Nuclear Development

Nuclear Energy and the Kyoto Protocol

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996); Korea (12th December 1996) and the Slovak Republic (14th December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 28 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

This publication presents key facts about nuclear energy and the Kyoto Protocol to the United Nations Framework Convention on Climate Change. It reviews the causes and consequences of global climate change, outlines the international framework aimed at alleviating and mitigating global climate change and reviews the potential role of nuclear energy in this regard.

Without prejudging the policies of individual Member countries towards nuclear energy and their national choices for addressing climate change concerns, the goal of this book is to clarify issues related to nuclear energy and the Kyoto Protocol. It provides data and analyses that policy makers may use to support national decision making.

This publication is a contribution of the Nuclear Energy Agency (NEA) to the OECD work on issues related to global climate change and more broadly to sustainable development. It was prepared by the NEA Secretariat assisted by a consultant, Leonard L. Bennett, whose contribution is gratefully acknowledged. It has also benefited from comments and suggestions from Member country representatives and international organisation observers in the NEA Nuclear Development Committee. It is published under the responsibility of the Secretary-General of the OECD.

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EXECUTIVE SUMMARY

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCC)[1] adopted in 1997 calls for greenhouse gas (GHG) emissions to be reduced by 2008-2012. During the 1990s, however, global emissions of CO_2 increased by almost 9% in spite of a decrease by almost 32% in the countries with economies in transition (EITs). The latter is due to the economic recession in these countries, and not as a result of determined GHG mitigation efforts. In most OECD countries, CO_2 emissions have gone up since 1990, not down. The total emissions for all OECD countries increased by more than 10% from 1990 to 1999.

A comprehensive analysis of GHG emissions from different electricity generation chains shows that nuclear power is one of the least carbon intensive generation technologies, with emissions from the full energy chain (FEC) amounting to only about 2.5-5.7 grams of GHG (expressed as grams of C-equivalent) per kWh of electricity produced (gC_{eq}/kWh), compared to some 105 to 366 gC_{eq}/kWh for fossil fuel chains and 2.5-76 gC_{eq}/kWh for renewable energy chains. Assuming that the nuclear units in operation have substituted for modern fossil-fuelled power plants, nuclear energy today is reducing CO_2 emissions from the energy sector by more than 8% world-wide (for the electricity sector, the reduction is about 17%).

In OECD countries, nuclear power plants have already played a major role in lowering the amount of greenhouse gases produced by the electricity sector over the past 40 years. Without nuclear power, OECD power plant emissions of carbon dioxide would be about one-third higher than they are at present. This is an annual saving of some 1 200 million tonnes of carbon dioxide, or about 10% of total CO_2 emissions from energy use in the OECD. The Kyoto Protocol emission targets call for total annual emissions in OECD countries to be reduced by about 700 million tonnes of carbon dioxide by 2008-2012, relative to 1990 levels. If all OECD nuclear plants were to cease operating in the coming decades, this would add 1 200 million tonnes of annual emission reduction that would have to be achieved to meet the Kyoto targets.

1. For details on the UNFCCC and the Kyoto Protocol see Chapters 5 and 6.

The benefit that nuclear energy brings in terms of reducing carbon dioxide emissions is not prohibited by the Kyoto Protocol. The construction of new nuclear power plants will contribute to meeting the targets of those countries that choose to continue with the nuclear option as a domestic energy supply source.

The Kyoto Protocol does, however, incorporate conditions that effectively exclude nuclear energy as an option for implementation under two of the three "flexibility mechanisms" that can be used, in addition to domestic action, by Annex I Parties[2] to the UNFCCC to meet their commitments. The three mechanisms are: projects implemented jointly (Article 6), the clean development mechanism (CDM, Article 12), and trading of emission reduction units (Article 17). Restrictions on nuclear energy do not apply to emission trading.

The debate over whether nuclear energy should be permitted in, or excluded from, the flexibility mechanisms appears to be driven by different concepts of sustainable development, and what types of energy systems fit within these concepts. In some views, there are no inherent features of nuclear energy that definitively would prevent it from being a component in sustainable energy strategies, and therefore the flexibility to continue and enlarge its contribution in the medium and long term should be maintained. Opposing views maintain that some specific features of nuclear energy – in particular issues related to safety, radioactive waste disposal, and proliferation of nuclear weapons – make its use unsustainable.

The 6th Conference of the Parties to the UNFCCC (COP-6) affirmed that it was up to the host Party to determine whether a project would contribute to its sustainable development; thus the CDM does not deny a non-Annex I country from deploying nuclear energy, but prevents the use of a CDM subsidy for its deployment.

At present, the targets and flexibility mechanisms refer only to the Kyoto Protocol compliance period (2008-2012). While the entry into force of the Kyoto Protocol would enhance the relevance of nearly carbon-free technology options, such as nuclear energy, the main possibility for nuclear energy to make a significant contribution to GHG emissions reduction would be after the Kyoto Protocol compliance period. It is in this longer term that the debate about the possible role of nuclear energy in sustainable development will be more important.

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2. See Appendix.

The exclusion of nuclear energy from two of the flexibility mechanisms for the present compliance period is largely symbolic in terms of nuclear energy development by 2012. Indeed, the number of nuclear units that might have been ordered owing to these mechanisms is very limited. However, the debate on nuclear energy that has led to its exclusion from the flexibility mechanisms of the Kyoto Protocol may have negative implications for the period after 2008-2012. It will be important that organisations such as the NEA continue to provide authoritative and reliable information on the potential future role of nuclear energy in strategies aiming towards mitigating or stabilising GHG emissions from the energy sector.

1. INTRODUCTION

This report aims towards presenting the implications that the United Nations Framework Convention on Climate Change (UNFCCC), and the provisions of the Kyoto Protocol to that Convention, might have on the future evolution of nuclear energy. The report begins (Chapter 2) by highlighting the potential risks of global warming and its consequences. According to the Intergovernmental Panel on Climate Change (IPCC), effects could include: increase in the severity and/or frequency of severe weather events; shift of climate zones, which could adversely affect food production in some regions; impact on already scarce water resources; damage to physical infrastructures due to sea-level rise and severe weather events; and adverse effects on economic activities. Next, the evolution of greenhouse gas emissions and concentrations in the atmosphere are presented in Chapter 3, showing the large (more than 30%) increase in atmospheric concentration of CO_2 since industrialisation (with increased burning of fossil fuels). It is noted that the present CO_2 concentration has not been exceeded during the past 420 000 years, and likely not during the past 20 million years. Chapter 4 highlights the important contribution being made by currently operating nuclear power plants to reduce CO_2 emissions. It is shown that, if the 438 nuclear reactors that are in operation in 21 countries (85% of the world's nuclear capacity is in OECD Member countries) were to be closed down and replaced by modern fossil-fuel-fired plants, CO_2 emissions from the world energy sector would rise by some 8% (by one-third in OECD).

The report then turns to the presentation of some key elements of the Framework Convention (Chapter 5) and the Kyoto Protocol (Chapter 6). The Kyoto Protocol flexibility mechanisms, and their implications for nuclear energy, are discussed in Chapter 7 (Joint Implementation and the Clean Development Mechanism) and Chapter 8 (Emissions Trading and Value of Carbon). It is pointed out that, if CO_2 emission reduction were the sole objective of the flexibility mechanisms, it would be expected that all technologies that could contribute to this objective would be candidates for implementation, with the most cost-effective technology being selected in any specific situation. This is not the case, however, since nuclear facilities are specifically excluded as candidates for implementation in two of the flexibility mechanisms, for meeting emission reduction targets in the Kyoto Protocol “commitment period” (2008-2012). It is noted that this exclusion is largely symbolic, since very few nuclear facilities could be implemented under the umbrella of those flexibility mechanisms and contribute to emission reductions by 2008-2012. However, there is a risk that the exclusion might be continued when future compliance periods and emission targets are negotiated.

The outlook for the time frame beyond 2008-2012 (i.e. “beyond Kyoto”) is treated in Chapter 9. It is highlighted that if the climate change negotiation process should reach agreement to stabilise atmospheric CO_2 concentrations at around twice the pre-industrial levels, then even more stringent emission reduction targets than those agreed to in the Kyoto Protocol will be required, and with the participation of all countries. Results from long term energy demand and supply scenarios are presented showing that expanded use of nuclear energy could play a very important role in energy strategies aiming towards mitigating or stabilising CO_2 emissions into the earth’s atmosphere.

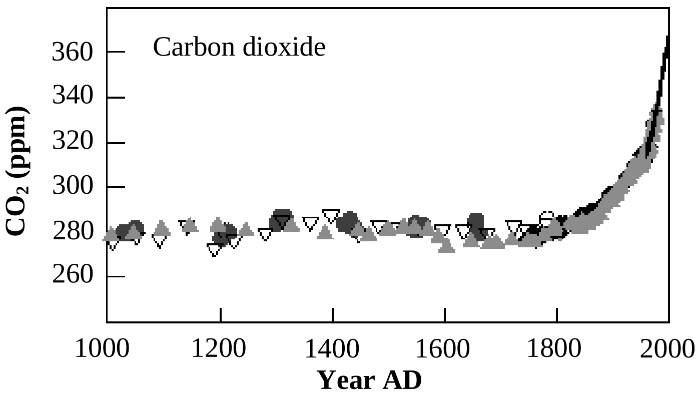
Finally, Chapter 10 presents a brief review of greenhouse gas emissions from the full energy chain of different electricity generation options, showing that nuclear energy has emissions at the low end of the range – about the same as renewable energy and much lower than fossil.

2. GLOBAL WARMING AND ITS CONSEQUENCES

The earth's climate is driven by a continuous flow of energy from the sun, which arrives mainly as visible light. About 30% of the incoming energy is scattered back into space, but most of the remaining 70% passes through the atmosphere and warms the earth's surface. In order that the earth does not become undesirably hot, this energy must be sent back into space. However, being much cooler than the sun, the earth does not emit energy as visible light, but rather in the form of infrared (invisible) radiation. This radiation cannot pass directly through the atmosphere, but is trapped by gases (such as water vapour, carbon dioxide, ozone, methane, nitrous oxide, and halocarbons plus other industrial gases) in the atmosphere. Apart from the industrial gases, all of these gases occur naturally and comprise somewhat less than 1% of the atmosphere. This may not sound like much, but the presence of these gases is enough to produce a natural "greenhouse effect" that keeps the earth some 30°C warmer than it otherwise would be – a difference that is essential for life as we know it [1].

The problem is that the atmospheric concentrations of all the main greenhouse gases (with the possible exception of water vapour) are increasing as a direct result of human activities. Carbon dioxide levels appear to have varied by less than 10% during the 10 000 years before industrialisation. In the 200 years since 1800, however, levels have risen by over 30% (see Figure 1).

Figure 1. **Atmospheric carbon dioxide concentration over the last millennium**



(Source: http://www.ipcc.ch/pub/spm22-01.pdf. Summary for Policy Makers – A report of Working Group I of the Intergovernmental Panel on Climate Change – IPCC Third Assessment Report – Climate Change 2001).

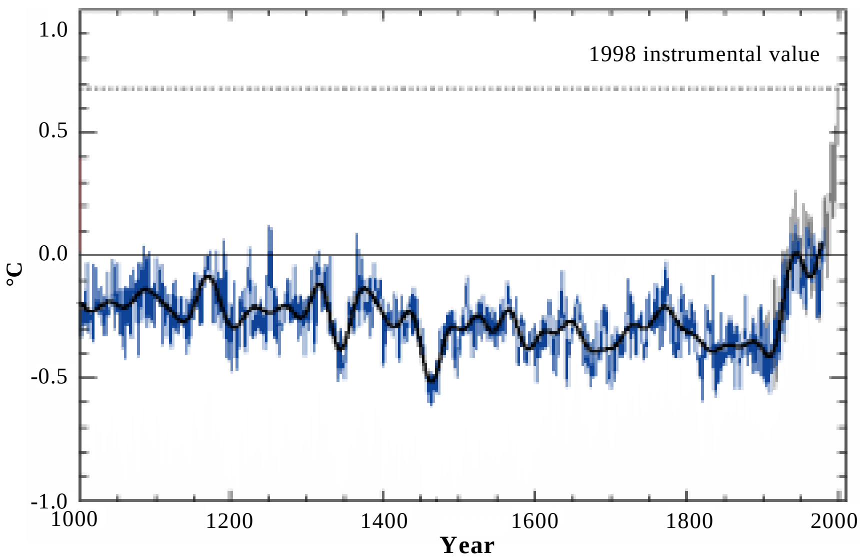
Even with half the CO_2 emissions being absorbed by the oceans and land vegetation, atmospheric levels continue to increase by over 10% every 20 years. The rising concen-trations of carbon dioxide (mainly from the burning of fossil fuels), methane and nitrous oxide (due mainly to agriculture and changes in land use), ozone (from automobile exhausts and other sources) and long-lived industrial gases (CFCs, HFCs and PFCs) are increasing the atmosphere's trapping of the infrared radiation emitted from the earth's surface. The result is an "enhanced greenhouse effect", leading to an overall warming of the earth's surface (see Figure 2) and the lower atmosphere, which, in turn, induces changes in the earth's climate.

Global Warming Potential of GHGs

The Global Warming Potential (GWP) is a measure of the ability of a gas to trap heat radiated from the earth's surface compared to a reference gas, usually CO_2. The GWP estimated by the IPCC for the most commonly emitted GHGs are given below.

- carbon dioxide (CO_2) = 1
- methane (CH_4) = 21
- nitrous oxide (N_2O) = 310
- sulphur hexafluoride (SF_6) = 23 900
- tetrafluoromethane (CF_4) = 6 500
- hydrofluorocarbons (HFCs): HFC-134a = 1 300
- chlorofluorocarbons (CFCs): CFC-114 = 9 300
- hydrochlorofluorocarbons (HCFCs): HCFC-22 = 1 700

Figure 2. **Northern hemisphere temperatures reconstruction**



(Source: http://www.ipcc.ch/pub/wg1TARtechsum.pdf. Technical summary: A report accepted by Working Group I of the IPCC but not approved in detail – IPCC Third Assessment Report – Climate Change 2001)

Climate change caused by human activities threatens to adversely affect the habitat and economy of virtually all countries. This threat is drawn from the conclusions of the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) [2], approved in early 2001, which was carried out by thousands of experts (natural and social scientists and technologists) in the appropriate fields of science from academia, governments, industry and environmental organisations around the world.

The Chair of the IPCC recently summarised the relevant IPCC findings in a paper presented to the Sixth Session of the UNFCCC [3]:

> "The overwhelming majority of experts in both developed and developing countries recognise that scientific uncertainties exist; however, there is little doubt that the earth's climate has warmed over the past 100 years in response to human activities and that further human-induced changes in climate are inevitable. The question is not whether climate will change further in the future in response to human activities, but rather by how much (magnitude), where (regional patterns), and when (the rate of change). It is also clear that climate change will, in many parts of the world, adversely affect socio-economic sectors, including water resources, agriculture, forestry, fisheries and human settlements, ecological systems (particularly coral reefs), and human health (particularly insect-borne diseases). Indeed, the IPCC TAR concluded that most people will be adversely affected by climate change.
>
> The good news is, however, that the IPCC reported that significant reductions in net greenhouse gas emissions are technically feasible due to an extensive array of technologies in the energy supply, energy demand and agricultural and forestry sectors, many at little or no cost to society."

Without the implementation of emissions control policies motivated by concerns about climate change, atmospheric concentrations of CO_2 are expected to rise from today's level of about 370 ppm[3] to 490-1 260 ppm by the year 2100, depending on the scenario. Stabilising concentrations below these "business-as-usual" levels will demand major efforts. For example, stabilising concentrations at 450 ppm would require global emissions to fall below 1990 levels within the next few decades. Given a growing world population and continued economic development, this would require dramatic improvements in

3. ppm (parts per million) or ppb (parts per billion, 1 billion = 1 000 million) is the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air. For example, 300 ppm means 300 molecules of a greenhouse gas per million molecules of dry air.

efficiency of energy use and technological changes in energy production systems, for example shifting to systems that emit little or no CO_2.

Climate models predict that, in the absence of efforts to control GHG emissions, the global temperature will rise by about 1.4-5.8°C by the year 2100 [1]. This projection is based on a wide range of assumptions about the main forces driving emissions, such as population growth and technological change. In general, a greater risk of damage is associated with a faster rate of climate change, owing to the difficulty of natural systems to adapt to a rapid rate of change.

Effects could include an increase in global precipitation and changes in the severity and/or frequency of extreme weather events (storms and flooding). Climate zones could shift, disrupting forests, deserts, range lands and other unmanaged ecosystems. As a result, many such systems could decline or fragment, and individual species could become extinct. Food security is unlikely to be threatened at the global level, but food production in some regions is likely to be adversely affected, leading to food shortages and hunger. Water resources will be affected as precipitation and evaporation patterns change around the world. Physical infrastructures will be damaged by sea-level rise and by extreme weather events. Economic activities, human settlements and human health will experience many direct and indirect adverse effects. The poor and disadvantaged are the most vulnerable to the negative consequences of climate change.

As noted by the Chair of the IPCC, the “good news” is that there exist many options for limiting GHG emissions in the short and medium term. Policy makers can promote energy efficiency improvements and other climate-friendly measures in both the production and use of energy, for example by providing an appropriate economic and regulatory framework for both consumers and investors. Such a framework should promote cost-effective actions, use of the best current and future technologies, and adoption of “no regret” strategies. Regulations, standards, tradable emissions permits, information programmes, voluntary actions, and the phase-out of counter-productive subsidies can all play a role. The deployment of these and other measures will, however, require strong leadership by governments and international organisations.

The Precautionary Principle calls for early measures to reduce greenhouse gas emissions even if scientific uncertainties on the risks associated with climate change remain rather large.

3. EVOLUTION OF GREENHOUSE GAS EMISSIONS AND CONCENTRATIONS IN THE ATMOSPHERE

In its Summary for Policy Makers [4], Working Group I of the IPCC concluded that "concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities". Detailed findings presented in their report for individual greenhouse gases are as follows:

- The atmospheric concentration of CO_2 has increased by 31% since 1750. The present CO_2 concentration has not been exceeded during the past 420 000 years and likely not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20 000 years.
- About three-quarters of the anthropogenic emissions of CO_2 to the atmosphere during the past 20 years is due to fossil fuel burning. The rest is predominantly due to land-use change, especially deforestation.
- The rate of increase of atmospheric CO_2 concentration has been about 1.5 ppm (0.4%) per year over the past two decades. During the 1990s the year to year increase varied from 0.9 ppm (0.2%) to 2.8 ppm (0.8%). A large part of this variability is due to the effect of climate variability (e.g. El Niño events) on CO_2 uptake and release by land and oceans.
- The atmospheric concentration of CH_4 has increased by 1 060 ppb (151%) since 1750 and continues to increase. The present concentration has not been exceeded during the past 420 000 years. The annual growth in CH_4 concentration slowed and became more variable in the 1990s, compared with the 1980s. Slightly more than half of current CH_4 emissions are anthropogenic (e.g. use of fossil fuels, cattle, rice agriculture and landfills). In addition, carbon monoxide emissions have recently been identified as a cause of increasing CH_4 concentrations.

- The atmospheric concentration of N_2O has increased by 46 ppb (17%) since 1750 and continues to increase. The present concentration has not been exceeded during at least the past thousand years. About a third of current N_2O emissions are anthropogenic (e.g. agricultural soils, cattle feed lots and chemical industry).
- Since 1995, the atmospheric concentrations of many of the halocarbon gases that are both ozone-depleting and greenhouse gases (e.g. $CFCl_3$ and CF_2Cl_3), are either increasing more slowly or decreasing in response to the Montreal Protocol and its Amendments. Their substitute compounds (e.g. CHF_2Cl and CF_3CH_2F) and some other synthetic compounds (e.g. perflourocarbons (PFCs) and sulphur hexaflouride (SF_6) are also greenhouse gases, and their concentrations are currently increasing.

The Kyoto Protocol (see Chapter 6) calls for GHG emissions to be reduced by 2008-2012. However, during the 1990s, as shown in Table I, global emissions of CO_2 increased by almost 9% in spite of a decrease by almost 32% in the EITs. The latter is due to the economic restructuring and recession in these countries, and not as a result of determined GHG mitigation efforts. In most OECD countries, CO_2 emissions have gone up since 1990, not down, and economic recovery in the EITs will boost their emissions as well.

Among the Annex I countries, the best progress has been made by the Europe group, where 1999 emissions were only 0.7% above their 1990 level. Nonetheless, by the 2008-2012 commitment period, the EU must actually reduce emissions to at least 8% below 1990. The situation is even less favourable in other OECD countries. The USA would be required[4] to reduce its emissions by 7% between 1990 and the commitment period, but the emissions increased by 15.2% from 1990 to 1999. In Canada, emissions were up 16.1%, compared to a required 6% reduction by 2008-2012. In Japan, the 1999 increase was 10.5% whereas the Kyoto Protocol requires an 8% reduction. Even Australia, which is allowed an 8% increase up to the commitment period had already increased by 23.8% in 1999.

4. It should be noted, however, that the USA has announced that it will not accept the Kyoto Protocol requirements for emissions reductions.

4. CO_2 EMISSION REDUCTIONS BY CURRENTLY OPERATING NUCLEAR POWER GENERATION

The issues in the debate about nuclear power in the context of climate change are discussed in a report by the International Energy Agency (IEA) [5], in which it was noted that Member countries of the IEA acknowledge the potential contribution of nuclear power to a sustainable energy mix. They adopted a statement of "Shared Goals" in 1993, which outlines the principles by which energy sectors of their economies can make "the fullest possible contribution to sustainable economic development". The Shared Goals make reference to nuclear power both in its contribution to energy supply diversity and to the environmentally sustainable provision and use of energy. The Shared Goals state that "a number of IEA members wish to retain and improve the nuclear option for the future, at the highest available safety standards, because nuclear energy does not emit carbon dioxide". However, the report highlights that nuclear energy faces a number of challenges in meeting its potential to contribute to a sustainable energy supply. One such challenge is to ensure that the fission products and long-lived radioactive wastes can be handled safely and without danger to the environment. Although acknowledging that the technical evidence seems to suggest that this challenge can be met, the report notes that achieving this in practice involves political uncertainty.

The World Energy Council [6] also emphasised the need to keep all energy options open, stating: "While some WEC members question the future of nuclear power, most believe the role of nuclear power needs to be stabilised with the aim of possible extensions. The latter think efforts to develop intrinsically safe, affordable nuclear technology needs to be encouraged." The statement goes on to say, "Ultimately, market criteria must prevail in the development of all energy resources".

At the end of 2000, there were 438 nuclear reactors being operated in 31 countries, with a total capacity of 351 GWe (about 85% of this capacity is located in Member countries of the OECD) [7]. During 2000, nuclear power plants produced 2 450 TWh, accounting for 16% of total electricity production world-wide, or almost 6% of global commercial primary energy consumption [8].

Table 1. **Regional and global CO_2 emissions from fuel combustion (million tonnes of CO_2) [Ref. 10, pp. 28-29]**

	1990	**1999**	**Change (%) 1990 to 1999**
Annex I	**13 811**	**13 592**	**-1.6**
Annex II	**9 942**	**10 952**	**10.2**
North America	*5 267*	*6 074*	*15.3*
Canada	421	489	16.1
USA	4 846	5 585	15.2
Europe	*3 344*	*3 368*	*0.7*
Austria	57.0	60.5	6.1
Belgium	106	119	11.8
Denmark	49.7	53.3	7.2
Finland	53.4	57.8	8.4
France (1)	364	361	-0.7
Germany	966	822	-15.0
Greece	69.0	81.5	18.2
Iceland	2.0	2.1	3.3
Ireland	32.2	39.9	24.1
Italy	397	420	6.0
Luxembourg	10.5	7.5	-28.3
Netherlands	156	166	6.4
Norway	28.5	37.1	30.4
Portugal	39.9	61.1	53.1
Spain	212	272	28.6
Sweden	48.5	48.2	-0.6
Switzerland (1)	41.1	39.8	-3.1
Turkey	138	183	32.2
United Kingdom	572	535	-6.5
Pacific	*1 331*	*1 511*	*13.5*
Australia	57.0	60.5	6.1
Japan	1 048	1 158	10.5
New Zealand	23.0	30.6	33.1
Economies in transition (EITs)	**3 869 (e)**	**2 639**	**-31.8**
Belarus	na	57.1	na
Bulgaria	76.1	43.8	-42.5

Table 1. **Regional and global CO_2 emissions from fuel combustion (million tonnes of CO_2) [Ref. 10, pp. 28-29] (cont'd)**

	1990	**1999**	**Change (%) 1990 to 1999**
Croatia	na	19.0	na
Czech Republic	150	111	-26.5
Estonia	na	14.7	na
Hungary	67.6	57.8	-14.4
Latvia	na	6.8	na
Lithuania	na	13.0	na
Poland	348	310	-11.0
Romania	172	86.6	-49.5
Russia	na	1 486	na
Slovak Republic	55.3	39.4	-28.9
Slovenia	12.8	15.0	17.0
Ukraine	na	379	na
Non-annex I	**6 840**	**8 822**	**29.0**
Africa	600	730	21.8
Middle East	584	886	51.8
Non-OECD Europe	119	67.5	-43.2
Other former Soviet Union	576	324	-43.7
Latin America	919	1 222	33.0
Asia (excl. China)	1 614	2 541	57.4
China	2 429	3 051	25.6
Marine Bunkers	348	424	21.6
Aviation Bunkers	280	335	19.8
World total	**21 279**	**23 172**	**8.9**

Notes:

(1) Emissions from Monaco are included with France, and those from Liechtenstein are included with Switzerland.

(e) Estimated value.

na Data not available.

Nuclear energy makes a significant contribution to the lowering of carbon emissions from the energy sector. A comprehensive analysis of GHG emissions from different electricity generation chains (see Chapter 10) shows that nuclear power is one of the less carbon intensive generation technologies, with no stack emission and emissions from the full energy chain (FEC) amounting to only about 2.5-5.7 grams of GHG (expressed as grams of C-equivalent) per kWh of electricity produced (gC_{eq}/kWh), compared to some 105 to 366 gC_{eq}/kWh for fossil fuel chains and 2.5-76 gC_{eq}/kWh for renewable energy chains. Assuming that the nuclear units in operation have substituted for modern fossil-fuelled power plants, nuclear energy today is reducing CO_2 emissions from the energy sector by more than 8% world-wide (for the electricity sector, the reduction is about 17%). A recently published report by the IEA [Ref. 19] noted that nuclear power has played a major role in lowering the amount of greenhouse gases produced by OECD power plants over the past 40 years. Without nuclear power, OECD power plant emissions of carbon dioxide would be about one-third higher than they are at present. This is an annual saving of some 1 200 million tonnes of carbon dioxide, or about 10% of total CO_2 emissions from energy use in the OECD. The Kyoto Protocol emission targets call for total annual emissions in OECD countries to be reduced by about 700 million tonnes of carbon dioxide by 2008-2012, relative to 1990 levels. If all OECD nuclear plants were to cease operating in the coming decades, this would add 1 200 million tonnes of annual emission reduction that would have to be achieved to meet the Kyoto targets.

The percentage of carbon dioxide avoided globally by nuclear and hydro energy from 1965 to 1993 is shown in Figure 3. It may be seen that the percentage of CO_2 avoided by hydro energy has increased by only a small amount, from around 6.4% in 1965 to 8.6% in 1993, while that avoided by nuclear power has grown from a very small value (0.2%) in 1965 to more than 8% in 1993. This shows that the expansion of nuclear power's contribution to energy supply has made an important contribution to the avoidance of CO_2 emissions world-wide.

The case of France is illustrated in Figures 4 and 5 which show, respectively, the contributions of different fuels to electricity generation by Electricité de France (EdF) and the resulting CO_2 emissions by EdF. As may be seen in Figure 4, the rapid expansion of nuclear power was very effective in displacing fossil fuels from electricity generation. In 1993, about 82.5% of the EdF electricity was generated by nuclear power plants (including non-EdF production, nuclear energy accounted for about 78% of France's total electricity production). Figure 5 shows the sharp decline in CO_2 emissions by EdF, that resulted from the decrease in fossil fuel combustion. The temporary rise in emissions during 1988-1991 was caused by conditions of low rainfall, which reduced production from hydro power, as well as some problems which led to reduced operation of the nuclear plants during this period. Both events necessitated an increase in operation of the fossil fuelled plants. This rise in emissions would have been even higher if there had not been a continuing growth in installed nuclear power capacity.

Figure 3. **Percentage of CO_2 avoided globally by hydro and nuclear energy**

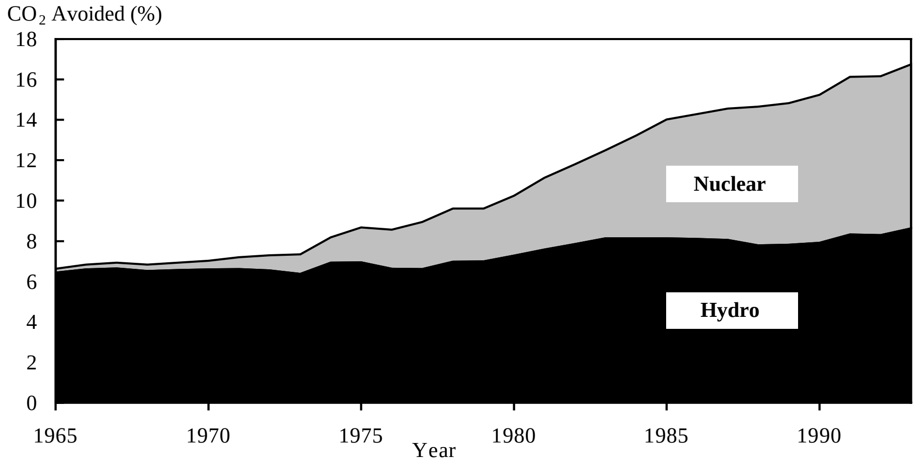


Figure 4. **Electricity generation by different fuels – the case of EdF**

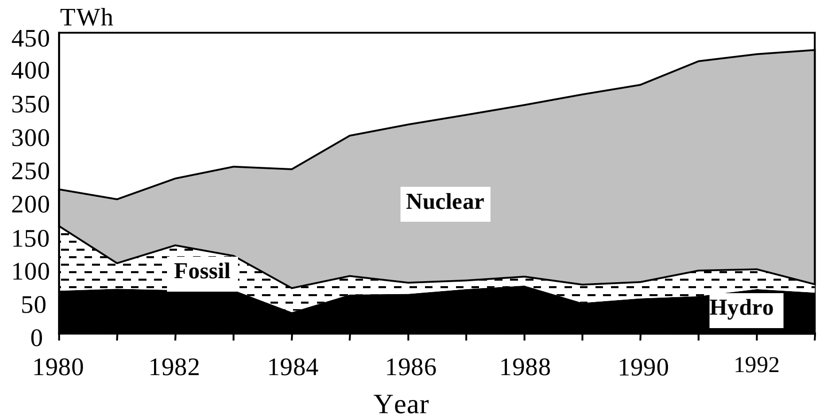
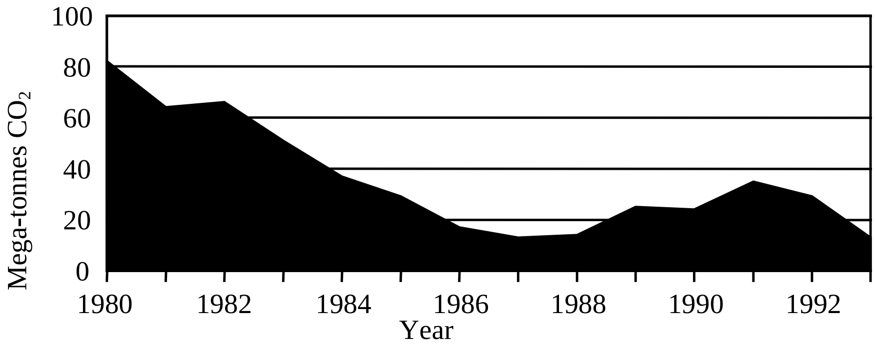


Figure 5. **Carbon dioxide emissions by EdF**



5. UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

The United Nations Framework Convention on Climate Change [9] was adopted in New York on 9 May 1992, following some two years of negotiation, and took effect on 21 March 1994. It has been ratified by around 180 countries that have recognised the need to stabilise the concentration of greenhouse gases in the earth's atmosphere.

The "ultimate objective" stated in the Convention is to achieve "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic (human-induced) interference with the climate system". The objective does not specify what the GHG concentration level should be, only that it should not be dangerous. The Convention further directs that "such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner". This highlights that the main concerns are about food production – perhaps the most climate-sensitive human activity – and economic development. It also suggests (as most climatologists believe) that some climate change is inevitable, and that adaptive as well as preventive measures are needed.

In Article 3, the Convention calls on Parties to be guided, *inter alia*, by the following principles:

- The climate system should be protected for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.
- The specific needs and special circumstances of developing countries, especially those that are particularly vulnerable to the adverse effects of climate change, and of those countries that would

have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration.

- Precautionary measures should be taken to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures should be cost effective.

- Parties to the Convention should co-operate to promote a supportive and open international economic system that would lead to sustainable economic growth and development in all Parties, especially developing countries. Measures taken to combat climate change should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade.

Two groups of Parties, mainly developed countries, are identified in Annexes I and II to the Convention (see Appendix of this report). Those listed in Annex I commit themselves specifically to:

- Adopt national policies, including policies and measures adopted by regional economic integration organisations, to limit its anthropogenic emissions of GHG and to protect and enhance its GHG sinks and reservoirs. Such policies and measures may be implemented jointly (Joint Implementation is discussed in Chapter 7) with other Parties, and assistance may be given to other Parties in contributing to the achievement of the objective of the Convention.

- Within six months of the entry into force of the Convention, and periodically thereafter, they are to communicate detailed information on their policies and measures as well as on the resulting projected GHG emissions (excluding those controlled by the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer) by sources and removals by sinks.

The Parties included in Annex II are to provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in complying with their obligations under the Convention (primarily the establishment of national inventories, using agreed methodologies, of anthropogenic GHG emissions by sources and removals by sinks).

6. THE KYOTO PROTOCOL

The Kyoto Protocol to the UNFCCC was adopted by consensus at the third session of the Conference of the Parties (COP-3) in December 1997, and was opened for signature for one year starting 16 March 1998 [9]. It will enter into force 90 days after it has been ratified by at least 55 Parties to the UNFCCC, including developed countries and economies in transition representing at least 55% of the total 1990 carbon dioxide emissions from this group of countries. Political disagreements in late 2000 and 2001 over how to implement the Protocol have slowed down the rate of ratification, but in the meantime, governments will continue to carry out their commitments under the UNFCCC.

The Protocol contains legally binding emissions targets for Annex I Parties, requiring them to reduce their collective emissions of six key greenhouse gases[5] by at least 5.2% up to the period 2008-2012 (the "commitment period"), with the emissions being calculated as an average over the 5-year period. The six gases are to be combined in a "basket", with reductions in individual gases translated into "CO_2 equivalents" that are added up to produce a single figure. The Protocol does not contain emissions targets for non-Annex I Parties.

Reductions in the three most important gases – carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) – will be measured against a base year of 1990 (with exceptions for economy in transition – EIT – countries). Cuts in three long-lived industrial gases – hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) – can be measured against either a 1990 or 1995 base year. A major group of industrial gases, i.e. chlorofluorocarbons (CFCs), are dealt with under the Montreal Protocol.

The global target for the Annex I group of countries is to be achieved through cuts of: 8% by Switzerland, most Central and East European states, and

5. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6).

the European Union (the EU group target will be met by distributing different reductions among its member states); 7% by the USA; 6% by Canada, Hungary, Japan and Poland. Russia, New Zealand and the Ukraine are to stabilise their emissions at the 1990 levels, while Norway may increase emissions by up to 1%, Australia by up to 8%, and Iceland by up to 10%. An exhaustive list of quantified emission limitation or reduction commitment for each Party is provided in Annex B to the Kyoto Protocol [9].

7. JOINT IMPLEMENTATION AND THE CLEAN DEVELOPMENT MECHANISM

The Kyoto Protocol defines three flexibility mechanisms that can be used by Annex I Parties, in addition to domestic actions, to assist them in meeting their emissions targets [10]. The three mechanisms are: projects implemented jointly (Article 6), the clean development mechanism (Article 12), and trading of emission reduction units (Article 17). The first two are discussed in this chapter, while the third is discussed in the next Chapter along with the value of carbon.

7.1 Joint implementation

Article 6 of the Protocol states that, "For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy", provided that:

- Any such project has the approval of the Parties involved.
- Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur.
- It (the Party wishing to acquire units) does not acquire any emission reductions if it is not in compliance with its obligations under Articles 5 and 7.
- The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.

It should be noted that the transactions permitted under Article 6 are limited to those between Annex I Parties.

Joint implementation (JI)[6] has been conceived as a mechanism to channel new funds into emission reduction activities, for example by promoting co-operation in the development of advanced technologies and their transfer from one Annex I Party to another. In practice, it is expected that JI normally will be carried out through partnerships between investing companies in highly industrialised countries and counterparts in countries making the transition to a market economy (i.e. EITs). The investing partner likely would provide most of the advanced technology and financial resources, while the counterpart (host country) would provide some funding (e.g. for domestically supplied equipment, materials and manpower), the site for implementation of the technology, the principal staff resources, and the implementing organisation to launch and operate the project.

Many of the implications of JI for nuclear energy are the same as those for the clean development mechanism (CDM), as discussed in Section 7.2.1 below, with the difference that JI involves projects implemented jointly between Annex I countries, whereas the CDM involves projects implemented in non-Annex I countries with financial assistance and technology transfer from Annex I countries.

7.2 The clean development mechanism

The clean development mechanism (CDM) is defined in Article 12 of the Protocol, which states that "The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3". The CDM aims to benefit both Annex I and non-Annex I Parties, in that:

- Parties not included in Annex I will benefit from the project activities that result in certified emission reductions (CERs).
- Annex I Parties may use the resulting CERs to assist in meeting their emission limitation and reduction commitments.

In interpreting Article 12, it is apparent that, in order for a project to qualify under the CDM, it must provide more than just emissions reductions.

6. Although it does not appear explicitly in Article 6, the term "Joint Implementation" has become a commonly used shorthand for referring to the actions that are described in this Article.

Specifically, a project should:

- Provide CERs that are additional to those that would occur in any event in the absence of the project (the criterion of “environmental additionality”).
- Benefit non-Annex I Parties in terms of technology, capital and know-how transfer (the criterion of “financial and technological additionality”).

Operational and institutional issues related to the CDM are discussed in Ref. [11], and issues related to the establishment of project emission baselines against which emission reductions of a CDM project can be measured are discussed in Ref. [12].

7.2.1 Implications of the CDM for nuclear energy

The possible role that nuclear energy could have in the CDM has been strongly debated, in particular during the Sixth Session of the Conference of the Parties to the UNFCCC (COP-6). It is obvious that use of nuclear energy, and renewable energy as well, would reduce emissions of CO_2 if these energy sources were implemented as CDM projects as a substitute for fossil fuel projects. Thus, if CO_2 emission reduction were the sole objective of the CDM, one would expect that all technologies that avoid such emissions would be candidates for implementation under this mechanism, with the most cost-effective option being selected in any particular situation.

However, during COP-6 discussions of Article 12, the Parties agreed: “To recognise that Parties included in Annex I are to refrain from using certified emission reductions generated from nuclear facilities to meet their commitments under Article 3.1”.

On the other hand, the Parties also agreed: “To affirm that it is the host Party’s prerogative to confirm whether a clean development mechanism project activity assists it in achieving sustainable development”. Thus, it would appear that a host Party might be able to declare that a nuclear energy project would contribute to its sustainable development. However, it is unlikely that an Annex I country would assist in the implementation of a nuclear energy project under the CDM, if it is not able to use the resulting CERs to meet its commitments.

The Kyoto Protocol, including its flexibility mechanisms, is the result of a highly political process in which trade-offs and compromises had to be reached in order to accommodate the conflicting interests of the different Parties and various stakeholders. As a result, it often is difficult to determine the basic objectives and underlying principles of the mechanisms, including the CDM.

The debate over whether nuclear energy should be permitted in, or excluded from, the CDM appears to be driven by different concepts of sustainable development, and what types of energy systems fit within these concepts. In some views, there are no inherent features of nuclear energy that definitively would prevent it from being a component in sustainable energy strategies, and therefore the flexibility to continue and enlarge its contribution in the medium and long term should be maintained [13]. Opposing views maintain that some specific features of nuclear energy – in particular issues related to safety, radioactive waste disposal, and proliferation of nuclear weapons – make its use unsustainable.

There is perhaps a third view that large-scale projects of any kind are not sustainable, and that the CDM should be used exclusively for projects that would lead to increased use of renewable energy sources and to improvements in energy efficiency. This latter view would largely exclude nuclear energy, since it usually involves large-scale projects (although smaller nuclear plants are in development), and also would exclude large hydropower projects and “clean coal” projects with trapping and sequestration of the CO_2. An additional factor, mainly relevant for small developing countries, is that large projects that could benefit only large countries would absorb rapidly all the available investments under the CDM umbrella.

Some recent statements for and against nuclear power as an option for GHG emission reduction and sustainable development are presented in the next box.

As mentioned above, COP-6 affirmed that it was up to the host Party to determine whether a project would contribute to its sustainable development; thus, no CDM project should be imposed on a host country. On the other hand, the exclusion of certain technologies from the CDM process has been viewed by some non-Annex I Parties as an infringement of their sovereign right to determine their own technological path for the future, and has the effect of imposing other technologies. The opposing view is that the CDM investing Parties, or even the CDM process itself, has a right to decide which technologies are “sustainable”, in particular if a technology has the potential for international effects, for example in the case of a nuclear accident having cross-border effects. Those holding this view note that excluding nuclear power from the CDM does not deny a non-Annex I country from deploying it, but only prevents the use of a CDM subsidy for its deployment.

It should be noted that Annex I countries, while not entitled to benefit from GHG reductions associated with building nuclear units in non-Annex I countries, can use nuclear power in their domestic supply for meeting their Kyoto targets.

A fact sheet by Friends of the Earth Scotland, 1998
Nuclear power is no solution to climate change: exposing the myths: The nuclear industry is hoping that concern over climate change will result in support for nuclear power. However, even solely on the grounds of economic criteria it offers poor value for money in displacing fossil fuel plant. Further, with its high cost, long construction time, high environmental risk and problems resulting from waste management, it is clear that nuclear power does not offer a viable solution to climate change. Rather a mixture of energy efficiency and renewable energy offers a quicker, more realistic and sustainable approach to reducing CO_2 emissions.

The National Environmental Trust, Washington, D.C., 1999
Nuclear Power: Not a Cost-competitive Solution to Global Warming. Its excessive costs, inadequate safety record, and lack of competitiveness make it clear that nuclear energy is the wrong solution to global warming. Instead, federal and local governments should focus more on energy efficiency research and the development of clean, safe, renewable sources like wind, solar, biomass, or geothermal.

J. Trittin, German Federal Minister for the Environment, Nature Conservation and Nuclear Safety, 2002
We want to start an energy policy for the future. We want to make a seamless policy. Renewable energy sources, more energy efficiency, saving energy and phasing out nuclear energy are elements of a responsible and sustainable energy policy.

Loyola de Palacio, Vice President of the European Commission and Commissioner for Transport and Energy, 2002
With the current state of the art, giving up the nuclear option would make it impossible to achieve the objectives of combating climate change. Paradoxically, the contribution of nuclear energy to the stabilisation of CO_2 emissions is often underestimated.
Phasing out nuclear would significantly undermine the possibility for Europe to face the main challenges, the sustainability of economic growth, which would be jeopardised by Europe's increased import dependency, and the fulfilment of the Kyoto commitments. For the latter, we must explore how best nuclear energy could contribute to the implementation of the flexible mechanisms.

US vice-president Dick Cheney, 2001
If you're really serious about greenhouse gases, one of the solutions to that problem is to go back, and let's take another look at nuclear power, use that to generate electricity without having any adverse consequences.

The UK Royal Society and The Royal Academy of Engineering, 1999
The potential problems for humanity during the next century are too serious to permit a relaxed attitude. The development both of renewables and of the nuclear option should be pursued with vigour. Only by so doing will future generations have appropriate choices available – some of which might be needed to avoid catastrophe.

In a report by the International Atomic Energy Agency (IAEA) [14], it was concluded that, based on a number of country case studies, nuclear power plants would lead to long-term certifiable GHG reductions relative to fossil fuel projects that otherwise would be implemented in these countries, thus satisfying the CDM criterion of environmental additionality. The case studies showed also that nuclear projects would meet the criterion of financial and technological additionality, in that supplemental financial resources would be required in order that the nuclear plants would be built instead of fossil fuel plants and that the implementation of the nuclear projects would involve technology transfers to the host country.

7.2.2 The CDM and nuclear energy after 2008-2012

At present, the CDM refers only to the Kyoto Protocol compliance period (2008-2012), owing to the fact that there are no agreed emissions targets beyond this period. Even if nuclear projects were allowed within the CDM, it is unlikely that any could be completed and generate CERs by 2012, taking into account the time needed to plan and construct nuclear plants. Therefore, the main possibility for nuclear energy to make a significant contribution to GHG emissions reduction within the CDM would be after the Kyoto Protocol compliance period, and it is in this longer term that the debate about the possible role of nuclear energy in sustainable development will be more important.

Although the exclusion of nuclear energy from the CDM for the present compliance period is largely symbolic (since it could not have contributed significantly in any event), the symbolism is important since this exclusion could become “locked in” when future compliance periods and emission targets are set. Furthermore, the question could arise as to whether projects (nuclear or other) initiated under the present CDM, but not generating CERs before the end of the present compliance period, should be eligible for CERs in future compliance periods.

Thus, the debate on nuclear energy that has led to its exclusion from the present CDM could have implications for the period after 2008-2012. It will be important that organisations such as the NEA continue to provide authoritative and reliable information on the potential role of nuclear energy in strategies aiming towards mitigating or stabilising GHG emissions from the energy sector. Some of the issues involved in the period after 2008-2012, already investigated in a report published by the NEA in 1998 [15], are discussed further in Chapter 9.

8. EMISSIONS TRADING AND THE VALUE OF CARBON

8.1 Emissions trading

Emissions trading (ET) as set out in Article 17 of the Protocol, permits Parties included in Annex I to participate in emissions trading for the purposes of fulfilling their commitments, under the condition that any such trading shall be supplemental to domestic actions.

The overall concept of ET is discussed in a recent publication by the International Energy Agency [16]. The anticipated buyers would be countries in which the cost of reducing emissions is high. Sellers would be countries in which the cost is lower, or whose actual emissions are lower than their Kyoto targets (e.g. the EITs). In its Executive Summary, the report notes that advocates of trading argue that it allows governments and businesses to reduce emissions wherever it is cheapest to do so, while opponents contend that trading is a bookkeeping device which substitutes paper transactions for real emission reductions. Issues related to monitoring, reporting and compliance with the Kyoto Protocol, including emissions trading, are discussed in Ref. [17].

According to the analytical studies and simulations carried out so far [see for example, Ref. 16], emissions trading, as a flexibility mechanism, does not appear to have any strong implications for nuclear energy, and therefore is not discussed further in the present report. However, if a trading regime eventually is implemented and leads to a market value for carbon emission avoidance, this could impact the competitiveness of nuclear energy in comparison to carbon emitting energy sources. Therefore, the value of carbon is discussed in the following section.

8.2 Value of carbon

The IEA report mentioned above [16] included an analysis of the contribution that international emission trading could make to meeting the Kyoto Protocol commitments at least cost, using a model based on econometric linkages between economic activities, energy prices and energy consumption, with optimisation of technology choices for power generation. The model considered only CO_2 emissions and applied the Kyoto emission reduction objectives (in percentage terms) to these emissions.

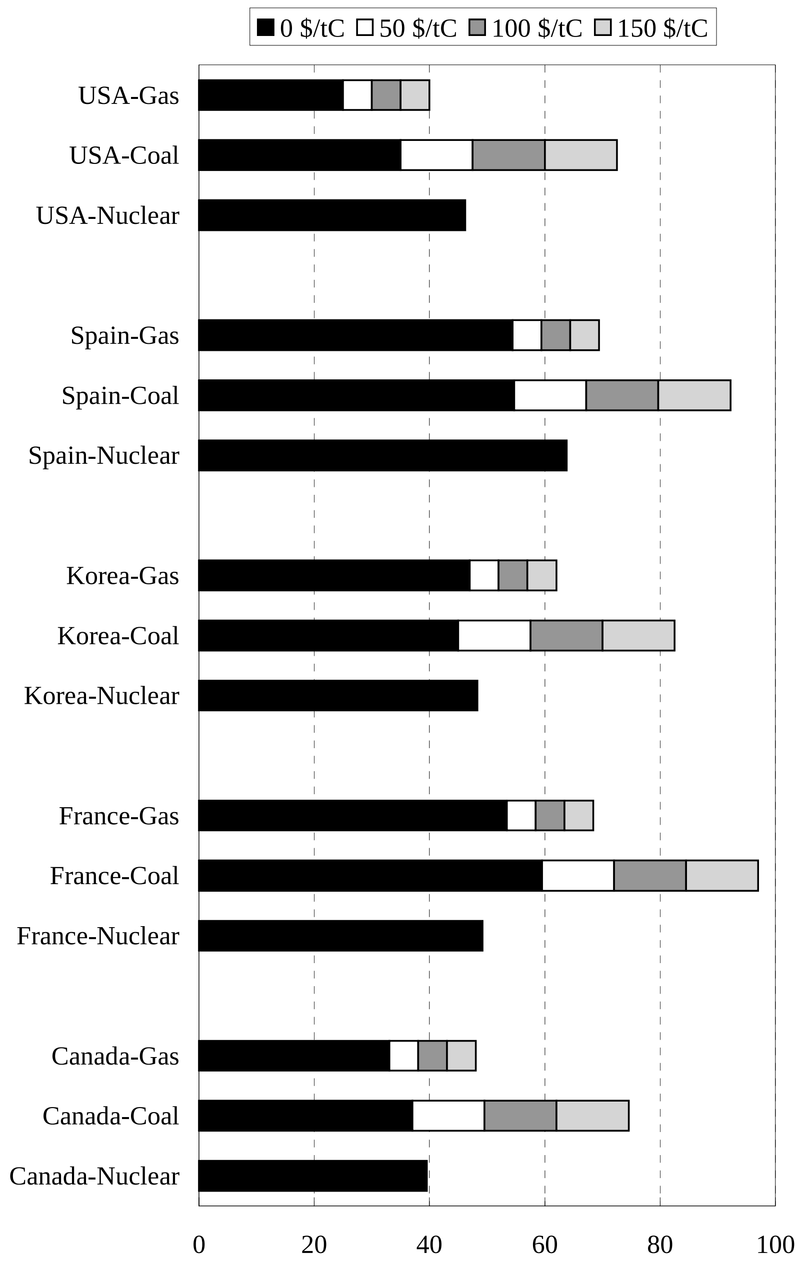
The results from the analysis, which is described in detail in the report, show a market equilibrium trading price of 32 US$ per tonne of CO_2 (118 $/t C), expressed in currency values of the year 2001 [see (Ref. 16, p. 43)]. This result is in general agreement with other results presented in Table 2 of the IEA report, which were derived using different models.

The world's first national scheme for trading in GHG emissions was launched recently in the UK [18]. Firms offering binding 5-year emission reduction caps, in exchange for a share of the financial incentives offered, bid into an auction which was held 11-12 March 2002. Thirty-four successful bidders – known as "Direct Participants" – will enter into the scheme and be free to trade from 2 April 2002 (organisations can meet targets by reducing their own emissions or by buying surplus allowances from another participating organisation). Together they account for binding emission reduction targets totalling 4 million tonnes (over 5% of the planned reduction in UK's annual emissions by 2010) of CO_2-equivalent by December 2007. The UK government will pay 53.37 UK£ (around 77 US$) per tonne of CO_2-equivalent (282 US$/$tC_{eq}$) reduction delivered.

If the trading price were to be taken as the "value of carbon", and interpreted as a tax on emissions from fossil fuel fired power plants, it would have a significant positive impact on the economic competitiveness of nuclear power plants. As a rule of thumb,[7] a carbon value of US$ 1/tC increases the cost of gas-fired generation by 0.01 US¢/kWh and of coal-fired generation by 0.025 US¢/kWh [5,19]. The projected costs of electricity generation by fossil-fired and nuclear plants has been studied by the NEA and IEA, yielding cost comparisons in different countries [20]. The effect of adding a cost for carbon emissions, using this rule of thumb, to the results presented in that study (with 10%/a discount rate) is shown in Figure 6 for a number of countries.

7. The rule of thumb values are based on the following assumptions: natural gas having a carbon content of 15 kgC/GJ is burned in a combined cycle plant having 55% thermal efficiency; coal having a carbon content of 27 kgC/GJ is burned in plant having 40% efficiency.

Figure 6. **Effect of carbon tax on levelised generation cost in different countries (10% discount rate)**



9. BEYOND 2008-2012

As discussed in previous sections, the Kyoto Protocol commitments by Annex I Parties for GHG emissions reductions apply only to the compliance period (2008-2012) of the Protocol. Furthermore, the emission targets set by the Protocol will reduce overall emissions by these Parties by a rather modest 5.2% relative to 1990 levels. At the same time, emissions by non-Annex I countries appear to be destined to continue to rise at significant rates, as these countries develop their economies and increase their energy production to meet the needs of growing populations. With steps toward implementing the Kyoto Protocol showing some progress (e.g. the recent decision for its ratification by the European Union), it may be expected that questions about mitigation commitments for future compliance periods and by all nations (including non-Annex I countries) will become the topic of international negotiations.

Current literature on the impacts of climate change points out that even small changes in the global mean temperature can produce significant impacts on unique and already threatened systems, such as coral reefs and glaciers, and on local populations in some regions, as well as increasing the risk of more frequent and stronger extreme weather events.

With respect to economic impacts of climate change, the literature indicates that with a relatively small rise in the global mean temperature, the damage distribution will not be uniform. Some regions will have negative impacts, particularly in regions that are most vulnerable, while other regions may even have positive impacts from improved climate conditions. However, with larger temperature increases, all regions are expected to have negative impacts. Thus, a challenge for climate policy making is to reach agreement on the level and rate of temperature change that would be acceptable in terms of the UNFCCC guiding objective to "prevent dangerous anthropogenic interference with climate change". Even if policy makers could agree on a preferred target limit on global mean temperature change, there are at present considerable scientific uncertainties on the atmospheric concentration of GHG that corresponds to a certain temperature change, as well on the level and rate of emissions that would not lead to exceeding a certain atmospheric concentration. Thus, setting long-term emission targets will be a difficult process.

Many impact studies assume 550 ppm (about twice pre-industrial levels) for the stabilised atmospheric CO_2 concentration in the year 2100, which is estimated to result in a global mean temperature rise of 1 to 3°C. If the climate change negotiation process should reach agreement to stabilise at this concentration, global emissions would have to peak by about 2025 and fall below current levels by 2040 to 2070 [3]. Achieving this result will require even more stringent emission reduction targets than those agreed to for the Kyoto Protocol commitment period, and with the participation of all countries.

A recently published study [21], that was carried out by an international expert group examined different scenarios of energy demand and supply up to the year 2100. The study group included three analytical teams (in Japan, Russia and the USA) using different models for benchmarking and consistency checking purposes, in order to ensure the robustness of the results.

The framework and findings from the report are highly relevant in connection with the role of nuclear energy in reducing climate change risks in the post Kyoto period. A primary objective of the study was to examine the potential role of nuclear energy in sustainable long-term (to the year 2100) energy policies aiming towards reducing emissions and stabilising atmospheric concentrations of GHG, in particular of CO_2.

The two scenarios of overall energy demand examined in the study cover contrasting possible futures. The first scenario, referred to as "business-as-usual" (BAU), assumes that future energy demand growth will not be influenced by policy measures (e.g. carbon taxes or binding emission reduction targets) aiming specifically towards protecting the environment. The second energy demand scenario, referred to as "ecologically driven" (ED), takes the contrasting view that specific environmental protection measures[8] will be implemented aiming towards reducing risks of global warming. The main features and consequences of the ecologically driven scenario are presented below with emphasis on the connection between nuclear energy development and GHG emissions.

For each of the two energy demand scenarios, the study considered two contrasting alternatives for nuclear energy. The first nuclear alternative, referred to as the "basic option" (BO), assumes that the growth in nuclear electricity production (non-electrical applications of nuclear energy were not considered) will be driven by the economic competitiveness of nuclear energy in

8. A carbon tax (linear increase by 30$/tonneC at 15-year intervals, beginning in the year 2005) was used as a proxy for such policy measures aiming at reducing GHG emissions.

comparison with other electricity generation options. The second alternative referred to as "phase-out" (PO), assumes that nuclear energy will be essentially phased out of electricity generation by around the middle of the century, irrespective of its economic competitiveness, driven by national decisions to turn away from nuclear energy. For purposes of the study, the progressive phase-out of nuclear was forced by imposing sharp increase in the capital costs of nuclear power plants.

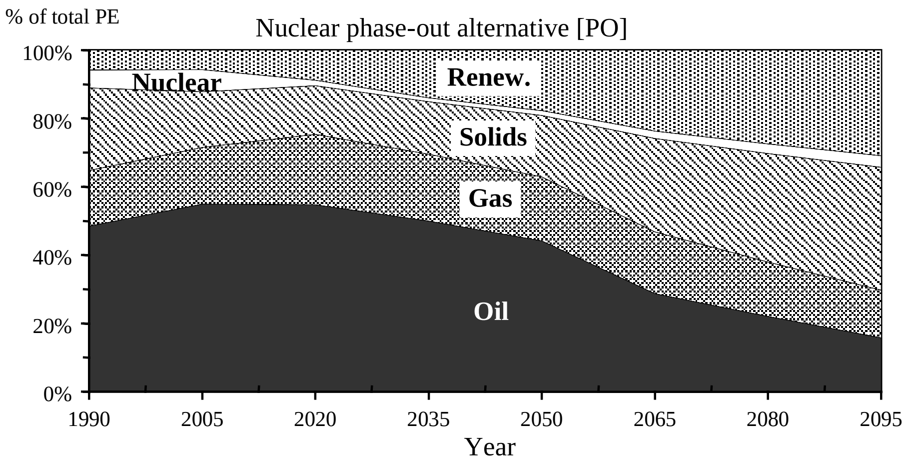
The energy demand scenarios and the nuclear energy alternatives are not intended to be predictive but they provide an analytical tool for investigating the effect that such contrasting evolution of energy demand and nuclear energy supply would have on the CO_2 emissions from the energy sector and other indicators such as the derived costs of energy supply.

The different scenarios for nuclear energy were driven mainly by capital cost, as well as the evolving cost of uranium as lower cost resources are consumed. For fossil fuel based energy, the costs of the fuel, determined by cost versus depletion relationships and, for the "ED" scenarios, the imposition of carbon taxes were the driving parameters. As these largely exogenous and independent variables change, the cost of energy, GDP, CO_2 emissions, and relative energy mixes shift according to the algorithms of the macro-economic/energy models used. Increasing the cost of nuclear energy decreases its market share, with the corresponding result that more fossil fuel is consumed, CO_2 emissions increase, energy prices increase somewhat, and GDP decreases by a small percentage. Likewise, as the imposition of a carbon tax makes fossil fuel more expensive, the shares of nuclear and renewable energy sources in the overall energy mix increase (to an extent dictated by their costs), leading to decrease in CO_2 emissions, increase in energy prices and decrease in GDP (the latter two effects being driven mainly by the increase in fossil fuel prices due to the carbon tax).

Technical progress was taken into account through assuming that the performance (e.g., conversion efficiencies, capacity factors, costs) of all supply technologies (nuclear, fossil and renewables) would progressively improve, but no dramatic "breakthrough" was assumed for any technology, mainly because modelling such breakthroughs implies large uncertainties and the outcomes do not enhance the robustness of findings and conclusions.

The interplay between these variables in governing the percentage contributions of different energy sources to total primary energy supply in the two ecologically-driven (ED) scenarios are shown in Figure 7 for the two nuclear development alternatives, i.e., basic option (BO) and phase-out (PO).

Figure 7. **Percentage contributions of different energy sources to total primary energy supply in the ecologically-driven scenario**



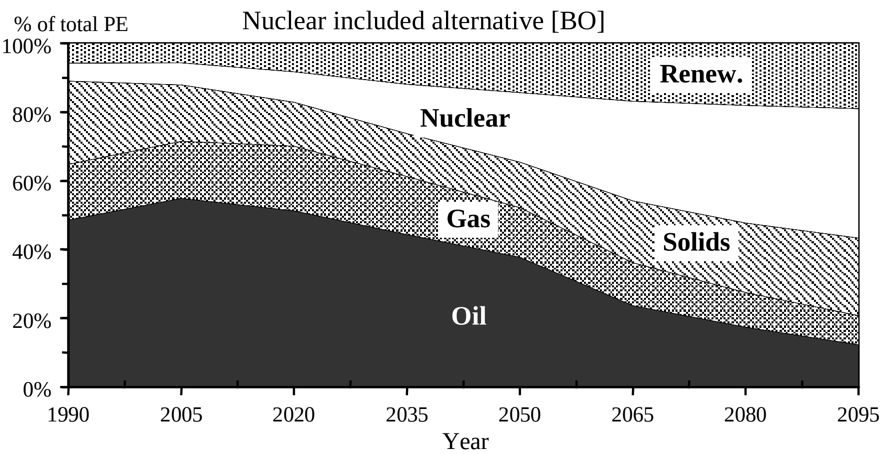
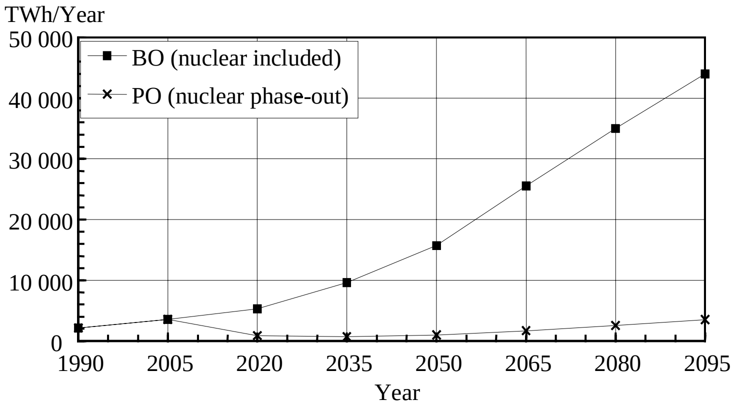


Figure 8 shows that nuclear electricity generation grows to around 44 000 TWh in the year 2100 in the BO scenario (nuclear included), or some 18 times higher than at present (2 449 TWh in the year 2000). The study indicated that there are adequate uranium resources to support this amount of nuclear energy, but that breeder reactors would need to be introduced around the middle of the century. In the nuclear phase-out (PO) scenario, the investment costs of nuclear power plants was increased sharply in an effort to drive nuclear energy out of the supply picture. As may be seen, although this tactic was not fully successful, nuclear electricity generation was indeed driven to a rather low level up to 2050, after which it returned to approximately today's level by the end of the century.

Figure 8. **Global nuclear electricity production in the ecologically-driven scenario (TWh/year)**



Annual net additions of nuclear capacity were calculated (for the BO alternative only) from the nuclear electricity generation, based on a plant load factor of 80%. As shown in Figure 9, the annual additions in the second half of the century are in the range from 80 to just over 90 GWe/a. Based on past experience, with some 40 GW of capacity having been added in some years, these levels of capacity addition are considered to be feasible, although requiring expansion of the nuclear plant manufacturing capability that exists today.

As can be seen in Figure 10, in the BO scenario the CO_2 emission rate at the end of the century is projected to decrease to around 25% below current (year 2002) levels. However, owing to the continued increase in emissions during the past decade, the emission rate at the end of the century is only slightly (around 4%) lower than 1990 levels. In the PO (nuclear phase-out) scenario, on the other hand CO_2 emissions at the end of the century are projected to be some 13% above year 2002 levels, and 35% above 1990 levels.

As a matter of interest, it may be mentioned that in the BAU scenario CO_2 emission rates at the end of the century were projected to be some 90% higher than at present with nuclear included (BO) and 115% higher with nuclear phase-out (PO), showing that the "ecologically-driven" scenario assumptions, in particular the imposition of a carbon tax, have been effective in driving down the emission rates.

Figure 9. **Annual net nuclear capacity additions for the BO nuclear alternative in the ecologically-driven scenario**

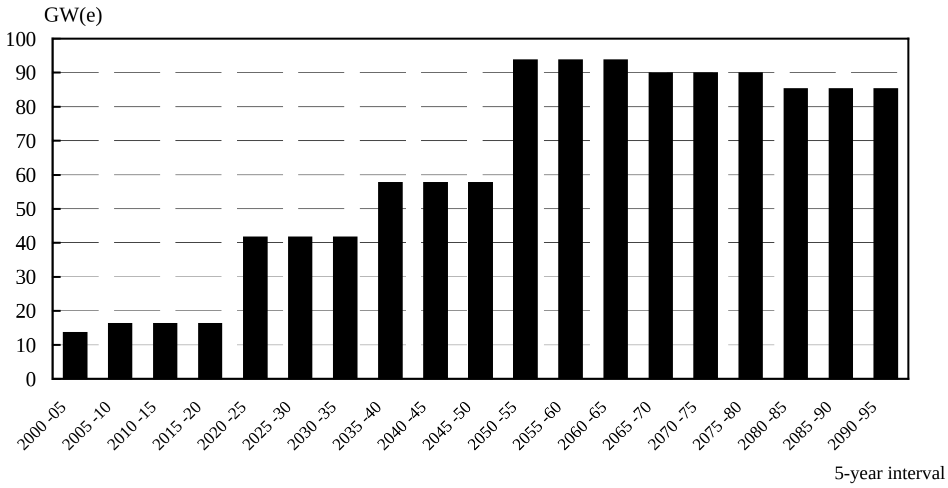
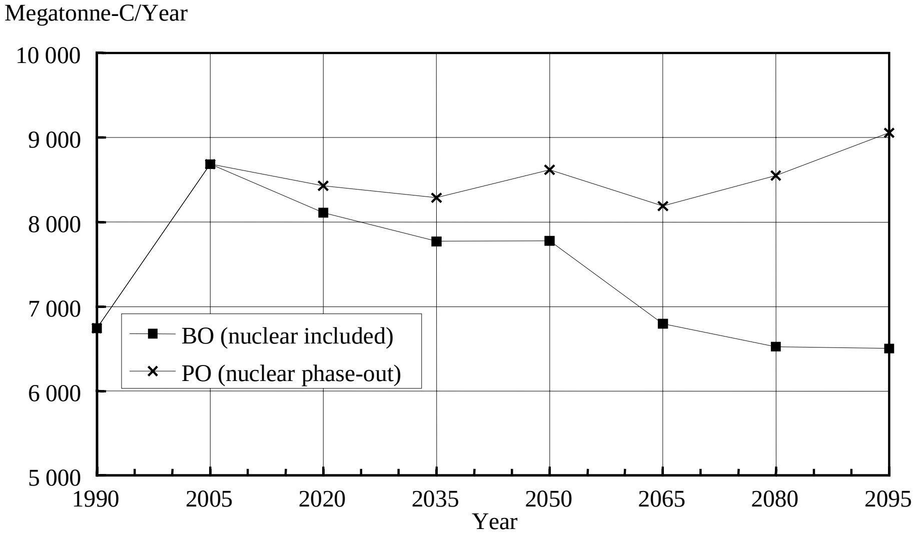


Figure 10. **Global carbon dioxide emissions (million tonnes C/year) in the ecologically-driven scenario**



Obviously, the extrapolation of energy demand and supply strategies 100 years into the future is fraught with large uncertainties, and the results from this study have to be viewed with great caution. Nonetheless, the study indicates that improved nuclear fission systems, building on experience with today's technologies, could make an important contribution to energy strategies aiming towards reducing emissions and stabilising atmospheric concentrations of greenhouse gases.

10. LOW-CARBON EMITTING ELECTRICITY GENERATION OPTIONS

The range of GHG emission factors for the full energy chains (i.e. including fuel use for mining, processing and transport of fuels, as well as for power plant construction and decommissioning) of different electricity generation options have been analysed in a number of studies. Typical results, expressed in grams of carbon-equivalent (including CO_2, CH_4, N_2O, etc.) per kilowatt-hour of electricity (gC_{eq}/kWh) are shown in Table II. The variations in estimates reflect differences in assessment methodologies, conversion efficiencies, practices in fuel extraction, preparation and transport to the location of the power plant, etc. For nuclear and renewable energy chains, there are no GHG emissions from the power plant, but there are some emissions from the other steps of the chain. For fossil fuel chains, on the other hand, the principal emissions are at the power plant, and only some 10-20% of the emissions are from other steps of the chain. The main factors that influence emission rates from different energy sources are summarised in Table III.

With regard to penetration of renewable energies into the electricity market, the IEA [23] noted that non-hydro renewable energy sources accounted for 2% of OECD electricity generation in 1997 and that this share is projected to reach 4% (Reference Scenario) to 10% (Alternative Scenario) by the year 2020. The broader deployment of renewable energy systems is hampered by their costs, which generally are high compared to conventional fuel sources, although some have shown sharp cost declines in recent years. The IEA concludes that, in general, electricity generation from renewables will remain a relatively expensive option, but that it could be cost-effective in some niche markets. Also, in the IEA World Energy Outlook 2001 [24], it is stated that:

- Most forms of renewable energy are not competitive when their costs, as measured by today’s markets, are compared with conventional energy sources.
- The costs of renewable energy technologies have already fallen but further cost reductions are needed for renewables to compete with the least costly fossil-fuel alternatives. The rate at which costs will decline in the future is uncertain.

Table 2. **Range of total GHG emissions (gC_{eq}/kWh) from electricity production chains [22]**

Energy/Technology	Plant emissions	Other chain steps	Total
LIGNITE			
1990s Technology (high)	359	7	366
1990s Technology (low)	247	14	261
2005-2020 Technology	217	11	228
COAL			
1990s Technology (high)	278	79	357
1990s Technology (low)	216	48	264
2005-2020 Technology	181	25	206
OIL			
1990s Technology (high)	215	31	246
1990s Technology (low)	195	24	219
2005-2020 Technology	121	28	149
NATURAL GAS			
1990s Technology (high)	157	31	188
1990s Technology (low)	99	21	120
2005-2020 Technology	90	16	105
SOLAR PV			
1990s Technology (high)	0	76.4	76.4
1990s Technology (low)	0	27.3	27.3
2010-2020 Technology	0	8.2	8.2
HYDROELECTRIC			
Reservoir (Brazil, theoretical)	0	64.6	64.6
Reservoir (Germany, high value)	0	6.3	6.3
Reservoir (Canada)	0	4.4	4.4
Run-of-river reservoir (Swiss)	0	1.1	1.1
BIOMASS			
high	0	16.6	16.6
low	0	8.4	8.4
WIND			
25% capacity (Japan)	0	13.1	13.1
<10% capacity, inland (Swiss)	0	9.8	9.8
10% capacity, inland (Belgium)	0	7.6	7.6
35% capacity, coastal (Belgium)	0	2.5	2.5
30% capacity, coastal (UK)	0	2.5	2.5
NUCLEAR			
high	0	5.7	5.7
low	0	2.5	2.5

Table 3. **Factors influencing GHG emission rates from different energy sources [22]**

Fossil fuels • Fuel characteristics such as carbon content and caloric value. • Type of mine and location. • Fuel extraction practices (affecting transport requirements and methane releases). • Pipeline losses for natural gas. • Conversion efficiency. • Fuel mix for electricity needs associated with fuel supply and plant construction and decommissioning. ***Hydropower*** • Type (run-of-river or reservoir). • Plant location (tropics vs. northern climate). • Energy use for building the dam. • Emissions from production of construction materials (concrete and steel), which are dominant for run-of-river and mountainous reservoirs. For reservoirs whose surface-to-volume ratio is large (typical of northern areas such as Canada and Finland) and in humid tropical regions (e.g. Brazil), the GHG emission rate is influenced by the decay of biomass covered during flooding and oxidation of surface sediment (responsible for large CH_4 emissions). CO_2 emissions exceed CH_4 emissions by at least a factor of 10 for reservoirs in northern areas. ***Wind*** • Energy use for component manufacturing and construction of the installation (tower and foundation). • Fuel mix for electricity needs associated with manufacturing and construction operations, which are highly country- and site-specific (e.g. inland vs. coastal location). • The annual yield or capacity factor (depends on average wind conditions at site), which identifies the effective productivity of the installation. The average wind speed is the key parameter when estimating the productivity of the installation (a 50% increase in average wind speed roughly doubles the annual yield).	***Solar photovoltaics (PV)*** • Quantity and grade of silicon used for cell manufacture. • Type of technology (amorphous vs. crystalline material). • Fuel mix for electricity needs associated with manufacturing. • Type of installation (rooftop, façade, dedicated structure). • Annual yield and assumed lifetime of the installation, which are important parameters when calculating emissions per kWh (also for wind energy). Solar and wind power have relatively low emissions per kW, but high values per kWh due to lower capacity factors (i.e. they are intermittent technologies). ***Biomass*** • Feedstock properties (moisture content and caloric value). • Energy use for feedstock production (growth, harvesting and transport). • Power plant technology. The CO_2 released during the burning of the biomass is offset by the uptake during growth of the biomass. ***Nuclear Power (light-water reactor)*** • Energy use for fuel extraction, conversion, enrichment, construction/decommissioning. • Fuel enrichment by gas diffusion, an energy intensive process, can increase nuclear chain GHG emissions by a factor of 10 compared to the centrifuge process; the laser process would have even lower energy requirements, and thus lower emissions, than the centrifuge. • Fuel mix for electricity needs associated with the enrichment step; highly country specific since it depends on the fuel mix in the local electrical generation system (e.g. France derives some 76% of its electricity from nuclear energy, with low emissions). • Fuel reprocessing and recycle can reduce the total nuclear chain GHG emissions by 10-15%, relative to the once-through fuel cycle.

- Under moderate fossil-fuel price evolution and assuming no major government policy changes, few renewable energy sources will be able to compete with fossil fuels. Renewable energy can be cost effective in specific applications. Some technologies, such as wind, are close to being competitive, while others need to see dramatic declines in their costs. In any case, renewables have to compete with many non-renewable energy forms whose costs are likely to decline.

- Costs are highly site specific and the best sites are used first. Costs for marginal sites are generally much higher.

The World Energy Council [6] also points to the high costs of renewable energy systems (modern biomass, solar and wind generation) as a barrier to their deployment on large scale, noting that, although the costs have been dropping in recent years, they will not be broadly competitive for many years. The WEC report goes on to say, "Nuclear power is of fundamental importance for most WEC members because it is the only energy supply which already has a very large and well-diversified resource (and potentially unlimited resource if breeders are used), is quasi-indigenous, does not emit GHG, and has either favourable or at most slightly unfavourable economics. In fact, should the climate change threat become a reality, nuclear is the only existing power technology which could replace coal in base load."

Appendix

COUNTRY CATEGORIES UNDER THE UNFCCC

Countries which are Parties to the UNFCCC are divided into three categories:

- Annex I Parties[9] are industrialised countries that have committed to take the lead in reducing greenhouse gas emissions, in the light of their responsibility for past emissions. These parties aimed, according to the terms of the UNFCCC, to return their emissions to their 1990 levels by 2000 [see 9]. Annex I Parties are divided into:
  - Annex II Parties, Members of the Organisation for Economic Co-operation and Development (OECD) as of 1992, including European countries and the European Union (EU) as such, Canada, the USA, Japan, Australia, New Zealand and Turkey (although Turkey never ratified the Convention).
  - Industrialised countries with economies in transition (so-called EITs), including countries from the Former Soviet Union (FSU), and from Central and Eastern Europe.

- Non-Annex I Parties, for the most part developing countries, which are subject to lighter obligations, reflecting their less advanced economic development and their lower GHG emissions to date (although the overall emissions for this group are now growing much faster than those of Annex I Parties).

9. Annex I Parties and Annex II Parties refer to countries listed in Annexes I and II to the UNFCCC.

Annex I Parties

Australia	Japan
Austria	Latvia (a)
Belarus (a)	Lithuania (a)
Belgium	Luxembourg
Bulgaria (a)	Netherlands
Canada	New Zealand
Czechoslovakia (a)	Norway
Denmark	Poland (a)
European Union	Portugal
Estonia (a)	Romania (a)
Finland	Russian Federation (a)
France	Spain
Germany	Sweden
Greece	Switzerland
Hungary (a)	Turkey
Iceland	Ukraine (a)
Ireland	UK
Italy	USA

(a) Countries that are undergoing the process of transition to a market economy (EITs).

Annex II Parties

Australia	Japan
Austria	Luxembourg
Belgium	Netherlands
Canada	New Zealand
Denmark	Norway
European Union	Portugal
Finland	Spain
France	Sweden
Germany	Switzerland
Greece	Turkey
Iceland	UK
Ireland	USA
Italy	

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OECD PUBLICATIONS, 2 rue André-Pascal, 75775 PARIS CEDEX 16
Printed in France.