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Monitoring greenhouse gases

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In order to tackle climate change it is necessary to have reliable information on the greenhouse gases (GHGs) which cause this phenomenon. Equipped with this information it is possible to make assessments of emissions trends and of the effectiveness of emissions mitigation policies, strategies and initiatives. Furthermore, this information allows assessments to be made of how far emissions reduction targets are being met at company, sector, national or global level. It also allows emissions trading schemes to function, since without credible emissions trading units such schemes have no integrity. This credibility is crucial to the confidence that buyers and sellers and the public will have in such a scheme. Accurate GHG emissions data are also vital for the study of the relationship between GHGs and global warming. This chapter will describe how greenhouse gases are monitored. It will provide a simple overview of this complex area that is not intended to be exhaustive, nor does it seek to cover all GHG-emitting entities, sectors or monitoring techniques.

The methods used to monitor GHG emissions vary greatly depending not only on the type of activity under scrutiny but also on the scale and the goal of the monitoring project undertaken. This chapter begins by looking briefly at greenhouse gases and their respective effects on climate. It then touches on the development of GHG emissions monitoring systems. The systems for emissions monitoring under the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and its 1997 Kyoto Protocol are then explained, followed by the European Union (EU) Emissions Trading Scheme. These sections explain how emissions are monitored and the rationale behind the structure of the monitoring system. They also examine the problem of how uncertainties in emissions estimation are dealt with and how emissions data are collected and managed. The recent emergence of non-state GHG registries of companies' and municipalities' emissions is also described. Finally, global and regional atmospheric emissions monitoring systems, which can complement the information provided by inventory-based emissions monitoring systems, are described.

Greenhouse gases and their effect on climate

The main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). Carbon dioxide is the most common GHG produced by human activities, accounting for 60 per cent of the increase in radiative forcing[1] since pre-industrial times.[2] Emissions of these six gases must be reported to the UNFCCC by each treaty party and constitute the 'basket' of gases to be reduced under the Kyoto Protocol. Annex I parties (that is, developed countries listed in Annex I to the UNFCCC) must also provide information on indirect greenhouse gases, namely carbon monoxide (CO), nitrogen oxides (NO_x) and non-methane volatile organic compounds (NMVOCs),[3] and also sulphur oxides. For policy formulation purposes greenhouse gases are often measured by their global warming potential (GWP) (see table 1).[4]

Greenhouse gas monitoring and the UNFCCC

Efforts to monitor gas emissions have developed as various risks and needs have been identified. Systems have evolved which either have been specifically designed or have come to include greenhouse gas monitoring. States (or regions) use emissions inventories to account for these gases. Emissions inventories are characterized by which gases they include, the geographic area they cover, the sectors or activities covered and the time range over which gases are emitted.[5] The greater the level of detail and the sectoral breakdown within an inventory the clearer will be the evaluation of what activities or entities are producing emissions and in what quantity. Greater detail also allows greater precision in formulating methods for reducing these emissions. However, the greater the level of detail the more difficult it is to draw up an inventory.

Many international organizations and states have initiated emissions monitoring schemes to manage the risks from various air pollutants. For example, in 1977

Table 1 The main greenhouse gases

Greenhouse gas	Anthropogenic sources	Atmospheric lifetime (years)*	Global Warming Potential (GWP)**
Carbon dioxide (CO_2)	Fossil-fuel combustion, land-use conversion, cement production	variable	1
Methane (CH_4)	Fossil fuels, rice paddies, waste dumps, livestock	12.2 +/−3	21***
Nitrous oxide (N_2O)	Fertilizer, industrial processes, combustion	120	310
CFC-12	Liquid coolants, foams	102	6,200–7,100****
HCFC-22	Liquid coolants	12.1	1,300–1,400****
Perfluoromethane	Production of aluminium	50,000	6,500
Sulphur hexafluoride (SF_6)	Dielectric fluid	3,200	23,900

Notes
* No single lifetime for CO_2 can be defined because of the different rates of uptake by different sink processes.
** GWP for a 100-year time horizon. Units are relative to CO_2.
*** Includes indirect effects of tropospheric ozone production and stratospheric water vapour production.
**** Net global warming potential (i.e. including the indirect effect due to ozone depletion).

Source
United Nations Environment Programme (UNEP), www.grida.no/climate/vital/05.htm (from 'Radiative forcing report', contribution of Working Group 1 to the Second Assessment Report of the IPCC, UNEP and WMO, in J.T. Houghton et al. (eds), *Climate Change 1995: The Science of Climate Change,* Cambridge University Press, Cambridge, 1996.

the United Nations Economic Commission for Europe (UNECE) initiated the European Monitoring and Evaluation Programme (EMEP), which provides an emissions inventory system for the 1979 Convention on Long-Range Transboundary Pollution (LRTAP) and supports monitoring of the progress of implementation of its protocols. Subsequently in 1985 the European Union (EU) set up the EU emissions inventory programme (CORINAIR) to establish a European air emissions inventory for a number of gases. In 1990 the European Environment Agency Task Force initiated inventories which extended the list of substances covered under CORINAIR to include greenhouse gases. EMEP and CORINAIR then began working closely together through the UNECE and in 1996 the Joint EMEP/CORINAIR *Atmospheric Emission Inventory Guidebook* was published. The EMEP/CORINAIR system is highly detailed and allows considerable accuracy in emission source description. This level of detail was required by the UNECE in order to gain not only total national emissions estimates by sector but also a precise awareness of the physical sources and geographical distribution of emissions.[6]

In response to the growing recognition of the threat of climate change, a global approach to greenhouse gas emissions monitoring began to be developed by the Intergovernmental Panel on Climate Change (IPCC).[7] Work began on this system in the early 1990s and also involved the Organisation for Economic Co-operation and Development (OECD) and the International Energy Agency (IEA). The goal of the IPCC is to develop guidelines and the use of comparable methodologies for GHG emissions monitoring and review systems to assist UNFCCC parties in developing national inventories of GHG emissions and removals. Under the UNFCCC, parties must now use the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* or compatible methodologies to estimate and report on their GHG emissions.[8]

The IPCC system provides both national totals of GHG emissions and a breakdown of emissions by economic sector. This sectoral approach demands less detail than the CORINAIR system,[9] which is based on individual emission sources (which are then categorized into sectors). The UNFCCC, being global in scope, aims to obtain information on national emissions from all states, whereas CORINAIR was primarily designed for use in EU countries. Drawing up a national inventory is a complex task which requires significant financial and institutional resources and, while CORINAIR requirements suited a group of states which is relatively homogeneous in terms of development, the IPCC had to cater for a diverse range of countries with different institutional, political, technical, geographical and economic circumstances. It is, however, the goal of the IPCC to continue to promote harmonization with other international and national GHG inventory methodologies in order to facilitate inventory compilation and improve accuracy and consistency.[10]

The IPCC system

Under the UNFCCC, Annex I parties (that is, developed countries listed in Annex I to the convention) must annually report to the UNFCCC Secretariat national inventories of their greenhouse gas emissions for a period covering a base year (normally 1990[11]) up to the last year but one prior to the year of submission. Non-Annex I parties (developing countries) submit inventories less frequently. The precise timing and frequency of their submissions are still under negotiation. The goal of the UNFCCC reporting requirements is to ensure that inventories are transparent, consistent, comparable and complete. These inventories will help in reviewing the implementation of the convention and assist in policy decisions relating to emissions reduction strategies. The inventories are publicly available on the UNFCCC website.

National inventories should consist of a national inventory report (NIR) containing detailed information on parties' inventories, and the common reporting format (CRF) which parties use to report their GHG data and for which the UNFCCC secretariat provides a software tool to facilitate reporting. To compile these inventories, states must identify the range of possible source and sink[12] activities that exist in their territory and evaluate their relative importance. According to the IPCC guidelines, parties are supposed to report all important GHG emissions. However, in practice the capacity to do this varies widely. Countries with little prior experience instead prioritize possible gases, sources and sinks in terms of their relative importance to global and national totals, and non-Annex I parties are only required to report to the extent that their capacities permit. According to the IPCC, CO_2, CH_4 and N_2O have the highest priority.[13]

Under the IPCC approach to emissions monitoring found in the *Revised 1996 IPCC Guidelines,* emissions estimates are usually a product of activity data and emission factors. The calculations can be highly complex, with many steps involved in the calculation of each term.[14] Activity data provide information on the amount of human activity which results in emissions or removals occurring over a given period. For example, in the energy sector annual activity data for fuel combustion sources are the total amounts of fuel burned. Emission factors provide a representative rate of emission for a particular activity level under a particular set of operating conditions.[15] The formula for this calculation is:

Emissions = activity data x emission factor.

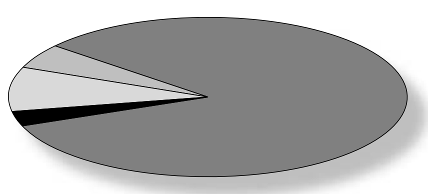
Emissions estimates can also be produced using an emissions measurement over a period of time (for example, an hour) multiplied by the number of such periods in a required estimation period (for example, the number of operating hours per year).

The IPCC provides default methodologies and values for emission factors and some activity data within a tiered structure of increasing levels of detail. However, these default methodologies, data and factors are necessarily general and it is therefore preferable, if possible, for states to create and use more detailed methodologies, emission factors and activity data as long as these are compatible with those of the IPCC. The IPCC guidelines often refer to methodologies developed elsewhere, such as those of the US Environmental Protection Agency (EPA), rather than providing their own in every case. It is also preferable for states to use higher tiers. The greater the level of detail and accuracy in the inventories the better informed policy decisions on emissions reduction will be.

Direct measurement of individual emissions sources is also permitted under the IPCC guidelines but is comparatively rare in this system. The subsections below outline the IPCC approach to emissions estimation by sector.

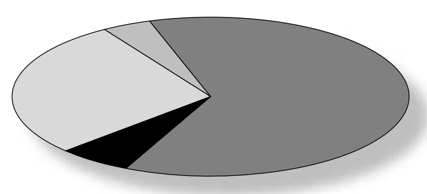
Figures 1 and 2 below show the sectoral emission profiles of Annex 1 and non-Annex 1 parties.

Figure 1 **Annex 1 parties (2004)**



- Agriculture (3%)
- Industrial processes (9%)
- Energy (5%)
- Waste (83%)

Figure 2 **Non-Annex 1 parties (1994 or closest)**



- Agriculture (6%)
- Industrial processes (28%)
- Energy (4%)
- Waste (62%)

Note Solvent and other product use and land-use change and forestry sectors are not included in order to preserve the simplicity of the charts.

Source UNFCCC, 'Counting emissions and removals, greenhouse gas inventories under the UNFCCC', 2003, www.unfccc.int.

Energy

When burned, carbon-based fuels produce CO_2 emissions.[16] By far the largest source, the oxidation of carbon when fossil fuels are burned, accounts for 70–90 per cent of total anthropogenic CO_2 emissions.[17] However, the energy sector is also responsible for emissions of CH_4, N_2O, NO_x, CO and NMVOCs. Emissions in this sector are divided into those from fuel combustion and those from fugitive emissions.[18] Examples of fuel combustion activities are public electricity and heat production, manufacture of solid fuels, manufacturing industry and construction, and transport (including civil aviation, road transport and navigation),[19] while examples of fugitive emissions are emissions from coal mining and handling, and oil and natural gas activities. Where local energy data are not available, data from the IEA or the United Nations Statistical Division (UNSD) can be used.

Two main approaches are available for calculating greenhouse gases in this sector —the reference approach and the sectoral approach. The reference approach requires the calculation of the national supply of fuel and of CO_2 emissions from fuel combustion. The IPCC breaks the process down into six steps: estimate apparent[20] fuel consumption in original units; convert to a common energy unit; multiply by emission factor to compute carbon content; compute carbon stored; correct for carbon unoxidized; and convert carbon oxidized to CO_2 emissions. The reference approach provides a speedy estimate of total CO_2 emissions but does not break down the emissions by sector. In order to make accurate abatement policy decisions, a sectoral breakdown of national CO_2 emissions is required using more detailed calculations than the reference approach. The estimation of non-CO_2 GHG emissions requires more detailed knowledge of activities and technologies (for example, combustion conditions, technology, emissions control policies and fuel characteristics) and here a sectoral approach is needed.

Industrial processes

The main emission sources in the industrial processes sector are production processes which chemically or physically transform materials. Many GHGs, including CO_2, CH_4, N_2O, PFCs, NO_x, NMVOCs and CO, can be released during these processes. There are several types of industrial process: in the chemical industry,[21] metal production, and the production and consumption of halocarbons and SF_6. Often total emissions from a sector originate from just a few plants. To estimate emissions in this sector, activity-level data are multiplied by the appropriate emission factor per unit of consumption/production. Production data for this sector are available from the UN and the US Bureau of Mines.

Solvent and other product use

Solvents and related compounds are a major source of NMVOCs but a small overall contributor to a state's greenhouse gas emissions. They are used in cleaning products for both domestic and industrial use. Paints and lacquers are also included in this category. These gases are emitted from a variety of dispersed activities which can be referred to as 'area' sources as they come from a large number of dispersed applications rather than large centralized 'point' sources, such as those in the industrial processes sector. Accurate emissions estimation in this sector is difficult and results can be highly uncertain. Emissions calculations can be based either on production, using annual production data and an appropriate emission factor, or on consumption of solvents or related substances. Emissions estimates based on consumption assume that any paint purchased is used shortly after purchase. Less original IPCC guidance exists for this sector because of the lower priority given to these gases.

Agriculture

Monitoring of the agriculture sector is divided into emissions from domestic livestock, rice cultivation, prescribed burning of savannas, field burning of agricultural residues and agricultural soils. Data for these areas come from the Food and Agriculture Organization (FAO),[22] the International Rice Research Institute (IRRI) and the IPCC, as well as from individual country studies.

Enteric fermentation and manure management are the primary sources considered in domestic livestock. Enteric fermentation produces CH_4 as a by-product of animals' digestive processes. Decomposition of animal manure under anaerobic conditions also produces CH_4.[23] The methodological issues are complex in this sector. However, in simple terms, in order to estimate emissions, an emission factor is applied to the number of animals of each livestock type. The IPCC provides default emission factors for the calculation. The same methodology applies to manure management.

In rice cultivation, anaerobic decomposition of organic material in flooded rice fields produces CH_4. Methane fluxes differ temporally, and with different soil types and textures. Fluxes also depend on other factors, in particular the water management regime. Because of the manifold complexities involved, a range of emission levels is required instead of a single number. The methodology for rice cultivation involves multiplying a methane emission factor by the annual harvested area, multiplied by the number of cropping seasons a year.

Savannas are tropical and subtropical formations with continuous grass coverage. Burning of savannas occurs every one to four years and produces CO_2 emissions.[24] The CO_2 will, however, be reabsorbed during the next growing season (although with the degradation of land over time some CO_2 will be lost). Other greenhouse gases (CH_4, CO, N_2O and oxides of nitrogen) will not, however, be reabsorbed. To estimate emissions for this sector the quantity of biomass that burns is calculated and then multiplied by the fraction oxidized and by the carbon fraction.[25] Ratios must then be applied to the carbon released in order to derive estimates of the non-CO_2 gas emissions.

Field burning of agricultural residues occurs sometimes for energy and sometimes as a way of disposing of waste. It results in emissions of CH_4, CO, N_2O and NO_x. Again, although CO_2 is emitted it is normally later reabsorbed during the next growing season.

Finally, N_2O emissions occur from direct emissions from soils and from nitrogen used in fertilizers. The emission estimation methodology for this area is based on emission factors and data from the FAO.

Land-use change and forestry[26]

Monitoring of this sector covers emissions to and removals from the atmosphere of greenhouse gases. This sector is responsible for emissions of CH_4, N_2O and certain indirect GHGs, but CO_2 is the main GHG in this sector. The primary activities to be monitored here are changes in forest and other woody biomass stocks, forest and grassland conversion, and the abandonment of managed land (cultivated and pasture land).[27] Methodologies for estimating emissions in this sector have traditionally been considered as particularly complex and direct measurements are difficult to perform. Problems of land area monitoring and complexities involved in monitoring natural processes are acute. The use of satellites to monitor land use and forestry has been suggested as one way of overcoming some of the difficulties of obtaining reliable data. A basic approach to emissions estimation is 'to make simple assumptions about the effects of land-use change on carbon stocks and the subsequent biological response to the land-use change, and to use these assumptions to calculate carbon stock changes and hence the carbon dioxide flux'.[28]

Waste

This sector is responsible for many greenhouse gases but the most important is CH_4. Disposal (for solid waste this means landfill, recycling or incineration) and treatment of industrial and municipal wastes can produce emissions of most of the important GHGs. With regard to land disposal of solid waste, the data needed for estimation are population statistics, waste statistics, degradable organic carbon (DOC) content and categories of waste disposal sites. The methodology for emissions estimation involves information such as the amount of waste deposited in different categories of waste disposal sites, the fraction of DOC and the amount which actually degrades, and the fraction of CH_4 in landfill gas. With regard to CH_4 from waste-water handling, the data needed include population statistics, the DOC, industry output, the amounts of industrial waste water and sludge produced, and the types of handling system in use. The amount of organic material in these streams determines the amount of CH_4 production. The methodology for this sector entails multiplying the amount of organic material in the waste water or sludge by an average emission factor for each waste-water or sludge source to derive the emissions estimates. Estimating N_2O emissions from human sewage requires knowledge of average annual per capita protein consumption, population statistics, the fraction of nitrogen in protein and an emission factor. To estimate emissions in waste incineration the carbon emitted must be separated into biomass and fossil fuel-based fractions, with only the fossil fuel portion being counted. Traditional air pollutants can be estimated from existing inventory systems.

Inventory management

Each party to the UNFCCC uses a different system to compile its inventory, based on its particular institutional structure. For instance, in the United Kingdom the

Department for Environment, Food and Rural Affairs (DEFRA) is responsible for planning and co-ordinating the UK inventory as well as its submission. The compilation and updating of the inventory is contracted out to a private consulting company. This company obtains data from yet other specialist organizations. Other government departments are also involved in providing data and methodological work.[29]

In order to maintain and improve the quality of inventories, certain procedures must be undertaken, including uncertainty management, verification and review. Users of emissions inventories need to understand the reliability of the estimations, both the totals and the component parts, depending on how detailed they need their information to be. National inventories usually contain a wide range of emission estimate types; for some it is easy to maintain a high level of accuracy, for others it is more difficult. Uncertainty estimates that are consistently produced will not only render decisions based on inventory estimates more informed but will also help prioritize efforts to improve the accuracy of inventories in the future. To this end the IPCC has not only provided instructions in its *Revised 1996 Guidelines* but has also produced an extensive new set of guidelines to provide good practice guidance and help states in uncertainty management of their national inventories; the guidelines were adopted by the Conference of the Parties (COP) to the UNFCCC in 2000.[30] Moreover, another good practice guidance report has been compiled solely for the land-use, land-use change and forestry sector in order to improve emissions estimation in this complex area. Finally, the IPCC hopes to produce a new revision of all these guidelines, to be released in 2006.

Quality assurance (QA) and quality control (QC) procedures form an integral part of inventory quality management and assist in the assessment of inventory completeness. QA is a 'system of routine technical activities, to measure and control the quality of the inventory as it is being developed', for example, accuracy checks on data acquisition. QC activities 'include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process'.[31] QA/QC procedures also cover the use of direct emissions measurement through continuous emissions monitoring.

Verification of emissions estimates reduces the risk of inaccurate inventories. It can be undertaken in a variety of ways. At the national level, comparison with other independently compiled national or regional inventories is useful to check completeness. Comparisons with other countries' inventories, comparison of activity data with independently compiled data sets, comparison of emission factors between countries and comparisons of national emission inventories with independently compiled international data sets (see below) are also useful. Comparison can be made with atmospheric measurements at the local, regional or global levels (see below). Direct source testing of key source categories can also be carried out.

The final step in ensuring that inventories are accurate and finding areas needing of improvement is the review procedure. Review of inventories is carried out annually and has three parts. First, the UNFCCC Secretariat conducts a brief check on the completeness of the inventory and checks that it is in the correct format; second, the secretariat then compiles a synthesis and assessment document which compares data across parties and highlights areas to be considered in the third part, which is the individual review process. Individual reviews are carried out by groups of experts who are nominated to a roster and co-ordinated by the secretariat. The individual review can be carried out in three ways: by in-country review, by centralized review (which takes place at the UNFCCC Secretariat) or by desk review (where the experts work from their home countries). The results of the reviews and the synthesis and assessment documents are made publicly available on the UNFCCC website.

The secretariat aims to ensure that expert review teams can cover all economic sectors and that their membership is balanced between Annex I and non-Annex I parties. Some 150 experts from 73 parties had been involved in review procedures as of 2003.[32] In addition, an inventory review training programme developed by the secretariat was launched in 2004 to promote broader representation from parties and to increase the number of available experts.

The quality of greenhouse gas monitoring so far

In general the quality of inventory compilation by Annex I parties to the UNFCCC has steadily improved, as has the timeliness of national inventory reporting: 36 parties[33] submitted their inventory within six weeks after the due date for 2004 compared to 29 in 2003 and 22 in 2002. However, there is room for improvement in parties' inventories: some were still incomplete when submitted.[34] Under the

Kyoto Protocol (article 5.1) Annex I parties must have in place national systems (institutional, legal and procedural arrangements) for estimating GHG emissions and removals no later than one year before the start of the first commitment period (2008). Annex I parties are still in the process of setting these systems up and progress in meeting the UNFCCC requirements differs widely between them. If parties do not meet the eligibility criteria for national systems they will be in non-compliance with the Kyoto Protocol and will be unable to participate in the protocol's flexible mechanisms.[35] If a sufficient number of parties are in this position at the beginning of the first commitment period, the protocol will be considerably weakened and time will be lost. Parties should therefore do their utmost to ensure that these systems are implemented promptly.

Non-Annex I parties are not as yet required to submit inventories annually. However, in the long term it is vital that these states are able regularly to compile high-quality national inventories. The UNFCCC has set up capacity-building measures for these states. The financial, technical and institutional barriers to inventory compilation differ from country to country but can often be severe. The degree to which Annex I parties support these measures financially will determine how quickly the developing country parties can improve their own inventories.

Other international emissions inventories

There are several independently compiled international emissions inventories that can be used to verify national inventories under the UNFCCC (as referred to above) and are valuable additional sources of information on greenhouse gases.

The IEA produces an annual statistical report on CO_2 emissions from fossil fuel combustion for more than 140 countries, including data going back to 1960 for highly developed countries and 1971 for other countries. The Carbon Dioxide Information Analysis Centre (CDIAC), which is part of the US Department of Energy (DOE) and was established in 1982, also provides various data on CO_2 emissions. The Global Emissions Inventory Activity (GEIA) Center, which was established in 1990 and is also based in the US, develops global emissions inventories from both natural and anthropogenic sources. The National Institute for Public Health and the Environment (RIVM) in the Netherlands, and TNO, a

Dutch consultancy, co-operated with the GEIA (so as not to duplicate its work) in developing another global emissions source database in the early 1990s. The Emission Database for Global Atmospheric Research (EDGAR) uses less detailed national data than the GEIA but seeks to be more comprehensive and complete in geographical coverage and source categories. Both the GEIA and EDGAR provide inventories for historical and recent emissions. It should be noted that the data used to compile these inventories are not entirely independent of each other or even of some of the data used for national inventories.

The EU Emissions Trading Scheme

On 1 January 2005 the EU Emissions Trading Scheme (ETS) is due to start. Although flexible mechanisms[36] to make emissions reduction efficient are provided for under the Kyoto Protocol, the EU decided to expand the environmental and economic efficiency benefits to be gained from emissions trading by creating an emissions trading scheme for companies in the EU. The ETS is designed to be compatible with but independent of the Kyoto Protocol. Under the ETS, member states devise national allocation plans which divide carbon emission allowances between companies and sectors (covering in total some 12,000 installations[37]). The allocation plan should lead to a given level of emissions reduction in the particular state. Trading occurs as companies with excess allowances sell them to other companies which need them.

A sound monitoring and reporting system is the backbone of a credible and functioning trading scheme. The EU has passed legislation[38] for monitoring greenhouse gas emissions under the ETS. A number of nations and various state governments in the United States have already implemented or are in the process of implementing emissions trading schemes of their own.[39] It is important that the monitoring provisions stipulated by these schemes are compatible with those of the ETS. In this way it will be possible to link the schemes, since the integrity of the emissions trading units can be ensured.

The monitoring of emissions under the ETS differs from monitoring practices under the UNFCCC and the Kyoto Protocol because the purposes and scope of the two monitoring systems differ: under the ETS only CO_2 is currently set to be monitored during the first commitment period, 2005–2007, in order to facilitate the inauguration of the scheme. More GHGs may be included in future commitment periods. Furthermore, the only sectors covered are energy activities, the production and processing of ferrous metals, the mineral industry, and industrial plants for the production of pulp and paper (accounting for about 45 per cent of CO_2 emissions from the EU countries).[40] The principles governing the monitoring and reporting guidelines are similar to those of the IPCC and the UNFCCC in that they strive for completeness, consistency, transparency and accuracy. Since the ETS is intended to be compatible and consistent with the UNFCCC and the reporting of other emissions data for the European Pollutant Emission Register (EPER), emissions must be labelled by applying codes from the IPCC common reporting format and the Integrated Pollution Prevention and Control (IPPC) source category code of the EPER.[41]

Under the ETS, operators[42] of installations must report their emissions annually to specified competent national authorities. The member states themselves must submit a report annually to the European Commission covering allowance allocations, application of the monitoring guidelines and compliance issues.

Under the monitoring requirements, emissions can be determined using a calculation-based methodology or a measurement-based methodology or a combination of the two.[43] Monitoring of emissions under the ETS by calculation uses an approach similar to that found in the IPCC guidelines. The formula is:[44]

Emissions = activity data x emission factor.

If emissions are calculated, the activity data, emission factors, oxidation factors, total emissions and uncertainty estimates must be reported. The determination of emission factors must be based on European Committee for Standardization[45] (CEN) standards and, if these are not available, with International Standards Organization (ISO) standards. If measurement is used, total emissions, information on the reliability of the measurement methods and uncertainty assessments must be reported.

The measurement of emissions under the ETS requires the use of continuous emission measurement systems (CEMS): an instrument monitors emissions directly and continuously by taking a part of the flue gas stream from a stack, measuring the pollutant concentration in this part and then extrapolating to the total gas flux. Adherence to certain CEN or ISO standards is again required. Measurement has been traditionally thought of as the most accurate form of monitoring for many parts of industry; indeed, the US Acid Rain Program and the EU Large Combustion Plant Directive require the use of CEMS. However, this may not be true for CO_2 emissions from energy use. In addition, although modifying a CEM which measures sulphur dioxide (SO_2) or N_2O to also measure CO_2 is relatively inexpensive, installing a CEM from scratch can be extremely costly. Furthermore, it has been found that CEMS tend to overestimate emissions. It is likely therefore that, on the whole, emissions calculation will be used instead.[46]

The ETS monitoring guidelines provide a selection of approaches, referred to as tiers, for determining activity data, emission factors, oxidation and conversion factors. The successful use of higher tiers has increased levels of accuracy.[47] Under the scheme, operators must use the highest tier approach unless it can be shown to the competent authority that it 'is technically not feasible or will lead to unreasonably high costs',[48] in which case a lower tier may be used.

Inventory management

The ETS contains several provisions for inventory management, including requirements for operators to use QA/QC and uncertainty assessment. It also requires operators' emissions reports to be checked by an independent accredited verifier who will consider the 'reliability, credibility and accuracy of monitoring systems and the reported data relating to emissions'.[49] However, several aspects of the verification regime are not yet fleshed out, including those relating to the responsibilities of the verification process and the verifier, verification methodology and level of assurance,[50] meaning the 'degree to which the verifier is confident in the verification conclusions that it has been proved whether or not the information reported for an installation taken as a whole is free from material misstatement'.[51] These issues are currently being worked on in order to have an effective system up and running before 1 January 2005.

Future success of monitoring

The ETS was developed and is being implemented rapidly. Early preparation by business and member states is fundamental to ensuring a smooth start to the first commitment period. Whether there will be a smooth start is in the balance:

many difficulties at the member state level relating to the transposition of legislation and the timely submission of appropriate national emissions allocation information have beset preparations for the scheme. To a great extent these difficulties are to be expected in the context of normal political bargaining and manoeuvring, and as long as the European Commission maintains a firm line this aspect of the preparations should not be an impediment to the start of the first commitment period. However, a recent report[52] has suggested that many companies are unprepared for the scheme in a variety of ways due to lack of confidence in its underlying framework. This lack of preparation has also affected the potential reporting capabilities of companies at an operational level.[53]

The success of the scheme therefore depends on (a) the ability and willingness of business to implement appropriate strategies for participation in and compliance with the scheme quickly, and (b) the ability of member states' governments both to inspire confidence in the scheme by ensuring that serious emissions allocation limits are set and to ensure that they have the administrative capacity to monitor and regulate the functioning of the scheme in their territory.

Corporate greenhouse gas registers

International and national emissions inventory systems are maturing both in terms of their coverage of emitting sectors (although some gaps still remain) and in terms of the quality of states' competence in this field. However, such systems are unable to show emissions from multinational corporations holistically: since the activities of these companies span the globe they fall, in terms of emissions accounting, between the limited legislative reach of national emissions monitoring systems, which target specific installations but can only do so in their own jurisdiction, and international monitoring systems, such as that of the UNFCCC, which have global reach but do not target specific companies. A number of initiatives have recently been launched in response, a prominent example being the Global Greenhouse Gas Register of the World Economic Forum (WEF), announced in December 2003.

The Global Greenhouse Gas Register is a web-based tool for corporations to voluntarily and publicly record their GHG emissions and reduction targets. It is the first global platform for corporations to make their emissions known and is designed to promote corporate GHG emissions transparency through companies committing themselves to a set of common measurement and reporting principles. It is also hoped that it will enhance energy efficiency and effective greenhouse gas management, and support the development of emissions trading schemes and regulatory requirements. So far 12 large companies which together account globally for some five per cent of Annex I parties' emissions have joined the scheme. The target is to have 20–25 companies included by the end of 2004. Companies are required to prepare an annual corporate-wide inventory for the register of the same six GHGs as under the UNFCCC. The major benefit of this venture for multinationals is that it allows the global emissions data of a company to be viewed, as opposed to only its national emissions data under national emissions reporting or trading schemes. Emissions registers can play an important role in engaging business in climate change activities.

The methodological basis for preparing the inventory is the Greenhouse Gas Protocol (see below) of the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD).[54]

The register also makes provisions for verification: companies either can arrange independent verification of their inventories or must allow checks to be made by accredited[55] verifiers organized by the register. Whichever type of verification companies undergo will be made clear in the reports.[56] The register will randomly select a number of companies which have not arranged independent verification (or are not already required to have it) for a review. Issues to be examined include credibility, reliability, and the accuracy of monitoring and documentation procedures. This process is not intended to be as detailed or accurate as verification under GHG trading schemes such as those of the EU or the UK and is designed to verify only to a 'minimal' level the principles mentioned above, in order to keep costs down. Consequently the focus of the verification procedures is to be at head-office level and site-specific visits are not intended.

The Greenhouse Gas Protocol Initiative was established in 1998 to develop internationally accepted accounting and reporting standards for use by companies and other organizations. It is currently used by a number of companies, including several global corporations. Moreover, in August 2004 Mexico decided to use a version of the protocol to assist its businesses in preparing GHG inventories, the first country to do so. The harmonization of reporting and accounting standards under this initiative should make policies such as carbon taxes, regulations and standards on emissions and emissions trading schemes easier to implement for both companies and governments. It aims to be consistent with most other GHG reporting schemes.

Sector-specific guidelines are also beginning to emerge: guidelines for reporting greenhouse gas emissions produced by the International Petroleum Industry Environmental Conservation Association (IPIECA) were completed in December 2003 and a compendium of GHG emissions estimation methodologies for the oil and gas industry was produced in April 2001 by the American Petroleum Institute. In addition, the ISO is currently developing an international standard for GHG accounting and verification which should be published within two years.

The recent emergence of these various initiatives to monitor greenhouse gas emissions demonstrates both that there is growing commercial support for action on climate change and a clear recognition of the importance of monitoring and reporting in such efforts. Even though the initiatives are often different in scope, structure and aims, it is encouraging that uniformity in monitoring, reporting and verification standards is being sought. Indeed, it is crucial, as these reporting platforms, trading schemes, standards and emissions reduction programmes grow in size and increase in number, that harmonization and standardization of accounting procedures continues in order to ensure that the data produced are truly comparable, transparent, accurate and credible, and therefore useful for mitigation policy decisions and emissions trading.

Global and regional atmospheric monitoring systems

International, national and corporate emissions inventories provide information that identifies who and what is responsible for greenhouse gas emissions, and in what quantity. The use of atmospheric emissions monitoring systems which measure concentrations of GHGs in the atmosphere complements this information. These systems are essential for understanding how emissions interact with the atmosphere and for furthering our understanding of how the climate responds to emissions from both natural and anthropogenic sources.

Several organizations currently perform atmospheric greenhouse gas monitoring. The National Oceanic and Atmospheric Administration (NOAA) monitors atmospheric CO_2 concentration from four observatories, in Alaska, Hawaii and Samoa and at the South Pole. In addition, the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO) measures GHGs in the atmosphere from several ground-based stations around the world. It is also possible to use aircraft equipped with monitoring instrumentation for atmospheric GHG monitoring.[57] Furthermore, satellites can be particularly useful for monitoring GHGs (as well as monitoring land-use change). A number of new ventures are under way: the Greenhouse Gas Observing Satellite (GOSAT)[58], due to be launched in 2007, will monitor the distribution of the density of CO_2 while Aura, developed and launched on 15 July 2004 by the US National Aeronautics and Space Administration (NASA), will distinguish between the natural and industrial influences on climate change. Data from Aura will also help to improve climate change computer models.

Efforts to monitor greenhouse gases in the atmosphere have hitherto been largely unco-ordinated, at least globally. However, as governments have recognized the need for more accurate climate-related information there has been a surge in initiatives to co-ordinate the diverse monitoring systems scattered around the world. In 1992 the Global Climate Observing System (GCOS) was established to co-ordinate and facilitate the observations and information required to understand climate change; subsequently in 1998 the Integrated Global Observing Strategy (IGOS) was set up to harmonize land- and space-based observing systems; and most recently, in April 2004, a framework plan for a co-ordinated earth observation system (known as the Global Observation System of Systems) was adopted at the Earth Observation Summit in Tokyo, Japan. If successfully implemented this initiative could substantially improve our ability to monitor GHG emissions and climate change.

Conclusion

It is apparent that in certain regions, such as Europe, there is already substantial capacity to perform monitoring at most levels, from the individual industrial plant to national estimates. However, this is not the case in much of the developing world, and efforts by the developed world to remedy this situation, using channels such as the UNFCCC, must therefore continue to be supported and be increased. Furthermore, emissions monitoring systems and techniques, while comparatively advanced in Europe, are by no means flawless, and there is a considerable amount of work to do to improve the quality of emissions monitoring. Corporate greenhouse gas registers are an effective means of spurring business into finding innovative ways to reduce emissions and of pinpointing the extent to which companies are succeeding. It is encouraging to see robust corporate monitoring schemes appearing. It is important that these schemes receive as much positive exposure as possible in order to encourage more companies to use them.

It is also encouraging to see the growth of initiatives to co-ordinate global atmospheric monitoring and satellite use: the combined results of the manifold systems will provide a wealth of new information. Finally, although GHG monitoring techniques now cover many sectors, several, such as international aviation, still need harmonized monitoring and reporting procedures.

Accurate greenhouse gas monitoring is vital for our understanding of what effect humans have on the environment and for deciding what actions to take to mitigate the problems identified. This chapter has shown that GHG monitoring is required at many different levels. GHG emissions monitoring is a relatively new phenomenon but the capacity to perform it is advancing quickly in terms of reliability, sectoral coverage and consistency between systems: the international community should continue to build on the progress already made.

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Endnotes

1 The term 'radiative' is used by the IPCC to denote 'an externally imposed perturbation in the radiative energy budget of the Earth's climate system' (J.T. Houghton et al. (eds), *Climate Change 2001: The Scientific Basis,* Contribution of Working Group I to the Third Assessment Report of the IPCC, Cambridge University Press, Cambridge, 2001, section 6.1.1).

2 Intergovernmental Panel on Climate Change (IPCC), *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *Volume 3,* ch. 1.8, www.ipcc-nggip.iges.or.jp/public/gl.invsi.htm.

3 These are known as indirect greenhouse gases since they are not important GHGs themselves but can influence the concentration of some GHGs. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3,* ch. 5.1.

4 In the IPCC Third Assessment Report, 2001 (see J.T. Houghton et al. (eds), *Climate Change 2001*), some GWP values have changed from those in the IPCC Second Assessment Report (SAR). However the values found in the SAR are currently being used for calculations in inventories under the UNFCCC. For the Second Assessment Report see J.T. Houghton et al. (eds), *Climate Change 1995: The Science of Climate Change,* Cambridge University Press, Cambridge, 1996.

5 US Environmental Protection Agency, www.epa.gov.

6 *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *Volume 1,* annex 2.

7 The IPCC was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988 in recognition of the potential threat of climate change.

8 UNFCCC, 'Review of the implementation of the commitments and of other provisions of the convention. National communications: greenhouse gas inventories from Parties included in Annex I to the convention. UNFCCC guidelines on reporting and review', FCCC/CP/1999/7, 1999, p. 5, www.unfccc.int/resource/docs/cop5/07.pdf.

9 One major difference between the systems is that the IPCC approach includes only anthropogenic sources, whereas the CORINAIR approach includes natural sources as well.

10 Moreover, a CORINAIR inventory can, with some manipulation, be converted into an IPCC inventory. Much progress has already been made in harmonizing the IPCC and EMEP/CORINAIR approaches. Over time various EU states have used different combinations of these systems, including basing data predominantly on CORINAIR or national methodologies or the IPCC approach or a combination of these systems. Few EU countries have used only the IPCC approach, since other approaches predate that of the IPCC. Andrea Moran and Julian Salt, 'International greenhouse gas inventory systems: a comparison between CORINAIR and IPCC methodologies in the EU', *Global Environmental Change,* vol. 7, no. 4, 1997, pp. 317–336; and 'International greenhouse gas inventory compilation systems: CORINAIR and the IPCC', 1996, Prepared for the EU Directorate General XII Environment Programme.

11 Some parties with economies in transition (EIT parties) use a different base year. See 'UNFCCC guidelines on reporting and review', FCCC/CP/1999/7, for details of which base year each EIT party may use.

12 'Sinks' refer to activities which remove greenhouse gases from the atmosphere.

13 The highest priority source is CO_2 energy sources, then CO_2 from land-use change. The next are CH_4 from major source categories—rice production, coal mining, oil and natural gas, enteric fermentation and animal waste, landfills and other waste, and biomass burning—then N_2O from agriculture, and other greenhouse gases. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *Volume 2,* 'Introduction'.

14 *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *Volume 3,* 'Introduction'.

15 *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *Volume 1,* 'Glossary 2'.

16 *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *Volume 2,* ch. 1.2.

17 Most carbon is emitted as CO_2 immediately during the combustion process. Some carbon is released as CO or CH_4 or non-methane hydrocarbons, which oxidize to CO_2 in the atmosphere within a period from a few days to 10–11 years.

18 Fugitive emissions can be intentional or unintentional and may arise from production, processing, transmission, storage or use of fuels and non-productive emissions from combustion. See *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *Volume 3,* ch. 1.1-2.

19 Under the UNFCCC parties do not include emissions from fuels purchased on their territory for use by international aviation and maritime traffic (known as 'bunker fuels') in their national totals, but report them separately.

20 'Apparent' consumption here signifies that the calculation tracks the consumption of primary fuels in an economy with adjustments from net imports and stock changes in secondary fuels but does not give actual consumption. See *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *Volume 1,* 'Glossary', for more details.

21 In the chemical industry a major source of GHG emissions is cement production: CO_2 is produced during the production of clinker, which is an intermediate product from which cement is made.

22 Data are published in the FAO *Production Yearbook*. The FAO mainly obtains these data from national data and questionnaires, although several other sources are used in the compilation process.

23 Nitrous oxide is also produced from this sector.

24 The burning of savannas is intentional and is used to improve the quality of the land. Benefits from the burning process include nutrient cycling and weed eradication.

25 A carbon fraction determines the amount of carbon released from the oxidized biomass.

26 Although the IPCC guidelines refer to land-use change and forestry, the term 'land use, land-use change and forestry' has now become the usual title for this sector in the UNFCCC negotiations.

27 This is broken down into three sectors: changes in carbon stored in soil and litter of mineral soils due to changes in land-use practices; CO_2 emissions from organic soils converted to agriculture or plantation forestry; and CO_2 emissions from the liming of agricultural soils.

28 *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *Volume 3,* ch. 5.3.

29 UNFCCC, 'Report on the in-depth review of the third national communication of the United Kingdom of Great Britain and Northern Ireland', FCCC/IDR.3/GBR, 8 May 2003, www.unfccc.int.

30 *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventorie*s, 2000, www.ipcc-nggip.or.jp/public/gp/english/.

31 *IPCC Good Practice Guidance*, ch. 8.4.

32 UNFCCC, 'Counting emissions and removals, greenhouse gas inventories under the UNFCCC', 2003.

33 The number of parties that are obliged or have volunteered to report as Annex I parties has fluctuated between 35 and 41.

34 UNFCCC, 'Methodological issues, greenhouse gas inventories', FCCC/SBSTA/2003/14, 2003; and individual reviews of greenhouse gas inventories 2003 and 2004, www.unfccc.int.

35 Flexible mechanisms include emissions trading, joint implementation and the clean development mechanism. See Molly Anderson, 'Verification under the Kyoto Protocol', in Trevor Findlay and Oliver Meier (eds), *Verification Yearbook 2002,* Verification Research, Training and Information Centre (VERTIC), London, December 2002, pp. 147–169.

36 See previous endnote.

37 Defined in the monitoring legislation as 'a stationary technical unit' where an activity covered by the scheme is carried out. European Commission, Decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council, Brussels, 29 January 2004, C(2004) 130 final.

38 European Commission, Decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions.

39 Australia, Denmark, New Zealand, Norway and the UK have national emissions trading schemes. States in the US which are interested in emissions trading include California and some in the northeast.

40 The Carbon Trust, www.thecarbontrust.co.uk, accessed September 2004.

41 European Commission, Decision of 17 July 2000 on the implementation of a European pollutant emission register (EPER) according to Article 15 of Council Directive 96/61/EC concerning integrated pollution prevention and control (IPPC), 2000/479/EC.

42 An operator is defined as a person who operates or controls an installation or, where this is provided for in national legislation, to whom decisive economic power over the technical functioning of the installation has been delegated (European Commission, Decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions).

43 The operator must demonstrate that measurement will give higher accuracy than calculation. In addition, the operator must corroborate the measured emissions by calculation.

44 If the emission factor does not take account of the fact that some of the carbon is not oxidized, the emission factor and activity data should also be multiplied by an oxidation factor.

45 For further information see www.cenorm.be/cenorm/index.htm.

46 Center for Clean Air Policy/TNO/FIELD, 'Study on the monitoring and measurement of greenhouse gas emissions at the plant level in the context of the Kyoto mechanisms', 2001, www.europa.eu.int/comm/environment/climat/pdf/finalreport0110.pdf.

47 For instance, with respect to emission factors for CO_2 emissions from combustion, tier 1 requires using IPCC factors, tier 2 requires using specific emission factors as reported to the United Nations Framework Convention on Climate Change Secretariat by the member state, and tier 2b requires the operator to derive emission factors for each batch of fuel based on either density measurement or net calorific value in combination with empirical correlation as determined by an external laboratory (European Commission, Decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions).

48 European Commission, Decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions, p. 12.

49 European Commission, Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

50 The European Accreditation Body has set up a working group to develop a Greenhouse Gas Guidance Note. The International Emissions Trading Association (IETA) has created several new working groups to develop, inter alia, Greenhouse Gas Auditor Training Programme requirements and a Greenhouse Gas Verification Protocol.

51 European Commission, Decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions, p. 6.

52 Ernst and Young, 'The European Emissions Trading Scheme: A challenge for industry or just an illusion?', 2004, www.ey.com.

53 Companies in the UK and the Netherlands are better prepared as they have emissions trading experience from their domestic trading schemes.

54 Companies can use other inventory programmes' protocols as long as they incorporate the standards provided for in the Greenhouse Gas Protocol.

55 The Global Greenhouse Gas Register will use existing GHG verification accreditation processes such as the United Kingdom Accreditation Service (UKAS).

56 Some companies have emissions from operations in both developed and developing countries. Their emissions in the developed countries are independently verified, but those in the developing countries are not. For such cases the register stipulates that emissions in the developing countries do not need to be verified as long as the companies' verified sites account for more than 75 per cent of their total emissions.

57 For instance, see www.earthobservatory.nasa.gov:8000/Newsroom/Campaigns/COBRA.html and, on the GAW programme, www.wmo.ch/web/arep/gaw/gaw_home.html.

58 This satellite is being developed by the Japan Aerospace Exploration Agency (JAXA) and Japan's Ministry of the Environment. See www.jaxa.jp/missions/projects/sat/eos/gosat/index_e/html.