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Preface

The following paper is a slightly revised version of a study prepared during the summer of 1989 in response to a request from the Enquete-Kommission des 11. Deutschen Bundestages "Vorsorge zum Schutz der Erdatmosphäre".* It addresses both conceptual and practical features of a verification system appropriate to satisfy eventual requirements of an international convention to control emissions of greenhouse gases. Due to the complexity of the "problematique", stemming from the interfaces between technology, society and international relations, the study must be seen as preliminary. This notwithstanding, we consider a limited distribution necessary to promote interactions with scholars working in the field.

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Abstract

Countries participating in a climate convention will have to commit themselves not to exceed a predetermined level of anthropogenic greenhouse gases (GHG) emissions. Such a convention will probably include international verification measures to survey the observance of the contractual obligations (verification of compliance).

A two-sided structure should be used to implement verification: A national authority in the member states should be established and entrusted with the task of determining the country's anthropogenic GHG emissions and of declaring them to an international organization. This organization should bear responsibility for verifying each party's compliance with the emissions' limits laid down in the convention (protocols).

Verification concepts derived from arms control, in particular those of the Non-Proliferation Treaty (NPT), are not suitable models for the verification of GHG emissions. This is largely due to the poor verification suitability of important emissions sectors. Therefore, the proposal is to develop a verification system based upon an approach whose main components are the national declarations of GHG emissions and the assessment of their plausibility in an international verification organization. Because the proposed verification system largely dispenses with inspections and controls through measuring techniques and devices, it can be seen as a confidence building instrument.

The core elements of the verification system are as follows:

- Calculation and declaration of energy consumption and the associated CO_2 emissions by the national authorities and verification of these declaration by the international authority by means of audit and other methods verifying the plausibility and reliability of the data.

- Use of space-based (and other) global remote sensing systems to monitor forests, deforestation and, if possible, infrastructural and land-use activities by member states in order to verify agreed commitments concerning forest protection, reforestation etc..

- Studies, audits and procedural verification in the sectors where emissions cannot be either precisely calculated or monitored by means of remote sensing (parts of the energy sectors, agriculture, waste disposal sites).

In comparison with the verification standards of arms control these surveillance measures for GHG emissions do not fulfil the strict quantification criteria of most extant verification systems because, first, the international organization is not in a position to collect its own data and other original information for most of the emitting sectors and, second, the probability to reveal a minor violation of the treaty is rather low.
However, this weakness in the verification system (the low verification density) can be relativized. The relevance of treaty violations must always be assessed with a view to their effect on the goal of the treaty. Therefore, for example, with global CO_2 emissions from the energy sector in the order of approx. 6 Gt C/a, a few million tonnes of "concealed" CO_2 emissions would not be of significance.

In establishing a verification system, the policy makers must always weigh up the envisaged verification density on the one hand against national, and above all international, acceptance of a dense verification system on the other. It must also be kept in mind that any verification only applies to those states which have acceded to a convention whereas non-participating states often enjoy the advantage of not being affected by the material provisions of a convention (e.g. the reduction goals of GHG) or by its verification regulations. For this reason, universality of membership must be an essential goal of this policy and should be achieved by both positive and negative incentives.

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Preliminary Remarks

The aim of our study is to make initial proposals for the design of a verification system appropriate for an international convention on anthropogenic emissions of greenhouse gases.[1]

Such a task is almost completely new. Our considerations cannot therefore be conclusive and completely rounded off, but rather open up a broad field of work for more extensive studies.

Central problems we had to face for working out the proposals were the lack of directives with respect to:
i) the extent of the obligations assumed by a nation party to such convention concerning declaration of intents (e. g. reduction targets) and
ii) the stringency of the verification (i. e. the verification 'density'). In principle, those directives should be given before the task of designing the verification system is initiated.

Since the elements of the logical sequence: obligation of declaration - verification density to work out an adequate verification system were not predetermined, we had to bridge the existing gaps ourselves. Our basic assumptions with respect to the material and formal elements of an international climate convention are the following: general obligation of the contracting nations to declare their intents (emissions' reduction, freeze, limited increase); based upon this, agreement on special arrangements for individual greenhouse gases (protocols); each party's free choice of ways and means to attain the declared targets.

1. Theoretical Aspects and Study Methodology

We define verification as the international control of the observance of contractually established measures and behaviours by means of tools and procedures agreed upon in an instrument of international law (verification of "compliance").[2] States may be both the subject or the implementer of verification activities, i. e. they are under surveillance and carry out also same activities in other countries.

The verification of compliance can, however, also be carried out by an International Organization (see Section 2). Verification activities are no police activities: they do not serve to enforce an international agreement in a particular state. In the same way as the prevention of treaty violation, this is the task of national institutions. Verification is a subsequent monitoring of compliance with a contract on the part of states, it discovers infringements after the event (ex post facto) and communicates this to the international community of nations which must then decide on measures to be taken (sanctions).

The demand for a verification of international agreements, the verification requirement, does not necessarily result from the subject of the regulations itself. This demand is derived from the structures and processes of international politics, which - in spite of objective constraints and a growing readiness to undertake international cooperation - is still characterized by a lack of information about the intentions of other states, by mutual mistrust, opposing interests and the possibility of gaining advantage by bypassing or infringing international agreements.[3]

According to prevailing understanding the establishment of a "climate regime" would result from cooperative, trustful action between states wishing to counteract the threat of the greenhouse effect. This identical goal and the unilateral commitment on the part of the states under international law involved in a climate convention might suggest that verification activities would not be necessary. This position of a "confidence bonus" towards the contracting parties must be contrasted with the following points:

- In general it is true that (international) environmental policy has attained a greater priority on the value scale of national politics and that environmental problems may have increasing implications for international security. This is becoming increasingly apparent in the problems of the greenhouse effect.[4] At the same time, international treaties on security-relevant fields (arms control) are subjected to ever stricter verification demands which, over and above the application of "National Technical Means" (NTM), also require the application of cooperative verification instruments and procedures. It is therefore not implausible to assume that the interlinkage of environment and security will also involve measures for the verification of international environmental agreements.[5]

- States which regard themselves as potential (absolute or relative) "winners" from the greenhouse effect or will be greatly affected by the necessary emission reductions, that is to say would suffer greatly from the costs of an implementation of climate strategies, could be coerced into acceding to the convention. Their interest in bypassing the agreed measures cannot therefore be ruled out. This may also be the case if some states faithful to the agreements reduce their emissions and thus also improve the environmental situation for those states who do not follow the provisions of the convention (a so-called "free-rider" situation).

- Those states contributing - for example through "debt for nature swaps" - to reduce the debt burden of "Third World" countries could press for a verification of undertakings to protect forests etc..

- Finally, the chances of forming an international regime are improved in general if instruments of verification are available and agreed upon.[6]

We therefore assume that there is a need for verification in the case of such a comprehensive and intrusive international package, as would have to be agreed in a greenhouse gas convention.

However, the question of the intensity of verification (verification density) which is regarded as necessary has not yet been answered. The verification density arises from the political relevance of the sector under consideration, the degree of mistrust about the readiness of states to observe contractual obligations, furthermore, from the level of information of those involved with respect to the ability of the contracting partners to implement contractual goals and the status achieved. The verification density aimed at is therefore the product of the political problem perception and definition process. It may range from an "appropriate verification", which only covers substantial treaty infringements over a predefined period of time, up to a "strict, absolute verification", where each contracting partner has to demonstrate compliance with the treaty under the permanent assumption that he intends to infringe the provisions. The demands made on the verification instruments and procedures correspondingly differ in their severity.

With the task given to us no directives were forwarded with respect to the verification density necessary to provide guidelines for the verification concept. Either of two methodological approaches can be selected in drawing up such a concept:

- A verification concept is drawn up on the basis of a postulated verification density. This procedure can be described as a top-down approach.

- The verification concept and density are oriented by the possibility of verification (bottom-up approach). It is determined on the one hand by the technical verification capability, i.e. the measuring, observation and monitoring procedures etc., as well as by the verification suitability of the object under consideration.

Theoretical verification considerations must be observed in making a decision in favour of one of the two approaches.

The verification suitability, verification capability and verification density interact in a verification system. The *verification suitability* denotes the structures and properties of the system to be subjected to surveillance (verification): These may make verification either easier or more difficult, in the case of complex systems they may even prevent verification. The verification suitability of a system is predefined and can only be altered, if at all, with a considerable expenditure of time and money. In the case of a greenhouse gas emission system it is determined, amongst other factors, by the number, accessibility and (im)mobility of the emission sources. Verification suitability must always be defined in relation to the verification procedures. An object to be controlled may display poor suitability with respect to one approach, and on the other hand good suitability with respect to another.[7] The *verification capability* depends, on the one hand, on the quality of the procedures used, which must make use of specific and precise methods and standards. Furthermore it also depends on the number, degree of maturity of the instruments, the quality of information evaluation, the abilities of the personnel etc. The verification capability may be increased by technical, staff and organizational improvements, but also by more extensive access to the object under control. Nevertheless, objective (technical limits of measuring and observation systems) and social limitations (costs, acceptance, legal limits) must be taken into consideration when expanding verification capability. As already mentioned, the *verification density* is derived from perceptions of the relevance of an object, the political systems (international relations) and the degree of international mistrust, as well as the need for information. Verification density and (up to the objective performance limits) verification capability can therefore be altered by political demands, whereas the verification suitability of a system is predefined, at least in the short and medium term.

The two alternative ways of determining verification density can be characterized as follows:

- In the top-down approach a verification density is predefined. With a given verification suitability, the verification capability must be built up in such a way that it can cope with verification requirements. However, this may come into conflict with technical and systemic boundary conditions so that the required verification density and the capability are not completely congruent. The "possibilities of verification success" may then be regarded rather sceptically.

- In the bottom-up approach, the verification capability is analysed on the basis of the verification suitability in order to design a verification system that provides indications of a verification density capable of being realized in practice.

The following discussion is based on the second approach. It was selected since this approach enables a technically and procedurally practicable verification system to be developed. In developing our verification proposals we have been at pains to include the acceptance of a surveillance system in our considerations, to estimate the costs (as far as possible), and to represent and assess verification alternatives. Our methodological procedure does not restrict the political freedom to make requirements insofar as a higher (lower) verification density can be strived for at any time. Whereas the implementation of a less strict verification should not be problematic, in the case of demands for a greater verification density:

- either the costs which would have to be expended to fulfil this greater verification need (by extending the verification instruments, procedures etc.) could be determined

- or the lower limit of the verification capability could be determined below which it would not be possible to maintain a greenhouse gas treaty since verification of "compliance" would no longer be regarded as possible.

In assigning the tasks to our working group the question arose of the applicability of the "Non-Proliferation Treaty" (NPT) "safeguards"[8] for monitoring greenhouse gas emissions. If one were to take the experience gained from these "safeguards" (and in particular from controls on the flow of fissionable material)[9] and to a certain extent the verification proposals in a chemical weapons convention[10] as a starting point for drafting a greenhouse gas verification system then the following structure would be conceivable. The emissions of greenhouse gases are measured and balanced at the emitters, a material balance is drawn up for each country and declared by a national surveillance authority. These data are verified by an international safeguards organization[11] by means of its own measurements. If the two values are in agreement then verification has been successful. If a difference, which cannot be explained, arises (Material Unaccounted For, MUF), then a treaty violation is assumed. As will be shown in the following sections, such a verification procedure is not suitable for greenhouse gases. This is due to several reasons:

- the poor verification suitability of significant emission sectors (see Section 3.1);

- the lack of suitable measuring systems for the continuous determination of areal emissions; this in sharp contrast with the nuclear field where relatively small quantities of nuclear material have to be "safeguarded";[12]

- the enormous measuring efforts required to cover even just part of the stationary sources, the associated costs and distortions of the cost structures of the energy industry, the bureaucratic load, the flood of information, the efforts for data processing and aggregation; furthermore, at least for the determination of CO_2 emissions, suitable calculation methods are available for the commercial energy sector;

- the discrepancy between the possible precision of measurements of stationary sources (deviation in the order of a few percent) and the considerably less precise assessment of emissions from areal emission sectors which cannot be covered by measuring systems (e.g. deforestation, agriculture);

- the national and international acceptance of a verification system would probably decline with increasing verification density; there is also a danger that the costs associated with a dense verification system would lead to a misallocation of capital resources in short supply which are really needed for abatement or adaptation strategies;

- moreover, the high costs and time expenditure involved in developing nationally justiciable measuring instruments for emission balancing capable of finding an international consensus should not be overlooked.

Neither the verification system of the NPT nor those (in some respects similar) suggested for a Chemical Weapons Treaty can therefore be used as a model for a verification of greenhouse gas emissions.

2. The Organizational Structure of a Verification System

Verification activities may be carried out by individual states or by an International Organization.[13] The decision for national or international verification is influenced by the number of contracting states and the subject of the treaty. If a treaty is concluded on a bilateral level then intergovernmental verification is to be expected as a rule, but not the intervention of an International Organization. The American-Soviet Strategic Arms Limitation Treaty (SALT, START) and the agreement on the scrapping of Intermediate- Range Nuclear Forces (INF) include bilateral verification agreements. Multilateral agreements may also make use of a reciprocal surveillance system. Thus for example local inspections by national representatives are envisaged in the multilateral arms control agreements within the framework of the Vienna negotiations. However, multilateral agreements of considerable security relevance, such as the NPT and the planned

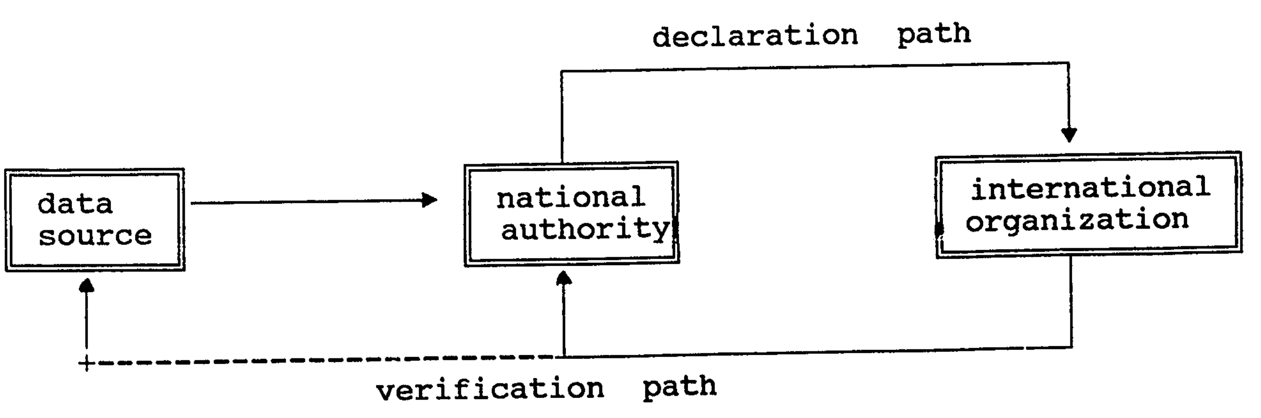
Chemical Weapons Convention, make use of an international safeguards organization. In this case, verification is no longer carried out by national representatives but by the staff of international organizations. This procedure has not yet been applied for international agreements on environmental and resource protection. Nevertheless, in some of these agreements there are initial approaches, modest in comparison with the challenge outlined here, for international verification. At best, reports about contractual compliance are drawn up and discussed, and secretariats collect information which can then be critically analysed.[14] For the reasons already mentioned, a greenhouse gas convention could take recourse to more substantial surveillance exercised by an international verification organization. If such an organization were to be established, then after the International Atomic Energy Agency (IAEA) and the (planned) Chemical Weapons Control Organization, it would be a further international verification organization operating worldwide.[15] The establishment of such an organization would give an important signal since the community of nations would then for the first time grant environmental policy a status equal to that of security policy. The member states should create a national surveillance authority as a partner for such an International Organization in implementing verification. This reflects the structure of the international system: international organizations cannot carry out their activities in the member states without information and cooperation from the national authorities. A national authority would have to carry out important tasks in the process of verifying a greenhouse gas convention. It would bear official responsibility for the declaration of national emissions or other convention- relevant activities by the country, and would acquire or aggregate for that purpose all data arising at the data sources (emitters, emission sectors), or otherwise obtained. Furthermore, it would be the liaison office for the International Organization in verification-relevant questions affecting a country or the community of nations.

Relations between the respective national authority and important emitters (data sources) are of a different nature in free market and planned economies. In free market economies the national authority must collect data from independent legal subjects (for example power station operators); furthermore, in federative countries the federal states with their competences are incorporated as an intermediate stage. In planned economies, this data acquisition is a process of internal information transfer (for example within individual ministries). To this extent, a national authority could make use of existing legal and administrative structures. However, the industrialized free market economies also have at their disposal a functioning structure of data collection and processing (trade inspection office, regional and national statistical offices) which could be essential support organizations or information providers for an authority. The administrative structure of a country is neither a factor which per se influences the efficiency of a national authority and the content of its declarations, nor need it restrict verification opportunities by an International Organization. This has been demonstrated by experience with IAEA "safeguards", which - irrespective of state structures - function quite well.

The tasks of the international surveillance organization consist in collecting national declarations, working out verification concepts in cooperation with the national authorities and also - based on this - drawing up "Implementation Reports". The latter provide information about the observance of the treaty on the part of individual states. In order to carry out its tasks, the International Organization must be in the position to make an independent assessment of the declarations it receives. The "internal structure" of a country must not influence the implementation of verification activities. The International Organization must always attempt to verify the accuracy of the declarations (and the data on which they are based) irrespective of the internal legal status (governmental, private or a mixed form) of a data source (i.e. the emitters). Moreover, the intensity with which a national authority attempts to implement the convention in its own country must not be of significance for the verification activities of the International Organization. This equal treatment of all states is necessary for political reasons. For verification purposes, the International Organization is entitled to request all necessary information from the national authority. This includes raw data sets and, in cooperation with the national authority, if necessary access to the data sources and verification of the data provided by them. A detailed, specific separation of necessary from superfluous information for each state, in the same way as regulations for the protection of sensitive operating information and possible access rights of inspectors, can only be established during the implementation of the verification regime. In this context, the regulations for the various greenhouse gases will be of different types. It must, however, be remembered that the general basis for verification must be regulated in the same manner for all states in a framework agreement. INFCIRC/153 is an appropriate example. Conversion of the framework agreement into specific verification activities in the individual countries must be agreed upon between the respective national authority and the International Organization, taking into consideration the specific situation of the verification object or the verification area. The "Facility Attachments" on the basis of INFCIRC/153 may serve here as a general example. Such facility attachments are too comprehensive, detailed and specific to be laid down in a framework agreement. In the case of a climate convention, the detailed regulation of the concrete verification measures will require a lengthy period of work which will only take its starting point from a framework agreement on verification.

Any contractually agreed reduction in greenhouse gas emissions, in the same way as the readiness to subject oneself to verification, represents a politically motivated limitation of national sovereignty. The extent is to be laid down in the convention by mutual consent (settlement of "convention-specific sovereignty questions"). In this respect, as a voluntary concession restricting sovereignty, verification involves no contradiction to national sovereignty. Nevertheless, problems may arise in the process of implementing the verification system affecting aspects of national sovereignty which are not regulated in detail in the framework agreement ("verification-specific sovereignty questions"). For example, the precise determination of access rights for inspectors in connection with classified information; the selection of inspectors according to national allocation formulae, the employment and possibility of rejecting inspectors by a national authority; the distribution of inspection activities between the nations and the financing of verification measures. Once the political decision for verification has been taken by the conclusion of a framework agreement, it should be possible to solve such verification-specific sovereignty problems, in a dialogue between national authorities and the International Organization.

The following **figure** gives a summary of the declaration and verification path of a climate convention:



Although the NPT and the Chemical Weapons Convention cannot be regarded as models with respect to verification instruments and measuring techniques, nevertheless the safeguards agreements of the NPT and the IAEA could exercise a certain model function in an organizational aspect. INFCIRC/153 envisages the establishment of a national safeguards system for the member states, which also supports the International Organization (IAEA) in implementing its tasks.[16] The organizational structure of the IAEA is a model which must be critically analysed for an international greenhouse gas surveillance organization.[17]

The Federal Republic has dispensed with a national authority for monitoring the nuclear sector in favour of an authority of the European Community (EC) which (in parallel to the IAEA) exercises verification activities in the member states on the basis of the Euratom treaty. The decision for or against an EC authority, thus rendering national authorities superfluous, will be influenced by whether each EC state intends to incorporate national emission goals in the climate convention or whether the Community alone will take over Western European targets which will then be distributed internally. However, even with national goals, the EC Commission, as in the regulation of chlorofluorocarbons (CFCs), could take on a strong position in the internal realization of the greenhouse gas convention and represent the Community at the International Organization. In view of progressing EC integration, the relation between the EC level and the national authority should be given detailed consideration. In this context it must be remembered that the Commission is considering employing EC environmental inspectors, in cooperation with the national authorities, in order to ensure application of environmental regulations in the member countries.[18] Such inspectors could also promote the EC-internal application of a greenhouse gas convention.

3. Considerations on the Verification of Greenhouse Gases

In this central section of our study, we shall first give reasons in Section 3.1. why measuring techniques are at most in exceptional cases suitable for the verification of a greenhouse gas convention. Section 3.2 concerns itself with the central greenhouse gas, CO_2, released by the commercial energy sector. In Section 3.3 the practicability of satellite remote sensing will be examined as an instrument for monitoring certain areal emission sectors, while Section 3.4 presents surveillance possibilities for emission sectors which cannot be covered by satellites or emission calculations. The subsequent Section 3.5 deals with the special case of CFCs. :

3.1. The Application of Measuring Techniques to Monitor Greenhouse Gases

Some basic remarks on the verification suitability of the emission sectors are needed before beginning our discussion of an application of measuring techniques to verify anthropogenic greenhouse gas emissions. These remarks supplement the theoretical discussion in Section 1.

Emissions of anthropogenic greenhouse gases take place in an open system with the atmosphere taking on the function of a dump.[19] These emissions are the byproducts of many and varied anthropogenic activities in numerous fields (sectors). The emission sources are very varied. Some of them which are stationary and emit large quantities of greenhouse gases are easy to identify and basically suited for direct quantifiable monitoring (coal-fired power stations, large industrial emitters). Other sources, however, are stationary but small, numerous and their emissions are not continuous but intermittent (domestic hearths, open fires for biomass burning). There are also mobile, generally small and very numerous sources (motor vehicles, cattle), whose emission behaviour is similarly intermittent. Finally, we are also faced with diffuse anthropogenic sources. In this case the surface area is of central significance since the emissions result from the addition of microscopically small processes (e.g. anaerobic fermentation in wet paddy fields or at refuse dumps) or from a destruction of vegetation (forest clearance by burning).

The poor verification suitability of the overall system of anthropogenic emissions results from this more or less pronounced openness of the emission sectors. The large numbers, the mobility, the large areas involved or else the small size of the emitters or the slight emission per unit time (anaerobic processes) generally do not permit the application of measuring systems to determine and balance the greenhouse gas emissions. Either, in the case of point sources, the efforts would be enormously great due to the large number of emitters, or else there is a lack of suitable methods for determining greenhouse gases rising from surfaces. The overall properties of the entire system are essentially little changed even if some subsystems such as the power station sector and CFC manufacture display relatively favourable verification suitability for measurements. These two sectors together only account for less than 25 % of the warming attributed to all anthropogenic greenhouse gas emissions.

In comparison to the greenhouse gas emission sectors, the nuclear sector displays a very high verification suitability since it represents a closed system subjected to safeguards via the stages of uranium enrichment, fabrication of fuel elements and their application in the reactor, reprocessing or final storage.

In attempting to explore the possibilities of employing measuring techniques to detect greenhouse gases, one discovers a well developed field of work which is being continuously extended and refined: scientific and industrial measuring techniques.

In general, a differentiation must be made between the measurement of atmospheric concentrations and measurement at an emission source. The atmospheric concentration of greenhouse gases is generally determined as a matter of scientific interest by evaluating representative samples taken from the air above the continents and oceans at various heights. However, continuous measurements are also undertaken from fixed sites: a well-known example is Mauna Loa (Hawaii), where the CO_2 concentrations of the atmosphere have been determined since 1958.

In all these cases, the substance sought after can be determined very accurately from the sample by physical or physico-chemical methods. Of the physical methods, non-dispersive photometry is most widely used. In the case of CO_2 it is specific and sensitive in the infrared range: the continuous CO_2 concentration measurements carried out by this method have a precision of under 0.1%. Gas chromatography, which can be coupled with mass spectrometry, is used to determine the atmospheric concentration of CFCs,[20] whereas CH_4, N_2O and O_3 in the atmosphere are determined by gas chromatography and spectrophotometric methods. The measuring methods are being constantly improved and their operation simplified by applying microprocessors.

The monitoring of greenhouse gas emissions directly at the anthropogenic sources may have two goals: firstly the determination of concentrations of pollutants in exhaust gas, and secondly the determination of overall emissions (the quantity of substances released). For the purpose of measuring concentrations in industrial applications, scientific measuring methods are adapted to the new tasks, while comparable measuring precisions are not always necessary. Nevertheless, for emission balancing apart from pollutant concentrations also the exhaust gas quantity has to be determined. To this end, the effluent's density and velocity as well as the diameter of a stack have to be known. The exhaust gas quantity can be determined in various ways. The use of ultrasonic instruments in the off- gas stack is one of the best methods although it has a measuring inaccuracy of 3 - 5%. The concentrations of SO_2, NO_x, CO and other substances are in part continuously measured in those facilities referred to in the Technical Instruction on Air Pollution Control (TA Luft) or the Large-Scale Firing System Regulation (GFAVO). The corresponding measuring technology is available and marketed[21] commercially. A detailed description of the measuring methods and measuring techniques for determining the concentration of pollutants in exhaust gases and the determination of exhaust gas volumes can be found in a publication issued by the Federal Environmental Agency (Umweltbundesamt - UBA).[22]

As far as measuring technology is concerned, there are no basic difficulties in balancing greenhouse gases. If a considerable demand for measuring technology for all the greenhouse gases should arise as a consequence of political directives then suitable instruments could be rapidly on the market. The real basic problem is therefore not to be found in technical inadequacies but rather in the poor verification suitability of the emission sectors for such measurements.

However, measurements at the emission sources as an international verification measure would also encounter "inherent" problems: high demands would be made on the measuring instruments with respect to practicability, accuracy, reproducibility, operational reliability etc.. In the international framework, extensive standardization measures would be required in order to set up binding standards for measuring procedures and instruments, to implement the measurements and evaluate the data. Finally, measures would have to be taken to combat manipulation of the measuring instruments and to ensure that the emissions from a plant would be completely covered (no bypass). This would require monitoring efforts similar to those for nuclear safeguards but with dramatically greater expenditure. The range of verification measures could be extended arbitrarily to include plant inspections, design verification and reverification (after refitting). It would also have to be ensured that undeclared plants clandestinely emitting greenhouse gases could be detected.

This brief outline of the problems makes it clear that, for all practical purposes, the general utilization of measuring technology to safeguard anthropogenic greenhouse gas emissions can be ruled out.

3.2. Verification of CO2-Emissions from the Energy Sector

3.2.1. Determining Energy Consumption

Data can be found in the literature both on global CO_2 emissions as well as on the CO_2 emissions in individual world regions and countries.[23] They are based on calculations using statistics about energy production and consumption.[24] The emissions of other atmospheric pollutants are also generally obtained by calculation (SO_2, NO_x, CO, organic compounds)[25]. Although calculation methods are in this sense "established", the publications display different data both with respect to worldwide and also national CO_2 emissions from the energy sector.

Precise calculations of CO_2 emissions capable of finding a consensus depend on several factors:

- the completeness and accuracy of the energy statistics;

- the accuracy (precision) of the conversion of energy data into emission values;
- the international comparability of statistics.

None of these conditions has been completely fulfilled to date.

Each country is at pains to determine its own energy consumption. Such information serves as a basis for decisions in national energy policy and economics. However, the problems already begin with the differentiation of commercial and non-commercial energy consumption. Above all countries in the "Third World" encounter difficulties in determining the non-commercial energy consumption, which in these states can account for up to 80% of the total energy consumption. However, complete determination of commercial energy consumption cannot always be ensured in both developing and industrialized countries. Energy statistics and their collection methods have evolved historically and also express specific national requirements. Thus for example the comparatively complete and accurate energy statistics of the Federal Republic (and before that the German Empire) reflect the strong dependence on imports, particularly liquid energy carriers. Countries rich in resources and with an energy sector economically self- sufficient are not always interested in achieving a comparable precision in their energy statistics. Centrally planned economies regard energy data as "sensitive" information and largely keep them classified. The following generalizations may be used: the quality of the energy statistics is correlated with the level of economic development of a country; covering non-commercial consumption, i.e. of biomass and dung, causes difficulties in the developing countries;[26] the availability of energy data is often politically controlled in many countries.

Furthermore, many countries base their statistics on different values for the energy content of fuels as well as for converting energy units (e.g. joules into TCE etc.). Thus, calculations of the energy consumption of a country for an identical period may give different results.

It is basically true to say that the Federal Republic has at its disposal one of the most precise and complete systems of energy statistics with an extremely high degree of disaggregation. However, even these statistics are not completely irreproachable. Through the collection and compilation of data a structure has developed involving the industrial associations of the energy sector, the Federal Ministry of Economics, the regional statistical offices, the Federal Statistical Office in Wiesbaden[27] and above all the Working Group for Energy Balances. None of the above mentioned collects and processes all the data, the statutory basis for the collections differs, and the Working Group on Energy

Balances is a private association. Within its framework the energy data obtained from a number of sources are brought together. In this connection, the public establishments cooperate with the Working Group on Energy Balances, but are not formally part of it. The Working Group on Energy Balances establishes a methodology for aggregating the in part inconsistent data, or determining energy data otherwise unavailable. The results thus obtained represent a semi-official calculation of energy consumption and are used as a reliable, independent data base for most work on the energy economy. Nevertheless, they do not represent an official energy balance; such a balance is not drawn up for the Federal Republic. Discussions with experts on energy statistics reveal that the degree of precision for values on primary and final energy consumption differ to some extent. In collecting data on primary energy consumption, "non- commercial energy carriers"[28] (waste and residues in industrial firing) are not covered. If this consumption is reduced in favour of energy carriers which are covered statistically then this effect is reflected in the energy statistics as increased consumption - it is therefore not microscopically small. However, it is planned to reform the data catalogue for industrial reporting which will then lead to a complete, precise data collection. According to information from the Federal Statistical Office, data on final energy consumption is less precise than that on primary energy use since the values for the consumption sectors of households and small businesses are not collected directly but rather represent a calculated "residual category".

We assume that, with the limitations mentioned above, energy statistics in the Federal Republic display a high degree of reliability: primary energy application can be determined with a maximum deviation of 1 %.[29] Such precision cannot be achieved for final energy consumption.

Internationally available energy statistics show that there are no data on final energy consumption for many countries, or else they are fragmentary and unreliable. The data situation is better for primary energy use. Thus for example, the United Nations (UN) compiles data on commercial primary energy use but not for the consumer sectors.[30] Although the IEA also provides some data for many countries about final energy consumption, nevertheless this remains patchy for some of them and the method of compilation cannot be directly reconstructed.[31] It would therefore seem appropriate to calculate the national declarations of CO_2 emissions on the basis of primary energy but not final energy use, especially since this then dispenses with the necessity of precisely estimating the conversion losses.

A serious problem is encountered in the different data collection methods and conversion factors used by the individual nations. The international comparability of energy statistics cannot be guaranteed - and precisely this would be a necessary prerequisite for internationally comparable declarations and verification. Although the UN attempts to set standards for the member states on determining their primary energy use, nevertheless - according to experts on energy statistics - they are not achieved in practice. A joint task of the International Organization and the national authorities would therefore be to develop a set of standards ("questionnaire") laying down uniformly for the members of a greenhouse gas convention all energy data to be collected and also the conversion factors, considered necessary for compiling comparable, comprehensive and accurate energy statistics. The medium- and long-term goal should be to collect data not only on primary energy use but also final energy consumption in order to improve the data base available to the International Organization for verification purposes. The acceptance of such a "questionnaire" could increase if countries were able to use such statistics to improve the basis for planning their own energy economy. The basic features of a "questionnaire" could be laid down in a framework agreement on verification which would then be concretized in the implementation phase of the surveillance regime.

3.2.2. Conversion of Energy Values into CO2-Emissions

Even the best energy statistics is of no avail in value if the conversion of energy into emission values, i.e. in our case CO_2, is imprecise since the declaration and verification of CO_2 represents the heart of a greenhouse gas convention. The methods and data for compiling these values must be reliable and capable of finding a consensus. Two problems thus emerge:

- determination of oxidation values, i.e. the fraction of the carbon atoms released as CO_2;
- determination of the carbon contents of the energy carriers.

The more efficient the firing practice is, the higher is the oxidation factor. In modern coal-fired power stations in the Federal Republic it is probably in the order of 98 to 99%, i.e. the C content in the ash (residues) would only be about 0.5 to 2%. This is also meaningful for safety reasons: if the C content exceeds a value of approx. 5% then there is danger of a smouldering fire. In many countries around the world, also in the COMECON region, power station technology is sometimes still used which only corresponds to the state of the art in the Federal Republic in the fifties or indeed to the German standard of the thirties and forties.[32] The oxidation factor is correspondingly lower, i.e. the C content of the ash may be significantly more than 5%. It could consequently be argued that the oxidation factor in the emission calculations should not be

0.99 as for example in the Federal Republic, but rather 0.95 or less. CO_2emissions would therefore be lower. However, if such arguments were to be accepted in a convention then, firstly, the verification efforts would increase: ash would have to be examined for its C content, or at least random samples would have to be taken. Furthermore, an incentive to improve power station technology would cease to exist. In contrast, if an oxidation factor of one were assumed (i.e. a complete conversion of C into CO_2) then this would represent an incentive for all countries to improve their firing practice. Although this would mean that "technically underdeveloped" countries would be at a disadvantage to certain extent for a lengthy period, nevertheless it can be argued that the carbon in the ash (used for example in road construction) oxidizes in the course of time and enters into the atmosphere. As a compromise, such countries could be granted a transitional period during which a gradually more stringent oxidation factor would be included in the emission calculations.

The different carbon contents of the energy carriers have a much greater influence on the emission results than the oxidation factors: As a rule, for present emission calculations global averages are used for hard coal and lignite, mineral oil (products) and natural gas. However, this is inadequate for a convention where states declare their CO_2 emissions and are subjected to verification. The C contents of the energy carriers (particularly coal and mineral oil) in the individual countries may deviate considerably from the global average. If the C content is lower then a country's emissions are overestimated, if it is higher they will lie below the actual emissions. National averages cannot be laid down without difficulty. For example, in the Federal Republic C contents of hard coal sorts have a fluctuation range of 20 %, while within the individual coal types this fluctuation may be up to 10 %; a deviation range can also be found for mineral oil products, whereas it is slight for natural gas. At any rate, all declarations of emissions on the basis of global averages are inadequate from the verification perspective; scenarios involving deception and "concealed" CO_2 emissions can be imagined. For this reason, the national declaration must accurately state the C contents of the energy carriers used, if possible not on the basis of national averages but in a disaggregated form. This information is as a rule already available with accuracy (a deviation of a few percent) in the Federal Republic of Germany. These data are determined analytically and, at least for hard coal, documented and even provide information about the C contents of coal from the individual pits etc..[33] This is not always the case for other countries, and moreover not with comparable accuracy. The International Organization must therefore urge the individual states by means of the "questionnaire" to accurately determine the C contents of the energy carriers used. The Organization must moreover be in a position to verify these data, if necessary by analysing random samples, measurements and other information. It will probably be impossible to avoid the use of certain averages (for example in power station complexes) in order to facilitate declarations and verification. This thus emerges as a difficult task for the international and national authorities since determination of C contents by a procedure capable of finding a consensus is an important pillar of the convention.

3.2.3. Verification

An International Organization cannot independently collect data about energy consumption. The staff required, the information quantity involved and the computer capacity necessary for data processing would be too great. Its activities must therefore concentrate on "recalculating" the energy and emission data.[34] A prerequisite for this is the transparency of collecting, aggregating and balancing the energy data, and also their conversion throughout all stages of the statistics. A second requirement is the broad, complete availability of information on energy conversion. In the opinion of a german statistics expert , this does not seem to be completely the case in the Federal Republic with its various agencies involved in the collection and processing of statistics. It may therefore be meaningful to examine whether the compilation of an official energy balance for the Federal Republic by one authority on the basis of a uniform Statistics Act would increase transparency. Admittedly, this study must be viewed against the background of other countries' as yet incomplete statistics, only reconstructable with difficulty: against this background statistics in the Federal Republic are already quite outstanding. It is therefore meaningful to increase in stages both the transparency and also completeness and precision of energy statistics in all countries. It should be possible to achieve this by means of the "questionnaire" to be drawn up by the International Organization in cooperation with the national authorities, which then has to be filled in by the states regularly and accurately. This questionnaire should contain:

- primary energy use broken down according to fuel (and as far as possible final energy use);
- the C contents of the energy carriers in as much detail as possible;
- conversion losses;
- also some raw data sets, if required for verification;
- energy conversion factors;

- and (depending on provisions in the convention) the oxidation factors.

If this information is available then the CO_2 emissions of any primary energy carriers containing carbon can be calculated by the following formula:

$$(PE/P - E + I - B - Ne) \times C \times 0 = Em$$

PE/P stands for the primary energy production of fossil fuels, E for the export and I for the import of fossil energy carriers, B for bunker and Ne for non-energetic consumption. C designates the carbon content of the fossil energy carrier and 0 the oxidation factor. From this the emission of CO_2 (Em) can be calculated.

It should also be possible to verify the declared emission values if, on such an information basis, the International Organization has sufficient energy and statistics experts at its disposal to verify the declarations with respect to their plausibility. If information on final energy consumption is also available then crosschecks based on primary and final energy become possible. However, since the C content of all energy carriers is not recorded with extremely high precision in any country there will always be a margin of uncertainty in declaration or verification. Furthermore, there are also deficiencies in records, conversion, etc. of energy use. These deficiencies add up and impair the possibility of verifying emission reductions. On the whole, according to our very tentative estimate, the imprecision of declaration or verification may by all means be in the order of several percent in statistically "good" industrialized countries and markedly higher in other states.[35] This would be even more the case if non-commercial consumption, which is very difficult to determine precisely, were to be included in declarations by developing countries. It should be considered whether the declaration of non-commercial consumption could be dispensed with[36] or declared separately from commercial consumption. In the latter case, verification could be directed towards estimating the plausibility of the data but not to "recalculating" a necessarily imprecise declaration of non-commercial consumption.

A "mixed" verification, i.e. the application of continuous measuring systems for large stationary CO_2 emitters, increases at best marginally the overall precision of the CO_2 balance for a country with very good energy statistics. Although the measuring accuracy of instruments for determining CO_2-emissions is not known precisely, nevertheless this still seems to be problematic. Furthermore, present instruments can only measure the off- gas volume with an accuracy of approx. 3 - 5%.

3.2.4. Conclusions

All in all, it must be remembered that present imprecisions of CO_2 calculation from the energy sector for some states may be in the order of magnitude of a reduction goal which may be agreed upon within the framework of a climate convention. The introduction of a "questionnaire" bringing greater precision in detection and an improvement in verification capability is therefore an urgent task which must be given priority in a greenhouse gas convention. We are fairly optimistic that an infringement of a convention can be detected by verifying the declarations of energy use and the CO_2 emissions if the deviation is less than 10% of the fossil energy use of a country.

In view of the measuring inaccuracies, the application of measuring instruments for CO_2 balancing does not improve the quality of verification possibilities. Moreover, the costs will be immense. Assuming that the CO_2 emissions of all 17,000 facilities in the Federal Republic subject to the TA-Luft (Technical Instruction on Air Pollution Control) or the GFAVO (Large-Scale Firing System Regulation) were to be monitored by measuring instruments then at least DM 100,000 per stack would have to be invested for the procurement, installation, calibration etc. of the measuring instruments to determine the off-gas volume and the CO_2 content of the waste air.[37] Assuming that each of the facilities were only to have three stacks to be monitored then this would amount to investment costs of approx. DM 5 billion for the 17,000 facilities. As a rough estimate, such a measuring system would only be able to monitor 4 % of Federal German CO_2 emissions.

3.3. Satellites as Instruments for Verifying a Greenhouse Gas Convention

3.3.1. The Verification Task

There are no measuring systems capable of continuously detecting anthropogenic emissions from areal sources and thus allowing an emission balance to be established. For these sectors emission data are always calculations based on more or less reliable studies of a section of the area, estimates and model results. For this reason, the CO_2, N_2O and CH_4 emissions from agriculture, land use and deforestation can only be roughly calculated. These data are not appropriate as a basis for the quantitative declaration of national emissions to an International Organization, since the verification of an unreliable declaration can only result in the determination of its imprecision and not the verification of compliance with a treaty.

We therefore propose that, primarily for the emissions associated to deforestation (and the carbon "sink" provided by reforestation), in the longer term also for the agricultural sector and changes in land use (for example large infrastructure measures), it is not the emissions which should be declared and verified but rather the status and development of these sectors themselves.

These emission sectors are in principle suitable for verification. Space-based remote sensing systems should be used as a basic instrument for detection and verification, but they must always be closely associated with air-based and above all ground-based "on-site activities".[38] The verification system in a fully developed configuration could then display the following structure. Depending on the final form of the convention, states or their national authorities should declare the area and status of their forests,[39] reforestation measures, the size and use of their agricultural areas and any planned changes, and give notification of any large-scale interventions in land use (e.g. for infrastructural measures). To this end, they must have the necessary data at their disposal (if necessary with assistance from other countries or the International Organization) also including satellite information.[40] By means of remote sensing and if necessary local inspections, the International Organization will verify whether the declarations are in fact being complied with, e.g. whether forest declared to be "virgin" actually remain free from perceptible human intervention. (The internal implementation of the declarations is the task of the national authorities). These basic features of a declaration and verification system should be laid down in a convention protocol. Such a declaration and surveillance system is staff- and resource-intensive, and cannot be fully implemented at present, and probably also in the foreseeable future, with the remote sensing systems stationed in space today. Air- and ground-based monitoring, which in contrast to the possibilities of large-scale monitoring by satellites, can only cover small sections, will continue to be of essential significance.

However, the justification for such a comprehensive system of global monitoring goes beyond a pure verification function. The information obtained with this system could be an essential component in efforts to understand the "planet earth" and modify our economic systems in such a way that the ecological cycles do not collapse even with a world population of 10 billion and more.[41]

3.3.2. Technical Potential and Limits of Remote Sensing Technology

Remote sensing of the earth has a tradition reaching back over fifty years. For the past twenty years not only aeroplanes but also satellites have carried out this task and provided photographs and other special and general data about the oceans, the atmosphere and the continents.[42] For observations of land surfaces, vegetation and their change (for example deforestation), as well as agricultural production (e.g. the cereal harvest to be expected in the USSR),[43] use may be made today, (apart from Soviet remote sensing satellites and the geostationary weather satellites, e.g. NOAA7 from the USA) of the American LANDSAT satellites and the French SPOT satellite.[44] LANDSAT and SPOT are operated by private companies, i.e. the photographs and data have to be purchased. Threshold countries such as Brazil and India are also making efforts to construct their own remote sensing satellites, the EC (ESA) and Japan operate their own programmes now at an advanced stage.

Remote sensing capabilities depend on the number and orbit of the satellites and the suitability of their instruments. The raw data thus obtained have to be recorded by adequate terminals and transferred for processing and evaluation undertaken with the aid of sophisticated, computer-aided data preparation and processing.

In view of the present spectrum of applications, satellite remote sensing may be regarded as an established technology. Admittedly, its present performance limits must not be disregarded:[45] thus for example it is not always possible to differentiate on the basis of photographs between clouds and smoke (as a consequence of forest fires); the same is true of a differentiation between burning of fields, pasture areas or forests. Infrared photographs do not always permit conclusions to be drawn about the size and the intensity of fires in forests etc.. Selective interventions in forests (selective tree felling) and other small-area activities with an extent of less than 20 metres[46] cannot as yet be observed directly. Although the spatial resolution of satellite pictures enables geometric areal variations to be identified, nevertheless non- geometric anthropogenic interventions in, for example, a forested area can only be differentiated from natural changes by making use of additional information. Furthermore, the possibility of identifying human activities from satellites does not only depend to a very great extent on the type of intervention (e.g. selective versus large-area tree felling), but also on the object's characteristics (for example the type of forest) and the season.[47] The possibility of monitoring human activities thus differs according to region. Satellite monitoring provides more promising results in one country or region than in another, thus representing a considerable political problem for a verification system. Finally, all passive sensors operating in the range of visible and infrared light are extremely weather-dependent and cannot penetrate clouds. It may therefore take years before cloud-free pictures of a region can be taken. The verification capability of present remote sensing satellites is therefore clearly limited.

There are, however, plans to improve the quality of remote sensing by means of new satellites and improved passive and active sensors (radar, lasers). NASA intends, in part in cooperation with the "European Space Agency" (ESA) and the " National Space Development Agency of Japan" (NASDA), to develop a financially and technically very sophisticated (and controversial) "Earth Observing System" (EOS),[48] known as "Mission to Planet Earth".

The EOS is intended to comprise:

- a series of orbital platforms passing the same point on the earth at the same position of the sun every 3 - 5 days equipped with various, also weather- and cloud independent, sensors with a spatial resolution between 30 m and 1 km. The sensors should also be in the position to detect the vegetation condition.[49] These platforms dispense with the need to distinguish among satellites for remote sensing of the atmosphere, oceans and earth,

- small satellites in lower orbit able to detect rapid developments (for example precipitation patterns) due to frequent passes (every 90 minutes),

- geostationary satellites, for which, however, improved sensors for observing the earth still have to be developed.

- In addition, hardware and software still has to be developed for processing and evaluating the enormous flood of data to be expected. The components of the overall system are still under discussion: criticism has been made of the high costs and also the necessity for such quantities of data in view of the extensive information already collected by present satellites and as yet unused.[50]

This criticism reveals that technological possibilities must not be pursued in isolation without considering the wishes of the users and a precise description of the tasks in hand. It is therefore advisable to reach international agreement on the tasks to be allocated to satellite observation within the framework of a climate convention. If agreements (protocols) on satellite monitoring are reached then the difficult process of interpreting satellite data, which as such provide no information, must be dealt with. To this end, the sensors have to be "calibrated", i.e. a specific piece of information in a picture element of a satellite photograph must correspond to a specific statement laid down in the convention. Extensive field studies in the observation areas are required for this purpose, similar to those that are being undertaken, for example, as part of the "International Satellite Land-Surface Climatology Project" (ISLSCP),[51] in order to obtain insights into the relations between the physical values measured by the satellite and the geophysical features of the observed surface, for verification is only practicable if its boundary conditions are defined from the very beginning. If such "calibrations" were to be laid down in detail within the convention then this might possibly involve considerable delays. It would be the joint task of the national authorities and the International Organization to make these provisions.

3.3.3. Political and Economic Problems of a Satellite Remote-Sensing System

After losing their monopoly in exploring and utilizing outer space, the two superpowers are at pains to at least secure their central position in space travel. This is one reason for the rejection of the French proposal made in 1978 for an international satellite agency for arms control. Since then other (groups of) states have developed or made plans for their own satellite systems, also for earth observation. They are probably today also unwilling to share their hardware and knowledge with other countries. Power politics, security and economic interests are at stake.

Such aspects of remote sensing gain significance if questions of the tasks and legal organization of satellite systems are to be clarified within the framework of a verification system. From the point of view of the International Organization, three models of access to satellite information can be differentiated:

- the owner model;
- a purchaser model;
- the lessee model.

The verification argument supports a satellite system in the possession of the International Organization. It would then be able to internally process and interpret all incoming data and would be relieved of the necessity of verifying the reliability of information it had not collected itself. Furthermore, satellites could be specially tailored to the Organization's tasks. The argument presented concerning "the global management of the earth" would also suggest that the necessary information should at least be collated and assessed on the level of an international organization, if not actually collected. An objection to this model is that the International Organization's satellite system would have to collect information which had at least in part also been collected by the satellite systems of individual countries or private enterprises. Regulations would also have to be set up for the use of information of economic, political and military use arising during verification activities. This could be of interest for countries unable to afford access to satellite information.[52] Problems also arise due to the unavoidable transfer of technology and know-how to an international organization. Moreover, the costs for such an international satellite system would be high: they are estimated at approx. US$ 400 million per satellite (development, start, operation).[53] On top of this are costs for receiving stations and processing and interpreting the data.

In the purchaser model, the International Organization buys the necessary satellite information. The Organization would not need to operate the satellite system and could use specifically prepared information. Nevertheless, it is doubtful whether all the required information could be made available by satellites not specially prepared for verification tasks.

A lessee model would also be conceivable whereby the International Organization would lease existing satellites for the period required to gather all information necessary for verification. But once again the problem of utilizing "excess information" would arise here.

Irrespective of its form and organization, satellite environmental verification leads to difficult problems in security, power politics and economics. These aspects must be given further consideration before reasonable proposals for satellite verification can be made.

3.3.4. Conclusions and Recommendations

Remote sensing by means of satellites has good prospects but at present has a limited potential and requires considerable development for the verification activities discussed here. Present satellite systems only have a very high verification capability for those anthropogenic activities which have a symmetrical form and display a minimum area of 20 x 20 = 400 metres square. This is the case for areal deforestation but often not for selective tree felling. The observation of agricultural areas to assess, for example, wet rice production and the development associated with extensive changes in land utilization rapidly reaches the limits both of its technical possibilities and also verification suitability. The areas are quite simply too great to be subject to worldwide detailed monitoring. Even the computer time required to transmit and evaluate the data would be very great. This is also basically true of the earth's forested areas, which in view of their great extent cannot be surveilled in practice. Nor does this appear necessary - thus simplifying the verification task. A selection should be made from amongst the declared forest areas of those particularly endangered by human activities and whose position is roughly or indeed very precisely known ("hot spots"). These virgin forests in remote regions should be at the centre of international verification activities.

If verification activities by means of satellite remote sensing are to be extended beyond observation of large- scale forest destruction to the tasks outlined above of monitoring selective tree felling, agriculture and changes in land use then a satellite system would have to display at least the following technical capabilities:

- high-resolution cameras with a pixel size of 20 metres or less;

- instruments for determining the height of an observed surface with an accuracy of less than 0.5 metres;[54]

- more spectral channels (a two- or three-figure number could be conceivable for future satellites);

- possibilities of compiling time series data for the areas under observation;

- new supercomputers to process the enormous quantities of data.

Such remote sensing systems would be able to create a new quality of surveillance measures. However, even then satellite remote sensing would still depend on coordination with air- and earth-supported activities. Satellites are often only in a position to identify those "critical points" where other verification instruments, such as local inspections, would have to be applied.

The question of which space-supported verification techniques will actually be developed and applied is still open. The decisive factors are not the technical limitations but rather the solution of power politics and economic problems associated with such a verification system, for the material and personnel resources involved will be enormous. If these resources should be made available then such comprehensive remote sensing must not be directed towards verification alone but should also be an instrument for managing various global, regional and local problems in the most varied sectors.

3.4. The Verification of Diffuse and Point Emission Sources

Agriculture is an important diffuse anthropogenic source of greenhouse gases: wet rice cultivation, ruminant herds[55] and the application of nitrogenous fertilizers discharge primarily CH_4 and N_2O into the atmosphere. With respect to the verification procedures discussed so far, the verification suitability of these sectors is extremely low or totally lacking. The emissions can neither be balanced by measuring systems nor monitored by satellites nor precisely assessed by calculations in such a way as to form the basis for national declarations and international verification.

Apart from CO_2, the energy sector also releases CH_4. This primarily occurs during extraction in the coal and mineral oil industries, and in the natural gas industry also during transport, distribution and utilization. In contrast to CO_2, this gas does not substantially arise during energy conversion but is rather so to speak, a side effect of the energy system. These point sources for greenhouse gases are similarly characterized by a very limited verification suitability.

The diffuse agricultural emission sources could be covered in a greenhouse gas convention in such a way as to aim at improving the food supply while reducing greenhouse gas emissions: for example by the development of new agro- industrial methods (e.g. new plants which bind nitrogen in the soil and reduce the use of fertilizers, reduction of CH_4 emissions from wet rice paddies by modifying fertilization procedures), a reduction in the use of fertilizers in countries with high agricultural excess production and a change in the food supply (substitution of plant products for meat).

Let us assume that such agreements were to be made and would have to be monitored. In this case, under no circumstances should national emissions from these sectors be declared and verified, for they depend on so many factors, which are difficult to calculate so that the data would not be reliable enough to permit verification. We have already indicated elsewhere that the verification of such declarations would then only indicate their low reliability but would not be able to demonstrate contractual compliance. In this case "indirect" surveillance of emissions would appear appropriate. In principle, an extension of the arable area can be observed by satellites. It is apparent that no statements can be derived from this concerning a reduction in the number of ruminants. Nor can this be determined by satellite remote sensing since the optical resolution of the sensors is not adequate. It is conceivable that this would be basically possible by verifying the countries' statistical data on the livestock figures and meat consumption. These figures are incomplete and imprecise for very many countries since accurate records of livestock are not kept and the meat consumption is not covered by statistically recorded markets. However, since such a reduction in consumption probably only involves the industrialized countries where statistics are available and seem to be precise, repeated examination of these statistics by the International Organization should be able to permit an estimate of whether the declared consumer trends are plausible. It would also seem possible to make a comparative examination of declarations on the amount of fertilizer applied if data on the production, imports and exports for the respective countries are available.

The extent to which these audits are effective depends first of all on the surveillance capability, i.e. the efforts involved, and on the transparency of the statistics, about which we are unable to make precise statements. In general, we doubt whether these emission sectors should be subjected to verification measures since the efforts would be enormous. It might be more meaningful to lay down a general obligation to promote "sustainable agriculture" in the convention. Country studies commissioned by the International Organization could contribute towards defining this concept and identify improvement potential for such a policy. This would not be verification in the real sense but rather information acquisition which would nevertheless permit qualitative insights into the emission sectors under discussion enabling them to be developed and providing positive incentives for change.

Only incomplete and contradictory data on the emission of methane from the energy economy are available worldwide. Therefore as a first step in a greenhouse gas convention, the states should be obliged to assess their emissions from these sectors. The studies on CH_4 emissions by the hard coal and natural gas industries in the Federal Republic are the central component of such an open flow of information. A later, material step could consist in reaching agreement on the reduction of methane emissions from the energy economy. International minimum standards on the energetic utilization or flaring of methane could be agreed both for the mineral oil industry where associated gas arises, as well as for the coal industry (pit gas). Compliance with the agreements could, once again, be assessed by studies giving at least rough indications of trends. Local inspections by representatives of the International Organization would also be conceivable in order to obtain further indications for converting the accepted measures and improving the quality of the technical procedures employed ("procedural verification"). For the natural gas industry, minimum standards of technical safety could be agreed upon for the production, transport, distribution and possibly user level in order to reduce the quantity of natural gas leaks and to reduce the risk of accidents. Once again, it may be possible to verify the measures by "implementation studies", in which not the emissions themselves but rather the agreed technical measures and the quality of the technical procedures are examined.

Similar monitoring measures could be conceived for agreements with the aim of reducing waste disposal sites. In this case "recycling" quotas could be agreed upon and also the flaring or energetic utilization of the resulting gases.

These proposals for verifying compliance with the treaty on the part of individual countries are very qualitative and are therefore only suitable for detecting contractual infringement in very flagrant cases. Their utility is, however, to be found in establishing an information basis enabling member states of a convention to take decisions about more extensive measures.

3.5. Verification of Chlorofluorocarbons

The CFCs 11/12 and halons at the centre of discussions on protection of the stratospheric ozone layer differ from the greenhouse gases or emission sectors discussed so far in several respects:

- The specific greenhouse gas potential of F 11 or 12 is 14-17,000 times as great as that of CO_2 and also exceeds N_2O and CH_4 by two orders of magnitude. Moreover, the CFCs remain in the atmosphere for an unusually long period (65 - 100 years).

- CFCs are only produced industrially; their rate of introduction into the atmosphere has been growing rapidly at 5% per year, in comparison to other greenhouse gases.

- Only a few companies (two in the Federal Republic) produce CFCs in an orderly and well-defined production process. World production at 800,000 tonnes is small in comparison to other greenhouse gases.[56]

All these factors point to a fairly favourable verification suitability for the CFCs.

In addition:

- There are political agreements on an international level about reducing the production of CFCs and on a regional level, above all within the EC, on an almost complete run down of CFC production.

- Approaches for monitoring can be found in the Montreal Protocol[57] and - on an EC level - with the regulation of the Council of the EC of 14.10.89.[58]

Depending on the material provisions of an international convention, two verification concepts are basically possible:

- if the production of a substance is banned then the non-production must be verified,

- if it is agreed that permissible production should be limited then verification activities must concentrate on establishing that this upper limit is not exceeded.

The verification of non-production can involve considerable, indeed blanket, surveillance activities in countries with a large chemical industry, unless they are concentrated on checking suspicious cases. However, verification of non-production is simpler in that an identification of a forbidden substance necessarily indicates an infringement of the treaty. Whereas if production is permitted up to a fixed limit then verification does not aim at establishing the presence or absence of the substance but rather establishing that the limits have been observed. This is an extremely difficult quantitative problem also facing the chemical weapons convention.

The verification of a CFC convention, whether on the basis of the Montreal Protocol or a more extensive agreement, must aim at monitoring the observation of upper production limits (varying greatly in industrialized and developing countries) since the production of CFCs for specific purposes is permitted by the Montreal convention for the foreseeable future. This is not very favourable from a verification point of view; a ban on production would have advantages.

Four approaches for verifying the observation of permitted upper production limits for CFCs can be put forward:

- Approach 1: The CFC production facilities are equipped with measuring systems for determining production quantities. The measured production quantities can be compared with the permitted quantities and a balance can be drawn up for each country providing information about treaty compliance. Experience from the non-proliferation of nuclear weapons can be used in this quantitative verification concept. The required measuring and balancing technology, which must be protected against manipulations, should be developed.

- Approach 2: The producers pass on the production figures and data concerning imports or exports of substances under surveillance to a national authority or the International Organization. The data are then verified on an international level with respect to their plausibility. Further monitoring is not envisaged. (This approach is reflected in the Montreal Protocol). This transfer of data basically represents a confidence-building measure.

- Approach 3: An international surveillance commission is granted access to production facilities at fixed intervals and attempts to draw conclusions about the magnitude of CFC production from the structure and design of the plant and also receives some production data. The commission makes a qualitative assessment of the reliability of the information provided and the non-suspect nature" of the facility design. Inspections by the "Arms Control Bureau" of the "Western European Union" (WEU) in chemical facilities of the Federal Republic aimed at verifying the non-production of chemical weapons could provide a model for such a verification system. This is also essentially a measure to create confidence since the commission's assessments cannot be proved.

- Approach 4: An obligation to provide reports and notification is agreed for all CFC producers containing the following information:

  - the production quantity, the place(s) and actual duration of production in the last defined period;
  - imports and exports, stocks of the substances;
  - planned production, envisaged production locations and production periods.

  The International Organization checks the producers' "books" and has the opportunity to undertake regular and surprise inspections at the chemical facilities in order to establish whether the production locations and periods correspond to the producers' notification. Continuous measuring systems are not applied, but it would nevertheless be conceivable that mobile measuring instruments could be used to verify non-production in those facilities not declared as production locations. This verification model displays considerable parallels to the surveillance measures envisaged for civil chemical weapons within the framework of the Chemical Weapons Convention.

Before beginning a brief assessment of these four approaches, it must be remembered that Regulation 3322/88 by the EEC on CFCs does not necessarily replace international verification. The Council Regulation may also be interpreted as an "internal strategy" to implement an international agreement which within the EC is no longer exclusively incumbent upon the states but also upon the community authorities. An international verification organization would then have to form its own picture of contractual compliance on the part of the EC states.[59]

The following picture results from an initial assessment of the four approaches. Thus the favourable verification suitability of the CFCs as well as the technical possibilities for measuring CFC production, which are available in principle, would appear to make the verification system described in the first approach seem feasible. However, we are unable to make any statements about measuring accuracies, probabilities of detecting "clandestine production" etc.. Even rough estimates require precise knowledge of the production process. A reliable statement about contractual compliance on the part of individual countries in approaches 2 and 3 is only possible to a very limited extent in view of the lack or inadequacy of information about the production process, non-existent possibilities of verifying the declared values concerning CFC production and no or only limited access to the production facilities. These approaches are therefore more suitable as steps towards creating confidence by means of a limited opening up of an emission sector previously screened off. If one takes verification capability and suitability as a starting point then approaches 1 and 4 seem most suitable for an effective surveillance regime. However, they display considerable differences as a consequence of their respective quantitative or qualitative orientation. Both the technical and administrative efforts and thus also the costs are probably considerably higher for quantitative monitoring by means of measuring systems than in the case of approach 4, which contains clearly qualitative verification elements and aims at establishing the plausibility of a declaration and not at a comparison between the target value and actual measurements.

The decisive question is, however, the perceptions of the political decision-makers concerning the adequacy of verification within the framework of the Montreal Protocol and thus the estimate of a risk of the clandestine production of CFCs. A risk results from the probability and consequences of an event. Irrespective of how the probability of clandestine production is assessed, the perception of the consequences displays basic differences, for example, vis-vis the NPT or the Chemical Weapons Convention. Several thousand tonnes of clandestinely produced CFCs do not affect global power or security structures in the least, whereas this may be very much the case with a diversion of nuclear material or the unnoticed production of substances which may be used for chemical weapons. These are therefore quite different risks, objectively seen, the perception of which necessarily influences the verification density. Nevertheless, it is conceivable that the verification envisaged in the Montreal Protocol will be regarded as inadequate. The "Chemical Weapons Model" (approach 4) would suggest itself as an alternative to the use of expensive measuring systems. It is more intrusive and cumbersome than approaches 2 and 3, but has a greater density and in our view a high potential for detecting treaty violations, without involving such high costs as approach 1.

However, there are also political and economic arguments against such a dense and intrusive verification system. Only those states party to the convention would be covered by verification and the associated burdens. Non-members could profit from the unrestrained use of CFCs and would not bear any of the costs for verification. The chemical industry involved in a verification regime would have to make considerable investments for converting production (substitute materials) and also for surveillance (inspection costs). There would thus be a negative incentive for membership. This problem structure is familiar from the international nuclear non-proliferation regime. Before tightening up the verification concept over and above the provisions of the Montreal Convention, careful consideration should be paid to the advantages and disadvantages of such a procedure with a view to the overall regime.

4. Summary and Recommendations

We assume that the countries participating in a climate convention will commit themselves not to exceed a fixed anthropogenic greenhouse gas emission in their country and to contribute by other measures towards reducing atmospheric pollution from their greenhouse gas emissions.

Such a convention will have to make use of international verification measures in order to survey the contractual fidelity of the member states (verification requirement). This verification requirement derives from the distrust between nations and lack of information which still exists in spite of increasing international cooperation, as well as the possibility of states profiting from bypassing international agreements.

In order to draft a verification concept for greenhouse gases, we have selected a methodological "bottom-up" approach, not deriving a verification system from political requirements but rather analytically taking verification theory into consideration. The concept and the intensity (density) of verification are characterized by the verification capability (measuring and observation procedures, control methods etc.) and also by the verification suitability of the sector to be verified (number, status, accessibility of the emission sources). Our proposals for possible verification concepts are based on this interlinkage of verification capability and suitability.

It is not possible to implement verification without an internationally agreed organizational structure. We have proposed a two-stage structure. It comprises, firstly, the establishment of national authorities in the respective member states entrusted with the task of determining their states' anthropogenic greenhouse gas emissions as laid down in the treaty and of declaring them (together with other information concerning measures against the greenhouse effect, for example reforestation) to an International Organization. Secondly, an International Organization to implement the verification activities and check whether the states have not exceeded the maximum permissible emissions and have followed all other agreements in the convention.

For the Federal Republic and other members of the EC, the question arises of whether national authorities (and individual emission limits) would correspond to the degree and intensity of European integration already achieved. For this reason, careful consideration should be given to the advantages and disadvantages of an EC authority, for example along the lines of the "European Atomic Energy Community" (EURATOM), within the framework of a greenhouse gas regime.

In the search for models for international verification concepts then one comes across arms controls, in particular the Non-Proliferation Treaty (NPT). A verification concept comparable to these agreements could take on the following form. States measure their greenhouse gas emissions and declare them to an International Organization which then implements control measurements and audits in the individual states. If the declaration and control measures are in agreement and if these figures correspond to the contractually agreed permissible emission quantities for the respective countries then contractual fidelity is established.

However, our considerations have led to the result that the NPT cannot represent an appropriate model. Although use is made today in large-scale technical facilities of measuring systems which continuously measure concentrations of some pollutants (SO_2, NO_x, CO) in the waste gas, they are not really relevant for the greenhouse problem. It would also be possible to measure the volume of waste gas and thus the total quantity of emitted substances but as a rule this is not done. It is therefore not surprising that such a "material balance" cannot be drawn up for greenhouse gases, since important greenhouse gases, in particular CO_2, are not considered to be substances requiring regulation under present emission protection laws. This situation is quite different in the nuclear sector; nuclear material is balanced or emissions of radioactive substances in the nuclear facilities are balanced both for safeguard activities and for reasons of radiation protection (in quite different ways). It must, admittedly, be remembered here that the quantities of material covered by the NPT safeguards are at lest five orders of magnitude smaller than the quantities of greenhouse gases to be monitored. The same is true of the number of nuclear facilities in relation to the number of greenhouse gas emitters.

More suitable and more economical measuring systems for the continuous detection and balancing of greenhouse gas emissions could undoubtedly be developed if politically necessary. However, this should not be done without considering the verification suitability of the emission sectors. Neither large-area greenhouse gas emissions (land use, deforestation) nor emissions from small, mobile sources (ruminants), nor leakages from pipelines can be measured and balanced. Although this is not so generally true of the traffic sector, households, industry and in particular power stations, which as point sources display a (more or less favourable) verification suitability. Nevertheless, with respect to these sectors it must be remembered that it is possible to calculate greenhouse emissions, above all CO_2, with a precision which is hardly worse and may indeed be comparable to measured results. Furthermore, the efforts required for emission calculations are considerably lower.

Although the possibility of using measuring systems for balancing purposes is largely ruled out by the poor verification suitability of most emission sectors, nevertheless this does not invalidate the need for the further development of measuring techniques. On the contrary, one of the important tasks of scientific and technical research and development would be to provide methods and apparatus for the continuous measurement and balancing of greenhouse gas emissions. Even if they cannot be applied to draw up emission balances, it is by all means conceivable that they may be used for random measurements in order to improve the quality and precision of methods for emission calculation, which is of great significance in a greenhouse gas verification system.

Our proposals, taking into consideration the verification suitability of the emission sectors and the verification capability, therefore aim at national declaration systems and an international verification system which can largely dispense with measuring systems. The elements of the convention and the international verification system, as well as the assessment of its effectiveness for the most important greenhouse gases are summarized in the synopsis (at the end of this text). The core elements of the national declaration systems and international verification system are as follows:

- Calculation and declaration of energy consumption and the associated CO_2 emissions by the national authorities and verification of these declarations by the International Authority by means of audits and other methods verifying the plausibility and reliability of the data.

- Use of space-based (and other) global remote sensing systems to monitor forests, deforestation and, if possible, infrastructural and land-use activities by member states in order to verify agreed assurances concerning forest protection, reforestation etc..

- Studies, audits and procedural verification in the sectors where emissions cannot be either precisely calculated or monitored by means of remote sensing (parts of the energy sectors, agriculture, waste disposal sites). A very qualitative verification system is also proposed for these cases.

For the Federal Republic and other members of the EC, the question arises of whether national authorities (and individual emission limits) would correspond to the degree and intensity of European integration already achieved. For this reason, careful consideration should be given to the advantages and disadvantages of an EC authority, for example along the lines of the "European Atomic Energy Community" (EURATOM), within the framework of a greenhouse gas regime.

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- Studies, audits and procedural verification in the sectors where emissions cannot be either precisely calculated or monitored by means of remote sensing (parts of the energy sector, agriculture, waste disposal sites). A very qualitative verification system is also proposed for these cases.

ciency, changing the energy mix and other measures for reducing the emission of greenhouse gases.

A verification system for CO_2 emissions from the commercial energy sector, if it follows the proposals in Section 3.2., would seem to us to be comparatively simple and economic to establish. It would be possible to demonstrate the feasibility of a verification system in the commercial energy sector without the demands made on detection probability for treaty violations having to be very high in the first place. If, for example, deviations from the calculated CO_2 emissions from the energy sector of up to 10% are possible then it would be meaningful to have as a goal the detection of deviations of more than 10%. In view of such imprecisions, the value of a verification would initially rather be found in making data sets on energy consumption, the C contents of fossil energy carriers etc. more precise and complete thus enabling an international comparison but not necessarily a verification of contractual fidelity. The International Organization can take this as a starting point and gradually extend and intensify the verification system: extension by including other greenhouse gases in the verification system and intensification by improved provision and checking of information with gradually increasing verification demands.

In establishing a verification system, the policy makers must always weigh up the envisaged verification density on the one hand against national, and above all international, acceptance of a dense verification system on the other. In must also be kept in mind that any verification only applies to those states which have acceded to a convention whereas non-participating states often enjoy the advantage of not being affected by either the material provisions of a convention or by its verification regulations. For this reason, universality of membership must be an essential goal of this policy and should be achieved by both positive and negative incentives.

Notes and References

[1] Our considerations therefore do not refer to natural emissions of greenhouse gases and their monitoring. It would not be possible to make this the subject of international agreements and verification.

[2] In the following text, the expressions "control, surveillance, monitoring" may be used as synonyms for "verification".

[3] Cf. Allan S. Krass, Verification: How much is enough? London/Philadelphia 1985.

[4] Cf. P. H. Gleick, Implications of Global Climatic Changes for International Security, A Working Paper for the Conference on "Developing Policies for Responding to Future Climatic Change", Villach, Austria, Sept. 28 - Oct. 2, 1987; W. Fulkerson et al., International Impacts of Global Climate Change, Oak Ridge National Laboratory, ORNL/TM- 11184.

[5] Cf. W. Fischer, G. Stein, "Internationale Technikübemachung", in: Seminar Technik und Gesellschaft, Programmgruppe TUG, KFA Jülich GmbH, in preparation.

[6] Cf. Oran R. Young, "The politics of international regime formation: Managing natural resources and the environment" in: International Organization, Vol. 43, Summer 1989, pp. 349-375.

[7] Cf. Sections 3.1 and 3.2.

[8] The guidelines to negotiate a safeguards agreement between a non-nuclear-weapons NPT member state with the International Atomic Energy Agency (IAEA) is published as IAEA "Information Circular" 153 (INFCIRC/153).

[9] Cf. M. Canty, W.-D. Lauppe, B. Richter, G. Stein, "Technikübemachung, Nichtverbreitung und Kernmaterialkontrollen" in: Annual Report 1987/88 of the Research Centre Jülich.

[10] Cf. S.J. Lundin (ed.), Non-Production by Industry of Chemical Warfare Agents: Technical Verification under a Chemical Weapons Convention, Oxford 1988.

[11] Cf. Section 2 for the organizational structure of the verification system.

[12] At the end of 1987 approx. 230 tonnes of plutonium, 30,000 tonnes of uranium of various degrees of enrichment and 50,000 tonnes of source material, e.g. depleted uranium, thorium or uranium with a very low U-235 concentration, were subjected to IAEA safeguards.

[13] In the case of regional agreements, verification may be the task of regional organizations. Examples of this are EURATOM and the (not yet operational) Organization for the Prohibition of Nuclear Weapons in Latin America (OPANAL). However, a climate convention requires a worldwide not a regional membership.

[14] Cf. W. Fischer, Die Verifikation internationaler Abkommen über Umwelt- und Ressourcenschutz, Forschungszentrum Jülich GmbH (KFA), KFA-WEI-IB-1/90, Jülich 1990.

[15] We are not talking here about the organizational affiliation and form. Approaches for such considerations can be found in: Nico Schrijver, "International Organization for Environmental Security", Bulletin of Peace Proposals, vol. 20, 2/1989, pp. 115-122. It is however probable that no existing international organization will be able to take over the verification tasks.

[16] Paragraph 7 requires a "National System of Accounting and Control of Nuclear Material"; the rolling text of the Chemical Weapons Convention envisages in Article VII the establishment of a national authority in the member states. The organizational structure of the planned convention on the prohibition and destruction of chemical weapons follows the NPT model.

[17] Cf. Lawrence Scheinmann, The International Atomic Energy Agency and World Nuclear Order, Washington D.C. 1987 (Resources for the Future).

[18] Dieter H. Scheuing, "Umweltschutz auf der Grundlage der Einheitlichen Europäischen Akte", in: EuR 2/1989.pp.152-192 (192).

[19] Cf. for further details: Schutz der Erdatmosphäre. Eine internationale Herausforderung, Zwischenbericht der Enquete-Kommission des 11. Deutschen Bundestages "Vorsorge zum Schutz der Erdatmosphäre", Bonn 1988.

[20] F.S. Roland et al., "Variations since 1979 in Tropospheric Concentrations of Halocarbons", in WMO Special Environmental Report No. 16, WMO-No. 647, Geneva 1985, pp. 13-32.

[21] Cf. e.g. Hartmann : Braun's (Frankfurt/Main) catalogue on gas analysis.

[22] UBA, Luftreinhaltung - Leitfaden zur kontinuierlichen Emissionsüberwachung, Reports 1/86, Berlin 1986.

[23] J.C. di Primio, W. Fischer, Die CO_2-Emissionen aus dem sektoralen Energieeinsatz, in: ET 1/2 1990, S. 50-51; H.J. Wagner, M. Walbeck, " CO_2Emissionen durch die Energieversorgung", in ET 2, 1988; cf. R.M. Rotty, G. Marland; "Fossil Fuel Combustion: Recent Amounts, Patterns and Trends of CO_2", in: J.R. Trabalka, D.E. Reichle (eds.); The Changing Carbon Cycle. A Global Analysis, New York etc. 1986, pp. 474-490; R. Rotty, G. Marland, N. Treat; The Changing Pattern of Fossil Fuel CO_2Emissions, DOE/OR/214400, TRO 14, Sept. 1984.

[24] The emissions, for example of CH_4, arising in production and consumption in the coal, mineral oil and natural gas sectors are not considered in this section. We are only concerned with CO_2emissions resulting from energy use.

[25] UBA, Luftreinhaltung 88. Tendenzen - Probleme - Lösungen, Berlin 1989.

[26] This may become a problem for countries with a large non- commercial consumption. If such a country can only declare its commercial consumption within the framework

of a greenhouse gas convention and if this consumption increases at the expense of non-commercial consumption then the energy consumption to be declared also increases (and the emissions associated with it). This need not actually be the case if consumption has merely been shifted towards the commercial sector. On the contrary, commercial energy, in particular if liquid energy carriers (petroleum) are substituted for wood, dung etc., may be used more efficiently, i.e. with the same provision of energy consumption may decrease and possibly also emissions. This example shows that a solution for dealing with non- commercial energy will have to be found in the convention.

[27] Cf. Statistisches Bundesamt, Wiesbaden, IV B 11, Bestandsaufnahme der Energiestatistiken, Wiesbaden (no year).

[28] UBA, Luftreinhaltung 88, p. 43; see also footnote 19.

[29] This value is based on our estimate derived from discussions wits statistics experts. It should be regarded as an indication of the extremely high reliability rather than as an exact figure.

[30] However, electricity is broken down according to method of generation; cf. United Nations (ed.), Energy Statistics Yearbook 1986, New York 1988.

[31] Cf. International Energy Agency, World Energy Statistics and Balances 1971-1987, OECD/IEA, Paris 1989.

[33] Cf. G. Zimmermeyer, F.H. Esser; "CO_2 und Treibhauseffekt" , in: ET 9/1989, pp. 558-566.

[33] Cf. Ruhrkohlen Handbuch, Essen 1987 (Verlag Glückauf).

[34] It should be briefly mentioned here that the "Protocol to the Agreement of 1979 on Large-Scale Air Pollution Concerning the Reduction of Sulphur Emissions or their Cross- Border Flow by at least 30%" (EC Convention) also envisages in Article 4 reporting on the level of emissions and the basis on which they were calculated. There are therefore already comparable approaches for verification by "recalculation".

[35] Attempts have been made to quantify the error range of a CO_2 calculation. The best attempt at such a determination can be found in G. Marland and R.M. Rotty ("Carbon dioxide emissions from fossil fuels: a procedure for estimation and results for 1950-1982", in: Tellus 4/1984, pp. 232-261). They estimate the uncertainty in emission determination as on average 6-10 % worldwide. It should be noted here that the "questionnaire" would undoubtedly enable greater precision.

[36] In its place a system of satellite monitoring could be planned in order to safeguard the utilization of firewood, the major non-commercial energy carrier (see be low).

[37] We assumed that the costs correspond to present expenses for instruments to determine the SO_2 concentration (cf. P. Davids, M. Lange, Die Großfeuerungsanlagen-Verordnung, Düsseldorf 1984, p. 250).

[38] For the supplementary role of eart-bound observation and the interaction of the three different levels cf. World Resources 1988-1999, New York 1988, p. 72f. Our remarks concentrate on remote sensing by means of satellites.

[39] With respect to tropical rain forest, the status categorization of sub-areas could for example be as follows: "virgin forest", "forest shield", selectively used "economic forest", "combined agriculture and forestry". The remaining forests in the industrialized countries, which are at present stable in area, and the other disappearing forest zones in the developing countries could also be categorized and declared. Only if the categorization of forest areas is regulated by agreement between individual countries and the International Organization can verification be carried out without conflict. At present, many calculations of the size of the areas of rain forest being destroyed suffer from different categorization (cf. J. Molofsky, Ch.A. S. Hall, N. Myers, A Comparison of Tropical Forest Surveys, DOE/NBB-0078, June 1986, Washington D.C.).

[40] This may give rise to the necessity of including in the climate convention regulations about providing information for those states who do not have adequate means for procuring information at their disposal.

[41] Cf. Scientific American, "Managing Planet Earth", September 1989.

[42] Cf. the contributions by Heinz Häberle and Peter-Christoph Storm in: Karl Kaiser, Stephan Frhr. von Welck (eds.), Weltraum und internationale Politik, Munich 1987

[43] Cf. J.D. Erickson, "The LACIE Experiment in Satellite Aided Monitoring of Global Crop Production", in: George M. Woodwell (ed.), The Role of Terrestrial Vegetation in the Global Carbon Cycle. Measuring by Remote Sensing, Chichester etc. 1984, pp. 191-217.

[43] Cf. the contributions by Hoffer, Billingsleg, Park, Woodwell etc. in: Woodwell (ed.), The Role of Terrestrial Vegetation, loc. cit.; the papers by Tucker et al. and also Woodwell et al. in: John R. Trabalka, David E. Reichle (eds.): The Changing Carbon Cycle: A Global Analysis, New York etc. 1986; furthermore: G. Esser, H. Lieth, "Evaluation of Climate Relevant Land Surface Characteristics from Remote Sensing", in: Proc. of the ISLSCP Conference, Rome, 2-6 December, 1985, ESA SP-248 (May 1986), pp. 205-211.

[45] The much greater monitoring capabilities of military satellites are not under discussion here.

[46] 20 metres corresponds to the side length of a "picture element" (pixel) of the best civil earth observation satellites available as yet.

[47] Esser, Lieth, "Evaluation", Tab. 3 and 4.

[48] Cf. Helen Gavaghan, "An Expedition to Earth", in: New Scientist 29.7.89, pp. 26-27; Eliot Marshall, "Bringing NASA Down to Earth", in: Science 16.6.89, pp. 1248-1251.

[49] Cf. M. Köhl, "Gegenwärtiger Stand der Methoden zur Inventur und Überwachung gefährdeter Wälder", in: Allgemeine Forstzeitschrift 22/1987, pp. 573-577; on research

activities in the Federal Republic concerning remote sensing of "new type of for forest decline" cf.: 2. "DFVLR-Statusseminar Untersuchung und Kartierung von Waldschäden mit Methoden der Fernverbindung", Tagungsband, DFVLR, Oberpfaffenhofen near Munich, 30.11.-2.12.1987.

[50] Cf. Marshall, "Bringing NASA Down", loc. cit., as well as the letter to Science from G.M. Woodwell (23.6.89, p. 452).

[51] As far as vegetation monitoring is concerned this means: "Each (satellite) image is made up of a number of "picture elements", pixels. (...). Within the area covered by a pixel, the nature of the surface could change dramatically, from dense to very sparse vegetation. (...) To solve this problem ISLSCP plans intensive field campaigns." (Cavaghan, "Satellite measurements", loc. cit., p. 27).

[52] Construction of a LANDSAT earth station costs approx. US$ 12-15 million, the annual operating costs are in the region of several million dollars (L.S. Spector, "Keep the skies open", in: Bulletin of the Atomic Scientists, September 1989, pp. 15-20).

[53] M. Krepon, "Peacemakers or rent-a-spies?", in: Bulletin of the Atomic Scientists, September 1989, pp. 12-15. This reference refers to a military observation satellite, but probably accurately reflects the magnitude of costs for a civil earth observation satellite.

[54] .Thus, for example, it would be possible to identify the gaps in a forest caused by selective tree felling; by means of height determination it would, for instance, be possible to differentiate the cultivation of field crops from reforestation measures; this is not always possible today even with infrared pictures.

[55] A ruminant is undoubtedly a point source. The scattered ruminant herds, in contrast, alter the quality of the observation object which now becomes a large-area, diffuse emitter.

[56] All data after: Enquete-Kommission, Schutz der Erdatmosphäre. Loc. cit.

[57] Cf. Official Journal of the European Communities, no. L 297 of 31.10.88 (Articles 6 and 7).

[58] Regulation (EEC) no. 3322/88 of the Council of 14, October, 1988 on certain chlorofluorocarbons and halons which lead to a destruction of the ozone layer, in: Official Journal of the European Communities L 297 of 31.10.1988.

[59] It should be noted here once again that for international verification the density of national controls cannot be of decisive significance for establishing compliance with a treaty.

[60] An exception to this might be remote sensing by the International Organization's own satellite. It could obtain the necessary information itself, and process and assess it internally.

[61]. The INFCIRC/153 formulation concerning adaptations of safeguards technology is as follows in paragraph 6: "(...) the Agency shall take full account of technological developments in the field of safeguards."

Synopsis of Verification Problems for Anthropogenic Greenhouse Gas Emissions

Greenhouse Gases	Emission Sector	Greenhouse Gas Convention Goal	Verification Methods	Verification Reliability
CO_2	energy	reduction in CO_2-emissions by: • reduction of the use of fossil energy • replacement of fossil energy carriers by non-fossil energy carriers	examination of declared energy and emission values on the basis of an extensive notification obligation (primary energy, final energy and conversion losses, imports, exports, bunkers, C contents, conversion factors)	tends to be high (improvement to the data base)
CO_2, CH_4, N_2O	forest / land utilization / energy	• reduction of deforestation / burning off forest areas / biomass combustion • reforestation	satellite remote sensing combined with air and ground monitoring; obligation to prepare reports an non-commercial energy use and audits (?)	high (large-scale clearances) to increasing (non-commercial energy use, selective tree felling)
CH_4, N_2O	agriculture	• development of agro-industial methods to reduce emissions • reduction of the use of fertilizers in some regions (?) • replacement of CH_4/N_2O-intensive products by other foodstuffs (?)	studies on agricultural structure and policy; auditing of data on agricultural production and use of fertilizers; satellite remote sensing for areal changes	not yet definable, but probably varying depending on the measure in question
CH_4	energy	• reduction of emissions from the coal, mineral oil and natural gas industries	verification of agreed minimum standards on natural gas use / flaring as well as minimum standards on the technical safety of pipelines etc. (implementation studies, procedural verification)	not yet definable
CH_4	waste disposal sites	• emission reduction (burning off etc.) (?) • decrease in waste disposal sites (recycling ?)	implementation studies, in part remote sensing (?)	not yet definable
CFCs	industry	• reduction • production ban	extensive obligation to make reports (notification of production quantities, locations, periods, imports and exports); verification of reports; on-site inspections	tends to be high