Nuclear power and its role in limiting emissions of carbon dioxide

Studies show that the use of nuclear energy is helping countries avoid emissions of CO_2 from electricity production

by
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and
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Roughly 80% of carbon dioxide — one of the most important gases linked to what is known as the "greenhouse effect" — originates from energy production and use. This atmospheric trace gas today accounts for more than 60% of the greenhouse perturbation.

The need to limit emissions of carbon dioxide (CO_2) from the production of energy and other industrial activities has commanded more international attention in recent years. So, too, has the potential role of nuclear power — which is free of CO_2 emissions — for electricity generation, a growing component of energy production systems worldwide. Nuclear power is one of the energy sources that has contributed substantially, and could contribute even more in the future, to the lowering of greenhouse gas emissions into the atmosphere.

In June 1992, the United Nations Conference on Environment and Development (UNCED), popularly called the "Earth Summit", was held in Rio de Janeiro, Brazil. It is considered by many to be one of the major international meetings of the century. Agenda 21, one of the main outputs of the meeting's action programmes, contains a strategy which links environment and development to improve the endangered sustainability of the Earth and its inhabitants. As a follow-up to the Stockholm 1972 Conference on the Environment, though in a new era of changed threats and opportunities, emphasis at the Earth Summit was on a new, strongly emerging, environmental subject, namely climate change. Of the two topics in this problem field — stratospheric ozone depletion and the greenhouse effect — the latter one has the strongest relationship with a basic need of humanity: energy.

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It is remarkable, however, how little attention was given to nuclear energy in most of the UNCED documents. For example, Agenda 21 does not include nuclear energy in its definition of "environmentally safe and sound and cost-effective energy systems, particularly new and renewable ones" from which an increased contribution is desired. *Our Common Future*, the report of the UN World Commission on Environment and Development to the Earth Summit, was rather critical about nuclear energy and largely underlies Agenda 21.

More recently, however, a publication issued by the environmentally conscious Club of Rome took a more positive view. Called the *Second Report to the Club of Rome*, it considers nuclear energy to be an indispensable part of a greenhouse-benign energy policy. The United Nations Framework Convention on Climate Change (FCCC) — the Earth Summit's document on climate change that was unanimously adopted and has been signed by 154 countries — is neutral about the various energy sources. The FCCC is becoming a widely accepted basis for national energy strategies, i.e. to stabilize "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." As a consequence, lowering the rate of greenhouse gas emissions has become a dominant factor in energy planning, alongside existing factors such as cost-effectiveness and security of supply.

Nowadays environmental and climate change policies are affecting energy production in many parts of the world. The IAEA's programme on comparative assessment of nuclear and other energy sources aims at providing tools and data for a comprehensive and fair comparison in the context of energy planning. It is very difficult, if not impossible, to express all environmental impacts from the different energy sources in common units. This article, therefore, limits itself to the greenhouse effect. In this context, it addresses the role which nuclear power has played in lowering CO_2 emissions compared to other energy sources, as well as the future needs of low-CO_2 emitting energy sources.

The message from the past

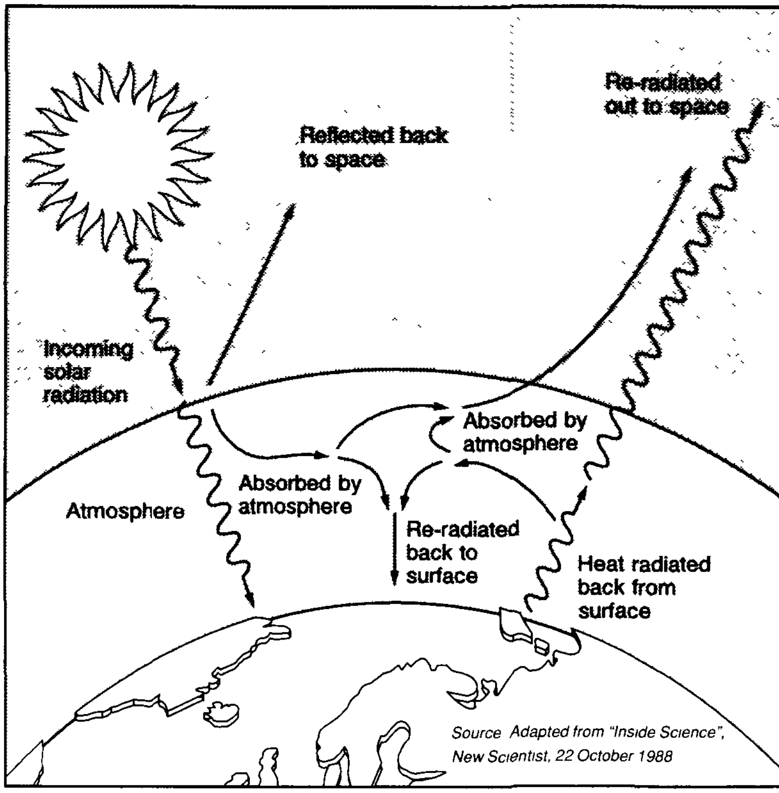
Atmospheric levels of CO_2 are increasing at a rate of about 0.4% per year. This increase is mainly due to the use of fossil energy, with associated global CO_2 emissions now estimated at about 24 000 megatonnes per year. The annual increase from the energy sector is rather constant at about 250 megatonnes CO_2 per year, mainly due to the increasing energy use by developing countries. Industrialized countries and those "in transition" have stabilized their emission rates since the mid-1970s.

Understanding this stabilization of the CO_2 emission rate could help to develop an energy strategy that is more benign to the environment. For this, a closer look at *per capita* CO_2 emissions might be useful. Such an analysis eliminates the population factor (the population growth of developing countries dominates the world population growth).

With the exception of countries in the Organization for Economic Co-operation and Development (OECD), where there was a slight decrease after 1973, *per capita* CO_2 emissions have had a general tendency to increase. *(See graphs, following pages.)* In the former Soviet Union, the increase after 1980 is rather small. Among developing countries, *per capita* CO_2 emissions show a steady increase at a rate of about 3.5% per year. Remarkable is the one order of magnitude difference in *per capita* CO_2 emissions between the industrialized and developing countries, which reflects the different standards of living and lifestyles.

We speculate that the stabilization of the *per capita* CO_2 emissions in industrialized countries is due to the penetration of energy sources having low or zero CO_2 emissions. One indication of this is the strongly increased share of electricity in energy production in industrialized countries since the mid-1970s, and the associated penetration of nuclear power in a number of countries.

However, further insight can be obtained from trends of the CO_2 emission factor. This is defined as the amount of CO_2 emitted per exajoule (EJ, or 10^{18} joule), a factor that can be compared for the different fossil fuels. For a specific country or region, the emission factor is a technological indicator of its greenhouse benignancy.



Source Adapted from "Inside Science", New Scientist, 22 October 1988

The greenhouse effect

The atmosphere functions like the glass in a greenhouse, protecting the Earth from cooling to levels far below the freezing point. However, the atmospheric levels of greenhouse gases have been increasing worldwide for more than a century. These increased greenhouse gas levels disturb the Earth's balance of incoming solar radiation and outgoing heat.

The radiative forcing of the atmosphere by anthropogenic greenhouse gases would not be dramatic if there were not an important feedback enhancement. This feedback is caused by the Earth's natural and most important greenhouse gas, namely water vapour. The humidity of the air increases when the atmosphere heats up, thereby further increasing the radiative forcing.

This process is considered to be a serious threat to humanity and to the environment, not only because of the resulting "global warming" (which some expect to be even beneficial). It additionally could lead to increased frequencies and severeness of floods, droughts, and hurricanes, which are threats more common to our daily experience and understanding. Of late, interest has been growing within the scientific community of the World Climate Programme in these extreme weather events. Altogether, most experts consider that there is sufficient reason to lower greenhouse gas emissions, in particular those from energy sources.

The need for a bundle of measures. What measures should be considered to avoid further perturbation of the greenhouse and stop the future anthropogenic climate change? An interesting study by Bert Bolin, the chairman of IPCC from its first days, answers this question. In his address in May 1989 to the IPCC Working Group III on Response Strategies, Bolin has shown that only a bundle of the strongest measures is effective in avoiding at least the greatest part of the two degrees global warming predicted for 2030.

Bolin's study reveals that, in order to avoid this two degrees of warming, one needs a complete ban of chlorofluorocarbons (CFCs) in 2000, to reforest at least half the land areas deforested since 1900, to lower the rate of fossil fuel use by 0.5% per year, and to improve the efficiency of energy end-uses significantly.

Generally, global and regional CO_2 emission factors show a continuous, relatively stable decrease. Developing countries have the lowest annual rate of decrease (-0.24 megatonnes of CO_2 per EJ), and the former Soviet bloc the highest (-0.43 megatonnes). For the world as a whole, and for OECD countries, the values are -0.29 and -0.33, respectively. These rather stable trends of worldwide improvement of energy systems with respect to their greenhouse benignancy are encouraging.

To illustrate the role of shifts in the mix of fossil fuels used in energy production, a specific CO_2 emission factor was defined as the amount of CO_2 emitted per EJ of fossil fuel used. Until the oil crisis of 1973, this specific emission factor was improving worldwide and in industrialized and developing countries alike. However, after 1973, this emission factor hardly changed at all, except for a slight decrease after 1985.

One reason why is that the year 1973 marked the end of a period of oil substitution for coal, which is more CO_2 intensive. Thereafter, there was no substantial change in the fossil fuel mix. The continued decrease of the average CO_2 emission factor has been due to other causes. After 1973, nuclear power, and to a lesser extent, hydropower, took over the role of improving the global average CO_2 emission factor. The avoidance of CO_2 emissions by the use of nuclear power increased from about 1% in 1973 to almost 7% in 1990, while that by hydropower grew from 6.5% to 8%. It is not surprising that countries with an extensive nuclear programme show strongly improved CO_2 emission factors, i.e. greenhouse-benign energy policies. Countries which implemented extensive nuclear programmes in the period 1965 to 1990 — such as Belgium, France, and Sweden — improved significantly the greenhouse benignancy of their energy strategies. They did so by reducing their CO_2 emission factors by about one or more megatonnes per EJ per year.

During the past decades the average CO_2 emission factors for the world and for the United States remained in the range of that of oil, namely 75 megatonnes of CO_2 per EJ. This further illustrates the beneficial role of nuclear power in lowering CO_2 emissions of countries like Sweden and France since the onset of their nuclear programmes in the mid-1970s. It also shows the important role of hydropower in Sweden and Norway. Furthermore, the data show the relative stability of the CO_2 emission factors in countries with large domestic energy resources such as China (coal), USA (coal and oil), and Norway (hydropower). This indicates the high priority given to security of supply, as compared to environmental sustainability, in national energy policies during the last decades.

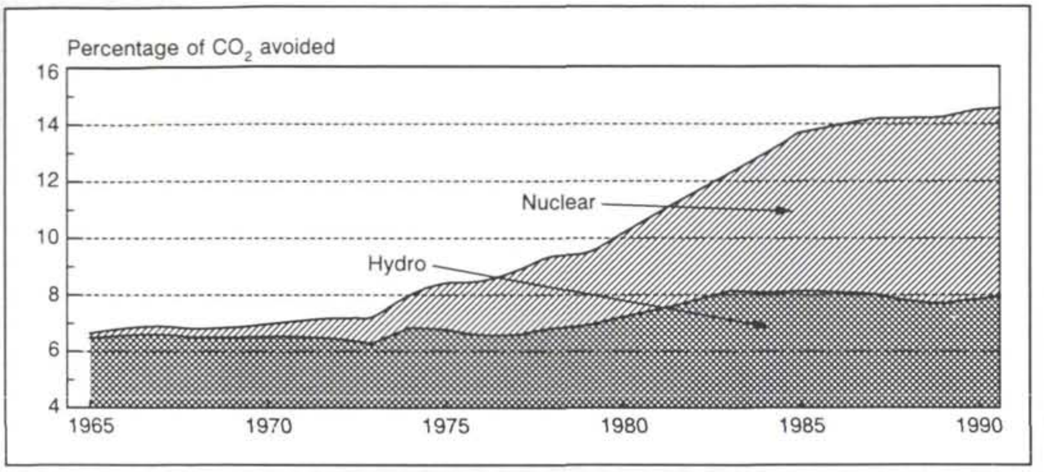
Messages from the future

There are many energy scenarios which have been developed in order to make long-term projections of energy-associated CO_2 emissions. Some of them consider nuclear energy supply explicitly. For illustrative purposes, the CO_2 emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), International Institute for Applied System Analysis (IIASA), and World Energy Council (WEC) are analyzed below. *(See graphs.)* Also discussed are three other cases that deal with different assumptions on population growth and equitable worldwide development.

IPCC scenarios. The IPCC's reference scenario (1a) assumes that the world population will reach some 11 billion inhabitants by the year 2100 and that the average economic growth will be a reasonable 2.9% per year until 2025 and 2.3% thereafter. Natural gas and renewable energy sources, especially solar energy and biofuels which are assumed to become competitive, increase significantly their shares of total energy supply. This scenario leads to a moderate increase of energy-related CO_2 emissions.

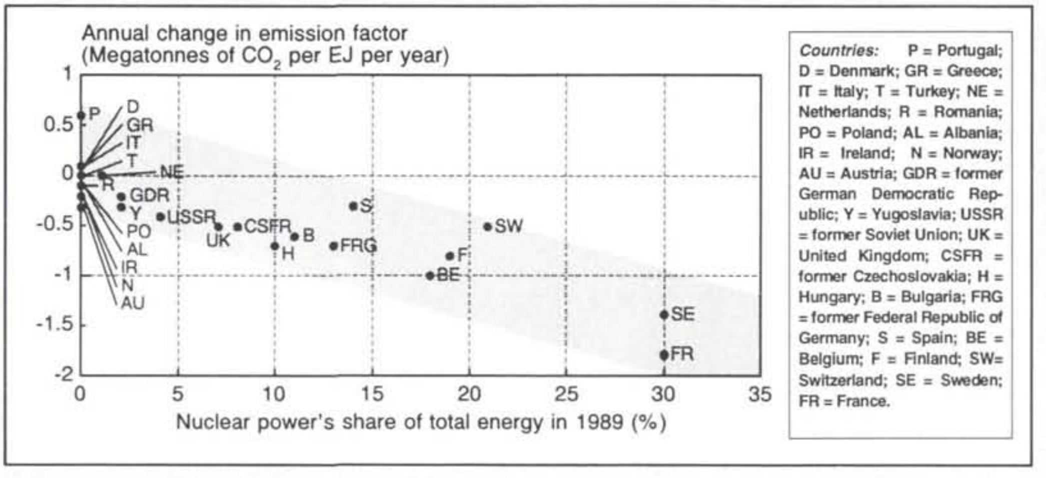
Three other IPCC scenarios hold different assumptions. Scenario-1e assumes the same population growth as the reference scenario but higher economic growth — 3.5% per year to 2025 and 3% thereafter. Natural gas is assumed to have the same development as in the reference scenario and nuclear power is assumed to be phased out by 2075. In this scenario, CO_2 emissions increase dramatically, by a factor of more than four, from 1990 to 2100. Scenarios-1c and 1d assume a lower population growth leading to 6.4 billion inhabitants in 2100; economic growth rates are also lower than in the reference scenario. Scenario-1c, which assumes the lowest rate of economic growth and a large development of nuclear power, leads to much lower long-term CO_2 emissions; they even decrease after 2025. Scenario-1d has rather stable emissions in the next century, since it assumes moderate economic and population growth rates and substantial penetration of renewable energy and to a lesser extent of nuclear power. Scenarios-1e and 1d, which show the correlation between low CO_2 emissions and a large share of nuclear power in the energy mix, illustrate the relevance of the nuclear option in implementing sustainable long-term energy strategies.

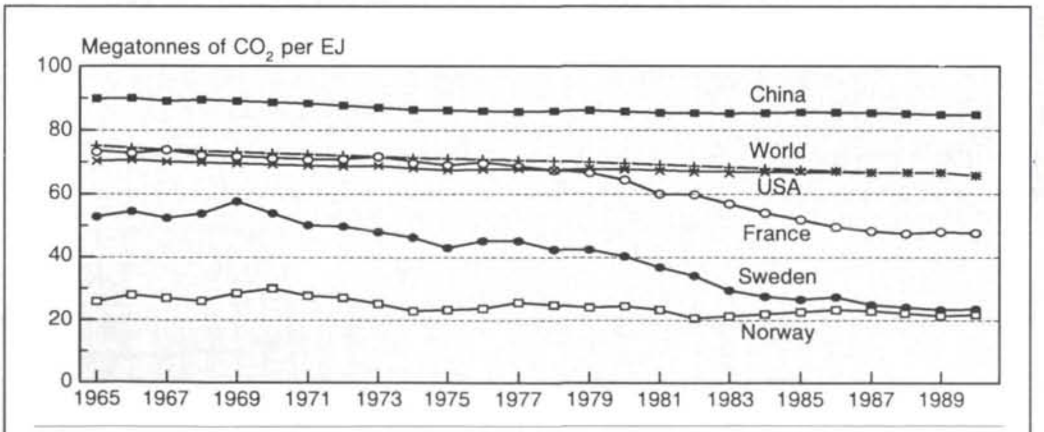
WEC scenario. The WEC Commission developed projections for energy demand to



Percentage of CO_2 avoided by the use of nuclear energy and hydropower

Nuclear energy use and CO_2 emissions

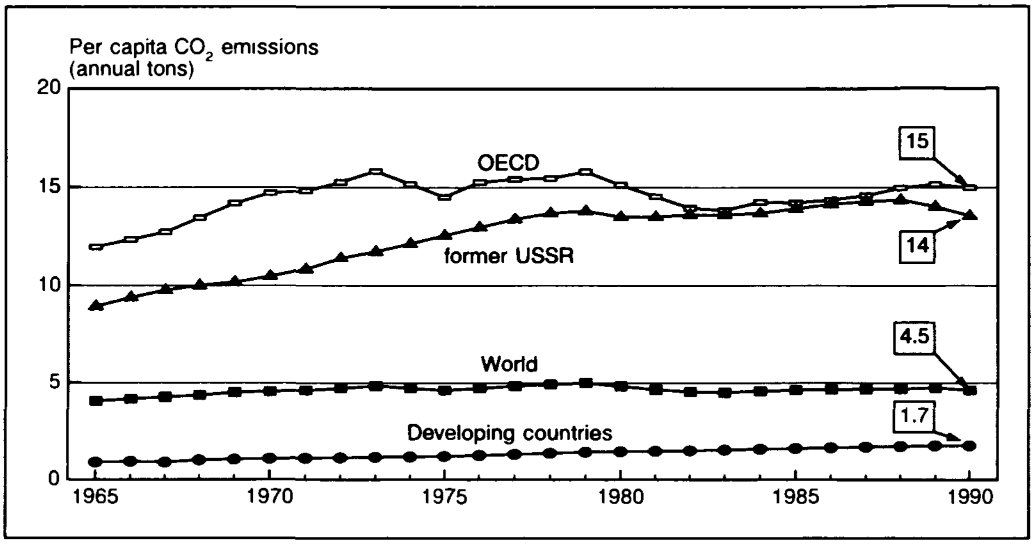




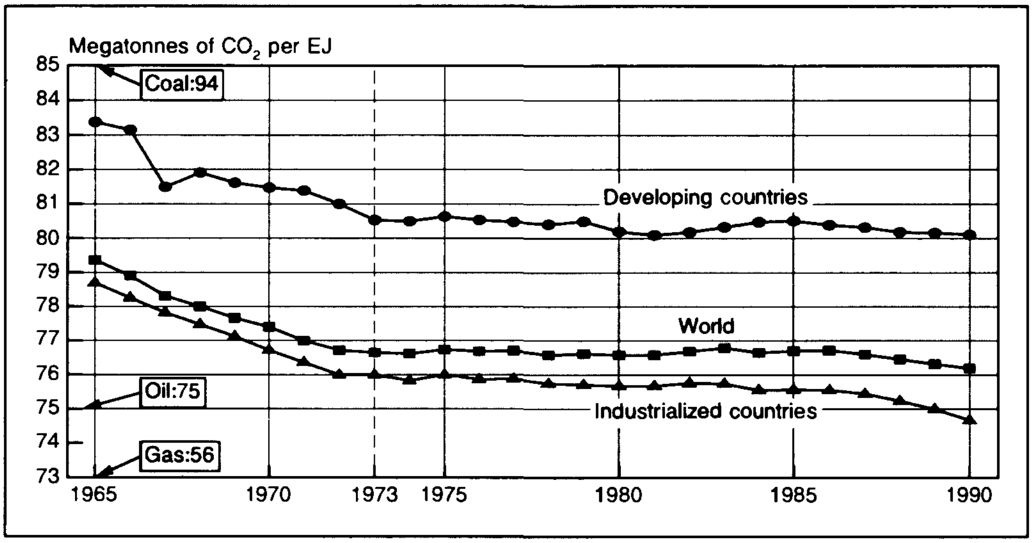
	Fossil share (%)	Non-fossil share (%) Nuclear	Hydro	Total
China	95	0	5	5
France	65	30	5	35
Norway	29	0	71	71
Sweden	34	31	35	66
United States	88	8	4	12
World	87	6	7	13

Shares of fossil fuels in energy consumption and selected national CO_2 emissions

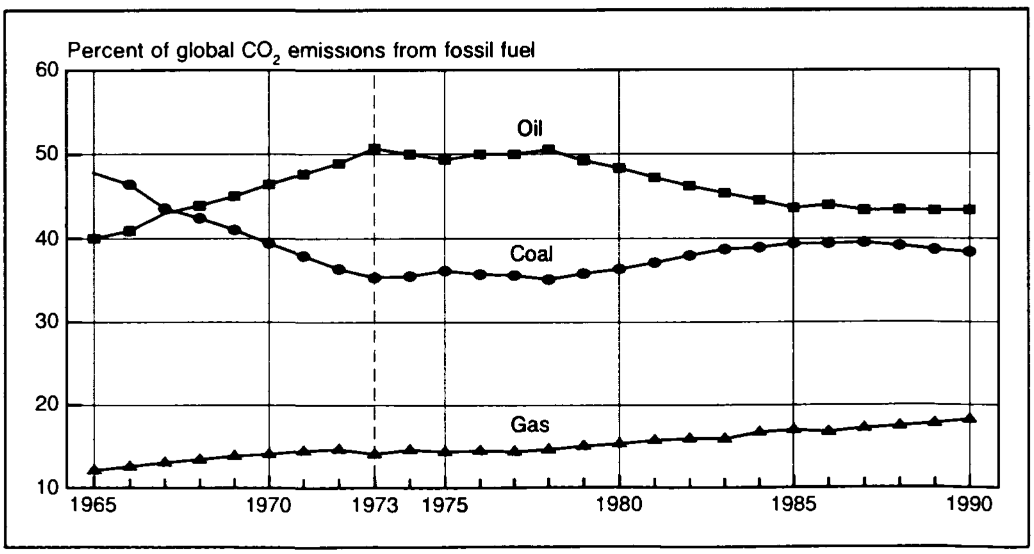
Per capita CO2 emissions by country groups



Trends in CO2 emissions, 1965-90



Percentage of CO2 emissions from the use of fossil fuels

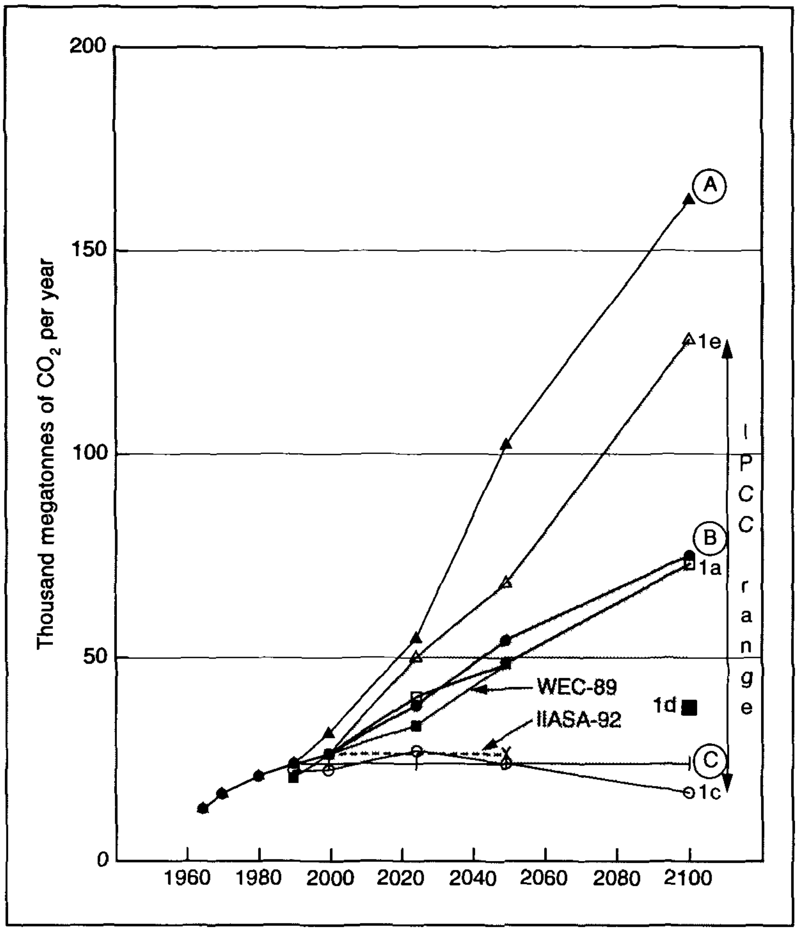


2020, assuming a rather low population growth of 1.4% per year to 2020. The WEC-89 reference case assumes a continuation of economic growth rates achieved in the second half of the 1980s and a faster reduction in energy intensity than historically recorded. Nuclear power would increase its share of primary energy supply worldwide by about 50% in the period 1990 to 2020. This stems from the WEC Commission's view that, with sustainability in mind, the nuclear option needs to be reevaluated, taking into account environmental issues and security of supply.

IIASA scenario. The IIASA-92 scenario, which assumes a large share of nuclear power in the energy supply, gives additional support to the view that non-CO_2 emitting technologies have to contribute substantially to energy supply in a greenhouse benign policy.

Other cases. Three other cases have been developed at the IAEA, based on views laid down in the Framework Convention on Climate Change. This Convention stresses worldwide equity of industrialized and developing countries as one of the basic concepts for sustainable development. This means that closing the socio-economic gap between rich and poor countries should be one of the pillars of a global climate policy. It also implies a future with regionally more balanced *per capita* energy consumption and CO_2 emissions. This likely is also a *conditio sine qua non* for full collaboration of developing countries in a global policy for sustainable environment. Nowadays, the average *per capita* energy consumption and the related *per capita* greenhouse gas emissions are one order of magnitude higher in industrialized than in developing countries. Therefore, the global demand for energy could become much larger in the next century for equity reasons and if, as expected, the world population grows to almost three times the present level.

The three cases analyze different ultimate equity levels, which are assumed to be reached in the course of the next century. This was done to illustrate the constraints for a sustainable global energy policy which aims at decreasing the lifestyle-determined economic gap between developing and developed countries. The cases further assume that worldwide equity of *per capita* CO_2 emissions is approached with a rate of 3% change per year in the ratio of *per capita* CO_2 emissions of industrialized to developing countries. The world population is assumed to reach 12 billion in 2075, which is in line with what the UN Population Fund considers likely. For the sake of transparency, it was assumed that there would be no shifts in fuel mixes and efficiency improvements.



Scenarios of energy-associated CO_2 emissions

Three cases were considered:

Case A. This case assumes that industrialized countries stabilize their *per capita* energy consumption and CO_2 emission at 1990 levels, and that developing countries make up their arrears in 50 years time. The result is not surprising, namely a huge global release to a level of 150 000 megatonnes of CO_2 per year — which is almost six times more than the present annual emission rate of 24 000 megatonnes.

Case B. This case assumes that in 2050 the global equity level of *per capita* energy consumption will be four times the present level in the developing countries and 2.5 times smaller than the present level in industrialized countries. This would imply the maximum feasible rate of investment in development. The resulting ultimate CO_2 emission rate of about 75 000 megatonnes of CO_2 per year is still very high, though in the range of the IPCC scenarios.

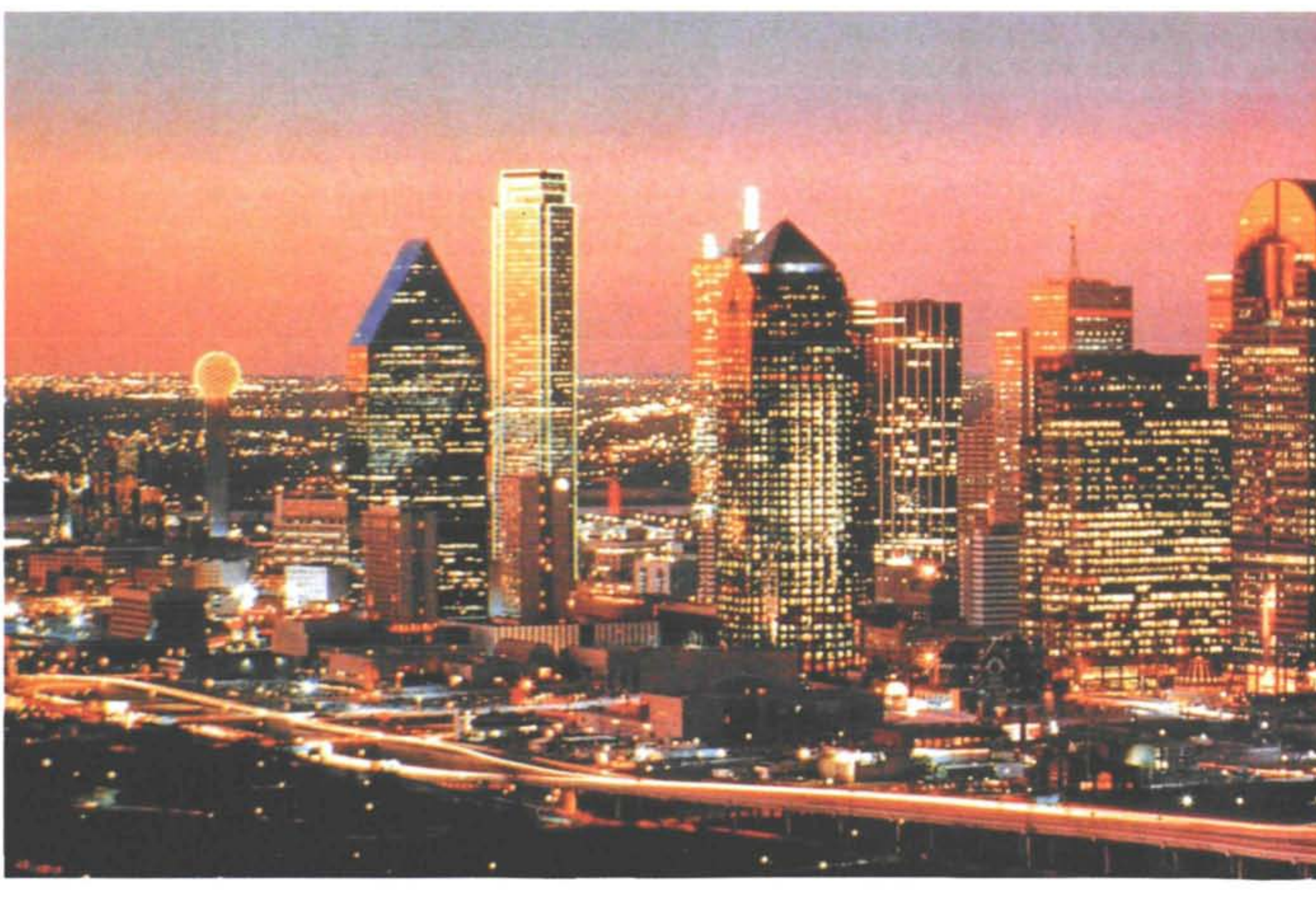
Case C. This is a normative case constrained by an assumed global rate of CO_2 emissions stabilized at the 1990 level. Equity is reached only at the end of the next century. This means, however, that not even the Toronto global goal (a 20% reduction from 1988 levels by the year 2005) is met. Nevertheless, this case is more or less identical with the IPCC scenario-1c, which assumes extensive nuclear development and is the lowest of all IPCC CO_2 emission scenarios. Implicit in this case is that the industrialized countries lower their CO_2 emissions by 70% and 80% in 2050 and 2100, respectively, in order to compensate for the increasing emissions from the developing countries. This would require a reduction target of about 100 million tonnes of CO_2 per year. The implied nuclear plant capacity expansion is clearly feasible, since it is comparable to the rate of plant installation that has already been achieved in the early 1980s.

Taken together, the three cases show that without strong measures the emission rates of greenhouse gases like CO_2 will increase to exceptionally high levels, mainly due to population growth and the equity-invoked lifestyle improvements in the developing countries. Furthermore, these cases imply that nuclear energy is required for achieving a worldwide strategy to abate climate change. This, in turn, would require more extensive involvement by developing countries in generating electricity using nuclear energy.

Reinforcing commitments

Energy scenarios assuming explicit contributions from nuclear power to energy supply clearly show that global emissions of CO_2 can be substantially reduced if nuclear energy can further penetrate the electricity market. A bundle of measures, including nuclear energy and energy efficiency improvements, is required in order to lower greenhouse gas emissions to a level at which no further anthropogenic perturbation of the greenhouse and associated climate change will take place. This implies a very large worldwide effort from both industrialized and developing countries, the latter needing substantial support in terms of funds, expertise and hardware, all aiming at lowering greenhouse gas emissions.

As a first step, however, all industrialized countries need to demonstrate that they take the greenhouse problem seriously by lowering their own, presently dominating, contributions to global emissions of greenhouse gases. In this context, countries inclined to phase-out nuclear energy will have to become convinced that such a move would make it difficult, if not impossible, to keep their commitments of at least stabilizing CO_2 emissions, much less reaching the Toronto global target. ❐



An important share of electricity in Chicago and other cities around the world is generated by nuclear energy. ***(Credit: ENEL)***