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# Global warming — facts, assessment, countermeasures

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**Abstract**

Global primary energy consumption amounts to 8.38 billion tonnes oil equivalent (OE) (1996) and is projected to increase by 1.3% per year for the industrialized countries and by up to 9.2% per year for the developing countries. Fossil energy's share was 7.541 billion tonnes OE in 1996 with rising tendency. The order of magnitude of proved reserves of fossil energy sources is 950 billion tonnes OE (1996), and certain present probable and possible reserves will become proved ones in the years to come. Fossil energy will, therefore, remain the number one energy source until far into the next century. The use of fossil energy produced 23.8 billion tonnes of carbon dioxide ($CO_2$) in 1996 with oil and gas contributing about 60% to this figure. It is estimated that continued use of fossil energy will lead to an increase of the average global temperature by 1.0–3.5°C in the coming 50–100 years. Though the forecasts of future $CO_2$-emissions from fossil energy use as well as the magnitude of their influence on global warming are much disputed, the impact of $CO_2$-emissions on global warming itself is widely admitted. There is much dissense on the climatic consequences of global warming. It cannot be ruled out, however, that these consequences may be detrimental to mankind. This has in a sense of a "no regret policy" triggered substantial activity worldwide to decrease emission of greenhouse gases, especially of $CO_2$, and various attempts have been made to set binding limits for the emission of these gases. The harmonized worldwide implementation of $CO_2$-reduction strategies is, however, far from being realized. OECD-countries have made substantial progress in applying these strategies. Nevertheless, the contribution of the industrialized countries to worldwide $CO_2$-emissions is still over-proportionally large. The cost of developing and applying $CO_2$-reduction technologies are tremendous and prohibitive for most of the emerging economies. There is an obligation of the industrialized countries in their own interest to develop and make available these technologies wherever they are needed. The cost/efficiency ratio of $CO_2$-reduction measures must be a decisive criterion for their application. There are serious obstacles, though, to reducing $CO_2$-emissions while satisfying the energy needs of our world, e.g. lacking international harmonization, national needs and egoisms, rapid growth of world population and strongly increasing energy demand of emerging economies. In summing up, though an anthropogenic contribution to global warming cannot be proved for the time being, it cannot be ruled out forever. Therefore, internationally harmonized measures for $CO_2$-reduction have to be taken in the sense of a "no regret policy" to avert potential damage from mankind and, thus, contribute in this sense to a sustainable development with fossil energy. 

*Keywords:* global warming; greenhouse effect; $CO_2$-emissions; global temperatures; climate models; fossil energy

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## 1. Introduction

Fossil energy sources today contribute 90% to worldwide primary energy consumption with oil and natural gas being the dominant sources with more than 60%. It is inevitable that using these resources affects our environment in many ways, some being only short-term events, others however of long-term importance.

In this article, the most persistent problem of fossil energy use, the generation of carbon dioxide as inevitable end product of all energetic use of oil, natural gas, and coal, is discussed.

The anthropogenic $CO_2$ is supposed to be responsible for the warming of the earth's atmosphere by the so-called greenhouse effect. It is feared that this warming might lead to a non-sustainable development of the earth. The existence of the greenhouse effect was first postulated by ARRHENIUS in 1896. According to his hypothesis, specific gases in the atmosphere of the earth, in the first place water vapor, but also carbon dioxide, methane, di-nitrogen oxide, ozone, and halogenated hydrocarbons, permit the transmission of the sun's radiation (short wavelengths) but not that of the long wavelength infrared radiation reflected by the surface of the earth. Without this naturally occurring effect, the average temperature of the earth's surface would be −18°C as compared to its real value of 15°C. This natural greenhouse effect is beneficial, since it forms the basis for the great variety of plant and animal life on earth. Where it is too strong or too weak, life cannot exist. Examples exist in our planetary system: The Martian atmosphere contains too little carbon dioxide which results in a temperature of about −60°C. The atmosphere of the Venus contains too much carbon dioxide contributing to a temperature of about +430°C!

Besides these naturally produced greenhouse gases, there are so-called anthropogenic gases generated by human activities, in the first place carbon dioxide, but also methane and other gases. The emission of these gases by industry, traffic, power plants, home heating, and burning of tropical forests creates the so-called anthropogenic greenhouse effect.

It is generally accepted that an increasing atmospheric concentration of these anthropogenic gases will lead to an increase of the global temperature. There are, however, widely differing opinions on the magnitude of this increase and on its impact on the global climate. There is growing concern that the anthropogenic greenhouse effect — if it indeed does exist — might lead to a non-sustainable development of the earth's climate with negative consequences for mankind. Fig. 1 shows the contributions of the above mentioned greenhouse gases to the natural and the anthropogenic greenhouse effect according to the view of some Austrian scientists. The

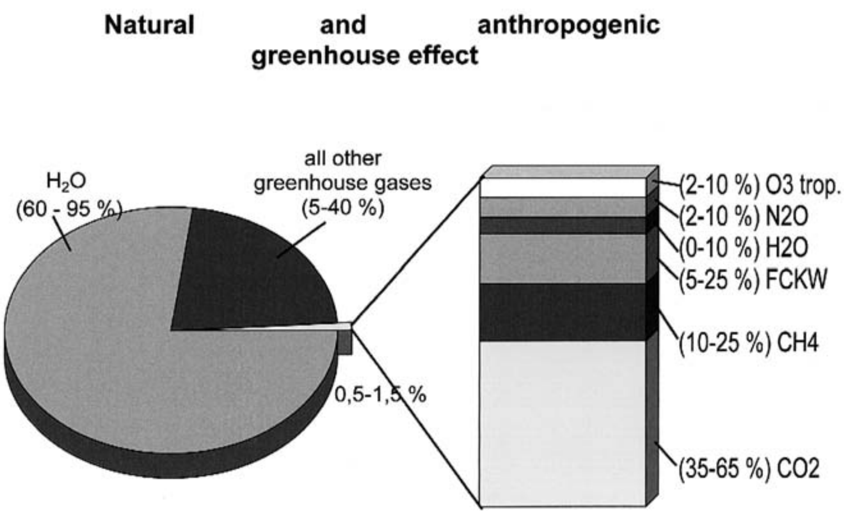


Fig. 1. Contribution of different gases to greenhouse effect.

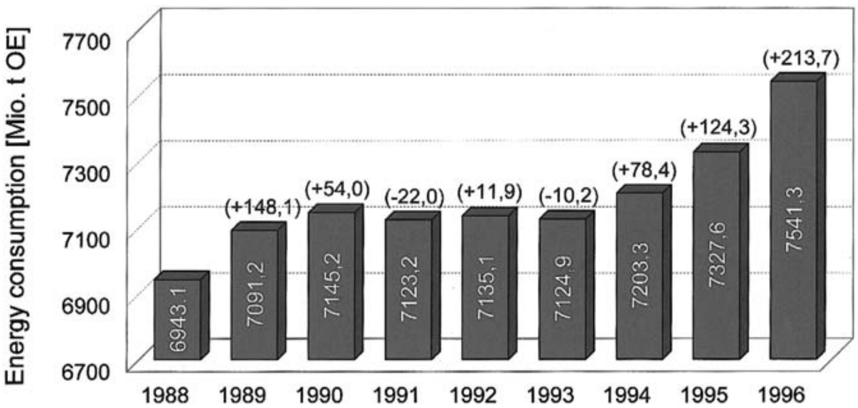


Fig. 2. World fossil energy consumption 1988–1996 (yearly increase/decrease).

large bandwidths indicate the substantial uncertainties involved.

This article will not and cannot give an undisputed answer to whether or not the continued use of fossil energy as the main contribution to the anthropogenic greenhouse effect will lead to a non-sustainable development.

It will, however, critically assess the presently existing knowledge on whether or not an anthropogenic influence on the global temperature can be proved and discuss the consequences which have to be drawn from this situation together with the problems to be solved.

## 2. Present situation, forecasts, trends

Fig. 2 displays the development of the global primary energy consumption from 1988 to 1996. It shows a generally increasing trend, which is only temporarily interrupted by the economic change in Eastern Europe (BP Statistical Review of World Energy, 1997).

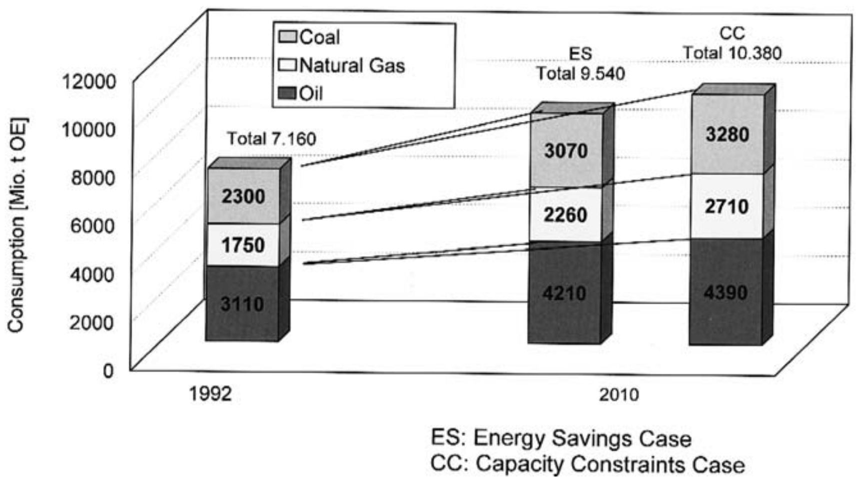


Fig. 3. Increase of world fossil energy consumption 1992–2010.

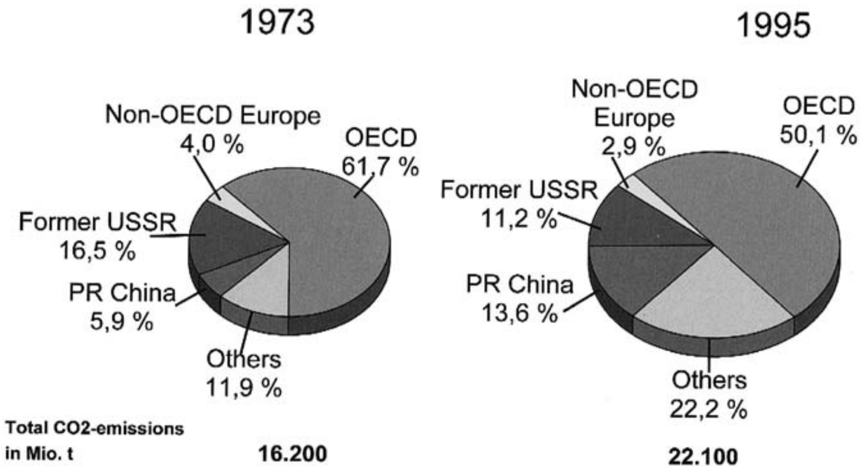


Fig. 4. Contribution of worldwide $CO_2$-emissions from fossil fuels by region for the years 1973 and 1995 (IEA, 1995).

Fig. 3 shows an IEA-forecast of the global fossil energy consumption for the period 1992 to 2010 (IEA, 1995–1997; Ziesing, 1995). As can be seen, there is an increase by 33–45% depending on the scenario. Consumption on the non-OECD world will increase at about four times (4.1%/a) the rate of the OECD-countries (1.1%/a). Yet OECD-countries will still consume 47% of primary energy as compared to 55% in 1996!

Figs. 4 and 5 show the development of the $CO_2$-emissions from using fossil energy for the time span 1973 to 1995 for different regions and for the different fossil energy sources, respectively. Though the OECD-countries have decreased their share by more than 11%, they are still contributing one half of the global emissions. The strongly increasing contribution of the Asian region, especially of China, and the substantial decrease of the share of Russia linked to the economic transition from the Soviet Union to present day Russia are interesting to note.

Fig. 6 gives a forecast of the global $CO_2$-emissions for the period 1992–2010. In agreement with

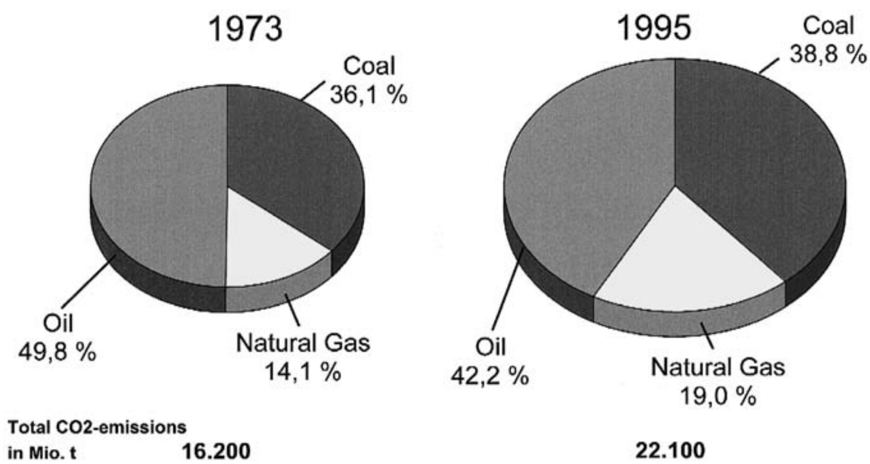


Fig. 5. Contribution to worldwide $CO_2$-emissions by fuel for the years 1973 and 1995 (IEA, 1995).

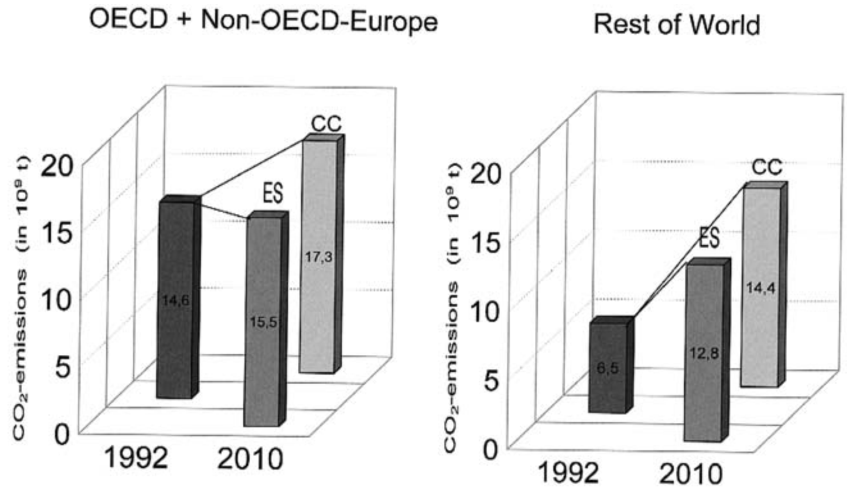


Fig. 6. Predicted increase of anthropogenic $CO_2$-emissions from 1992 to 2010 (IEA, 1995).

the rapid increase of primary energy consumption in the non-OECD world, the increase of $CO_2$-emissions is strongest in this region, though it is still small by absolute figures. This is underscored by Fig. 7 (per capita increase/decrease of $CO_2$-emissions).

It is predicted that the $CO_2$-concentration of the atmosphere will increase from its present value of about 350 ppmv to 600–900 ppmv by the year 2050.

These figures form the basis for our subsequent discussion. Apart from the uncertainties of every forecast, this basis is reliable. In directing our discussion towards the assessment of the anthropogenic greenhouse effect, we are confronted with three complexes of important questions:

1. What is the data basis we have at hand for detecting changes in the global temperature, and how reliable is it?
2. How does an increase of $CO_2$-concentration in the atmosphere influence the average global temperature in the complex coupled system atmosphere–hydrosphere–pedosphere and how can it be separated from non-greenhouse gas-related influences

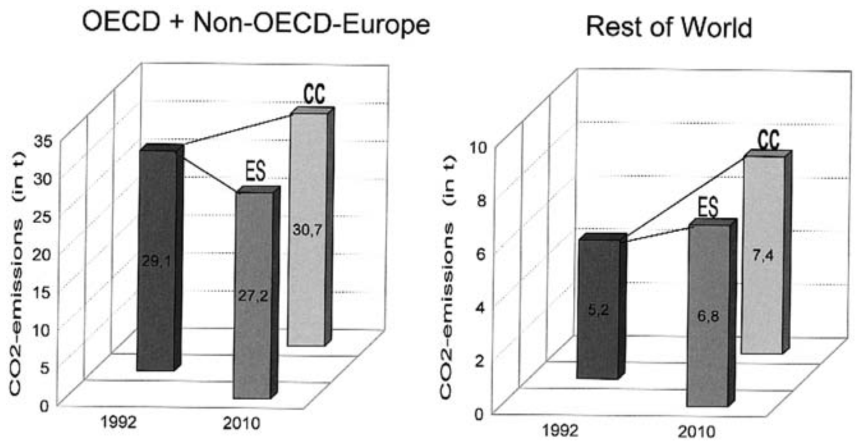


Fig. 7. Predicted increase of per capita anthropogenic $CO_2$-emissions from 1992 to 2010 (IEA, 1995).

on that temperature (e.g. solar activity, changes of the inclination of the earth's axis)?

3. What is the sensitivity of the global climate with respect to increasing atmospheric concentrations of greenhouse gases? Or, in other terms, what is the inertia of the system atmosphere–hydrosphere–pedosphere with respect to changes of the atmospheric concentration of greenhouse gases?

## 3. Data basis for global temperatures

There are basically three methods for measuring temperatures at or close to the surface of the earth:

–thermometer measurements on the earth's surface
–radiosonde measurements
–satellite measurements.

The latter two measure the temperature in the troposphere/stratosphere.

Systematic thermometer and radiosonde measurements have only existed in the last several decades. Thermometer measurements are made mainly onshore; seaborne measurements apart from being difficult to make are performed mainly along the large shipping lanes and leave large and possibly important parts of the oceans out of consideration. Altogether, geographic coverage of thermometer measurements is rather sparse (worldwide 1400 measurement stations, practically all onshore), and the results are often biased by the effect of nearby heat sources like cities or airports. Considerable effort has been spent to make adjustments to the observed values, but the adjustments often were of the same order of magnitude as the suspected trend of temperature variation. Therefore, the reliability of these temperature records has to be assessed critically (Christy, 1997).

Satellite measurements are truly global ones. In contrast to the ground-based temperature readings, they are measuring the average temperature of the troposphere which should be especially affected by warming as a consequence of increasing greenhouse gases. Unfortunately, these measurements only exist for the past 20 years.

The Intergovernmental Panel on Climate Change (IPCC) surface temperature history reveals for the last 100 years a temperature rise of about 0.7°C. At least half of this warming occurred pre-1940, i.e. at a time, when anthropogenic greenhouse effect was at best negligible. This leaves about 0.3°C for a suspected anthropogenic greenhouse effect. And even this may be too much, since it is known that the end of the nineteenth century as a reference basis was an especially cool time so that any warming trend thereafter would be untypically high.

All in all, the reliable record of global temperature and its variations is of very short duration. Considering the fact that the natural short to long-term variations of the global temperature generated e.g. by solar activity or volcanos and other so far unknown reasons it is evident that temperature rises attributed to the anthropogenic greenhouse effect are hardly statistically significant.

## 4. Climate models, climate predictions, and their assessment

Powerful climate models compute the complete three-dimensional circulation of the coupled system of oceans and the atmosphere. A typical model subdivides ocean and atmosphere in a multitude of discrete layers (from the sea bottom to the upper boundary of the atmosphere). Each layer consists of a two-dimensional lattice of thousands of points. The model solves the coupled equations for the transport of heat, momentum, atmospheric humidity and ocean salinity for this three-dimensional system. A typical grid resolution is $500 \times 500$ km. Physical processes active on a smaller scale cannot be resolved; they are parameterized, that means averaged over one grid cell. It is obvious that for a global computation incorporating all the relevant physical processes like natural variability, variations (anthropogenic too!) of the concentration of greenhouse gases in the atmosphere and their vertical distribution, effect of clouds, of aerosols, ocean currents, salinity variations in the oceans, sea ice etc. with sufficient resolution leads to excessive computing time even for the fastest existing supercomputers.

There are more drawbacks with the application of existing climate models (Cubasch et al., 1995;

Michaels, 1997; Kellow, 1997; Kerr, 1997; Michaels and Knappenberger, 1996; Santer et al., 1996; Calder, 1997; Pearce, 1997):

*Instability of coupled ocean / atmosphere models.* Even if an ocean or atmosphere climate model can simulate for itself the present climate, this does not mean that the same good results are obtained, if both are coupled together. Experience shows that interactively coupling both models together in general leads to a phenomenon called "climate drift". This means that such a coupled model develops over time from a realistic climate state to a new, unrealistic one. To overcome this problem, so-called flux adjustments are applied, correcting the fluxes e.g. of heat or fresh water from the atmosphere into the ocean and vice versa. These flux corrections are frequently as large as the fluxes themselves and can, therefore, be considered as genuine manipulation quantities. As climate modeller, you have, therefore, the choice between using flux corrections to properly history-match the present climate, or doing without flux corrections with the consequence of working with an unrealistic climate state. In more drastic terms, you have the choice between pestilence and cholera!

*Feedback problems.* A climate model which simulates the present climate sufficiently well can predict the development of the climate over extended future time periods only, if it quantitatively takes care of and incorporates the climate changes occurring during these time periods, e.g. cloud/radiation feedback effects, interactive biosphere, ground hydrology, aerosols, interactive carbon cycle. An issue which is discussed controversially is the positive feedback of water vapor to the atmosphere triggered by anthropogenic greenhouse gas-induced warming. This effect would greatly reinforce global warming. Each of these feedback effects must be calculated in a separate model, which would blow up the computing capacity of any institution.

*Sensitivity against initial conditions.* Climate models normally start with the greenhouse gas concentration of today. But even today, informations on the temperature or salinity distribution of the oceans are sparse, let alone for time periods long ago. Monte Carlo simulations have, however, shown that the results of climate models critically depend on the initial conditions of the physical parameters involved.

*Future concentrations of greenhouse gases.* Predictions of future development of atmospheric greenhouse gas concentrations are uncertain. This is not only true for the emissions, but also for our knowledge of the global carbon cycle which determines how the greenhouse gases are exchanged and distributed between ocean and atmosphere.

*The "Cold Start Problem".* Most present coupled ocean/atmosphere climate models assume that ocean and atmosphere are in equilibrium with the present concentration of greenhouse gases. Neglecting the historical development of the greenhouse gas concentration means that any previous warming due to those gases is left unconsidered. It is estimated that this error can amount to about 0.4°C within 50 years.

*Coupling between the earth's surface and the mid-troposphere.* From the early 1960s to the late 1970s, the free troposphere was warming strongly, while the surface was slightly cooling. After this, things changed completely: the surface was warming strongly, whilst the temperature of the troposphere from 1.5 km upwards remained more or less stable. This indicates that the coupling between surface and mid-troposphere is not as close as assumed in climate modeling.

The predictions on global warming based on climate models reflect the development of these models since 1988. Their still immature state as well as the insufficient understanding of many physical and chemical processes which determine the climate and its change are evident (Fig. 8).

In 1988, indications on global warming appeared to take more and more shape. As a consequence of this, the above mentioned IPCC was instituted, consisting of 170 specialists. The objective of this panel was to scientificly investigate the suspected effect of global warming. The first IPCC report was issued in 1992. Based on the increase of carbon dioxide concentration from 270 ppmv in 1870 to 350 ppmv today, it suspected a human influence on the global climate. Starting from here and based on assumed emission scenarios, the very immature climate models of that time predicted a warming of up to 8°C until the year 2100. As climate models became more and more refined, the predictions were corrected down to a warming of up to 6°C (Rio Conference) and then to 1.0–3.5°C with an average of 2°C in the IPCC report of 1996; this corresponds to a warming

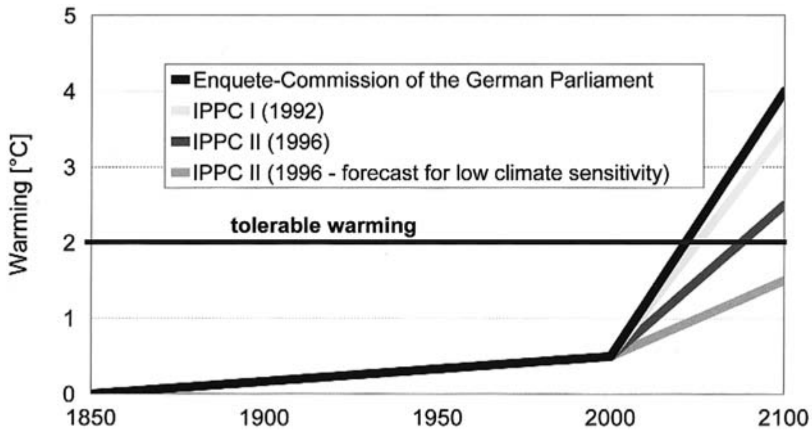


Fig. 8. Different forecasts for climate change.

rate of 0.1 to 0.3°C per decade (Fakten und Argumente, 1997). In the light of the above mentioned facts, even these predictions are based on statistically not significant data and very coarse climate models and are, therefore, of qualitative rather than quantitative character. They are by no means a justification for panic reactions, for penalizing energy taxes or overly stringent legislation.

Coming back to the second question asked further above, it has to be stated that neither the existing data base nor the capabilities of present climate models allow to separate the influence of natural effects like variations of the inclination of the earth's axis, solar activity or natural aerosols from a suspected anthropogenic warming of the atmosphere. A firm trend of an anthropogenic greenhouse effect is, therefore, not established for the time being.

Some remarks have to be made with respect to the third question on the sensitivity of the earth's climate on an increase of the temperature of the atmosphere. The apparent lack of dramatic and damaging global warming despite an increase of atmospheric $CO_2$ from 270 to 350 ppmv in the last 100 years indicates clearly that the sensitivity of the climate is less than assumed by many people or that the climate reacts in a very inert way on changes in the $CO_2$-concentration. Especially the oceans are retarding climate changes. By this inert reaction of the oceans, climate changes which occurred centuries ago are still influencing our present climate. It is, however, also true that climate changes occurring today will influence the climate of the future.

The climate of the earth has never been static. There have been times when the atmospheric $CO_2$-concentration was much higher than it is today. Climate is continuously assaulted by many disturbances and has to react and has reacted through hundreds of millions of years. Under the influence of these disturbances, it has assumed a specific state at any time without having an alternative. With this in mind, the demands of Article 2 of the Rio Convention on Climate Change do not make any sense as general statements, but only when they are focused on safeguarding the well-being of mankind (food production, sustainable economic development). "Damaging" global warming has to be understood in this sense. It is also only in this sense that the limit for a "sustainable" warming of 0.1–0.2°C per decade as propagated by climatologists has to be understood.

## 5. Countermeasures against damaging global warming

The discussion of the previous sections showed that based on the global temperature record of the last hundred years and considering the still immature state of available climate models, the existence of an anthropogenic greenhouse effect cannot be proved

unambiguously and quantitatively for the time being. This does not mean, however, that it does not exist. Even if we cannot detect a significant trend of anthropogenic global warming now, it is probable that it will become visible someday if we are going on with business as usual. After all, a qualitative correlation between $CO_2$-content and temperature of the atmosphere does exist. With a problem of such importance for mankind, it appears prudent to take precautionary measures now in the sense of a "no regret policy".

The climate conferences of Toronto (1988), Rio de Janeiro (1992), Berlin (1995) have undertaken to design and install such measures by setting binding limits for $CO_2$-emissions. So far, these attempts have been more or less unsuccessful.

There are several reasons, as follows, for this lack of success.

(1) The Rio Convention did not properly consider the individual needs and interests of the different nations. Asking for a uniform $CO_2$-reduction commitment for all nations in an extremely heterogeneous world, where the industrialized countries with about one fifth of the global population produce more than 70% of the global $CO_2$-emissions cannot be considered reasonable and cannot work. This problem is illustrated in Table 1.

(2) The final protocol of the Kyoto conference 1997 (Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1997) is an improvement as compared to Rio and a step in the right direction in that it sets different binding $CO_2$-emission levels for different countries. However, the emission share of the industrialized countries is still very high and hardly acceptable for the emerging economies. The possibility to trade emission certificates gives the rich countries an unfair advantage over the poor ones and tempts them to go on with business as usual. The option to trade $CO_2$-emissions against reforestation efforts is equally problematic, since reforestation is not possible everywhere in the world and its effect on the atmospheric $CO_2$-concentration is very unclear. On the other hand, the emission limits of the Kyoto protocol appear to be too massive to be realized without damaging the economies of the industrialized countries. It has, therefore, to be expected that the $CO_2$-emissions regulations negotiated in Kyoto will turn out to be not as binding as anticipated and hoped.

(3) In the light of the discussion of Sections 3 and 4 and from a point of view of a "no regret policy", the planned $CO_2$-emission reduction measures appear to be exaggerated. This lowers the motivation of countries to strictly apply them.

So, what has to be done in this situation?

In the first place, the data base for the climate models has to be improved, especially as far as the oceans are concerned. Our understanding of the physical and chemical processes of atmosphere/hydrosphere/pedosphere interaction, of cloud generation, of the impact of clouds on ground temperatures, and the surface/troposphere coupling to name a few, has to be enhanced. With this enhanced understanding, climate models have to be further improved to obtain more reliable climate predictions. The time lag between increase of atmospheric $CO_2$-concentration and its impact on the climate has to be thoroughly determined.

On this rational basis, in a second step, $CO_2$-emission reduction measures have to be designed which are commensurate with the observed trends as well as with predictions from improved climate models. Horror scenarios are unjustified and should be discarded. Exaggerated reactions like energy- or $CO_2$-taxes should be avoided, since they damage economies more than a tolerable increase in atmospheric $CO_2$-concentration!

Table 1
The global "dirty dozen"

| Carbon dioxide emissions 1995 | | |
|---|---|---|
| Country | Total emissions in million tonnes | Per capita emissions in tonnes |
| USA | 5475 | 20.52 |
| VR China | 3196 | 2.68 |
| Russia | 1820 | 12.26 |
| Japan | 1126 | 9.03 |
| India | 910 | 0.9 |
| Germany | 833 | 10.24 |
| Great Britain | 539 | 9.29 |
| Ukraine | 437 | 8.48 |
| Canada | 433 | 14.83 |
| Italy | 411 | 7.19 |
| South Korea | 370 | 8.33 |
| Mexico | 359 | 3.93 |

Source: Oak Ridge National Lab.

In the third place, the international harmonization of these measures should be achieved in a way acceptable to a clear majority of nations. This is the most formidable task, since it has to consider the present situation as well as the most likely future developments; it has to take care of individual national needs and interests as well as the capabilities of various countries to develop and implement $CO_2$-reduction technologies. It has to consider not only ecological aspects but also economic consequences. Joint implementation is an important element in this task, since it makes sure that those countries which are in a state to develop efficient $CO_2$-reduction technologies make these available tocountries where a maximum $CO_2$-reduction can be achieved at minimum cost.

Inside these general objectives, what are the strategies for reducing anthropogenic $CO_2$-emissions?

1. *Avoid* $CO_2$-emitting processes where possible
2. *Improve* energy efficiency (combined cycle generation, isolation of buildings, vehicles)
3. *Replace* $CO_2$-intensive processes by less $CO_2$-emitting ones (e.g. replacing coal by gas)
4. *Substitute* $CO_2$-emitting processes by $CO_2$-"free" ones (renewable energy, nuclear energy,fuel cells).

## 6. What has been achieved until now?

There is no doubt that awareness of the need to preserve our environment has grown worldwide during the last decades, though in many parts of the world this awareness is hidden behind more urgent needs to be satisfied.

In the industralized countries $CO_2$-emissions are growing slower than energy consumption mainly because of replacing fossil energy by nuclear and renewable energy and by replacing coal by natural gas. Overall, energy efficiency of industrial production has been enhanced. As an example, the share of German industry in German energy consumption has dropped from about 50% in the 1950s to about 27% at present.

The big industries, especially in most of the OECD-countries, have made substantial progress in applying $CO_2$-reduction and other environment protection measures. Opposite to public opinion, the oil industry is in the forefront of these efforts as shown by the following examples.

– The European refining industry has, according to CONCAWE, improved its energy efficiency since 1980 by more than 20%. For this reason, it could stabilize its own fuel consumption at a level of 6% of the crude oil throughput, though in this time, additional energy was needed to (1) increase its conversion capacity, (2) produce octane and MTBE for replacing lead, and (3) reduce the sulphur content of diesel and gas oil.

– By applying enhanced drilling technology and using advanced materials, sea water contamination by offshore drilling has been reduced drastically, in the North Sea, e.g. by 75% since drilling activities started there. Drilling muds today are mostly biodegradable. Oil-based muds are practically not used in offshore operations any more.

– Offshore oil spills originating from transport of oil have been reduced to less than 0.003% of the worldwide oil consumption. This can locally still lead to severe damages, but the achievement has to be acknowledged.

– Emissions of sulphur dioxide, sulphur content of mineral oil products, and oil content of refinery waste waters were drastically reduced.

– Oil companies like Shell and BP are heavily investing in solar energy.

– Environmentally enhanced petroleum products were developed (Booth et al., 1997).

These examples show that the oil industry undertakes substantial efforts to protect the environment as effectively as possible. It is important to state that most of these efforts are done on a voluntary basis. This is the most effective and most economic way of protecting the environment, especially if it is accompanied by an independent, thorough monitoring process and supported by, e.g. tax incentives. It is in any case more effective and by far more economic than stringent and inflexible penalizing legal measures, which by the way normally have a very bad cost/efficiency ratio and are often problematic to enforce.

There is still a great potential for reducing $CO_2$-emissions, especially in the following areas

– households (better insulation, more efficient heating or air conditioning installations)

– traffic (further improvement of mileage by better fuels and motor technology, alternative propulsion concepts (fuel cells), improvement of public traffic, homogenization of traffic fluxes by intelligent traffic control).

Apart from this, ongoing efforts to increase the share of economic renewable energy must be intensified, though figures like those recently predicted by the Shell Transport and Trading Co. (50% share by the year 2050) appear overly optimistic.

## 7. Problems with $CO_2$-reduction measures

There are serious obstacles, though, to reduce or even stabilize global $CO_2$-emissions:

– Too slow progress of international harmonization of $CO_2$-reduction measures, extreme heterogeneity of nations, national egoisms
– Rapid growth of world population
– Strongly increasing energy demand of emerging economies
– Still too high $CO_2$-emissions of industrialized countries
– Insufficient development state of joint implementation measures.

The basic reason for these obstacles is evident from Fig. 7. If mankind turns out to be unable to solve these problems, the so far undetectable anthropogenic greenhouse effect may become very real, and it might then be too late for a "no regret policy".

## 8. Summary and conclusions

– Global consumption of fossil energy (oil, natural gas, coal) is predicted to increase by 33–45% from 1990–2010.

– Global anthropogenic $CO_2$-emissions are predicted to rise by 34–46% from 1990–2010 if the present trends are extrapolated.

– An established and generally accepted quantitative relationship between rising atmospheric $CO_2$-concentration and global warming does not exist at present, mainly because of

- an insufficient data basis
- lacking understanding of important physical processes of the atmosphere/hydrosphere/pedoshere interaction
- the immature state of climate models.

– A statistically significant global warming trend as a consequence of anthropogenic $CO_2$-emissions cannot be unambiguously detected for the time being.

– Nevertheless, on the basis of the existing qualitative correlation between atmospheric $CO_2$-content and global temperature, the predicted substantial increase of anthropogenic $CO_2$-emissions requires appropriate precautionary reduction measures in a sense of a "no regret strategy".

– However, the drastic demand to stabilize $CO_2$-emissions on the 1990-level until 2008–2012 is not supported by any significant evidence of anthropogenic atmospheric warming at present. To achieve this stabilization, OECD- and Non-OECD-European countries would have to reduce their $CO_2$-emissions by 44–47% until 2010, if $CO_2$-emissions in the other countries develop according to the IEA-forecast (IEA World Energy Outlook 1995). This appears to be too massive a reduction to be achieved without doing harm to national economies.

– As in the past years, $CO_2$-reduction measures should be developed and implemented on a voluntary basis and supported by governments, e.g. through tax incentives. Industrialized countries have a special responsibility in this respect.

– *International harmonization* of $CO_2$-reduction efforts is of utmost importance. It requires establishing a fair system to distribute these efforts according to the specific conditions and capabilities of the individual countries. Joint implementation is an especially recommendable tool in this context.

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