Climate Targets under uncertainty

Analysis with The ETSAP-TIAM Model

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EMF-22 Washington DC, Feb 2008

Acknowledgments

- ETSAP is the main sponsor of this work
  - Giancarlo Tosato (ETSAP program leader, Italy)
  - Denise Van Regemorter, KUL, Belgium: Demands
  - Uwe Remme, IER-Stuttgart, Germany: Database review and improvement
  - Antti Lettila, VTT, Finland: GAMS code
- US EPA
  - F. Delachesnaye: data on other gases and on biological carbon sequestration
- IEA, ETP division
  - Dolf Gielen: input data on sequestration etc.
- NSERC (Research Council, Canada)
  - Financial Support

I: OBJECTIVE

Assess the feasibility, cost, and means of maintaining average surface temperature increase within the **2 ºC to 3ºC** range (long term), under high economic and climate **uncertainty**

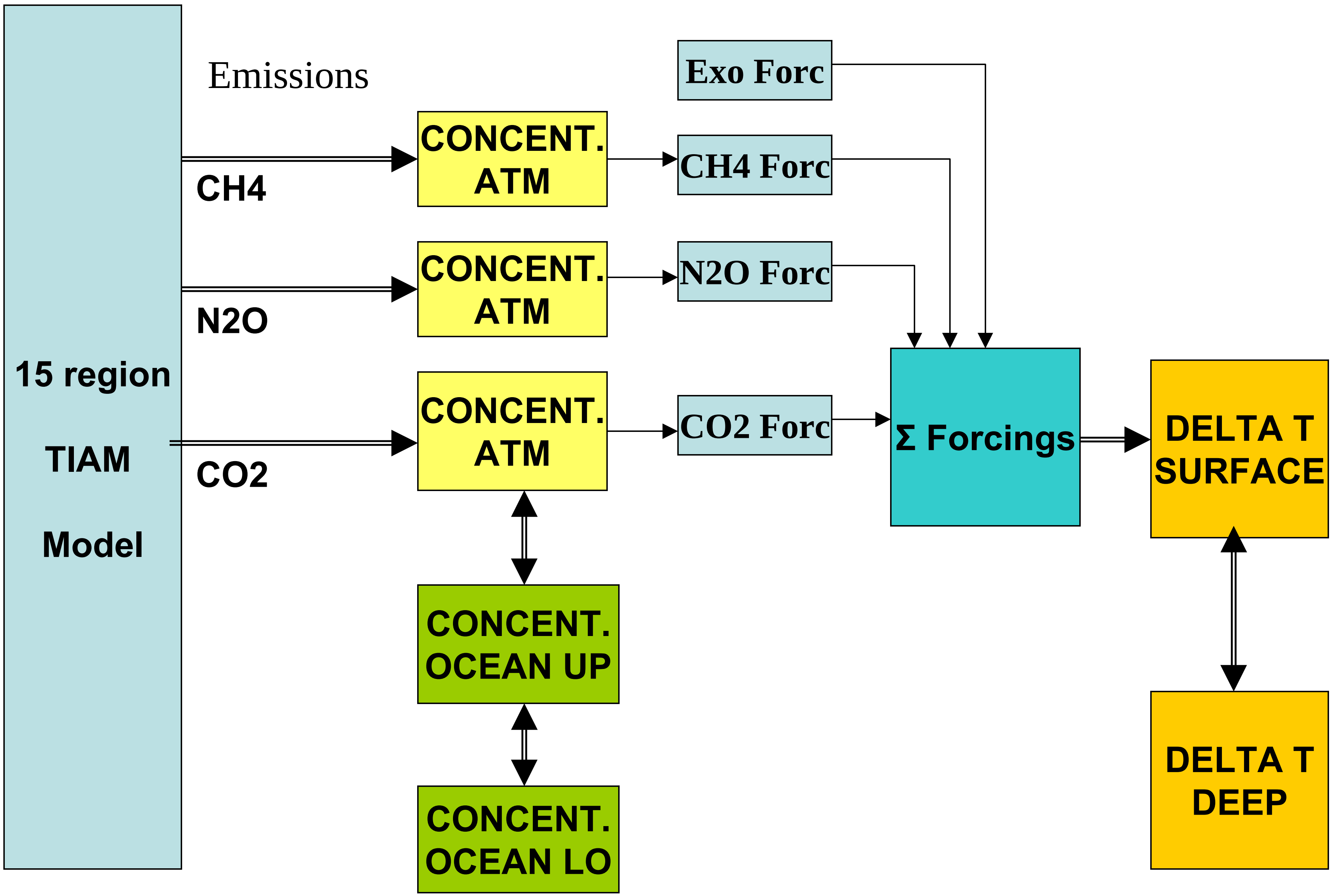
II: METHODOLOGY

ETSAP-TIAM

(TIMES Integrated Assessment Model)

- Technology rich, integrated energy/emissions model
- Dynamic inter-temporal partial equilibrium (with variable-length periods)
  - Based on maximum total surplus (L.P.) with own-price elastic service demands
- Linked to a CGE model (GEM-E3 or GEMINI-E3) to obtain reference case socio-economic drivers for initial service demands
- 15 regions linked by ~10 commodity trades
- Horizon to 2100, salvage value at EOH

Schematics of TIAM Climate Module



Original Climate equations (adapted from Nordhaus and Boyer, 1999)

Concentrations of GHG's

CO2 mass: 3-layer model (Nordhaus and Boyer 1999)

- $CO2_{atm}(t) = Emi(t) + CO2_{atm}(t-1)*(1-f_{atm,up}) + CO2_{up}(t-1)*f_{up,atm}$
- $CO2_{up}(t) = CO2_{up}(t-1)*(1-f_{up,atm} - f_{up,lo}) + CO2_{lo}(t-1)*f_{lo,up} + CO2_{atm}(t-)*f_{atm,up}$
- $CO2_{lo}(t) = CO2_{lo}(t-1)*(1-f_{lo,up}) + CO2_{up}(t-1)*f_{up,lo}$

CH4 mass: 1-box expon. decay model (Monni et al, 2003)

N2O mass: 1-box expon. decay model (Monni et al, 2003)

Climate equations in TIAM

Radiative forcings (IPCC 2001, 2007)

$\Delta F_{CO2}(t) = \gamma/\ln 2 * \ln [CO2_{atm}(t)/CO2_{atm} (pre\text{-}ind)]$

$\Delta F_{CH4}(t) =$

$\Delta F_{N2O}(t) =$

with: f(x,y)=

Lag

Climate sensitivity

Temperature Change (2 layer model)

$\Delta T_{up}(t) = \Delta T_{up}(t-1) + \sigma_1 *\{ \Delta F(t) - 3.7/C_s *\Delta T_{up}(t-1) - \sigma_2 [\Delta T_{up}(t-1) - \Delta T_{lo}(t-1)] \}$

$\Delta T_{lo}(t) = \Delta T_{up}(t-1)* \sigma_3 + \Delta T_{lo}(t-1)* g_{22}$

(At equilibrium: **$\Delta F(t) = 3.7/C_s *\Delta T_{up}$**)

Linear approximations

- The 3 forcing equations are replaced by linear approximations within the intervals of interest, for instance : 375 ppm-550 ppm for CO2

- Each approximation is halfway between the chord and the // tangent of the exact curve

- Within the selected range, the errors made on Forcings never exceed 2% (well within the inherent uncertainty of exogenous forcing values)

Approach taken

- Impose an upper bound on $\Delta T_{atm}(2100)$
- Run TIAM (stochastic LP in extensive form)
  - Uncertain Cs and Lag
  - Uncertain GDP growth rates (most TIAM demands are correlated to GDP)
- Observe climate variables (Concentrations, Forcing, Temperature Δt_{atm})
  - Up to 2100: from TIAM results
  - Beyond 2100: from Excel simulation sheet

III. Scenarios

Uncertainties considered

Uncertainties treated explicitly via Stochastic Programming

– Climate sensitivity C_s and Lag parameter σ_1
– Economic growth (and thus GHG emissions)

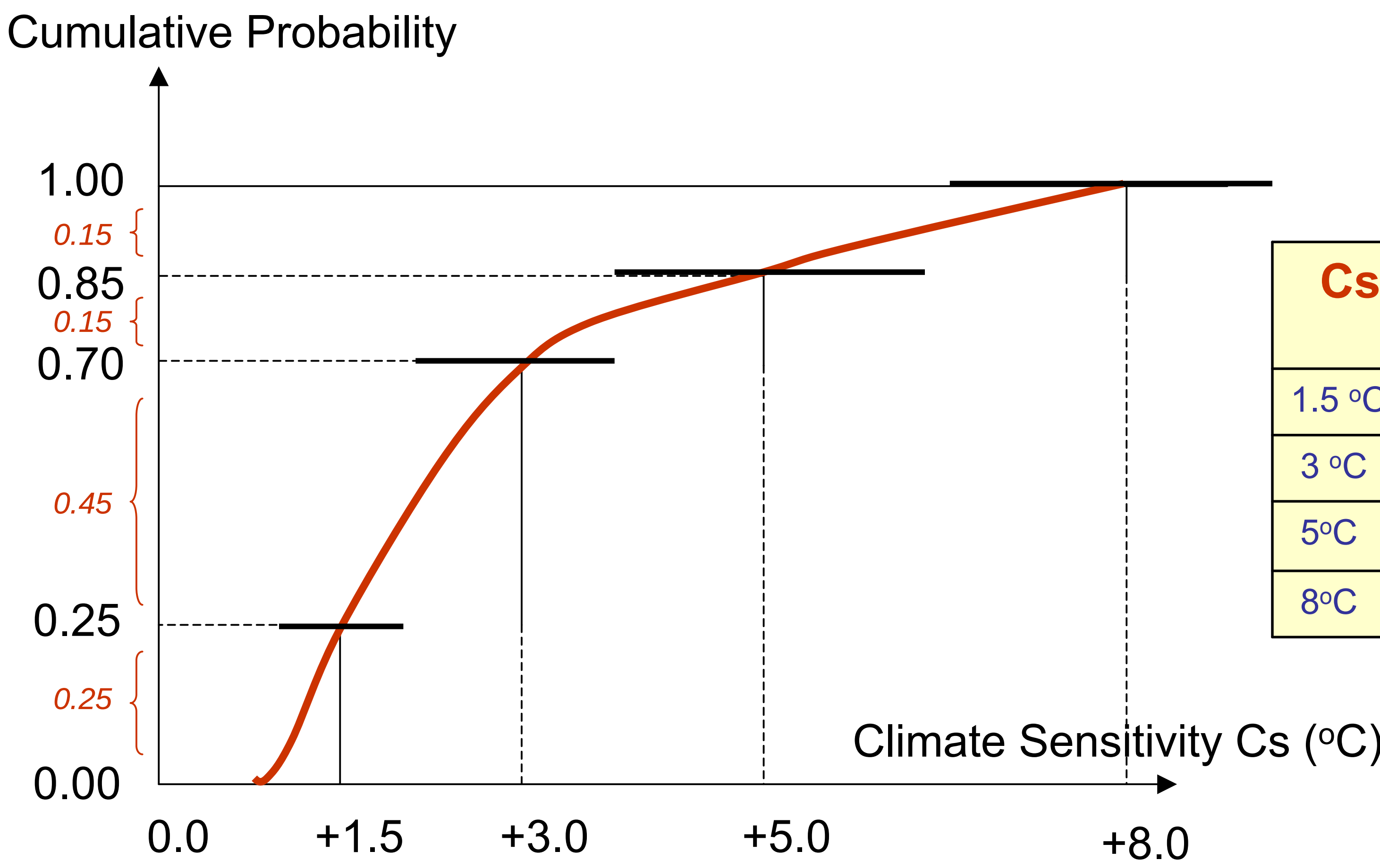
Other uncertainties, explored via and Alternate reference scenario

Description of Uncertainties
(as per EMF-22, 2005)

	Economic Growth	**Climate Sensitivity C_s**
Unknown until and including	2040	2040
First certainty period in TIAM	2050	2050
Values	2 scenarios High and Low (High growth ~ 2 x Low Growth) *Equal likelihood 0.5*	4 possible values (1.5, 3, 5, 8 ºC) with Lag parameter adjusted accordingly *Discrete Probability Distribution*

PDF of C_s

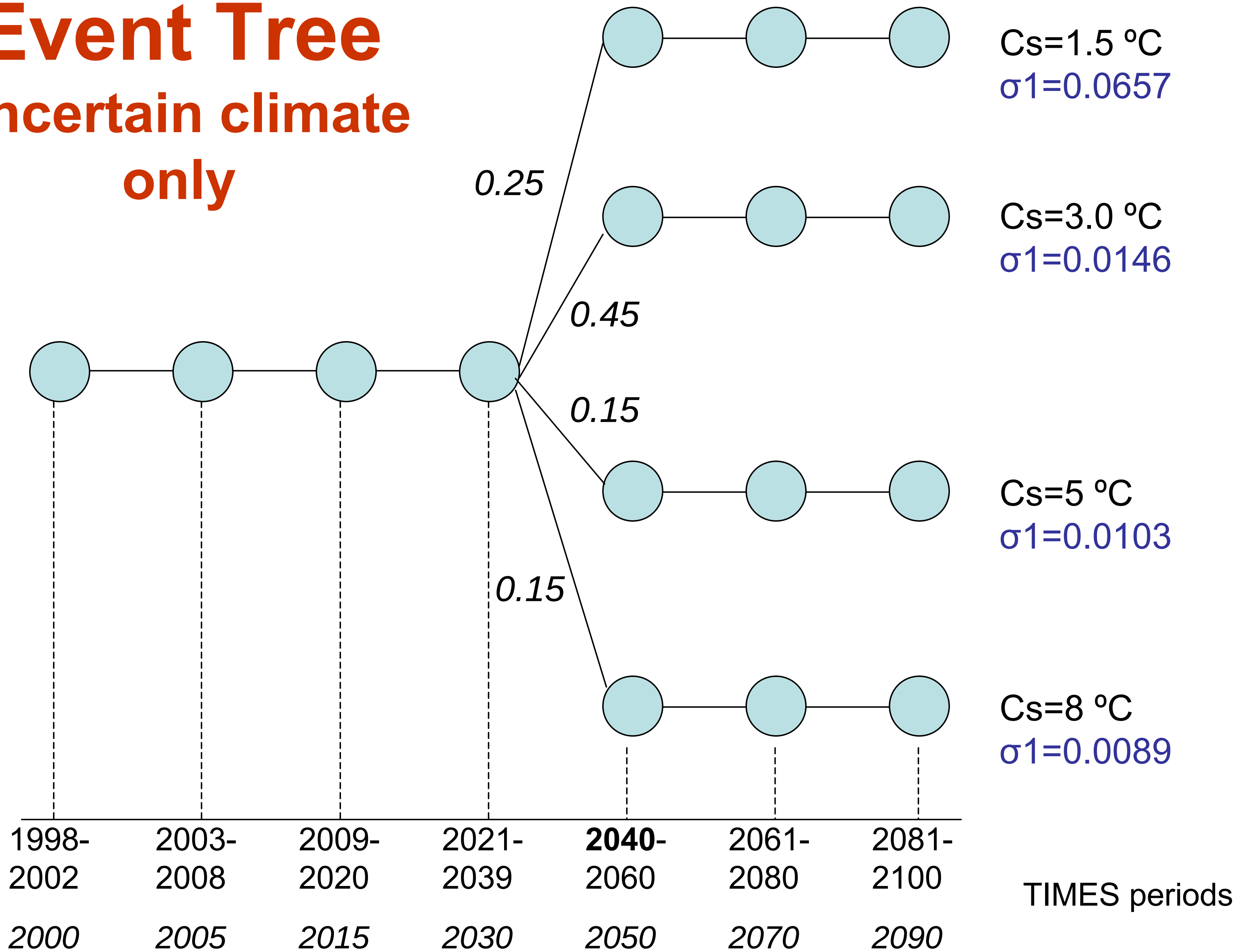
(from Schlesinger and Andropova, 2001; Yohe et al. 2004)



Cs	Prob	Lag σ_1*
1.5 °C	0.25	0.0657
3 °C	0.45	0.0146
5°C	0.15	0.0103
8°C	0.15	0.0089

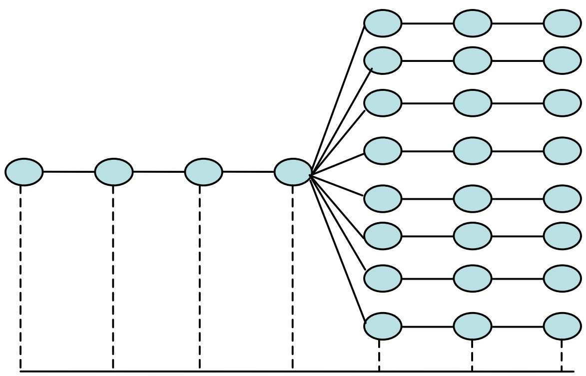
Event Tree

Uncertain climate only



- **If both C_s and demands are uncertain**

  – After 2040, GDP* growth is uncertain



- LOW (2/3 of Base) with prob. 0.5
  GDP_{2100}: 7*GDP_{2000}

- HIGH (4/3 of Base) with prob. 0.5
  GDP_{2100}: 12*GDP_{2000}

**Note: Most TIAM demands are strongly correlated to GDP*

► **HOWEVER: Results show that Stochastic demands do NOT require new hedging decisions that are different from those adopted under Stochastic Cs only scenario.**

► **No need to anticipate GDP growth**

Is Hedging relevant ?

Hedging is relevant if decisions prior to 2040 are different under hedging than under Base (which ignores climate issues)

Otherwise, '*wait and see*' is a good policy

Main interest of a hedging strategy = what to do prior to the resolution date

Observation: Hedging is relevant for climate uncertainty but not for GDP growth uncertainty

Two Reference Scenarios

Case I. Average Development Base Case (somewhat close to IPCC SRES B2 scenario):

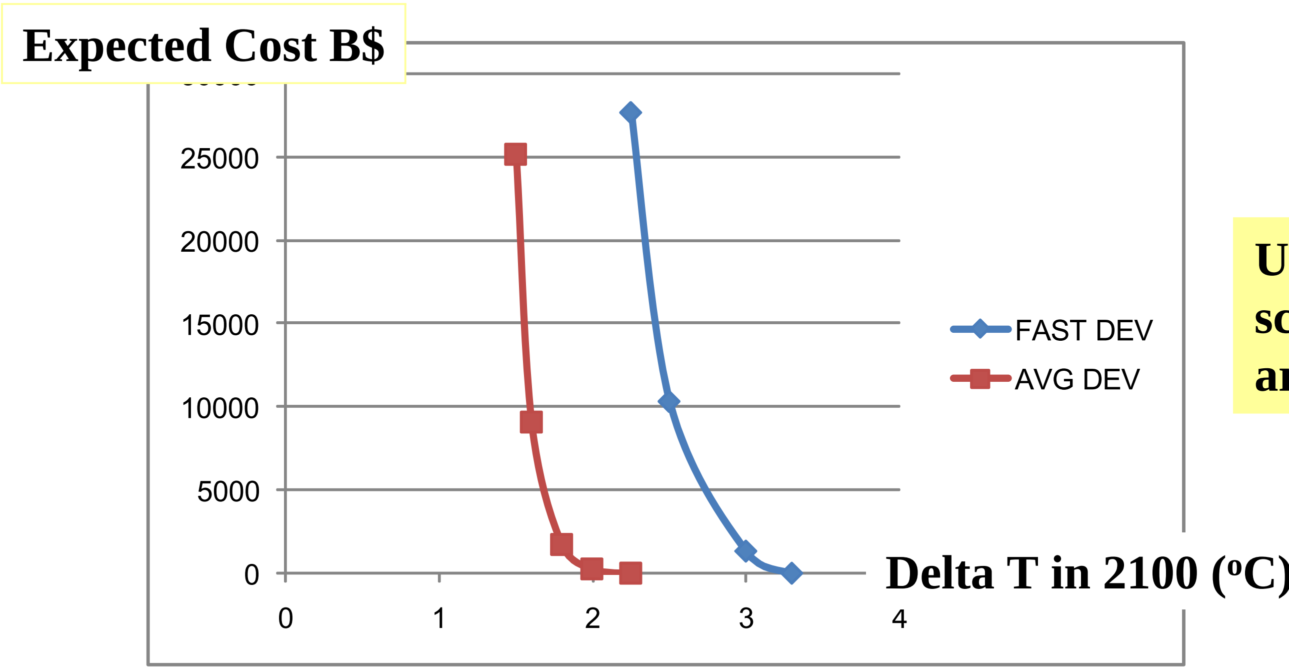
- World GDP 2100 = 8*GDP in 2000 (avg 2.3%/yr)
- Moderately high technical progress
- Large oil resources (by region)
- Large Biomass resources (by region)
- Moderately large Nuclear allowed (Region dependent)

Two Reference Scenarios Cont'd

Case II. Fast Development Base Case:

- World GDP 2100 ~ 14*GDP in 2000 (avg 2.9%/yr)
  - Higher technical progress in CGE model
- Larger Nuclear potentials (region dependent)
- Larger Hydro potentials (region dependent)
- Advanced vehicles (and fuels) available earlier
- Same oil resources (by region)
- Same Biomass resources (by region)

Eight temperature targets under two scenarios, climate uncertainty only



Under the Fast development scenario, reachable targets are shifted by ~ 0.7-0.9^oC

Expected costs of various targets (B$ NPV)

Delta T	1.5	1.6	1.8	2	2.25	2.5	3	3.3
FAST	[redacted]				27,700	10,300	1,300	0
STD	25200	9080	1692	250	0	0	0	0

NPV of world GDP ~ 950,000 B$ under STD and ~1,200,000 B$ under FAST

IV: RESULTS for 2 contrasted scenarios

- Explicit uncertainty on Cs only
  - FAST DEVT Scenario
    2.5°C target in year 2100
  - Average Devt Scenario
    1.8°C target in year 2100

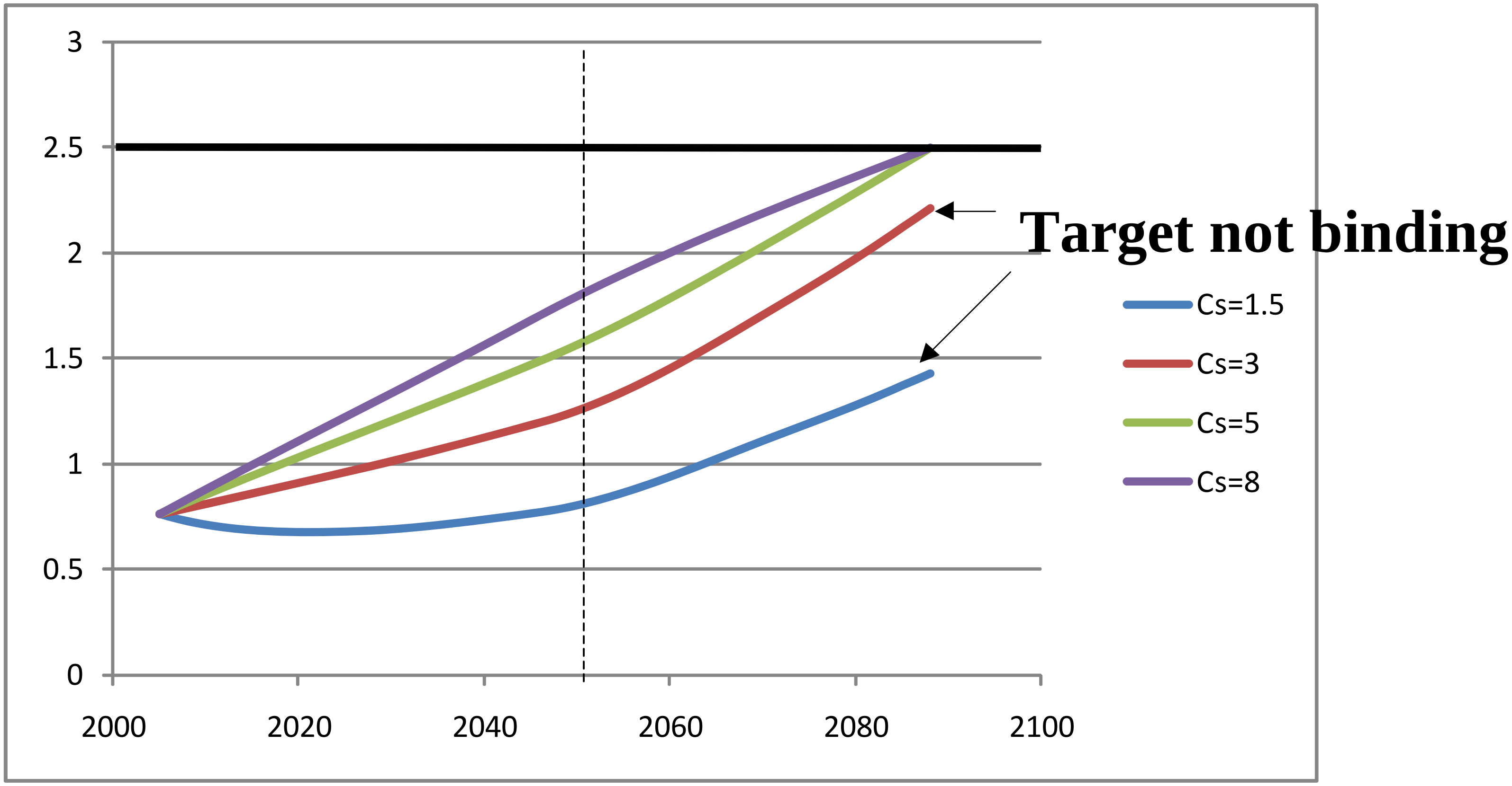
Expected Value of Information (EVI) for the Avg Devt. Scenario, target 1.8oC

Resolution date	Expected Loss of surplus	Expected value of information
2040	1,692 B$	-
2005 (perfect info)	1,135 B$	EVPI = 557 B$
2020 (earlier info)	1,230 B$	EVII = 462 B$

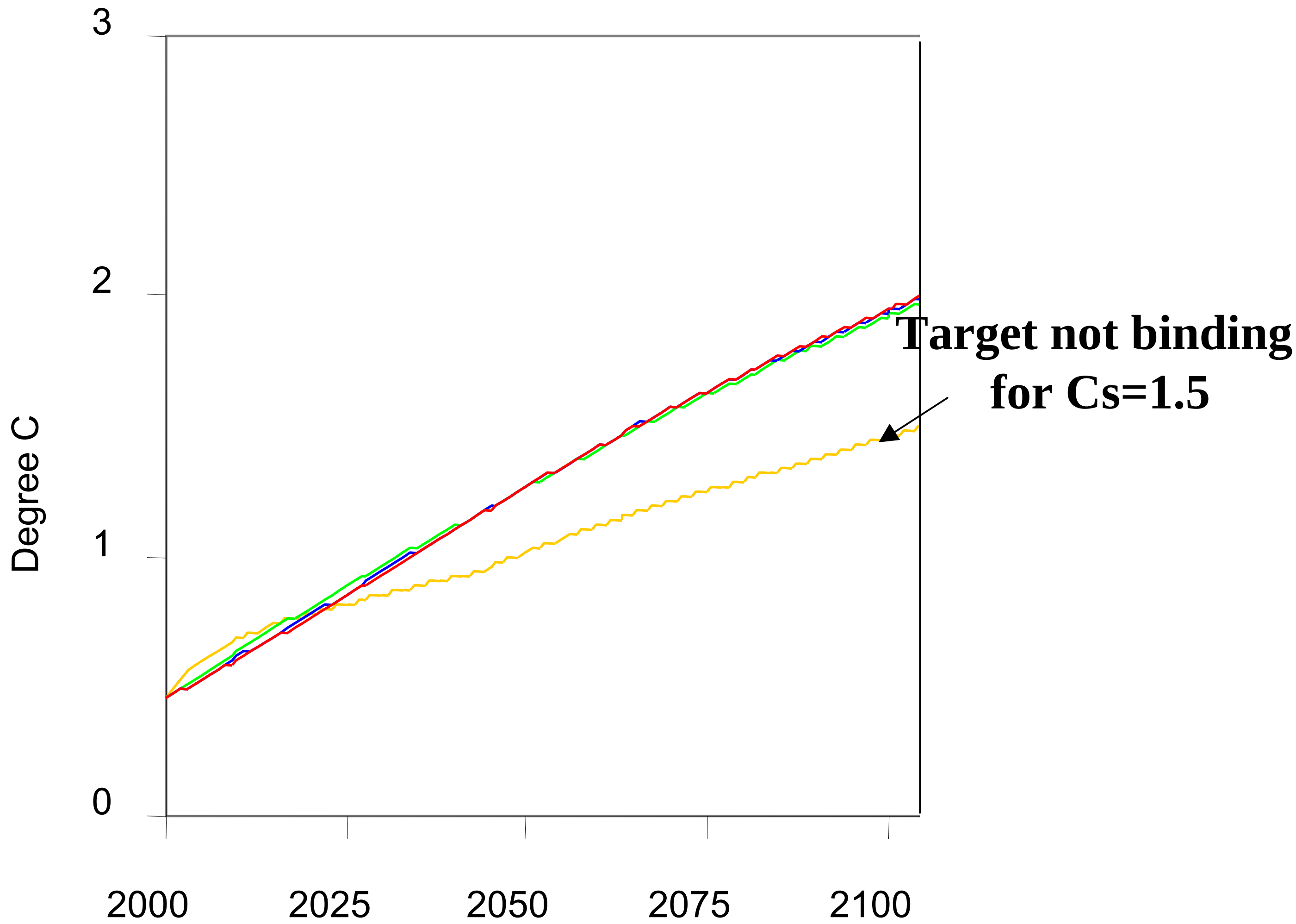
for the Fast Devt. Scenario, target 2.5oC

Resolution date	Expected Loss of surplus	Expected value of information
2040	10,340 B$	-
2005 (perfect info)	3,690 B$	EVPI = 6,650B$
2020 (earlier info)	To Do	To Do

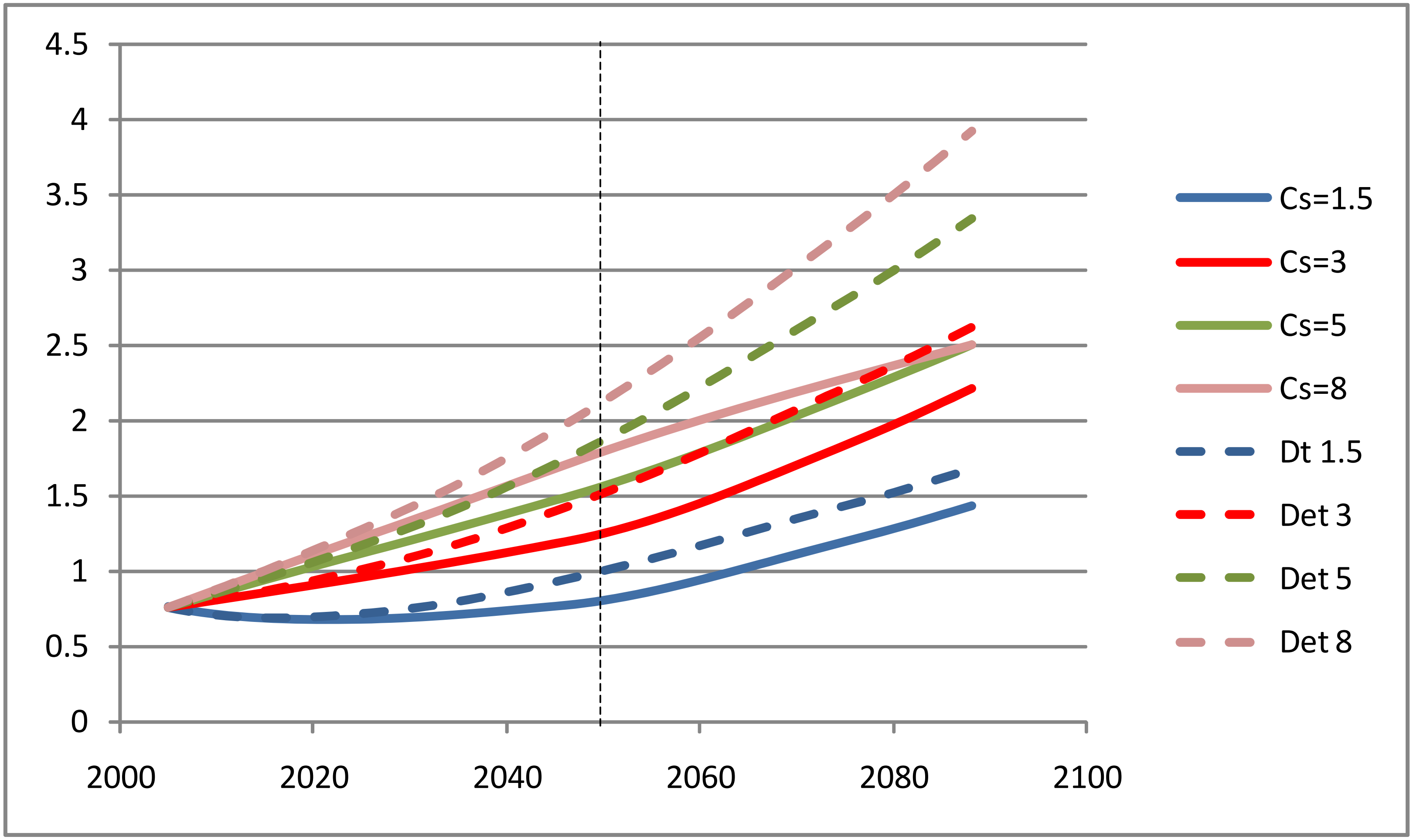
Short term evolution of temperature (Hedging, Fast devt, Target=2.5oC)



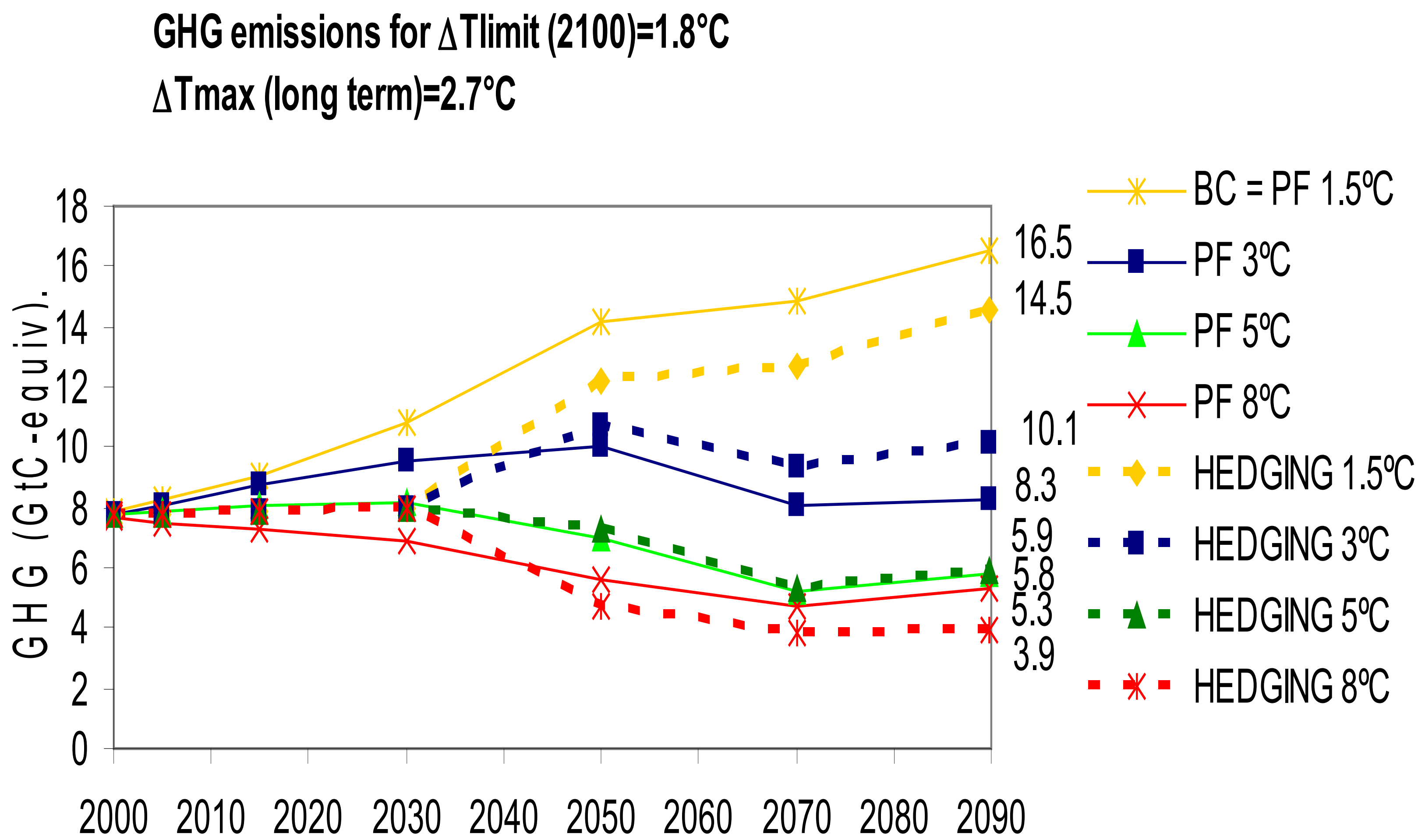
Short Term Temperature evolution Hedging, Avg Devt, Target=1.8oC



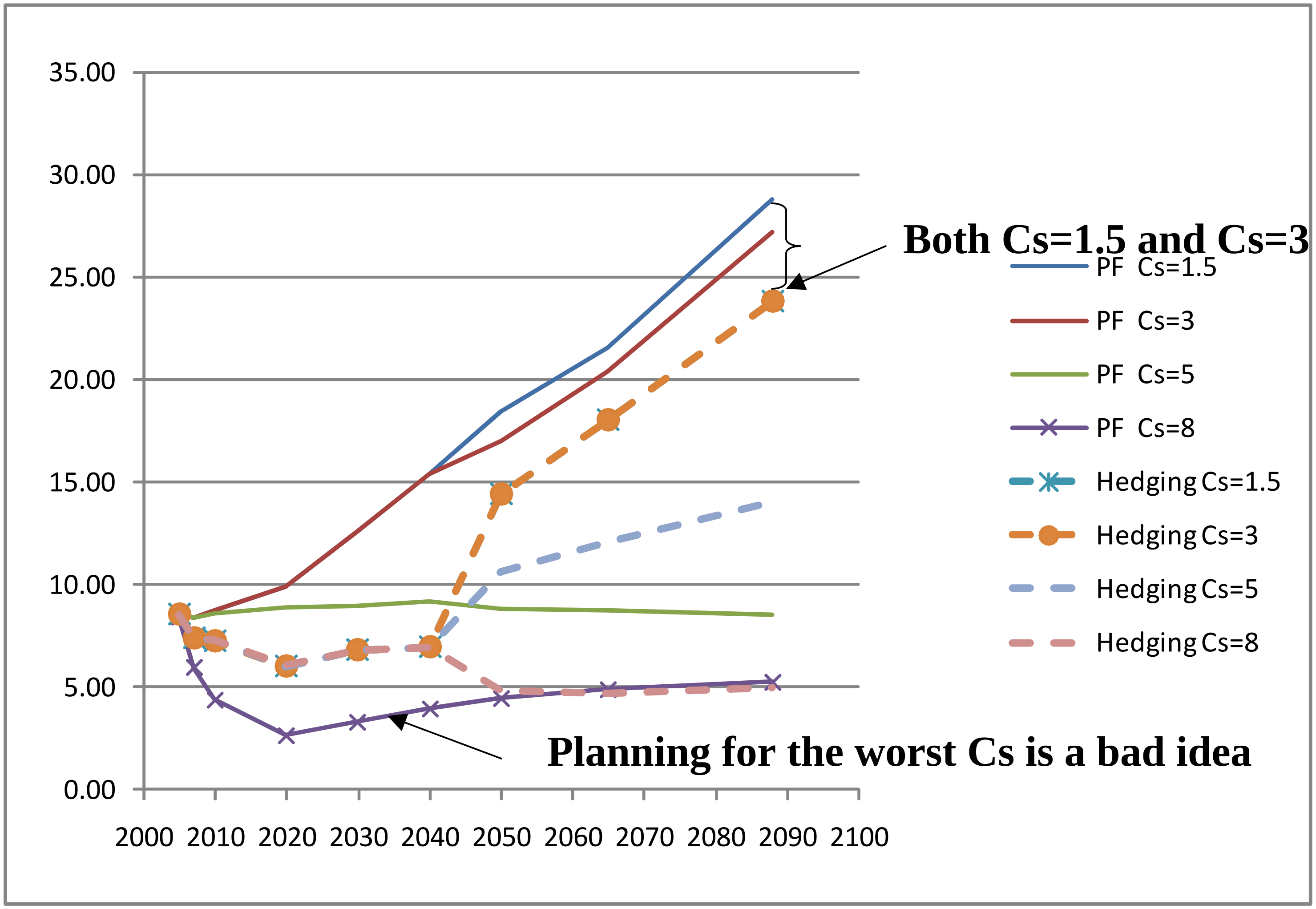
Short term evolution of temperature Hedging and Blind strategies, Target=2.5oC



GHG Emissions
Avg Devt, Target=1.8oC

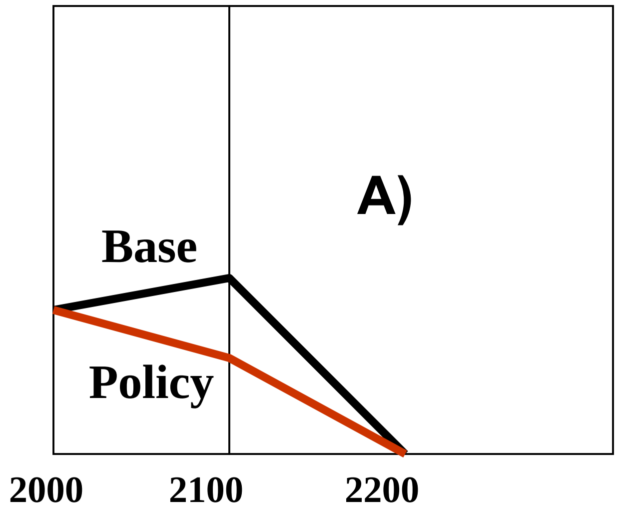


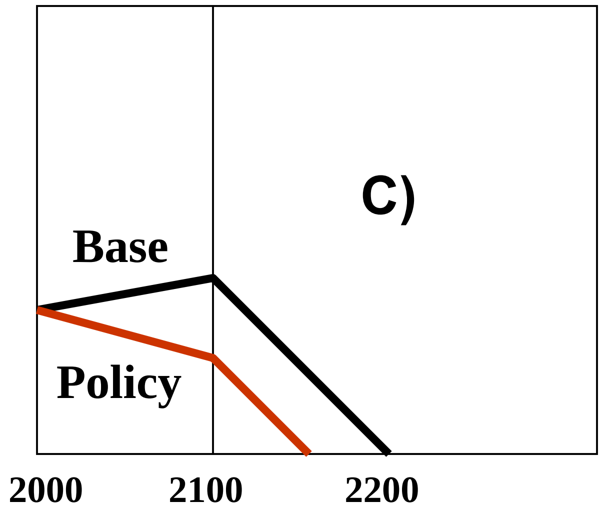
GHG Emissions
Fast Devt, Target=2.5^{o}C



Longer term Temperature

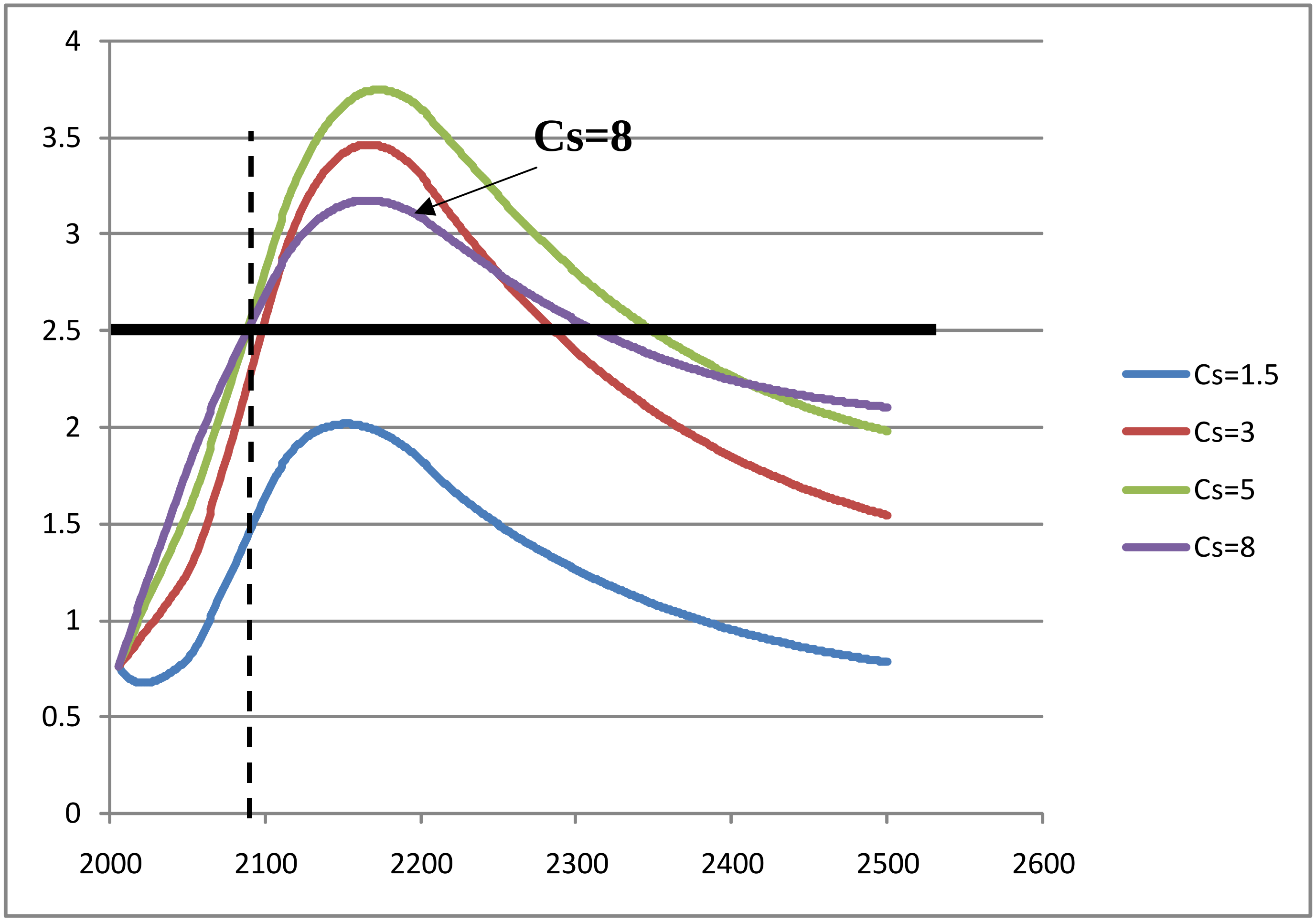
- Model horizon: 2100
- We need an emission profile beyond 2100
- Three alternative assumptions
  - A) Emissions decline to 0 over 100 years
  - B) Emissions decline to 0 over 200 years
  - C) Emissions decline to 0 at fixed rate (0.28 GtC/year)





Long term temperature evolution Hedging, Target = 2.5 oC in 2100

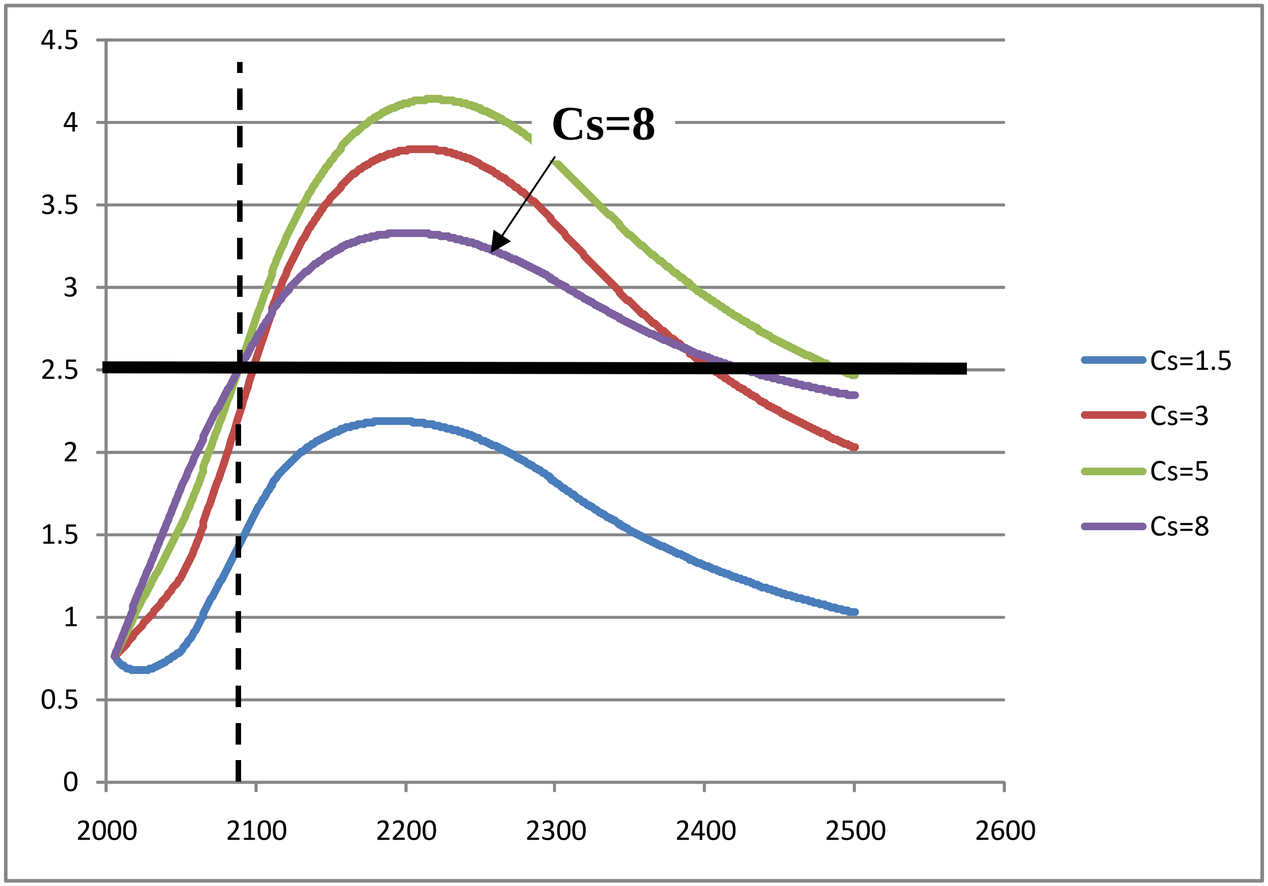
assuming emissions after 2100 disappear in 2200



Cs=8 has a lower peak temperature than Cs=5 or 3 !

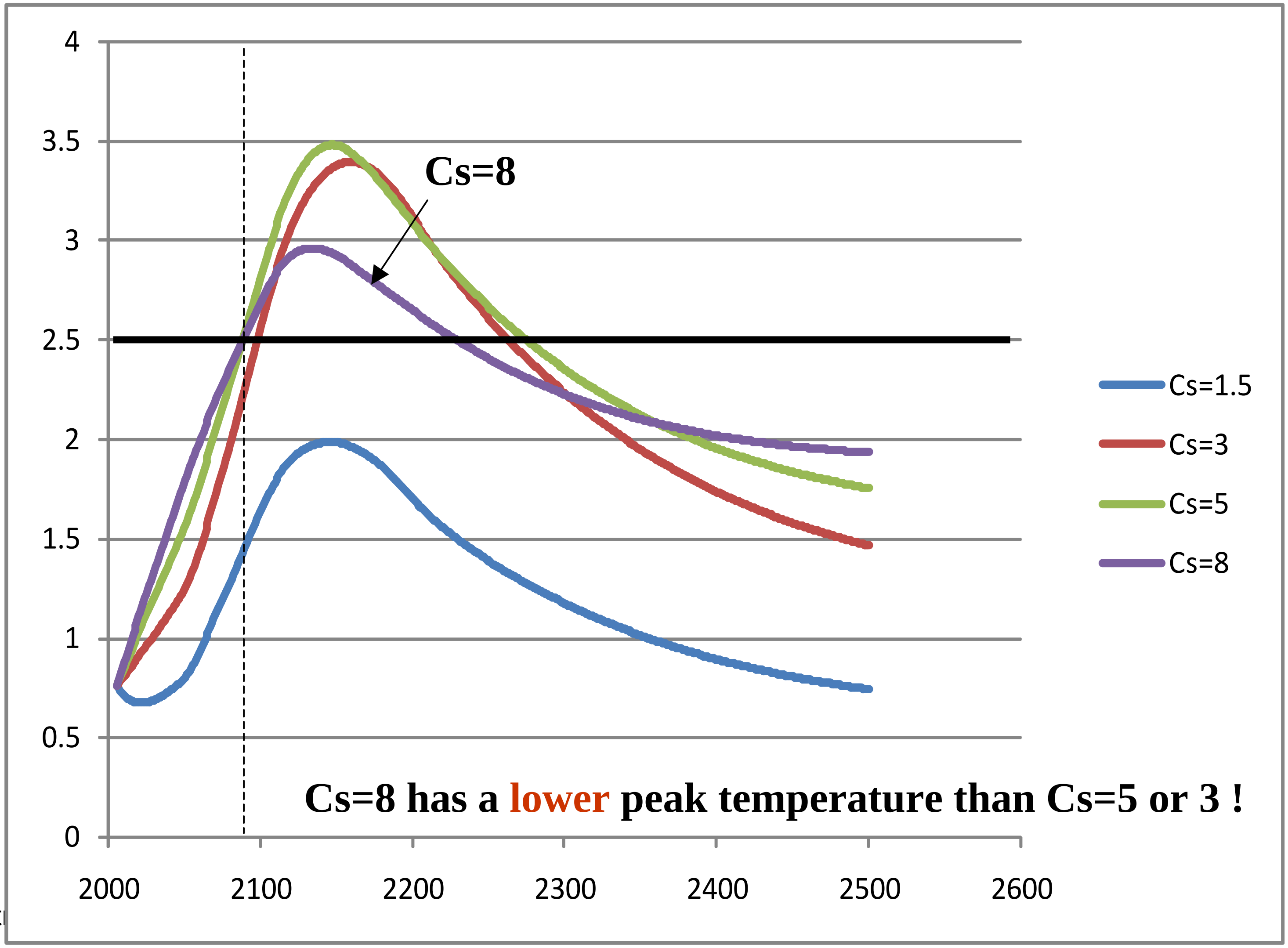
Long term temperature evolution Hedging, Target = 2.5 oC in 2100

assuming emissions after 2100 disappear in 2300



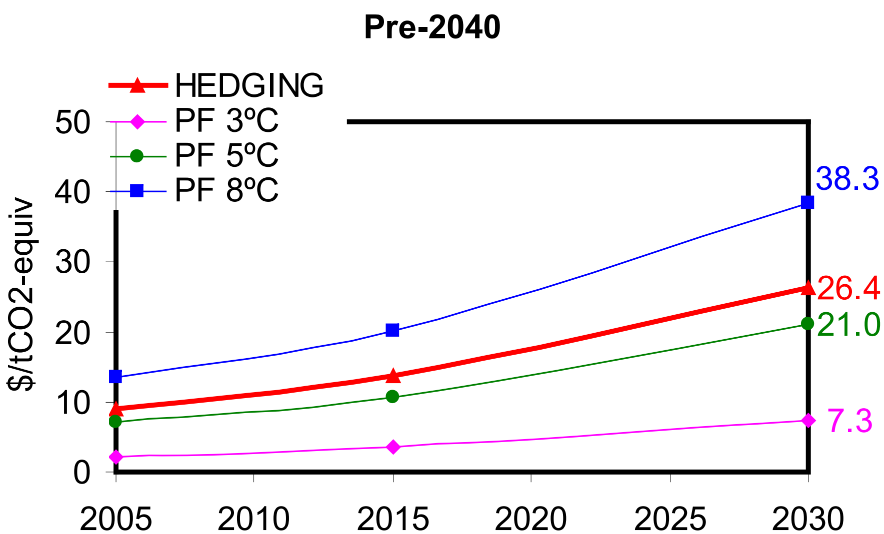
Cs=8 has a lower peak temperature than Cs=5 or 3 !

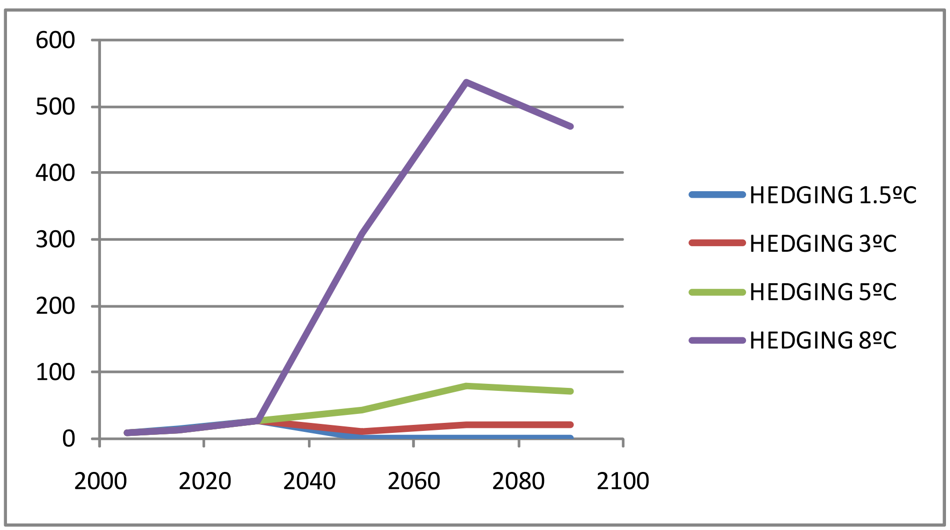
Long term temperature evolution
Hedging, Target = 2.5 oC in 2100
assuming emissions after 2100 decrease at rate 0.28 GtC/year



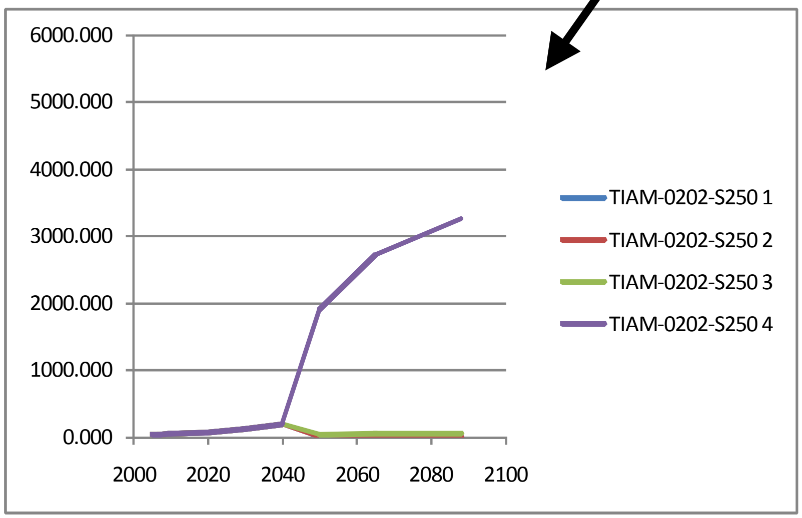
GHG Price
Avg Devt, target= 1.8oC

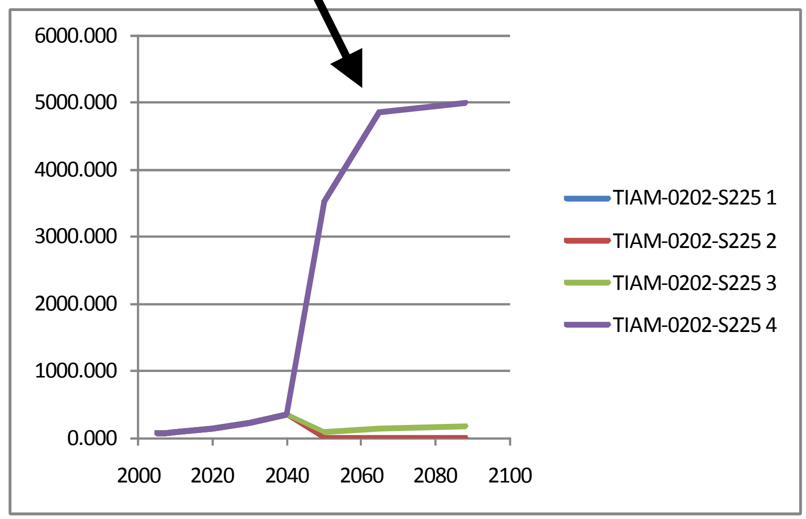
- Hedging differs from all perfect forecast strategies
- Low price before 2040: CH_4 and forestry measures help !
- Long term high price: due to the absence of CH_4 abatement options in agriculture



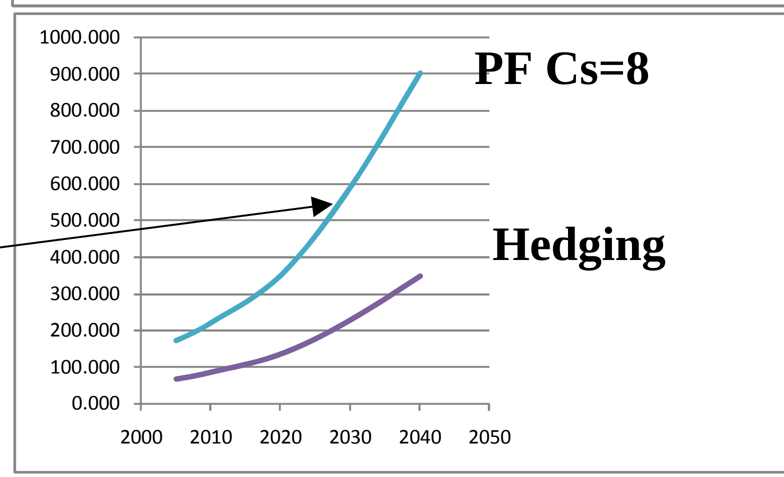


GHG Price, Fast Devt
Targets= 2.5 and 2.25 oC





Planning for the worst Cs is a bad idea



Main conclusions

- Long term Temp target achievable under Cs uncertainty at reasonable expected cost :
  - 2.7 ºC in Avg Devt scenario
  - 3.5 ºC in Fast Devt scenario, in spite of enhanced technical progress
- **Hedging is important for Cs uncertainty, but not for economic uncertainty (tentative)**
- High EVPI: incentive for research on Cs
- Stochastic programming produces a **hedging strategy** against climate uncertainty, that is not always well approximated by any PF strategy
- **Hedging strategy** not always well approximated by any deterministic strategy

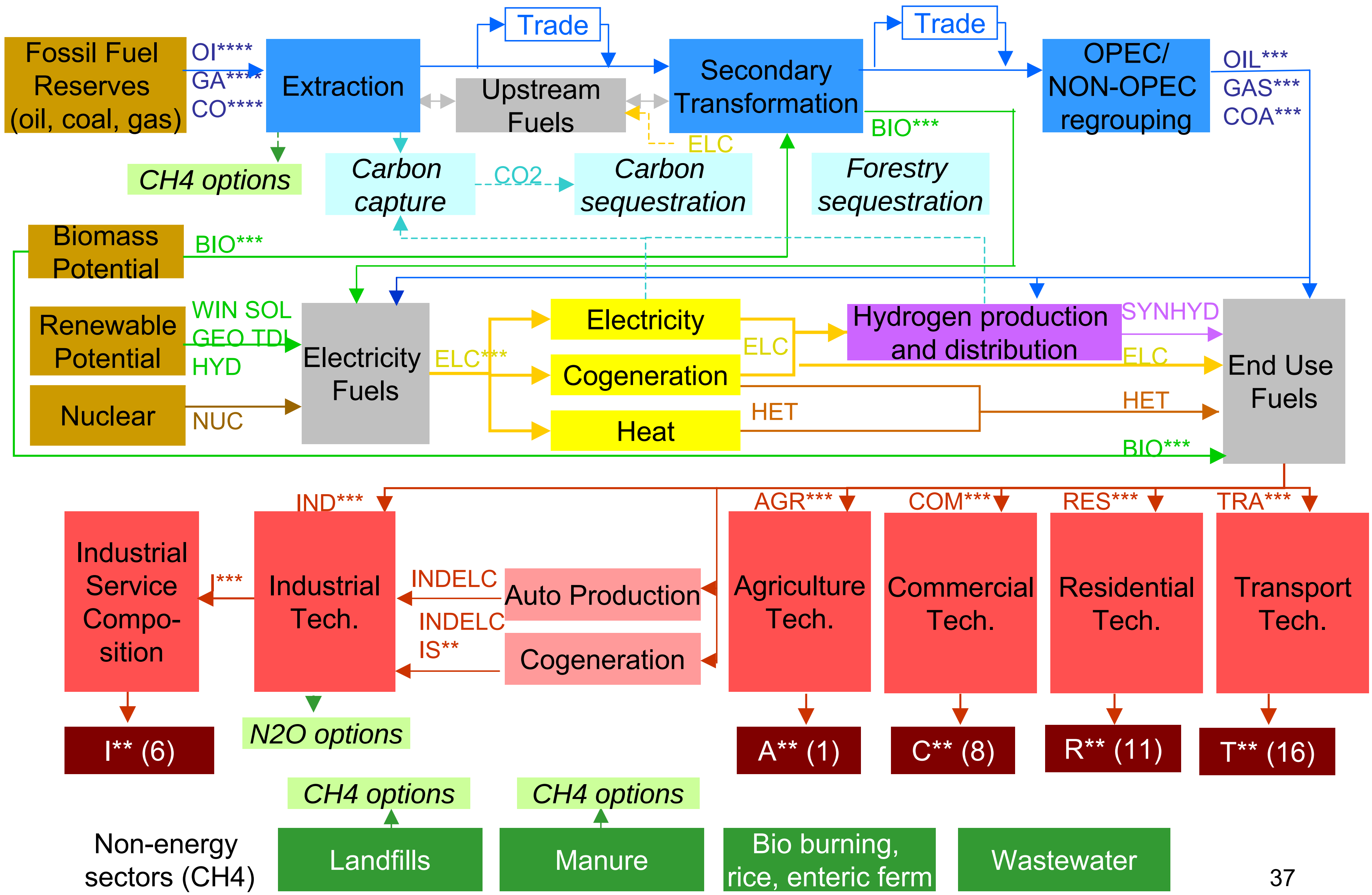
To Do

- **Further analyses**
  - Detailed technological and regional analysis
  - Evaluate expected cost of *wait-and-see* strategy (i.e. follow Base until 2040, then optimize)

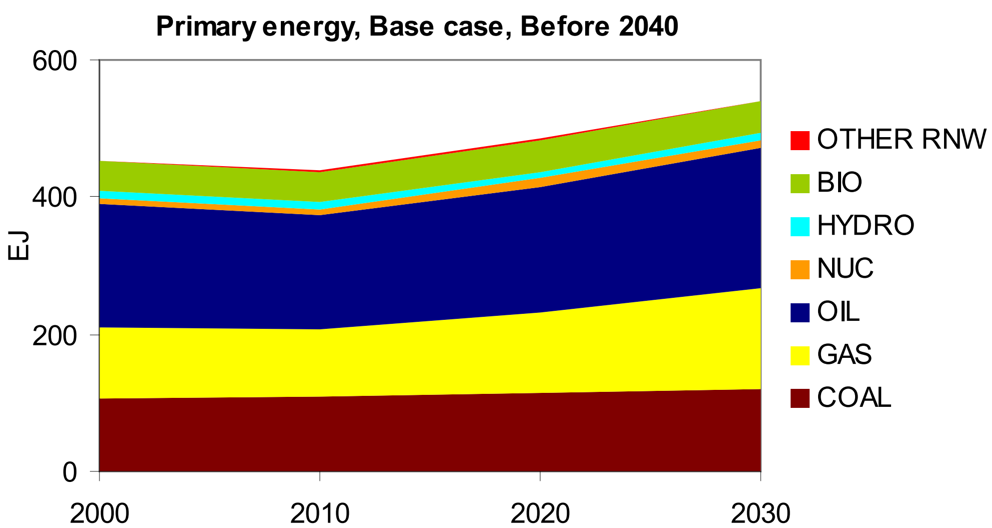
- **Model improvements**
  - Refine relationship Lag ⟷ Cs
  - Enhance the model with feedbacks from Climate to Economy
    - Eg. modified demands for space heating and cooling, hydro potentials, release of methane from permafrost, land use changes,…

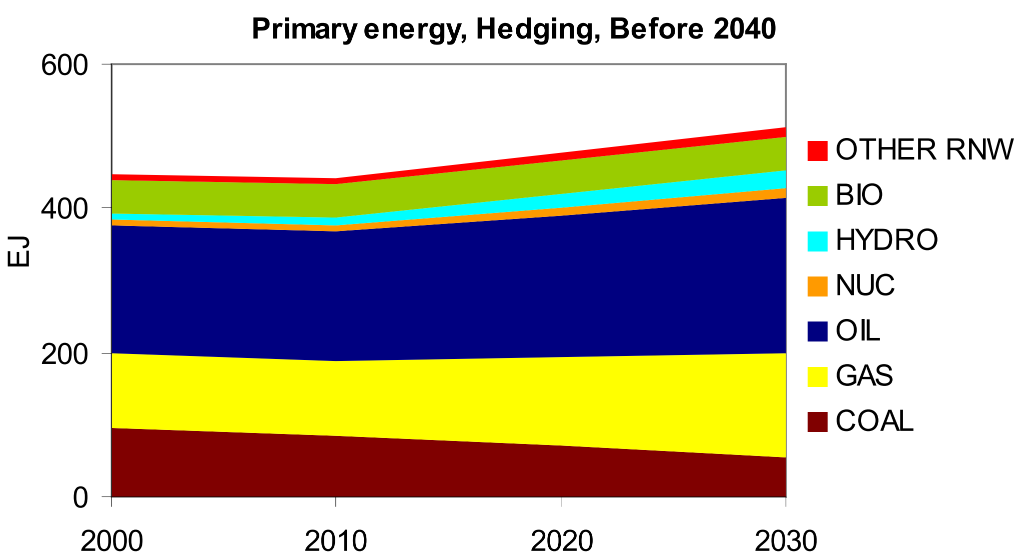
Complements: additional results for the Avg Devt Scenario Target=1.8°C in 2100

Reference Energy System of TIAM



Primary Energy before 2040





Hedging actions

- Decrease of coal (mainly power plants, very slightly in industry)
- Sequestration by forests
- Hydro, wind
- N_2O and CH_4 abatement
- Moderate Demand reductions
- More nuclear (2030)

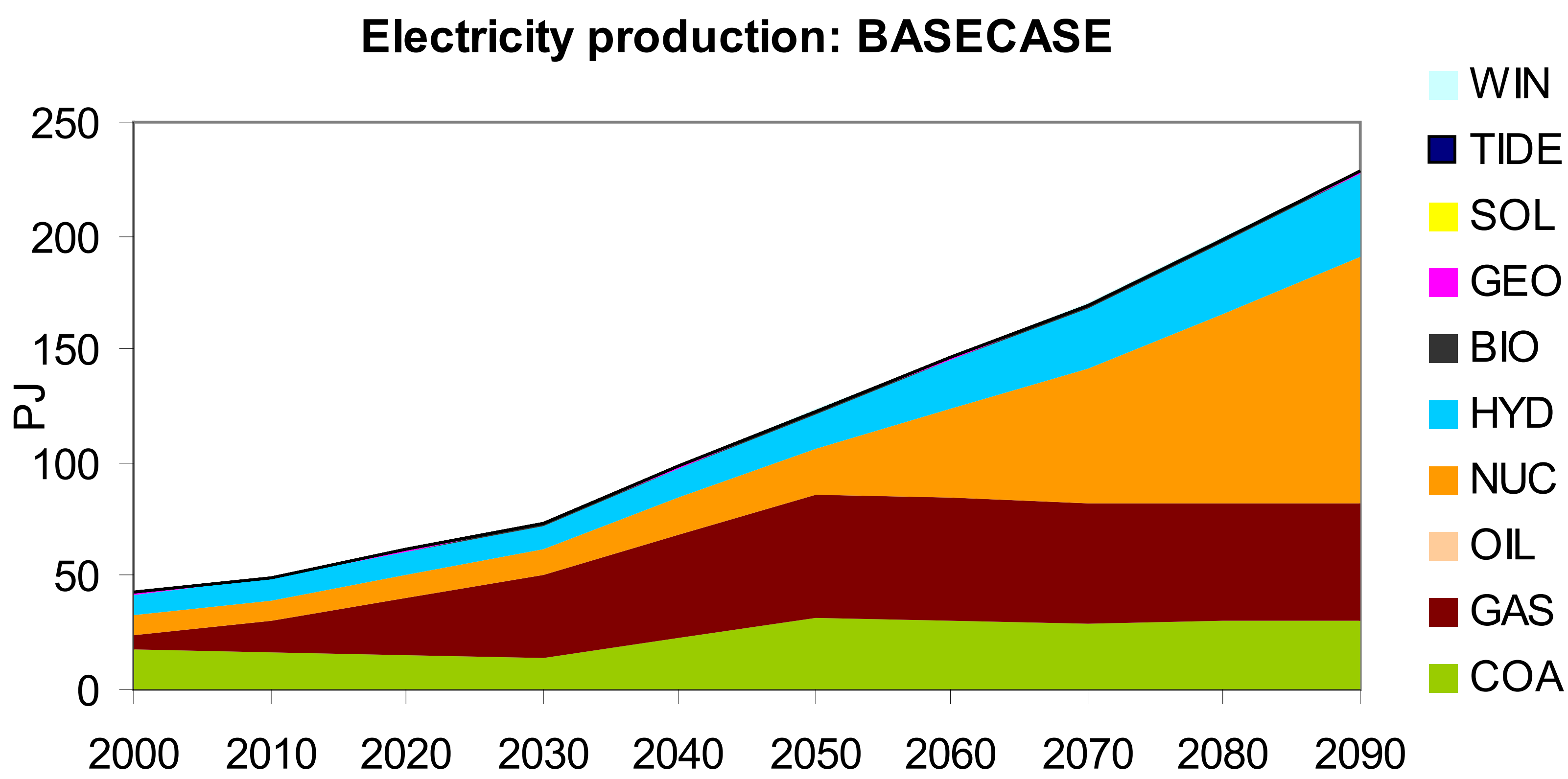
Non-hedging actions

- Power plants with CO_2 capture
- Energy substitution in end-use sectors
- H2 for transport (weak, late)

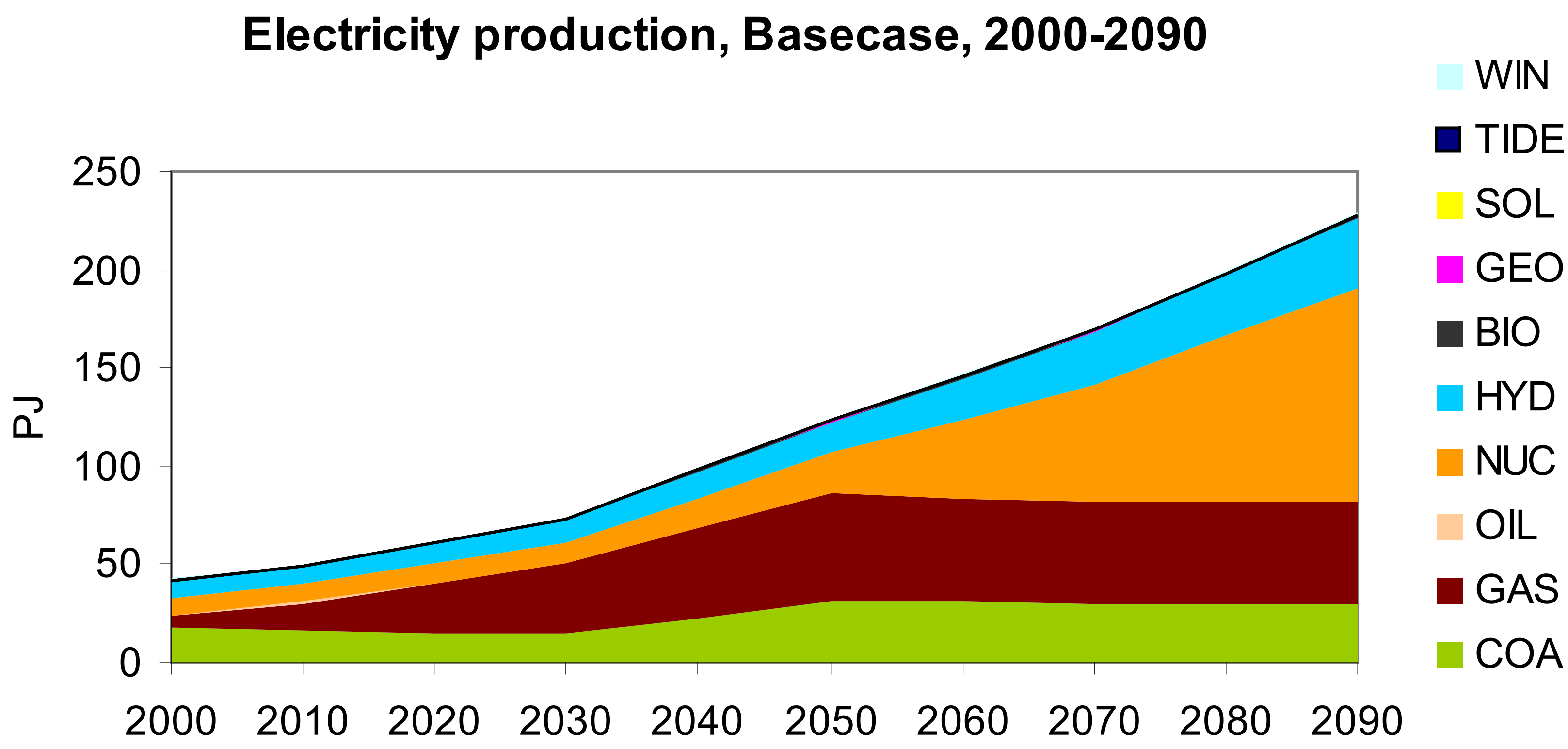
Post-2040 abatement actions (for large values of Cs)

- **Power plants:** Hydroelectricity, Nuclear, Wind, Solar (very late), CCS
- **Transportation:** Large Substitution of RPPs by alcohols and gas (not by H2 and Elec)
- **Buildings:** Substitution of gas and RPPs by electricity, mainly for space heating
- **Industry:** Substitution of coal by gas (and electricity) in some industries
- **Demand** reductions (economic feedback)

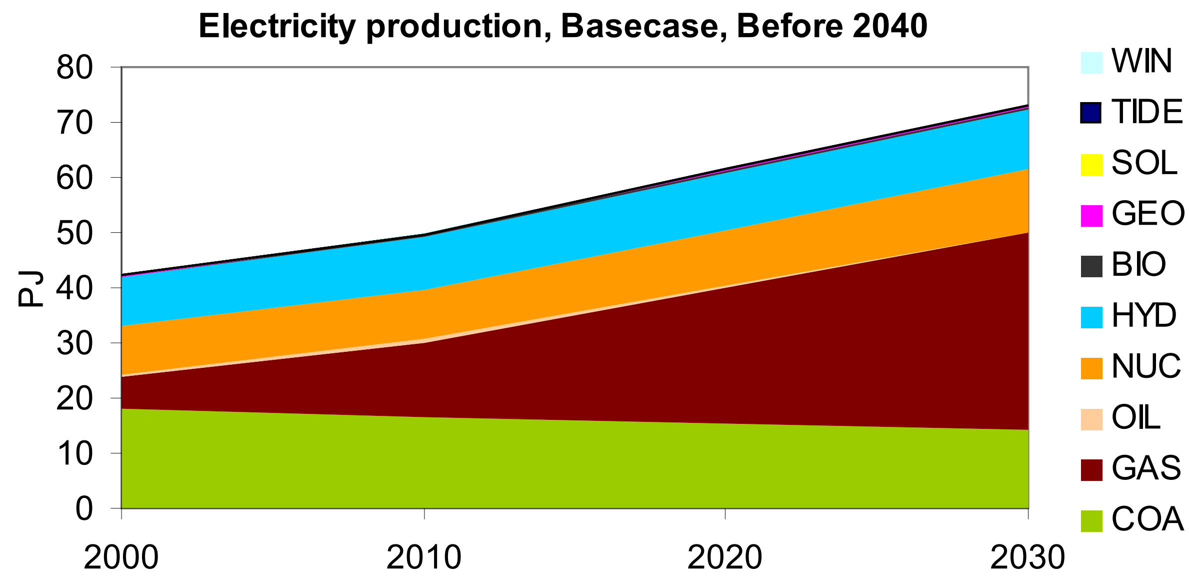
Electricity production by fuel

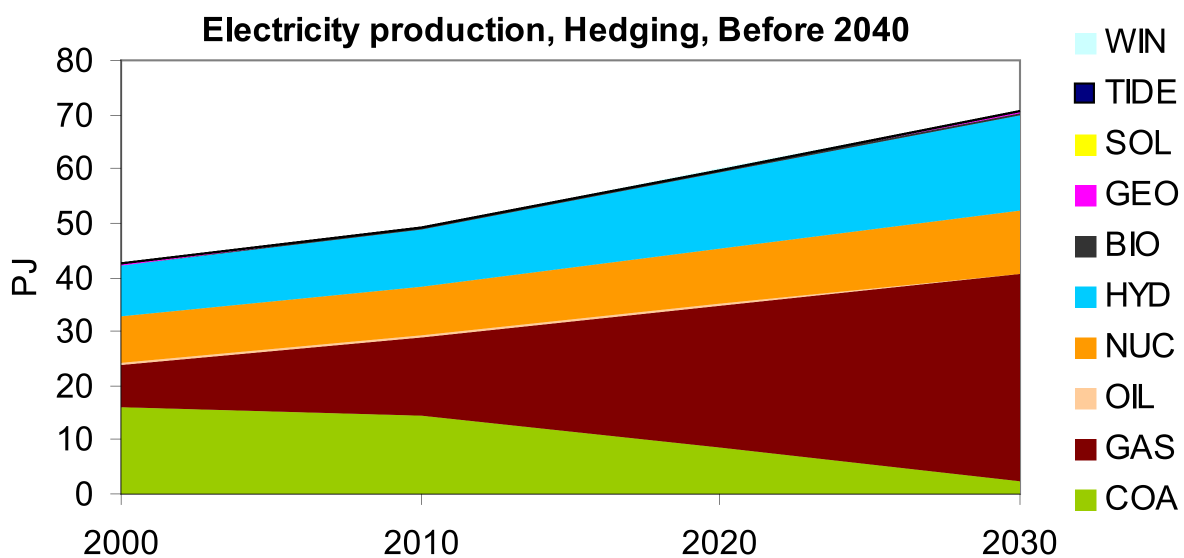


Electricity production by fuel (basecase)



Electricity production by fuel (hedging)





Power plants

PLANT TYPE	Scenario	2000	2005	2015	2030	2050	2070	2090
	TIMES period	*1998-2002*	*2003-2008*	*2009-2020*	*2021-2039*	*2040-2060*	*2061-2080*	*2081-2100*
COAL FIRED	BASE, PF Cs=1.5ºC	18	17	16	14	32	30	30
	PF Cs=3ºC	16	16	16	8	5	5	6
	PF Cs=5ºC	16	16	11	0	13	9	7
	PF Cs=8ºC	16	16	11	1	14	11	7
	HEDGING Cs=1.5ºC					26	28	29
	HEDGING Cs=3ºC					13	7	8
	HEDGING Cs=5ºC	16	16	11	0	11	9	7
	HEDGING Cs=8ºC					16	13	13
OIL+GAS FIRED	BASE, PF Cs=1.5ºC	6	10	18	36	55	52	52
	PF Cs=3ºC	8	10	19	35	55	38	30
	PF Cs=5ºC	8	10	20	35	33	26	23
	PF Cs=8ºC	8	10	18	24	30	26	21
	HEDGING Cs=1.5ºC					47	49	51
	HEDGING Cs=3ºC					51	41	43
	HEDGING Cs=5ºC	8	10	19	32	35	26	23
	HEDGING Cs=8ºC					30	26	28
NUCLEAR	BASE, PF Cs=1.5ºC	9	8	10	11	20	59	109
	PF Cs=3ºC	9	8	10	11	23	72	130
	PF Cs=5ºC	9	8	10	11	27	74	134
	PF Cs=8ºC	9	8	10	13	28	74	134
	HEDGING Cs=1.5ºC					20	59	109
	HEDGING Cs=3ºC					20	71	120
	HEDGING Cs=5ºC	9	8	10	12	27	74	134
	HEDGING Cs=8ºC					28	74	137

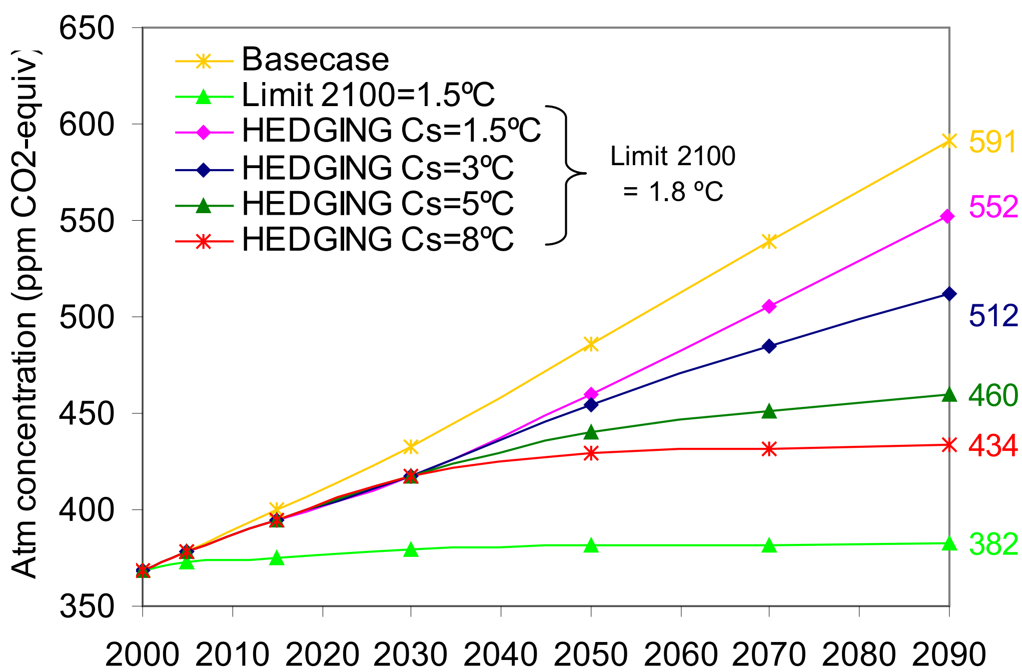
Power plants (cont.)

HYDRO	BASE, PF Cs=1.5ºC	9	9	10	11	15	27	36
	PF Cs=3ºC	9	9	10	17	34	43	48
	PF Cs=5ºC	9	9	12	21	35	43	49
	PF Cs=8ºC	9	9	13	27	35	43	49
	HEDGING Cs=1.5ºC					26	32	38
	HEDGING Cs=3ºC					33	42	47
	HEDGING Cs=5ºC	9	9	13	24	35	43	49
	HEDGING Cs=8ºC					35	45	52
BIOMASS	BASE, PF Cs=1.5ºC	0	0	0	0	1	1	1
	PF Cs=3ºC	0	0	0	0	1	2	1
	PF Cs=5ºC	0	0	0	0	5	5	3
	PF Cs=8ºC	0	0	0	2	6	4	3
	HEDGING Cs=1.5ºC					1	1	1
	HEDGING Cs=3ºC					1	1	0
	HEDGING Cs=5ºC	0	0	0	0	5	5	3
	HEDGING Cs=8ºC					9	6	5
OTHER RENEWABLES	BASE, PF Cs=1.5ºC	0	0	0	0	1	1	1
	PF Cs=3ºC	0	0	0	0	1	1	1
	PF Cs=5ºC	0	0	0	0	2	3	3
	PF Cs=8ºC	0	0	0	0	3	4	4
	HEDGING Cs=1.5ºC					1	1	1
	HEDGING Cs=3ºC					1	1	1
	HEDGING Cs=5ºC	0	0	0	0	2	3	3
	HEDGING Cs=8ºC					5	8	9
TOTAL	BASE, PF Cs=1.5ºC	42	44	55	73	124	170	229
	PF Cs=3ºC	42	44	55	73	119	161	216
	PF Cs=5ºC	42	43	54	68	115	161	219
	PF Cs=8ºC	42	43	53	67	116	162	218
	HEDGING Cs=1.5ºC					122	170	229
	HEDGING Cs=3ºC					119	163	220
	HEDGING Cs=5ºC	42	43	54	69	115	161	219
	HEDGING Cs=8ºC					123	173	244

Sensitivity analyses

Temperature change (2100) = 1.5ºC

- *Smallest achievable target*
- *Corresponds to Max (long term) = 2.1ºC*
- *Extreme situation, feasible at very large cost*
- *GHG concentration must stay almost constant*



Reduction of demands (examples)