Global carbon budget and challenges for making low carbon society- Why Asia matters?

Shobhakar Dhakal
Executive Director, Global Carbon Project

*Visiting Associate Professor, Graduate School of Environmental Studies, Nagoya University
*Guest Research Scholar, International Institute for Applied Systems Analyses (IIASA), Austria
International Scientific Programs on Global Environmental Change Science

Goal
Policy-relevant understanding of the global carbon cycle and its management
Outline

1. CO₂ in climate change context
2. CO₂ emissions from fossil fuel and cement, and drivers
3. CO₂ Emissions from Land Use Change
4. Natural CO₂ sinks
5. Closing the global carbon budget
6. Conclusion
Few climate change indicators

- Earth’s surface temperature in rising
- Sea level is rising
- Northern hemisphere snow cover is declining

Source: IPCC AR4 WG 1 Report, pp 14, 6
Radiative Forcing of Various Greenhouse Gases

Radiative forcing is the quantitative measure of the strength of different human and natural agents in causing climate change (relative to 1750)

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>CO₂</th>
<th>NO₂</th>
<th>CH₄</th>
<th>Halocarbons</th>
<th>RF values (W m⁻²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
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<tr>
<td>Stratospheric water vapour from CH₄</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
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<tr>
<td>Stratospheric and tropospheric</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>Med</td>
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<tr>
<td>Surface albedo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.34 [0.31 to 0.37]</td>
<td>Continental to global</td>
<td>Low</td>
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<tr>
<td>Land use</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental to global</td>
<td>Med</td>
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<tr>
<td>Black carbon on snow</td>
<td></td>
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<td></td>
<td>0.35 [0.25 to 0.65]</td>
<td>Continental to global</td>
<td>Med</td>
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<td>Direct effect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.07 [0.02 to 0.12]</td>
<td>Continental to global</td>
<td>Low</td>
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<tr>
<td>Cloud albedo effect</td>
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<td></td>
<td></td>
<td></td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med</td>
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<tr>
<td>Linear contrails</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.1 [0.0 to 0.2]</td>
<td>Local to continental</td>
<td>Med</td>
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<tr>
<td>Solar irradiance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Total net anthropogenic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.7 [-1.8 to -0.3]</td>
<td>Continental to global</td>
<td>Low</td>
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<td></td>
<td>0.01 [0.003 to 0.03]</td>
<td>Continental to global</td>
<td>Low</td>
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<td></td>
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<td></td>
<td></td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
</tbody>
</table>

Global average radiative forcing (RF) estimates and ranges in 2005, IPCC AR4

LOSU: Level of scientific understanding

- Anthropogenic radiative forcing strength is far greater than the natural factors such as solar irradiance.
- As a gas, CO₂ is of prime importance.
- CO₂ has complex dynamic because it is also linked to land and ocean uptakes.
CO₂ Concentration in Ice Core Samples and Projections for Next 100 Years

Projected (2100)

Vostok Record
Law Dome Record
Mauna Loa Record
IPCC IS92a Scenario

Source: C. D. Keeling and T. P. Whorf; Etheridge et.al.; Barnola et.al.; IPCC
Atmospheric CO₂ Concentration

Year 1750: 280 ppm (about)
Year 2008: 385 ppm

38% above pre-industrial, over 100 ppm rise

1970 – 1979: 1.3 ppm y⁻¹
1980 – 1989: 1.6 ppm y⁻¹
1990 – 1999: 1.5 ppm y⁻¹
2000 - 2008: 1.9 ppm y⁻¹

Data Source: Pieter Tans and Thomas Conway, NOAA/ESRL
Factors that Influence the Airborne Fraction

1. The rate of CO$_2$ emissions.

2. The rate of CO$_2$ uptake and ultimately the total amount of C that can be stored by land and oceans:
   - Land: CO$_2$ fertilization effect, soil respiration, N deposition fertilization, forest regrowth, woody encroachment, …
   - Oceans: CO$_2$ solubility (temperature, salinity), ocean currents, stratification, winds, biological activity, acidification, …
Fossil Fuel Emissions and Cement Production

[1 Pg = 1 Petagram = 1 Billion metric tonnes = 1 Gigatonne = 1x10^{15}g]

1990 Emissions: 6.2 Pg C y^{-1}
2006 Emissions: 8.2 Pg C y^{-1}


2008
Emissions: 8.7 PgC
Growth rate: 2.0%
1990 levels: +41%
2000 levels: +29%
2000-2008
Growth rate: 3.4%

Per Capita Emissions (tC/person y^{-1})
Global emission per capita

348 PgC emissions in 1850-2007
Growth rate: 1.0% per year
Growth rate: 3.4% per year
Fossil Fuel Emissions: Actual vs. IPCC Scenarios

- 2007-8: 2% growth
- 2006-7: 3.4% growth

Projection 2009
Emissions: -2.8%
GDP: -1.1%
C intensity: -1.7%

Regional Shift in Emissions Share

- Annex B countries growing slowly
- Non-Annex countries growing rapidly

Largely China and India

- China largest emitter: passed USA in 2006
- India overtook Russia to become third

Fossil Fuel Emissions: Top Emitters (>4% of Total)

Global Carbon Project 2009; Data: Gregg Marland, CDIAC 2009
Regional Emission Pathways (1980-2005)

Raupach et al 2007, PNAS

Developed Countries

No improvements in carbon intensity

Least Developed Countries

Rising emission
Cumulative Fraction of Total Fossil Fuel Emissions 2008

<table>
<thead>
<tr>
<th>Number of Countries</th>
<th>Country</th>
<th>Cumulative Fraction</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>.232</td>
</tr>
<tr>
<td>2</td>
<td>USA</td>
<td>.419</td>
</tr>
<tr>
<td>3</td>
<td>India</td>
<td>.477</td>
</tr>
<tr>
<td>4</td>
<td>Russia</td>
<td>.530</td>
</tr>
<tr>
<td>5</td>
<td>Japan</td>
<td>.573</td>
</tr>
<tr>
<td>6</td>
<td>Germany</td>
<td>.599</td>
</tr>
<tr>
<td>7</td>
<td>Canada</td>
<td>.617</td>
</tr>
<tr>
<td>8</td>
<td>UK</td>
<td>.633</td>
</tr>
<tr>
<td>9</td>
<td>South Korea</td>
<td>.652</td>
</tr>
<tr>
<td>10</td>
<td>Iran</td>
<td>.668</td>
</tr>
<tr>
<td>20</td>
<td>Poland</td>
<td>.800</td>
</tr>
<tr>
<td>50 (2005)</td>
<td>Belarus</td>
<td>.941</td>
</tr>
<tr>
<td>100 (2005)</td>
<td>Moldova</td>
<td>.992</td>
</tr>
<tr>
<td>210</td>
<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>

3 countries 50% Global Emissions
10 countries 2/3 Global Emissions
Top 5 + EU 80% Global Emissions

Gregg Marland, CDIAC 2009
Balance of Emissions Embodied in Trade 2004

Peters and Hertwich 2008, Environ. Sci. & Tech., updated

Warm colors → Net importers of embodied carbon
Cold colors → Net exporters of embodied carbon

MtC
BEET

MtC
Transport of Embodied Emissions

CO₂ emissions (PgC y⁻¹)


Carbon emissions from traded products are assigned to the producers.

Carbon emissions from traded products are assigned to the consumers.

Share of Non-Annex is smaller but rising rapidly.

Additional energy-related CO2 emissions by country and region in 2030 vs 2006 (ref scenario)

China contributes 20% to global energy-related CO2 emissions in 2006

Additional global CO2 in 2030 over 2006: 12.6 GtCO2, about half from China

2006 GigaTons CO2
Total: 27.89
OECD : 12.79
Non-OECD : 14.12
China : 5.65
India : 1.25

(Note: this is CO2 equivalent; NOT Carbon; need to divide by 3.667 to compare)
Energy-related CO2 emissions in cities by region in the Reference Scenario

Out of 12.6 GtCO2 global CO2 addition in next 25 years, cities contribute 11 Gt or 87%

89% of cumulative increase in 2006-2030 in urban CO2 comes from non-OECD countries ( Mostly, India and China)

WEO, 2008; Dhakal 2009
Role of urban area: Global urban population and share of urban agglomeration by size

- Almost all future global population growth from urban population, mostly in Asia
- Additional 1.8 bn in next 25 years (2030-2005), mostly in Asia

< Dhakal, 2009 >
Based on UN Urban Population Statistics 2007 updates
Asia’s role in global CO2 from fossil fuels

• China over-passed USA as the greatest emitter since 2006
• India surpassed Russia and now third largest emitter
• China (23.2%), India (5.8%), Japan (4.3%), South Korea (1.9%) and Iran (1.6%) are amongst top 10 global CO2 emitters: totalling 36.8% in 2008
• Embodied CO2 emission in trade: China is the biggest carbon importer; Europe, US and Japan are CO2 exporters; meaning, Asia is a key region if we expand debate to consumption responsibility too
• Future new emission is going to happen in Asia, mostly China and India
• Future global incremental emissions will take places urban areas with Asian developing countries playing major role
Carbon Emissions from Land Use Change

2000-2007 (Net av. an. emission)

- Tropical Americas, 41% 0.6 Pg C y\(^{-1}\)
- Tropical Asia, 43% 0.6 Pg C y\(^{-1}\)
- Tropical Africa, 17% 0.3 Pg C y\(^{-1}\)

1.5 Pg C y\(^{-1}\)

Tropical deforestation: 13 Million hectares each year
Tropical deforestation mostly responsible for emissions

[2007-Total Anthropogenic Emissions: 8.5 + 1.5 = 10 Pg]

160 Pg C emission in 1850-2007 from Land Use Change

Canadell et al. 2007, PNAS; FAO-Global Resources Assessment 2005
Carbon Emissions from Tropical Deforestation

Historical Emissions from Land Use Change

1.5 Pg C y⁻¹
(16% total emissions)

R.A. Houghton, unpublished
Net CO₂ Emissions from LUC in Tropical Countries

2000-2005

CO₂ emissions (TgC y⁻¹)

Brazil 60%

Indonesia

Venezuela


Nigeria

Cameroon

Peru

Philippines

Colombia

Nicaragua

Nepal

India

RA Houghton 2009, unpublished; Based on FAO land use change statistics
2008 CO2 emissions from LUC has significantly decreased from previous year. Probably due to wet La Niña conditions and reduced reforestation rate.
Asia’s role in global CO2 from land use change

- Asian contribution in increasing dramatically in global CO2 emission from the land use change
- Indonesia remains key country
- Despite being big countries, the CO2 from land use of China and India are smaller unlike their fossil fuel CO2 emissions
Fraction of total CO$_2$ emissions that remains in the atmosphere

Trend: $0.27 \pm 0.2 \% \text{ y}^{-1} (p=0.9)$

Means the efficiency of sinks in removing CO$_2$ from atmosphere has decreased by 5% over the last 50 years, and will continue to do so in the future.

Le Quéré et al. 2009, Nature-geoscience; Canadell et al. 2007, PNAS; Raupach et al. 2008, Biogeosciences
Efficiency of Natural Sinks

Long term trends show that the natural sink has increased size but the efficiency of sink (to uptake the additional carbon as fraction of total anthropogenic CO2 emissions) has declined to keep airborne fraction from increasing.

**Land Fraction**

- Net uptake
  - Land
    - 3 PgC/yr in 2000-8
    - 3.6 PgC in 2006
    - 2.9 PgC in 2007
    - 4.7 PgC in 2008 (La Niña)

**Ocean Fraction**

- Slower growth of ocean sink compared to growth pace of emissions
  - 2.3 PgC/yr in 2000-8

Canadell et al. 2007, PNAS
Causes of the Declined in the Efficiency of the Ocean Sink

• Part of the growth decline is attributed to a 30% decrease in the efficiency of the Southern Ocean sink over the last 20 years.

• This sink removes annually 0.7 Pg of anthropogenic carbon.

• The decline is attributed to the strengthening of the winds around Antarctica which enhances ventilation of natural carbon-rich deep waters.

• The strengthening of the winds is attributed to global warming and the ozone hole.

Le Quéré et al. 2007, Science
Human Perturbation of the Global Carbon Budget

2000-2008

CO₂ flux (Pg C y⁻¹)

Sink

Source

deforestation

tropics

extra-tropics

Human Perturbation of the Global Carbon Budget

2000-2008

fossil fuel emissions

7.7

deforestation

1.4

Human Perturbation of the Global Carbon Budget

![Graph showing carbon fluxes from 1850 to 2000](image)

- **Fossil fuel emissions**
- **Deforestation**
- **Atmospheric CO₂**

**Time (y)**

1850, 1900, 1950, 2000

**CO₂ flux (Pg C y⁻¹)**

Sink

Source

Human Perturbation of the Global Carbon Budget

Human Perturbation of the Global Carbon Budget

Human Perturbation of the Global Carbon Budget

![Graph showing CO₂ flux (PgC y⁻¹) over time (y) from 1850 to 2000.](image)

- **Source:**
  - Fossil fuel emissions
  - Deforestation

- **Sink:**
  - Atmospheric CO₂
  - Ocean
  - Land

- **Time (y):** 1850 to 2000

- **CO₂ flux (PgC y⁻¹):**
  - 7.7
  - 1.4
  - 4.1
  - 3.0 (5 models)
  - 2.3 (4 models)
  - 0.3 Residual

Fate of Anthropogenic CO₂ Emissions (2000-2008)

1.4 PgC y⁻¹

7.7 PgC y⁻¹ +

4.1 PgC y⁻¹

3.0 PgC y⁻¹

2.3 PgC y⁻¹

45%

29%

26%

55% of emission is taken back by sink

Le Quéré et al. 2009, Nature-geoscience; Canadell et al. 2007, PNAS, updated
Conclusions (i)

- Anthropogenic CO₂ emissions are growing 3.5 times faster since 2000 than during the previous decade.
- Anthropogenic CO₂ emissions are growing above the worst case emission scenario of the Intergovernmental Panel on Climate Change (IPCC).
- Developing Countries are now emitting significantly more carbon than Developed Countries.
- The economic crisis will likely have a transitional impact on the growth of CO₂ emissions and a undetectable effect on the growth of atmospheric CO₂ (because the much larger inter-annual variability of the natural sinks).
• The efficiency of natural sinks has decreased by 5% over the last 60 years (and will continue to do so in the future), a trend not fully captured by climate models.
  • implying that the longer it takes to begin reducing emissions significantly, the larger the cuts needed to stabilize atmospheric CO$_2$.

• Sink-source dynamics have led to an acceleration of atmospheric CO$_2$ growth 27% faster since 2000 than in the previous two decades, implying a stronger climate forcing and sooner than expected.

• Asia plays important role in both emission from the fossil fuel and the land use changes and key region for carbon management at carbon source and land carbon sinks
Corinne Le Quéré
School of Environment Sciences, University of East Anglia, Norwich, UK
British Antarctic Survey, Cambridge, UK

Michael R. Raupach
Global Carbon Project, CSIRO Marine and Atmospheric Research, Canberra, Australia

Josep G. Canadell
Global Carbon Project, CSIRO Marine and Atmospheric Research, Canberra, Australia

Gregg Marland
Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

Laurent Bopp
Laboratoire des Sciences du Climat et de l’Environnement, UMR 1572 CEA-CNRS-UVSQ, France

Philippe Ciais
Laboratoire des Sciences du Climat et de l’Environnement, UMR 1572 CEA-CNRS-UVSQ, France

Thomas J. Conway
NOAA Earth System Research Laboratory, Boulder, Colorado, USA

Scott C. Doney
Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA

Richard A. Feely
Pacific Marine Environmental Laboratory, Seattle, Washington, USA

Pru Foster
QUEST, Department of Earth Sciences, University of Bristol, UK

Pierre Friedlingstein
Laboratoire des Sciences du Climat et de l’Environnement, France

QUEST, Department of Earth Sciences, University of Bristol, UK

Kevin Gurney
Department of Earth and Atmospheric Sciences and Department of Agronomy, Purdue University, Indiana, USA

Richard A. Houghton
Woods Hole Research Center, Falmouth, Massachusetts, USA

Joanna I. House
QUEST, Department of Earth Sciences, University of Bristol, UK

Chris Huntingford
Centre for Ecology and Hydrology, Benson Lane, Wallingford, UK
GCP-Carbon Budget Consortium

Peter E. Levy
Centre for Ecology and Hydrology, Bush Estate, Penicuik, UK

Mark R. Lomas
Department of Animal and Plant Sciences, University of Sheffield, UK

Joseph Majkut
AOS Program, Princeton University, PO Box CN710, Princeton, New Jersey, USA

Nicolas Metzl
LOCEAN-IPSL, CNRS, Institut Pierre Simon Laplace, Université Pierre et Marie Curie, Paris, France

Jean P. Ometto
Instituto Nacional de Pesquisas Espaciais, São José dos Campos-SP, Brazil

Glen P. Peters
Center for International Climate and Environmental Research, Oslo, Norway

Colin Prentice
QUEST, Department of Earth Sciences, University of Bristol, UK

James T. Randerson
Department of Earth System Science, University of California, Irvine, California, USA

Steven W. Running
School of Forestry/Numerical Terradynamic Simulation Group, University of Montana, Missoula, USA

Jorge L. Sarmiento
Atmospheric and Oceanic Sciences Program, Princeton University, Princeton, USA

Ute Schuster
School of Environment Sciences, University of East Anglia, Norwich, UK

Stephen Sitch
School of Geography, University of Leeds, Leeds, UK

Taro Takahashi
Lamont-Doherty Earth Observatory of Columbia University, New York, USA

Nicolas Viovy
Laboratoire des Sciences du Climat et de l’Environnement, CEA-CNRS-UVSQ, France

Guido R. van der Werf
Faculty of Earth and Life Sciences, VU University, Amsterdam 1081 HV, Netherlands

F. Ian Woodward
Department of Animal and Plant Sciences, University of Sheffield, Sheffield, UK