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What are the likely dynamics of the carbon-climate-human system into the future, and what points of intervention and windows of opportunity exist for human societies to manage this system?

THE GLOBAL carbon cycle

Ecological and Earth Sciences in UNESCO

Global Carbon Project

Earth System Science Partnership

DIVERSITAS IGBP IHDP WCRP

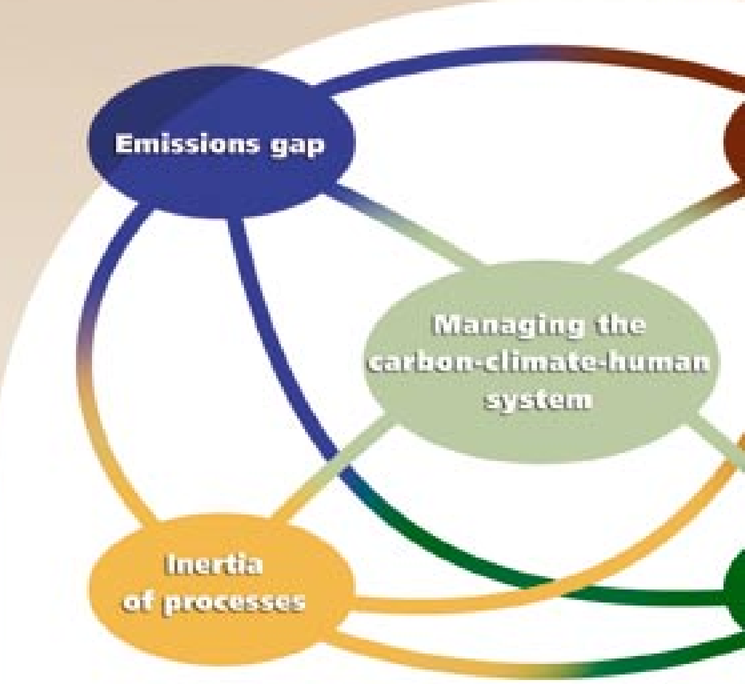
The carbon-climate-human system

The carbon-climate-human system

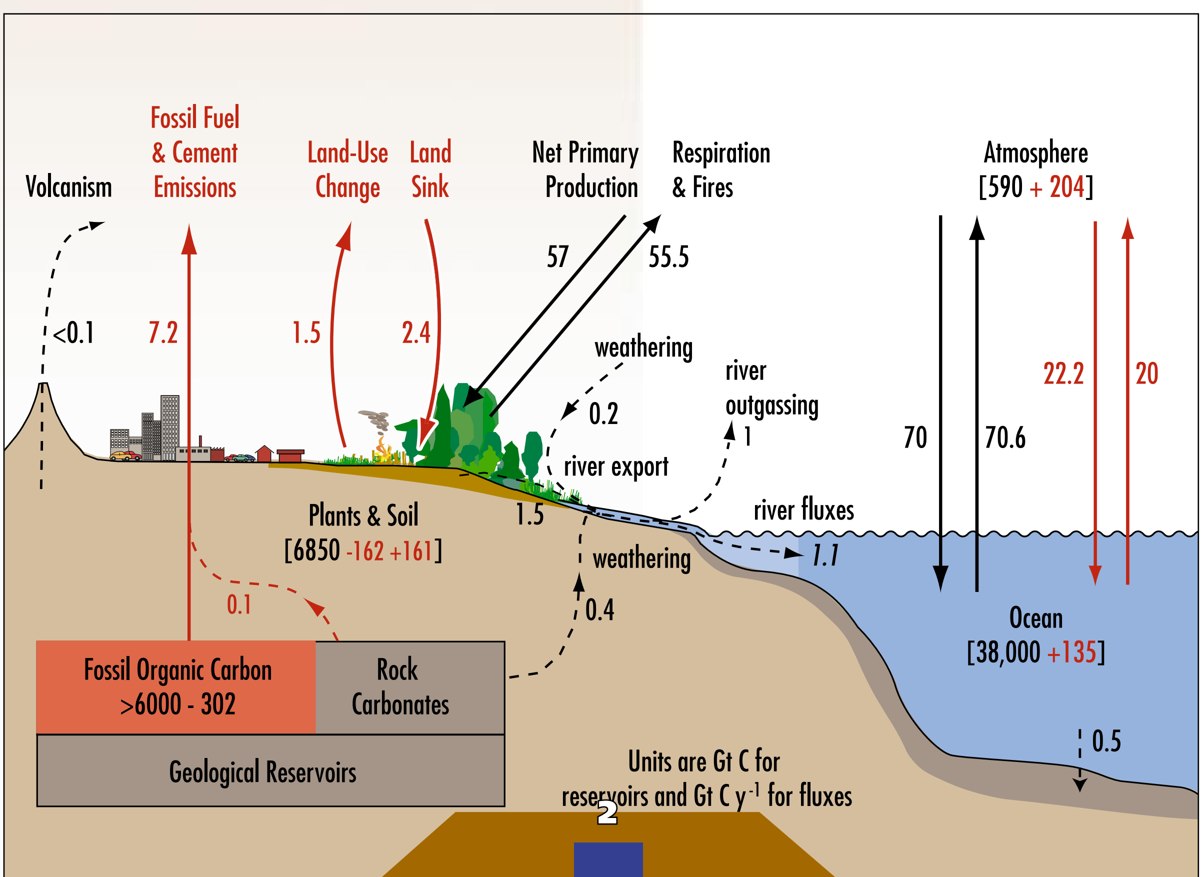
There is growing acceptance that human-driven climate change is a reality. This has focused the attention of the scientific community, policy-makers and the general public on the main causes of such a change: rising atmospheric concentrations of greenhouse gases, especially carbon dioxide (CO_2), and changes in the carbon cycle in general.

There are profound interactions between the carbon cycle, climate, and human actions. These interactions have fundamental implications for the long-term management of CO_2 emissions required to stabilize atmospheric CO_2 concentrations. The coupled carbon-climate-human system encompasses the linked dynamics of natural biophysical processes and human activities.

Some of its key attributes include: the *emissions gap*, *vulnerability*, *inertia of processes*, and the need for a *systems approach* that integrates carbon management into a broader set of rules and institutions governing the human enterprise.



Current (2000-2005) global carbon cycle. Pools of carbon are in Gt and annual fluxes in Gt C y^{-1}. Background or pre-anthropogenic pools and fluxes are in black. The human perturbation to the pools and fluxes are in red.



ppm: parts per million – Gt C: Billion tonnes of carbon

Emissions Gap

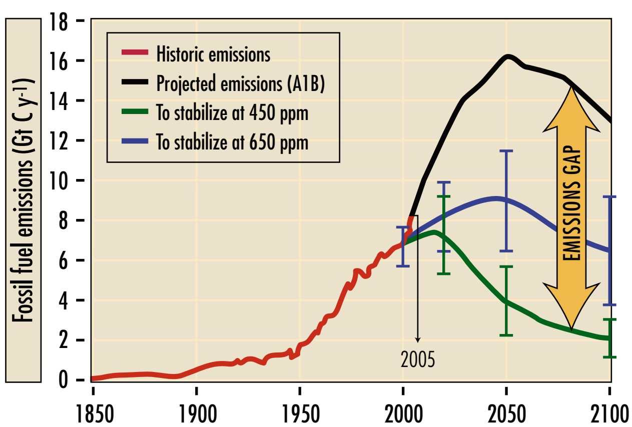
Decreasing future CO_2 emissions is crucial to stabilize the climate, but no single technology or approach will be sufficient. Instead, a large portfolio of solutions is required to address the technological and economic realities of disparate regions. Elements of this portfolio include:

- replacement of fossil-fuel-based energy systems with technologies that provide energy services while emitting little or no CO_2 into the atmosphere;
- greater efficiency in energy generation from fossil fuels;
- conservation and efficiency in energy use;
- geological or increased biological sequestration of CO_2.

There is evidence that sufficient technological strategies will not arise automatically through market forces. Appropriate policy settings are therefore needed to stimulate the required change.

The need for a combination of technology, market forces and policy-initiated signals is well illustrated with the concept of the *emissions gap*. The emissions gap is the difference between unconstrained CO_2 emissions and the future emissions needed to stabilize atmospheric CO_2 at a level which carries an acceptably low risk of dangerous interference with the climate system. Despite the assumptions that by the end of the 21st century at least half of the power energy will be generated from renewable sources, the emissions gap could be as much as 12 Gt C y^{-1} by the middle of this century in the absence of an appropriate economical and policy mitigation framework.

Closing the gap between the present levels of CO_2 emissions and the necessary levels of future emissions for stabilization of athmospheric CO_2 will require a combination of both technological and socio-economic and political strategies.



Prepared by Michael R. Raupach

The trajectory of current emissions follows the IPCC-SRES (2000) 'A1B' scenario (a globalised, technologically advanced world where energy production builds on a broad portfolio of fossil- and non-fossil-fuel sources). Current emissions are growing much faster than rates required for stabilization at either 450 or 650 ppm.

Vulnerability

Studies have shown that ecosystems tend to respond to a warmer climate by releasing more carbon to the atmosphere and actually accelerating climate change. This change is expected to occur during this century because natural carbon pools containing hundreds of billions of tonnes of carbon might become vulnerable turning into carbon sources as global warming and deforestation continue.

Some of the most *vulnerable pools* are: carbon in frozen soils and sediments, carbon in cold and tropical peatlands, biomass-carbon in forests vulnerable to fire, methane hydrates in permafrost and continental shelves, and ocean carbon concentrated by the solubility and biological pumps.

Preliminary analyses indicate that over the next 100 years the vulnerable carbon pools could release enough carbon to cause an increase of around 200 ppm in atmospheric CO_2, on top of a CO_2 increase from fossil fuel combustion in the order of 200 - 500 ppm.

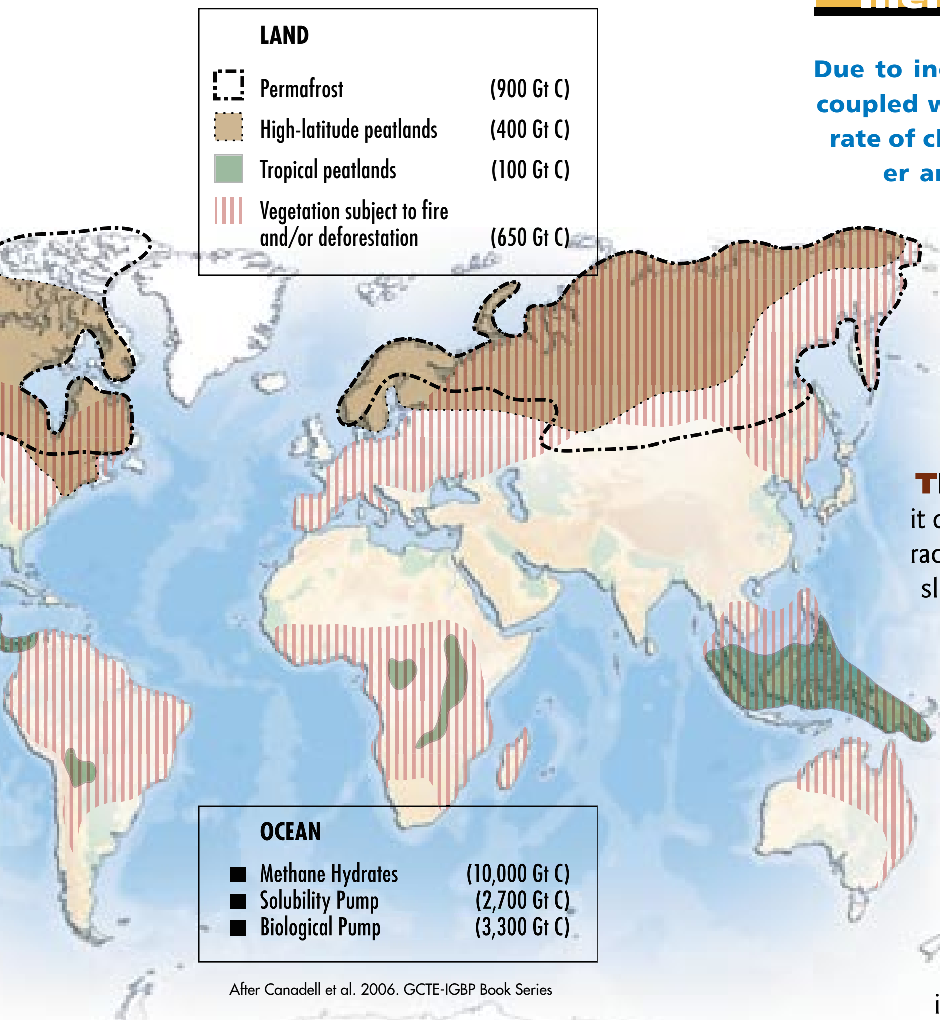
Additional system vulnerabilities will result from changing atmospheric CO_2 concentrations, including the acidification of oceans that will lead to widespread changes in marine biota, and affect the capacity of oceans to store carbon.

Significance of CO_2 mitigation optio

	Rapidly Deployable
Minor Contributor ≤ 3%	◆ Biomass co-fire in coal-fired power plants ◆ Cogeneration – small scale distributed ◆ Expanded use of natural gas combined cycle ◆ Hydropower ◆ Wind without storage equal to 10% of electric grid ◆ Niche options: wave and tidal, geothermal, small scale solar ◆ Forest management
Major Contributor > 3%	◆ Carbon storage in agricultural soils; no-till cultivation, cover crops ◆ Improved appliance, lighting and motor efficiency ◆ Improved buildings ◆ Improved industrial processes ◆ Improved vehicle efficiency ◆ Non-CO_2 gas abatement from industrial sources including coal mines, land fills, pipelines ◆ Non-CO_2 gas abatement from agriculture including soils, animal industry ◆ Reforestation/land restoration ◆ Stratospheric sulphate aerosol geoengineering

After Caldeira et al. 2004. SCOPE 62

Vulnerable Carbon Pools



After Canadell et al. 2006. GCTE-IGBP Book Series

ns by deployment timescale

Not Rapidly Deployable

- Building-integrated photovoltaics

- Biomass to hydrogen or electricity, possibly with carbon capture and sequestration
- Biomass to transportation fuel
- Cessation of net deforestation
- Energy efficient urban and transportation system design
- Fossil fuel carbon separation with geologic or ocean storage
- Highly efficient coal technologies e.g. Integrated Gasification Combined Cycle (IGCC)
- Large scale solar with H_2, long-distance transmission, storage
- Next generation nuclear fission
- Reduced population growth
- Wind with H_2, long-distance transmission, storage
- Speculative technologies – direct atmospheric scrubbing, space solar, fusion, exotic geoengineering, bioengineering

Inertia of processes

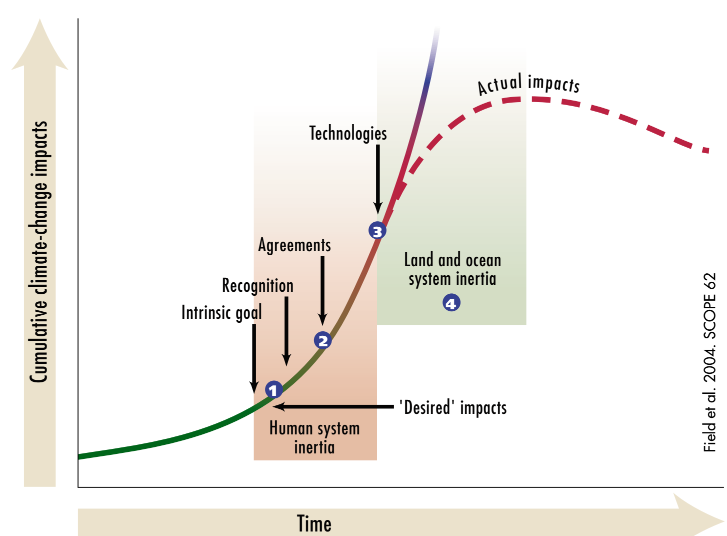
Due to inertia in human reaction to climate change, coupled with inertia inherent in natural systems, the rate of climate change is predicted to be much greater and more difficult to reverse than originally estimated.

In the biophysical system, *inertia* depends on several factors: slow oceanic uptake of CO_2, long-lived CO_2 in the atmosphere, saturation of the land net carbon sink, and the role of oceans in buffering changes in atmospheric temperature.

The inertia of human reaction to climate change makes it difficult to rapidly reduce the carbon intensive character of global development. Energy systems respond slowly to energy innovations because of the huge capital and institutional investment in fossil-fuel-based systems for both stationary and transport energy.

The interplay of these forces is such that it will take decades to achieve decreases in the effects of the present anthropogenic CO_2 emissions. Even when these emissions do begin to decrease, atmospheric CO_2 will continue to rise for up to as much as a century, and global temperatures will increase for two or more centuries, locking the world into continued climate change for this period.

Effective management of this system inertia depends on early and consistent actions.



Inertia of processes in the coupled carbon-climate-human system.

There are delays associated with:
1. identifying and accepting that climate change is a reality;
2. negotiating agreements on how to deal with it;
3. developing and implementing the technology required; and
4. internal dynamics of the land and ocean systems.

Due to these delays, rates of climate change will be far greater than originally identified as acceptable.

Signs of trouble : Key carbon measurements and projections pointing to rapid acceleration of the carbon-climate feedback.

Atmospheric CO_2 concentrations

- CO_2 concentration in 2006 has reached 380 ppm, 100 ppm higher than pre-industrial times
- 380 ppm is the highest CO_2 concentration in the last 600,000 years and probably in the last 20 million years
- For the period 2000-2005 the growth rate of atmospheric CO_2 was 2.05 ppm per year, the highest growth rate on record and a significant increase from earlier trends (1.25 for 1970-1979, 1.58 for 1980-1989, and 1.49 for 1990-1999)

Carbon emissions

- Over the last 100 years fossil fuel emissions have increased by more than 1200%
- Carbon emissions from fossil fuel combustion and cement production in 2005 were 7.9 Gt C, 28% higher than in 1990 (Kyoto Protocol base year)
- Over the last five years deforestation, almost exclusively occurring in tropical regions, was 1.5 Gt C per year, accounting for one fifth of total anthropogenic carbon emissions

Carbon futures

- The world's energy demand is expected to rise by 50% by 2030, and unless major changes are implemented rapidly, 80% of that increase will come from fossil fuels (oil, gas, and coal).
- With current international strategies, global emissions are expected to rise to between 12 and 18 Gt C per year by 2050 (2 to 3 times levels in 2000)
- Net CO_2 removal by the terrestrial biosphere is highly variable and is expected to decrease by the middle of the 21st century

Systems Approach

Towards sustainable management of the carbon-climate-human system

Managing the carbon-climate-human system to achieve atmospheric CO_2 stabilization requires integrated solutions. These solutions should be based on effective criteria for comparing options, accounting both for their impacts on greenhouse gas emissions and impacts on ecosystems and human societies.

Examples of other impacts showing the need for a systems approach are:

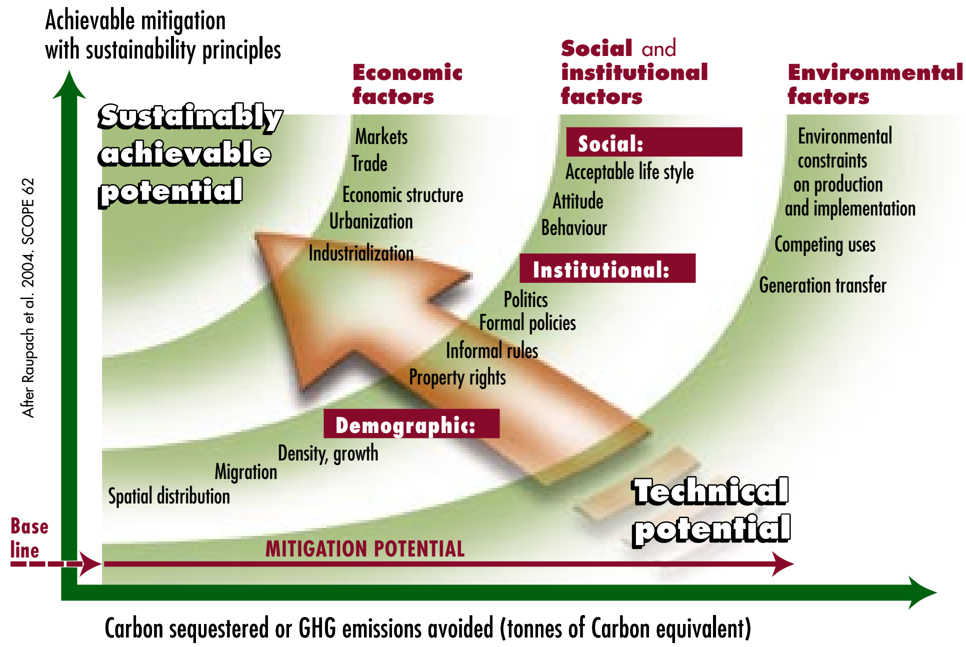
- the potential impacts of large afforestation programmes on the hydrological cycle, particularly on downstream agricultural activity and wetland conservation;
- the likely impacts of ocean iron fertilization on the composition and functioning of marine biota; and
- issues of security, disposal, and societal acceptance for nuclear energy and carbon sequestration options.

Four kinds of tools, working together, are needed to drive the required changes:

- **technical:** a portfolio of mitigation options;
- **economic:** market mechanisms for maximizing the effectiveness of mitigation;
- **policy:** regulatory instruments for limiting emissions, such as an internationally consistent carbon price signal;
- **cultural:** patterns of consumption, social organization, knowledge and values.

Integrating these tools into managing the carbon-climate-human system should be implemented through policies which consider the potential of emissions mitigation, resource trade-offs and the socio-economic constraints and opportunities consistent with pathways of development, equity, and sustainability.

Effective management of the carbon-climate-human system requires **early actions**. The above tools are necessary to prevent the system from moving towards high CO_2 concentrations that are locked in for decades to centuries because of system inertia and lead to increasing vulnerability of the carbon cycle and therefore an acceleration of positive carbon climate feedbacks.



Effects of economic, environmental, and social and institutional factors on the mitigation potential of a carbon management strategy.

Readings

This policy brief draws on:

Annual update of the global carbon budget: www.globalcarbonproject.org/budget.htm

Field CB, Raupach MR (2004) The Global Carbon Cycle. Integrating Humans, Climate, and the Natural World. SCOPE 62, Island Press, Washington.

Global Carbon Project (2003) Global Carbon Project: Science framework and implementation. Canadell JG, Dickinson R, Hibbard K, Raupach M, Young O (eds), Earth System Science Partnership Report No. 1. GCP Report No. 1, 69pp, Canberra.

IPCC – Climate Change 2001: http://www.grida.no/climate/ipcc_tar/

Useful links

SCOPE-Scientific Committee on Problems of the Environment: http://www.icsu-scope.org

Island Press: http://www.islandpress.org

Global Carbon Project: http://www.globalcarbonproject.org

Integrated Global Carbon Observation: http://www.ioc.unesco.org/igospartners/carbon.htm

Trends in Atmospheric Carbon Dioxide: http://www.cmdl.noaa.gov/ccgg/trends/

Carbon Cycle Greenhouse Figures: http://www.cmdl.noaa.gov/gallery2/v/gmd_figures/ccgg_figures/

Maps of global carbon trends from World Resource Institute: http://earthtrends.wri.org/maps_spatial/index.php?theme=3&C

BP Statistical Review of World Energy: http://www.bp.com/productlanding.do?categoryId=91&contentId=7017990

International Energy Agency: http://www.iea.org/Textbase/subjectqueries/index.asp

World Climate Research Programme: http://www.wmo.ch/web/wcrp/wcrp-home.html

Hydrology for Environment, Life and Policy - Water and Climate Programme: http://www.unesco.org/water/ihp/help

Global Change in Mountain Regions: www.unesco.org/mab/ecosyst/mountains.shtml

Adaptation to Climate and Coastal Change in West Africa: http://english.accc-afr.org/

International Ocean Carbon Coordination Project: http://www.ioccp.org

Intergovernmental Oceanographic Commission of UNESCO – Climate: http://ioc.unesco.org/iocweb/climateChange.php

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