Climate Change: The Science and Vulnerabilities

ESCAP/WTO ARTNeT Capacity-Building Workshop
for Trade Research

In Collaboration with National University of Lao

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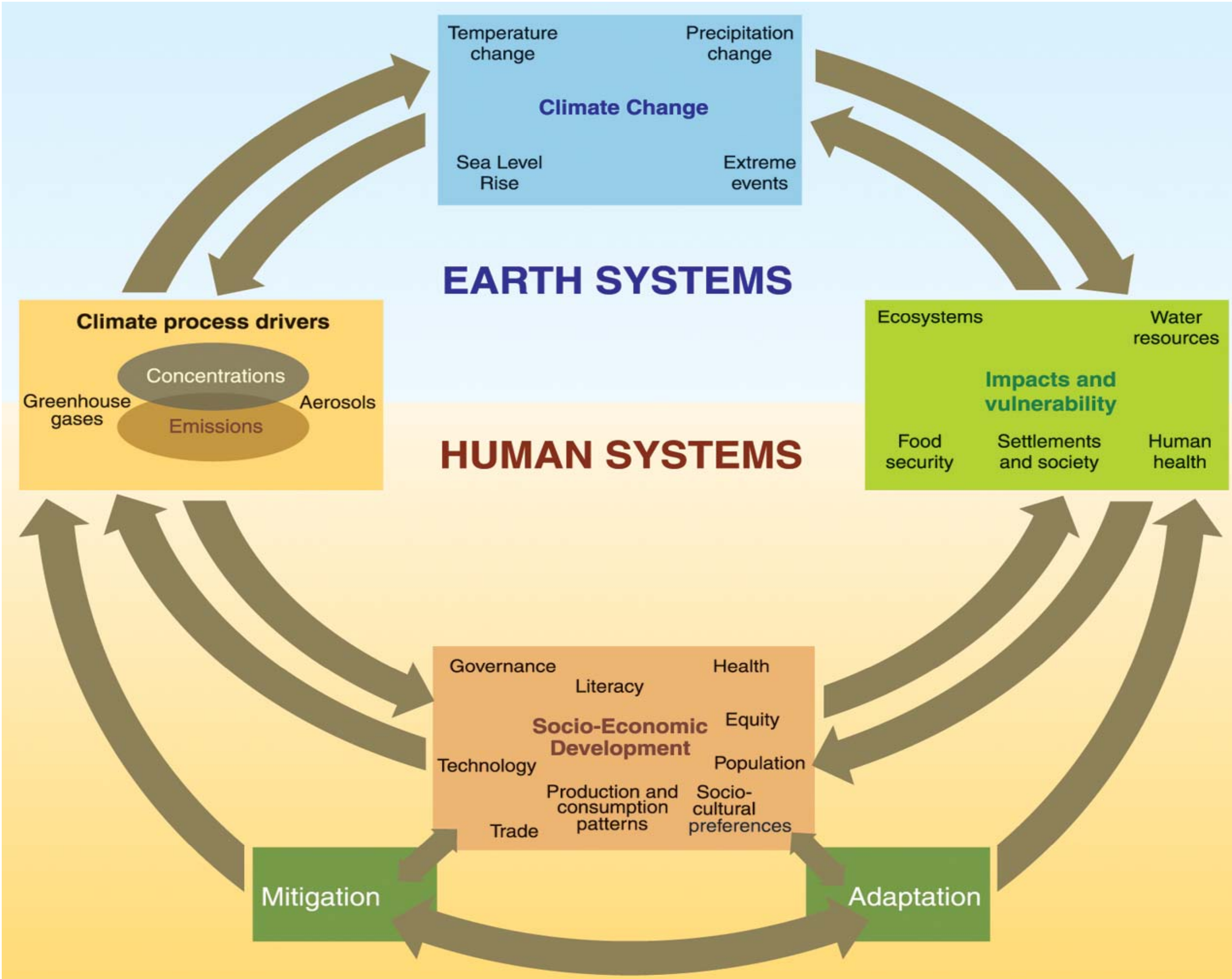
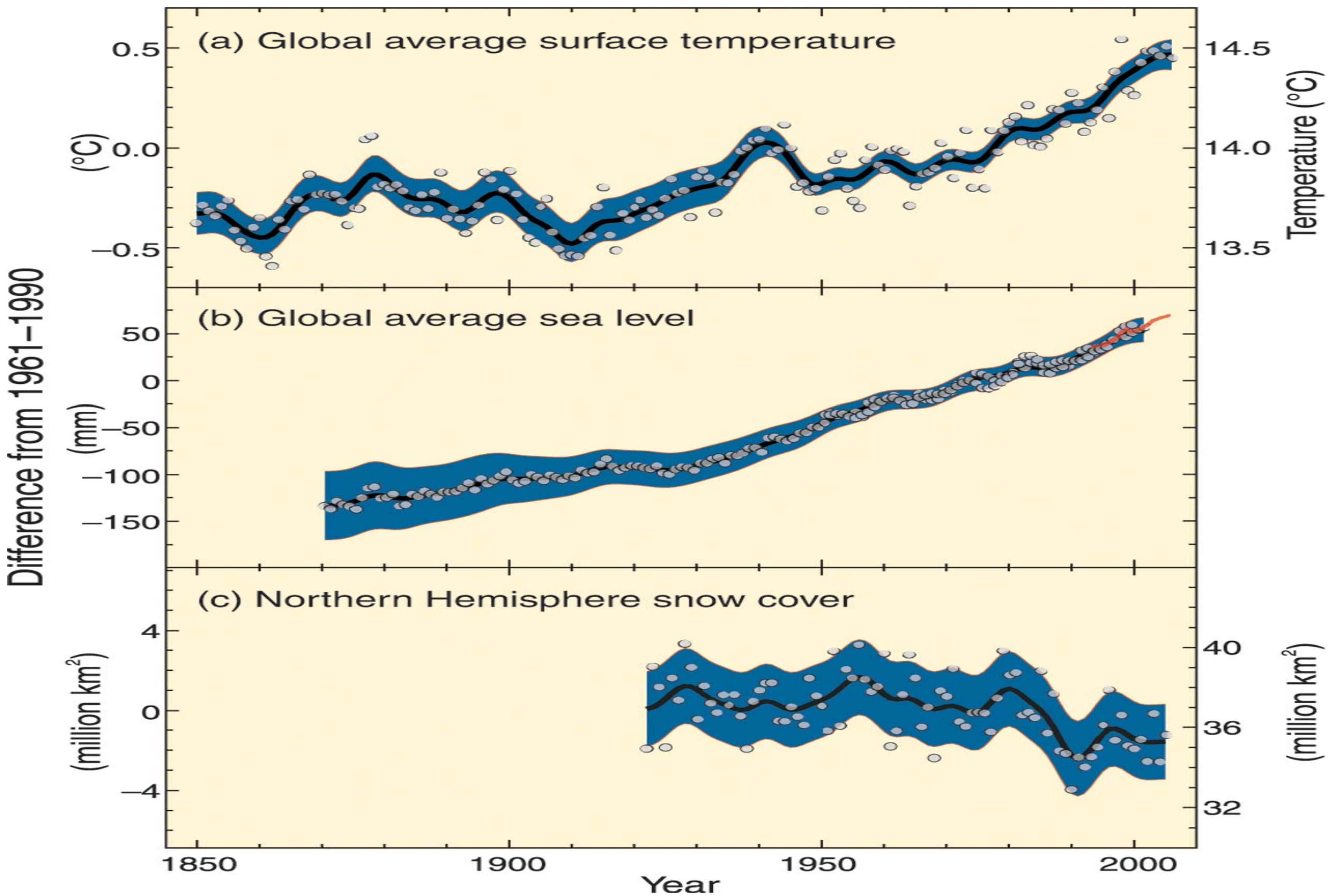
Main Topics

- The science
- Vulnerabilities
- Sources of emissions
- Paths to mitigation
  - Abatement
  - Adaptation

Earth and Human Systems (IPCC, 2007)

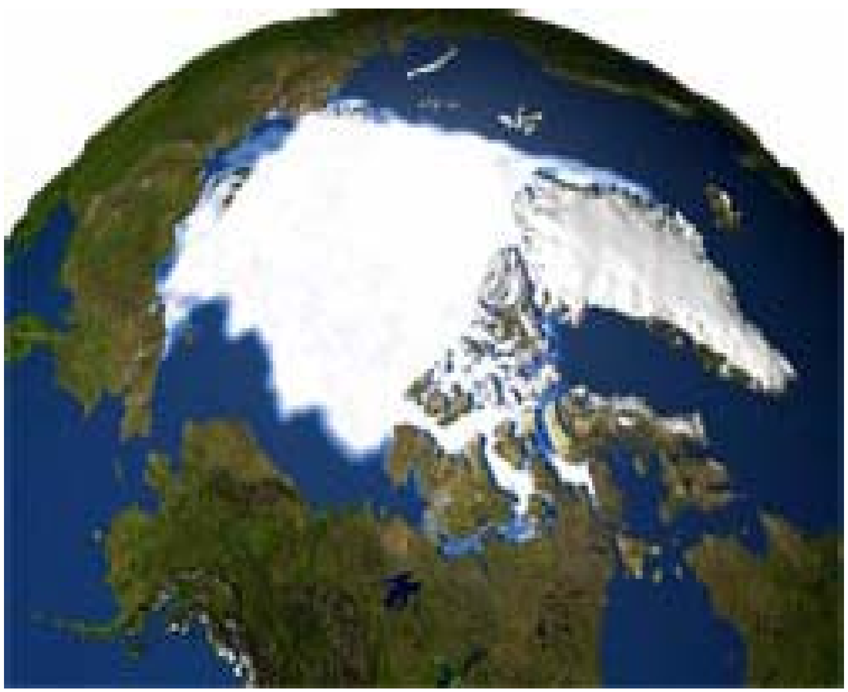




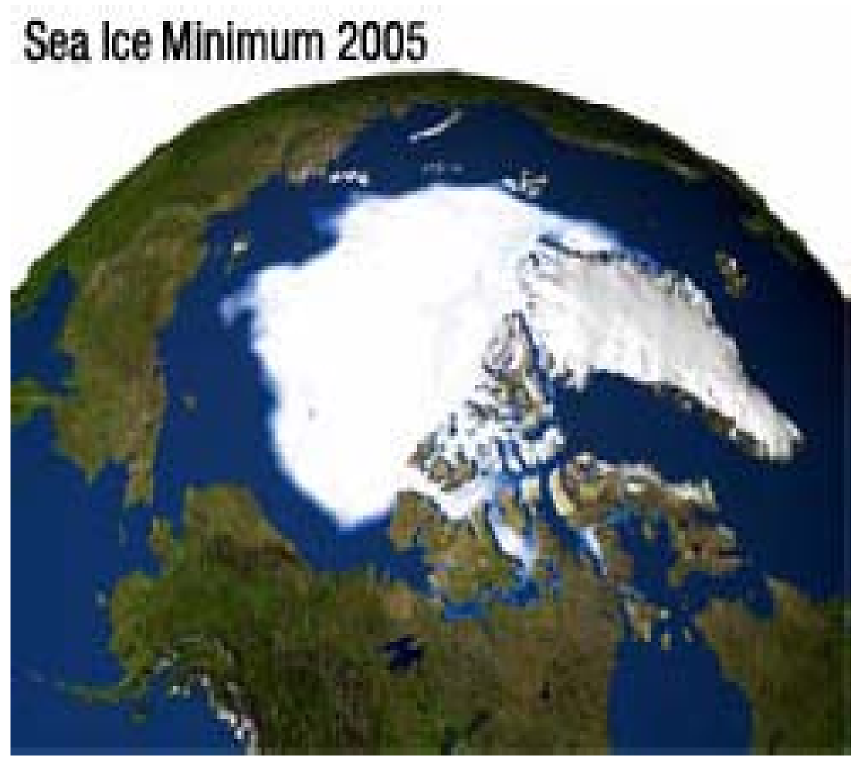
Source: IPCC (2007)

NASA – Goddard Space Flight Centre

Observed sea ice, September 1979



Observed sea ice, September 2005



Determinants of earth’s climate (1)

- Climate: average values of atmospheric conditions (atmosphere, land surface, snow, ice, oceans, rivers, lakes, living oganisms)
- Climatic balance requires that heat exchange between the sun and earth is in equilibrium
- the sun radiates heat to the earth and some is reflected back
- But some radiation gets though and warms the earth

Determinants of earth’s climate (2)

- The earth re-radiates heat back to the sun but some is trapped on the way up by greenhouse gases (GHGs) in the atmosphere, including CO_2, methane, nitrous oxide, CFCs, ozone, water vapour
- As GHGs become more concentrated, the earth heats up so that adequate infrared energy is passed to maintain equilibrium. This means average earth temperature rises because equilibrium requires a hotter earth
- Anthropogenic influences (“forcings”)

Determinants of Earth's Climate (3)

- Earth gets energy from sun – 342 watts/sq.m/sec
- 107 w/sq.m/sec reflected back by clouds, aerosols, albedo effect
- 235 w/sq.m/sec gets through to warm the earth
- The earth re-radiates this warmth back into space
- Earth is quite transparent to sun's short-wavelength radiation (0.2 to 4.0 micrometres)

Determinants of Earth's Climate (4)

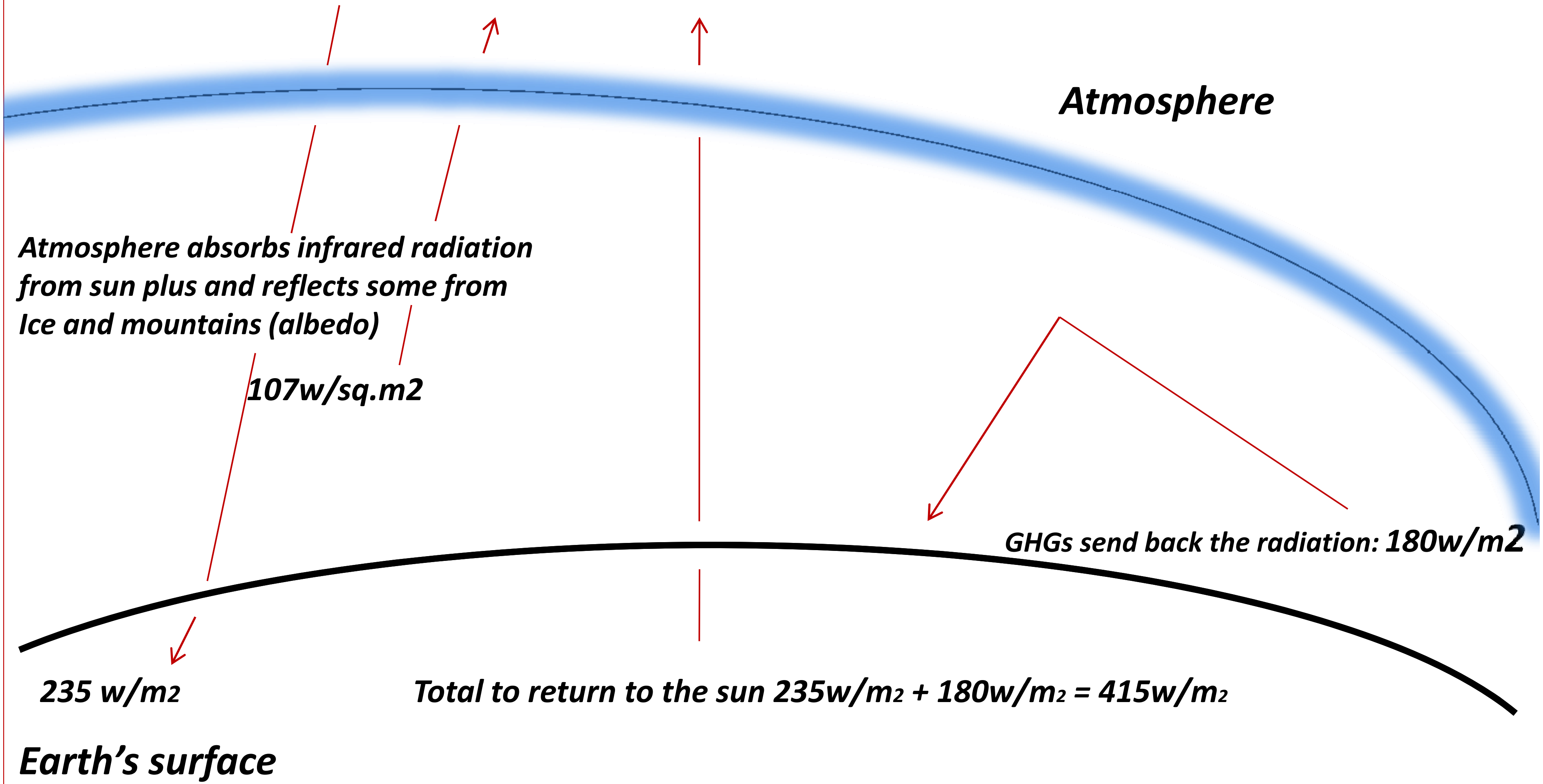
- Earth is less hot than the sun, so wavelength it radiates is longer (4.0 to 100.0 micrometres)
- GHGs opaque to energy of this wavelength so trap 180 w/sq.m/sec, and re-radiate it back to earth
- Temperature equilibrium requires that earth radiates back what the sun radiated down, i.e. 342 w/sq.m/sec, which means it has to radiate back 235 w/sq.m/sec + 180 w/sq.m/sec = 415 w/sq.m/sec e equivalent to an annual average global tempertature of approx 15^{o}C

Determinants of Earth's Climate (5)

- Thus, as the atmospheric concentration of GHGs rises, the proportion of the long wavelength energy radiated from Earth that is re-radiated back down to Earth duly rises (above the current 180 w/sq.m/sec level)
- Correspondingly, the amount of earth-radiated energy that escapes to space via the atmosphere falls below the equilibrium value of around 235 w/m2/sec.

The greenhouse mechanism ***(Cline W.R. 1992 & Lehman 2007)***

Solar radiation - 342w/m2 Radiation from Earth (infrared)



Determinants of earth's climate (6)

- Three fundamental ways to change earth's radiation balance:
  - Changing incoming solar radiation (orbital change or changes in the sun)
  - Changing the fraction of solar radiation that is reflected ("albedo" effect)
  - Altering radiation back from the earth (changing GHG concentrations)
- Feedbacks and non-linear relationships

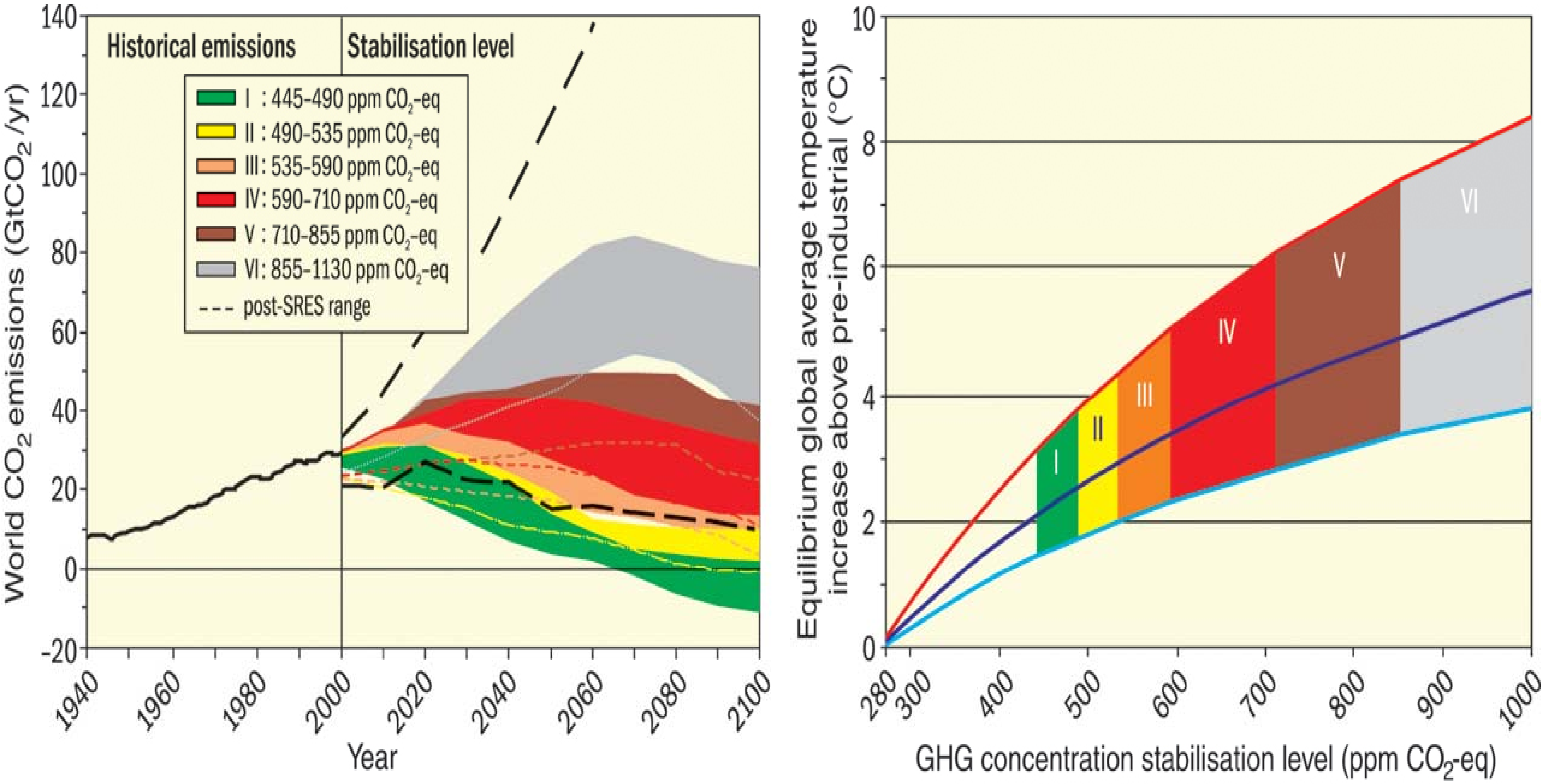
Policy Challenge in Emission Numbers and Temperature

- Pre-industrial emission levels: 280 parts per million of carbon dioxide (ppmCO_2*e*)
- Current: 430 ppmCO_2*e*, rising 2 ppmCO_2*e* per annum (pre-industrial - never above 300 ppmCO_2*e* for last 650,000 years)
- Upper-limit target: 550 ppmCO_2*e*
- Temperature implications at upper limit: increase of 3 degrees C from pre-industrial

Policy Challenge in Emission Numbers and Temperature (cont.)

- Increase up to 5 degrees C would be equivalent to temperature difference between today and last ice age
- 5 degrees C considered socio-politically untenable (warming, precipitation, sea levels, freak climate events etc.)
- Relation between GHGs (emissions) and temperature is non-linear (significant uncertainty about feedback effects)

CO2 emissions and equilibrium temperature increases for a range of stabilization levels (IPCC 2007)



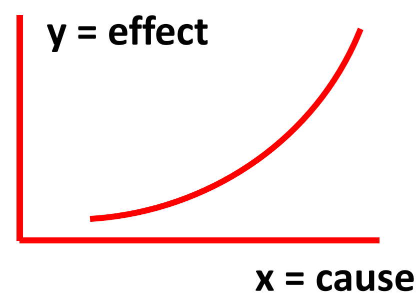
Temperature projections at stabilization relative to pre-industrial levels, ºC

Stabilisation level (ppmv CO2 equivalent)	IPCC TAR 2001	Hadley Centre	Eleven studies (Meinshausen)
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
Source: Stern, N. et al. (2006), ch.1.			

Vulnerabilities

Relationship Between Rising Damages and Impacts

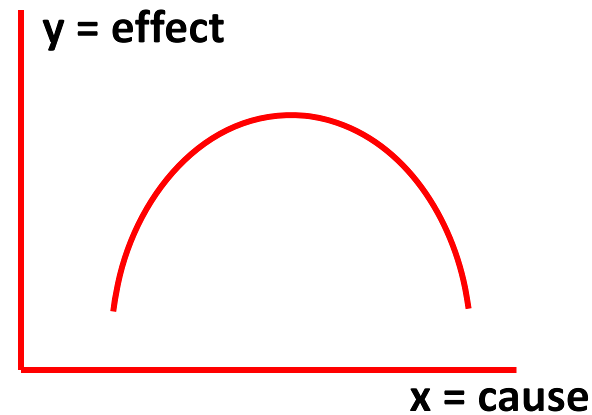
- Non-linear ($y = x^n$)



  - e.g. Water-holding capacity of air increases exponentially with temperature, water cycle intensifies and generates more extreme weather events
  - Storm damage: infrastructure damage will increase in a non-linear manner with wind-speed
  - Cost of sea wall construction proportionately greater as defence height increases

Relationship Between Rising Damages and Impacts (2)

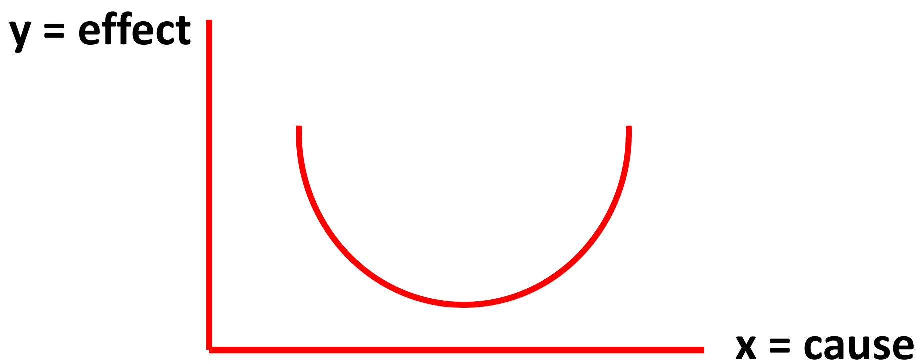
Inverse parabola ($y = x^{-n}$)



- e.g. In cooler regions warming could improve crop-growing conditions that will then deteriorate beyond a critical temperature level

Relationship Between Rising Damages and Impacts (3)

U-shaped curve



- e.g. Sharp increase in mortality once temperature passes critical level, but initial reductions in mortality with warming in cold regions

Countries Most Affected by Climate-Related Threats (IBRD 2009)

Droughts	Floods	Storms	Sea levels	Agriculture
Malawi	Bangladesh	Philippines	Low-lying islands	Sudan
Ethiopia	China	Bangladesh	Vietnam	Senegal
Zimbabwe	India	Madagascar	Egypt	Zimbabwe
India	Cambodia	Vietnam	Tunisia	Mali
Mozambique	Mozambique	Moldova	Indonesia	Zambia
Niger	Laos	Mongolia	Mauritania	Morocco
Mauritania	Pakistan	Haiti	China	Niger
Eritrea	Sri Lanka	Samoa	Mexico	India
Sudan	Thailand	Tonga	Myanmar	Malawi
Chad	Vietnam	China	Bangladesh	Algeria
Kenya	Benin	Honduras	Senegal	Ethiopia
Iran	Rwanda	Fiji	Libya	Pakistan

Vulnerabilities: Asia Region

Key points:

- High level of exposure and sensitivity
- Region on average quite vulnerable to the effects of climate change
- Vulnerabilities vary from one nation to another
- Studies show increases in the intensity or frequency of extreme weather events
- Most sensitive sectors: water and agriculture
- Most sensitive regions: temperate and tropical Asia

The four regions of Asia

1. Arid and semi-arid Asia:

More than 20 countries of the Middle East and Central Asia.
Dominated by Grasslands, rangelands, and deserts
Important cyclonic activity but little precipitation

Recent activity:

- Increasing surface air temperature *(1-2°C over the past 100 years)*
- Acute shortage of water resources, affecting human settlements
- Threats to biodiversity
- Diversion of water system has led to an adverse impact on fisheries and fishery habitat.

2. Boreal Asia:

Northern margin of the Eurasian continent Boreal forest covering the region Siberia and 3 Siberian rivers + the world's largest and oldest lake (Baikal lake)

Recent activity:

- Global warming has a positive impact on agriculture on this region as it expands growing season and the increase in air
- Temperatures lead to an increase in soil temperature.
- Evidence of recession of permafrost

3. Temperate Asia:

Eastern part of the Eurasian continent, including eastern China, Japan, the Korean peninsula, Mongolia, and Chinese Taipei
Dominated by cultivated and irrigated broad plains

Recent activity:

- Surface warming and shifts in rainfalls in the region
- Higher rates of warming in Tibetan Plateau
- Severe droughts and floods

4. Tropical Asia:

This region includes South and South-East Asia
Ecologically rich in natural and crop-related biodiversity
Mainly agricultural regions but also 7 of the 25 largest cities in the world

Recent activity:

- Agriculture productivity in this area is particularly sensitive to increasing temperatures and studies show significant changes in nature and monsoons.

Determinants of Vulnerability

According to the Australian Greenhouse Office report, *Climate Change Risk And Vulnerability*, vulnerability to climate change depends on:

- Exposure: Asia is exposed to extreme conditions in particular the influences of monsoons.

  + Particularly influenced by El Niño-southern oscillation and cyclones
- Sensitivity: Nations and sectors have different sensitivity to climate change. Ability to manage water storage and infrastructure have an impact on a region's sensitivity and therefore on its vulnerability to climate change.
- Adaptive capacity: Some Asian regions have experienced rapid structural change and growth that help to adapt to climate change (e.g. China and India)

  Other regions have suffered from stagnating growth that leaves limited options to the adjustment (e.g. small island states)
- Rapid exploitation and degradation of natural resources due to rapid urbanisation reduces the amount of resources to address climate change effects.

Examples of climate change impacts (I)

Agriculture and food production	Hydrology and water resources	Oceans and coastal zones	Biodiversity and natural ecosystem	Human health
• Water stress, increasing temperatures • Increasing frequency of el Niño, affecting rice, maize and wheat production • Irrigation systems affecting water quality and supply • Sea level rise + frequent storms = inundation of prime agriculture and crop damage	• Changing pattern of runoff and river flows. • Glaciers melting faster (except in some regions due to winter precipitations) •Water shortages in regions such as China. • Arid and semi-arid regions have problems meeting water demand	• In the Boreal coastal zone sea-ice formation and decay • Permafrost influenced by global warming • In monsoon Asia, cyclone-prone coastlines •Sea Water intrusion in coastal plains due in part to severe droughts • Coral bleaching	• Increased intensity and spread of forest fires due to spring precipitation •Reduced growth of grass lands and increasing bareness of the ground surface • Increased solar radiation, drying up of wetlands (Pakistan, Bangladesh, India and China)	• Heat waves and extreme summer temperatures • Serious health risks and deaths (bacterial proliferation) • Severe floods, droughts and rainfall associated with poverty diarrhoea and infectious diseases • Drinking water contamination, water-borne diseases

Source: Climate change 2007, The Fourth Assessment Report of the Inter-Governmental Panel on Climate Change

Projected temperature changes for Asia/ Pacific subregions

Region		Season				
	Year	**Annual *(Average annual temperatures in °C)***	**From December to February *(°C)***	**From March to May *(°C)***	**From June to August *(°C)***	**From September to November *(°C)***
Arid and semi-arid Asia	2030	1.2 (0.6 - 2.3)	1.3 (0.6 - 2.7)	1.2 (0.5 - 2.4)	1.2 (0.5 - 2.3)	1.2 (0.6 – 2.2)
	2070	3.2 (1.3 - 7.1)	3.4 (1.3 - 8.3)	3.2 (1.0 -7.3)	3.1 (1.1 - 7.1)	3.1 (1.2 – 6.8)
Temperate Asia	2030	0.9 (0.4 - 1.9)	1 (0.4 - 2.5)	0.8 (0.3 - 1.3)	0.8 (0.4 - 1.7)	0.9 (0.4 - 1.8)
	2070	2.4 (0.9 - 5.7)	2.8 (0.9 - 7.7)	2.3 (0.8 - 5.5)	2.2 (0.8 - 5.3)	2.4 (0.9 - 5.6)
North Tropical Asia	2030	0.8 (0.4 - 1.3)	0.8 (0.4 - 1.4)	0.8 (0.4 - 1.4)	0.8 (0.4 - 1.4)	0.8 (0.4 - 1.3)
	2070	2.1 (0.9 - 4)	2.1 (0.8 - 4.1)	2.1 (0.9 - 4.2)	2 (0.8 - 4.1)	2 (0.8 - 4)
South Tropical Asia	2030	0.8 (0.4 - 1.3)	0.8 (0.4 - 1.3)	0.8 (0.4 - 1.4)	0.8 (0.4 - 1.3)	0.8 (0.4 - 1.3)
	2070	2.1 (0.9 - 4)	2.1 (0.9 - 4.1)	2.1 (0.9 - 4.2)	2.1 (0.8 - 4.1)	2.1 (0.8 - 4)

Source: Climate Change in the Asia/Pacific Region
A Consultancy Report Prepared for the Climate Change and Development Roundtable
ª central estimate of warming (low warming scenario-high warming scenario)

Main future impacts and challenges (I)

Agriculture and food	Hydrology and water resources	Coastal and low lying areas	Natural ecosystem and biodiversity	Human health and social vulnerabilities
• Decreases in cereal production but differences among regions: ➢East, South Asia: increasing crop fields ➢Central, South Asia: decreasing crop fields • Asia rice production could decline by3.8% • Northward shift of agricultural zones	• Impacts + or - depending on the areas • Changes in runoff of river basins could affect the power output of hydropower generating countries (e.g. Tajikistan) • Increased probability of events such as mudflows or avalanches	• Rising rates of sea-level between 1.5-4.4mm/yr • Sea level rise leads to higher wave and storm and has an impact on coast protection structures and on the residence of million of people	Asia's biodiversity at risk • Boreal forests moving North • Forest ecosystem affected (e.g. Korean pines forest, Japan and Pakistan) • Spread of forest fires in North and South-East Asia	• Climate change-related diseases appear such as heat stress or pollen disease (which increases when temperature rises) • Studies have shown links between high temperatures and cerebral infarction, ischemia and infectious and viral diseases.

Main future impacts and challenges (II)

Agriculture and food	Hydrology and water resources	Coastal and low lying areas	Natural ecosystem and biodiversity	Human health and social vulnerabilities
• Decrease in milk yields in animals (due to limited herbaceous production and water intake) • Reduction of primary fish production in the tropical oceans	• Melting glacier have - impact on downstream agriculture • Environmental problem due to droughts and floods: expansion of areas under severe water stress	• Most affected coast: South Asia (along coast from Pakistan, India, Sri-Lanka and Bangladesh) • Possibilities of low lying area inundations, drowning coastal marshes and wetlands; and increasing salinity of rivers, bays and aquifers.	• Natural grassland coverage and grass yield projected to decrease • Permafrost degradation leading to ground surface subsidence and pounding (e.g. for a 3 °C temperature rise, most Tibetan Plateau glaciers shorter than 4 km will disappear)	• Climate change has an impact on natural resource system and therefore affects human sustenance and livelihoods (migration) And it could led to Instability and conflicts • Production losses may increase undernourished population • Financial aspects (damages costs)

Source: Climate change 2007,The Fourth Assessment Report of the Intergovernmental Panel on Climate Change

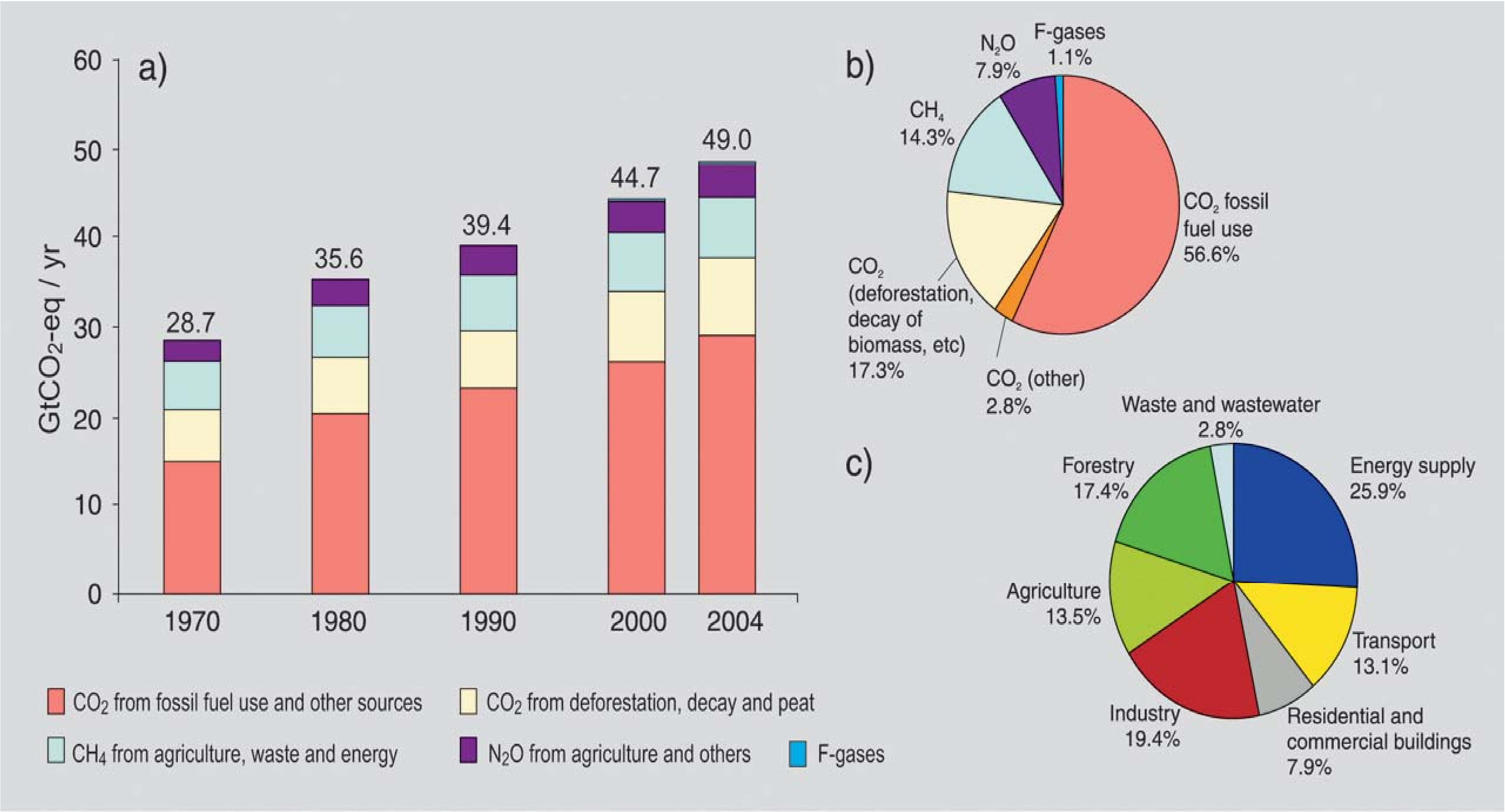
Sources of Greenhouse Gases, Emissions Growth and Paths to Mitigation (Abatement and Adaptation)

Recap: Understanding and Projecting Emissions Growth

Four facts:

- GHG concentration currently is 430ppm CO_2e (1800 about 280ppm)
- Emissions are development-driven: close correlation between emissions/head and GDP/head both across time and across countries
- Emissions since 1950 have grown at 2.5% per year: in 2000 were 42Gt CO_2e
- North America + Europe responsible for 70% of CO_2 emissions post-1850

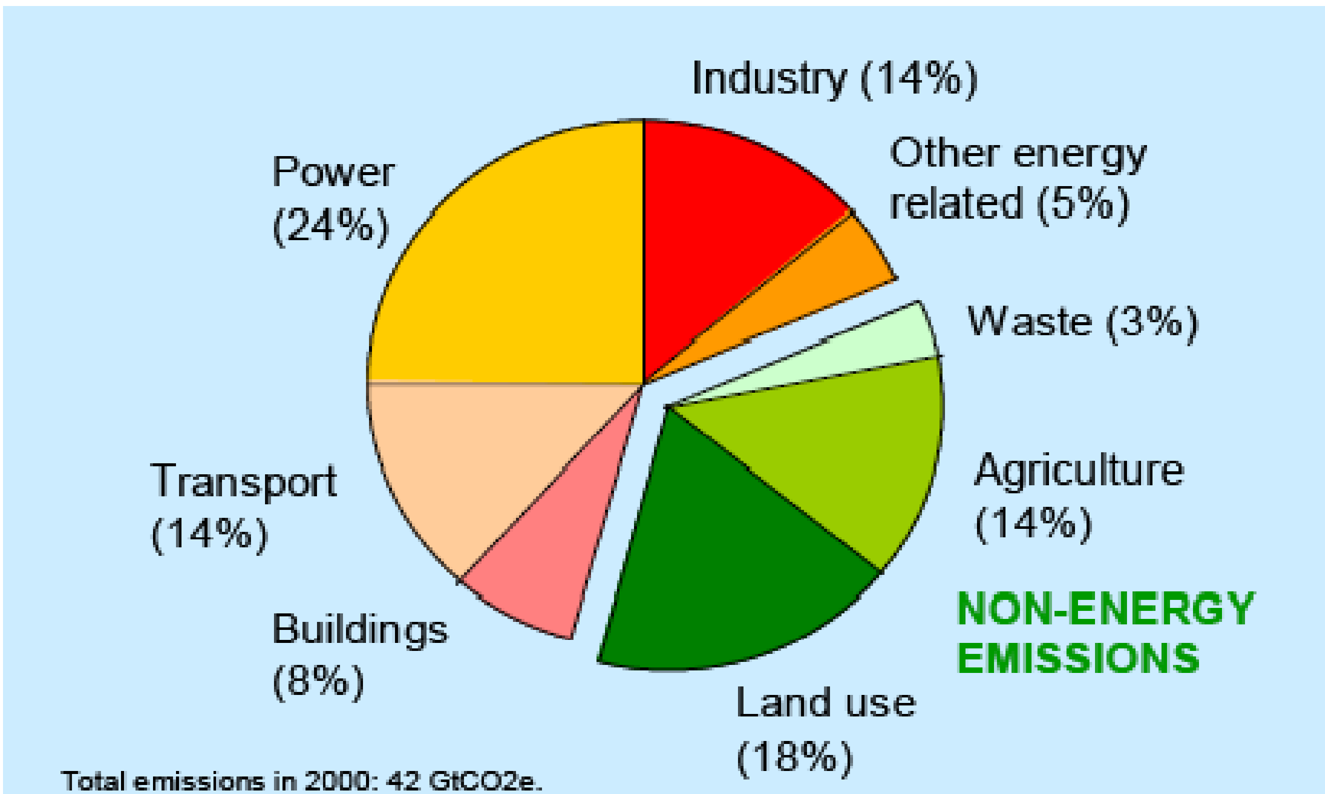
Main Sources of Anthropogenic GHGs



GHG Emissions by Sector

Energy breakdown:

- **Two-thirds (28Gt) energy-related**
- **One-third (14Gt) non-energy-related: land use + agriculture**



Shares of Global CO_2 emissions by country (2004)

Henson, “Climate Change” (2007)

Country	Percentage	Country	Percentage
United States	20.9	Mexico	1.5
China	17.3	South Africa	1.5
Russia	5.3	Iran	1.5
India	4.6	Indonesia	1.3
Japan	4.3	France	1.3
Germany	2.8	Brazil	1.1
Canada	2.2	Spain	1.1
United Kingdom	2.0	Ukraine	1.1
South Korea	1.6	Australia	1.1
Italy	1.6	Saudi Arabia	1.1

Kaya Identity

The Kaya Identity is useful for understanding the proximate determinants of *energy-related* emissions (i.e. the two-thirds)

$F = P * (G / P) * (E / G) * (F / E)$, where:

F is CO_2 emissions from human sources,

P is population,

G is GDP

E is primary energy consumption

So F depends on population, GDP per head, energy intensity of GDP, and the carbon intensity of energy

The table abstracts from population size and focuses on emissions per head, which are related to income per head, carbon intensity of energy, and energy intensity of GDP

Country/ grouping	CO_2 per head	GDP per head	CO_2 emissions/ energy use	Energy use/GDP
USA	20.4	34430	2.52	230.8
EU	9.4	23577	2.30	158.0
UK	9.6	27176	2.39	140.6
Japan	9.8	26021	2.35	155.7
China	3.0	4379	3.08	219.1
India	1.1	2555	2.05	201.3
OECD	11.7	24351	2.41	193.0
Economies in transition	7.7	7123	2.57	421.2
Non-Annex 1 parties	2.2	3870	2.48	217.8
World	**4.0**	**7649**	**2.43**	**219.5**

Notes from previous table:

- Wide variation in emissions per head as a function mainly of income per head and to a lesser extent energy intensity of output, while carbon intensity of energy is very similar across countries
- Some factors determining the ratios change slowly (e.g. energy endowments), others faster (relative prices of energy sources, technology, production structures)

This table breaks down annual growth rates of energy-related CO_2 emissions (1992-2002) in % into (accounting) contributions from: GDP growth per head, Δ in carbon intensity of energy use, Δ in energy intensity of GDP and population growth

Country/ grouping	CO_2 emissions ($GtCO_2$)	GDP per head	Carbon intensity	Energy intensity	Population
USA	1.4	1.8	0.0	- 1.5	1.2
EU	0.2	1.8	- 0.7	- 1.2	0.3
UK	- 0.4	2.4	- 1.0	- 2.3	0.2
Japan	0.7	0.7	- 0.5	0.2	0.3
China	3.7	8.5	0.5	- 6.4	0.9
India	4.3	3.9	1.1	- 2.5	1.7
OECD	1.2	1.8	- 0.3	- 1.1	0.7
Economies in transition	-3.0	0.4	- 0.6	- 2.7	- 0.1
Non-Annex 1 parties	3.3	3.5	0.3	- 2.0	1.6
World	**1.4**	**1.9**	**- 0.1**	**- 1.7**	**1.4**

Notes from previous table

- Emissions are growing at the same rate as population for the world, that is, by 1.4%p.a.
- Carbon intensity is hardly changing
- Falls in energy intensity are, therefore, roughly compensating for growth in GDP/head

Choosing the abatement path over time (Stern Chap. 8)

Suppose the aim of stabilizing is 550ppm CO_2eq

Lock-in Delayed abatement requires faster rates of decline of emissions later on. One cost of this is that both investment and R&D effort may be inefficiently skewed towards high-emission technologies.

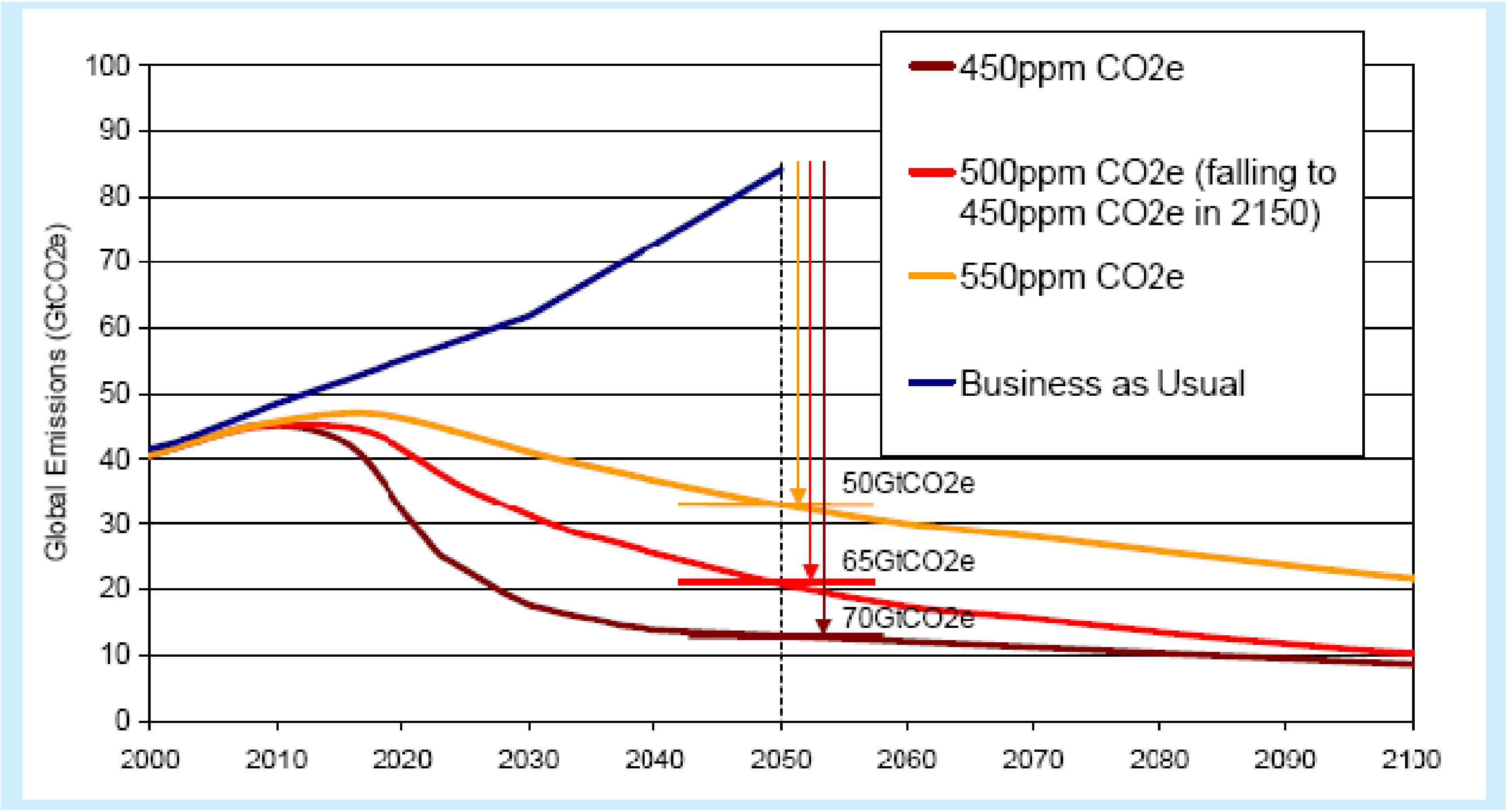
Irreversible impacts of warming on an 'overshoot' path, global temperature also overshoots.

Future technological advance This could reduce abatement costs later on, favouring delay, but might depend on current abatement, favouring early action

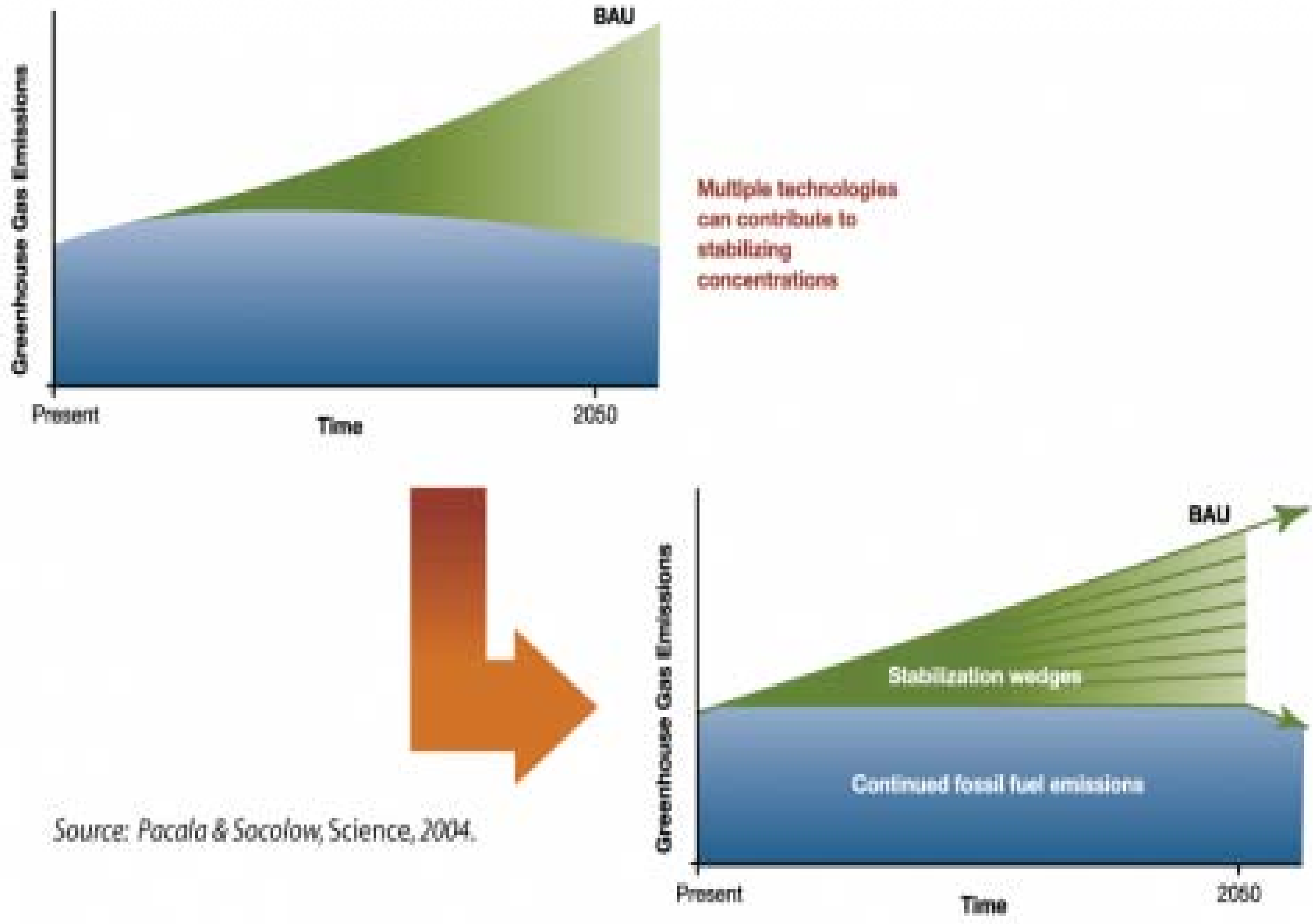
'Eta' effect Other things equal, it is better to pin the abatement costs on our richer descendants than on ourselves.

Illustrative emissions paths

What this graph shows is that, on the orange path, an emissions cut of about 25% by 2050 corresponds to a cut of about 60% on BAU at that date



Pascala and Socolow: The Wedges Concept



Source: Pacala & Socolow, Science, 2004.

The stabilization wedges

- Intensified application of existing technologies could stabilize today's emissions of CO_2 up to 2050
- Stabilization is represented by a "flat" trajectory of fossil fuel emissions at 7 GtC/year, and BAU is represented by a straight-line "ramp" trajectory rising to 14 GtC/year in 2054. The "stabilization triangle," located between the flat trajectory and BAU, removes exactly one-third of BAU emissions.
- There are 15 wedges, but 7 needed. Refer only to energy-related CO_2 emissions, so their baseline is 25Gt CO_2 (compare 28Gt CO_2eq on slide 2).

The 15 wedges

- Efficient vehicles
- Reduced use of vehicles
- Efficient buildings
- Efficient coal plants
- Gas for coal
- Capture and storage technologies X 3
- Nuclear for coal
- Renewables X 4
- Reduced de-forestation and reforestation
- Conservation tillage

Scope for renewables in emission abatement (Heal, VoxEU)

- We can replace some fossil fuel power with renewable power without a major cost increase, but we cannot hope to replace a major fraction of our fossil power with intermittent power sources such as wind and solar – unless we can develop storage technologies.
- Without such storage technology, we will have to rely on non-renewable but carbon-free power sources – such as nuclear power and coal with carbon capture and storage – to provide a significant part of our power

Abatement costs: key underlying assumptions

Summarizing the routes to reduced emissions

Reduced demand for emissions-intensive goods and services

Efficiency gains from existing, cost-effective technologies (house insulation, fuel efficiency in cars)

Application of technologies that are not (very) cost-effective at current market prices (wind and wave power: relevance of learning-by-doing externality, which could justify subsidy even without climate change)

Reduction of non-fossil-fuel emissions (limiting deforestation)

Resource costs

Estimated to be between -1% and +3.5% of GDP in ch.9 of the Stern Review

But ‘broader-based’ estimates in ch.10 of the Stern Review are in the range -2% to +5%. Why this difference in the range?

Uncertainty over (a) needed scale of abatement, (b) pace of technological advance and innovation, (c) ‘policy flexibility’.

Policy flexibility refers to how efficiently the world’s choices over ‘when’, ‘what’ and ‘where’ will be. ‘Where’ is especially tricky: Halting deforestation in Amazonia may be an efficient abatement tool, but who will bear the costs?

Adaptation and Abatement

- Abatement refers to actions which affect atmospheric concentrations of GHGs over time
- Adaptation refers to actions which reduce costs given GHG concentrations
- Assuming that the marginal benefit from either adaptation or abatement is a declining function of expenditure in each case, then the balance between them should be chosen to equalize the marginal benefits.

Autonomous versus policy-driven adaptation

- What kinds of adaptation can be left to private actions? Basic reasons why private actions will be insufficient:
  - Uncertainty and imperfect information; missing markets, including public goods; financial constraints, particularly those faced by the poor; bounded rationality - lack of cognitive power to make precise optimization decisions
- So policy intervention may be justified:
  - information provision; regulation (land-use planning and performance standards); public good provision; finance (filling gaps in credit availability)

Regulation for Abatement and Adaptation

- Particular relevance to adaptation and subsidization
- The potential costs of alternative regulatory choices
  - **C** is the (differential) cost of a regulation and **R** is the consequent (differential) reduction in emissions, so **C/R** is the implicit price of carbon which can be compared with the social cost of carbon (see R.K. Eastwood here and elsewhere)

Varying costs of mitigation

(Llewelyn)

Activity	Implicit cost of carbon ($)	Social cost of carbon ($)
Electricity from land-based wind turbines	0.14 (negative)	30
Hydro electricity	Negative	30
Energy-efficient light bulbs	10	30
Draught-proofing insulation for a house	130	30
Reducing automobile emissions	700 – 2,300	30
Solar thermal electricity	500	30
Solar photo-voltaic cells	6,300	30