POSSIBILITIES FOR CARBON DIOXIDE EMISSION REDUCTION RESULTING FROM NUCLEAR POWER USE

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Abstract

Each energy resource is connected to certain environmental impacts and risks which must be taken into account. In recent years attention has been focused on the climate change effects of burning fossil fuels, especially coal, due to the carbon dioxide which this releases into the atmosphere. If the electric energy produced in nuclear power plants were produced in coal-fired plants, the global CO_2 emissions would rise for more than 2.000 million tons, a significant value in comparison with 4.000 million tons which is recommended as a target for emission reduction by the year 2005 at the Toronto Conference on the Changing Atmosphere. Possibilities for carbon dioxide emission reduction which would be the result of the nuclear option acceptance are discussed in this paper.

Introduction

Human activities, including the burning of fossil fuels, land-use change and agriculture, are increasing the atmospheric concentrations of greenhouse gases which tend to warm the atmosphere. These changes are projected to change regional and global climate and climate-related parameters such as temperature, precipitation, soil moisture and sea level. Although the exact consequences of the mentioned human-induced factors are still uncertain, the scientific community agrees on the fact that mankind is undoubtedly able to influence the Earth's climate. The possible effects of increased greenhouse gases concentrations are still highly uncertain. However, the world community is unanimous in the opinion that climate changes must be addressed on global scale. Several international conferences were held in order to reach an agreement on binding obligations to limit greenhouse gases emissions, primarily carbon dioxide, the most recent being the third Conference of the Parties in Kyoto (1-10 December 1997).

The final Protocol commitments consist of an overall emission reduction by the industrialised countries of an average 5,2 percent for the period 2008-2012 below 1990 levels for carbon dioxide, methane and nitrous oxide, and below 1995 levels in the case of the HFCs, PFCs and SF6 [1]. The EU, USA and Japan have to reduce their emissions by 8%, 7% and 6% respectively. Some industrialised countries, namely Australia, Iceland and Norway, will be allowed to increase their emissions; Russia and Ukraine have to stabilise their emissions at 1990 levels. Countries that are undergoing the process of transition to a market economy have

agreed to reduce their greenhouse gases emissions below levels in the base year or period which was established pursuant to decision 9/CP.2 of the Conference of the Parties at its second session; Croatia is one of them. Although the Protocol leaves many issues to be resolved at a later stage - accounting for greenhouse gases sinks, emission trading, etc. - it is generally appreciated for containing legally binding commitments, providing industry the level of certainty it needs to anticipate climate change policies.

Energy and climate change

Approximately 75% percent of the world's carbon emissions are the result of combustion of fossil fuels for energy production. Unfortunately, no emissions abatement technology is commercially available for carbon yet. Among the fossil fuels, coal has the most carbon per unit of energy, natural gas has the least and petroleum is in the middle. Over the past two decades, total carbon emissions from energy consumption rose by about 50 percent, trailing energy use which rose by more than 70 percent [2], Table 1. For each of the five-year periods the percentage difference in energy consumption and carbon emission rise is also given. An important reason for the slower rise in carbon emissions was the development of nuclear power generation, primarily in the industrialised countries.

Table 1 World energy consumption trends and associated carbon emission

	1970	1975	%	1980	%	1985	%	1990	%	1995	%
Mtoe	5.300	6.300	19	7.450	18	7.950	7	8.750	10	9.200	5
10^6 t C	4.200	4.800	14	5.300	10	5.600	6	5.800	4	6.010	4

Today the industrialised countries of the Organisation for Economic Cooperation and Development (OECD) are responsible for more than 50 percent of global carbon emissions (Table 2), [3]. If energy consumption levels in the non-OECD countries were to match those in the OECD on a per capita basis, world energy consumption and associated carbon emission would increase about three times relative to current levels.

Table 2 Energy consumption and associated carbon emission in 1995

	OECD	non-OECD	global	if global energy consumption were at 1995 OECD level
Mtoe	4.487,4	3.650,5	8.137,9	23.962,8
TOE per capita	4,15	0,78	1,41	4,15
carbon, Mt	3.129	2.880	6.010	16.708

There are two important factors influencing the expected global energy demand rise (Figure 1, [4]): population growth and economic activity expansion. The largest shares of world economic growth and population growth are expected in areas where current energy use is small relative to that in the industrialised countries of the OECD. However, substantial gains in income in both developed and developing areas of the world are expected to be achieved without comparable gains in energy requirements. Energy intensity of economic activity is projected to decline steadily world-wide. Further declines are expected reflecting expanded use of energy-efficient technologies. Substantial uncertainty is associated with any long-term projection of energy demand - sources of uncertainty include economic growth rated, energy prices and the intensity of energy use in developing economic systems.

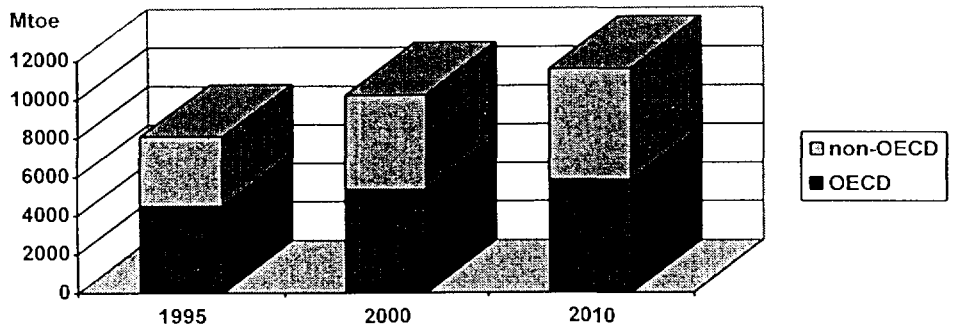

Figure 1 Projection of future energy demand

The future carbon emission calculations in this paper have been conducted under the following assumptions: population is expected to increase by more than two billion people between 1990 and 2010 (this increase is almost exclusively attributable to increases in the non-OECD population); in the non-OECD countries, energy consumption per capita is projected to grow slightly between 1995 and 2010, from 0,78 to some 0,85 Mtoe per person; energy consumption per capita in the OECD grows slightly faster, from 4,15 to 4,8 Mtoe per person between 1995 and 2010.

Electricity production is far from the only source of CO_2 and other greenhouse gas emissions. In some regions of the world, emissions from the industrial sector exceed those of the electric power sector; emissions from the transportation sector are significant as well. Carbon emissions from the agricultural, residential and commercial sector can also be important. In general, electricity generation accounts for 25-35% [4] of global carbon emissions at present. However, the alternatives to petroleum for transportation are limited by issues of cost and infrastructure; there is greater opportunity for switching between electricity production technologies. For that reason electricity has a special place in the search for strategies to reduce greenhouse gas emissions. It tends to be associated with particularly large and noticeable energy supply facility decisions, attracting special social and political attention, and these decisions tend to be unusually capital intensive and more centralised than in industry or transportation. Therefore, it is necessary to consider future energy supply options in the context of sustainable development, which provides growth but does not degrade the environment in the long term. It should be noted that impact reduction by the electric power sector needs to be combined with that by other sectors if ambitious global targets are to be reached.

Possible role of nuclear energy

Because energy-related emissions are among the leading causes of carbon dioxide emissions, influencing climate change, there will be growing pressure on all countries to reduce the amounts of coal and oil they use. Nuclear power is the only fully developed non-fossil electricity generating option with the potential for large-scale expansion. It can contribute substantially to meeting the sustainable energy challenge. The most difficult problems associated with nuclear energy often appear to be political rather than technical.

The possibility for carbon dioxide emission reduction resulting from nuclear power use will be given special attention in this paper. For illustration, let us consider a 1.000 MW power plant, 5.000 hours annually in operation, with the efficiency of 35%. Heating value of a ton of oil equivalent is 41.686 MJ. Carbon emissions per unit of fossil fuel equal 0,93 tC/toe, 0,82 tC/toe and 0,57 tC/toe for coal, fuel oil and natural gas, respectively. Table 3 presents

approximate carbon emissions from such a plant, depending on the fuel used. It must be noted that the values shown here correspond only to the operation of each of the plants and that certain amounts of carbon are being emitted in other stages of power plant's life cycle. However, the most significant emissions take place during the electricity generation stage, except for the nuclear power plant cycle.

Table 3 Approximate carbon emissions from a 1.000 MW power plant, 5.000 h/yr, 1.000 t/yr

	coal	natural gas	oil	nuclear
carbon emission (1.000 t/yr)	1.150	700	1.000	0

World electricity production is going to rise irreversibly, reaching the value of more than 1.800 Mtoe [4] in the year 2010, Figure 2. Under the assumption that the input fuel mixture follows the current trends, around 1.230 Mtoe will be gained from fossil fuels, i.e. coal, natural gas and oil. Some 33 percent of total electricity will be produced from non-carbon fuels, i.e. hydro (18%) and nuclear (15%) power.

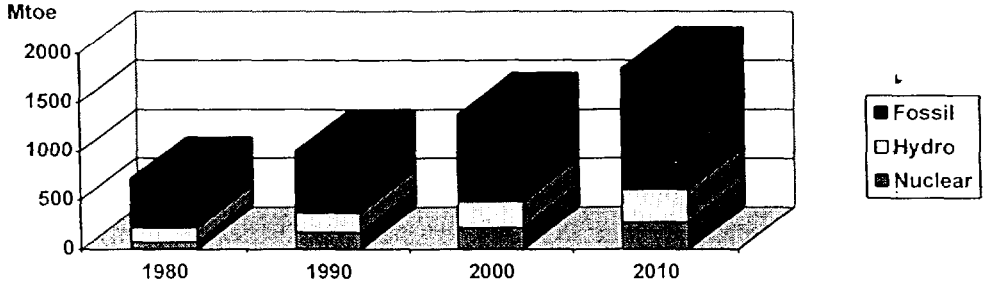

Figure 2 World gross electricity production

When calculating future carbon emissions resulting from fossil fuel combustion a projection of coal, oil and gas mixture must be given. It is expected that the share of oil in power generation is going to decline, accompanied with expansion of natural gas use [4], Figure 3. Furthermore, as the observed time period is relatively short in terms of major technology breakthroughs, no change in electricity generation efficiency is supposed.

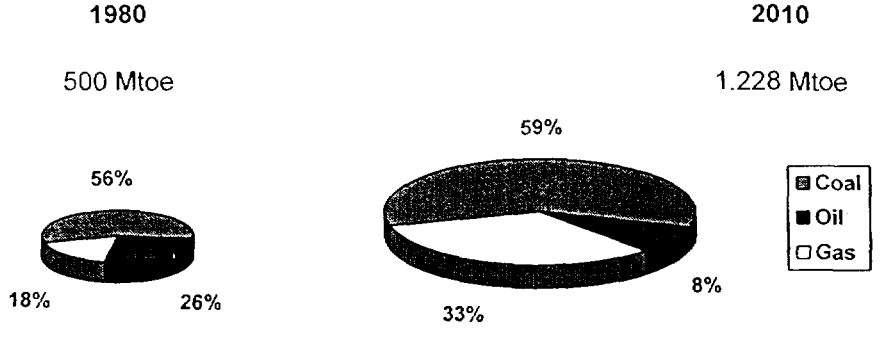

Figure 3 Fossil fuels input to power generation

The global carbon emissions in the year 2010 will equal some 8.800 Mt [5] with more than 3.100 Mt originating from fossil-fuelled power stations (Table 4), which is a significant value compared with the total carbon emissions. If all the electricity were produced in fossil-fuelled power plants and under the assumption that each of the fossil fuels would maintain its projected share in power generation input, the total carbon emission from power sector would

be some 33% higher, i.e. around 1.000 Mt of additional carbon would be emitted in the year 2010.

Table 4 Projected carbon emissions from electricity production, year 2010

	electricity produced (Mtoe)	primary energy (Mtoe)	carbon emission (Mt)
coal	725	2.175	2.185
oil	98	294	245
gas	405	1.215	700
total	**1.228**	**3.684**	**3.130**

If nuclear-intensive development scenario were adopted, and some 20 percent of total electricity were produced in nuclear utilities instead of in fossil-fuelled power plants, nuclear power plants would account for around 90 additional Mtoe electricity produced. In terms of carbon emission, this figure equals from 150 to 270 Mt carbon, depending on the type of fuel substituted.

Possibilities for carbon emission reduction in Croatia resulting from nuclear power use

Croatia is a country undergoing the process of transition towards a market economy. Such countries are also obliged to reduce greenhouse gases emission relative to the base year emission levels. However, to make the transition process less demanding, these countries are allowed to establish a base year or period other than 1990, depending on national economies trends and prospectives. Due to the war which was imposed to Croatia and subsequent decrease of economical activities, it is expected that Croatian authorities will choose 1990 as a base year for emission levels reduction.

Table 5 presents carbon dioxide emission in Croatia in 1990 with each sector percentage share in total emission [6]. It must be noted that the electricity sector situation in Croatia is somewhat specific: namely, several Croatian power plants are located outside Croatia, i.e. in other former Yugoslav republics. Emissions originating from these power plants must also be taken into account.

Table 5 Carbon dioxide emission in Croatia, 1990

	thermal power plants*	industry	fuel production and distribution	general consumption	mobile sources	total
CO_2, t/yr	3.748.700*	7.763.535	439.070	4.264.151	4.525.270	23.807.167
%	15,7	32,6	1,8	17,9	19,0	100,0

* only TPPs located in Croatia

Around 3.313 GWh of electricity consumed in Croatia in 1990 was produced outside the country in lignite fired power plants owned by Croatian Utility [7], which caused additional 3.730.500 t of emitted CO_2. It is expected that the emission level relative to which future reductions will be calculated will be established by adding this value to the emission originating from power plants located in Croatia. If so, the 1990 CO_2 emission level for Croatia will equal 7.479.200 tons and the needed 5% reduction will be about 7,1 Mt.

The average annual increase of future electricity consumption in Croatia for the period 2001-2030 is expected to be within 1,8 and 2,3 percent. The projected power system development based on the assumption that future consumption will follow the lowest of the forecasted paths is highly unlikely because it presumes consumer-side efficiency increase which is quite improbable in the near future. However, the estimations in this paper are all conducted under this assumption in order to illustrate what this, the most environmentally friendly scenario, means in terms of future carbon dioxide emission. The base year is 2001, with 2.840 MW installed capacity and 15,6 TWh production. At the end of the observed period, i.e. in the year 2030, the needed capacity will be 4.840 MW and the annual consumption 30,3 TWh.

The base case scenario is governed only by economic considerations, with no other limitation but natural gas availability. Namely, it is expected that future natural gas supply will not exceed 850 Mm^3; additional 200 MW in gas-fired TPPs will be owned by independent power producers. New power plants will be needed because of future increase in electricity demand and existing power plants decommission. Existing utilities retirement is favourable in terms of CO_2 emission because most of these plants are coal-fired high carbon emission facilities. The planned capacities, the type of fuel and the year of entering operation for the three discussed cases are presented in Table 6.

Table 6 Years of new capacities addition during the observed period for each of the analysed cases

fuel	imported coal		natural gas			nuclear fuel	hydro
capacity, (MW)	330	480	100	200	300	600	throughout the period
base case	2003*, 2006*, 2024, 2028	2022	2013	2003*	2011, 2014	2016	580 MW
case II	2003*, 2006*, 2026, 2030	-	2013	2003*	2011, 2015	2016, 2022	341 MW
case III	2003*, 2006*	-	2013	2003*	2011, 2014	2016, 2022, 2026	286 MW

* independent power producers

The expected carbon dioxide emission in the observed period is presented in Figure 4. Estimations show that at the turn of the century CO_2 emission will be somewhat higher than 5 million tons. If decisions on power sector investments were based only on economic considerations (base case), at the end of the observed period the annual CO_2 emission would be over 12,2 million tons which is intolerable in terms of planned emission reduction. Obviously, future power system development decisions must take into account other aspects beside power plants economics. Nuclear power is the only fully developed large-scale electricity production option which is able to cut down carbon emission. In case II, with two NPP installed, carbon dioxide emission in the year 2030 would not exceed 8,8 million tons. The reduction relative to the base case is significant, but not satisfying in terms of the Kyoto Protocol. Besides, after the year 2025 there is a substantial increase in CO_2 emission due to installment of two additional coal-fired plants (Table 6), a trend which must be changed. Therefore, a third case (case III) in which three NPP are projected has been introduced. In this case carbon dioxide emission is even lower and by the year 2030 will be reduced to the year 2000 level, i.e. to some 5,2 million tons, which is, at the same time, well below the 1990 emission level. However, the rise in emissions after the year 2030 is unavoidable and can be noticed in Figure 4.

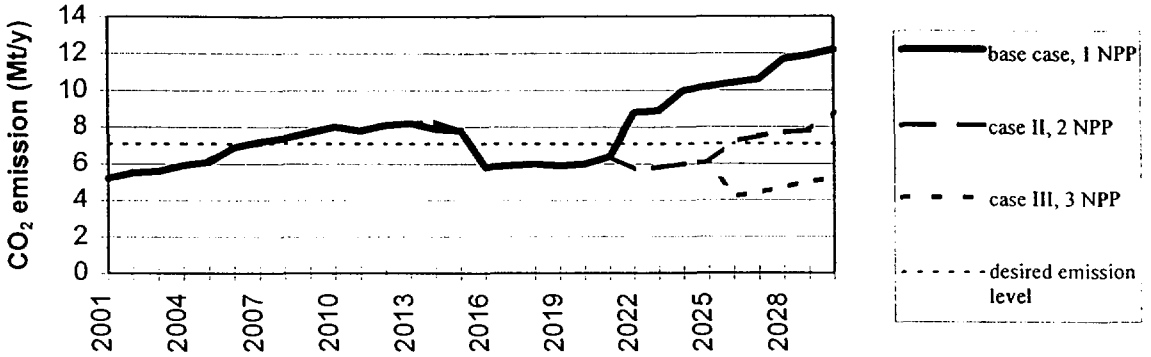

Figure 4 Carbon dioxide emission between 2001 and 2030 in the discussed cases

All the above mentioned figures are presented in Table 7. It must be kept in mind that the only purpose of the discussed cases is to assess nuclear power impact on carbon dioxide emission and not to anticipate future power system expansion.

Table 7 Comparison of CO_2 emission in the analysed cases with 1990 level and cumulative emission during the observed period (t)

	emission in 2030	cumulative emission (Mt)	emission in 1990	5% reduction	cumulative emission for the 1990 emission level (Mt)	5% reduction:
base case	12.184.694	236				
case II	8.785.280	204	7.479.200	7.105.240	224	213
case III	5.176.251	189				

As can be seen in Table 7, only the case with three installed nuclear power plants ensures the 5% emission reduction relative to the 1990 emission level. Another important issue is the cumulative emission over the observed period. When compared to the cumulative emission for the 1990 emission level between the year 2001 and 2030, it can be seen that some 10 percent reduction can be achieved if two NPP were installed (case II) and more than 18 percent reduction in case with three nuclear power plants.

It must be noted that all calculations here have been conducted under the assumption that the 1990 carbon dioxide emission level for Croatia will take into account emissions originating from Croatian power plants located outside the country. If that will not be the case, none of the analysed cases will be able to achieve goals in future emission reduction. Namely, the 1990 CO_2 emission would equal some 3,7 Mt, the 5% reduction would be around 3,5 Mt and the associated cumulative emissions would equal 111 Mt and 100 Mt, respectively. Throughout the observed period emission remains higher than 4 Mt in all three of the analysed cases. It has been calculated that even if four NPP were installed and the first entered the operation already in 2010, the CO_2 emission in 2030 would be 3,3 Mt. However, the associated cumulative emission is 152 Mt, which is higher than desired cumulative emission.

Conclusions

In facing up to man-made climate change, human beings are going to have to think in terms of decades and centuries. Many of the effects of climate shifts are still highly uncertain and will not be apparent for two or three generations, but it is already obvious that a number of human

activities give rise to the so-called greenhouse gases atmospheric concentration, which could eventually lead to rise in mean temperature at our planet.

The two most important factors enhancing environmental impacts of human activities are the expected population rise and the continuous rise of social standard, especially important in undeveloped countries and countries in transition. Because energy consumption is strongly related to the quality of life, and because energy use is one of the leading causes of carbon dioxide emission, future energy supply options must be thoroughly evaluated. Among various forms of energy necessary for modern life, electricity is the most capital intensive and centralised. Because of that, electricity sector has perhaps the most important place in the search for strategies to reduce greenhouse gas emissions.

Around 75 percent of total carbon emissions is attributed to fossil fuel consumption, in which electricity has its share of some 40 percent. If carbon emission is to be reduced, non-fossil fuel options for electricity production must be embraced. Today the only two large scale and economically competitive non-fossil electricity generating options are hydro and nuclear energy, the latter having the potential for large scale expansion. Nevertheless, although the technology is fully developed and commercialised, the political questions remain unresolved, primarily safety issues and waste disposal problem. Renewable energy sources, i.e. solar, wind, geothermal, tidal energy and biomass, also present a low-carbon electricity production option. However, due to economical considerations their present deployment is relatively low.

In assessment of potential nuclear power role in CO_2 emission in Croatia, three scenarios differing in the number of nuclear power plants installed have been evaluated. Under the assumption that future carbon dioxide emission levels will have to be 5 percent lower relative to the 1990 emission levels and that the 1990 emission level will also take into account the emissions originating from Croatian power plants located outside the country, only the hypothetical case with three nuclear power plants installed offers a possibility to reach and keep the desired emission level before the year 2030. In terms of cumulative emission, the case with two installed NPP allows for around 10 percent reduction relative to the cumulative emission if the annual emission were kept at the 1990 level throughout the observed period. At the same time, if three NPP were in operation, cumulative emission would be some 18 percent lower. It must be noted that the only purpose of the discussed cases is to stress out the difficulties the Croatian power system will have to face in terms of future carbon dioxide emission and not to anticipate its future expansion.

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