv	R&D	-35	-57 to -9	-35	-57 to -9	-30	-53 to -7	..	
	C-E 550ppmv	LBD	-41	-60 to -20.1	-41	-60 to -20	-39	-58 to -19	..	
	B-C	R&D	0	-0 to 0	0	-0 to 0	-2	-15 to -1	0.7	0.3 to 4.6
	B-C	LBD	0	-0.2 to 0	0	-1 to 0	-9	-37 to -5	3.2	1.5 to 15.0

Table 11.5.*3:* *Learning rates of electricity generating technologies in bottom-up energy system models.*
Source: Sijm (2004)

(a) *one-factor learning curves*

[%]	ERIS	MARKAL	MERGE-ETL	MESSAGE
Advanced coal	5	6	6	7
Natural gas combined cycle	10	11	11	15
New nuclear	5	4	4	7
Fuel cell	18	13	19	-
Wind power	8	11	12	15
Solar PV	18	19	19	28

Source: Messner (1997), Seebregts et al. (1999), Kypreos and Bahn (2003a), and Barreto and Klaassen (2004).

(b) two-*factor learning curves*

	ERIS		MERGE-ETL	
[%]	LDR	LSR	LDR	LSR
Advanced coal	11	5	6	4
Natural gas combined cycle	24	2	11	1
New nuclear	4	2	4	2
Fuel cell	19	11	19	11
Wind power	16	7	12	6
Solar PV	25	10	19	10

Source: Barreto (2001), Barreto and Kypreos (2004b), and Bahn and Kypreos (2003).

Table 11.5.4: *The EIA's Analysis of the Kyoto Protocol, McCain-Lieberman Proposal, and Bingman/NCEP Proposal: US in 2020.*
Source: Morgenstern (2005)

	Bingaman	McCain-Lieberman	Kyoto (+9%)
GHG emissions (% domestic reduction)	4.5	17.8	23.9
GHG emissions (tons CO_2 reduced)	404	1346	1690
Allowance price ($2003 per ton CO_2)	8	35	43
Coal use (% change from forecast)	-5.7	-37.4	-72.1
Coal use (% change from 2003)	14.5	-23.2	-68.9
Natural gas use (% change from forecast)	0.6	4.6	10.3
Electricity price (% change from forecast)	3.4	19.4	44.6
Potential GDP (% loss)	0.02	0.13	0.36
Real GDP (% loss)	0.09	0.22	0.64

Table 11.5.5*: A comparison of model estimates of (a) domestic carbon prices, (b) wefare, GNP and terms of trade for the EU ETS in 2010 to achieve the Kyoto target 2010.*
Source: Viguir, 2003, p.478
Note for definition of areas see panel (c)

(a) *A comparison of model estimates of domestic carbon prices*

	EPPA US$95/tC	GTEM US$95/tC	POLES US$95/tC	PRIMES US$95/tC
GBR	91	113	133	123
DEU	119	177	107	88
FR	136	—	220	144
ITA	147	—	352	173
ROE	160	—	—	221
ESP	184	—	—	134
FIN	217	289	—	150
NLD	293	—	—	536
SWE	310	358	—	219
DNK	385	400	—	189
EEC	159	155	188	135
USA	229	—	177	—
JPN	201	—	238	—

(b) A comparison of model estimates of wefare, GNP and terms of trade

	Welfare	GNP	Terms of trade
DEU	−0.63	−1.17	1.10
FR	−0.67	−1.11	1.11
UK	−0.96	−1.14	−0.77
ITA	−1.01	−1.47	1.54
ROE	−1.23	−2.12	1.07
FIN	−1.90	−2.73	1.67
ESP	−2.83	−4.76	2.06
SWE	−3.47	−5.11	1.18
DNK	−3.97	−5.72	−0.74
NLD	−4.92	−7.19	0.55
USA	−0.49	−1.01	2.39
JPN	−0.22	−0.49	2.70

(c) Definitions of regions

Annex B	
United States	USA
Japan	JPN
Europe	EEC
Denmark	DNK
Finland	FIN
France	FR
Germany	DEU
Italy	ITA
Netherlands	NLD
Spain	ESP
Sweden	SWE
United Kingdom	GBR
Rest of Europe[a]	ROE
Other OECD	OOE

Table 11.5.6*:* *A comparison of GDP loss rates for China across models in 2010*
Notes: 1) Marginal carbon abatement costs were originally measured at 1990 prices in GLOBAL 2100, at 1985 prices in GREEN, and at 1987 prices in Zhang's CGE model, but were converted to 1995 prices in order to be compared with that from China MARKAL-MACRO.
2) The figures in parentheses indicate the percentage of reductions required, the associated marginal abatement costs and the GDP loss rates in order to achieve the same amount of carbon reductions as those in Zhang's model.
Source: Chen, 2005, p. 894.

Model	Abatement rate (%)	Marginal carbon abatement cost[a] (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[b]	20(27)	59(69)	0.732(0.938)
	30(40)	75(119)	1.026(1.749)

Table 11.6.1: *Observed retirement rates and lifetimes of major GHG-related capital stock.*
Source: Worrel and Biermans (2002)

	Retirement rate rate %/yr	Average lifetime (years)
Agriculture	2.0	50
Mining	2.0	50
Construction	2.0	50
Food	1.7	59
Paper	2.3	43
Bulk chemicals	2.3	43
Glass	1.3	77
Cement	1.2	50
Steel		
Basic oxygen furnaces	1.0	100
Electric arc furnaces	1.5	67
Coke ovens	1.5	67
Other steel	2.9	34
Primary aluminium	2.1	48
Metals-based durables	1.5	67
Other manufacturing	2.3	43

Table 11.6.2: *A summary of technology policy tools*
Source: Alic, Mowery and Rubin (2003) supplemented from Sanden and Azar (2005) and Grubb (2005)

Direct government funding of research and development (R&D)	Direct of indirect support for commercialization and production: indirect support for development	Support for learning and diffusion of knowledge and technology
• R&D contracts with private firms (fully funding or cost-shared) • R&D contracts and grants with universities • Intramural R&D conducted in governmental laboratories • R&D contracts with industry-led consortia or collaborations among two or more of the actors above	• Patent protection • R&D tax credits • Tax credits or production substiides for firms bring new technologies to market • Ta credits or rebates for purchasers of new technologies • Government procurement • Demonstration projects • Green labelling • Assured market shares • Technology incubators (managerial support for university spin-outs) • Technology accelerators (multiple field-testing/in-situ demonstration)	• Education and training • Codification and diffusion of technical knowledge (screening, interpretation, and validation of R&D results; support for databases • Technical standard-setting • Technology and/or industrial extension services • Publicity, persuasion, and consumer information (including awards, media campaigns, etc).

Table 11.7.1: *Distribution of losses among OPEC countries on the basis of OWEM's Annex-B trading scenario.*
Source: Barnett (2004) p. 2085

	% of OPEC revenue 1999	Losses in 2010 (billion $)	Losses in 2010 as a % of 1999 GDP	Ranking in terms of losses as % of GDP
Saudi Arabia	28	4	2	5
Iran	11	1.5	0.4	9
Venezuela	10	1.4	0.7	7
Nigeria	9	1.3	1.2	6
Iraq	9	1.3	2.2	4
UAE	9	1.3	3.1	2
Kuwait	7	1	2.2	4
Libya	6	0.9	2.3	3
Algeria	5	0.7	0.5	8
Indonesia	3	0.4	0.07	10
Qatar	3	0.4	3.3	1

Table 11.8.1: *Implications for air-quality co-benefits form GHG mitigation studies*

Authors	Country	Target year	Sector	Delta CO_2 emissions	C price US-$/t C	Difference in coal use	Impact on air pollutant emissions	Difference in health impacts	Health benefits US $/t C	Difference in air pollution control costs	Total benefits
EIA 1998	US	2008-2012	Power sector	-31%		-77%					
		2008-2013	Power sector	-36%		-92%					
Burtraw 2003	US	2010	Power sector		25 $/t C				8 $/t C	4-7 $/t C	

Canton 2000	Canada	2010	All sectors	- 9%		SO_2: -9% NO_x: -7% PM: -1%		42 $/t C (12-77)	
Wang & Smith 1999	China	2020	Power sector	15% below BAU	40 $/t C		4,400-5,200 premature deaths/yr		
		2020	Domestic sector	15% below BAU	5 $/t C		120,000-180,000 premature deaths/yr		
O'Connor 2003	China	2010	All sources	15% below BAU					no loss in net welfare
Aunan 2004	Shanxi. China	2000	Cogeneratio n		-108 $/t C			117 $/t C	
		2000	Modified boiler design		-22 $/t C			86 $/t C	
		2000	Boiler replacement		-10 $/t C			117 $/t C	
		2000	Improved boiler management		33 $/t C			117 $/t C	
		2000	Coal washing		82 $/t C			314 $/t C	
		2000	Briquetting		98 $/t C			433 $/t C	

Morgenstern 2004	Taiyuan, China		Phase-out of small boilers	80%	-95%	138-642 $/t C		
Bussolo & O'Connor 2001	India		All sources	13-23% below BAU				no welfare loss
Joh et al. 2003	Korea	2020		5-15%		6.8-7.5 $/t C		
Van Vuuren 2005	Europe	2020	All Sources	4-7%	SO_2: 5-14%			
Syri et al. 2001	EU-15	2010	All Sources	-8%	SO_2: 13-40% NO_x: 10-15%		-10%	
Fichtner et al., 2003	Baden-Wuerttemberg, Germany							
Proost et al. (2004)	Belgium	2010-2030	All Sources	7-15%				30% of mitigation costs
Syri et al., 2002	Finland	2010	All Sources	Kyoto compiance	SO_2: -10% NO_x : -5% PM: -5%			
Bye et al. (2002)	Nordic countries		All sources	20-30%			35-80 $/t C	-0.4% to -1.2 % of

						GDP
Cifuentes (2001)	Mexico City, Santiago, Sao Paulo, New York	2020			64,000 premature deaths/yr	
Mc Kinley et al	Mexico City		5 mitigation options	0.8 Mt C/yr	100 premature deaths/yr	
Dessus et al.	Santiago de Chile	2010		20% below BAU		no welfare loss

FIGURES

Figure 11.3.1: *Global GDP per capita, 1990 international $*
Source: Maddison (2001)

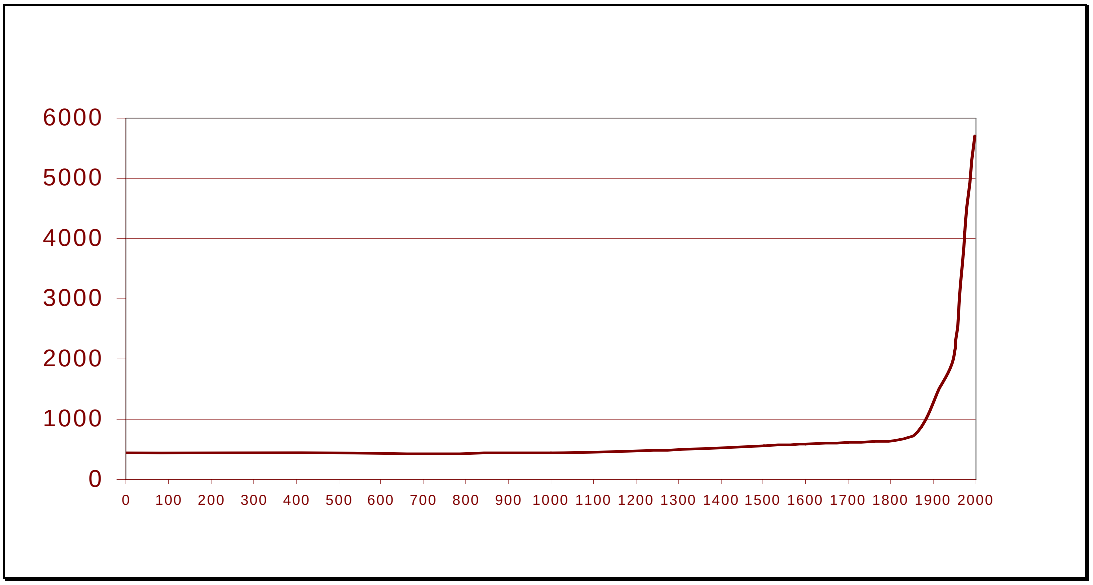


Figure 11.3.2*:* *Global GDP, 1990 international million $*
Source: Maddison (2001)

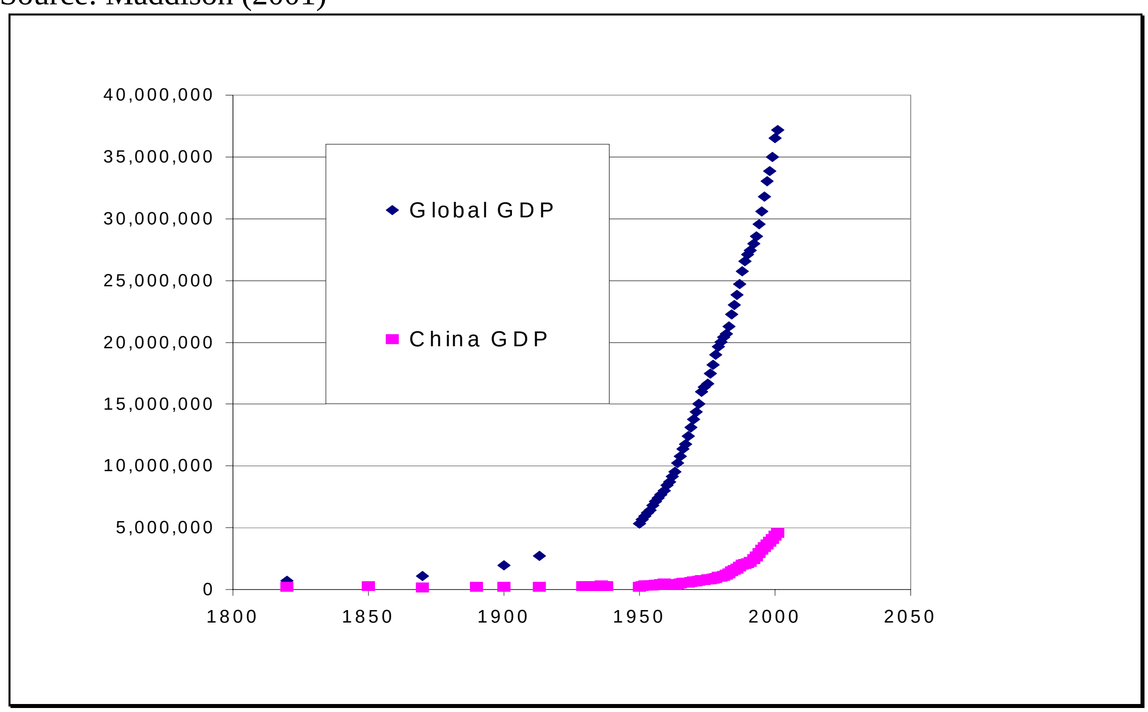


Figure 11.3.3: *Carbon Intensity of the Global Economy: Units of CO2 per $ Global GDP*
Source: Tooze (2006)

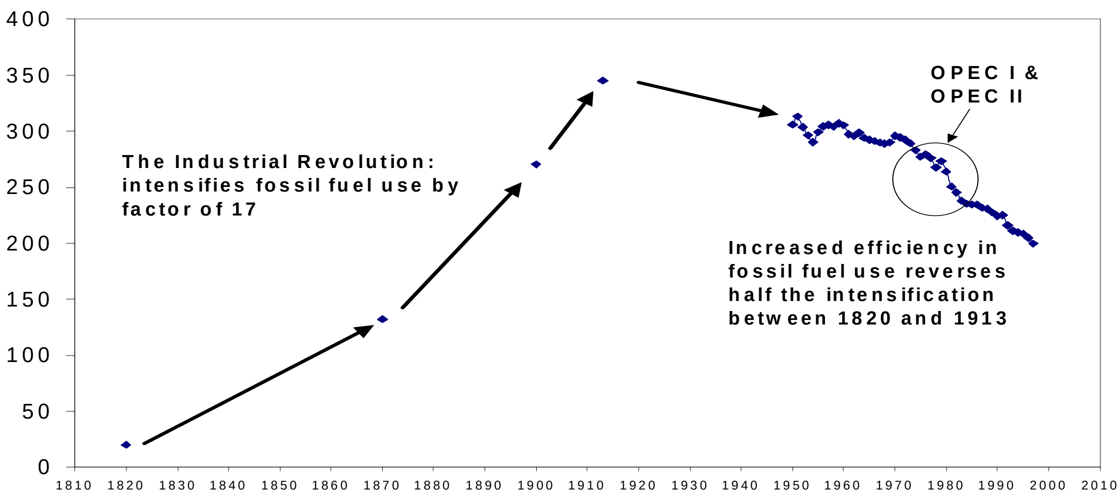


Figure 11.3.4: *CO2 emisions and GDP*
Source: Tooze (2006)

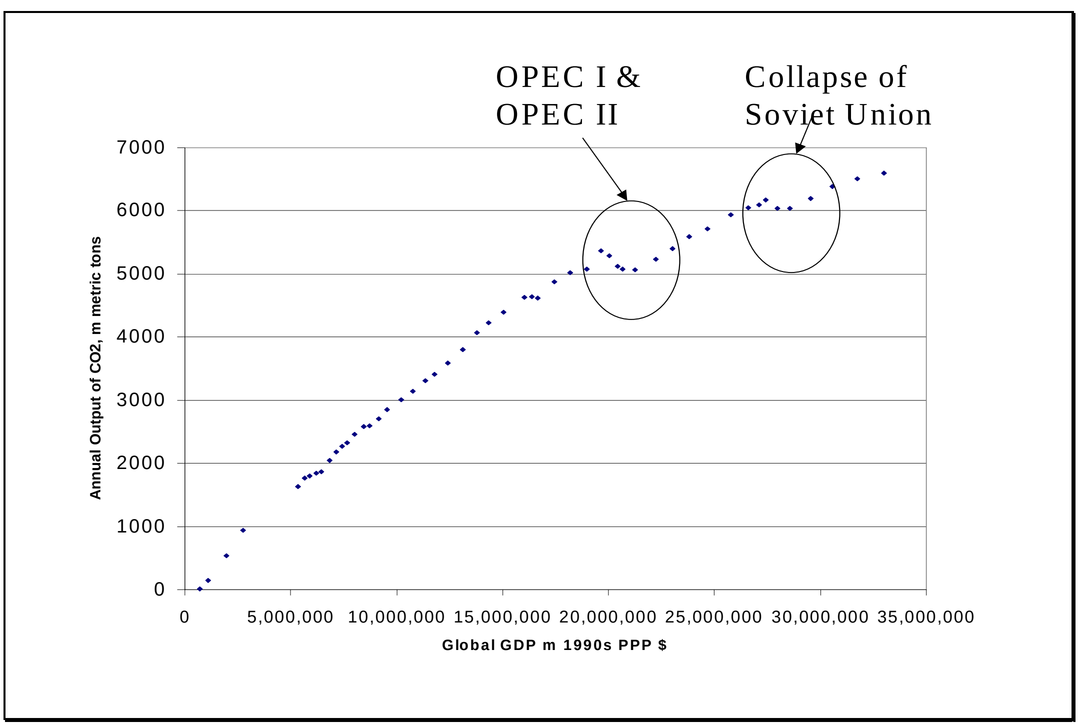


Figure 11.4.1: *Interactions of CO2 mitigation measures in electricity supply- and demand- sectors*

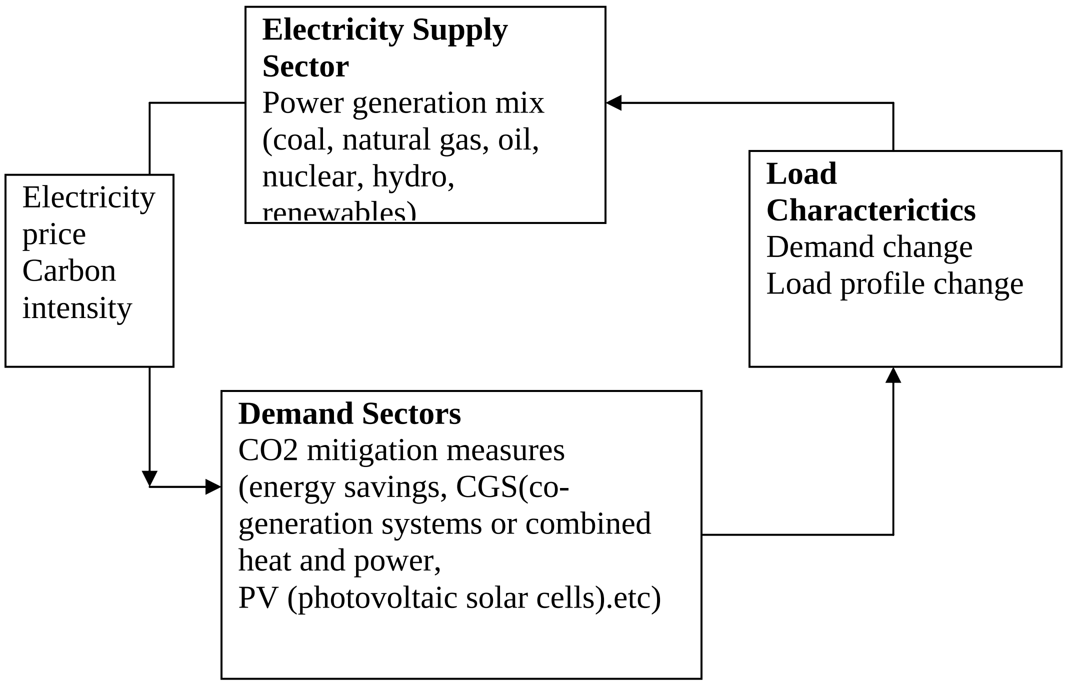


Figure 11.4.2: *Possible interactions among energy, land-use, and waste-management sectors caused by bioenergy use*

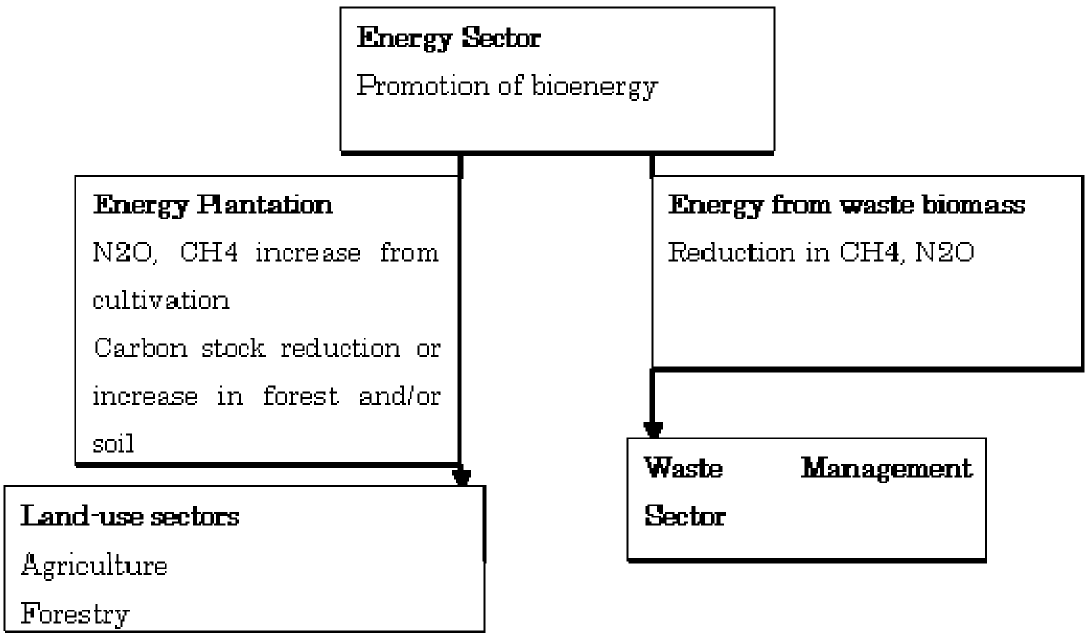


Figure 11.4.3*:* *GDP losses under different tax regimes. Source: (Kainuma et. al.)*

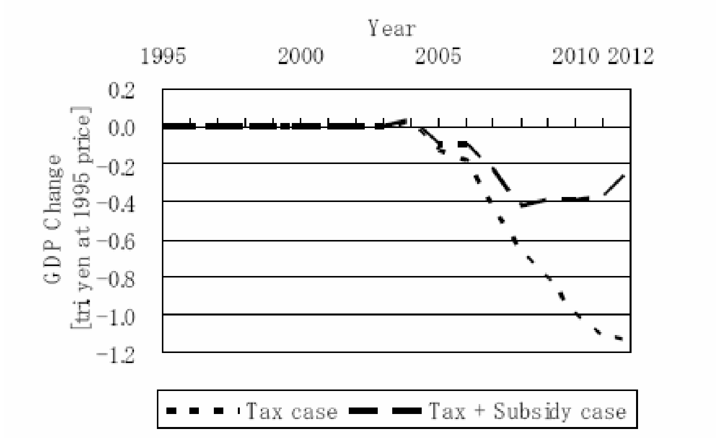
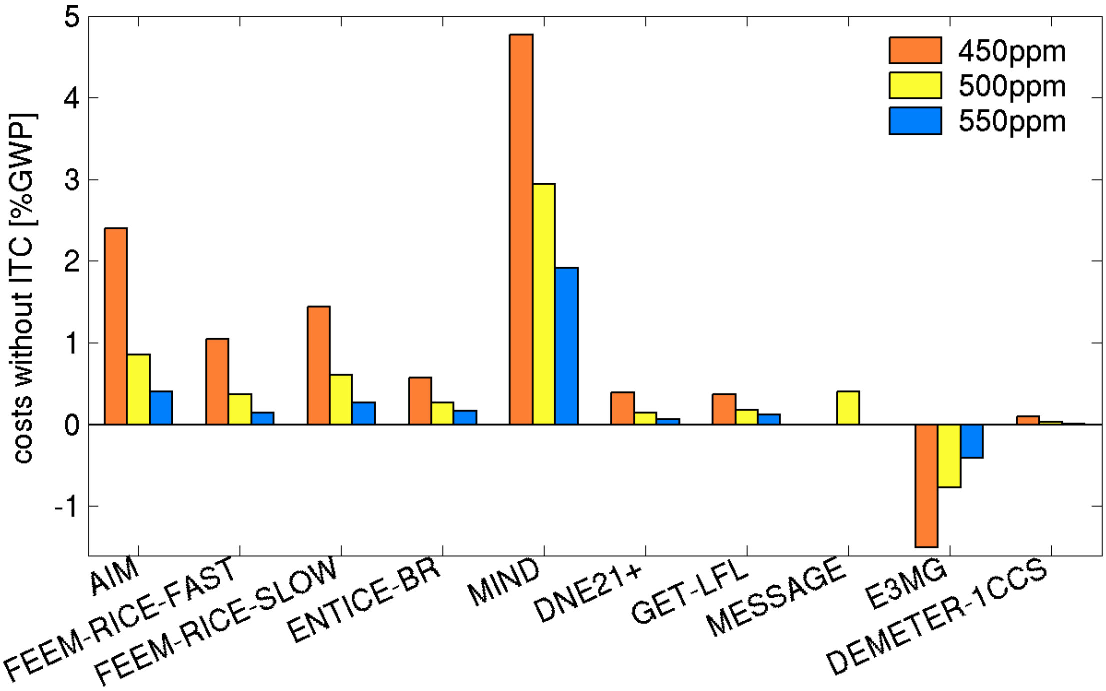
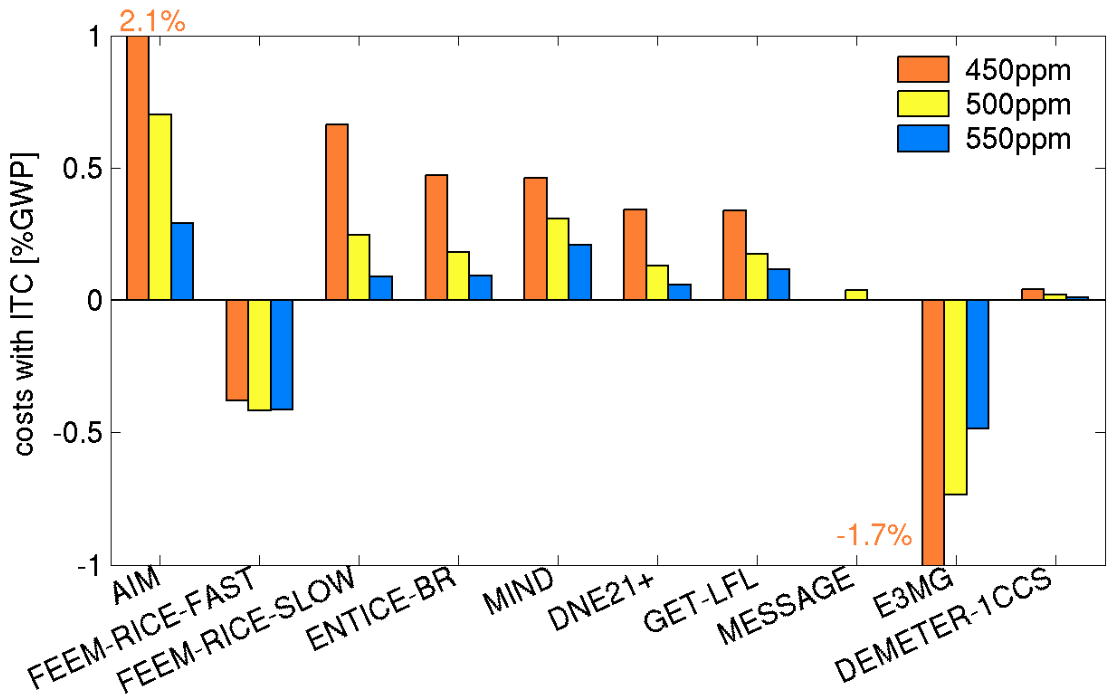


Figure 11.5.1*:* *Mitigation Costs as % of Gross World Product (GWP) (a) without induced technological change (ITC) (b) with ITC. All models report gross world product, except DNE21+, which reports the increase in energy system costs relative to the baseline, and GET-LFL, which reports the difference in producer and consumer surplus. All values are aggregates from 2000 to 2100, discounted to the 2000 present value at a 5% discount rate. The data in this figure is restricted to models where acception is recommended, minor revisions provided.*
Source: Edenhofer, Lessmann et al. under revision (all reviewers have recommended publication after minor revisions).



(a) without ITC


2.1%
-1.7%
450ppm
500ppm
550ppm
costs with ITC [%GWP]
1
0.5
0
-0.5
-1
AIM
FEEM-RICE-FAST
FEEM-RICE-SLOW
ENTICE-BR
MIND
DNE21+
GET-LFL
MESSAGE
E3MG
DEMETER-1CCS

(b) with ITC

Figure 11.5.2: *Carbon tax projections for the 550mmpv stabilization scenario.*
Source: Weyant (2004).

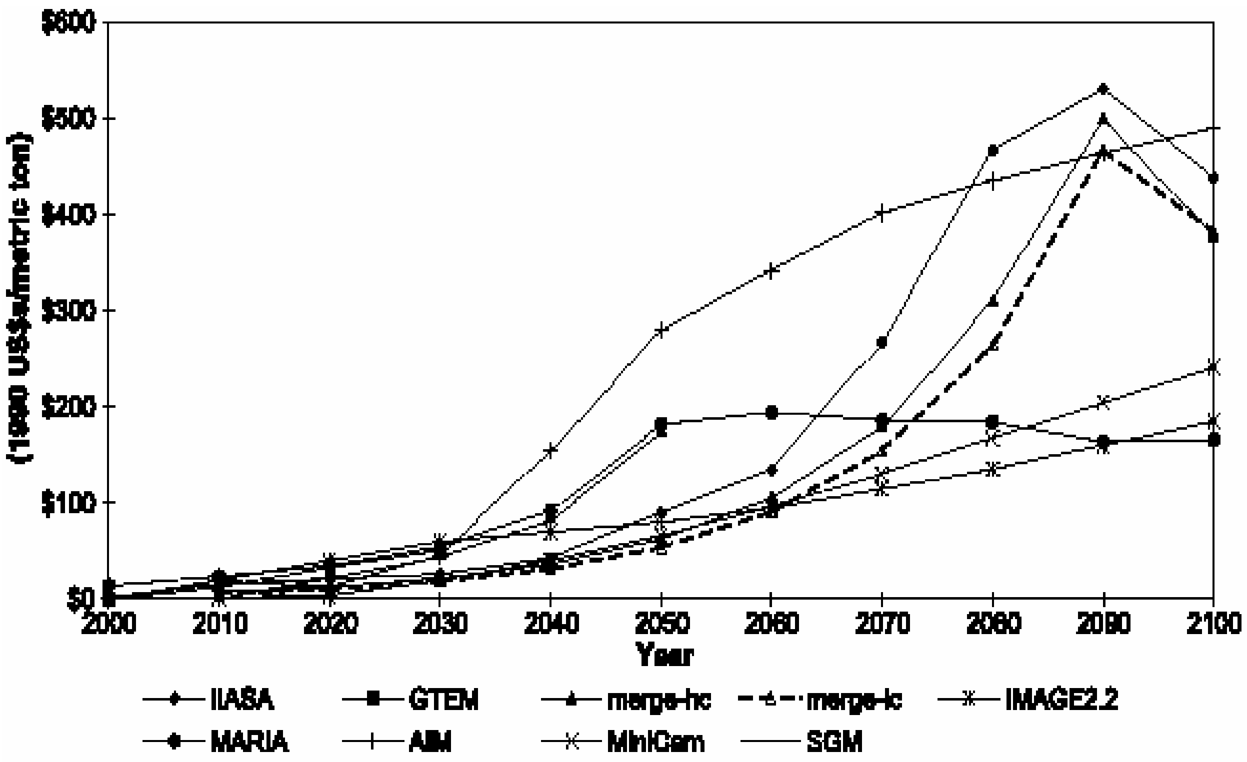


Figure 11.5.3: *Key sensitivities for the emission permit price from the FAIR model applied to the Kyoto Protocol under the Bonn-Marrakesh Accords.*

Source: den Elzen and Both (2002) p. 43.

The following key factors and associated assumptions were chosen for the analysis:

- *Baseline emissions:* LOW reflects the B1 scenario and HIGH the A1F scenario (IMAGE-team, 2001); our reference is the A1B scenario.
- *Hot air banking:* the LOW case reflects no banking of hot air while in the HIGH case, all hot air is banked; the reference case is one in which hot air banking is optimal for the Annex-I FSU (see Figure 5.7 in Section 5.6).
- *Marginal Abatement Cost (MAC) curves:* the MAC curves of WorldScan are used in the reference case while the MAC curves of the POLES model represent the HIGH case.
- *Participation Annex-I:* at the LOW end, we examined the participation of Kazakhstan while the HIGH end reflects US re-entry.
- *Sinks:* a LOW case has been constructed by assuming CDM sink credits capped to 0.5 per cent of base year emissions (instead of 1 per cent), carbon credits from forest management based on data submitted by the Parties (which are lower than the reported values in Appendix Z, see Pronk, 2001) and low estimates for carbon credits from agricultural and grassland management using the ALTERRA ACSD model (Nabuurs et al., 2000). The HIGH case reflects sinks credits based on high ACSD estimates for agricultural and grassland management and maximum carbon credits from forest management as reported in Appendix Z. In total, the LOW case implies 70 MtC while the HIGH case 195 MtC of carbon credits from sinks-related activities. The Marrakesh Accords represent the reference case of 120 MtC.
- *CDM accessibility factor:* this reflects the operational availability of viable CDM projects and is set at 10 per cent of the theoretical maximum in the reference case. In the LOW case, we assume no accessibility, while in the HIGH case the factor is set at 30 per cent.
- *Transaction costs:* the transaction costs associated with the use of the Kyoto Mechanisms is set at 20 per cent in the reference case, at 10 per cent in the LOW case and at 30 per cent in the HIGH case.

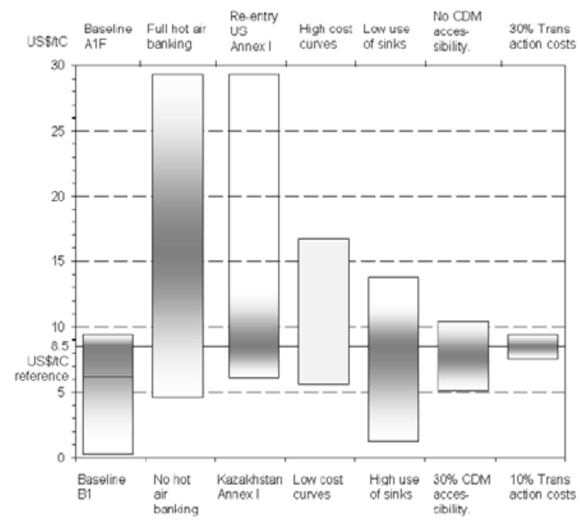


Figure 11.5.4: *A comparison of Marginal Abatement Curves for China in 2010 from different models.*
Source: Chen, 2005, p.891.

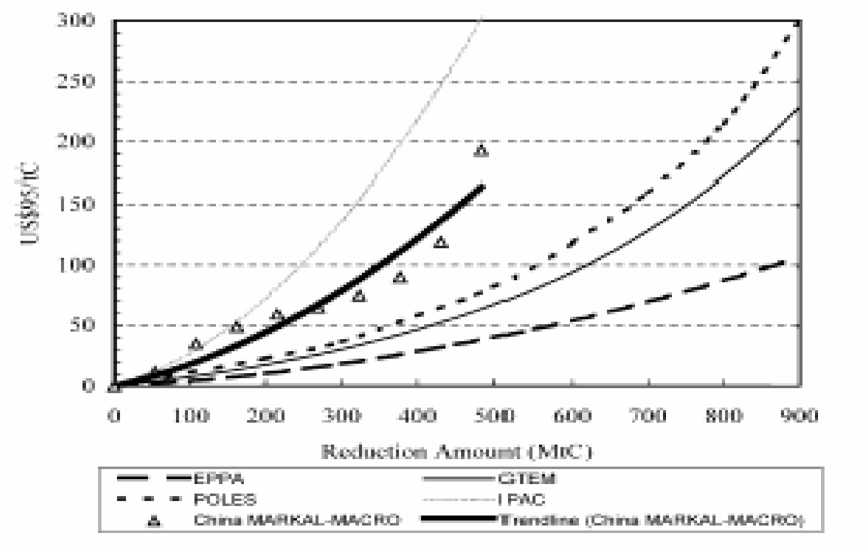


Figure 11.6.1: *Fuel sources of CO2 emissions 1751-2003.*
Source: WRI (2005)