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An International Carbon Office to assist policy-based science

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The international political commitment to limit global warming to 2 °C urgently requires the stabilisation of radiative forcing from carbon dioxide (CO_2) and other greenhouse gases (GHG) in the atmosphere. This can be achieved only with information on the full balance of GHG, including both the natural and the anthropogenic emissions and sinks. The public's support of political efforts to limit global warming hinges on robust and transparent information from the scientific community. Here we argue that the existing institutions that support the science of climate change are not adequate to support the policy needs, particularly for the monitoring and assessment of the earth's biogeochemical cycles. To assist in the stabilisation of GHG, an International Carbon Office (ICO) needs to be created to provide full GHG balance at a regional and global level, and to respond quickly to other needs for information as they emerge. An ICO with a specific mandate would guarantee sustained scientific engagement in the long-term.

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Risks of failing to stabilize greenhouse gases

The stabilisation of radiative forcing from GHG in the atmosphere requires specific scientific assistance because at present, it is not possible to verify that measures to reduce GHG emissions are effective. The radiative forcing of anthropogenic GHG around year 2005 was shared between CO_2 (55.5%), methane (CH_4; 16.1%), ozone (O_3; 11.7%), CFC-12 (5.5%), nitrous oxide (N_2O; 5.4%) and other constituents with smaller contributions [1•]. CO_2, CH_4 and N_2O are part of complex natural cycles, with multiple sources and sinks interlinked with human activities (Figure 1). Thus the emissions of these GHG are not directly related to their atmospheric concentration on short time scales (years to decades).

For CO_2, only 45% of the annual emissions stay in the atmosphere on average [2•]. The remaining 55% is absorbed by two natural 'CO_2 sinks' in terrestrial ecosystems and the ocean (Figure 1). The CO_2 sinks have large natural variability which is not well constrained and partly masks the annual changes in atmospheric CO_2 concentration brought about by CO_2 emissions [3•]. The mismatch between emissions and concentrations is well illustrated by the recent global financial crisis, which drove a slowdown in CO_2 emissions from industrial production but no discernable effect on the atmospheric CO_2 growth [3•,4]. Similarly for CH_4, all emissions were absorbed by the natural sinks between 1999 and 2007, mainly through chemical reaction with natural cleaning agents in the atmosphere. Since 2007, however, CH_4 emissions exceeded the natural sinks but the causes of this imbalance in the CH_4 budget are unknown.

GHG emissions also interfere with the nitrogen cycle, directly in the emissions and destruction of N_2O, and indirectly in the production and destruction of O_3. The nitrogen cycle is even less well known than the carbon cycle, yet sources and sinks of N_2O cut across the human and physical systems (Figure 1). Nitrogen sinks are less effective in removing N_2O from the atmosphere, resulting in a long lifetime (~300 years) and a high fraction of the emissions remaining airborne every year.

It has been suggested that large and abrupt changes in the Earth's carbon reservoirs can occur, such as the Amazon dieback [5,6] or the decomposition of frozen carbon stores in the Arctic [7], and that the long-term response of the oceanic CO_2 sink to climate change may lead to a slow but persistent additional build-up of CO_2 in the atmosphere [8], as observed in past climates [9]. A few recent studies have identified observed responses of the CO_2 sinks to

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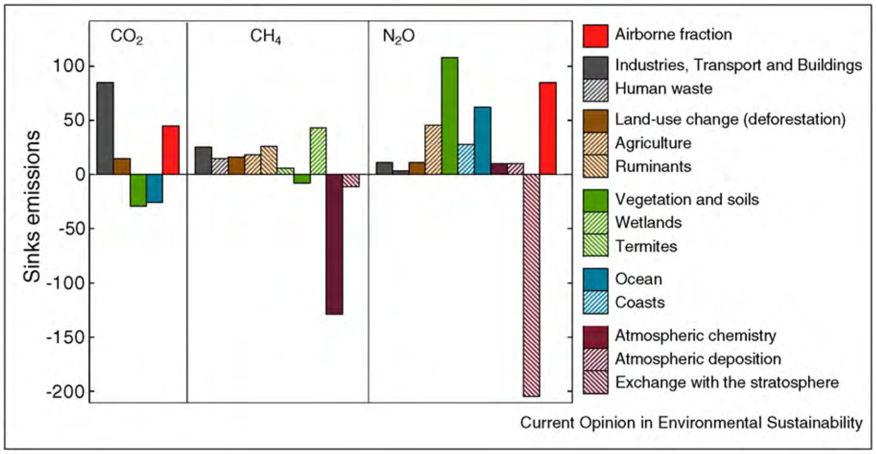
Figure 1



Emissions and sinks of CO_2, CH_4 and N_2O showing the interference of the human perturbations with the natural cycles. Numbers show the relative contribution (in percent) to the total emissions for each GHG. The fraction of the annual GHG emissions that stay in the atmosphere (the 'airborne fraction') is also shown in red. CO_2 figures are for 2000–2008 [3•], CH_4 and N_2O figures are for around 2000–2005 based on [17,18].

recent climate change [2•,8] and to extreme events [10,11]. Such responses would influence the concentration of GHG in the atmosphere and interfere with national and international efforts to reduce GHG emissions.

Effectiveness of emission reductions

There are several reasons why active measures to reduce GHG emissions may not be effective. Some GHG emissions and sinks are difficult to quantify and may not be correctly accounted. This is particularly important for CO_2 emissions and sinks from deforestation and forest management, CH_4 emissions from wetlands and fires, and N_2O emissions from agriculture. Although national anthropogenic emissions of GHG other than CO_2 are monitored [12], full global sources and sinks are not compiled on a year-to-year basis; only their atmospheric concentrations are systematically monitored. Also, GHG emissions directly reported by each country may be inaccurate because of methodological issues, scope of accounting (such as soil carbon, land use, black carbon, shipping and aviation), inconsistent system boundary definitions, and incompleteness in the information base. Finally, there are many countries where inadequate accounting infrastructure can lead to large errors in inventories [13].

In such a poor knowledge-based context, there will be a time delay of many years before we know whether measures undertaken to eventually stabilize GHG concentrations are effective or not. To ensure that reductions in GHG emissions are effective, the full anthropogenic and natural components of the carbon and nitrogen cycles must be quantified and monitored at multiple scales. This is a task that the scientific community can do, but not within current institutions and with the current gaps in observation networks.

Key gaps in institutional structure

Although a number of institutions already address aspects of GHG monitoring and reporting, key gaps exist in several areas. No institution is mandated to compile, analyse, report and archive information on full GHG cycles, neither at the regional scale nor at the global scale; no institution is mandated to identify precursors of large and/or abrupt changes in the natural carbon reservoirs or to monitor the evolution of key reservoirs.

In addition to key gaps, there are a number of existing activities which lack specific long-term mandates or operate at a scale that is too small to inform the international policy process. These include the co-ordination, acquisition, reporting and archiving of observations on the *natural* GHG cycles, currently done by national and regional organisations or specific targeted projects. National organisations have specific objectives, often related to local issues with limited time horizons. Observations acquired with national funding are in part co-ordinated at the international level by the Group on Earth Observation (GEO). This ensures that observations from different nations can be compared and combined at the scale of continents, and that gaps in sampling, methods or standards are identified. There is, however, no contingency to expand existing observations to areas not covered by national efforts. As a consequence, the existing bottom-up effort to monitor natural cycles results in large under sampling of key regions such as tropical regions, extreme Northern latitudes, and the Southern Ocean. The synthesis of information on the global carbon balance has been attempted by the Global Carbon Project (GCP)

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[2•,3•,14•,15], but this effort is based on voluntary contributions of people time and has a finite lifetime.

The role of science in carbon management

Science has a dual role in improving our capacity to manage the natural cycles and to address the problem of climate change: it can generate knowledge and can support the implementation of actions. Given the prevalence of uncertainty in the natural sources and sinks of GHG, it is clear that a sophisticated mechanism for monitoring the natural cycles can play an essential role for full GHG accounting. Improved monitoring can also help set in place early warning systems. Much of our experience with early warning systems arises in connection with natural disasters (e.g. the Asian Tsunami in 2004, Hurricane Katrina in 2005) and large-scale human accidents (e.g. the Chernobyl disaster in 1986). The possible large and abrupt changes in the carbon reservoirs highlight the need to anticipate the occurrence of critical thresholds. The ability for early detection of CH_4 emissions from frozen Arctic stores or the slowdown of key ocean sinks would provide the necessary information to re-evaluate mitigation targets and management strategies when possible. The Cooperative Programme for the Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe (EMEP; http://www.emep.int), created to address the problem of acid rain, serves as a successful precedent.

Science can also contribute to the development and implementation of regulatory arrangements to control human actions which may perturb the natural cycles and disrupt the climate system. It can play a role in the measurement, reporting, and verification (MRV) needed to provide assurance that parties are living up to commitments to reduce GHG emissions and, in the process, to build confidence in the effectiveness of agreed mitigation targets and regulatory arrangements. The role of science in verifying compliance with the rules relating to demilitarisation and the protection of ecosystems built into the 1959 Antarctic Treaty and its Environmental Protocol is well known. A concerted effort in better monitoring and understanding the carbon cycle can play a key role in developing tools that permit the verification of compliance in a manner that does not require intrusive inspection systems. The introduction of such tools played a critical role in the success of the strategic arms limitation agreements of the 1970s and 1980s [16].

A new International Carbon Office to assist the policy process

A new set of arrangements between policy and the scientific community is required to provide unbiased information on the global and regional balance of GHG. These include specific mandates to ensure that necessary activities are carried out in a regular, long-term manner, that the infrastructure necessary to ensure adequate observations is in place, and that the reported analyses from which policy relevant information is based are available, transparent and reproducible. A practical way to support necessary activities would be to create an ICO with the mandate to:

- *Compile, analyse, report and archive statistics and information on the global and regional balance of CO_2 and other GHGs.* A comprehensive analysis of GHG balance would help identify anomalies either in the reporting of GHG emissions or in the expected behaviour of natural sources and sinks. It could lead to the development of non-intrusive means of verifying compliance with commitments of GHG reductions. The archiving of raw data and derived products in a form that is easy to access for all interested parties would ensure transparency and encourage external scrutiny.
- *Identify and monitor the most important CO_2 sinks and natural reservoirs of carbon.* The ICO would assess and report the size and vulnerabilities of the natural reservoirs, and ensure that the continuous monitoring of the sensitive reservoirs can be adequately implemented by relevant organisations. The ICO would also assist in monitoring of future activities which might attempt to manipulate CO_2 sinks at large scales (geoengineering).
- *Facilitate the development of methods* that can help fill the gaps in full GHG accounting, reduce uncertainty in existing estimates, and provide independent verification of reported emissions.

The ICO would work closely with GEO and national research and operational centres to fulfil its mandate. The ICO would not replace the existing infrastructure, but it would provide additional information and statistics not currently available. It would strengthen the review process of the United Nations Framework Convention on Climate Change (UNFCCC) on reported emissions as it would provide an independent verification that national efforts lead to global outcomes. The ICO would also complement the efforts of the IPCC's task force on National Greenhouse Gas Inventories (TFI) that oversees the methodology for the calculation and reporting of national GHG emissions and removals as it would facilitate the use of the latest methodologies and observations, in order to properly link the emissions and sinks accounting with the atmospheric growth rates.

An ICO, either independent or attached to an existing institution or consortium of organisations, recognized as an intergovernmental body and endowed with adequate funding would enable the scientific community to carry out these vital tasks effectively, and deliver in a timely fashion the information necessary to help limit global warming to 2 °C and avoid dangerous interference with

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the climate system. The current discovery-based scientific environment is essential to ensure progress in fundamental knowledge and to understand of the climate system, but it is inadequate to support the political process in the context of a rapidly changing climate. Yet only the scientific community can provide the vital information needed to ensure transparency and instate confidence in the process of stabilising radiative forcing from GHG in the atmosphere.

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