PRICING CO_2 EMISSIONS

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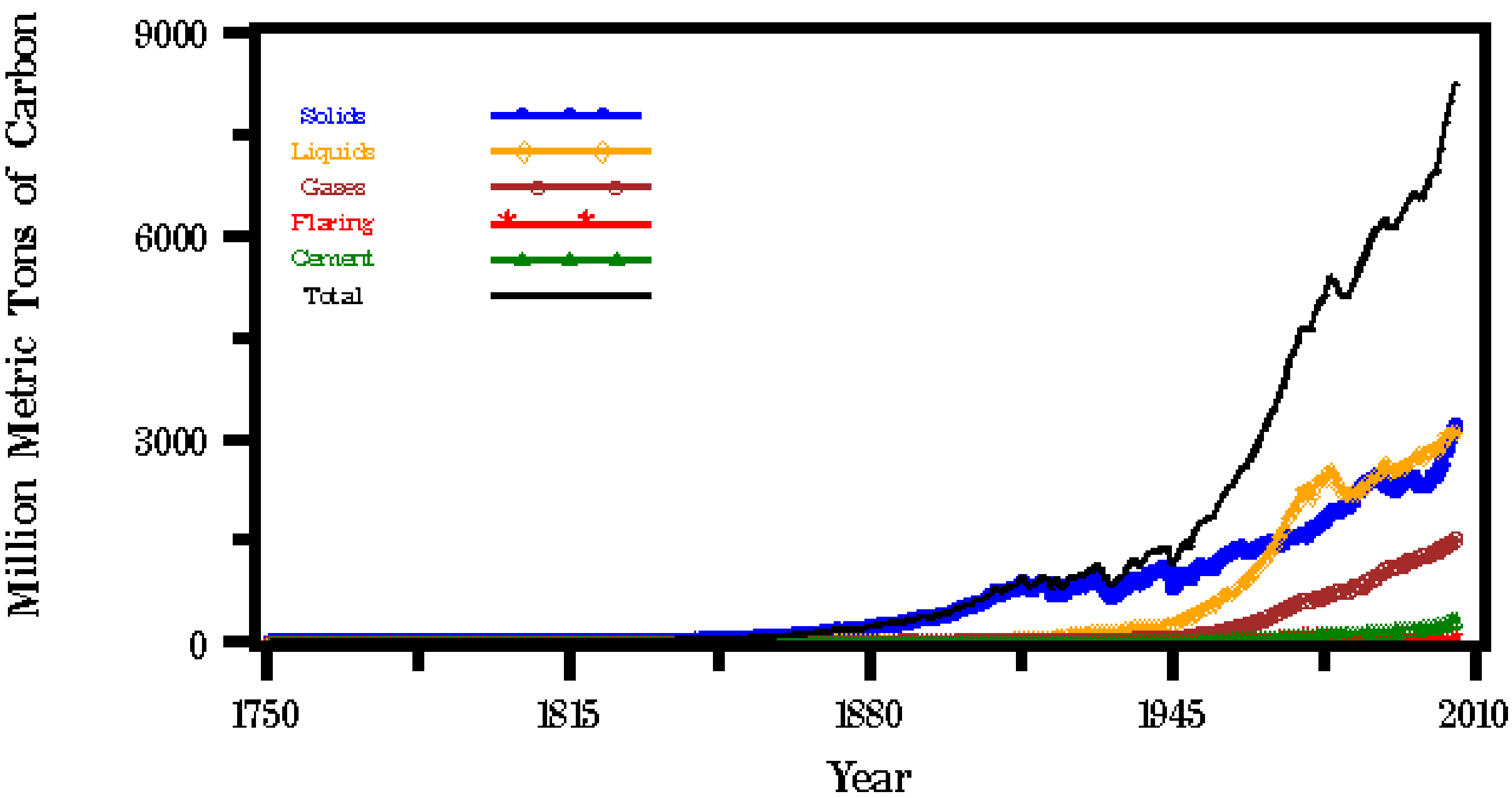
CLIMATE CHANGE POLICY: AN ECONOMIC PERSPECTIVE

Climate change is an externality with a difference:

- Global
- Mitigation and associated costs must start now while benefits of avoiding significant adverse impacts of climate change occur (far) in the future
- Uncertainty over science, technology and economics
- Potentially catastrophic and irreversible costs of climate change ("fat tails")

GLOBAL CO2 EMISSIONS

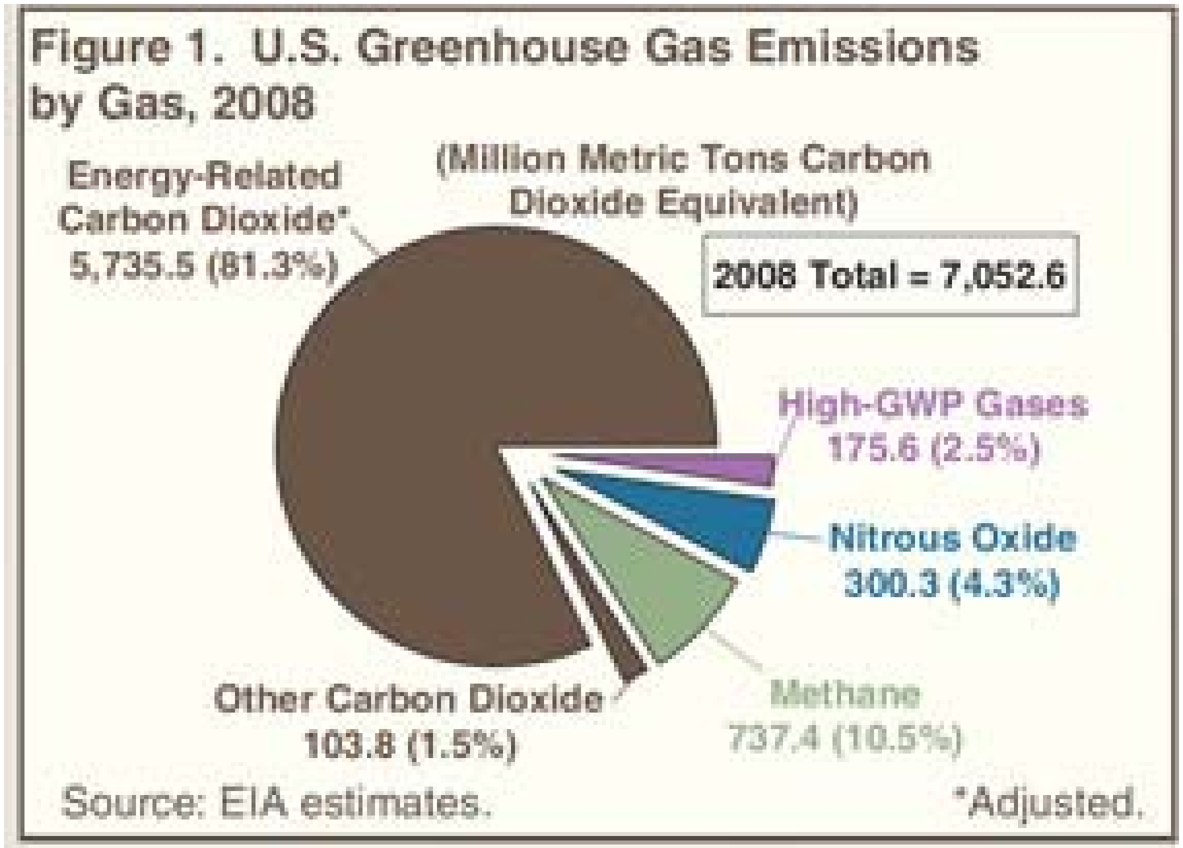


Source: Carbon Dioxide Information Analysis Center

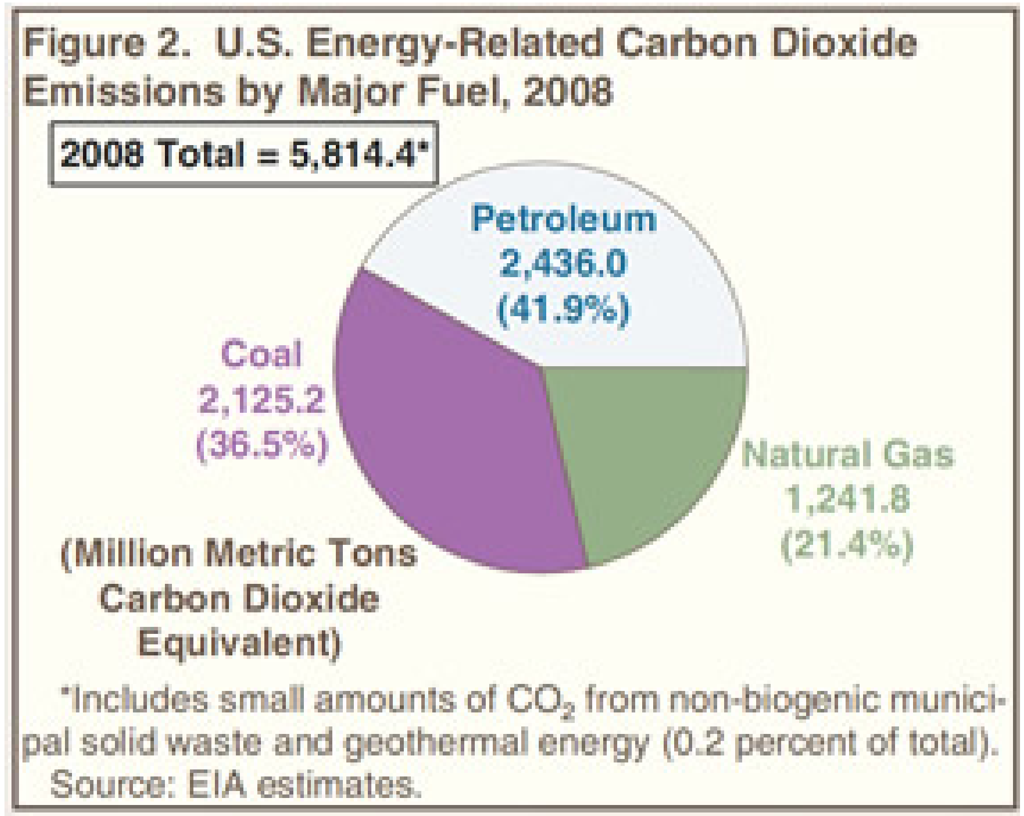
U.S. Anthropogenic Greenhouse Gas Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO_2e)	6,187.4	7,209.8	7,052.6
Change from 1990 (Million Metric Tons CO_2e)		1,022.4	865.1
(Percent)		*16.5%*	*14.0%*
Average Annual Change from 1990 *(Percent)*		*0.9%*	*0.7%*
Change from 2007 (Million Metric Tons CO_2e)			-157.3
(Percent)			*-2.2%*

Source: U.S. EIA



Source: U.S. EIA



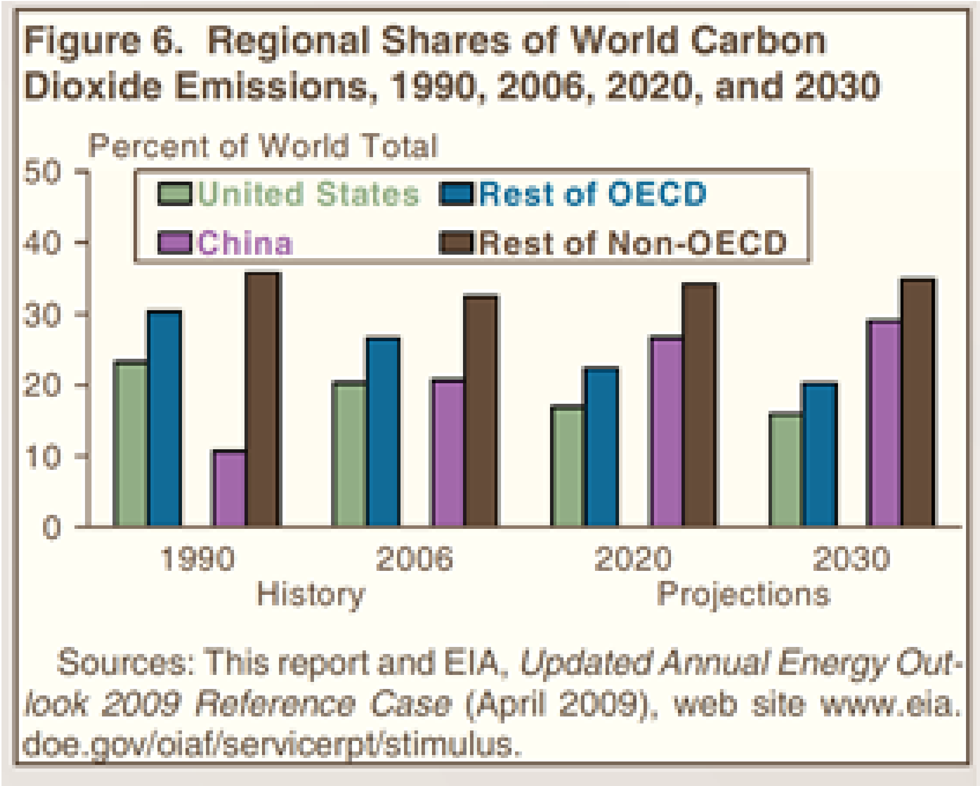
Source: U.S. EIA

World Energy-Related Carbon Dioxide Emissions, 1990, 2006, and 2030

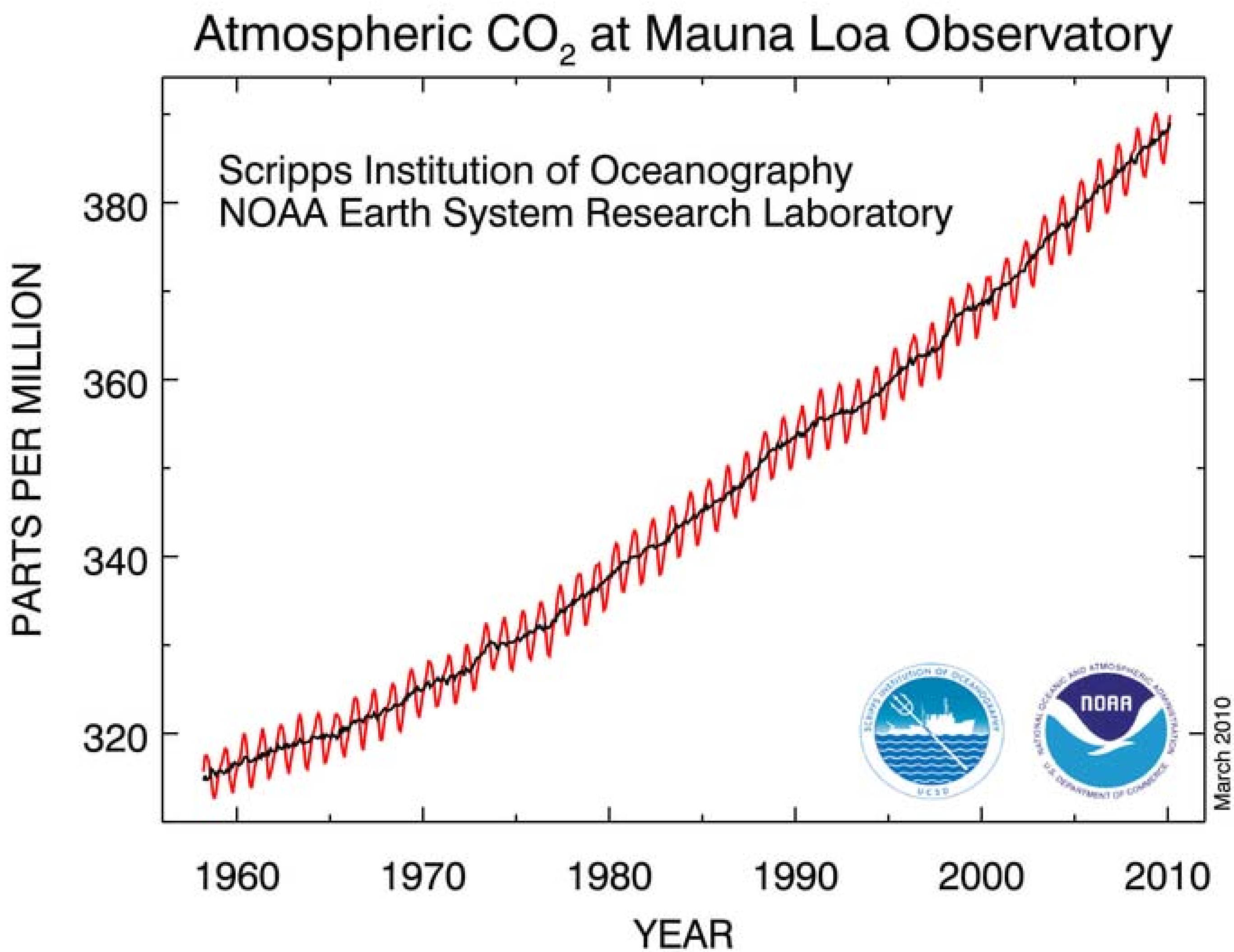
	1990	2006	2030*
Estimated Emissions (Million Metric Tons)	21,518	29,017	40,178
Change from 1990 (Million Metric Tons)		7,499	18,660
(Percent)		*34.8%*	*86.7%*
Average Annual Change from 1990 *(Percent)*		*2.0%*	*1.6%*
Change from 2006 (Million Metric Tons)			11,161
(Percent)			*38.5%*

*EIA, *International Energy Outlook 2009*.

Source: U.S. EIA



Source: U.S. EIA


Atmospheric CO2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
380
360
340
320
1960
1970
1980
1990
2000
2010
YEAR
March 2010

Source: NOAA

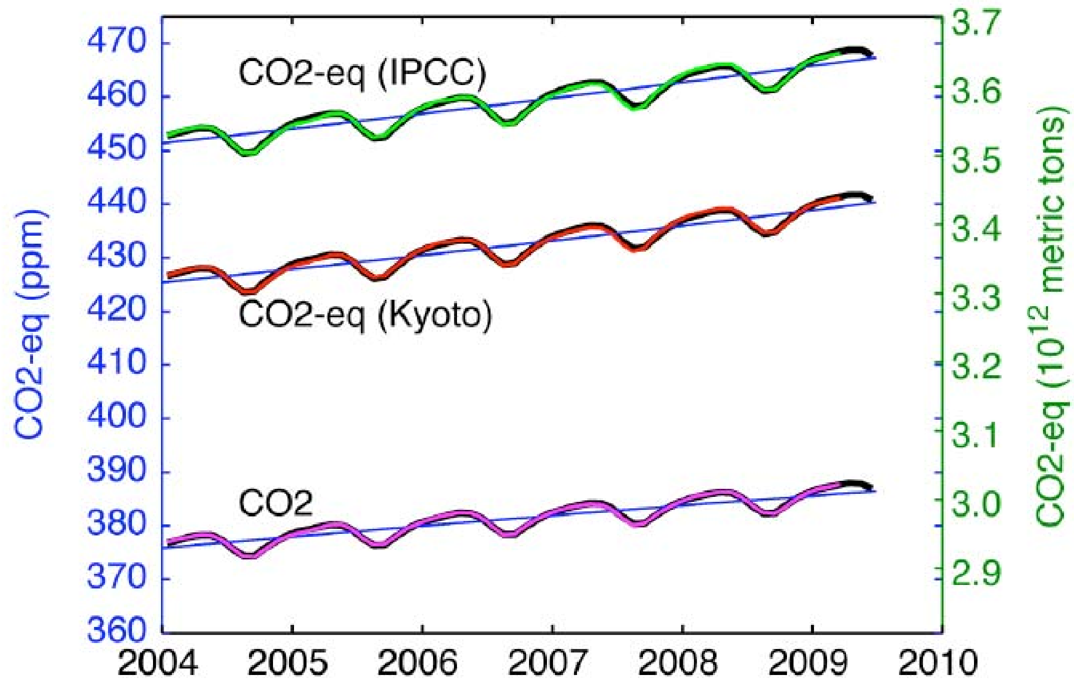
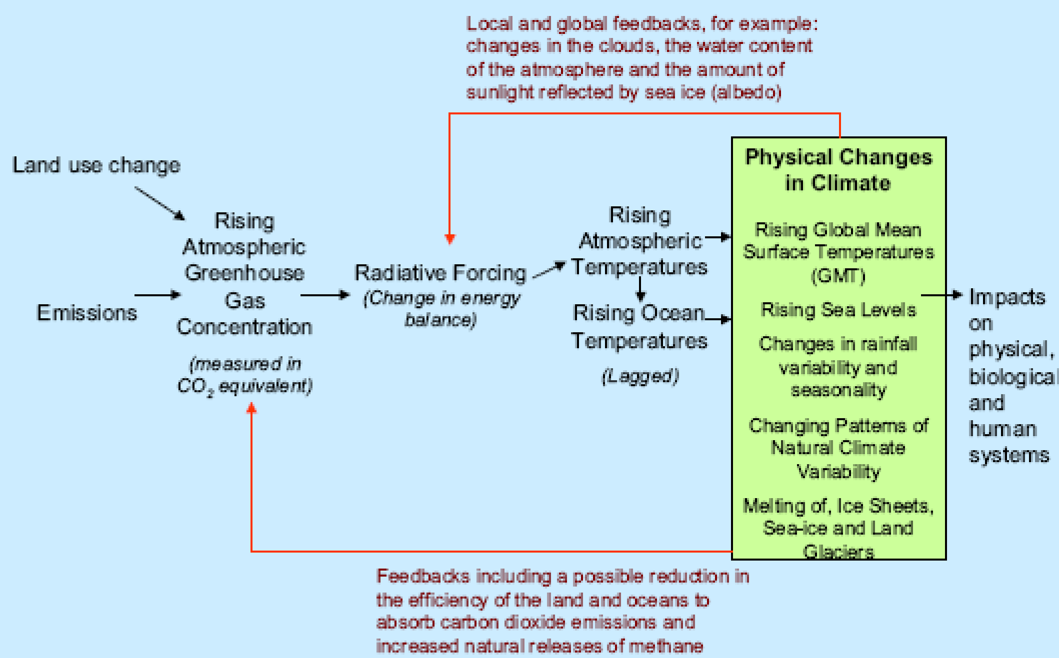


Figure 2. Total CO_2-eq (ppm on left-hand scale and metric tons on right-hand scale) from observed GHG mole fractions (oscillating colored lines), full 6-term equation (6) fit to the observations (oscillating black lines), and 3-term Legendre polynomial only fit to observations (smooth blue lines), for the "CO_2 Only", "Kyoto Gases" and "IPCC Gases" cases. The "All Gases" case is only 0.2 ppm above the "IPCC-Gases" case and is not shown as it would be indistinguishable on the scale of the graph.

Source: MIT Joint Program, Report #174 (2009)

Figure 1.4 The link between greenhouse gases and climate change.



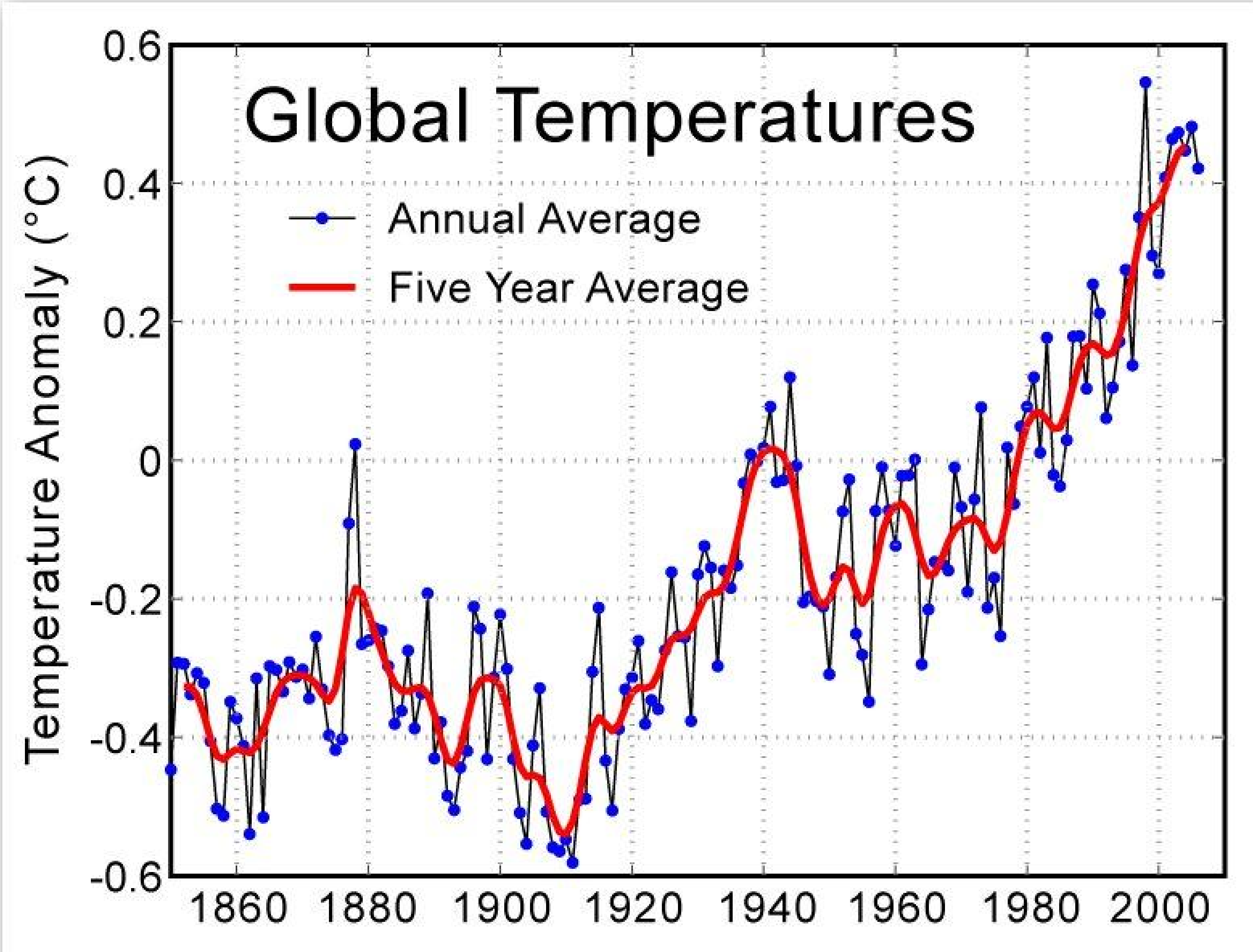
Stern Review (2006)

Table 1.1 Temperature projections at stabilisation

Meinshausen (2006) used climate sensitivity estimates from eleven recent studies to estimate the range of equilibrium temperature changes expected at stabilisation. The table below gives the equilibrium temperature projections using the 5 – 95% climate sensitivity ranges based on the IPCC TAR (Wigley and Raper (2001)), Hadley Centre (Murphy *et al.* 2004) and the range over all eleven studies. Note that the temperature changes expected prior to equilibrium, for example in 2100, would be lower.

Stabilisation level (ppm CO_2 equivalent)	Temperature increase at equilibrium relative to pre-industrial (°C)		
	IPCC TAR 2001 (Wigley and Raper)	Hadley Centre Ensemble	Eleven Studies
400	0.8 – 2.4	1.3 – 2.8	0.6 – 4.9
450	1.0 – 3.1	1.7 – 3.7	0.8 – 6.4
500	1.3 – 3.8	2.0 – 4.5	1.0 – 7.9
550	1.5 – 4.4	2.4 – 5.3	1.2 – 9.1
650	1.8 – 5.5	2.9 – 6.6	1.5 – 11.4
750	2.2 – 6.4	3.4 – 7.7	1.7 – 13.3
1000	2.8 – 8.3	4.4 – 9.9	2.2 – 17.1

Stern Review (2006)



Source: Hadley

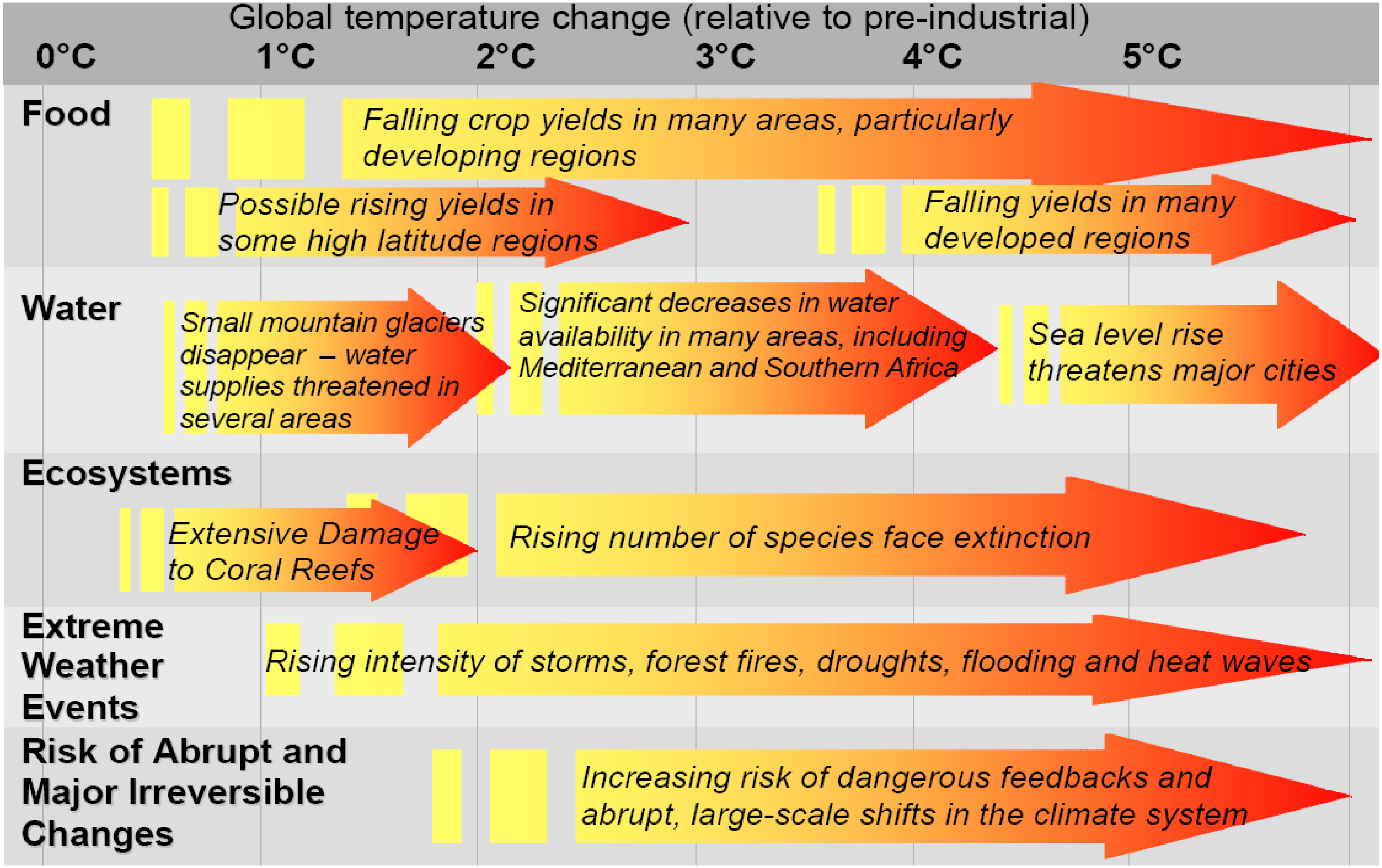

Global temperature change (relative to pre-industrial)
0°C
1°C
2°C
3°C
4°C
5°C
Food
Falling crop yields in many areas, particularly developing regions
Possible rising yields in some high latitude regions
Falling yields in many developed regions
Water
Small mountain glaciers disappear – water supplies threatened in several areas
Significant decreases in water availability in many areas, including Mediterranean and Southern Africa
Sea level rise threatens major cities
Ecosystems
Extensive Damage to Coral Reefs
Rising number of species face extinction
Extreme Weather Events
Rising intensity of storms, forest fires, droughts, flooding and heat waves
Risk of Abrupt and Major Irreversible Changes
Increasing risk of dangerous feedbacks and abrupt, large-scale shifts in the climate system

Table 5.2 Summary costs of extreme weather events in developed countries with moderate climate change. Costs at higher temperatures could be substantially higher.

Region	Event Type	Temperature	Costs as % GDP	Notes
Global	All extreme weather events	2°C	0.5 - 1.0% (0.1%)	Based on extrapolating and increasing current 2% rise in costs each year over and above changes in wealth
USA	Hurricane	3°C	1.3% (0.6%)	Assumes a doubling of carbon dioxide leads to a 6% increase in hurricane windspeed
	Coastal Flood	1-m sea level rise	0.01 – 0.03%	Only costs of wetland loss and protection against permanent inundation
UK	Floods	3 – 4°C	0.2 – 0.4% (0.13%)	Infrastructure damage costs assuming no change in flood management to cope with rising risk
Europe	Coastal Flood	1-m sea level rise	0.01 - 0.02%	Only costs of wetland loss and protection against permanent inundation

Notes: Numbers in brackets show the costs in 2005. Temperatures are global relative to pre-industrial levels. The costs are likely to rise sharply as higher temperatures lead to even more intense extreme weather events and the risk of triggering abrupt and large-scale changes. Currently, there is little robust quantitative information for the costs at even higher temperatures (4 or 5°C), which are plausible if emissions continue to grow and feedbacks amplify the original warming effect (such as release of carbon dioxide from warming soils or release of methane from thawing permafrost).

Source: Stern Review (2006)

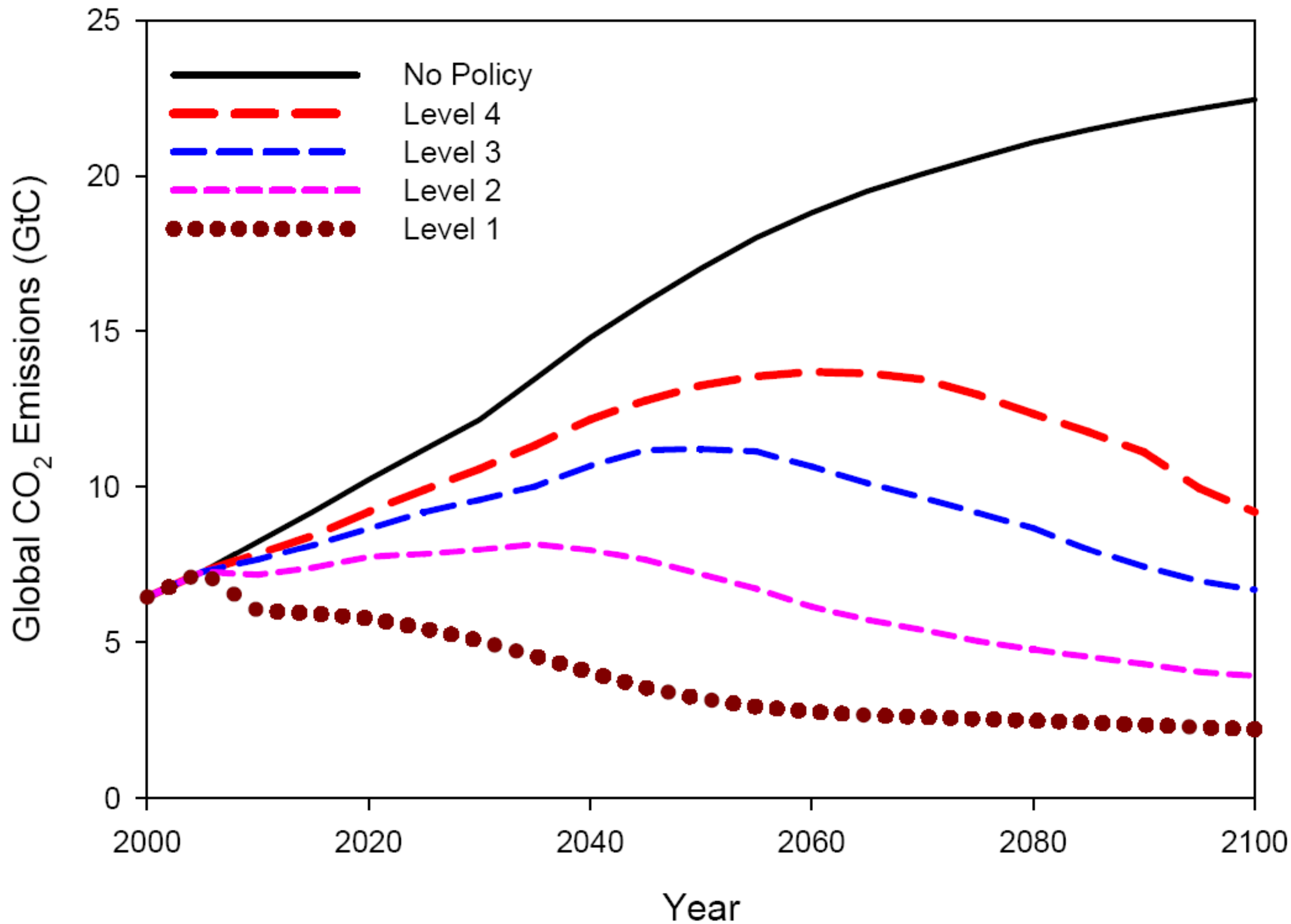


Figure 9. Reference projections of global CO_2 Emissions under No Policy and concentra stabilization targets of 750, 650, 550, and 450ppm, as defined in Clarke *et al*. (2007).

Source: MIT Joint Program Report No. 165 11/08

METHODS TO REDUCE CO_2 EMISSIONS

- Reduce the rate of growth of demand for energy (energy efficiency) without significantly reducing economic growth and social welfare
  - End-use (e.g. vehicles and appliances)
  - Production (e.g. power plant efficiency)
- Substitute low-carbon for high carbon fuels in electricity generation and other industrial sectors (e.g. nuclear for coal, wind for fossil-fueled generation, biofuels for gasoline and diesel fuel)
- Capture and store CO_2 from fossil fuels and burn hydrogen-rich synthetic gas or pure hydrogen
- Adapt to climate change to reduce the costs of its impacts
- Geo-engineering to reduce the impacts of GHG emissions in the medium term (transition)

MECHANISMS TO INTERNALIZE GHG EXTERNALITIES

- An efficient GHG system should meet GHG emission stabilization targets at the lowest cost possible
  - Taking uncertainty and new information into account
  - Recognize that there is portfolio of options with uncertain attributes
  - Stimulate innovation and decentralized decisions
- Placing a price on GHG emissions is the best way
    - Emissions taxes
    - Property rights-based cap and trade systems (which also place a price on CO_2 emissions)
    - "prices vs. quantities"
- Regulations and subsidies
    - Emissions regulations
    - Direct subsidies/obligations for non/low-carbon sources of energy
    - Energy efficiency standards
    - R&D subsidies for low-carbon technologies

PLACING A PRICE ON CO_2 EMISSIONS IS THE BEST POLICY APPROACH

- Efficiently exploits diverse consumer and producer circumstances by stimulating decentralized “self-interested” decisions
- This is especially important when there is uncertainty about the costs of alternative mitigation options
- Makes low carbon supply technologies more profitable
- Increases energy prices making energy efficiency more profitable
- Increases the financial attractiveness of R&D focused on low-carbon technologies and energy efficiency

Table 1: Costs of Electric Generation Alternatives

	Overnight Cost	Fuel Cost	Levelized Cost of Electricity
	$/kW	$/MMBtu	¢/kWh
Nuclear	4,000	0.67	8.4
Coal (low)	2,300	1.60	5.2
Coal (moderate)	2,300	2.60	6.2
Coal (high)	2,300	3.60	7.2
Gas (low)	850	4.00	4.2
Gas (moderate)	850	7.00	6.5
Gas (high)	850	10.00	8.7

Notes: The low, moderate, and high fuel costs for coal correspond to a $40, $65, and $90/short ton delivered price of Central Appalachian coal (12,500 Btu), respectively. Costs are measured in 2007 dollars.

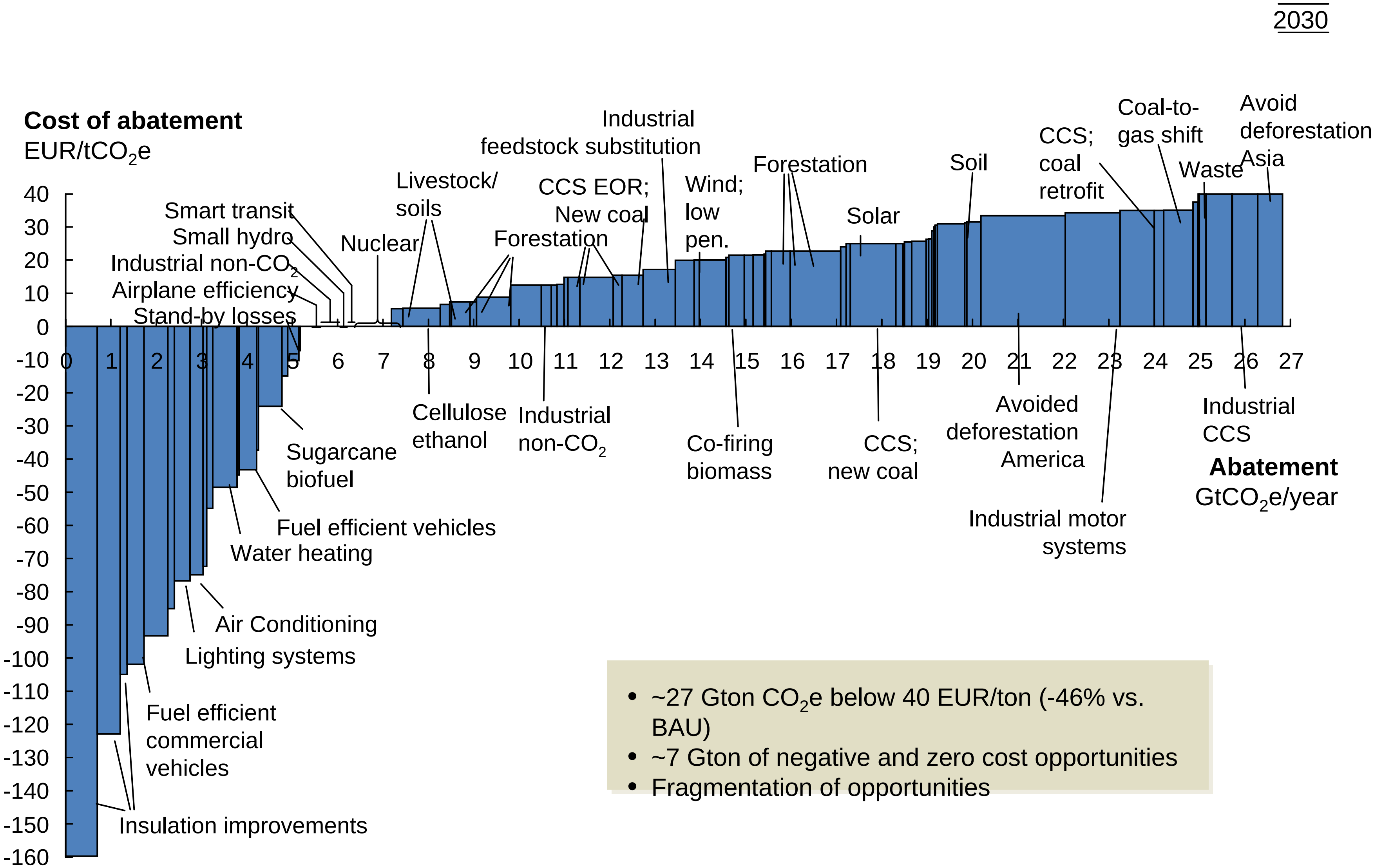
Joskow and Parsons (2009) as reported by Du and Parsons (2009)

Table 2: Costs of Electric Generation Alternatives, Inclusive of Carbon Charge

	Overnight Cost	Fuel Cost	Levelized Cost of Electricity w/carbon charge $\$25/tCO_2$	w/carbon charge $\$50/tCO_2$
	$/kW	$/MMBtu	¢/kWh	¢/kWh
Nuclear	4,000	0.67	8.4	8.4
Coal (low)	2,300	1.60	7.3	9.4
Coal (moderate)	2,300	2.60	8.3	10.4
Coal (high)	2,300	3.60	9.3	11.4
Gas (low)	850	4.00	5.1	6.0
Gas (moderate)	850	7.00	7.4	8.3
Gas (high)	850	10.00	9.6	10.5

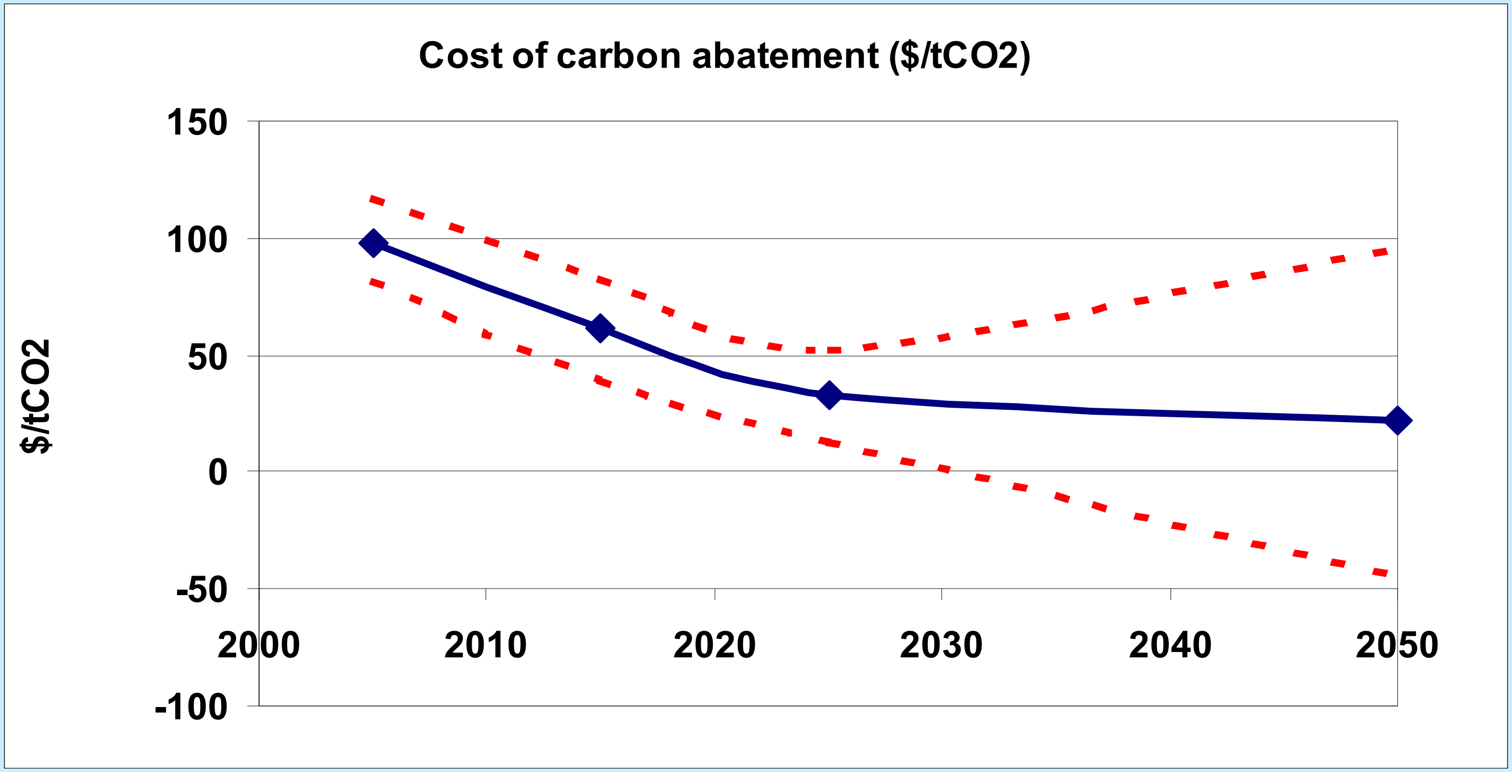
Joskow and Parsons (2009) as reported by Du and Parsons (2009)

McKinsey bottom-up approach



- ~27 Gton CO_2e below 40 EUR/ton (-46% vs. BAU)
- ~7 Gton of negative and zero cost opportunities
- Fragmentation of opportunities

Figure 9.5 Average cost of reducing fossil fuel emissions to 18 $GtCO_2$ in 2050*



*The red lines give uncertainty bounds around the central estimate. These have been calculated using Monte Carlo analysis. For each technology, the full range of possible costs (typically ± 30% for new technologies, ±20% for established ones) is specified. Similarly, future oil prices are specified as probability distributions ranging from $20 to over $80 per barrel, as are gas prices (£2-6/GJ), coal prices and future energy demands (to allow for the uncertain rate of uptake of energy efficiency). This produces a probability distribution that is the basis for the ranges given.

Source: Stern Review (2006)

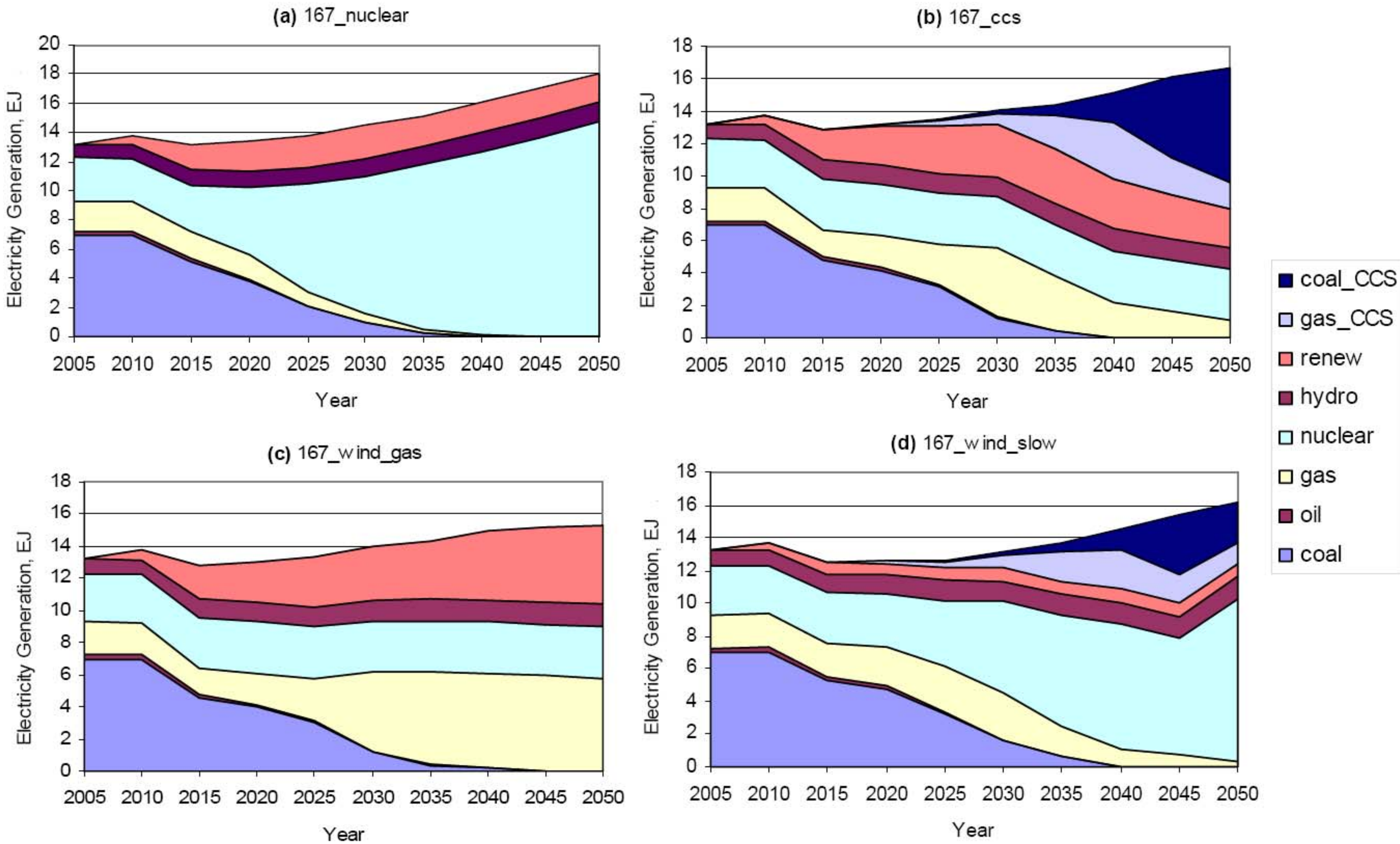
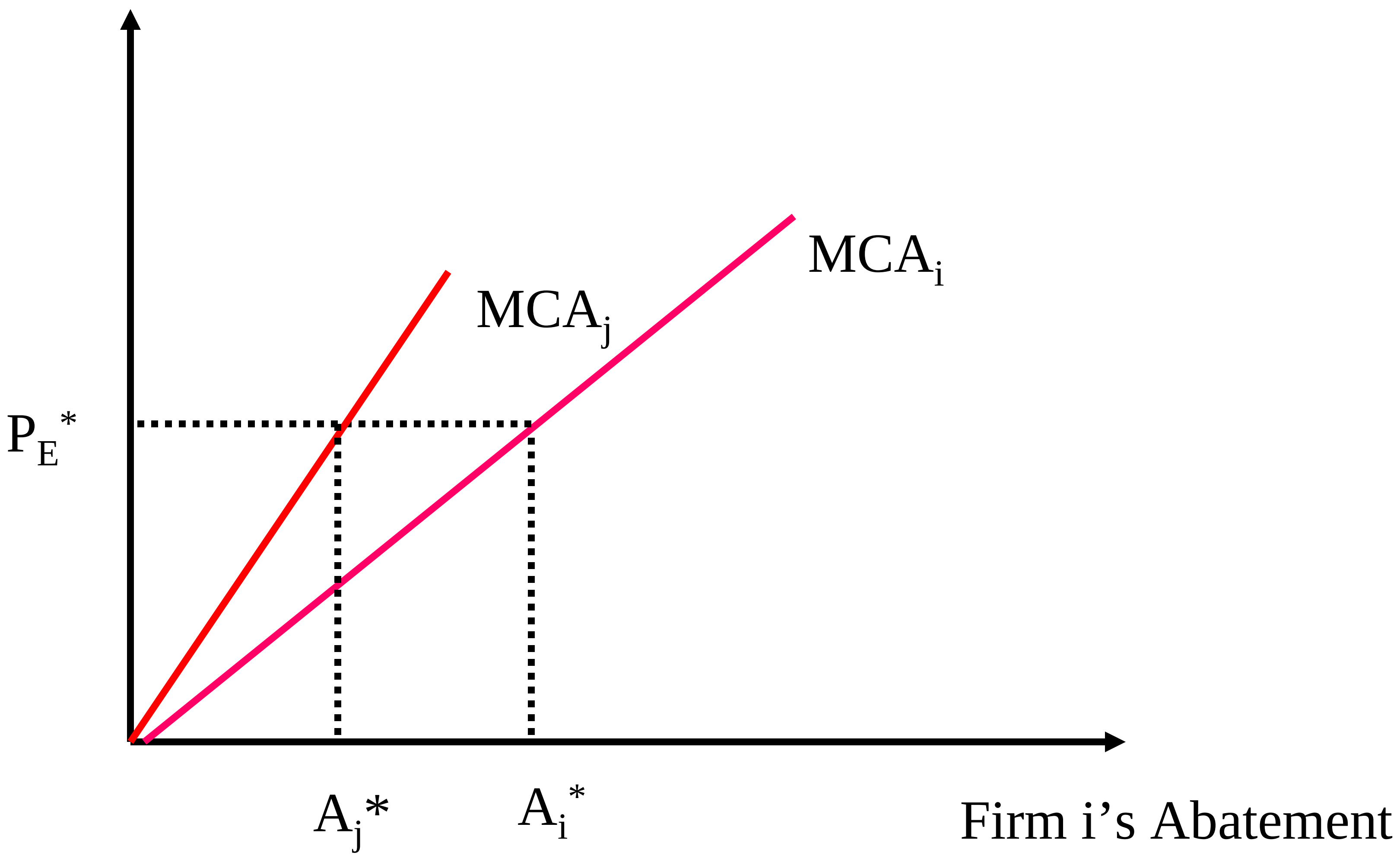


Figure 7. Alternative Technology Assumptions and Generation Choices: **(a)** 167_nuclear, **(b)** 167_ccs, **(c)** 167_wind_gas, **(d)** 167_wind_slow.

Source: MIT Joint Program Report No. 173 April 2009

FIRM LEVEL ABATEMENT



CAP AND TRADE
PROPERTY-RIGHTS BASED MECHANISM

- Set cap at the optimal level/trajectory of aggregate pollution (E*)
- Issue E* tradeable emission permits for each year. These could be auctioned off by the government or allocated in some other way
- Require all sources to acquire enough permits to cover their emissions and allow a market for emissions permits to develop
- Allow banking and borrowing over reasonable time horizons to support flexibility in mitigation responses
- Emission permit trading will establish an emissions price P_E and the economic effects are essentially the same as for a tax

EMISSION TAXES VS. CAP AND TRADE

- Are we more confident about getting the price trajectory or the quantity trajectory right?
- What are the costs of getting the price or the quantity trajectories wrong?
- Domestic Political Considerations
  - Use permit allocation to "buy" 60 Senate votes
  - Is the prefect the enemy of the good?
- Extensive U.S. experience with cap and trade
- International Linkage Considerations
- Cap and trade fits better with the way the science conceptualizes the problem
- Americans don't like taxes compared to similar (often more costly) alternatives for controlling pollution

HYBRID SYSTEMS

- Create cap and trade system with emissions quantity targets and associated aggregate emissions permits
- Establish a “backstop” price or “safety valve” at which the government will sell additional permits to cap the marginal cost
- Adjust safety valve from time to time as more information about mitigation costs and damages resolves uncertainty

SHOULD WE WAIT FOR THE UNCERTAINTIES TO BE RESOLVED?

- Many of the uncertainties regarding the science, the costs of climate change and the costs of mitigation cannot be easily resolved now
- But complete resolution is not necessary to make the case for embarking on mitigation policies now.
- We know enough to conclude that doing nothing is costly even with lower bound estimates
- Irreversibilities further increase the costs of waiting
- Waiting increases the likelihood of catastrophic consequences

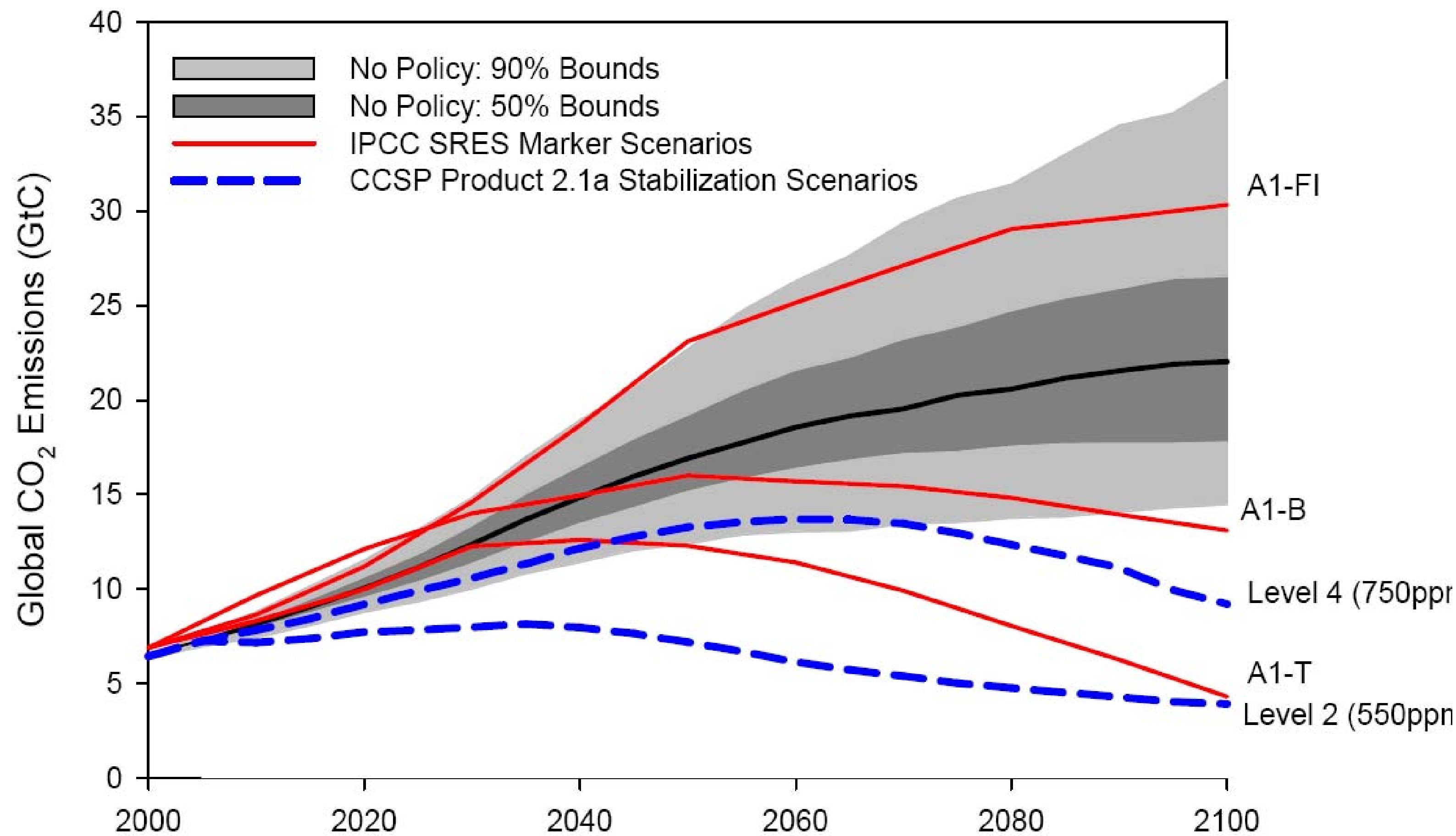


Figure 10. Global anthropogenic emissions over time. Shaded regions show the 50% (darker shading) and 90% (lighter shading) probability bounds on EPPA emissio the no policy case. The red lines indicate the IPCC SRES marker scenarios, with scenario label to right of graph. The blue dashed lines indicate the Level 4 (750 and Level 2 (550ppm) stabilization scenarios from Clarke *et al*. (2007).

Source: MIT Joint Program Report No. 165 11/08

Table 1.1 Temperature projections at stabilisation

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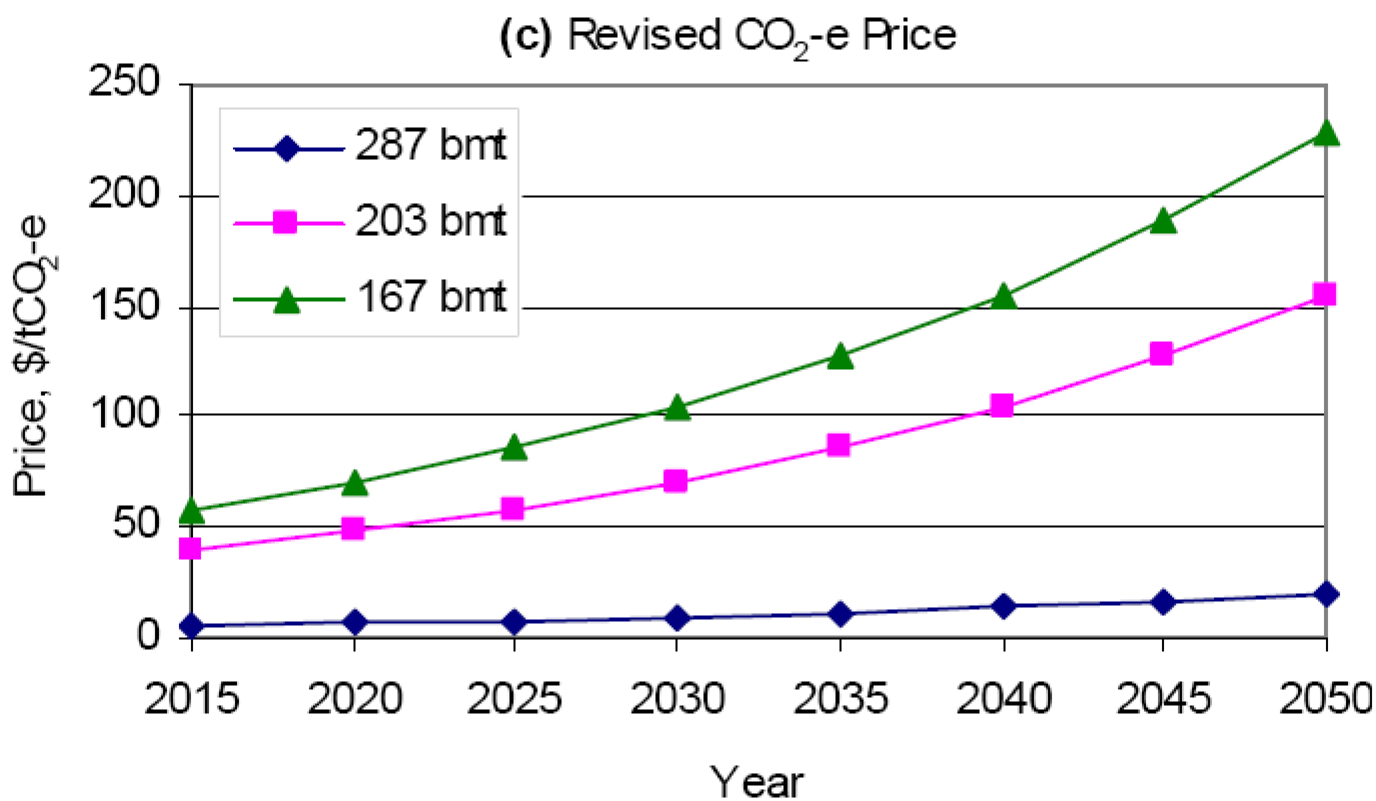
1000	2.8 – 8.3	4.4 – 9.9	2.2 – 17.1

Stern Review (2006)

WHY IS EFFECTIVE POLICY RESPONSE SO HARD?

- Uncertainty about certain aspects of the science have used an excuse to do nothing
- Mitigation policies are costly and uncertain even if the best policies are put in place and the "avoided costs" are difficult to quantify
- The public has been educated poorly about the science and potential costly consequences of climate change. Activist scientists have created credibility problems of late.
- The most significant costs of climate change are far in the future while the mitigation costs are now. What is the right discount rate?
- Commitments by several major GHG emitting countries is needed
- Mitigation costs vary widely across countries, within countries, and across industries creating complex interest group politics created interest group politics challenges
- Ethical controversies between developed and developing countries



Source: MIT Joint Program Report No. 173 April 2009

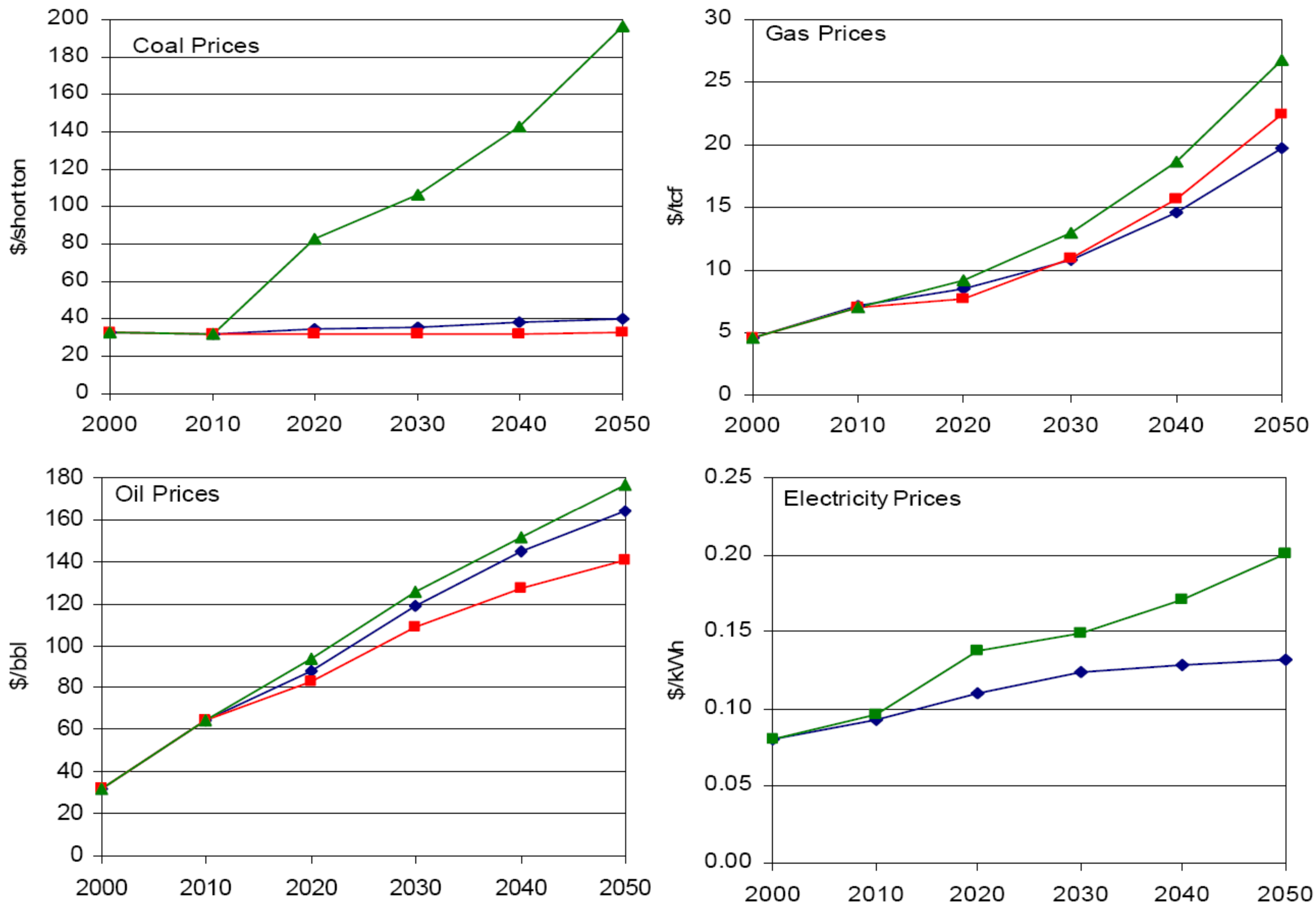


Figure C8. Energy Prices in H.R. 2454 with Medium Offsets (reference prices in blue, consumer prices in green, and producer prices in red).

Table C2. Cost per Household (in dollars) of H.R. 2454 with Different Offsets, Annual and Discounted to 2010 at 4%.

	H.R. 2454				**Total Cost**			
	Med Offsets		**Full Offsets**		**Med Offsets**		**Full Offsets**	
	Annual	**Discount to 2010**	**Annual**	**Discount to 2010**	**Annual**	**Discount to 2010**	**Annual**	**Discount to 2010**
2010	0	0	0	0	81	81	81	81
2015	68	56	97	80	326	268	355	292
2020	319	215	283	191	704	475	668	451
2025	588	326	419	232	1058	587	889	494
2030	1036	473	556	254	1563	713	1083	494
2035	1433	538	771	289	1994	748	1332	500
2040	1867	576	1043	322	2449	755	1625	501
2045	2354	597	1366	346	2907	737	1918	486
2050	2695	561	1562	325	3225	672	2091	436
Average	**1223**	**404**	**720**	**247**	**1701**	**607**	**1198**	**451**

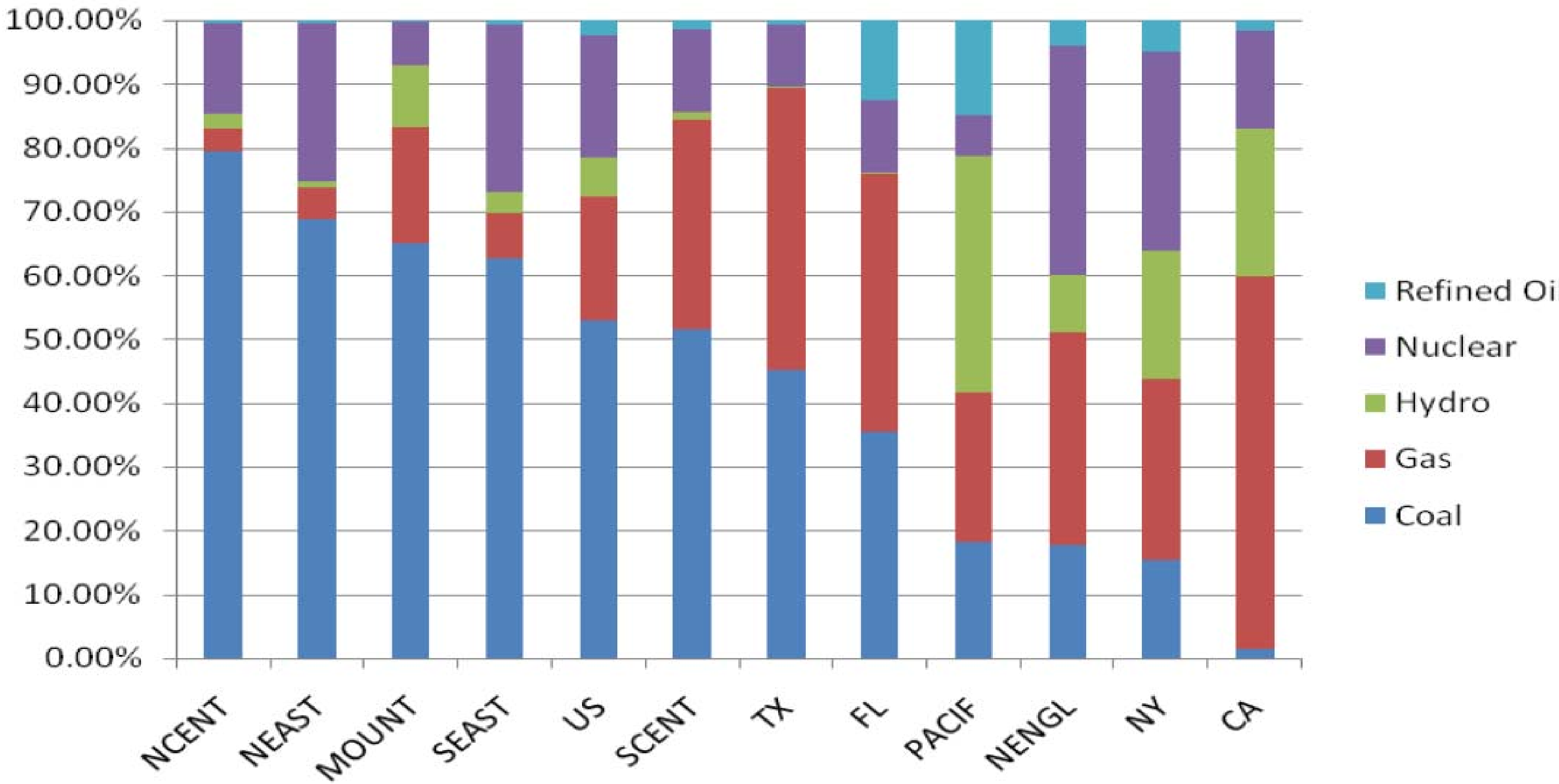


Figure 6. Regional Electricity Generation by Fuel Source.

Source: MIT Joint Program, Report # 182

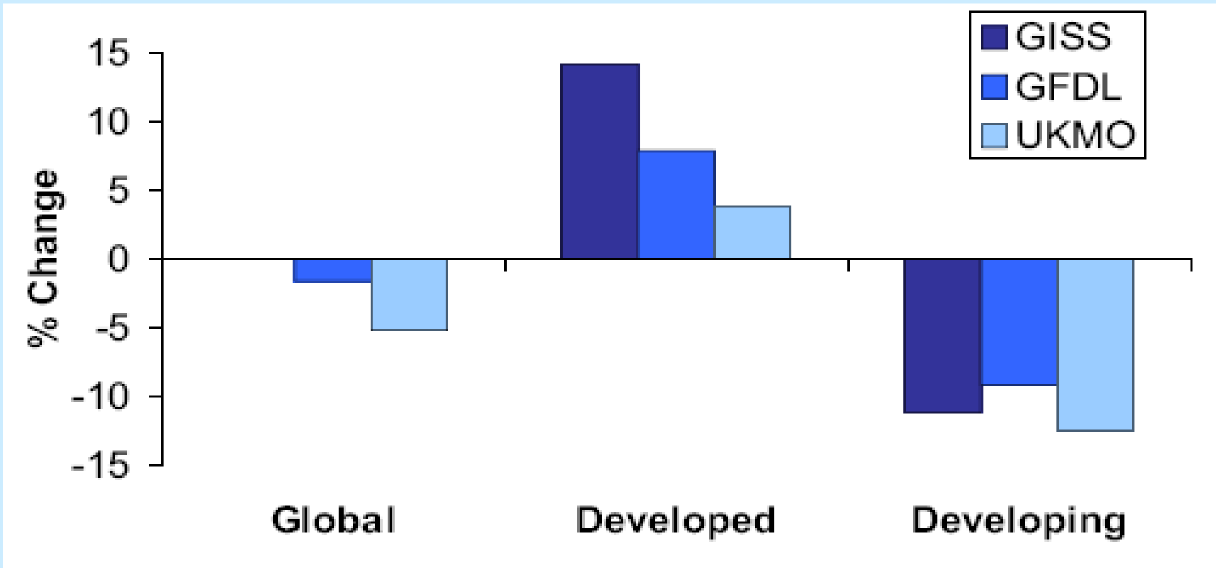
$15/ton CO2e

Table 6. Impacts on Fuel Prices Inclusive and Exclusive of GHG Charge (in %).

	Coal		**Natural Gas**		**Refined Oil**		**Electricity**
	inclusive	exclusive	inclusive	exclusive	inclusive	exclusive	inclusive
AK	50.6	-15.0	14.8	-4.6	3.0	-2.4	3.5
CA	71.8	-6.4	10.2	-3.1	4.7	-0.2	8.5
FL	72.8	-5.4	11.5	-3.1	5.1	0.0	9.9
MOUNT	89.5	-10.6	9.9	-2.3	4.8	-0.2	14.8
NCENT	76.2	-6.8	11.1	-1.7	5.3	0.2	19.8
NEAST	69.4	-7.9	9.5	-3.3	5.1	0.0	14.2
NENGL	73.8	-4.5	9.5	-1.4	4.9	0.0	12.0
NY	71.8	-6.4	10.6	-0.7	5.0	0.0	7.5
PACIF	33.1	-4.2	13.5	-1.1	4.9	0.4	1.7
SCENT	81.5	-6.6	8.2	-2.8	5.0	0.0	12.3
SEAST	68.8	-7.4	9.3	-2.8	5.2	0.1	15.2
TX	76.5	-7.2	8.6	-4.2	5.0	-0.3	8.2
US	72.9	-6.9	9.8	-2.9	5.1	0.0	12.8

Source: MIT Joint Program, Report # 182

Figure 3.5 Change in cereal production in developed and developing countries for a doubling of carbon dioxide levels (equivalent to around 3°C of warming in models used) simulated with three climate models (GISS, GFDL and UKMO Hadley Centre)



Source: Parry *et al.* (2005) analysing data from Rosenzweig and Parry (1994)

Note: Percent changes in production are relative to what they would be in a future with no climate change. Overall changes are relatively robust to different model outputs, but regional patterns differ depending on the model's rainfall patterns – more details in Fischer et al. (2005). The work assumed mostly farm-level adaptation in developing countries but some economy-wide adaptation in developed countries. The work also assumed a strong carbon fertilisation effect - 15 – 25% increase in yield for a doubling of carbon dioxide levels for responsive crops (wheat, rice, soybean) and a 5 – 10% increase for non-responsive crops (maize). These are about twice as high as the latest field-based studies suggest – see Box 3.4 for more detail.

Figure 6.5 a. Baseline-climate scenario, with market impacts and the risk of catastrophe.

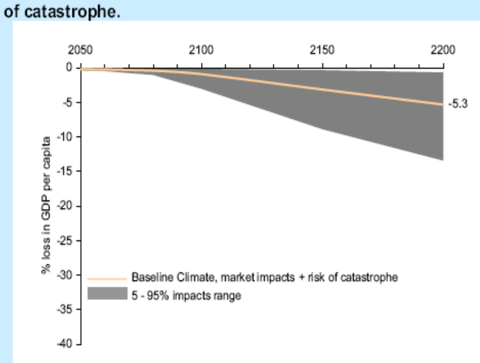


Figure 6.5b. High-climate scenario, with market impacts and the risk of catastrophe.

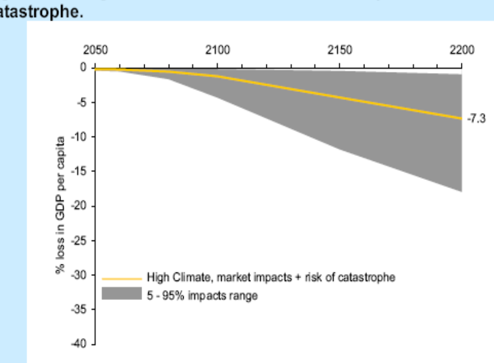


Figure 6.5c. High-climate scenario, with market impacts, the risk of catastrophe and non-market impacts.

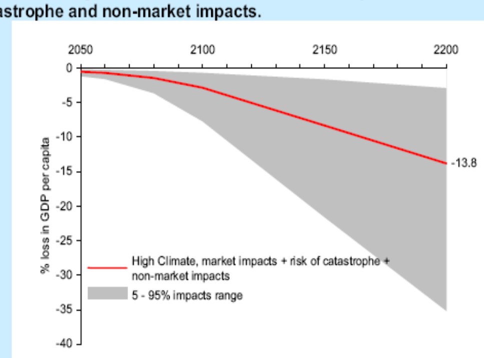


Figure 6.5d. Combined scenarios.

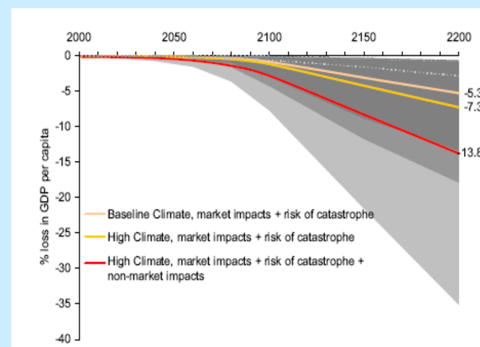


Figure 6.5a-d traces losses in income per capita due to climate change over the next 200 years, according to three of our main scenarios of climate change and economic impacts. The mean loss is shown in a colour matching the scenarios of Figure 6.4. The range of estimates from the 5th to the 95th percentile is shaded grey.

Stern Review (2006)

CURRENT POLICY MENU

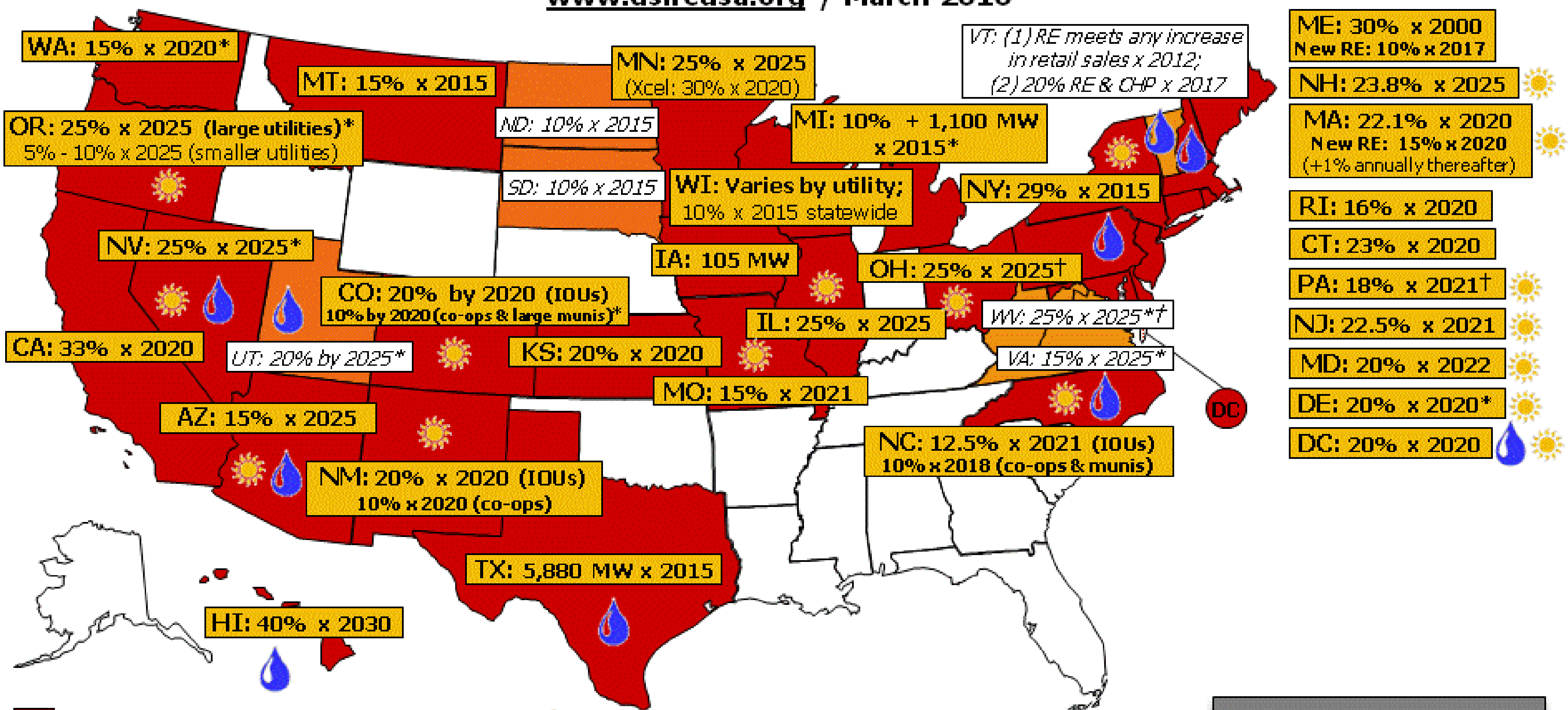
- National Cap and Trade Policy
  - Start mostly with free allowance allocations based on historical emissions and adaptation burdens
  - Gradually auction more allowances
  - Use money to subsidize energy efficiency and low carbon supply technologies
- Emissions Taxes
  - Perhaps on petroleum and gas products at retail
- Renewable Electricity Portfolio Standards
- Tighter Auto and Appliance Efficiency Standards
- Tax subsidies and loan guarantees for low-carbon supply technologies and CCS
- Overlapping state and regional portfolios of all of the above (CA, RGGI). Federal Pre-emption?

DSIRE

Database of State Incentives for Renewables & Efficiency

Renewable Portfolio Standards

www.dsireusa.org / March 2010



State renewable portfolio standard

State renewable portfolio goal

Solar water heating eligible

Minimum solar or customer-sited requirement

* Extra credit for solar or customer-sited renewables

† Includes non-renewable alternative resources

29 states + DC have an RPS

(6 states have goals)

CONCLUSIONS

- GHG Stabilization at 550ppm requires significant global reductions in GHG emissions from BAU
- There are no silver bullets and the cost of mitigation is significant but are not "catastrophic" (1-2% of real GDP forever) if the most efficient mitigation mechanism are used and we believe that the cost of climate change is even higher
- Many current policies lead to inefficient mitigation responses (CA ~ $600/ton for PV program)
- Placing a significant price on GHG emissions provides decentralized incentives to adopt the least cost mix of supply and demand-side mitigation and incentives for innovation
- Cap and trade was thought to a be politically more attractive than emissions taxes to establish a CO2 price and easier to link with programs in other countries
- Cap and trade has gotten a bum rap and very inefficient mitigation policies are being implemented instead
- We need to get on a better long-run policy path to keep the costs of mitigation as low as possible

BACKUP

EMISSIONS TAXES

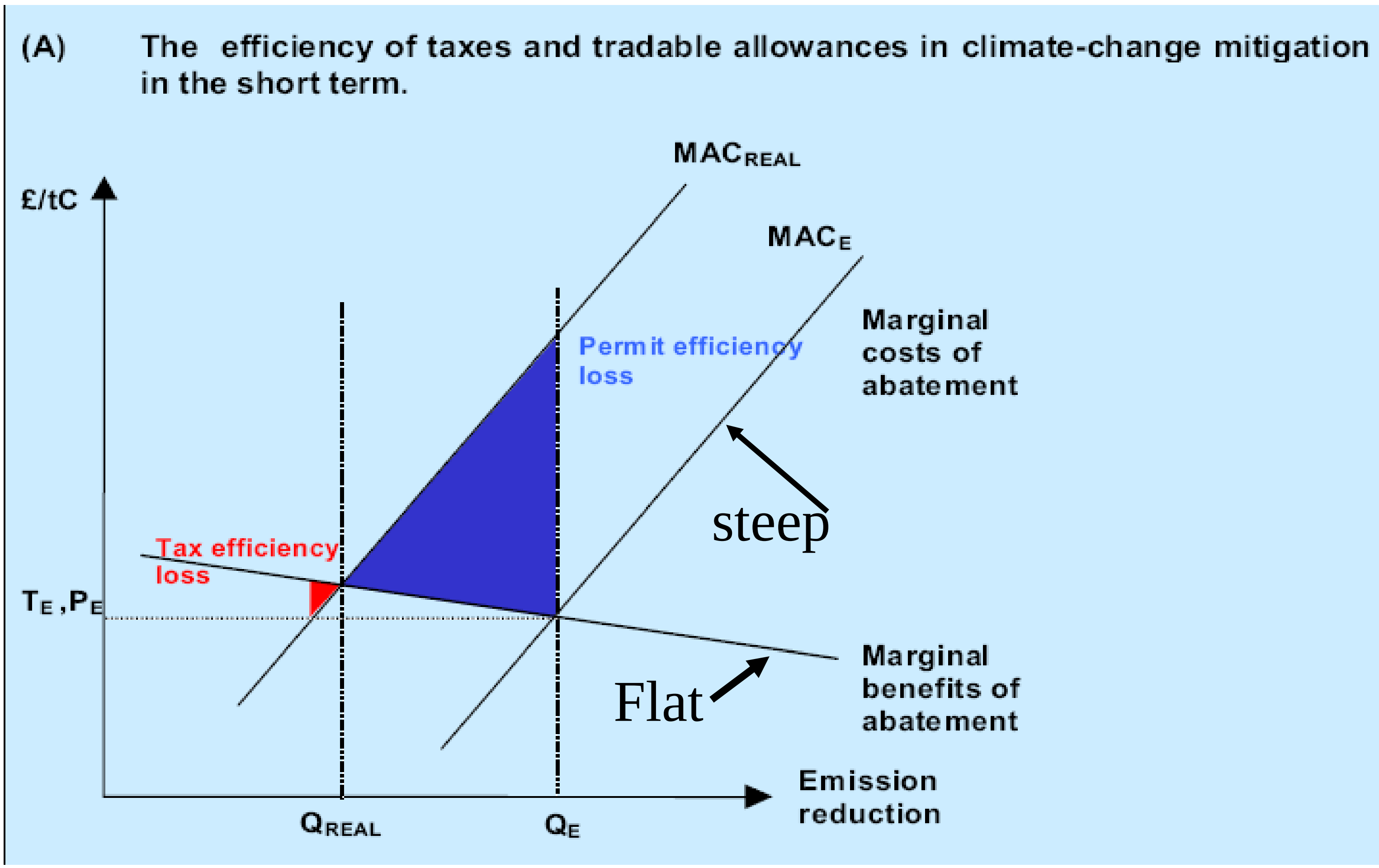
- An emissions tax (or "fee") system requires defining the appropriate fee level that properly "prices" the external effects of the pollution

- This fee level P_E is defined as the level that equates marginal damages of additional emissions with the marginal cost of additional abatement (both are very uncertain)

- Producers must now pay a fee on any GHG that they (or perhaps their customers) emit and will have the incentive to reduce emissions up to the point where the marginal costs of abatement are equal to the fee

Firm's pollution costs = $P_E(E\text{-}A) + C_A(A)$
Cost minimization → $C_A'(A) = MC(A) = P_E$

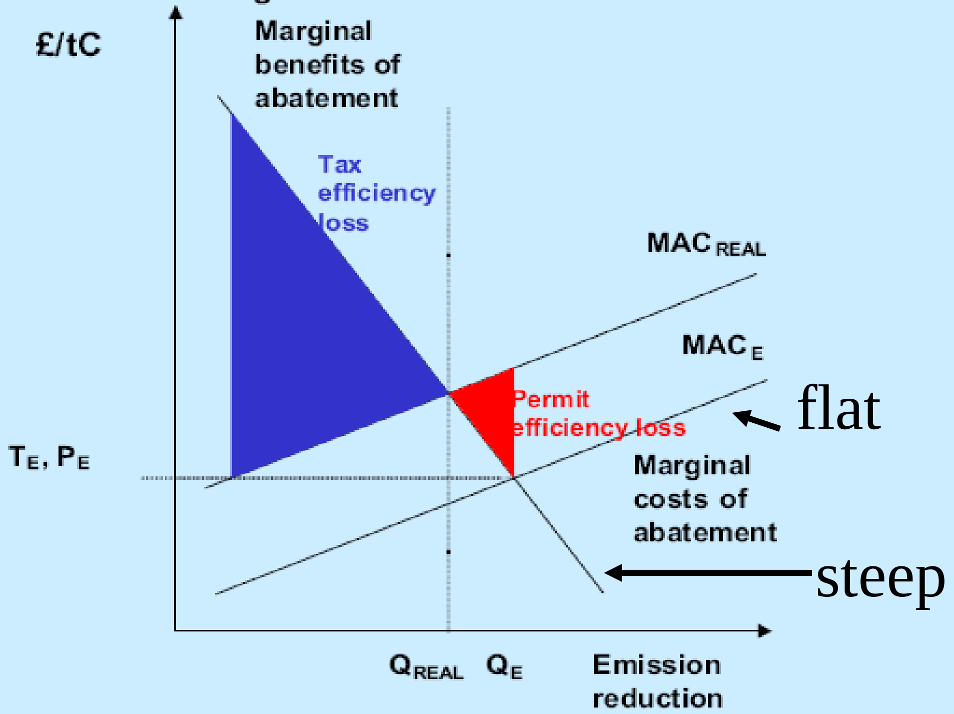
Cap and Trade Systems Fix the Quantity of Pollution But Create Uncertainty Over the Cost



Source: Stern Review, Part IV, p. 313

Emissions Taxes Fix the Price and Marginal Cost of Pollution Abatement But Leave the Quantities and Marginal Damages Uncertain

(B) The efficiency of taxes and tradable allowances in climate-change mitigation in the long term.



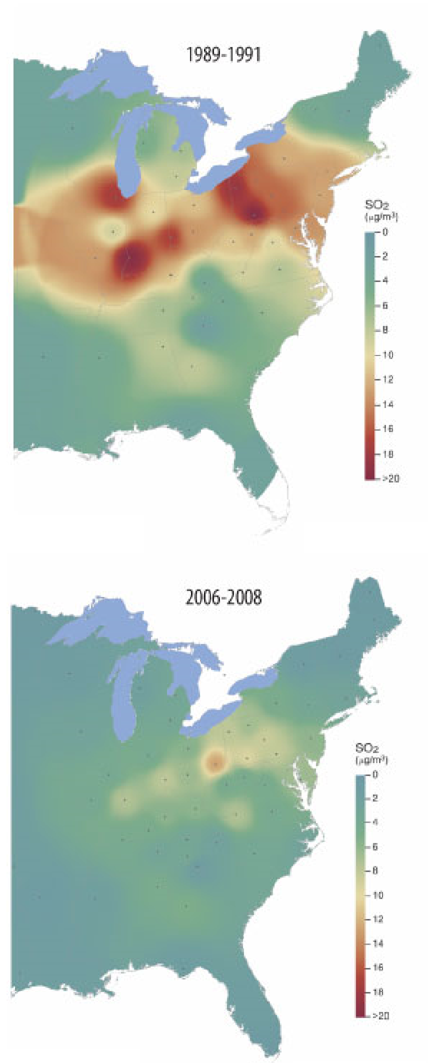
This contrast between short-term and long-term marginal cost and marginal benefit curves gives rise to the problem of how to combine a tax-like regime in the short term with a quantitative constraint in the long term. A rule is needed for updating the tax in the light of new information about costs over the long term and the ex post quantity of emissions.

Source: Stern Review, Part IV, p. 314

1990 PROGRAM TO CONTROL SO_2 EMISSIONS

- Relies on cap-and-trade program to control SO_2 emissions from power plants (70% of SO_2 emissions)
- Sets national cap on SO_2 emissions of 9 million tons per year (or about a 50% reduction from 1985 levels)
- Cap met in two phases
  - 1995-1999 control emissions on dirtiest 263 power plants
  - 2000 forward 9 million ton cap applies to all power plants
- Most permits were allocated to existing sources and some are auctioned annually
  - All sources must have continuous emissions monitoring equipment
  - Unused permits available for a year may be "banked" for future years if they are not used

Annual Mean Ambient SO_2 Concentration

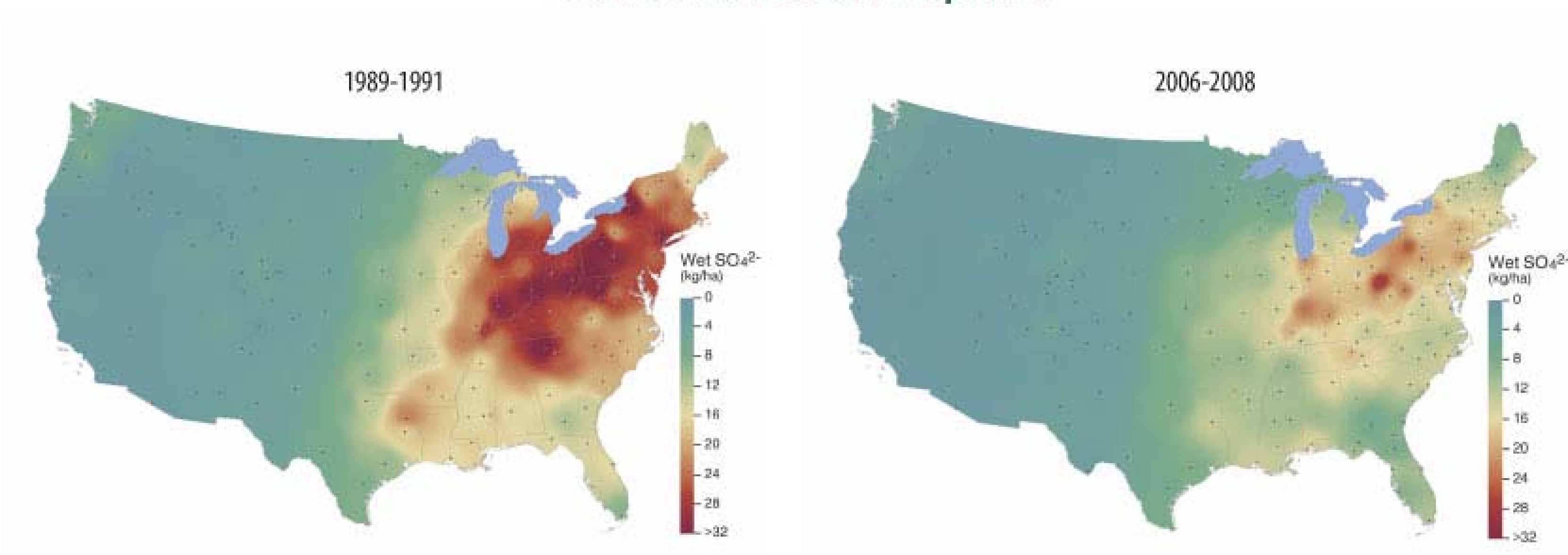


Notes:

- For maps depicting these trends for the entire continental United States, visit <www.epa.gov/castnet>.
- Dots on all maps represent monitoring sites. Lack of shading for southern Florida indicates lack of monitoring coverage in the 1989-1991 period.

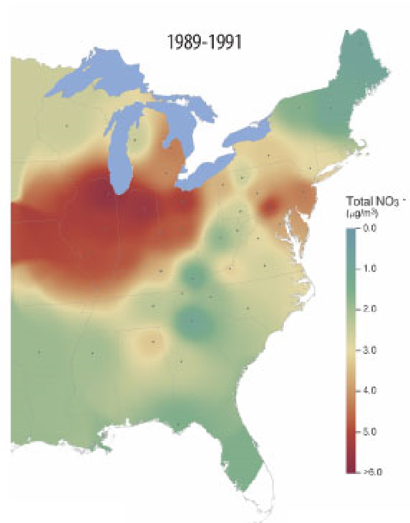
Source: CASTNET, 2009

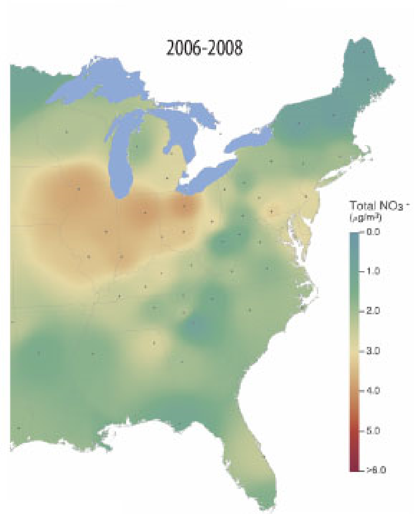
Annual Mean Wet Sulfate Deposition



Source: NADP, 2009

Annual Mean Ambient Total Nitrate Concentration





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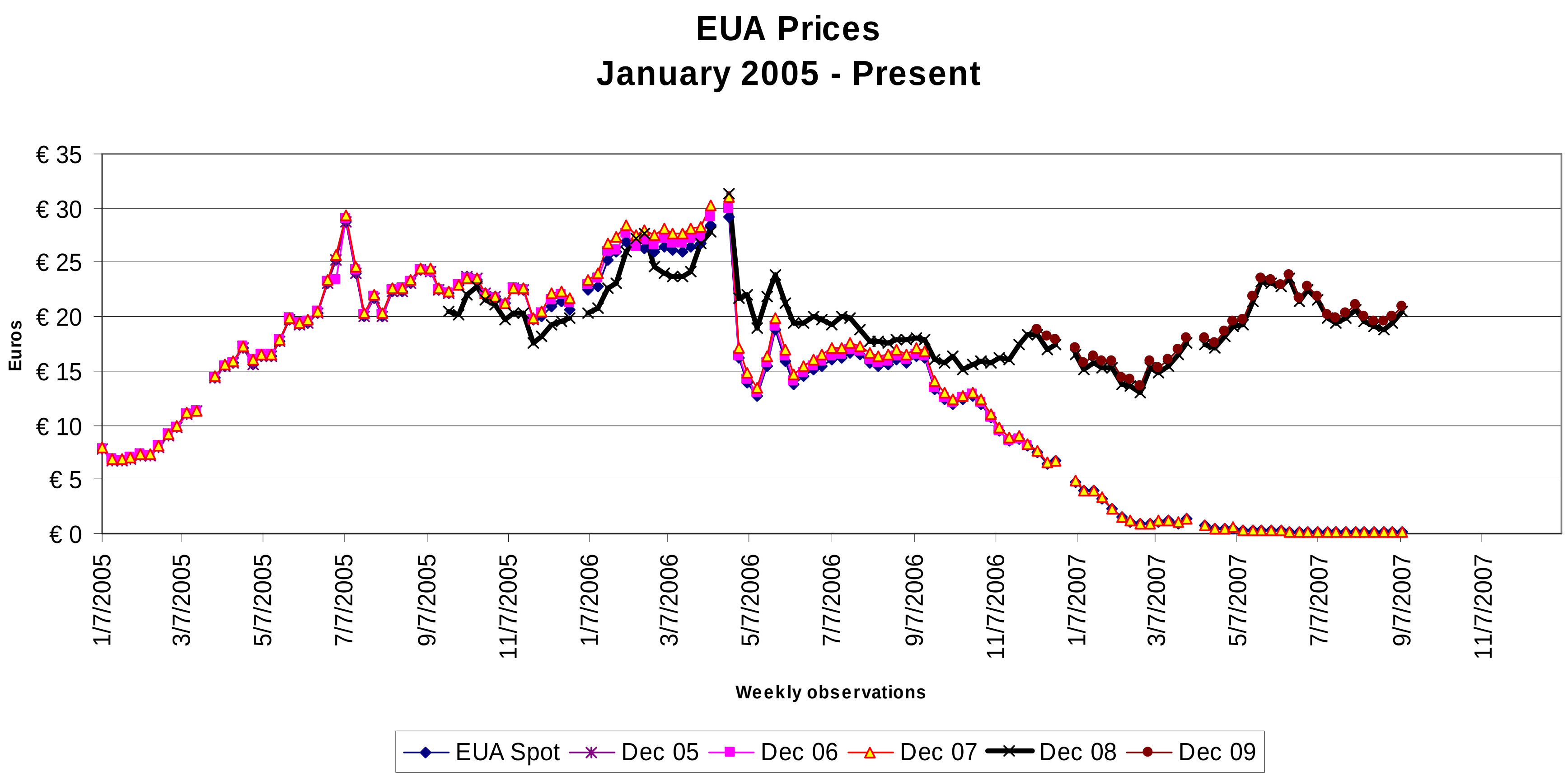
Source: CASTNET, 2009

Average Monthly SO_2 Allowance Price, August 1994 - May 2009

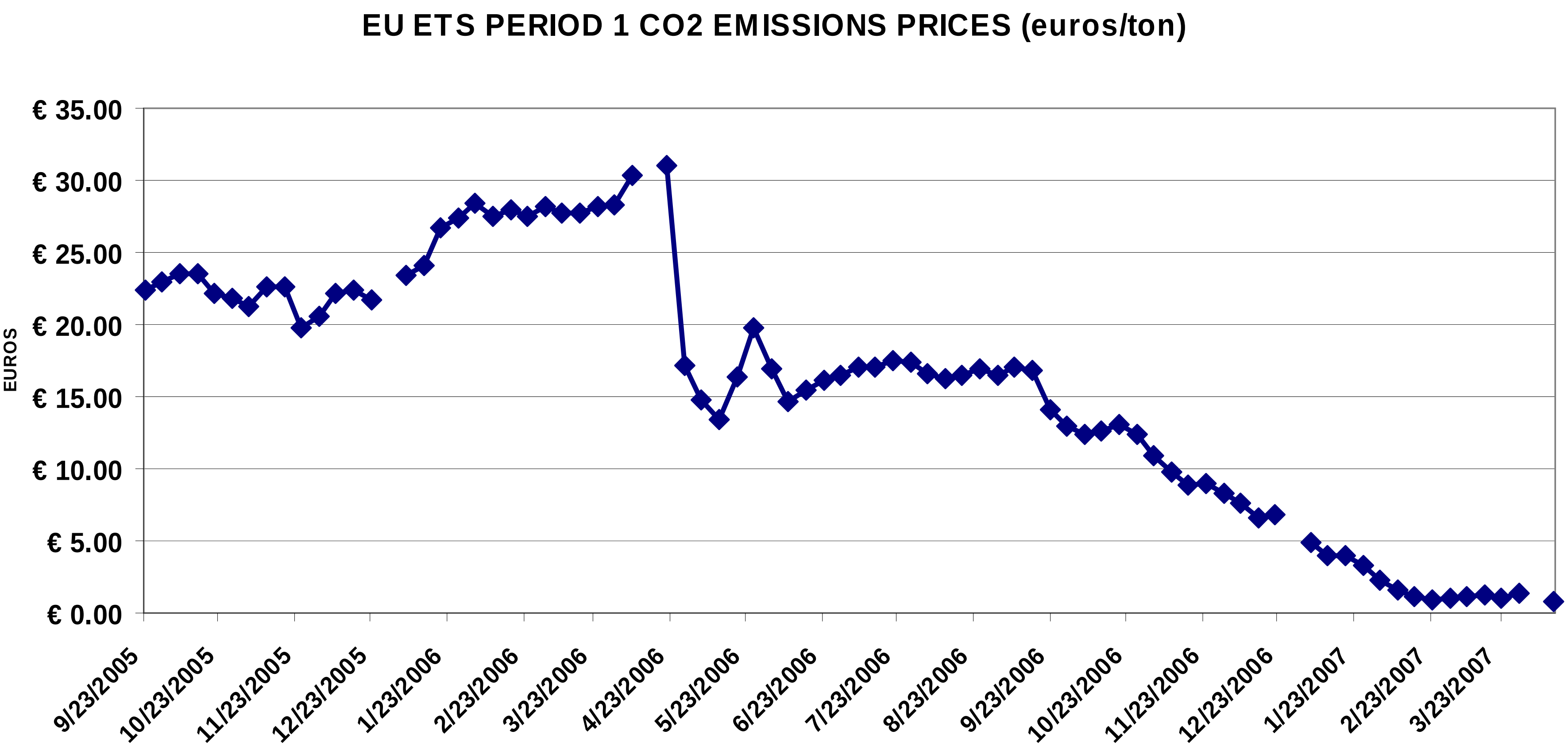
Source: CantorCO2e Market Price Index, 2009

EU ETS

- First international cap and trade system involving all 27 EU countries
- Two phases:
  - 2005-2007 (trial period)
  - 2008-2012 (Kyoto Commitment period)
- Covers industrial and electricity generation sources (not transport) accounting for less than 40% of EU emissions
- Linkage to developing countries through CDM and to other annex 1 countries through trading credits
- Individual countries have additional mechanisms in place (e.g. subsidies for wind generation)
- Each country assigned target emissions reduction goals (burden sharing to reflect different rates of economic growth)
- 95+% of allowances in Phase one were allocated for free
- Program designed and implemented very quickly



MIT CEEPR (2007)



MIT CEEPR (2007)