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ASSESSMENT OF ENVIRONMENTAL IMPACT OF NUCLEAR AND OTHER OPTIONS FOR ELECTRICITY GENERATION IN CROATIA

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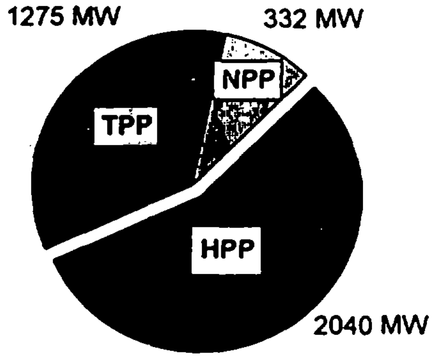
Abstract

Possible scenarios of future electricity production and supply, especially their environmental impact and social acceptability, have recently been put in the focus of overall interest. This paper analyzes the **air impact** and costs of possible developing options, **varying the fuel types** for future power plants. **Nuclear option** has also been taken in consideration. Two categories of costs have been introduced [1]: **internal cost** (investment, O&M and fuel cost) and **external cost** (monetary equivalent of the environmental damage caused by plant operation).

Main indicators of the Croatian power system



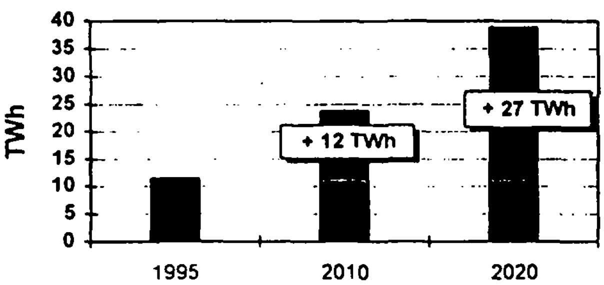
Croatian power system, with total available installed power of **3647 MWel**, can be considered small. At present, more than 50% of total installed power accounts for hydroelectric and less than 10% for nuclear power plants (Figure 1). Among thermal power plants, dominating are conventional and cogeneration plants, both oil-fired with the possibility of burning natural gas as an alternative fuel. Apart from that, natural gas is burned in the only two peak-load combined-cycle plants.

Figure 1. Structure of the generating facilities in the Croatian electrical power system

Due to the war in Croatia, electricity consumption dropped in the period 1990-1993 from 14,5 TWh to only 10,5 TWh [2], but afterwards it started recuperating, together with the normalization of the war issue. In 1995, electricity consumption was about 11,5 TWh.

Forecast of the future electrical demand

According to [3], Croatian GNP should rise in the period till 2020 by an average annual rate of 5%, in order to reach the pre-war GNP in the near future, preferably by the year 2000. Assuming that the elasticity coefficient between GNP and electricity consumption equals 1, **the needed increase rate of electricity consumption should be 5% per year** (Figure 2). Future peak load was estimated according to the same 5%-increase assumption.



	TWh	MW (peak)
1995	11,5	2000
2010	23,9	4000
2020	38,9	6500

Figure 2. Electricity consumption in years 2010 and 2020, based on 5% yearly increase rate

Remark: Elasticity coefficient represents a ratio between relative electricity consumption increase (%) and relative GNP increase (%). In developed European countries it is proven that elasticity coefficient is greater than 1, even close to 2. Value 1 is taken here as a minimal reasonable value.

Tool for calculation and evaluation

On the basis of electrical demand forecast, projections of the needed new generating capacities, as well as future developing scenarios have been made. **Emission (SO_2, NO_x, particulates and CO_2-equivalents) and cost calculation** for various developing options, that will be considered in the following text, are made using the **EM - The Environmental Manual for Power Development**, a software package recently developed in Germany and coordinated by the World Bank.

The purpose of the EM package is to evaluate environment and cost impacts of different energy projects and system expansion plans, and to identify environmental control options and suitable project alternatives. The EM model provides the **generic ("built-in") data base** in which relevant information about typical power plants and their supporting infrastructure is included. Generic data records are a substitute for information on energy options under consideration. Generic records can be used either unchanged for approximate calculations, or can be **adjusted to user's specific situation** for more accurate analysis.

Two time horizons: year 2010 and year 2020

In order to cover both the mid-term and the long-term projections, two time horizons and accordingly, two developing projections have been analyzed: the first one till the year **2010**, and the second one till **2020**. Only **additional** power plants needed till 2010 (i.e. 2020) are observed, that is emission and cost calculations have been made for additional capacity only. Further, it was assumed that none of the existing plants will be retired till 2020, although some of them are already close to the end of their life-time. Each developing projection consists of several options that differ in the shares of fuels for future power plants. Fuels under consideration are **low-sulfur coal (1% sulfur), natural gas** and **nuclear fuel**. It is important to point out that **no fuel restrictions** in the future have been assumed.

Each option assumes the same hydroelectric power of 184 MW, which is taken as a fixed capacity. It refers to two HPPs with best chances to be realized, but are not necessarily the only possible hydro-projects. Anyhow, new exploitable hydro-potential in Croatia is very limited, so any additional hydroelectric plant would not influence much on the need for thermal power plants.

Characteristics of the candidate generation units are given in Table 1.

Table 1. Characteristics of the observed generation units in future developing scenarios

PLANT TYPE	Capacity (MW)	η %	Investment[1] (US$/kW)	O&M cost[1] (US$/kW·a)	Fuel Price[1] (US$/MWh in)	(US$/GJ)
HYDRO - big	140	-	2000	40	-	-
HYDRO - medium	44	-	2500	50	-	-
NUCLEAR - PWR	600	33	2400	80	1,7	0,47
COAL/low S/ + ECT	300	37	1200 + 275 = 1475	30 + 17 = 47	7,2	2,0
GAS - combined cycle	200	46	700	14	16,2	4,5

ECT = emission control technology

[1] Investment and O&M cost data were taken from the EM generic data base, while fuel price from [4]

It is important to emphasize that emissions from the observed plants are all **in compliance with European Union's (EU) air standard**, that is, equipped with appropriate emission control technologies. The investment needed for desulfurisation (wet scrubber) is 263 $/kW, and for $DeNO_x$ device (SNCR) 12 $/kW, which makes altogether around 275 $/kW of extra investment to meet the existing EU regulations.

Developing strategies till the year 2010

By the year 2010 Croatia will need another **2000 MW of electrical power and 12 TWh of electrical energy**. In Table 2, there are listed four options of the new installed power regarding the used fuel: *gas*, *coal-gas*, *coal* and *nucl-coal-gas* option. Their names suggest the dominant fuel in each option. For instance, option 1 (called *gas*) includes maximal installed capacity in gas CC plants (eight units, 200 MW each, which makes 1600 MW of gas plants), while the rest accounts for one coal unit (300 MW) and two hydroelectric plants (together 184 MW). Option 4, called *nucl-coal-gas,* assumes one nuclear plant with rated capacity of 600 MW, while the remaining power demand is met by two gas units (400 MW) and three coal units (900 MW). Although the last, nuclear, option is rather unrealistic for such a short period, because of numerous reasons (one of them being public opinion disapproval), it was included just for comparison.

Table 2. Structure of the new generating capacities *till 2010* in MWel, regarding the fuel used

Option / PLANT TYPE	*1 (gas)*	*2 (coal-gas)*	*3 (coal)*	*4 (nucl-coal-gas)*
HPP	140 + 44	140 + 44	140 + 44	140 + 44
gas TPP	8 x 200	4 x 200	2 x 200	2 x 200
coal TPP	1 x 300	4 x 300	5 x 300	3 x 300
NPP	0	0	0	1 x 600

Results of the EM calculation - **airborne emissions** (SO_2, NO_x, particulates) and **greenhouse gases** (represented by the CO_2-equivalents) - are given in Figure 3. Particulates are given in a ten-time enlarged scale, while CO_2-equivalents in a 1000-time reduced scale, in order to fit the same graph.

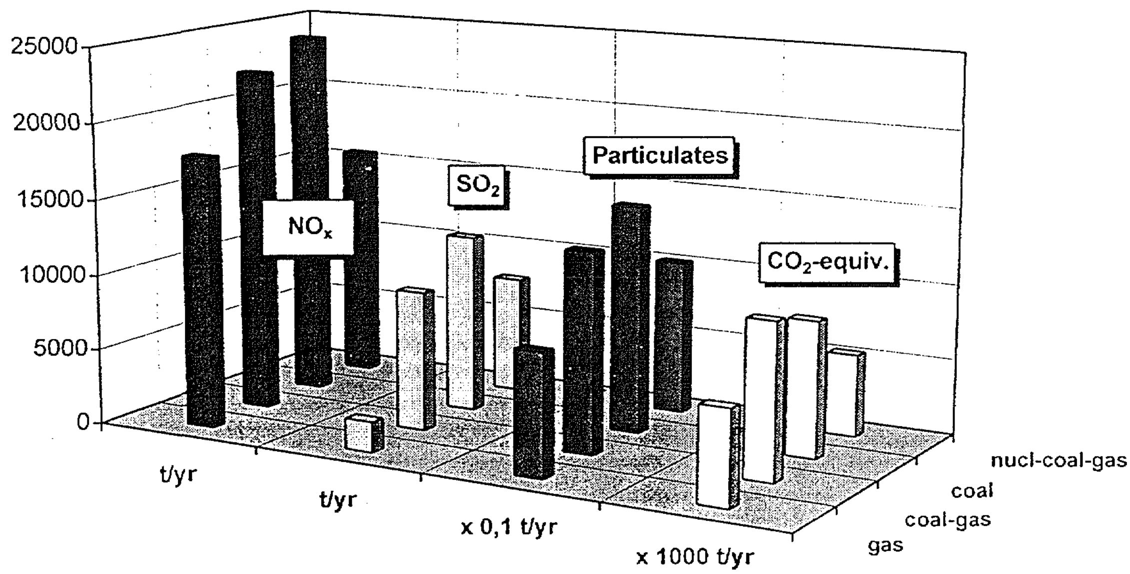


Figure 3. Airborne emissions and greenhouse gases for the *2010* scenario

As expected, the gas option is the most environmentally sound, while the coal option causes the biggest pollution. Since the nuclear option includes considerable share of coal plants (900 MW, see Table 2), it turned out to be the second best regarding the pollution. (Nuclear plants themselves do not cause any airborne emissions or greenhouse gases on the electricity generation level). It is confirmed once again that nuclear plants, apart from gas-fired plants, are best available solution for cutting down CO_2 emission. This fact is significant because there still exist no commercially justified direct methods for reducing CO_2 emission from a power plant.

Costs, expressed annually, are observed over a 30-year period (Figure 4). Real costs, called **internal**, include investment, operating and maintenance (O&M) and fuel cost. **External** costs are proportional to the level of pollution and represent equivalent monetary value of environmental damage due to construction and operation of the observed plants. Both internal and external costs are observed in **annual values** with an interest rate of 8%.

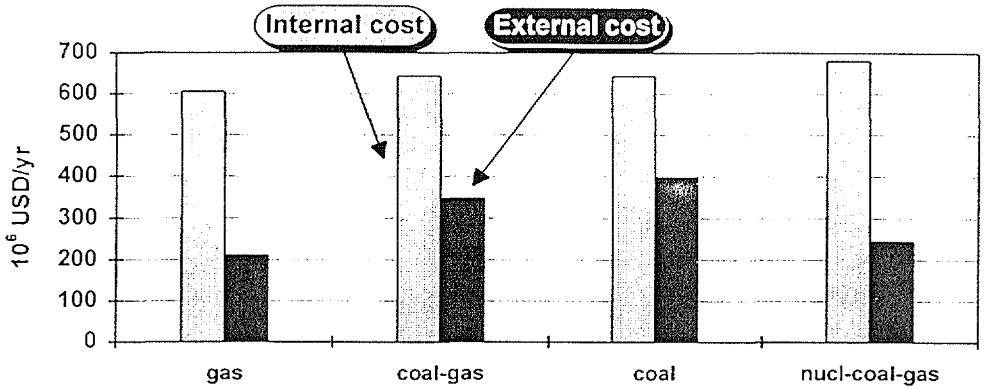


Figure 4. Internal and external costs of the generating capacities added till *2010*

Although the gas option has the lowest internal as well as external costs, uncertainty of future natural gas supply and dependence on import make the gas developing strategy unreliable. If external costs would be incorporated in the price of electricity, that is if they would stop being a virtual category, the coal option would definitely turned out the most expensive. One should keep in mind that **low-sulfur coal** (1% sulfur) has been used, and all needed emission control devices implemented. External costs would naturally be much higher if this was not the case.

Developing strategies till the year 2020

Assuming that electricity consumption will continue to grow with **5% escalation rate** after the year 2010 as well, Croatian electricity grid will need to expand quite rapidly: additional **4500 MW and 27 TWh/yr** (with respect to the present state) will be needed to meet the electrical demand in the year 2020. Since nuclear option should by all means be taken in consideration till 2020, options 1-4 include one or more nuclear power plants, while only the last option is completely non-nuclear (see Table 3). For example, option 1 assumes as much as 4 nuclear plants, 6 gas CC units and 3 coal plants, which is 2400 MW in NPPs, 1200 MW in gas and 900 MW in coal plants. As in every option, there is 184 MW of hydroelectric power also included. Options 2 and 4 both include 2 nuclear units, but differ in the share of coal and gas. Option 3 assumes only one nuclear plant and approximately the same capacity in coal (1800 MW) as in gas (2000 MW).

Table 3. Structure of the new generating capacities till *2020* in MWel, regarding the fuel used

Option / PLANT TYPE	*1 (nucl-max)*	*2 (nucl-gas)*	*3 (nucl-coal-gas)*	*4 (nucl-coal)*	*5 (no-nucl)*
HPP	140 + 44	140 + 44	140 + 44	140 + 44	140 + 44
gas PP	6 x 200	10 x 200	10 x 200	4 x 200	9 x 200
coal PP	3 x 300	4 x 300	6 x 300	8 x 300	9 x 300
NPP	4 x 600	2 x 600	1 x 600	2 x 600	0

As shown in Figure 5, the no-nuclear option (5) causes highest emission levels, even twice as high compared to nucl-max option (1). The effect of coal share is obvious: the wider usage of coal, the higher emissions.

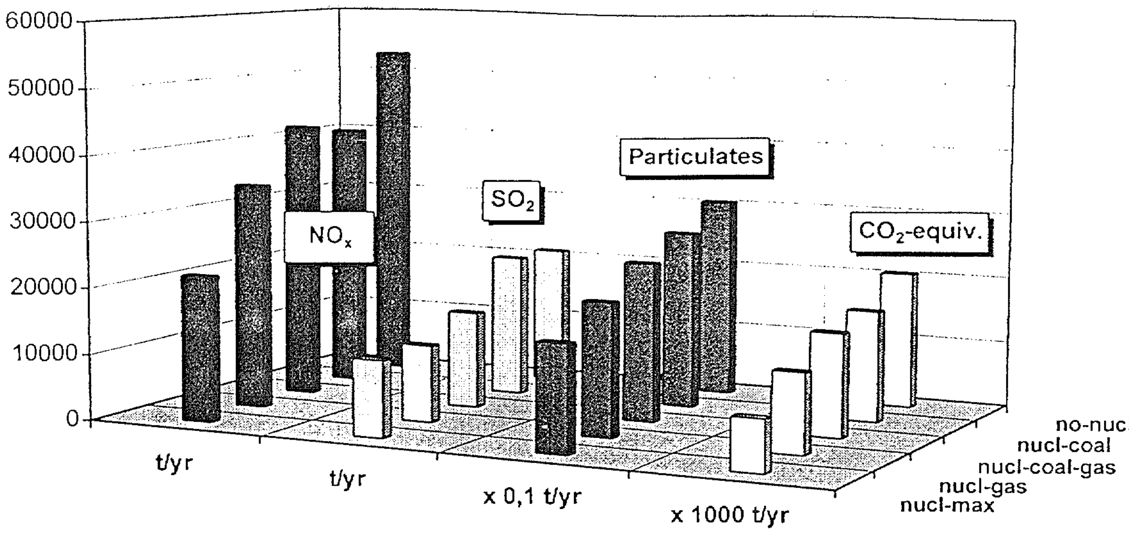


Figure 5. **Airborne emissions and greenhouse gases for the** ***2020*** **scenario**

Internal costs rise with the number of nuclear plants, while external costs act the other way round because they are proportional to emissions. Altogether, total costs are lower for "nuclear-friendly" options.

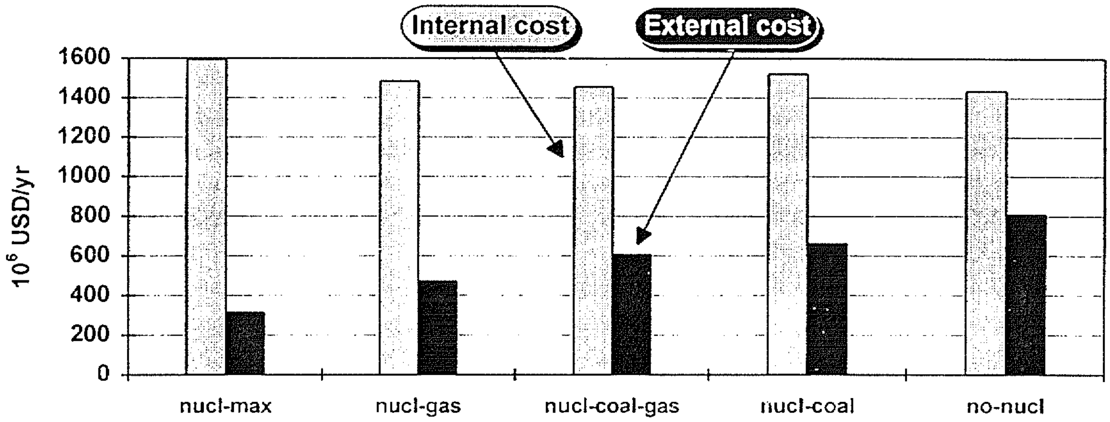


Figure 6. Internal and external costs of the generating capacities added till ***2020***

To find out how big would be the investment needed for emission control technology (ECT) only, one should multiply the specific ECT cost **(275 US$/kW)** by projected **capacity of coal plants**. (Only coal plants request mitigation measures, whereas gas plants are already in compliance with EU air standard, and need no additional ECT.) For example, if the coal units were represented by as much as 1500 MW (like the coal option in the 2010 scenario), an investment of some 400 million US dollars would be needed to equip them with appropriate emission control devices. Roughly speaking, about 15% of investment, i.e. of annual internal cost accounts for emission control, which certainly is a considerable expenditure.

Figure 7 indirectly shows the effect of imposed control measures and air standards on further emission trends. Here, **total emissions** in years 2010 and 2020 are presented, obtained as a sum of 1990-measured value and average additional value, resulting from our two developing projections. Ever growing emission trends indicate it will be practically impossible to "freeze" emissions (especially CO_2) at some level and keep them constant after a certain point in the future. As a result of strict regulations for SO_2, it will on average rise by some 0,6% yearly, even though the electricity production will rise at a rate of 5% per year. Unlike that, NO_x and CO_2 emissions will grow by some 6% per year. This means that SO_2 emission control is not only much more efficient than NO_x control (wet scrubber abatement factor is more than 90%, while SNCR abatement factor is only 50%), but also that imposed EU regulations are more restrictive for SO_2 than for NO_x.

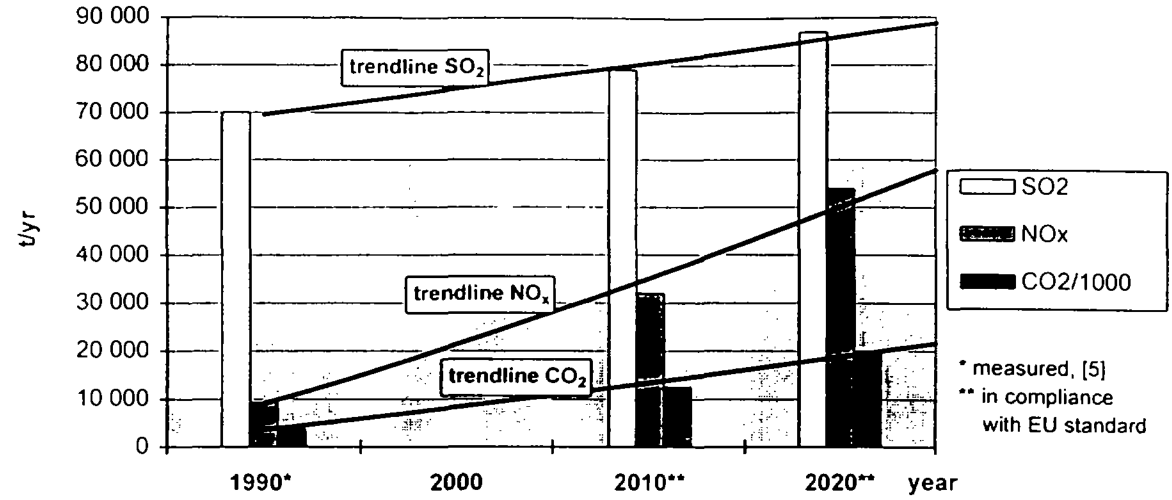


Figure 7. Emission trends based on average pollution level in the future

Given values in Figure 7 reflect a state where all **new** plants are equipped with sufficient ECT, but the **existing** plants do not have any ECT implemented. Although adding emission control in the existing coal and fuel-oil plants would help reduce emissions increase rate, more effective measures would be **orientation towards nuclear plants** as well as demand side management.

Conclusion

Assuming the 5% increase rate of electricity consumption in Croatia, several developing options till the year 2010, i.e., 2020 have been created, regarding the possible primary resources: **low-sulfur coal, natural gas and nuclear fuel.** Air emissions are proportional to the share of coal plants, since **coal plants are major polluters.** Hence, any non-nuclear option cause higher emissions than the nuclear option, because electrical demand has to be met by coal and gas plants. Till the year 2010, the most environmentally and financially acceptable would be **the gas option**, with the domination of combined-cycle (CC) plants. However, further intense increase of electrical demand in the period 2010-2020 would request a very large number of gas CC units, that would in turn not only enlarge the costs of the gas option but also cause location problems. Apart from that, there is an open issue of future gas supply and trying to reduce dependence on fuel import, all of that not being in favour of predominant usage of gas.

In favor of **nuclear plants** speak zero emissions on the plant level (supporting infrastructure as a part of the nuclear energy chain has not been considered), which means that NPP can be the solution for cutting down CO_2 emission. One of the reasons against the nuclear option is high investment needed. However, if environmental damage would have to be paid for (in form of external costs), it turns out that the cheapest would be exactly the nuclear option. Taking all the pros and cons in consideration, it would be necessary and reasonable **to include at least one nuclear power plant in the long-term construction plan** (till 2020).

References

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