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ASSESSMENT OF UNCERTAINTIES IN THE PROJECTED CONCENTRATIONS OF CARBON DIOXIDE IN THE ATMOSPHERE

Report based on Proceedings of the International Workshop held at
Netherlands Energy Research Foundation, ECN,
Petten, Netherlands, 4–6 July 1990

Prepared for publication by

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with participation of the following invited speakers

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P. P. Tans (USA), T. M. Tavares (Brazil), D. R. Turner (UK).

*Membership of the Commission during the period (1986–1991) in which the report was prepared was as follows:

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Assessment of uncertainties in the projected concentrations of carbon dioxide in the atmosphere

CONTENTS

INTRODUCTION

The possible impact of the increase of CO_2 concentration in the atmosphere on climate, has prompted IUPAC to organize a workshop on the assessment of uncertainties in the projected concentrations of CO_2. Commission VI.4, Atmospheric Chemistry, as part of the Applied Chemistry Division, together with ECN (Netherlands Energy Research Foundation) were asked to act as organizers.

The aim of this workshop was to investigate the range of uncertainty for the most important sources and sinks. It was decided to focus attention on these sinks and sources primarily. Obviously interactions exist between the future CO_2 concentration and the level of other pollutants, e.g. by way of fertilization effect of coastal waters, between CO_2 concentration and future climate etc. But these links cannot be quantified at this point of time, so they were not part of this workshop.
Other gases, which are radiatively active, could have a large influence on changes of climate, but in order to discuss the problems of the CO_2 cycle in depth, it was decided to limit the scope to this particular subject.

The organizers identified four major causes for the uncertainty in the projections of future CO_2 concentrations:
1. Emissions by deforestation and changes in land use.
2. Uptake of CO_2 in the form of a fertilization flux (growth of vegetation is enhanced at higher CO_2 concentrations).
3. Uptake of CO_2 by the oceans.
4. Emissions due to the use of fossil fuels.

The first item has been subject of a number of recent symposia, so it was decided to focus on the latter three.
A number of experts on different aspects were asked to present a paper:
Dr. Jae Edmonds: Uncertainties in energy scenarios and their consequences for CO_2 emissions.
Dr. Gerd Esser: Uncertainties in the dynamics of biosphere developments with the accent on deforestation.
Dr. Jan Goudriaan: Uncertainties in biosphere/atmosphere exchanges, CO_2 enhanced growth.
Dr. Peter Tans: Overall atmospheric trend assessment.
Dr. David Turner: Air/Sea Exchange.

The following members of the Commission of Atmospheric Chemistry were invited to present a short paper on national or regional recognition of the greenhouse issue and the consequences thereof, especially regarding adaptation or limitation strategies; Dr. Hajime Akimoto, Japan, Dr. Hans-Jörg Grosse, former Eastern Germany, Dr. Ulviye Özer, Turkey, Dr. Xiaoyan Tang, People's Republic of China and Dr. Tania Tavares, Brazil.

The workshop was chaired by Dr. Sjaak Slanina and Dr. Peter Okken, who acted as editors for the final report of the workshop, on behalf of the Commission VI.4, Atmospheric Chemistry. The papers were discussed intensively during the workshop and the general observation was made that the different subjects indeed fitted very well together to generate an overview of the state of knowledge and that the conclusions of the different experts were in agreement, at least in qualitative sense.
This report contains all contributions presented during the workshop and the conclusions reached during the final discussions.

RECOMMENDATIONS FOR FUTURE RESEARCH

The uncertainties in the uptake of CO_2 by the oceans can be effectively addressed to by combining approaches based on ΔpCO_2 measurements and estimates of piston velocity by direct measurements of fluxes using either labeled CO_2, gradient measurements or eddy correlation techniques. Research along these lines has not been started yet in the different international programs, but should get priority. The existing international programs will furnish additional data on average ΔpCO_2 values, which also are essential for deriving the CO_2 uptake.

A better estimation of the CO_2 fertilization flux can be reached by extending measurements of carbon dioxide and its stable isotopes, to regions in the continental interiors, assessment of the integrated fluxes of different vegetation systems over long periods of time and mechanistic biological research in the accumulation of carbon in vegetation and soils due to the CO_2 fertilization effect.

Good documentation of changes of land use via satellite surveillance in combination with better knowledge of the effects caused by these changes and a more extensive series of measurement of ^{14}C and ^{13}C are the only means available to obtain estimates of the CO_2 fluxes caused by deforestation and changes of land use.

Awareness in the developing countries of the problems caused by global pollution and its possible effects is very important. Not only on the political level but also on the scientific level knowledge regarding global pollution is an essential factor determining the attitude of the developing countries. IUPAC can and must fulfill an important role in this process, based on IUPAC's good contacts with both developed and underdeveloped nations.

CONCLUSIONS REGARDING UNCERTAINTIES IN SOURCES AND SINKS

The following overview of fluxes can be given:
1. Emissions by the use of fossil fuel, $5.5\ 10^{15}$ g C per annum at the present. This is the best characterized flux, the uncertainty is in the order of 5 to 10%. Future predictions of this flux are very difficult in view of the uncertainties in economic development of especially the developing countries.
2. Emissions by deforestation and changes in land use. This flux is in the order of 1 to 2 10^{15} g C per year and is less certain compared to the emission by use of fossil fuel.
3. Uptake in the oceans amounts to a flux of 1 to $2.5\ 10^{15}$ g C per annum. This flux is quite uncertain in view of the uncertainties in piston velocities and the averaged value of ΔpCO_2 measurements. The most probable range is between 1 and $2\ 10^{15}$ g C.
4. Uptake by CO_2 fertilization. This flux could range from 1 to $3\ 10^{15}$ g C per year, a probable range is 1 to $2.5\ 10^{15}$ g C per year.
The existence of a large fertilization flux is an important parameter in formulating optimized abatement measures. If we assume a fossil fuel flux of $5.5\ 10^{15}$ g C, a flux due to change in land use of $1.5\ 10^{15}$ g C, uptake in the ocean amounting to $1.5\ 10^{15}$ g C and a fertilization flux of $2.5\ 10^{15}$ g C, the difference of $3\ 10^{15}$ g C between sinks and sources accounts for the accumulation of CO_2 in the atmosphere. If we are able to stop the deforestation, the difference between sinks and sources would be in the order of $1.5\ 10^{15}$ g C, corresponding to 27% reduction of the emissions by fossil fuel. Measures directed to stop deforestation and optimizing agricultural production are probably cheaper than reductions in the order of 60% or more of emissions by fossil fuel. The relatively low agricultural productivity per unit land area of the countries containing the large tropical forests (0.1 to 0.2 of the potential production per unit of land area, to be compared with 0.6 to 1.1 for European countries) leaves room for such policy. In this case a combination of different measures, reduction of the use of fossil fuel, reforestation and optimizing agricultural activities could be effective and leave some room for extension of emissions from the developing countries.

UNCERTAINTIES IN THE GLOBAL CARBON CYCLE

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Before embarking upon a discussion of some major inadequacies in our understanding of the current global carbon cycle, it might be advantageous to first mention those aspects about which our knowledge is fairly secure.

1. The actual rate of increase of the total atmospheric CO_2 burden has been measured accurately since 1956, and during the last 10 years has been on average about 1.5 part per million (ppm) per year. One ppm corresponds to about $2.1*10^{15}$ g C (2.1 Pg C) in the entire atmosphere.

2. The total amount of CO_2 released by the combustion of fossil fuels has been about 5 to 5.5 10^{15} g C per year during the last decade. The uncertainty in the release figures has been estimated to be between 5 and 10 percent.

3. The pre-industrial atmospheric concentrations are known because they have been measured in ice cores with different ice accumulation rates from Greenland and Antarctica. We have been very fortunate that nature appears to have invented for us the perfect storage container, namely air bubbles in ice, for many of the trace gases of current interest.

4. Today's rise in CO_2 concentrations is mainly due to the combustion of fossil fuels. There are four pieces of evidence to support this statement: (i) the CO_2 increase since the last century follows, to a first approximation, the rate of fossil fuel combustion, (ii) the rate of the global atmospheric CO_2 increase during the last decade has been twice as large as during the late fifties to early sixties, when the rate of fossil fuel combustion was also half the present rate, (iii) the concentration difference between Mauna Loa (20° N) and the South Pole has increased roughly in proportion to the fossil fuel increase, and (iv) the decrease in the $^{13}C/^{12}C$ ratio of atmospheric CO_2 implicates a source of carbon that is depleted in ^{13}C, either biomass or fossil fuels, while the decrease in atmospheric ^{14}C before 1950 is consistent with the large-scale addition of ^{14}C free (fossil) CO_2.

However, when it comes to predicting CO_2 levels many decades into the future, assuming certain scenarios of fossil fuel combustion, our knowledge is much less secure. The largest problem is the lack of a quantitative understanding of the mechanisms responsible for the uptake of the amount of CO_2, known to be removed from the atmosphere each year. Are the oceans or the terrestrial ecosystems the major uptake reservoir, and to what extent can they be relied upon during the coming decades? A number of existing problems in our present understanding of the carbon cycle will be briefly discussed in the following text.

Tropical deforestation. The total global amount of carbon that needs to be removed by natural systems, such that the remaining net atmospheric increase amounts to the observed 3.0 10^{15} g C per year, is only approximately known. Evidence exists that vegetation, including forests, acts as a net sink. If the destruction of tropical forests releases only 0.5 10^{15} g C per year of CO_2, the removal has to be about 2.8 10^{15} g C per year; if the forest destruction is 2.5 10^{15} g C, 4.8 10^{15} g C must be withdrawn from the atmosphere annually. The uncertainty of the amount of carbon involved with deforestation stems mainly from two causes: (1) uncertainty in the extent to which burned forests are permanently cleared or alternatively, are allowed to grow back, and (2) in the actual carbon inventory of burned forests.

Ocean uptake. Estimates of the uptake of the fossil fuel CO_2 excess by the world's oceans have generally been in the range of 1.5-2.5 10^{15} g C per year. Various ocean models, from box models to three-dimensional general circulation models, tend to give such an answer when they are calibrated with historical time series of atmospheric ^{14}C. Because the ocean area in the southern hemisphere is roughly twice that in the northern hemisphere, one would expect significantly more uptake in the southern hemisphere. However, that notion is not supported by atmospheric observations, which show a rather small concentration difference between the two hemispheres. If the oceans are the major uptake reservoir for the excess atmospheric CO_2, then the ocean basins of the northern hemisphere have to absorb much more, compared to those in the southern hemisphere. The observed difference in CO_2 partial pressure between the ocean surface and the atmosphere in the North Atlantic and the North Pacific appears much too small for that to be the case. Therefore, it is doubtful that the oceans are currently the major uptake reservoir for the atmospheric CO_2 excess. However, in the long run, on a timescale of centuries, the oceans must be the major uptake reservoir for CO_2 because of their sheer size. The implication is that ocean uptake is possibly much slower than previously believed.

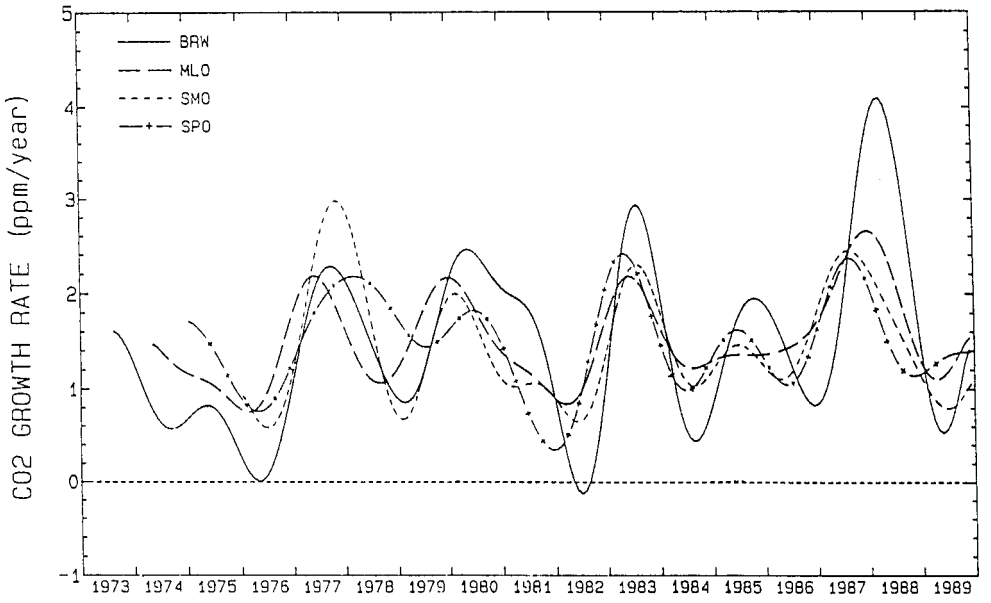

Fig. 1. The rate of increase of atmospheric CO_2 (after removal of the seasonal cycle) as measured at four background observatories operated by the U.S. National Atmospheric and Oceanic Administration. BRW, Point Barrow, Alaska (71 N, 157 W); MLO, Mauna Loa Observatory, Hawaii (20 N, 156 W); SMO, Samoa (14 S, 171 W); South Pole (90 S).

Terrestrial CO_2 uptake. The variability of the annual variations in CO_2 concentrations has been caused by net uptake of CO_2 by natural systems and has been much greater than can be explained by the minor variations of the fossil fuel emissions. In Fig. 1 the growth rate of CO_2, with the annual cycle removed, is displayed for the four NOAA/CMDL stations. The data at each of these sites has been selected for "background" conditions, excluding local influences on the records. There appears to be a correlation with the El-Nino events of 1982-1983 and 1986-1987. The variations are greatest at the northernmost station of Barrow, the same site where the influence of the terrestrial vegetation of the northern hemisphere land masses is largest.

The interhemispheric concentration gradient is also subject to considerable inter-annual variation. The difference between the average 1981-1987 gradient and that in 1988 is shown in Fig. 2, illustrating that the observations at Barrow (Fig. 1) are not an exception, but indicative of an effect in the entire Arctic basin. The large temporal variations in the growth rate of CO_2 are probably much harder to explain by invoking oceanic effects than by assuming relatively minor climatic perturbations leading to droughts etc. on the land, thereby affecting the terrestrial carbon budget.

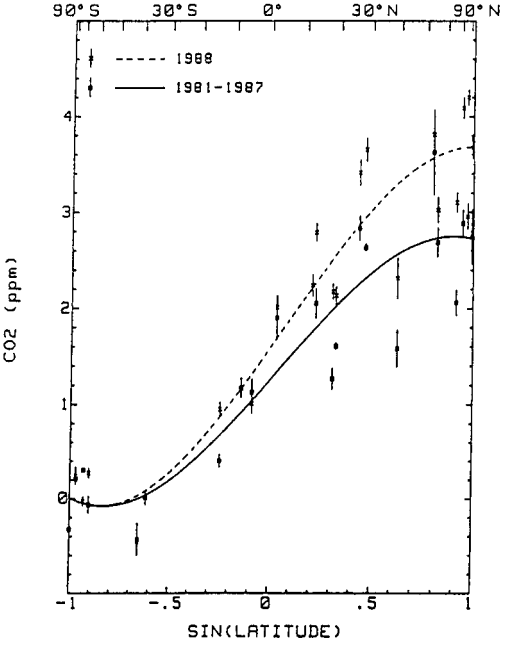

Fig. 2. Latitudinal distribution of annual mean CO_2 concentrations measured at flask sampling sites of NOAA/CMDL. Plotted are concentration differences between sites as a function of sine of latitude. The interhemispheric concentration gradient was significantly larger during 1988 than the average gradient during 1981-1987.

At this stage it is only a hypothesis that the terrestrial ecosystems at temperate northern latitudes are responsible for most of the uptake of fossil fuel CO_2. If some form of global fertilization (CO_2, nitrogen) is occurring, it should have shown already in tree rings. It has also been hypothesized that decomposition might be slower due to lower nitrogen to carbon ratios in the litter in a situation of CO_2 fertilization. Also a build-up of organic matter in soils, the total carbon content of which has been estimated to be about twice that of the atmosphere, could take place.

If the terrestrial ecosystems are indeed currently the major global sink, there would be concern that the storage of carbon might be vulnerable to climatic perturbations and to further direct human intervention. This type of storage is not as "inaccessible" as the deep oceans, which have a turnover time of the order of a thousand years. Also the ultimate uptake capacity for carbon of terrestrial systems is likely to be considerably smaller than that of the oceans.

One of the conclusions of the foregoing is that our capability for quantitative predictions is not very good. If an agreement would be made between nations to keep atmospheric CO_2 below a certain ceiling, we could not at this time predict with much confidence the level of global CO_2 emissions required to stay below such a ceiling. However, it is already quite clear that draconic reductions in CO_2 emissions will be required to significantly slow the present rate of increase of the atmospheric burden because of the dominance of fossil fuel combustion in the global budget.

The present CO_2 increase would be halted if total emissions were cut by about $3\ 10^{15}$ g C per year, but the cuts in emissions required to stay at this level would very likely increase over the years, depending on the response of the oceans and the terrestrial ecosystems to such a new fossil fuel strategy.

ASSESSMENT OF UNCERTAINTIES IN THE PROJECTED CONCENTRATIONS OF CO_2: AIR–SEA EXCHANGE

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Introduction

The carbon dioxide partial pressure (pCO_2) of much of the surface ocean is in disequilibrium with the atmosphere. The general picture is one of supersaturation in equatorial regions and undersaturation in temperate and polar regions. These disequilibria result in substantial fluxes of carbon dioxide between the atmosphere and the oceans. Man's activities currently result in the release of approximately $5.5\ 10^{15}$ g carbon per year to the atmosphere as CO_2, of which some $3\ 10^{15}$ g C remains in the atmosphere.

The oceans have generally been assumed to act as the sink for the 'missing' CO_2, but recent estimates of the air-sea flux of CO_2 based on oceanographic data (Tans et al. 1990) suggest that the oceanic sink is only around $1.6\ 10^{15}$ g per annum, which is much too small to balance the atmospheric CO_2 budget. This implies either that the air-sea flux was substantially underestimated, or that there is a substantial unidentified terrestrial sink. The problems involved in estimating the air- sea flux are discussed in the following sections.

Factors controlling the air–sea flux

The flux F of carbon dioxide between the atmosphere and the sea surface at any point is given by

$$F = K_z\ \Delta pCO_2\ \alpha \qquad (1)$$

or

$$F = K_z\ (pCO_2(atm) - pCO_2(water))\ \alpha \qquad (2)$$

K_z is termed the piston velocity, and represents the physical driving force for CO_2 exchange. K_z has the dimensions of velocity. The remaining terms represent the chemical driving force for CO_2 exchange: ΔpCO_2 is the partial pressure difference between the atmosphere and the surface water, and α is the solubility of CO_2 in the surface seawater. In order to be able to calculate the air-sea flux of CO_2 it is therefore necessary to know each of the parameters in equation (2). Moreover, in order to estimate the net annual air-sea flux F_{TOT}, equation (2) must be integrated over the whole of the surface ocean and over 12 months.

$$F_{TOT} = \int_t \int_y \int_x K_z\ (pCO_2(atm) - pCO_2(water))\ \alpha\ dx\ dy\ dt \qquad (3)$$

This integration requires a knowledge of each of the parameters identified in equation (3) over large time and space scales. The solubility of CO_2, α, is accurately known as a function of salinity and temperature, and the atmospheric partial pressure pCO_2 (atm) is also well known from measurements made at an international network of sampling stations. The two remaining parameters $\underline{K}_z$ and pCO_2 (water) present somewhat more of a problem.

Piston velocity

The major determinant of piston velocity is wind speed. The majority of piston velocity measurements have been carried out using non-reactive gases such as radon or sulphur hexafluoride as tracers. Liss and Merlivat (1986) have derived an empirical relationship between piston velocity and wind speed (Fig. 1), which has been confirmed by recent field measurements in the North Sea using ^3He and sulphur hexafluoride as non-reactive tracers (A.J. Watson et al. unpublished data). However, it can be seen from Fig. 1 that the piston velocity estimated for CO_2 from bomb ^{14}C invasion is significantly larger than that expected from the Liss and Merlivat relationship. Tans et al. (1990) showed that global air/sea flux estimates of CO_2 based on bomb-^{14}C piston velocities were twice as great as those based on Liss-Merlivat piston velocities: the value of 1.6 10^{15} g carbon per year quoted above is based on bomb-^{14}C piston velocities. There is clearly an urgent need to determine the true piston velocities for CO_2, and to understand any differences from the values determined by the use of non-reactive tracers.

CO_2 introduced into seawater undergoes hydration and ionisation reactions:

$$CO_2\ (aq) + H_2O \rightleftarrows H_2CO_3 \qquad (4)$$

$$H_2CO_3 \rightleftarrows HCO_3^- + H^+ \qquad (5)$$

$$HCO_3^- \rightleftarrows CO_3^{2-} + H^+ \qquad (6)$$

The hydration reaction (eqn. 4) is the slowest, and is thus the rate determining step in reactions of dissolved CO_2. If these reactions were to proceed to a significant extent during the passage of CO_2 from the atmosphere to the bulk seawater phase, the resulting changes in the pCO_2 gradient across the air/sea interface would result in an enhanced CO_2 flux, corresponding to a higher piston velocity.

Quinn and Otto (1971) carried out a detailed analysis of this problem using a stagnant film model, and concluded that CO_2 hydration was too slow to give rise to a significant flux enhancement. However, they noted that catalysis of CO_2 hydration, e.g. by carbonic anhydrase in the sea surface microlayer, could result in a significant flux enhancement.

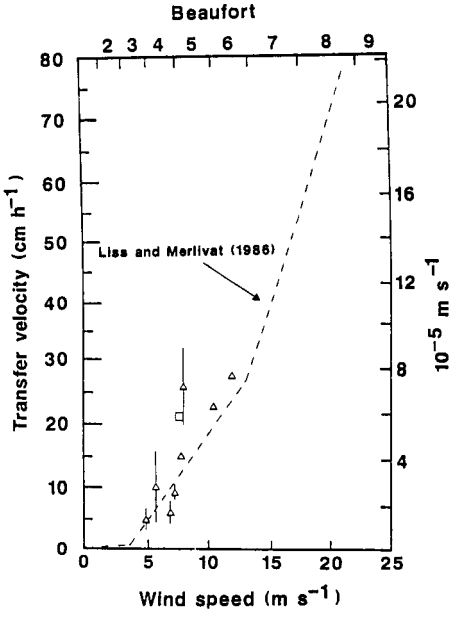

Fig. 1. Transfer velocity (piston velocity) as a function of wind speed.
Δ non-reactive tracer measurements
□ mean value based on bomb-^{14}C invasion.

Carbon dioxide partial pressure in surface waters

This parameter presents the greatest challenge to a successful integration of eqn. (3). Two major types of process contribute to the observed pCO_2 disequilibria between surface waters and the atmosphere. Physical processes are a major determinant in certain areas of the ocean: upwelling of carbonate-rich deep water in equatorial regions results in high pCO_2 values, while cooling of surface waters in polar regions causes a reduction in pCO_2 below the atmospheric level. More complex and dynamic changes result from biological activity in the surface layers of the ocean, most particularly in temperate and polar waters where biological activity shows a strong seasonality, with spring blooms of phytoplankton a major feature. This seasonality shows very clearly in Fig. 2. Although these data are derived from a model, rather than field measurements, the sharp drop in pCO_2 in the spring at 47°N is very similar to that observed by US scientists during the 1989 JGOFS Spring Bloom Study at 47°N. Sharp variations can occur in space as well as time. Fig. 3 shows the large mesoscale variations in pCO_2 which were observed in the North Atlantic during spring 1989. The changes are clearly linked to variations in primary production as revealed by chlorophyll measurements (Fig. 3).

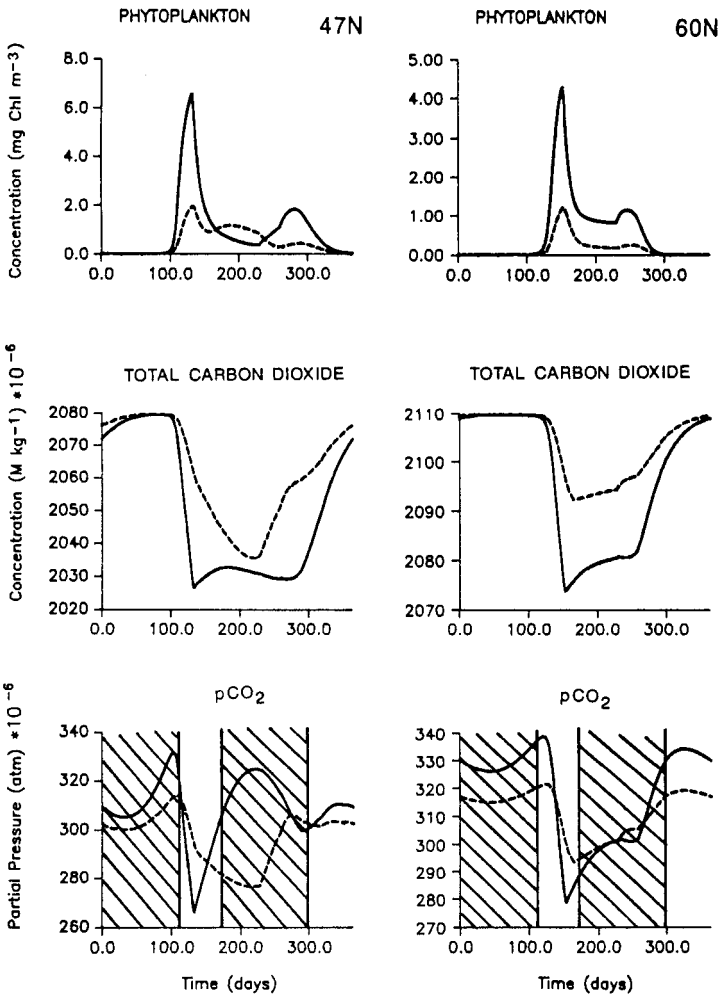

Fig. 2. Model output of pCO_2 and related parameters in the North Atlantic. Full lines represent the surface mixed layer and broken lines the thermocline. The hatched areas of the pCO_2 plots show the parts of the year used by Tans et al. for CO_2 flux estimates. (A.H. Taylor et al. unpublished data).

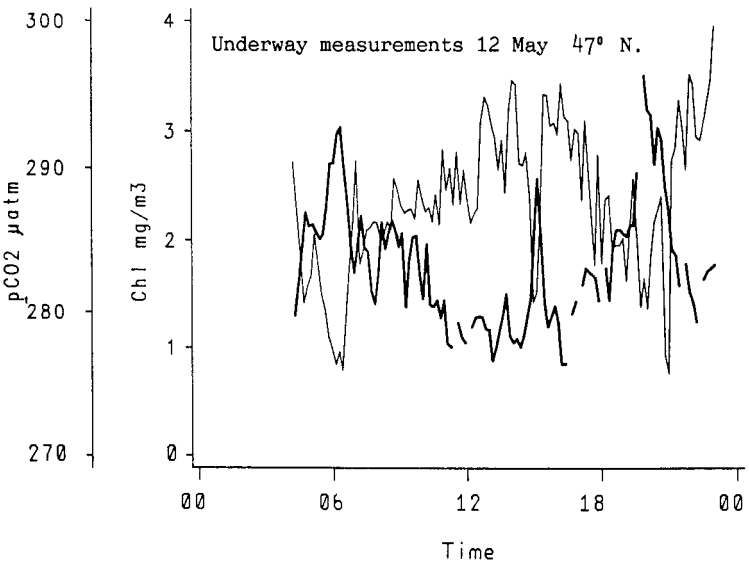

Fig. 3. Measurements of pCO_2 (thin trace) and chlorophyll (thick trace) in North Atlantic surface waters at approximately 47°N, 20°W in May 1989. The horizontal axis represents distance as well as time: the ship was steaming at 8 knots throughout these measurements. (A.J. Watson et al., unpublished data).

Balancing the atmospheric budget

Tans et al. (1990) have recently published a detailed analysis of the global atmospheric budget of CO_2, and the potential role of the oceans as a sink. Their models were constrained not only by the gross atmospheric budget, but also by the observed latitudinal gradient of $\overline{pCO_2}$(atm). This latter constraint is particularly important, since it can only be satisfied if the bulk of the CO_2 sink is in the Northern hemisphere. Tans et al. concluded that the mean $\Delta\overline{pCO_2}$ implied for the Northern hemisphere oceans is unrealistically large, and that there must in addition be a large terrestrial CO_2 sink in the Northern hemisphere in order to balance the atmospheric budget.

It should, however, be recognised that it is extremely difficult to assign realistic confidence limits to estimates of air-sea flux of carbon dioxide based on oceanographic data and integrated in the manner of eqn. (3). The values of $\underline{K_z}$ and $\Delta\overline{pCO_2}$ used are necessarily averaged over large spatial and temporal scales. The calculations reported by Tans et al. averaged $\Delta\overline{pCO_2}$ over a 2° x 2° spatial scale, and for two periods of the year. Wind speeds applied to the 2° boxes were monthly averages. While this represents the state of the art in terms of currently available data, it is clearly inadequate when integrating the product of two parameters ($\underline{K_z}$ and $\Delta\overline{pCO_2}$) which can have spiky, episodic distributions in both space and time. In certain areas, much of the air-sea flux may be associated with storm events (high $\underline{K_z}$), or with spring phytoplankton blooms (which result in high $\Delta\overline{pCO_2}$ as rapid primary production reduces $\overline{pCO_2}$(water); see Fig. 2).

These events will be poorly represented in mean values averaged over periods of months, particularly if the episodes themselves have not been adequately sampled. Some of the problems involved can be illustrated with reference to Fig. 2. The hatched areas of the $\overline{pCO_2}$ plots correspond to the two periods of the year (January-April, July-October) over which Tans et al. averaged $\overline{pCO_2}$: it can be seen that it is possible to miss a significant part of the air to sea flux using this type of averaging procedure.

It may be argued, of course, that the area of the North Atlantic which has received detailed attention from the JGOFS programme, and on which the model of Fig. 2 is based, may not be representative of the temperate waters of the world ocean. However, Minster et al. (1990) recently reported modelling studies based on data collected at Ocean Weather Station P in the North Pacific, including a model of the seasonal cycle of $\overline{pCO_2}$. This model was used to compute the net annual air to sea flux of CO_2 in the manner of eqn. (3), albeit on an extremely limited spatial scale. This was then compared with flux estimates based on limited sampling of $\overline{pCO_2}$ values from the model. The general conclusion was that monthly measurements of $\overline{pCO_2}$ represented the minimum frequency necessary to obtain a reliable flux estimate. This indicates that current integrations of the global air/sea flux of CO_2 according to eqn. (3) should be assigned large uncertainties.

Conclusions

In assessing the fate of CO_2 released to the atmosphere, the uptake of CO_2 by the oceans represents a major area of uncertainty. Current state of the art estimates suggest that the oceanic sink for CO_2 may only be about half that required to balance the atmospheric budget, challenging the widely held view that the oceans represent the major sink. Either the estimate of the oceanic sink is substantially in error, or there is a very large, unidentified, terrestrial sink, or both. It is clear from a brief review of the procedures by which the oceanic sink has been estimated that the seasonal cycle and spatial distribution of $\overline{pCO_2}$ in surface ocean waters constitute the major source of uncertainty. The Joint Global Ocean Fluxes Study (JGOFS) is already beginning to tackle some of these problems, and additional field measurements will be carried out on cruises of the World Ocean Circulation Experiment (WOCE). However, field measurements alone can never provide the necessary spatial and seasonal coverage. This can only be achieved by developing models of the seasonal cycle of $\overline{pCO_2}$ appropriate to different regions of the ocean, and making full use of sea truth and satellite measurements to calibrate and verify the models.

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UNCERTAINTIES IN BIOSPHERE/ATMOSPHERE EXCHANGES: CO_2 ENHANCED GROWTH

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Introduction

Green plants need CO_2 to grow. A higher concentration of atmospheric CO_2 will stimulate the photosynthetic process, promoting plant growth and productivity. At the same time the efficiency of plant water use is increased, hence growth stimulation is possible without an increase in water demand for transpiration. On the other hand, climate warming may partly offset the direct CO_2-effects . The positive direct effect of CO_2 on plant growth is often smaller under nutrient-poor conditions, but is fully retained when water shortage limits plant growth. The effects of climatic change will not be evenly distributed over the world. In cool and temperate climatic zones plant growth will be stimulated, but in the tropics a further increase in temperature will have negative effects.

Current estimates for the amount of carbon in the terrestrial biosphere are: 450-600 10^{15} g C in living biomass and 1200-1400 10^{15} g C in soil organic matter in various forms. In the period 1800-1990 some 210 10^{15} g C of fossil carbon have been burnt, of which about 136 10^{15} g C has remained in the atmosphere and raised the CO_2-concentration from 285 to 350 ppm. The partitioning of the past and present rates of carbon release between various components of the oceans and the biosphere is still uncertain. Two contrasting hypotheses for this partitioning were investigated, using a simulation method.

Definitions

The flux of assimilated CO_2 is stored in various biospheric pools, from where the carbon is eventually recirculated to the atmosphere. A scheme for a classification of the fluxes is given in Fig. 1, and some definitions are further explained below.
Gross Primary Productivity (GPP) is the gross carbon fixation of the photosynthetically active organs (mostly the leaves), for global studies usually expressed in 10^{15} g of C yr^{-1}. This flux is hard to estimate, but probably between 80 and 200 10^{15} g C yr^{-1}.
Net Primary Productivity (NPP) is equal to GPP minus the respiratory losses of the plants themselves. It is equal to the flux of plant material that becomes available to the other organisms that live on it (heterotrophic consumption), e.g. by grazing or by decomposition of dead material. This flux is estimated to be 40-60 10^{15} g C yr^{-1}.
Net Ecosystem Production (NEP) is equal to NPP minus the heterotrophic consumption. It presents the net growth of an ecosystem during an undisturbed period. Globally this flux is about 4-7 10^{15} g C yr^{-1}.
Net Biospheric Uptake (NBU) is equal to NEP minus loss by fire and direct human disturbance. This flux is between 0 - 1 10^{15} g C yr^{-1}, which means that the biosphere is a sink, notwithstanding burning of forests.

Reference hypothesis

This "Reference Hypothesis" (Table 1) is roughly identical to the one described by Goudriaan and Ketner(1984) and by Goudriaan(1989). According to this Reference Hypothesis, the total terrestrial biosphere has shown a decrease of 33 10^{15} g C over the last 200 years and 109 10^{15} g C was absorbed by the oceans. At present the biosphere is a net sink for carbon and not a net source (Table 1), in contrast to conclusions of other researchers (Bolin,1986).
These authors have based their figures on statistics of land reclamation, and multiply the rate of land reclamation with the carbon surface density, characteristic for deforested land.

Decrease in soil carbon is also taken into account. This method results in an estimate of the global rate of release of about 1.2 10^{15} g C yr^{-1} (on basis of 15 Mha yr^{-1} and a change in surface density of 0.08 10^{15} g C Mha^{-1}, or of 8 kg C m^{-2}).
This method however ignores reforestation and widespread regrowth on abandoned land. It also ignores the slowness of release of soil carbon. These factors reduce the release rate to a second estimate of 0.5-0.8 10^{15} g C yr^{-1}.
The third factor, which turns the biosphere from a source into a sink (Fig. 2), is the worldwide stimulation of photosynthesis by rising atmospheric CO_2 concentrations, the so-called CO_2-fertilization effect. Many experimental data (Kimball,1983; Goudriaan and Unsworth,1990) show that this effect may be as large as a 0.5% stimulus per % increase of total atmospheric CO_2. At present, the rate of increase of atmospheric CO_2 is 1.5/350 or about 0.4 % per year. A relative stimulus of 0.5 would result in an increase of 0.2% per

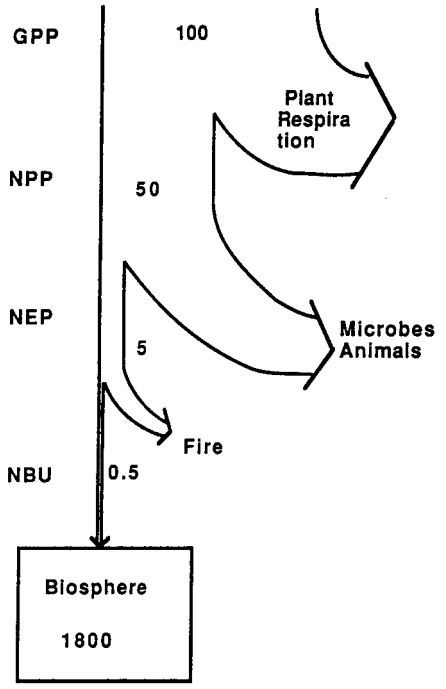

Fig. 1. The major types of terrestrial carbon fluxes in 10^{15} g C yr^{-1}, as consumed by the plants themselves, by heterotrophic organisms, by fire, and eventually used for net storage.

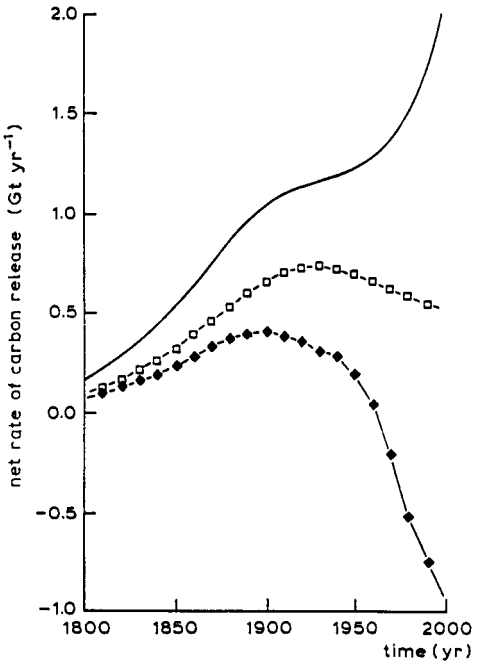

Fig. 2. Net rate of terrestrial release of carbon when only deforestation is considered (——), when regrowth worldwide is also considered (-□-□-), and when CO_2-fertilization worldwide is also considered (-◆-◆-).

TABLE 1. Two simulated Hypotheses for the year 1990. In the Reference Hypothesis the relative stimulus of atmospheric CO_2 with respect to terrestrial net photosynthesis had a value of 0.5, in Hypothesis 2 it was set at 0.7, and the exchange rate at the air-sea interface was halved to arrive at the same atmospheric CO_2-concentration.

Variable	observed	Reference Hypothesis	Hypothesis 2	
F_{fossil}	5.80	5.80	5.80	10^{15} g C /yr
F_{atm} ->sea	?	2.32	1.81	10^{15} g C /yr
F_{atm}->biosph	?	0.75	1.28	10^{15} g C /yr
d_{atm}/dt	2.7±0.2	2.73	2.72	10^{15} g C /yr
$[CO_2]_{atm}$ (285 in 1780)	350±0.5	349.7	349.8	ppm
$^{13}\delta_{atm}$ (-6.0 in 1780)	-8.0±0.2	-7.93	-8.18	promille
$^{14}\delta_{atm}$ (-23.0 in 1780)				
1950:	-46±3	-46.9	-35.7	promille
1970:	450±20	533	667	promille
1980:	220±20	216	349	promille
1990:	?	93	199	promille
Biosphere (1894.5 in 1780)	?	1861.9	1887.0	10^{15} g C
increment	?	-32.6	-7.5	10^{15} g C
Ocean [1]	?	38894.5->39004.1	38727.0->38811.3	10^{15} g C
increment	?	109.6	84.3	10^{15} g C

1) The initial ocean profile and total content of carbon depends on the assumed surface exchange rate. F_{atm}->sea flux should be zero in the starting year 1780.

year of the storage capacity in the terrestrial biosphere, corresponding to about 4 10^{15} g C additional storage capacity per year. However, this increased capacity is not instantaneously realized, because slow compartments lag behind. Numerical simulation shows that the differences in longevities from leaves to resistant soil carbon reduce the realized CO_2 fertilization effect to about 1.5 10^{15} g C yr^{-1}.
In combination with the estimate for regrowth, the global terrestrial biosphere is estimated to exhibit a release rate of -0.75 10^{15} C yr^{-1} or, in other words, to act as a net sink of about 0.75 10^{15} g C yr^{-1}.
Two variants of this reference hypothesis can be formulated. In one of them the CO_2 fertilization effect is not expressed as increased productivity per unit surface area, but as decreased decomposition of wood and soil organic matter. In the other variant the vegetated areas are increased, instead of the carbon surface densities.
These three mechanisms (increased surface productivity, decreased decomposition rates, and increased vegetation areas) may occur simultaneously, and can replace each other in model calculations. It is remarkable that the global mean concentration of carbon isotope in the major pools hardly differ for these variants. However, it is to be expected that a further analysis of isotopic records in the different geographic and structural pool components will enhance the possibilities to discriminate between the hypotheses.

Hypothesis 2

Tans et al.(1990) have concluded on basis of the North-South gradient of atmospheric CO_2 that biospheric carbon uptake must be larger and ocean uptake must be smaller than hitherto believed. A possible realization of this hypothesis is given in Table 1. Global NPP must grow by 0.35% per year instead of by 0.25% per year. This rate corresponds with a hypothetical CO_2-fertilization effect of 0.7% which is a very high figure, in fact too large to attribute to CO_2 alone. Other factors such as global eutrophication, should also contribute for such a large stimulus to occur.
As before, the distribution of the stimulus of growth rate over surface NPP, increased longevity and increased vegetated area is immaterial for the values of concentrations in the atmosphere.
Surprisingly, the ^{13}C isotope figures cannot serve to discriminate between Hypothesis 1 and 2, at least if only their global means are considered. The insensitivity of the isotope record to partitioning of uptake between ocean and biosphere is due to two compensating factors:
a) When the ocean absorbs less carbon, its ability to dilute the isotopically depleted fossil carbon is also less, and the isotopic record should show a faster decline.
b) On the other hand, the biosphere preferably takes up the lighter C-isotope, and with a faster biospheric growth isotopically enriched CO_2 will remain in the atmosphere. This effect will reduce the downward trend of the atmospheric isotope content.
However, the ^{14}C record, especially after the nuclear tests, did show clear differences (Table 1). For hypothesis 2 the simulated rate of return of the peak of radiocarbon in the atmosphere was too slow, at least during the first decade around 1970. For unknown reasons, during the last decade the observed rate of return has slowed down a bit, and both hypotheses can probably be reconciled with the data.
More geographic and structural detail in isotopic data will be needed to clarify some of these inconsistencies.

Conclusions and discussion

Even a slight imbalance in the growth of terrestrial ecosystems on a global scale is sufficient to absorb the carbon released by deforestation (Lugo & Brown, 1986). Such an imbalance may be caused by the fertilization effect of increasing atmospheric CO_2, as assumed here, but other environmental factors may be involved as well. Notably, the soil can store significant amounts of carbon. For instance, a 3 % increase in carbon content (relative to carbon, not to soil weight) results in a carbon sequestering of 50 10^{15} g C. Detection of this fertilization effect by sampling methods in the field is extremely difficult, because of the large natural heterogeneity that exists on practically every spatial scale.
Deforestation for permanent human use is significant, releasing CO_2 at a rate of about 0.5 to 1 10^{15} g C yr^{-1}. On the other hand, this rate of release can be more than compensated by global stimulation of growth by atmospheric CO_2. From the point of view of the activity of the biosphere, a net biospheric uptake of 0.5 - 1.5 10^{15} g C yr^{-1} is a plausible range. We still do not fully understand how a higher biospheric (and lower ocean) uptake can be reconciled with the observed record of ^{14}C in the atmosphere.

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UNCERTAINTIES IN THE DYNAMICS OF THE BIOSPHERE WITH THE ACCENT ON DEFORESTATION

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Introduction

The carbon balance of the terrestrial biosphere is the most complex part of the global carbon cycle. The high diversity of contributing organisms from different life zones, the complexity of space-time scales of the relevant processes, and the high degree of intercorrelations of fluxes and control relations complicate the understanding of the system. Some processes like land-use changes and forest clearings and all processes related to soil organic carbon must be considered especially uncertain.

The entire terrestrial biosphere contains probably three times the amount of carbon in the atmosphere. Roughly 2/3 of the carbon belongs to the soil organic carbon. Circa 50 x 10^9 tons of carbon are annually fixed through the flux net primary productivity of land surfaces. Decomposition processes eliminate about the same amount and return this to the atmosphere. Medium to long-term disturbances of this production-decomposition equilibrium cause sources or sinks of carbon in terrestrial system, while short-term disturbances which occur during the annual cycle do not contribute to biospheric sources or sinks. The models thus have to quantify small disturbances of large fluxes, while a strong annual cycle is present.

This paper is mainly based on results of the Osnabrück Biosphere Model which calculates the relevant terrestrial processes on a 2.5 degrees grid.

Processes considered by the models

Actual models of the terrestrial carbon cycle are "balancing" models. The changes of carbon pools in those models are calculated by balancing the related fluxes. Single fluxes or groups of closely related fluxes are considered as processes.

Pools
The principal carbon pools of the terrestrial biosphere include:
- Phytomass (carbon pool in living plants).
- Litter (carbon in dead but not yet decomposed plant material).
- Soil organic carbon (the heterogenous pool of carbon contributing to the soil humus).

Those pools are generally subdivided into different compartments which react differently in relation to the fluxes. Litter for example is commonly partitioned into the slowly decomposing polyphenolic compounds (like lignin) and the faster decomposed compounds carbohydrates, proteins, and others.

Fluxes
The principle fluxes which transport the carbon between the biospheric pools and give rise to exchange between biospheric and non-biospheric pools include:
- Net primary productivity (net flux atmosphere → green plants).
- Litter production (flux living phytomass → litter).
- Litter depletion (flux litter → atmosphere).
- Production of soil organic carbon (flux litter → soil organic carbon).
- Depletion of soil organic carbon (flux soil organic carbon → atmosphere).
- Leaching of soil organic carbon (flux soil organic carbon → groundwater → rivers → ocean).

Calculation of fluxes and data situation
The present models include these pools and fluxes. The calculations are performed regionally, i.e. they are based on a global grid. It is generally not possible to characterize fluxes in the models by distinct values since these fluxes are too divers in space and time and only very limited numbers of measured data are presently available. Therefore attempts were made to relate the fluxes to their driving functions. Those driving functions are mainly climate elements, soil attributes, and others, which are commonly available as global grid-based data sets.

Thus (relatively scarcely measured) biospheric fluxes are calculated in the models from readily available environmental variables. Empirical functions relate those environmental variables to the fluxes or flux coefficients. The reliability of the functions reflects the reliability of the data set used to calibrate the functions and the experience of the persons who selected the data sets.

Processes influenced by forest clearing and land-use changes
The productivity of agricultural areas is considerably lower than the productivity of the replaced natural vegetation types in most countries of the world. Based on the yield data published in the FAO yearbooks, the productivity of agricultural crops may be calculated by use of conversion factors yield to productivity which are available for important crops. Commonly the agricultural productivity does not exceed 15-20% of natural productivity. If natural vegetation is cleared the productivity is subsequently reduced to very low values.

The cleared phytomass is either burnt or left behind on the fields and decomposed naturally. In either case the carbon pool of the phytomass is converted to CO_2 and emitted into the atmosphere with timescales of days up to a few years. If charcoal is produced the lifetime is considerably longer.

The reduced productivity of fields in contrast to natural vegetation also reduces the production of litter and soil organic carbon. Because the depletion of those pools of dead organic matter is probably not influenced this leads to a loss of soil organic matter and humus compounds.

Since the principle biospheric processes are affected by these human activities it is important to know quantitatively the cleared areas and the sites where clearing occurs. The latter is the most important factor. It is not sufficent to know the vegetation type affected, since with a particular vegetation type very different carbon fluxes may actually be correlated on different sites. Moreover, the change of areas and sites influenced by humans in the past 130 years must be known and scenarios must be available for projections into the future.

Data sets on a country basis are available which include the distribution of agriculturally used areas and their changes in the past. These are mainly based on evaluation of statistical data. According to these data the global agricultural area has developed almost linearly. Data on changes in the past 10 years are particularly uncertain since these generally not distinguish between actually cleared areas (which may have been cleared earlier already) and those which are definitely transformed from natural stands to other forms of land use (i.e. shifting cultivation).

Model results

Carbon turnover by fluxes
The terrestrial biosphere binds carbon at a rate of approximately 50 10^{15} g [10^9 t]/yr. A similar amount is emitted to the atmosphere by biospheric decomposition processes. Roughly 2/3 of the decomposed amount of carbon originates from the litter pools, about 1/3 from decomposition of soil organic carbon.

The observed temperature rise since 1860 (circa 0.6-0.8°C) has caused an additional emission of CO_2 due to enhanced decomposition processes which probably amounts to 10 10^{15} g.

Carbon content of biospheric pools
The global phytomass contains circa 650 10^{15} g carbon. From this pool only 3 10^{15} g C are due to agricultural crops.

In the period 1860-1950 the global phytomass showed a net reduction of about 40 10^{15} g C. Since 1950 a minor increase of about 10 10^{15} g is modelled. The reason for that behavior is discus- sed below.

The litter pool contains about 100 10^{15} g of carbon. The soil organic carbon adds up to about 1500 10^{15} g globally.

Considering the fluxes the mean residence time of carbon in the different biospheric pools is 13 years for phytomass, 3 years for litter, and 140 years for soil organic carbon.

Land-use changes, forest clearings, and the fertilization effect

Replacing natural forest vegetation by agricultural crops generally reduces the phytomass considerably from 15-20 kg.m^{-2} carbon to less than 1 kg.m^{-2}. The annual anthropogenic CO_2 emissions due to clearings globally amount to 1 10^{15} carbon which is roughly 20% of the fossil source.

The emissions from cleared areas since 1860 are close to 100 10^{15} g C. Scientists suggest that part of this amount may have deposited as charcoal (during shifting cultivation). There are, however, no reliable data on charcoal production and its lifetime under tropical climate conditions.

The above mentioned impacts due to forest clearing and land-use changes should lead to a drastic reduction of the global phytomass. This reduction is not reflected in the models (see Table 1). Since 1950 even a slight increase is modelled. The reason is the fertilization effect of the rising atmospheric CO_2 concentration and probably of other anthropogenic emmissions like nitrogen compounds and others. The phytomass reduction in the entire period 1860-1980 thus has only reached a level of 30 10^{15} g C instead of 100 10^{15} g C which were emitted from clearings.

TABLE 1. Development of the global sums of the major carbon pools of the terrestrial biosphere and the atmosphere in the period 1860-1980. Results of a model run with standard climate (no changes). The terrestrial pools are stated in 10^{15} g C, the atmospheric concentration in µl/l.

Year	Pools					Accum. fluxes	
	Atmo-sphere	Phytomass		Litter	SOC	Deforest.	Fertil. effect
	[µl/l]	nat.	agri.	[10^{15} g C]			
(1)	(2)	(3)	(4)	(5)	(6)		
1860	285.0	668	1.6	91	1536	- 0	0
1870	286.7	663	1.7	92	1537	- 7	2
1880	288.6	658	1.9	92	1538	-15	5
1890	290.7	654	2.1	92	1539	-22	8
1900	293.1	650	2.2	92	1539	-30	12
1910	296.1	646	2.4	92	1538	-37	15
1920	299.4	643	2.5	92	1538	-44	19
1930	303.2	639	2.6	92	1538	-54	25
1940	307.0	636	2.8	92	1537	-63	31
1950	311.6	633	2.9	92	1536	-73	38
1960	317.6	634	3.0	92	1535	-81	47
1970	326.5	637	3.1	92	1533	-89	58
1980	338.8	644	3.2	92	1531	-96	73

TABLE 2. Net changes of global carbon pools due to three scenarios for the period 1860-1980. Standard climate means constant mean annual temperature and average annual precipitation in the entire period, temperature increase relates to a change of the mean annual temperature of each grid element coupled to the atmospheric CO_2 to yield +3.5 °C for double CO_2 (+0.8 °C in 1980), no CO_2 fertilization assumes that NPP is not influenced by the atmospheric CO_2 level. Values are net changes in 10^{15} g C and 10^{15}.a^{-1}, respectively. Negative prefix indicates
losses of the respective pool to the atmosphere. Mauna Loa means ΔCO_2 1958-1980 [µl.l^{-1}] measured at the Mauna Loa observatory, Hawaii.

	standard climate	temperature increase	no CO_2 fertil.
CO_2 (1860) [µl.l^{-1}]	285	283	261
ΔCO_2 1958-1980 [µl.l^{-1}]	+22.6	+23.3	+37.4
Mauna Loa		+23.2	
phytomass	-23	-20	-83
litter	+1	-0.5	-5
soil organic C	-5	-12	-26
ocean	+76	+78	+112
atmosphere	+114	+117	+164
fossil source		-163	

The existence of such a large fertilization effect (probably 70 10^{15} g C) has long been controversial. If a fertilization effect is ignored in the models a CO_2 concentration as low as 260 $\mu l.l^{-1}$ has to be assumed for the year 1860 to get the right value of 340 $\mu l.l^{-1}$ in 1980. In contrast, the ice cores suggest an atmospheric concentration of 283 ± 3 $\mu l.l^{-1}$ for 1860, which is in excellent agreement with model results under consideration of CO_2 fertilization (Table 2).

Conclusions

The biosphere is an important part of the global carbon cycle during the past 130 years; the low net contributions of the biosphere of about 30 10^{15} g carbon hide the real importance of the biospheric fluxes. The carbon emissions due to clearings amount to 2/3 of the emissions from fossil sources in the past 130 years. At present they contribute less than 20% (1 $10^{15}.a^{-1}$) to the total anthropogenic CO_2 emissions.

At present it is not possible to estimate the reliability of the model predictions. The models have to be considered as working hypotheses rather than as results which can be proved in terms of statistical confidence. Therefore, independent data which have not been used during calibration of the model functions should be used to verify the model results. Those data include the atmospheric CO_2 concentration and the fractionation of carbon isotopes. Especially the high seasonal dynamics of the carbon cycle could be used to prove the models via atmospheric CO_2 gradients, since several carbon fluxes which compensate over a year or several years, are deconvoluted (not in the same phase) on a monthly time scale.

UNCERTAINTIES IN ENERGY SCENARIOS AND THEIR CONSEQUENCES FOR CO_2 EMISSIONS

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Introduction

The current interest in the "greenhouse" issue stems from the observation that the concentrations of such gases as CO_2, CH_4, N_2O, $CFCl_3$, and CF_2Cl_2 have been increasing. Changes in the concentrations of these gases hold the potential for changing the Earth's climate. This paper will focus on uncertainties in the forecast of net emissions of CO_2 to the atmosphere by human activities. The net emission of other greenhouse gases such as CH_4, N_2O, $CFCl_3$, and CF_2Cl_2, although important, is not discussed. Furthermore, only the net emissions of CO_2 from human activities are addressed. The vastly greater annual fluxes of carbon pertaining to the natural carbon cycle are the focus of other papers in this collection, as is the interaction between net emissions of CO_2 to the atmosphere and the atmospheric concentration of CO_2. The importance of human activities as a potential disturbance to the natural carbon cycle, coupled with the importance of CO_2 as a potential disturbance to the Earth's radiation budget, argues for the special attention given here.

In general the uncertainty associated with the future emissions of CO_2 to the atmosphere stems from two sources: uncertainties associated with present sources and rates of net emissions, and the future course of those human activities associated with emissions. We shall discuss each of these topics in turn.

Uncertainties in historical net CO_2 emissions from human activities

Anthropogenic emissions of CO_2 are released principally from two human activities: Fossil fuel use, approximately 5.7 10^{15} g C/yr in 1988, and land use changes (deforestation), approximately 1.5 10^{15} g C/yr in 1988, with lesser amounts released by industrial processes such as cement manufacture, 0.1 10^{15} g C/yr in 1986. Fossil fuel CO_2 emissions can be estimated with relatively good confidence. Confidence limits for global fossil fuel CO_2 emissions of ±10% are frequently cited. Even if these bounds are overly optimistic by a factor of two, they are considerably narrower than the bounds that surround most other greenhouse gas emissions. Fossil fuel CO_2 emissions are known with much greater certainty than CO_2 emissions from land use change. Manmade emissions of CO_2 take place against a background of natural exchanges between the atmosphere and oceans and the atmosphere and the terrestrial biosphere, which are enormous. Each of these fluxes is estimated to exceed 100 10^{15} g C/yr.

Fossil Fuel CO_2

More is known about fossil fuel CO_2 emissions than about any other gas. Since 1860, global annual emissions of fossil fuel CO_2 have increased from 0.1 to approximately 5.7 10^{15} g C/yr in 1988. From 1945 through 1979, the rate of CO_2 emissions from fossil fuel use grew at 4.5%/yr.

Emissions declined from 1979 until 1983 but have risen subsequently. The U.S., U.S.S.R. and P.R.C. account for half of the world's fossil fuel CO_2 emissions. U.S. fossil fuel CO_2 emissions accounted for more than 40% of global emissions in 1950. This share has steadily declined to less than 25% in 1989. U.S. CO_2 emissions peaked in 1973 (1.27 10^{15} g C/yr) and again in 1979 (1.30 10^{15} g C/yr) and remained below that level in 1986 (1.20 10^{15} g C/yr), the last year for which global statistics for all nations are available.

Global average per capita emissions of fossil fuel CO_2 to the atmosphere are approximately 1 tonne C/capita/yr. U.S. emissions exceed 5 tonnes C/capita/yr. Carbon content varies by fuel. Of fossil fuels, natural gas is lowest (13.7 10^{12} g C/EJ); coal is highest (23.8 10^{12} g C/EJ); and oil falls between the two (19.2 10^{12} g C/EJ). The mining of oil shales in carbonate rock formations would add an additional stream of CO_2 to the atmosphere; its magnitude would depend on the grade of the resource and the technology employed to extract it. The transformation of primary fossil fuel energy, as for example from coal to electricity or from coal to synoil or syngas, releases carbon in the conversion process. Energy technologies such as hydroelectric power, nuclear power, solar energy, and conservation (including energy efficiency improvements) emit no CO_2 to the atmosphere. Traditional biomass fuels, such as crop residues and dung, release CO_2 to the atmosphere but are in a balanced cycle of absorption and respiration whose time frame is short. The use of other biomass fuels such as firewood may provide either a net annual source or sink for carbon, depending upon whether the underlying biomass stock is growing or being exhausted. Improvements in the efficiency of energy conversion technologies reduce the rate of emission of greenhouse gases per unit energy service provided.

Deforestation and Land-Use Changes

Approximately 560 10^{15} g C is in the form of terrestrial biomass, principally stored in forests. This is estimated to be about 15% to 20% ($\approx$120 10^{15} g C) less than was present in the mid-19th century. On a global basis, this is estimated to vary less than about 10 10^{15} g C through the seasons as leaves and grasses grow and die.

Knowledge of the net annual emissions of carbon from land-use changes is far less certain than emissions' estimates for fossil fuel use. Emissions of net annual CO_2 release from land-use changes have been estimated for the year 1980 by various researchers. Net release is calculated as the difference between annual gross harvests of biomass, plus releases of carbon from soils, less biomass carbon whose oxidation is long delayed (e.g., stored in forest products such as telephone poles, furniture, and housing) and additions to the stock of standing biomass. Houghton et al. (1985) estimate 1980 emissions to be between 0.5 and 4.5 10^{15} g C/yr. This range is narrowed in Houghton et al. (1987) to between 1.0 to 2.6 10^{15} g C/yr. Detwiler and Hall (1988) estimate 1980 emissions from the tropics to be in the range 0.4 to 1.6 10^{15} g C/yr. Net emissions from land-use change are dominated by tropical deforestation. Houghton et al. (1987) estimate that all but 0.1 10^{15} g C/yr of net release are from tropical forests.

Estimates of deforestation in 1980 are greatest for Brazil, Columbia, the Ivory Coast, Indonesia, Laos, and Thailand. Estimates of net CO_2 emissions from land-use change have increased for recent decades. Prior to 1950, significant deforestation is estimated to have occurred in the temperate latitudes as well as in the tropics. While a matter of heated debate, it has been suggested that increases in the atmospheric concentration of CO_2 could act to accelerate the rate at which plants store carbon. Estimates of net CO_2 release form land-use change do not take the possibility of a CO_2 fertilization effect into account.

Uncertainties in Forecasts of Future CO_2 Emissions

In parallel to the discussion of historical net CO_2 emissions, we first discuss fossil fuel CO_2 emissions and then address the issue of emissions from land-use change.

Future Fossil Fuel CO_2 Emissions

The extrapolation of trends, showing CO_2 emissions from fossil fuels to grow at 4.5%/yr, led early researchers to expect atmospheric CO_2 concentrations to reach 600 ppm in the early part of the 21st century. The rate of growth of fossil fuel emissions is now expected to be less than 1%/yr. Recent analysis of uncertainty in future fossil fuel CO_2 emissions pushed the expected (median) date, by which 600 ppm concentrations of CO_2 would be reached, to late in the 21st century and possibly not until the 22nd century. Non-fossil fuel emissions sources, in particular land-use changes, were not included in that analysis.

The fossil fuel resource base provides no constraint on future atmospheric CO_2 release. The present atmospheric stock of carbon is approximately 740 10^{15} g C (1988). The estimated resource of fossil fuels is huge by comparison. While the carbon content of conventional oil and natural gas resources is only slightly more than half as large as the current atmospheric stock of carbon, coal resources are an order of magnitude larger. The carbon content of unconventional oil resources is 55 times larger than the current atmospheric stock of carbon. The pool of carbon available for combustion might be constrained to 4000 10^{15} g C by considering only those resources recoverable under present technologies. Even this severely constrained resource definition provides no physical constraint on climate change from fossil fuel use. Approximately 80% of the coal resource base is thought to be in three countries: the U.S., U.S.S.R., and P.R.C. There are approximately 800 10^{15} g C is in the form of coal, recoverable with today's technologies, within the jurisdictional boundaries of the world's other countries.

The future rate of fossil fuel use remains largely uncertain. Forecasts of emissions for the year 2075 vary by almost two orders of magnitude, with associated atmospheric concentrations varying by a factor of 3 to 4. The uncertainty in CO_2 emissions arises out of underlying uncertainties surrounding major human activities such as economic growth, the rate of energy efficiency improvement, and the type and rate of economic development experienced by the developing world. Variations in the rate of population growth and the estimated resource base of fossil fuels do not produce variations in emissions forecasts comparable with the previously mentioned factors.

Future Deforestation and Land-Use Changes

The causes of land-use change vary from country to country and make the development of forecasts of future net emissions very difficult. The dominant factors affecting deforestation include the conversion of forests to agricultural and pasture lands, logging, and fuelwood harvests. Unlike fossil fuel CO_2 emissions, cumulative net emissions from land-use change are bounded from above in a meaningful way by the total stock of terrestrial-biomass carbon. Thus, while annual emissions are highly uncertain for any given year, cumulative emissions cannot exceed 560 10^{15} g C. Annual emissions forecasts under business-as-usual conditions vary within a range similar to that for 1980 estimated emissions. Future net reforestation is also possible. Estimates of 1 10^{15} g C/year or less net release are not uncommon, although some rapid deforestation scenarios contain peak emissions of 5 10^{15} g C/year for brief periods.

Feedback Effects on Future CO_2 Emissions

The possibility exists for significant climatic feedbacks on carbon emissions via the release of carbon stored in clathrates in Arctic regions. Estimates of potential releases are highly speculative but potentially of an order of magnitude equivalent to current fossil fuel CO_2 emissions. This carbon may be released in the form of CH_4. The attendant effect on the CH_4 budget would be significantly greater than on the CO_2 budget.

Other feedbacks could also be significant. These include, but are not limited to, a tendency for reduced fossil fuel use for heating, but a tendency for increased energy use for cooling. Other indirect effects include changes in efficiency for electric power generation if water resource availabilities change, increased energy requirements for irrigation if climate patterns reduce soil moisture and water resource availability, and possible enhanced production of biomass energy resources due to the CO_2 fertilization effect.

Reducing Future CO_2

More attention has been focused on the question of emissions reductions for CO_2 than for any other gas or human activity, with the exception of CFC applications. The two principal sources of CO_2 emissions are fossil fuel use and deforestation and land-use changes.

Fossil Fuel Emissions

CO_2 is an unavoidable by-product of the combustion of carbonaceous fuels. The level of emission depends upon the amount of carbon per unit energy contained in the fuel. For fossil fuels the hydrogen-to-carbon ratio is critical. Emissions can be reduced in five different ways:

1. energy conservation reducing the energy required to provide any energy service, such as space heating, goods transport, and electric power generation. Energy conservation does not mean doing without.

2. fuel substitution changing the fuel mix to increase the proportion of low or non-CO_2 emitting fuels relative to high CO_2 emitting fuels, as for example from coal to natural gas or from natural gas to nuclear or renewable energy.
3. scale hanging the scale of the overall human and energy systems, as for example by changing population, or the level of overall economic activity or simply doing without and thereby having less of the fruits of energy use.
4. activity mix changing the composition of energy-using activities, as for example away from the production of goods that use ferrous metals to those useing plastics or away from goods and toward services.
5. carbon removal and recovery removing carbon either after combustion via traditional scrubbing or tree planting, and disposing of the carbon in a permanent repository, or removing the carbon before the fuel is combusted and then disposing of the carbon.

All emissions reductions options apply one or more of the above principles. The nuclear and renewable power options are fuel switching options, while lifestyle changes would exert an influence through several avenues including energy conservation, fuel switching, and activity mix.

We begin by noting that energy conservation is achieved by applying technologies that produce the same level of energy service while using less energy. We use the term "technology" in broadest possible context to describe how societies organize to produce the goods and services they desire. Thus the application of technology can mean either the introduction of a new machine, or simply a new way to organize the present array of humans and machines. It is important to emphasize that conservation means technological improvement, not doing without.

One of the earliest studies to focus on the potential for fossil fuel CO_2 emissions reductions was Rose et al. (1983). This study concluded that one of the most important factors governing the rate of future fossil fuel CO_2 emissions was the rate of introduction of new energy conserving technologies. Edmonds et al. (1986) concluded that this was one of the three critical factors governing future fossil fuel CO_2 emissions. Both of these studies were "top down" studies which focused on the macro level of the energy system, and did not provide details regarding individual technologies that might be applied.

More recently a series of studies has been published that applied a "bottom up" analysis of the role energy conserving technologies might play in CO_2 emissions reductions. These studies include Cheng et al. (1985), Goldemberg et al. (1987), Fulkerson et al. (1989), and Chandler et al. (1988). These studies suggest substantial unutilized technological potential for energy efficiency improvements ranging from improved lighting technologies, electric motors, internal combustion vehicles, gas turbines, and building shells. These studies also indicate that these technologies are likely to penetrate the market because they are financially attractive under present economic conditions. Furthermore, the accelerated introduction of these technologies would further reduce energy and in particular fossil fuel demands and thereby reduce CO_2 emissions.

Several of these studies, for example, Goldemberg et al. (1987) and Chandler et al. (1988), advocate policies such as automobile fuel economy standards, energy taxes, and/or building code changes, to accelerate the introduction of these technologies. These studies have generally been microeconomic in nature and have not assessed feedback consequences of policies within a market equilibrium setting. Key issues remaining to be explored include the effect of accelerated investments on capital markets, economic growth, competitiveness, and energy prices. For example, will the adoption of new energy conserving technologies lower the cost of energy services sufficiently that additional quantity demanded of the service increases and reduces the overall effectiveness of the measure? Will the introduction of new, more efficient technologies improve both energy and labor productivity simultaneously, and since labor productivity improvements increase GNP, and thereby the scale of energy demand, result in lesser CO_2 reductions than anticipated by the "bottom up" studies?

CO_2 scrubbers are also technically feasible, although costs are high for central power stations (electric power generation costs would double) and prohibitive for small scale energy use. Alkanolamine scrubbing has been used to co-generate power and CO_2 for commercial sales at a natural gas fired plant in Lubbock, Texas. Other technologies are also under study. Injection of CO_2 into salt domes or directly into deep oceans are the two major repositories currently considered, although depleted oil and gas fields could provide another more limited set of storage sites. Insufficient information exists to evaluate these strategies' full costs, efficacy, and environmental risks. Tertiary oil recovery does not provide a repository of a scale comparable to global emissions.

Biomass plantations have also been suggested as a mechanism for CO_2 removal. The scale of the effort required to remove an additional 5 10^{15} g C/yr from the atmosphere is approximately equal to doubling the net annual yield of all the world's closed forests or planting new fast growing forests over an area equivalent to the total of global forest clearing to date. The cost of such a scheme is speculative at present.

It is possible to use coal as a feedstock for hydrogen, removing the carbon for return to the mine. The feasibility, economics, and environmental consequences of such technologies have not been addressed.

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NATIONAL AND REGIONAL RECOGNITION OF THE GREENHOUSE ISSUE AND THE CONSEQUENCES THEREOF IN JAPAN

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Administrative background

Interest in the greenhouse issues has seen a soaring increase in Japan the past couple of years. In order to set official guidelines for administrative activities, an Advisory Committee on Climate Change was established in the Environment Agency in May 1988, aiming to organize the scientific information available and to focus the direction of the national policy on this issue. The first interim report was published on November 1988, which established guidelines on the promotion of specific and important research projects as well as on prevention based on the international consensus on the issue. The recommendations in the report were reflected in the Japanese government's action policy for the first meeting of the UNEP/WMO who sponsored the IPCC meeting held in November of the same year.

Japan participates in all three groups of IPCC and has the position of vice-chairman of the second working group which compiles reports on the effects of the global warming on the natural and socio-economical systems. It also takes part as the chairman of the energy and industry subgroup of the third working group which discusses on actions for prevention measures. Recognizing the diversified nature of the issues, the Environmental Agency and the Ministry of International Trade and Industry (MITI) were designated to be responsible for the second working group and the energy and industry subgroup of the third working group of IPCC, respectively, under coordination of the Ministry of Foreign Affairs.

Evaluation of impacts

In the framework of general discussions on the various aspects of impacts of global warming on the natural and socio-economical effects, Japan has been concerned deeply about impacts on sea level rise, climatic change and agriculture. These are discussed specifically.

Sea level rise at the Jomon period (the period of Jomon pottery; Jomon means straw-rope pattern)

In the "Jomon period", about 5,000 to 8,000 years ago, the sea level was 4-5 meters higher than now around Japan. The evidence for this is based on the distribution of shell mounds scattered around in Kanto area(surrounding Tokyo area) along the then existing coastlines. About 12,000 years ago, the ice age was over and ice started to melt rapidly. The melting has finished more than 7,000 years ago, when the Jomon transgression was observed. During a period of 2,000-3,000 years, around 6,000 years ago, the global average temperature that is estimated was 2-4°C higher than at present.

This range of temperature increase is expected to be in the middle of the next century because of the doubling of atmospheric CO_2. Sea level rise, caused by this warming, would have disastrous impacts on Japan. However, the Jomon transgression was not caused simply by a temperature rise of this size. When the ice melted and the sea exerted more pressure, the earth crust had to rise to recover isostasy. Since the earth crust rises slowly, a long time lag occurs between the sea level rise and the land rise, which is the primary cause of the phenomena occurring in the Jomon period.

Climate change in Japan and East Asia

Although it has been well recognized that the spacial resolution of the present numerical models describing the climate system is not good enough to make reliable prediction of quantitative climatic change on a regional scale, qualitative scenarios in Japan and East Asia have been proposed. The MRI(Meteorological Research Institute) model predicts that rainfall decreases around 20-30° northern latitude, and soil moisture decreases accordingly. This is in agreement with results of other models. However, the change in the amount of rainfall around Japan is estimated to be small, since Japan is located around the middle of rain-decreasing mid-latitude and rain-increasing subtropical areas.

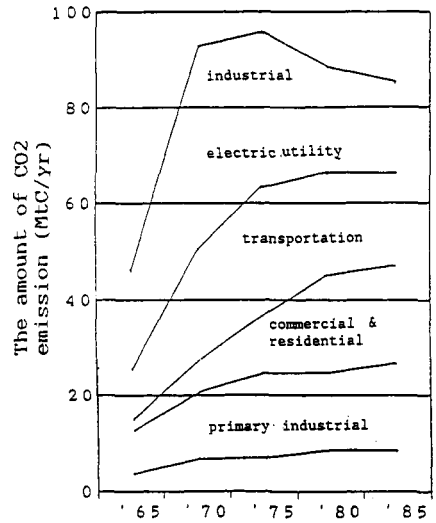

Fig. 1. The annual trend of the CO_2 emission from each energy sector in Japan.

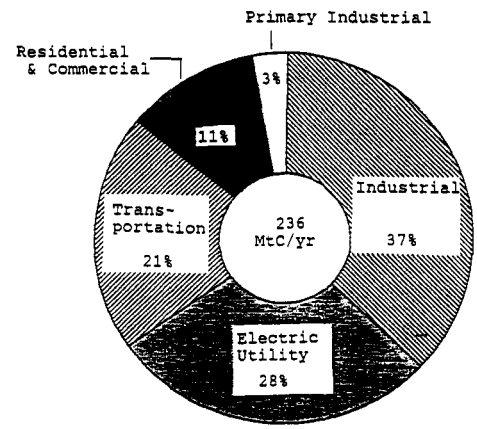

Fig. 2. The emission of CO_2 from each energy sector in Japan in 1985.

According to the model predictions, the monsoon circulation during summer in the tropical area strengthens, whereas monsoons weakens during winter. An important change is that the nature of rainfall becomes a more tropical one, which means that for Japan rainfall will be very unstable. If rainfall becomes torrential as predicted by the models, water does not tend to seep into the soil but flow away, and net water storage in the soil decreases and will lead to less soil moisture.

Effects on agriculture in Japan

The average temperatures in July and August greatly affect flowering, earing and ripening of Japanese paddy rice. According to model predictions regarding the average temperature in July and August, the 25 °C isoline is expected to move from northern Kanto Plain to northern Tohoku region when CO_2 concentration doubles. Also the 30 °C isoline appears in western and southern Kyushyu and part of Shikoku Island. At a temperature over 30 °C Japonica type of rice will likely be affected by high temperature impediment.

Net plant productivity (dry weight/area/year) will increase by about 9% nationwide if the natural vegetation will adapt smoothly and no changes in plant diseases and pests occur as the climate changes.

Emission of greenhouse gases in Japan

CO_2

In 1985 Japan released about 236 10^{12} g C of CO_2, which contributes to about 4.5% of the world total emission. Figure 1 shows the change of the emissions of CO_2 at different sectors of energy consumption during 1965 to 1985. The contributions to CO_2 release from each sector in Japan in 1985 is depicted in Fig. 2, showing that the emission from the industrial sector is highest, than followed by the emission at the electric utility sector. The decreasing trend of CO_2 emission from the industrial sector as shown in Fig. 1 is due to the effect of "energy saving measures" in a broad sense and to leveling-off of the release from the electricity utility sector is mainly due to fuel switching from coal to oil and natural gas.

Methane

Another greenhouse gas, methane, is of considerable concern in Japan. The natural and anthropogenic source strength for methane of Japan has been estimated. Figure 3 illustrates the result of an estimation of methane release from various sources in Japan. As shown in Fig. 3, release from rice paddies and cattle contribute to the highest percentages followed by landfill / reclamation of solid waste. Total release of methane in the country is estimated to be about 0.98 10^{12} g CH_4/yr i.e. about one

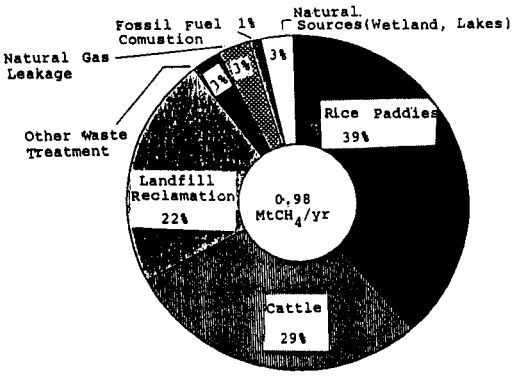

Fig. 3. Emission of methane from various sources in Japan

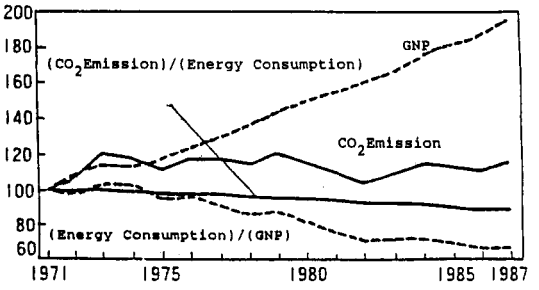

Fig. 4. Annual trend of CO_2 emission, (CO_2 emission)/(Energy Consumption), (Energy Consumption)/(GNP), and GNP in Japan during 1971-1987. Normalized to 1971.

million tons of methane, which is about 0.2% of the global emission of about 500 10^{12} g CH_4/yr including natural sources. If we only take anthropogenic sources, Japanese emission of 0.95 CH_4/yr is about 0.3% of the global emission of about 300 10^{12} g CH_4/yr from human activities.

CO_2 control scenarios and policy options

The following equations often used to evaluate the relationship between the amount of CO_2 released and GNP are:

$$\underline{C} = \underline{X}\ \underline{Y}\ \underline{Z} \qquad (1)$$

$\underline{C}$: Amount of CO_2 emission
$\underline{X}$: (Amount of CO_2 released)/(Energy consumption)
$\underline{Y}$: (Energy consumption)/(GNP)
$\underline{Z}$: GNP

$$d\underline{C}/\underline{C} = d\underline{X}/\underline{X} + d\underline{Y}/\underline{Y} + d\underline{Z}/\underline{Z} \qquad (2)$$

According to these equations, it is clearly to see how much CO_2 emission per energy consumption ($\underline{X}$) and energy efficiency ($\underline{Y}$) should be controlled and improved in order to reduce CO_2 release while keeping the GNP at a certain level. Looking back at Japan's experience after the oil crisis, the GNP was able to grow 4% annually despite the fact that the amount of carbon dioxide emission remained at the same level by the effort of energy saving as illustrated in Fig. 4.

Short-term policy of Environmental Agency consists of efforts to cope with the global warming issues by taking the following actions:

1) Use of more efficient heat insulation and solar heating for residences.
2) Promotion of co-generation, fuel cells and solar PV.
3) Tree-planting in cities to reduce maximum temperature in summer.
4) Recycling of paper and other resources.
S) Recovery and re-use of waste heat.
6) Promotion of small combined electric heat-pump / air-conditioning appliances.
7) Introduction of electric cars.
8) More efficient public transportation and freight train systems.

* The content of this paper is mostly quoted from the following publication. Environment Agency, The Government of Japan: "Impacts and Response Strategies Concerning Climate Changes", Interim Report of Sub-Groups on Impacts and Response Strategies, The Advisory Committee on Climate change, June 1989.

GREENHOUSE EFFECTS/ACTUAL SITUATION AND STRATEGIES OF THE GDR

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Introduction

Up to the peaceful revolution in November 1989 in the former GDR the situation on the field of environmental protection was characterized according to the statement of the old Environ- mental Minister, Dr. Reichelt, before the "Round Table" by the following facts:
- The reports about the environmental situation of the former GDR had the highest level of security after 1982. Only three copies existed for the Prime Minister (W. Stoph), Economy Minister (S. Mittag) and the Security Minister (E. Mielke).
- The ministry of economy had the responsibility for the environmental politics of the former GDR; in this ministry there did not exist a strategy for the environmental protection.

As a result of this situation:
- The administration for environmental protection only had an alibi function.
- Results of measurements were top secret and did not have any consequences for industry and agriculture.
- The ministery of environment repeatedly and purposely issued fase values for international reports.
- The former GDR did not develop any research in the field of ecology.
- Researches in ecotoxicology, hygiene, atmosphere physics etc. did not have any measured values for their work.

On the other hand engaged scientists of the former GDR have worked on the field of environmental protection partly without support of the government and their institutions. I remember papers and discussions about the greenhouse effect of colleagues from the Meteorological Service of the former GDR, from the Institute of Energetics, and from the Heinrich-Hertz Institute. Researchers of the Central Institute of Isotope and Radiation Research, Leipzig, have developed and partly realized a program for measuring of CO_2-concentrations in Zingst (Baltic Sea) and in Antartica (Schirmacher Oase), in which they have determined the isotope ratios $^{12}C/^{13}C/^{14}C$ in CO_2 to get information on the history of the CO_2-concentration in the air under different conditions (no plants and animals, no industries).

CO_2-emission/actual situation of the GDR

In the GDR a special situation exists contrary to other industrial states, characterized by the following facts:
- The lignite production (circa 310 10^{12} g/a) is nearly a third of the world production.
- The electricity production of the GDR (total ca.115.000 GWh) relies almost entirely (ca. 83%) on burning of lignite (nuclear energy ca. 10%, others ca. 7%).
- The average energy consumption per inhabitant (1986: former GDR: 7.944 t per inhabitant, FRG: 5.672 t per inhabitant is in comparison to other industrial countries very large.

The main reason of such a situation is seen above all in the socialist economy politics of autarchy of the GDR after the construction of the wall in 1961. This situation has lead to emissions of ca. 375 10^{12} g CO_2/a, ca. 5 10^{12} g SO_2/a, 2,2 10^{12} g/a dust and ca. 1 10^{12} g NO_x/a. More over the permanent extension of lignite mines has resulted in a reduction of the agricultural area (-5.6% from 1951-1987), connected with additional problems in water economy and recultivation.

As the former GDR also emits additional air pollutions (e.g. H_2S, mercaptanes, halo-carbons, HCl, HF, NH_3, amines, dust etc.) water and soil pollutions from power stations, chemical plants, metallurgy, agriculture, cars etc. large efforts for decreasing of emissions of toxic compounds are necessary in the future. The reduction of the CO_2-emission must be included in such activities.

Basic strategy for decreasing of CO_2-emissions of the GDR

Considering the situation it was necessary to pull the "ecological emergency brake" in the former GDR. To decrease regional environmental burdens the new government has closed several chemical plants, reduced the production or converted the carbon basis from lignite to petrol. Simultaneously a new energetical concept has been developed, which is based on a changing of the structure of the industry with the aim to decrease rapidly the specific energy consumption per inhabitant. The main activities are the following:
- Changing of the production of the former GDR from raw (and so material- and energy-intensive) products to more refined products.
- Introduction of new energy-reduced technologies.
- Improvement of new energy-reduced technologies.

- Improvement of the efficiency of lignit-fired power stations, utilization of the waste heat and coupled heat-power-production.
- Import of natural gas and petrol as fuel and as carbon basis for chemical plants (often less expensive than new investments).
- Finishing of the nuclear power stations under construction, with improved security standards (e.g.: KKW-Nord 8x440 MW, KKW-Stendal 4 x 1000 MW).
- Utilization of alternative energy sources (wind, sun, biogas, geothermal, water etc.).
- New prices for energy, which effect more economy in energy use.

By means of such a concept we hope to reduce the lignite production from circa 310 10^{12} g/a to circa 260 10^{12} g/a in 1992 and to circa 160 10^{12} g/a (minimum 200 10^{12} g/a) in 2000. The average energy consumption per inhabitant is to decrease more than 2%/a. By use of additional waste cleaning devices in lignit-fired power stations and in chemical plants we hope to reduce the emissions in the year 2000 by:

- CO_2 > 20%;
- dust > 60%;
- SO_2 > 85%;
- NO_x > 40%.

New lignite mines are not necessary any more. It will enable forestation -decreasing!) and will improve the water economy. I believe that such a concept is a good contribution of the former GDR to mitigate the Greenhouse effect.

THE POSITION OF TURKEY ON THE GREENHOUSE ISSUE

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Policies to stabilize the concentration of CO_2 in the atmosphere must include a reduction of fossil fuel use, a cessation of deforestation and an expansion in forest areas. Such policies will help to reduce the emission of other greenhouse gasses (CH_4, N_2O and CO) as well. The necessary changes will not be easy. The balance among reductions in fossil fuels, deforestation and reforestation will have to take into account the need for lands and ecosystems other than as defined from the perspective of climatic change (1).

The following studies have been conducted for the purpose of improving the environment in Turkey. The Economic Development Initiative (DPT) which preserves human health and natural balance has been strengthened since 1986. Çevre Kanunu (The Turkish Environmental Protection Act) came into existence in 1983. As a result a regulation has been put into effect which is to preserve the quality of air in 1986. Since 1986, regularly scheduled sulphur dioxide and smoke measurements have been obtained by means of the H_2O_2 method in cities whose populations exceed one hundred thousand. The biggest cities, such as Ankara and Istanbul, have yet to be included in these regulatory activities. The systematic measurement of CO_2 is not started in Turkey yet. The Government has not received any proposed CO_2 measurement projects yet.

Five year development programs which determine the objectives that health and education services should reach in addition to production, investment and energy sectors, have been carried out by the Turkish Government since 1964 with the approval of the Turkish Grand National Assembly. In the VIth five year development program which covers the period between 1990 and 1994, environmental problems are discussed in detail for the first time. In May 1990 it become a legal obligation to transfer or develop relevant technology to reduce environmental pollution, when energy is produced from fossil fuels, or from other resources and when this energy is transformed into another type of energy and transmitted and used (2).

As is the case in other countries of the world the consumption of primary energy and electricity increases in Turkey, where 55.225.000 people live in the Anatolian and Thrace regions that cover 776.000 km². The rate of increase in population is around 2%. In Table I, the consumption of primary energy and gross electricity per person are presented for Turkey and various other countries. In our country, which is in the process of developing authorities are aiming to provide for the ever increasing demand for energy, which is the result of industrialization, by means of clean energy resources. In Table II, the rate of increase in the production of primary energy between the years 1984 and 1989 and the increase rate of the 1990-1994 period are given. The increased consumption of lignite, natural gas and crude oil has had a negative impact on the environment as it has increased the emission of carbon dioxide. On the other hand, the percentage of the increase in the consumption of clean energy types such as hydroelectricity and geothermal

TABLE 1. Amount of consumed electric and primary energy per person

country	amount of consumed amount per person: primary energy (KEP)	electric energy (KWH)
U.S.A.	7475	11130
Japan	6587	5567
W. Germany	3110	6740
France	3574	5817
England	3582	5255
Italy	2454	3665
Spain	1925	3270
Greece	1847	2862
Turkey	845	750
OECD-Europe	3110	4980
OECD-Total	4630	4925

KEP: Kilogram Equivalent Petroleum

TABLE 3. The number of saplings produced in Turkey between the period of 1982-1988 and forested area

years	number of saplings produced (million)	forested area (Ha)
1982	314	
1983	426	131.996
1984	384	160.608
1985	473	192.659
1986	542	208.312
1987	546	233.746
1988	589	249.651

TABLE 2. Progress in the production of primary energy in Turkey

	annual production of 1989	rate of increase (%) between 1984-1989	projected rate of increase (%) between 1989-1994
Coal (1)	3500	-0.7	5.2
Lignite (1)	42.150	9.9	9.8
Crude Oil (1)	3076	8.1	1.3
Natural Gas (2)	100	20.1	24.6
Hydro Power (3)	24.200	12.5	7.3
Geothermal Energy (3)	40	12.7	8.4
Wood (1) (A)	17.167	-0.7	-1.4
Residues of Animals and Crops (A)	11.300	-5.2	-0.8
Energy-not for commerical purposes	7.750	-2.0	-1.2
Grand total (4)	29.003	4.8	5.2

A : approximately
(1) : thousand ton
(2) : million m^3
(3) : Gwh
(4) : thousand TEP (ton equivalent petroleum)

energy in the five year period of 1984-1989 has not increased to a desirable level. Moreover, Turkey, which is between the 36°-42° north latitudes, has the probability of getting the approximate annual amount of 1500 kwh/m^2 of solar energy. While the amount of solar energy produced was 1.1 T.E.C. (ton equivalent hard coal) in 1983, this amount reached 3.3 T.E.C. in 1989; solar boilers are only for hot water production.

Forest areas occupy 25.9% of Turkey's total area, being 11.4% fruitful forest area and 14.5% unfruitful forest area. To consume carbon dioxide, which causes the greenhouse effect, by means of photosynthesis, initiatives have been started in recent years to form green lines around big cities and new forest areas. The Third week of March is celebrated as a Tree Festival in Turkey. Local forest authorities give saplings to citizens and to schools so that they may be planted.

In Table III the number of saplings produced to be planted and the areas of forestration in each year between the period of 1982-1988 are given. The total area of forestration was 1.198.681 (Ha) in 1957 and between the years 1958-1982 1.035.770 (Ha) area was forestrated. In the last five years, an area of 1.176.972 (Ha), which is equal to 1/3 (one-third) of the area in which trees have been planted for 31 years, has been covered by the saplings. According to the inventory data of forestration, the potential area of Turkey's forestration is 5.412.155 hectars. To cover this area with trees, it will be necessary to plant trees to cover 300.000 hectars per year (3).

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NATIONAL AND REGIONAL RECOGNITION OF THE GREENHOUSE ISSUE AND THE CONSEQUENCES THEREOF IN CHINA

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Introduction

For a long period, environmental attention has only focussed at the severe local and regional pollutions in China, not addresssing sufficiently to global environmental problems. In recent years the international attention on global problems and increased scientific knowledge on the greenhouse issue have caused the Chinese public and government to show much concern for this problem. A high tide of interest in the greenhouse issue is rapidly on the rise in China.

Since July 1985, The Institute of Atmospheric Physics, Academia Senica, has started the monitoring of several greenhouse gases, CO_2, CH_4, CFC-11, CFC-12 in a remote site in the province of Ganshu (Table 1). The emission of CH_4 from the rice paddies in Guan County of the Sicuan province and Hongzhou the city of the Zejian province has been measured in the recent two years. The Academy of Meteorological Sciences has monitored CH_4 tropospheric concentration in the different geographical and ecological sites, and the CH_4 flux in clean air (Table 2). The Peking University and Research Academy of Environmental Sciences are conducting measurements of CH_4 emission and CH_4 concentrations in the Beijing area as well. A continental baseline station in a remote area for measurement of all greenhouse gases is planned to be built in the province of Qinghai, supported by WMO.

Since 1988 the State Science and Technology Committee has paid more attention to the greenhouse issue. A Blue Book of Climate has been edited. It deals with the historical, current and future climate change in China and, in particular, with the impacts of greenhouse gases on climate and sea level change in China.

The GFDL, GISS, NCAR and OSU models of the United States and theUKMO model of the United Kingdom have been used for prediction of the temperature changes in different areas of

TABLE 1. Trace gas levels in Minging Station, Ganshu Province (1985-1987)

Gas	Unit	Average level (1987)	Increase rate % per year	Global average	Increase rate % per year
CO_2	ppmV	3.56	0.3	354	0.45
CH_4	ppmV	1.76	1.7	1.72	0.9
CFC11	pptV	263	5.0	280	4
CFC12	pptV	429	2.3	484	4

TABLE 2. Tropospheric concentration of CH_4 in China

Site	Latitude	Longitude	Elevation	Site type	Sampling time	Mean C_4 Conc. (ppbV)
Chanbai Mount	42°01'(N)	128°05'	2623.9	volcanic Mountain	1988.7	1813.1 8.2
Wutal Mount.	39°02'(N)	113°32'	2895.8	arid Mountain	1988.7	1754.6 1.9
Basha Grasslands	41°12'	116°32'	659.7	Grassland	1988.5	1916.9 ± 19.8
Shandlanzi background	40°31'	117°07'	260.0	hills	1988.9	1884.9 ± 49.3
Gucheng station	38°51'	115°34'	17.2	hills	1988.9	2142.5 ± 245.8
Suburb Beijing	39°48'	116°23'	31.5	plan	1988.6-10	1923.3 ± 70.4

TABLE 3. Energy consumption in China

Year	Total energy consumption, 10^{12} g	Composition %			
		coal	oil	gas	hydroelectricity
1980	602.75	71.81	21.05	3.14	4.00
1982	626.45	73.91	18.74	2.53	4.82
1984	709.04	75.27	17.45	2.37	4.91
1986	808.88	76.03	17.03	2.26	4.65

China assuming a CO_2 concentration increase of 100%. The prediction results show that the climate change caused by doubling CO_2 will benefit the north-eastern area, and will have a negative impact on the central and northern area. A new GCM model is being developed by Chinese scientists.

CO_2 emission in China

China has the 3rd largest energy infrastructure in the world, following the USA and the USSR. The country is also the world's largest consumer of coal (Table 3). The production output of coal passed 1 10^{15} g C in 1989. In 1988, 76.1% of the nation's energy depended upon coal. This high level of coal consumption is not expected to change significantly in the future.

The main source of CO_2 emission in China is coal burning. The Blue Book gives a very rough estimate of CO_2 emission of whole China, 480 10^{12} g C from coal burning and 510 10^{12} g C from fossil fuel burning. Recent estimates show that the total CO_2 emission in 1985 is 370 10^{12} g C, which contributes to about 7.1% of the world total emission, corresponding to 0.34 ton C per caput.

Policy options for reducing CO_2 emission

Promotion of energy efficiency and conservation

Energy is used very inefficiently in this country. The overall energy utilization efficiency amounts to less than 30% (comparable to the developed countries in the 1950's). If the energy efficiency in China could be brought up to that of developed countries today, ca. 40% of its coal consumption - roughly 400 10^{12} g of coal per year - could be saved. On a per unit basis, Chinese industries consume twice as much energy as Indian industries and several times as much as industries of developed countries like U.S.A., Japan and France. The energy efficiency in the residential sector is even lower. Energy production and in particular coal mining itself are plagued by similar problems. The primary prediction shows that the energy consumption could be reduced by 30% in 2000, if major actions are taken, such as district heating, use of combined cycle co-generation units, etc.

Improvement of the energy structure

China has a big potential in developing hydroelectricity. If the total amount of hydroelectric power and nuclear electric power is increased from 5% of 1985 to 8% in 2000, CO_2 emissions will be reduced in a range of 20 10^{12} g C.

Strengthening reforestation and tree-planting

The forest coverage in China has increased remarkably since 1949. Although during 1981-1988 the forest coverage contineously increased with 0.9% per year, the actual stockpile of forest decreased 308 MM^3, equivalent to 1.5 times of the annual growth amount. Notably, most of this decrease happened in mature trees. It was caused by irrational and indiscriminate felling of trees and forest fire. A preliminary estimate shows that this kind of deforestation contributes to about 40% of the total greenhouse effect in China.

Development of new substituted energy, such as solar, wind and hydrogen energy.

Use of high quality fuels, such as natural gas or petroleum products, yielding considerably lower levels of CO_2 emission.

China is planning to reduce its dependence on coal from 76% currently to 70% in 2000 and 50-60% in 2030 in order to reduce CO_2 emission to a large extent.

CO_2 EMISSIONS FROM BRAZIL: ASSESSMENT OF UNCERTAINTIES, NATIONAL RECOGNITION AND CONSEQUENCES THEREOF

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Estimates of Brazilian CO_2 emissions from fossil fuel burning and cement manufacturing in 1986 were 52.5×10^{12} g C/yr (ref. 1), corresponding to $0.38\ 10^{6}$ g C per capita. This represents 0.94% of the world's equivalent emissions and 4.53% of the emissions of the USA of 1982 (ref. 1), and in per capita terms 33.5% of the world's per capita emissions and 7.6% of the USA's per capita emissions. Our estimates for Brazilian emissions in 1990 are 57.0×10^{6} tons C/yr which corresponds to $0.39\ 10^{6}$ g C per capita, representing a slight increase in terms of world's emissions in the last four years. However, Brazilian CO_2 emissions from fossil fuels raised 315% from 1960 to 1986, in an average rate of 13.7% per year as compared to world's average rate of 4.3% per year in the same period of time (ref. 1).

The CO_2 emissions of Brazil since 1950 for the different sources, are shown in Figure 1. The main cause of the CO_2 emission increase during this period is the combustion of liquid fractions of petroleum. It can be seen that the first oil crisis, in 1973, did not affect Brazilian oil consumption, but as a consequence of the second oil crisis in 1978, the CO_2 emissions decreased, picking up again in 1985, as oil prices decreased.

The annual trend of CO_2 against the gross internal product, GIP, and the primary energy consumption can be seen in Figure 2. Carbon dioxide emissions correlate very well from 1970 until the second oil crisis. This deviates from developments in the industrialized countries, where the gross national product, GNP, increases much faster than the CO_2 emissions. Until 1978, Brazil had not taken any measures to conserve energy or to increase the efficiency of its use; after 1978 the industrial processes and automobile engines have been improved. More detailed analysis of the curve is not possible, since the data from United Nations 1986 World Energy Data Base (ref. 1) do not coincide with data from IBGE (Brazilian lnstitute of Geography and Statistics) (ref.2). For instance, for 1970, lBGE reports that 43% of the total primary energy consumption was due to use of wood, but the data of Figure 1 indicates that only 11% is due to solid fuel. The energy consumption (Figure 2) continued to increase during the Brazilian recession of the beginning of the eighties, due to the expansion of hydroelectric services to the rural areas and to the exodus of countryside people to urban areas, increasing hydroelectric power consumption in the large cities and not contributing to the GIP. In 1970 hydro-electrical energy represented 16% of the total energy consumption of this country (ref. 2.). In 1987, this percentage increased to 30%.

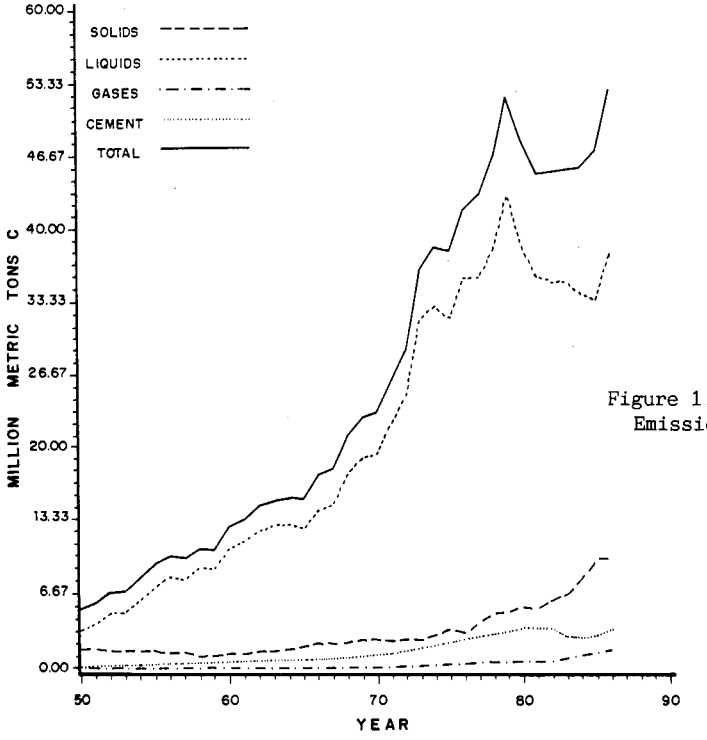

Figure 1. Annual trend of Carbon Dioxide Emissions in Brazil, 1950-1987. (Ref. 1.)

TABLE 1. Number of constructions of hydroelectric, thermoelectric and nuclear power stations being postponed by the 1990-1999 plan.

Number of years of postponement	Power station		
	Hydroelectric	Thermoelectric	Nuclear
< 0	2	3	0
1	8	8	0
2	11	1	0
3	17	1	2
4	14	0	0
≥ 5	35	0	0
Total number of stations to be built	87	13	2
Variable power of stations, MW	19 - 6000	50 - 315	1300

(from ref. 3 - under license)

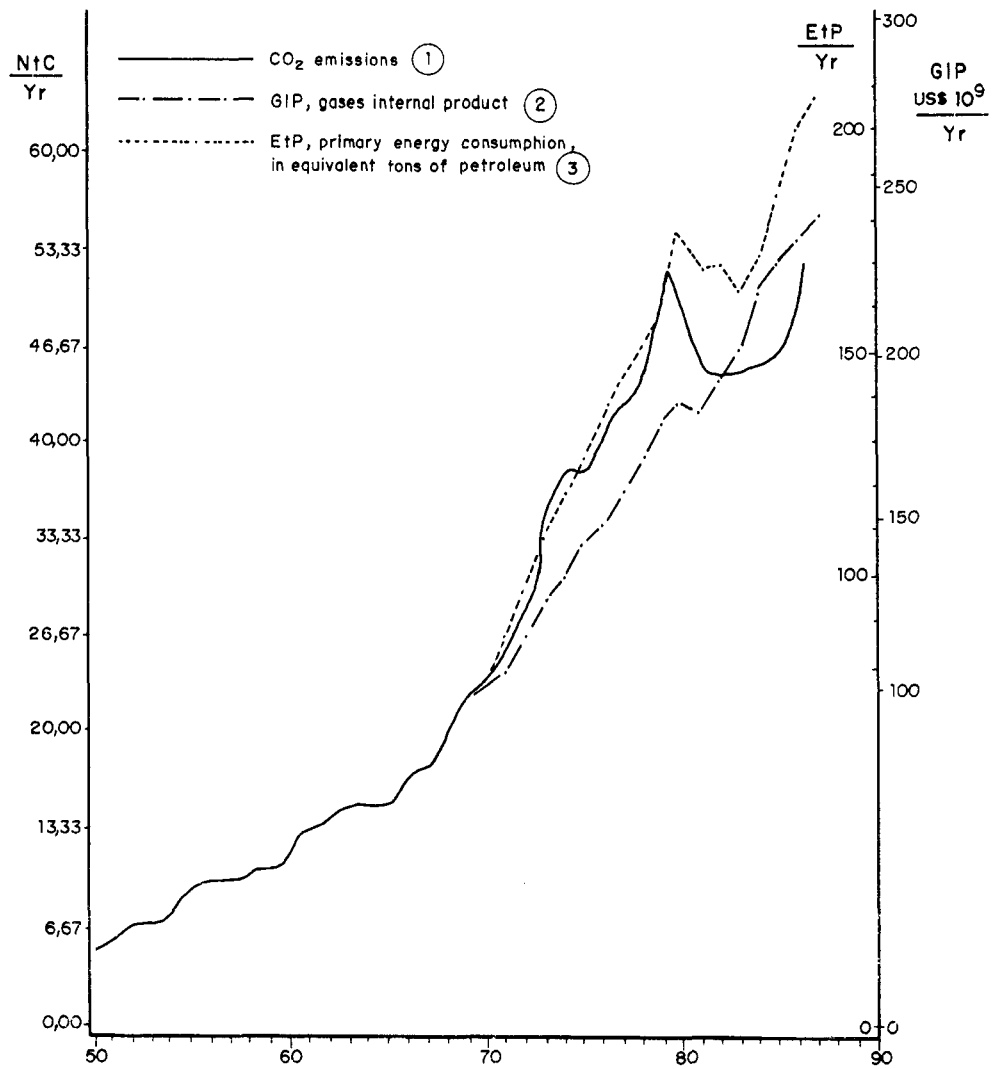

FIGURE 2 : Annual trend of CO_2 emission, GIP and EtP in Brazil in the last duades normalized to 1970.

(1) from reference 1

(2) from reference 2, corrected for Brazilian inflation to 1980 calculated into US dollars by the average of the monthly averages of the exchange rates of 1980.

(3) from reference 2

The low Brazilian CO_2 emissions from fossil fuel combustion per capita are due to: 1) Hydroelectric power (85% in 1984 and 94.3% in 1989 (ref.3)) predominating over thermoelectric power (15% in 1984 and 5.7% in 1989) (ref. 3). If all electric power would be produced by fuel oil there would be an increase in fossil fuel consumption of 70%: 2) Use of ethanol from sugar cane as vehicle fuel. Carbon recycling of the ethanol prevents an additional 12.5% of present carbon emissions from liquid fossil fuels to be released (13×10^6 m^3/yr of ethanol are used in automobiles, substituting the combustion of 10.8×10^6 m^3/yr of gasoline); 3) Low energy per capita consumption due to low socio-economic level of 70% of the population. (However, this favourable situation has little perspective to continue as discussed below.)

Most of the low cost hydroelectric power is already being utilized, and expansion of its use will involve high investments and high ecological costs. Production and distribution of electric power for general consumption has been a monopoly of the government in the last few years. However, because of insufficient state funds to meet the growing electricity demand of the country, combined with the recent tendency of privatization of the Brazilian society, private enterprise is allowed to produce and to sell energy for public consumption through the state controlled distribution system. As a consequence, the completion of several of the already initiated state owned hydroelectric power stations has been postponed and permission has been given for the construction of private thermoelectric stations, using coal and oil. These stations demand much lower investments than hydroelectric stations: Construction of 19 small and large hydroelectric power stations has been postponed 2-3 years, 49 of 4, 5 or even of a greater number of years. 3 New thermoelectric plants, financed by foreign investments, have been included in the Government Plan (ref. 4) (Table 1). Assuming an average power of 150 MW for each of the thermoelectric stations, operating 24 hr during the entire year, the production of the three private plants being presently built will be 450 MWh. For thermoelectric operated on oil, approximately 5.4 MWh corresponds to the release of 1 ton C to the atmosphere, whereas around 23% higher carbon release is expected from the production of the same energy from coal. Circa 0.73×10^{12} g C/yr will be released to the atmosphere from the three thermoelectric stations being built, if operated on oil, and 3.2×10^{12} g C/yr when all planned thermoelectric stations are in operation, which represents 1.3% and 5.6% increase, respectively, of Brazilian (ref. 3) emissions from fossil fuel burning.

In Brazil, alcohol is used as a fuel either in the hydrated form (92- 94% ethanol) in motors with compression rates of 12:1 or in a 22 ± 1.0 % mixture with gasoline, in normal car motors, with compression rates of 8.8:1, substituting tetraethyl lead. Around 4 million cars (approxmately 1.5% of the world's total number of cars) run on ethanol presently in Brazil. The percentage of alcohol-driven cars from the total sale of cars (ref. 5), starting in 1979, is displayed in Figure 3. Alcohol is energetically viable, due to the re-utilization of the sugar cane bagasse in the destillary itself or in other

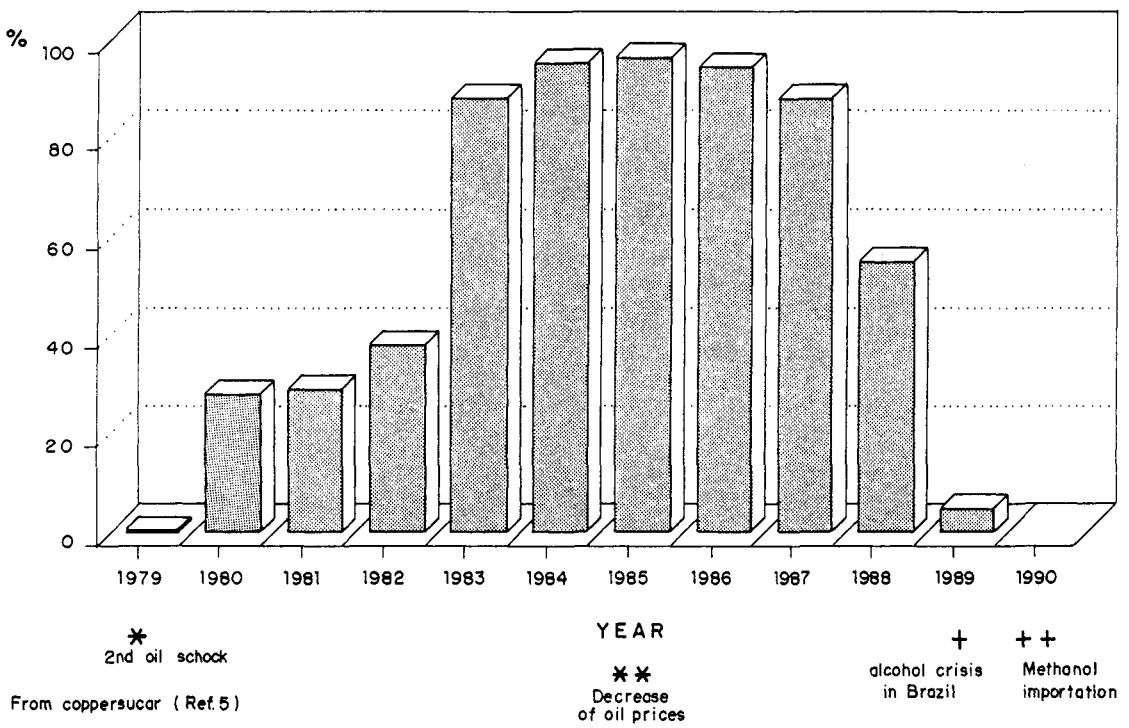

Figure 3. Percentages of alcohol vehicles in the total sale of cars.

industries for energy production. This differs from the alcohol produced from corn in other countries, particularly the USA. One ton of sugar cane produces an average of 75 L of ethanol and 125 kg of total bagasse (dry basis). The heat capacity of the bagasse (normal 50% humidity) is 3,470 kcal/kg dry bagasse. Therefore each ton of sugar cane produces 216,875 kcal/ton of sugar cane in the form of bagasse (ref. 6). The heat capacity of ethanol is 5,280 kcal/L. Therefore, each ton of sugar cane produces 396.000 kcal/ton of ethanol. The estimated energy spent in the production and transportation of sugar cane for a typical situation like the one of Sao Paulo (80 ton/ha yr), expressed as liters of diesel (1 L = 8,400 kcal) (for fertilizers, herbicides, soil preparation, harvesting and transportation) is 6.721.000 kcal/ha yr. This is equivalent to 800 L of oil/ha yr, or 10.0 L oil/ton sugar cane produced, which equals 84,000 kcal/ton of sugar cane. When the mill is fairly good designed and operated, 2/3 of the bagasse is used in the mill itself and 1/3 is used elsewhere. In this situation, the energetic balance is as such (ref. 6):

1 ton sugar cane = 75 L ethanol + 125 kg bagasse

Energy from bagasse used by mill: $\frac{2}{3}$ x 125 x 3,470 = 289,166 kcal/ton sugar cane

Energy from bagasse left over: $\frac{1}{3}$ x 125 x 3,470 = 144,583 kcal/ton sugar cane

Net energy left over from bagasse: 144,583 - 84,000 = 60,583 kcal/ ton sugar cane

Total energy produced (ethanol + net from bagasse):
396,000 kcal/ton sugar cane + 60,583 kcal/ton = 456,583 kcal/ton sugar cane

This is equivalent to 54 L diesel/ton sugar cane.

With better design and operation, around 50% reduction of the use of bagasse could be reached and, therefore, 528,875 kcal/ton sugar cane can be produced. This is equivalent to 63 L diesel/ton sugar cane.

However, during 1989, the Brazilian ethanol fuel production was insufficient because of unfavourable cost, when compared to the low world price of oil and to the more attractive world price of sugar. As a consequence of this alcohol crisis, only 5% of the cars produced during the first semester of 1990 ran on alcohol. Natural gas derived methanol had to be imported and mixed with ethanol and gasoline, to account for the shortage of over 1 billion liters of ethanol (ref. 7). The world prices of oil and sugar cane products and eventually the effects of alcohol use will define the new Government policy of Brazil in continuing the alcohol-fuel program.

At a short term, no increase in the socio-economic level of the Brazilian population belonging to the lower class is expected. However, the energy consumption per capita, as well as the total consumption tend to increase. Distribution of electricity is being expanded to rural areas, where ancient agricultural techniques are being replaced on a large scale by modern mechanized techniques. During the last two decades, there has been a significant transfer of population from rural unelectrified areas to cities, which increases the energy consumption per person. On a total basis, during the last 20 years, the country experienced a rapid industrial and populational growth. The industrial expansion followed the increase in GIP (Figure 2). The population growth reached a peak of 2.9% per year during the sixties and seventies (ref. 8). Figure 4 shows the curves of birth and mortality rates of the Brazilian population. Until 1870 both rates were high, and population increase was mainly due to immigration, which declined after 1930. During the end of the XIXth century, mortality started to reduce, due to improvements in basic sanitary conditions. This reduction was even higher after 1940, with the introduction of sulphamides and antibiotics, and the introduction of DDT and other pesticides which reduced the insect transmited illnesses, such as malaria. The decrease of death rate rather than increase of birth rate was responsible for the highest rates of population growth in Brazil. After 1970, the birth rate began to decrease rapidly in all regions and social classes of the country. The total fertility rate (number of children per 50 year old woman) was reduced to 19% from 1980 to 1984, which leads to a prediction of a total reduction of 47% from 1980 to 1990. This implies an annual growth of 2.4 million people to the present population of 150 million (ref. 8). The decrease of Brazilian population fertility is not a result of governmental action, but rather of the private medical or individual intiative to make use of the modern services, infrastructure and new technologies of birth control (ref. 8). According to tendencies of the curves (Figure 4) and other more recent data, the present rate of population growth should be 1.8%, with projections for reduction to 1.4% by the year 2000 and stabilization at 0.9% by 2020. The last census of Brazil took place in 1981 and the next one will be in 1991. However, the Brazilian Institute of Geography and Statistics, IBGE, fears that higher fertility rates will be encountered, contrary to former expectations. These expectations are based on preliminary data from prefectures of municipalities in rural areas (ref. 9).

Estimates of Brazilian's net CO_2 emissions from tropical deforestation vary broadly, mainly because of uncertanties on the C uptake from recovering forests, grasslands and

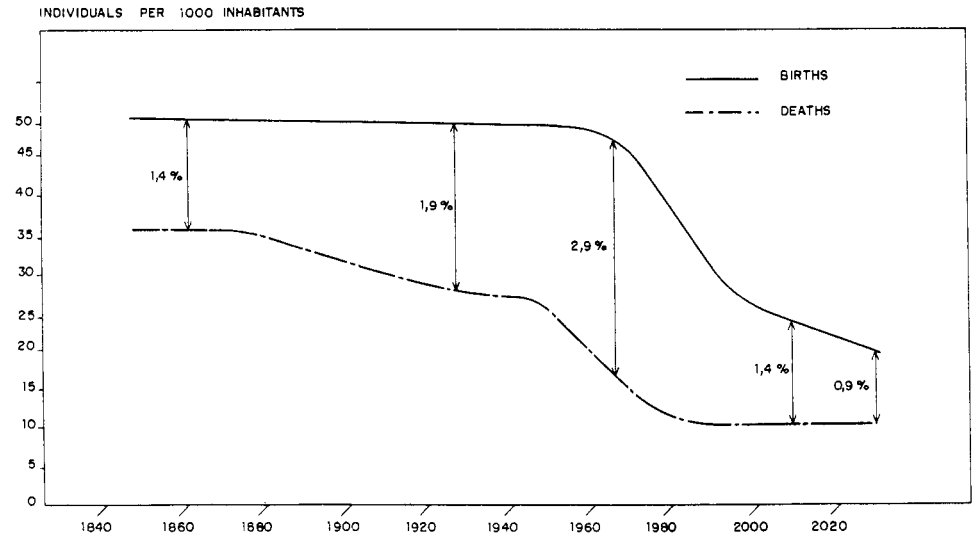

Figure 4. Brazilian demographic transition (ref. 5).

soil, and also because of uncertanties in the estimates of annual deforestation and corresponding forest density and on the fraction of unburnt phytomass and inorganic carbon which is left over in the soil and uncertainties in the depletion of soil organic carbon and retention in the forest water bodies. For 1987 it has been estimated that 336 x 10^{12} gs C/yr were emitted by Brazil's deforestation (6.5 times the C emissions from fossil fuel burning and cement production), compared to a world's total of 1,659 x 10^{12} g C/yr from this acitivity (ref. 10). Deforestation is believed to have been even more extensive in 1988. In 1989, the Brazilian Government claimed that just 5% of the Brazilian part of the Amazon forest had been deforested against the until now more widely accepted figure of 12%. An extensive area of the Amazon region has been deforested for gold mining purposes. The Federal Government estimates it to be 3.2 x 10^6 ha. Until now a figure of 16.7 x 10^6 ha was assumed, which would account for 4.8% of the Amazon region forest (ref. 11).

Brazilian leading societies and politicians are rapidly becoming aware of global environmental effects, such as 'greenhouse effect', and its relation to deforestation and forest burning, as well as to its potential consequences. There is, however, a nation wide feeling that the developed countries have already destructed their own forests in the past and are presently responsible for the greater part of the carbon emissions. Brazilians argue that part of the Amazon forest itself has been destroyed by foreign enterprises, especially those of the USA, Japan and Germany. They are also aware that various other trace gases contribute to the global warming significantly, and that Brazil's emissions of these gases, from antropogenic source, are of minor importance. It has also been pointed out the past and present exportation of latent heat from the Amazon forest to colder regions (ref. 12) estimated in one billion megawatts/hr, which corresponds, on oil price basis, to US$ 17 trillions/yr at oil prices of 1989. This represents 58 times the present Brazilian PIB. A tax has been suggested as a compensation for the economical profits of temperate countries from the preservation of this forest, independent from the greenhouse effect issue (ref. 13).

Brazil is pressed by the increase of its population and has an urgent need for development, which will cause a substantial increase in energy demand and use of natural resources. In addition Brazil's foreign debt amounts to more than US$ 120 billions. Constraints on usage of natural resources because of global environmental effects will hardly be accepted by the politicians and the population.

The environmental policy of the Brazilian Government has shifted from a purely nationalist policy of the 70's, in which we considered our environment our own business, to the current position of the new president, who took office in March 1990, in which debate on the environment issue is considered necessary.

The former Brazilian Government has been heavily pressed by the developed countries to preserve its nature. International financial institutions have decided that any loan for development should take into account ecological consequences. As a result, Brazilian Government announced, in April 1989, an ambitious new environmental program ('Our Nature') which, among other things, called for:

1. Zoning the Amazon region for agriculture, mining and other uses, preserving a substantial amount of forest;

2. Interrupting, temporarely, raw timber exports and tax incentives which made it profitable for cattle ranchers to clear great forest areas;
3. Regulating the production and sale of toxic chemicals used in mining and agriculture.

Supervision of conformation to environmental legislation is the greater challenge for government action, because of restricted technical resources.

The new Brazilian Government is taking further measures regarding environmental protection:

1. Mr. José Lutzemberger, a veteran ecologist, holder of the Alternative Nobel Price (1988) and strong defender of preservation of the Amazon, has been appointed to become head of the new Brazilian Environment office which is directly linked to the president's office.

2. All tax incentives for farming were eliminated;

3. Detection of Amazon forest burning is being carried out by INPE, Sao Paulo, through satelite. On detection, immediately warning is given to IBAMA, who takes action by imposing fines (a total of US$ 15 million of fines were given during April, 1990);

4. Concrete actions are being taken against prospecting for gold in areas reserved for Brazilian indians.

Presently, the clearance and burning of the Amazon forest has been slowed down significantly.

A new program of reforestation, FLORAM (ref. 14), defended internationally by the present Government, proposes a worldwide reforestation programme to absorb 115×10^{12} g C in 30 years, which would reduce today's atmospheric carbon concentration from 356 ppm to the pre-industrial concentration of 292 ppm if all other fluxes of CO_2, CO_2 emissions and CO_2 sinks, were balanced. Which would means that most of the fossil fuel emissions have to be cut off.
Brazil would be responsible for 4.3% of this reforestation, through international funding, by reforestating 20.15×10^6 ha/yr, 671.5×10^3 ha/yr during 30 years and by recovering, through enrichment, 15×10^6 ha of the Amazon forest and 30×10^6 ha in northeast of Brazil. Estimated potential productivity for reforested areas is 7.74 tons C/ha yr and for recovered areas is 1.32 tons C/ha yr, including leaves and branches which, in average, accounts for 1/3 of forest phytomass. Predictions are made considering forest periodic cutting and industrialization of forest production, but no specifications of products are given, assuming its use will result in no phytomass decomposition. FLORAM recognizes that the aim of such a programme is to gain 20 to 30 years time to develop and implement massive use of clean energy sources, such as nuclear fusion, solar energy, hydrogen, etc., and that it will be meaningless if deforestation/forest burning and fossil fuel burning are not sharply slowed down.

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