The terrestrial biosphere as a net source of greenhouse gases to the atmosphere

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Objectives:

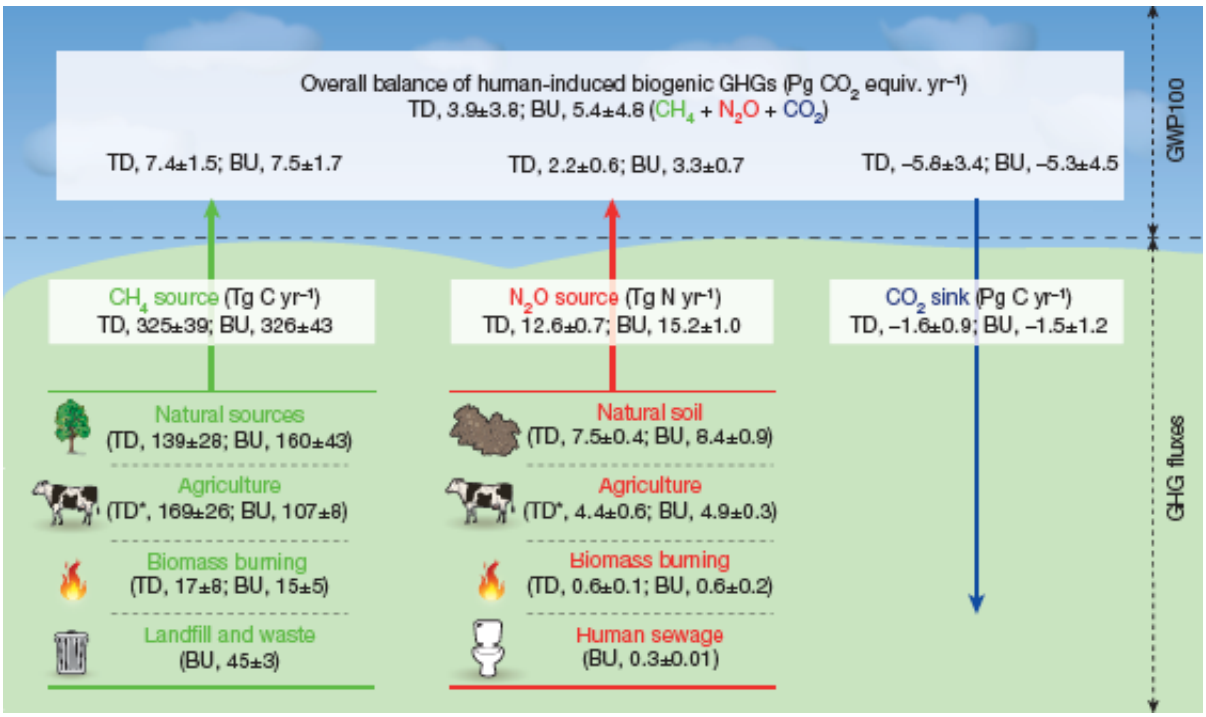
- The terrestrial biosphere plays an important role in regulating atmospheric composition and climate through the release or absorption of the greenhouse gases (GHGs) carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).
- The terrestrial biogenic fluxes of these individual gases have been studied extensively, but the net biogenic greenhouse gas balance of all three which results from anthropogenic activities and the effect on the climate system remains uncertain.
- This study was designed to quantify the global net biogenic greenhouse gas balance which results from anthropogenic activities between 1981 and 2010 and its effect on the climate system.
- The authors use a dual constrained approach, combining 28 bottom-up (BU) studies (using inventory, statistical extrapolation of local flux measurements, and processed-based modeling) with 13 top-down (TD) atmospheric inversions to generate their estimates of biogenic fluxes of the three gases.
- The anthropogenic contribution to the biogenic flux of each GHG was distinguished by removing modelled pre-industrial emissions from contemporary GHG estimates.
- The authors use CO_2 equivalents based on global warming potentials on a 100-year time horizon (GWP100) and also on a 20-year time horizon (GWP20).

New Science:

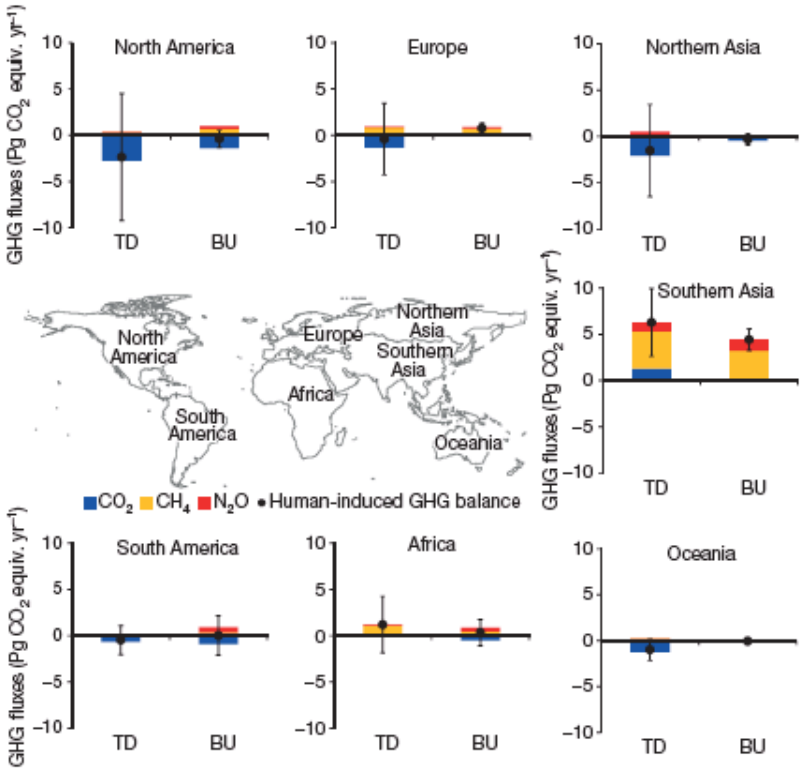
- There is a net positive cumulative impact of the three greenhouse gases on the planetary energy budget, with a best estimate in petagrams of CO_2 equivalent per year of 3.9 ± 3.8 (TD) and 5.4 ± 4.8 (BU) based on the GWP100 metric.
- The cumulative warming capacity of concurrent biogenic methane and nitrous oxide emissions is a factor of about two larger than the cooling effect resulting from the global land carbon dioxide uptake from 2001 to 2010.
- Over a 100-year time horizon, the largest contributors to this twofold offset of the land CO_2 sink are agriculture and waste (i.e., CH_4 from paddy fields, manure management, ruminants and landfill and waste, along with N_2O from crop cultivation, manure management, human sewage and indirect emissions).
- The concentration of atmospheric CO_2 has increased by nearly 40% since the start of the industrial area while CH_4 and N_2O concentrations have increased by 150% and 20% respectively.
- When the global warming potential is calculated with a 20-year metric (GWP20), the radiative forcing of contemporary (2000s) human-induced biogenic CH_4 emission alone is 3.8 (TD) or 4.2 (BU) times that of the land CO_2 sink in magnitude but opposite in sign.
- Human-induced biogenic GHG fluxes vary by region, with the fluxes in Southern Asia (which has 90% of the global rice fields and 60% of the world's nitrogen fertilizer consumption) in particular leading to a large net climate warming effect.

Significance:

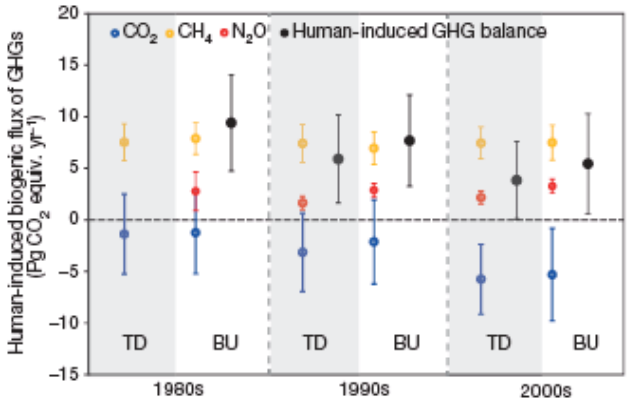
- This study highlights the importance of including all three major GHGs in global and regional climate impact assessments, mitigation options, and climate policy development.
- Some CH_4 and N_2O emissions were present during pre-industrial times, while the global pre-industrial land CO_2 uptake was approximately in balance with the transport of carbon by rivers to the ocean and compensatory ocean CO_2 source.
- Anthropogenic activities such as land-use change, agriculture and waste management have altered terrestrial biogenic greenhouse gas fluxes, and the resultant increases in CH_4 and N_2O can contribute to climate change.
- The findings, particularly the GWP20 values, point to cutting CH_4 emissions as an effective pathway for rapidly reducing the GHG-induce radiative forcing and the rate of climate warming in a short time frame.
- Improved fertilizer use efficiency, rice management, and animal diets could substantially reduce global agricultural N_2O and CH_4 emissions.
- Reduction in agricultural N_2O and CH_4 in Southern Asia may help mitigate climate change.
- Much more work on regional GHG budgets is needed, particularly for tropical areas, as large uncertainty is revealed in both TD- and BU-derived GHG estimates.
- The results of this study suggest that adoption of best practices to reduce GHG emissions from human-impacted land ecosystems could reverse the biosphere's current warming role.



The overall biogenic GHG balance of the terrestrial biosphere in the 2000s. Topdown (TD) and bottom-up (BU) approaches are used to estimate land CO2 sink, CH4 and N2Ofluxes for four major categories merged from 14 sectors (Extended Data Table 1). Global warming potential (GWP100) is calculated after removing preindustrial biogenic emissions of CH4 (125 ± 14 Tg C yr−1) and N2O (7.4 ± 1.3 Tg N yr−1). Negative values indicate GHG sinks and positive values indicate GHG sources. TD* indicates estimates of agricultural CH4 and N2O emissions that include CH4 sources from landfill and waste, and an N2O source from human sewage, respectively.



The balance of human-induced biogenic GHGs for different continents in the 2000s (based on GWP100).
Blue bars represent CO2 flux, yellow CH4 flux and red for N2O flux with pre-industrial fluxes removed. Black dots indicate net human-induced GHG balance; error bars, ± s.d. of estimate ensembles.



Changes in the decadal balance of human-induced biogenic GHGs in the past three decades (based on GWP100).
Data points show individual gases (blue for CO2, yellow for CH4, and red for N2O) and net human-induced GHG balance (black) derived from biogenic sources with pre-industrial biogenic CO2 sink, and CH4 and N2O emissions removed. Error bars, ± s.d. calculated from various estimate ensembles.