Energy Institute
“Hrvoje Požar”, Ltd.
Zagreb, Croatia

EKONERG

# ENPEP – IMPACTS STUDY

## - draft report –

## CROATIA

**Project Leaders:**

Energy Institute Hrvoje Pozar

Damir Pesut M.Sc.

EKONERG Holding

Vladimir Jelavic, M.Sc.

**Authors:**

Energy Institute Hrvoje Pozar

Davor Percan, M.Sc.

EKONERG Holding

Zeljko Juric, B.Sc.

# ACKNOWLEDGMENTS

The authors would like to thank the Argonne National Laboratory (DIS) experts for help and support throughout this study: Mr. Guenter Conzelmann, Mr. Bruce P. Hamilton, Mr. Vladimir Koritarov and Mr. Tom Veselka together with Mrs. Lucille M. Langlois from IAEA.

Zagreb, December 1998

# CONTENTS


**I FOREWORD ........ 6**

**II INTRODUCTION........ 8**

**III BACKGROUND ........ 9**

**III.1 CROATIAN ELECTRIC SECTOR EMISSIONS** ........ 9
**III.2 AIR EMISSIONS**........ 9
**III.3 INTERNATIONAL COMMITMENTS AND REGULATIONS** ........ 14

**IV USE OF IMPACTS........ 16**

**IV.1 ANALYSIS OF DEVELOPMENT SCENARIOS**........ 16
*TPP Rijeka........ 17*
*IV.1.1 Scenario 1........ 19*
*IV.1.2 Scenario 2........ 19*
*IV.1.3 Scenario 3........ 19*

**V AIR EMISSIONS AND COSTS ........ 22**

**V.1 AIR EMISSIONS** ........ 22
**V.2 COSTS**........ 33

**VI CONCLUSION ........ 37**

# I FOREWORD

At present, a great task is before Croatia. It involves the restructuring of the electric sector in its legislative, institutional and economic aspect. The general approach to energy management is also bound to be changed. The completion of the afore is likely to determine the future development of the Croatian electric sector. An open electricity market, adequate legislation and developed institutions will be at the forefront of this process.

The elaboration of a long-term development plan (Master Plan) for the Croatian electric sector was one of the first steps in the restructuring process. Changes in the electric sector, a sub-sector of the energy sector, influence the overall energy system. That is why a systemic approach to electric sector planning is required. Nonetheless, any modeling process, including electric sector modeling, requires some simplifications. The process needs to reflect the relations and parameters which influence the electrical energy sector. The construction of generation facilities (but also distribution and transport) is very capital intensive. As a consequence, erroneous estimates in the planning process can negatively influence not only the electric system, but also the entire economy. Since planned capacity influences the allocation of capital, overcapacity in the system may result in a lack of capital in other sectors of the economy. On the other hand, undercapacity may result in underproduction, thus necessitating imports of electricity, often at less than favorable prices. This may limit the development of other sectors of the economy and the society in general.

The Master Plan covers the time between the years 2001 and 2030. It is for the first time that a plan is drafted for such an extensive period in the Republic of Croatia. The plan encompasses all the activities and features of the Croatian electric sector (production, transport and distribution). Estimating the future development of the entire sector involves the management of uncertainty. Uncertainty is managed by developing various assumptions regarding the future development of the electric sector and developing adequate input parameters. A set of parameters underlining a sector development assumption is called a **development scenario**. It is composed of input parameters which planners cannot influence (i.e. electricity consumption, the volume of capital investments in new facilities, etc.). **Development options** consist of parameters which can be influenced by the planners (i.e. the quantity of natural gas which, in a scenario, will be used for electricity production, etc.). In this report, for simplicity, all variations of input parameters will be labeled as **scenarios**.

The International Atomic Energy Agency (IAEA) has been implementing a Technical Cooperation (TC) Project on Energy and Nuclear Power Planning Study in the Republic of Croatia under the Agency s Reserve Fund since 1996. The main objective of the project is to upgrade the local capacity for energy, electricity and nuclear power planning. This is to be achieved by creating a core team of experts who would be able conduct planning studies under varying economic and technological development assumptions. The Croatian team is composed of experts from the Energy Institute Hrvoje Po ar and EKONERG Holding (Energy Research and Environmental Protection Institute). These institutions have been involved in national-level energy and electricity planning and research, and their experts have been trained in the use of the IAEA planning models (MAED, WASP, ENPEP, etc.) through their participation on regular training courses organized by the Agency. Argonne National Laboratory (ANL) has provided technical support and expertise in the use of the planning models. The expert group started work on the ENPEP IMPACTS model in April 1998.

The **EN**ergy and **P**ower **E**valuation **P**rogram (ENPEP) has been applied for integrated energy and environmental planning in the Republic of Croatia. The modules that are an integral part of ENPEP have been utilized both as stand-alone and in conjunction with other modules as described in this report. The IMPACTS module of ENPEP was used to analyze environmental impacts, environmental costs and resource requirements of specific energy system configurations. This draft report presents the Croatian national team s research experience in the application of the ENPEP IMPACTS model to the development of the Croatian electric sector.

Elaboration of the Master Plan for the Development of the Croatian Electric Sector Until 2030 and the Draft Energy Sector Development Strategy of the Republic of Croatia focused the attention of Croatian energy experts toward the future development of the electric sector. A significant amount of information on the Croatian electric sector and its features had to be gathered in order to prepare these documents. That is the reason why ENPEP IMPACTS focuses only on the electric sector and related emissions for the time being. In the future the model will also be applied to the analysis of other energy sector subsectors (i.e. transport, industry, housing ).

# II INTRODUCTION

The approach used in the ENPEP IMPACTS analysis was to develop an energy system configuration from technical and economic considerations. Once designed, its environmental impacts and costs were evaluated. Analysis focused on air impacts as air pollution mitigation measures and technologies are numerous and widely applicable. As a consequence, air pollution mitigation measures and technologies constitute a significant portion of overall development costs for new production facilities.

Regional and global environmental issues such as the greenhouse effect, ozone pollution, acid rains and others are another reason for taking a closer look at air emissions and their contribution to local, regional and global pollution. Waste generation, water impacts, noise, land take, visual and other impacts are more or less local in character and will be the subject of project-oriented environmental impact assessments.

Combustion of fossil fuels for electricity generation is an important source of air emissions. The main pollutants from combustion processes are sulfur dioxide ($SO_2$), nitrogen oxides ($NO_x$), carbon monoxide (CO), particles and greenhouse gases. Apart from their damaging influence on health, $SO_2$ and $NO_x$ are also known as acid gases due to their transformation during long distance transport into acid ingredients which leave wet (acid rain) and dry atmospheric sediment. Nitrogen oxides, in combination with Volatile Organic Compounds (VOC), generate a photo-oxidative gas ozone ($O_3$), with harmful impacts on health and vegetation. Toxic elements (e.g. heavy metals) and compounds are often bound with particulate matter, whereas $CO_2$ is thought to have the most prominent role in the global warming effect.

IMPACTS module of ENPEP can be used in a stand-alone fashion or in conjunction with other modules. In the analysis of the Croatian electric sector development scenarios, the module was used in conjunction with ELECTRIC. For each of the development scenarios, an expansion plan that adequately meets demand for electric power at minimum cost was elaborated. IMPACTS module was then used to estimate air impacts and air pollution costs for each expansion scenario. Experts from EKONERG Holding provided the emission factors and other necessary environmental data for existing and planned power plants.

This report will provide an overview of the basic features of the Croatian electric system with an emphasis on the thermoelectric system. Emissions from the Croatian electric sector will be presented, as well as international treaties and obligations in the field of environmental protection to which the Republic of Croatia is party. The report presents the assumptions and features underlying each expansion scenario in the period between 2001 and 2030. Environmental impacts (especially air impacts) of electric sector development scenarios are analyzed as well as emissions and costs associated with sulfur dioxide ($SO_2$) and particulate matter.

# III BACKGROUND

## III.1 CROATIAN ELECTRIC SECTOR EMISSIONS

The electric sector is greatly responsible for the present state of the environment on local, regional and global levels. Environmental impacts of all energy sources in the energy chain, ranging from energy generation to consumption, are diverse. Environmental issues include atmospheric emissions of pollutants, urban pollution, acid rain, high concentrations of ground ozone, global issues related to emissions of greenhouse gases and others.

Because of inadequate regulations, some Croatian facilities exerted a severe impact on the environment in the past. Legal obligation to perform environmental impact assessments represented a significant turning-point in 1986 when environmental impact statements could be found in a very limited number of European countries. One of the most significant examples of local pollution in the past involved high concentrations of sulfur dioxide around Plomin TPP at a time when only coal with a high sulfur content from the Rasa coal mine and low chimneys were utilized.

It has to be emphasized that national energy sector emission balances published over the last few years include atmospheric emissions of pollutants. At the same time, the underlying principles in Croatian electric sector development planning are economic and environmental considerations. It is worth mentioning that the Croatian Electric Utility Company Hrvatska Elektroprivreda (HEP), has published a declaration as the first step in the establishment of a systematic environmental protection control according to the practices of modern Western companies and international standards (ISO 14000).

## III.2 AIR EMISSIONS

Hydro-meteorological and other factors largely determine the share of a particular energy source in electricity generation (Table III.2-1). Croatia is a country that depends mainly on hydropower to generate most of the electricity it needs. At the end of 1995, the Croatian power system had 2076 MW installed in hydro power plants.

**Table III.2-1. Electricity generation from different energy sources**

| Generation (GWh) | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|
| **Hydro** | 4287 | 4889 | 5164 | 7190 | 5260 |
| **Nuclear (Krško)** | 1875 | 2196 | 2279 | 2180 | 2393 |
| **Thermal** | 4231 | 2568 | 2740 | 2522 | 3578 |
| **Import** | 460 | 1539 | 1221 | 166 | 1562 |
| **Total** | **10853** | **11192** | **11404** | **12058** | **12793** |

The total installed capacity in conventional thermal power plants, gas and diesel generating sets was, at the end of 1995, 1339 MW or 30 percent of the total installed production capacity for the Republic of Croatia. Thermal power plants were constructed according to the availability of primary energy or raw materials in the following locations: Plomin (hard coal), Jertovec (lignite, later fuel oil, then gas and combined cycle), Sisak (liquid fuel, petroleum products), Rijeka (liquid fuels, petroleum products and coke gas), Osijek (liquid fuel, petroleum products and natural gas) and Zagreb (liquid fuel, petroleum products and natural gas). Some of the above are designed as cogeneration facilities producing both electricity and heat. The cogeneration facilities are the backbone of centralized thermal systems in the cities of Zagreb and Osijek.

In 1997, the total electricity generated in Croatia was around 12,800 GWh. From this total, 41 percent can be attributed to the hydroelectric sector, 28 percent to thermal units, 19 percent to nuclear and 12 percent to imports. A certain growth in energy demand during the 1993-1997 period can also be observed.

The share of various fossil fuels utilized for electricity generation within the last few years can be observed in Table III.2-2.

**Table III.2-2. Ratios between fossil fuels in power plants**

| | Natural gas (%) | Fuel oil (%) | Coal (%) |
|---|---|---|---|
| 1993 | 42,6 | 48,4 | 9,0 |
| 1994 | 47,2 | 50,1 | 2,7 |
| 1995 | 19,3 | 74,3 | 6,4 |
| 1996 | 36,9 | 59,2 | 3,9 |
| 1997 | 29,9 | 57,7 | 12,5 |
| **Average '93-'97** | **35,2** | **57,9** | **6,9** |

Pollutants emitted from thermal power plants with the most significant environmental impacts are $SO_2$, $NO_x$, particles and $CO_2$. Change in $SO_2$, $NO_x$, particles, and $CO_2$ emissions from thermal power plants for the period 1980-1997 is given in Figure III.2-1. It can be seen that emissions from thermal power plants are declining, especially in case of sulphur dioxide. The reasons for this are a decrease in electricity production, a larger share of low sulfur fuel oil in fuel consumption (S<1 percent), use of coal mixture (import + domestic) and reduced operation of TPP Plomin.

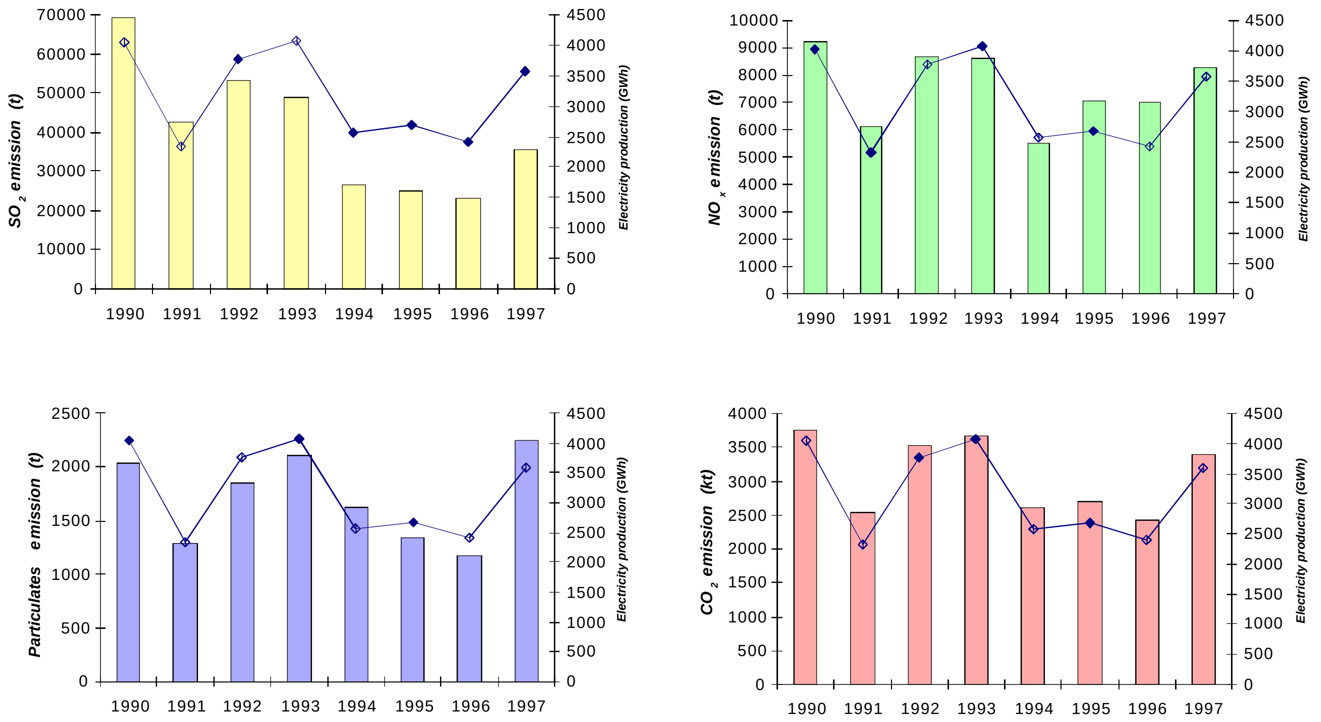



**Figure III.2-1 $SO_2$, $NO_x$, particles and $CO_2$ emissions from thermal power plants, 1980-1997**

The emissions of "acid" gasses ($SO_2$ and $NO_x$) can primarily be attributed to TPP Plomin (48 percent), TPP Rijeka (17 percent) and TPP Sisak (15 percent). Other thermal power plants participate with less than 20 percent in the emission of acid gasses. In comparison to 1990, emissions of $SO_2$ have decreased by 69 percent in 1997, $NO_x$ by 24 percent, particles by 42 percent and $CO_2$ by 35 percent.

Emission reductions for all pollutants, particularly $SO_2$, from thermal power plants are presented in Table III.2-3.

**Table III.2-3 Emission reduction of Croatian National Electricity Sector in year 1997 compared to 1990**

| | $SO_2$ | $NO_x$ | Particles | $CO_2$ |
|---|---|---|---|---|
| Emission reduction (%) in 1997 compared to 1990 | - 48,5 | - 10,3 | + 10,8 | - 9,5 |
| Reduction in power generation in TPPs (%) in 1997 compared to 1990 | - 11,4 | | | |

The reduction of emissions resulted from:

(1) decrease in power generation,

(2) higher consumption of low-sulfur fuel oil (S<1 percent), and

(3) the utilization of a mixture of domestic and imported low-sulfur coal in the Plomin Thermal Power Plant (the only coal-fired TPP in Croatia).

Thermal power plants account for between 24.8 and 49.7 percent of Croatian $SO_2$ emissions. Facilities owned by the Croatian Electricity Utility Company are responsible for 9.5 to 19.2 percent of total $NO_x$ emissions, and 14.1 to 15.7 percent of total $CO_2$ emissions (Figure III.2-2).

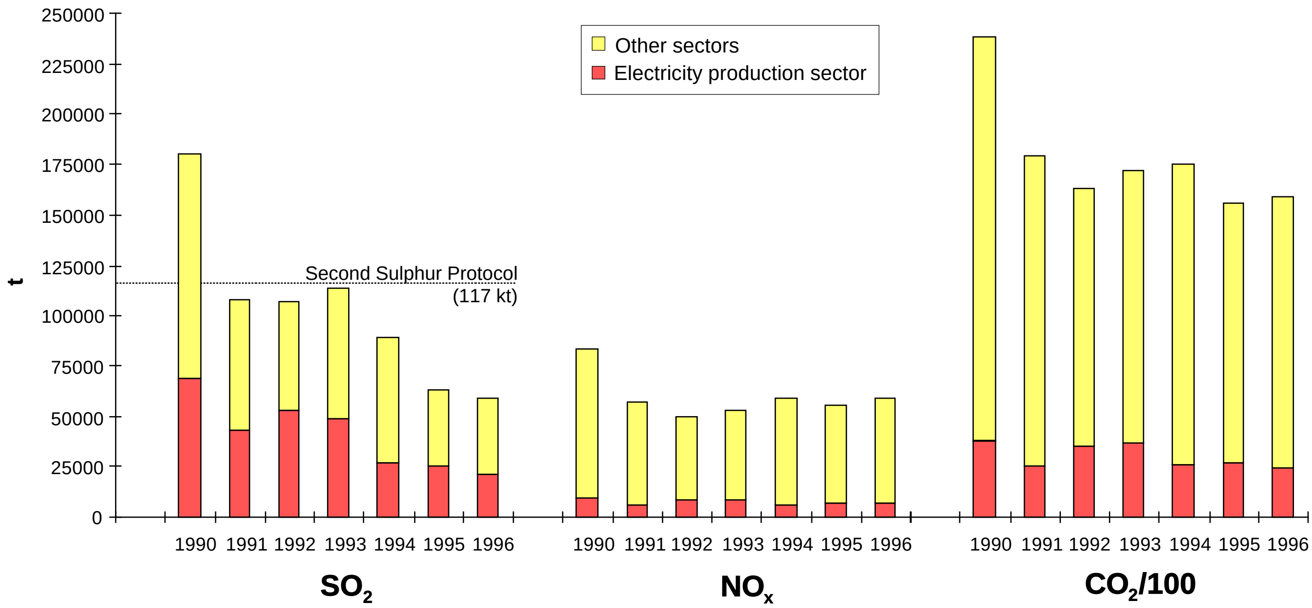
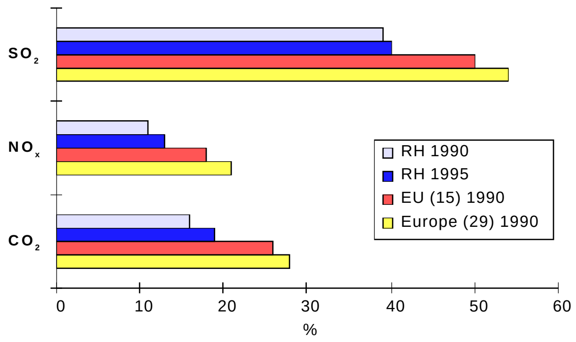


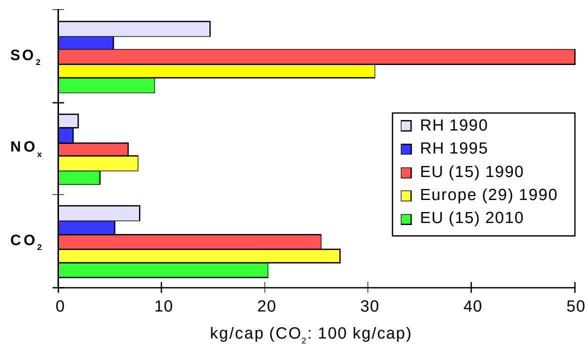

**Figure III.2-2 $SO_2$, $NO_x$ and $CO_2$ emissions from thermal power plants in comparison to total Croatian emissions between 1990 and 1996**

When comparing the contribution of the electricity sector to total emissions, the Croatian electricity sector is proven less damaging to the environment than is the case in European Union member countries (Figure III.2-3a).

Figure III.2-3b compares Croatian *per capita* emissions from the electricity sector with the European Union  s.The data on EU power sector emissions were taken from the CORINAIR database (Sector 01 from SNAP90 nomenclature). It can be seen that Croatian (HEP) emissions, compared to EU emissions are 1.6 times lower for $SO_2$, 3.5 times for $NO_x$, and 3.2 for $CO_2$.




a)




b)

**Figure III.2-3 Comparison of Croatian and EU emissions of electricity sector:**
**a) ratio in total emission**
**b) emission per capita**

Medium and long-range transboundary air pollution transport results in sulphur and nitrogen depositions as well as in high concentrations of atmospheric ozone which damages forests and crops. Sulphur and, particularly, nitrogen depositions exceed tolerance levels for woodlands, especially in the region of Gorski Kotar. The situation has changed in the past few years when all emission levels in Croatia considerably decreased. Calculations conducted under the auspices of the Convention on Long-Range Transboundary Air pollution (LRTAP) indicate that Croatia is an "importer" rather than an "exporter" of pollution. This has been particularly obvious during the last years, when emissions of all pollutants decreased by 10 to 50 percent. Figure III.2-4 illustrates sulfur emissions from the Croatian electric sector and the contribution of Europe and Croatia to sulfur deposition.

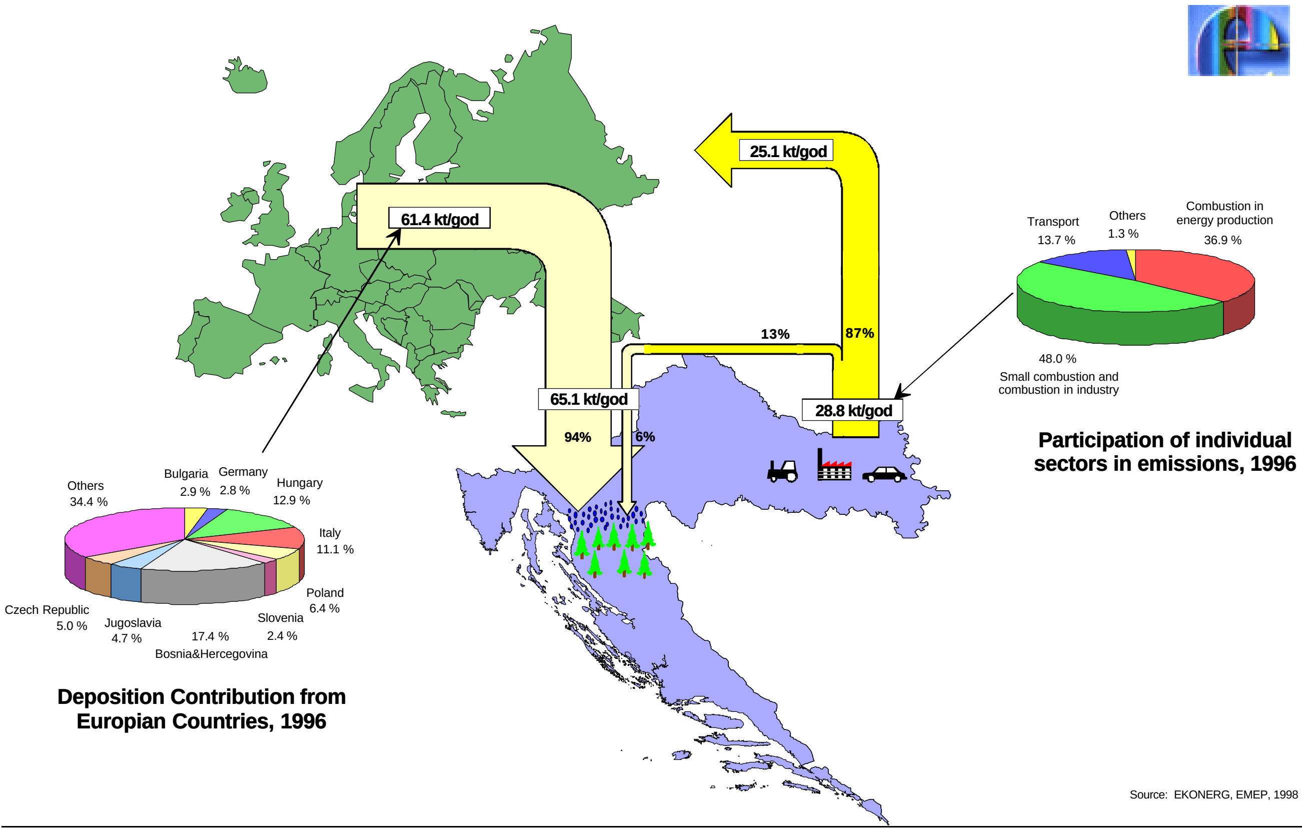



**Figure III.2-4 Balance of sulfur ($SO_2$-S) emissions and depositions in Croatia, 1996**

Figure III.2-4 shows that Croatian thermal power plants account for less then 3 percent of total sulfur deposits, and less than 0.3 percent of nitrogen deposits. These quantities are for the entire Croatian territory, and they should be considered as an order of magnitude relevant for the purpose of this report.

## III.3 INTERNATIONAL COMMITMENTS AND REGULATIONS

The most important international commitments undertaken by the Republic of Croatia regarding electric sector emissions are those under the Second Sulfur Protocol, and the Climate Change Convention (the abridged names of the protocols).

The Second Sulfur Protocol requests that, by the year 2010, $SO_2$ emissions in Croatia be reduced by 35 percent compared to 1990 (117,000 t in 2010). At present, the Second $NO_x$ Protocol is under preparation. If Croatia becomes a party to the Protocol, it will undertake new obligations pertaining to the regulation of $NO_x$ emissions.

The obligations under the Kyoto Protocol call for a 5 percent reduction of greenhouse gas emissions by 2010 in relation to the base year. Croatia has not yet defined a base year for the implementation of the Kyoto obligations; but if 1990 were selected as the base year, the *per capita* reductions would have an order of magnitude[1] of around 4.8 t $CO_2$.

[1] The value given is indicative for the purpose of this report.

# IV USE OF IMPACTS

## IV.1 ANALYSIS OF DEVELOPMENT SCENARIOS

The long-term expansion scenarios were based on projections of the future development of the Croatian economy. The assumptions concentrate around an average GDP growth rate of 4.85 percent *per annum* in the period between 1994 and 2025. Although industrial production growth rate is assumed to be lower than that of the GDP, industrial activity would increase in the planning period. Structural changes in the energy sector would result from a decrease of energy intensive industries from the present 30 percent to 25 percent in 2025. At the same time, a penetration of new technologies is expected which would result in a decrease in energy intensity for heating purposes.

An increase in the volume of trade is expected, as is a population increase from the present 4.77 million inhabitants to 4.87 million resulting from natural population growth and immigration. The population increase is required to follow the expected GDP increase. A population increase would most probably be accompanied by an increase in the number of households. A significant increase in new housing with improved isolation is also expected. An increase in the standard of living is expected to result in an increase of demand for heat and hot water accompanied by an increase in demand for electricity for non-heating purposes.

An increase in the volume of rail and road traffic is expected. The most significant increase is predicted to be in pipeline traffic. A distinct feature of energy sector development would be an intensive national-level gasification.

The described assumptions represent the basis for the calculation of electricity consumption. Once future consumption was predicted, it was compared to Croatia s total installed (effective) capacity which is, at present, 3728 MW. Of this total, only 1242,5 MW (33 percent) correspond to thermal generating units. Table IV.1-1 includes a description of existing thermal power plants as well as plants in construction and their respective retirement years.

**Table IV.1-1 Existing thermal power plants and plants in construction**

| Plant | Fuel | MW | Construction | Retirement |
|---|---|---|---|---|
| **TPP Rijeka** | fuel oil | 320 | 1979 | 2015 |
| **TPP Sisak (unit 1)** | fuel oil / natural gas | 210 | 1970 | 2010 |
| **TPP Sisak (unit 2)** | fuel oil / natural gas | 210 | 1976 | 2014 |
| **CHPP Zagreb East (unit 1)** | fuel oil / natural gas | 32 | 1962 | 2009 |
| **CHPP Zagreb East (unit 3)** | fuel oil / natural gas | 120 | 1979 | 2010 |
| **CHPP Zagreb East (combined-cycle)** | natural gas / e. l. fuel oil | 190 | 2000 | |
| **CHPP Zagreb West (unit 1)** | fuel oil / natural gas | 12,5 | 1970 | 2000 |
| **CHPP Zagreb West (unit 2)** | fuel oil / natural gas | 30 | 1979 | 2010 |
| **CHPP Zagreb West (gas turbine)** | natural gas / e. l. fuel oil | 2x25,6 | 1998 | |
| **CHPP Osijek (block 1)** | fuel oil / natural gas | 45 | 1984 | 2015 |
| **CPP Osijek (gas turbines 1)** | natural gas / e. l. fuel oil | 25 | 1976 | 2011 |
| **CPP Osijek (gas turbines 2)** | natural gas / e. l. fuel oil | 25 | 1976 | 2011 |
| **CCPP Jertovec (combined-cycle 1)** | natural gas / e. l. fuel oil | 44 | 1978 | 2012 |
| **CCPP Jertovec (combined-cycle 2)** | natural gas / e. l. fuel oil | 44 | 1978 | 2012 |
| **TPP Plomin (unit 1)** | coal | 125 | 1970 | 2015 |
| **TPP Plomin (unit 2)** | coal | 210 | 1999 | |

Electricity demand forecasts served as a basis for the development of production facility expansion scenarios. The expansion of production capacity will be needed to satisfy the demand for electricity and compensate for retired plants. The general planning objectives for calculating optimal expansion paths included:

- creating adequate domestic generating capacity to satisfy potential demand,
- abiding to Croatian environmental regulations (emissions of pollutants have to be below maximum regulated levels),
- diversification of energy sources. The principal sources in the planning period will be coal and natural gas with the possibility of examining the nuclear option in conjunction with other energy sources.

The above needs to be achieved sustaining minimal production costs. Table IV.1-2 presents three long-term expansion scenarios for the Croatian electricity sector. Candidate plants are labeled according to fuel types (GPP = natural gas powered plants, CPP = coal powered plants, HPP = hydro powered plants, NPP = nuclear powered plants) and capacity (MW).

**Table IV.1-2 Description of the analyzed expansion scenarios**

| *Year* | *Scenario 1 (104)* | *Scenario 2 (105)* | *Scenario 3 (106)* |
|---|---|---|---|
| *2001* | | | |
| *2002* | GPP300 | GPP300 | GPP300 |
| *2003* | | HPP-Lesce | HPP-Novo Virje |
| *2004* | | | |
| *2005* | | | |
| *2006* | GPP300 | HPP-Podsused | HPP-Podsused |
| *2007* | | GPP300 | |
| *2008* | | | NPP600 |
| *2009* | | HPP-Drenje | HPP-Drenje |
| *2010* | | | |
| *2011* | CPP480 | CPP480 | |
| *2012* | GPP300 | HPP-Novo Virje | HPP-Lesce |
| *2013* | | GPP300 | NPP600 |
| *2014* | | | |
| *2015* | GPP300 | GPP300 | HPP-Ombla |
| *2016* | GPP300 + GPP200 | GPP300 | 2 x GPP300 |
| *2017* | | | |
| *2018* | GPP100 | HPP-Ombla | HPP-Krcic |
| *2019* | | GPP200 | |
| *2020* | HPP-Ombla | | GPP300 |
| *2021* | CPP480 | HPP-Krcic | |
| *2022* | | CPP480 | GPP300 |
| *2023* | GPP300 | | |
| *2024* | | | |
| *2025* | | | |
| *2026* | | GPP300 | NPP600 |
| *2027* | CPP330 | | |
| *2028* | | GPP200 | |
| *2029* | | | |
| *2030* | HPP-Novo Virje | GPP200 | |
| *Total (MW)* | **3593** | **3694** | **3634** |

### IV.1.1 Scenario 1

Scenario 1 has a pre-defined ratio between gas powered plants and coal powered plants in total installed capacity of new units. Two thirds of the total installed capacity of new units are covered with gas powered plants, while one third are coal fired plants.

The prices of gas for this scenario are assumed to be US$ 3.9/GJ, while coal prices are estimated at US$ 1.8/GJ. Table IV.1-2 shows that the first facility is a gas power plant of 300 MW which would enter into the electric system in 2002. The second facility which was chosen for this expansion scenario is also a gas powered plant of 300 MW in 2006. The total capacity of gas powered plants in this scenario is 2,100 MW, while 1,290 MW is produced by coal and 203 MW by hydro power plants.

### IV.1.2 Scenario 2

Scenario 2 assumes a significant role of renewable resources and cogeneration along with an intensive construction of hydro power plants. It is difficult to plan the future development of new technologies for the utilization of renewable energy sources in a 30-year planning period. Nevertheless, having in mind strict environmental and other regulations that the energy and electric sectors will have to conform to, it can be expected that developed countries are likely to invest significant amounts of capital into the development of classical and renewable energy and electricity generation technologies. Croatia is likely to follow the practice of many European Union countries which have already initiated the promotion and stimulate the use of renewable energy sources.

Looking at candidate hydro power plants from a purely economic perspective, they cannot compete with the feasibility of gas and coal fired plants. However, having in mind the fact that they are facilities requiring predominantly domestic technology and know-how thus stimulating the development of domestic industrial production and development, their role becomes increasingly significant. Moreover, although hydro power plants do impact the environment, the magnitude of impacts is lower than is the case with fossil fueled plants. Public opinion, which is an important factor that needs to be taken into account, also favors the use of hydro power over fossil fuels.

Scenario 2 assumes that electricity production from renewable resources (including cogeneration) will reach 3 TWh. It has also been assumed that every three years a hydro power facility enters into production. As in the other scenarios, the first plant to enter into production is a 300 MW gas powered plant in 2002. It has been suggested that the first hydro power plant entering into production be Le æe HPP because it is already in preparatory phase. Le æe HPP would be followed by Podsused HPP in 2006 and other plants until 2021 and the construction of KrŁiæ HPP.

### IV.1.3 Scenario 3

The obligations under the Kyoto Protocol require a 5 percent reduction in greenhouse gas emissions. Assuming that 1990 is taken as base year and that reductions will be distributed proportionally among all sectors of the economy, electric sector greenhouse gas emissions would also have to be reduced by 5 percent. Should the emissions quota not include emissions from thermal power plants owned by the Croatian Electric Utility Company on the territory of other states of the former Yugoslavia (Bosnia-Herzegovina and Serbia), the annual greenhouse gas emissions for the electric sector would be limited to 3,560 kt. Scenario 3 shows the necessary expansion structure if electric sector $CO_2$ emissions are to be maintained below Kyoto values.

The most distinctive feature of the scenario is the lack of coal fired thermal power plants. The scenario assumes that a hydro power facility will enter into production every three years. Another important feature of the scenario is the construction of three nuclear power plants in the planning period with the first plant entering into production already in 2009.

Nevertheless, should Plomin 1 and 2 thermal power plants remain in operation for the entire duration of their life-cycle, even such a structure of the Croatian electric sector would not be able to meet $CO_2$ emission levels. In some years, gas fired plants would have to take over a significant production quota if the emissions are to stay within limits. Otherwise, an additional nuclear power plant would be needed instead of two 300 MW gas powered plants.

By the year 2030 the installed capacity will be as shown in Figure IV.1-1, according to each scenario.

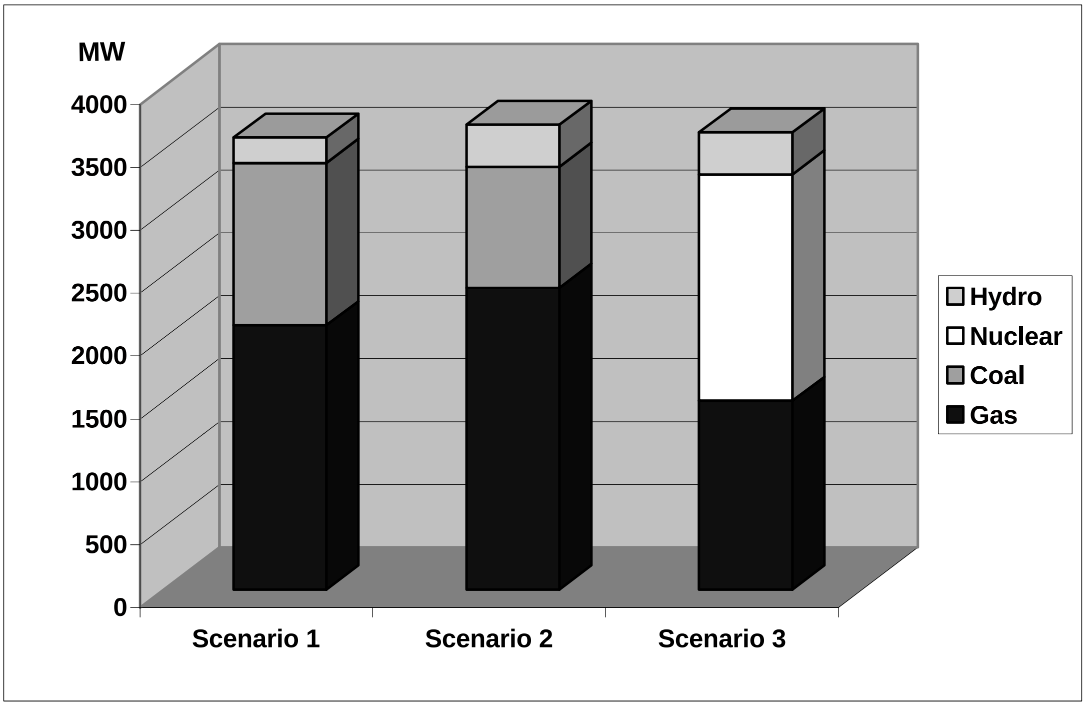



**Figure IV.1-1 Installed capacity across different scenarios (until 2030)**

To summarize, the construction of 2100 MW new gas combined cycle power plants, 1350 MW new coal thermal power plants and two hydro plants is planned in scenario 1. Greater utilization of renewable energy, cogeneration and vigorous construction of hydro plants is foreseen in scenario 2. Scenario 3 is oriented toward the decrease of $CO_2$ emissions, and meeting Croatian targets within the framework of the Kyoto protocol.

# V AIR EMISSIONS AND COSTS

## V.1 AIR EMISSIONS

Air emissions calculations were based on fuel consumption data imported from the ELECTRIC module of ENPEP. Emission factors (Table V.1-2), fuel characteristics, and the characteristics of pollution control technologies (for candidate thermal power plants) were defined in IMPACTS module and combined with fuel consumption data from ELECTRIC. It was assumed that the planned coal fired plants will be fitted with two basic types of control technologies: Electrostatic precipitators for particulate matter and wet scrubbers for $SO_2$.

Emissions calculations *do not* include fuel consumption for own use which is ca. 2 percent for gas fuelled facilities, ca. 3 percent for fuel oil thermal power plants and ca. 4-6 percent for coal fuelled plants. As a consequence, real emission levels are somewhat higher than indicated in the tables and figures.

### Sulfur Oxides ($SO_x$)

Emissions of Sulfur Oxides ($SO_x$) include sulfur dioxide ($SO_2$) and a smaller quantity of sulfur trioxide ($SO_3$). Sulfur oxides are the product of coal and fuel oil combustion. Quantities of emitted $SO_x$ are proportional to the sulfur content of the fuel. Nonetheless, it is estimated that around 95 percent of sulfur in the fuel turns into $SO_2$ during the combustion process.

Table V.1-1 and Figure V.1-1 show projected future $SO_x$ emissions obtained by performing IMPACTS analysis for three electric system expansion scenarios. Assumptions underlying model input data included a 1 percent sulfur content of fuel oil and a 1 percent sulfur content of coal. Wet scrubbers were assumed to be the sulfur control technology in the model, and their abatement efficiency was estimated at 90 percent for coal fired plants (the only exception being Plomin I TPP which, at present, has no installed control technology).

**Table V.1-1 Projections of $SO_2$ emissions for the analyzed expansion scenarios**

| | *1990* | *1995* | *Future Emissions (tons)* | | | | |
|---|---|---|---|---|---|---|---|
| | | | 2001 | 2005 | 2010 | 2020 | 2030 |
| *Emissions* | 69,434 | 25,090 | | | | | |
| *Scenario1* | | | 19,555 | 18,101 | 18,206 | 3,138 | 6,805 |
| *Scenario2* | | | 19,555 | 18,626 | 18,664 | 3,060 | 5,359 |
| *Scenario 3* | | | 19,555 | 18,626 | 13,502 | 786 | 806 |

**Table V.1-2 Emission factors.**

| *Facility* | *Sisak* | *Other Fuel Oil Plants* | *Dujmovaca* | *Other Natural Gas Plants* | *Plomin I* | *Plomin II* | *C330* | *C480* |
|---|---|---|---|---|---|---|---|---|
| ***Fuel Characteristics*** | Fuel Oil | Fuel Oil | Natural gas | Natural gas | Hard Coal | Hard Coal | Hard Coal | Hard Coal |
| ***Heat Content (MJ/kg or MJ/m$^3$)*** | 40,2 | 40,2 | 33,3 | 33,3 | 25,1 | 25,1 | 25,1 | 25,1 |
| ***Sulfur Content (%)*** | 1,0 | 1,0 | | | 0,5 | 1 | 1 | 1 |
| ***Ash Content (%)*** | | | | | 11,1 | 11,1 | 11,1 | 11,1 |
| ***Carbon Content (%)*** | 82 | 82 | | | 67 | 67 | 67 | 67 |
| ***IMPACTS Energy Assign-ment*** | PP4 1 | PP4 1 | GAS 1 | GAS 1 | CBI 2 | CBI 2 | CBI 2 | CBI 2 |
| ***Technology Characteristics*** | | | | | | | | |
| ***PM control efficiency (%)*** | | | | | 99,1 | 99,5 | 99,6 | 99,6 |
| ***$SO_X$ control efficiency (%)*** | | | | | | 90 | 90 | 90 |
| ***$NO_X$ control efficiency (%)*** | | | | | | | 50 | 50 |
| ***Emission Factors*** | | | | | | | | |
| ***PM (g/GJ)*** | 14,9 | 14,9 | 1,8 | 1,8 | 35,8 | 19,9 | 15,9 | 15,9 |
| ***$SO_X$ (g/GJ)*** | 480,7 | 480,7 | 0,9 | 0,9 | 405,7 | 79,6 | 79,6 | 79,6 |
| ***$NO_X$ (g/GJ)*** | 122,4 | 134,4 | 229,5 | 90 | 258,6 | 258,6 | 258,6 | 258,6 |
| ***$CO_2$ (kg/GJ)*** | 74,9 | 74,9 | 54,9 | 54,9 | 97,9 | 97,9 | 97,9 | 97,9 |

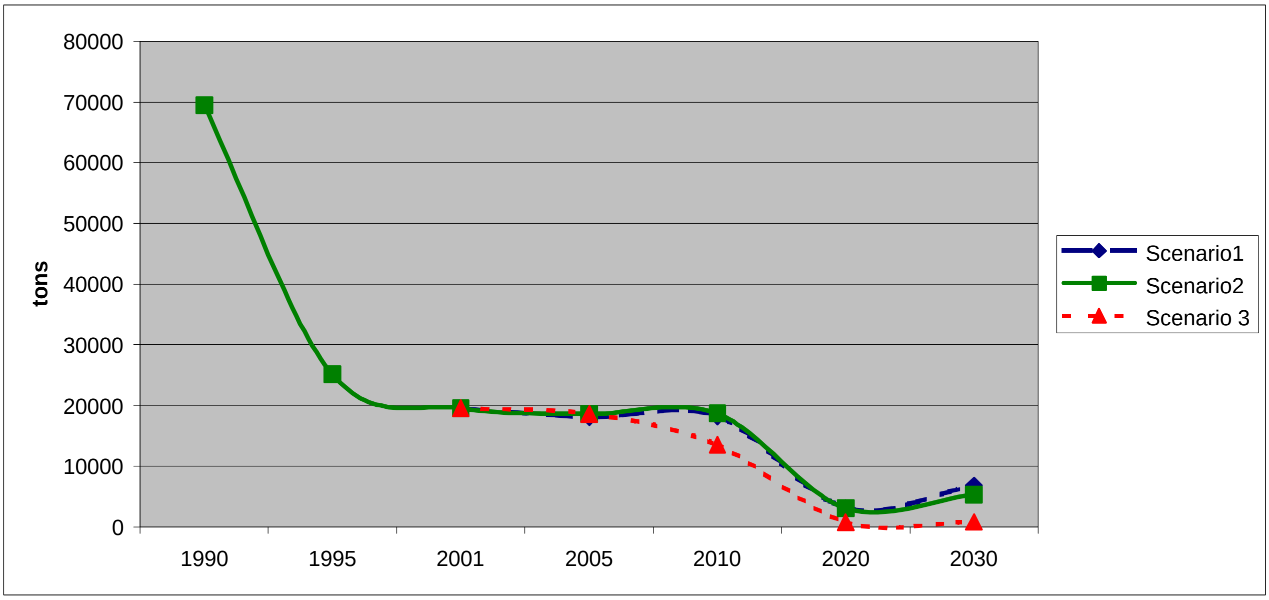



**Figure V.1-1 Projections of $SO_2$ emissions for the analyzed expansion scenarios**

It can be seen that $SO_x$ emissions decrease across the three scenarios in the analyzed planning period. The notable reduction in $SO_x$ emissions results from the retirement of fuel oil and coal power plants after the year 2010. Fuel oil and coal power plants would be substituted either with gas fired plants which have very small or no $SO_x$ emissions, or coal fired facilities utilizing coal with 1 percent sulfur content and wet scrubbers (with an assumed 90 percent $SO_x$ removal efficiency). The emissions reductions are especially visible in scenario 3 which has no coal facilities.

## Nitrogen Oxides ($NO_x$)

Nitrogen oxides are formed either by thermal fixation of atmospheric nitrogen in the combustion chamber or by oxidation of nitrogen which is present in the fuel. The primary product from nitrogen combustion is nitrogen 2-oxide ($NO_2$). Just as with sulfur oxides, all nitrogen compounds emitted through combustion processes in thermal power plants are expressed in terms of $NO_2$ molecular weight ($NO_X$).

Projected $NO_x$ emissions across the three analyzed expansion scenarios can be seen in Table V.1-3 and Figure V.1-2.

**Table V.1-3 Projections of $NO_x$ emissions for the analyzed expansion scenarios**

| | 1990 | 1995 | Future Emissions (tons) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 2001 | 2005 | 2010 | 2020 | 2030 |
| ***Emissions*** | 9,286 | 7,056 | | | | | |
| ***Scenario1*** | | | 11,268 | 11,956 | 13,216 | 13,101 | 19,498 |
| ***Scenario2*** | | | 11,268 | 12,130 | 13,381 | 12,418 | 18,331 |
| ***Scenario 3*** | | | 11,268 | 12,130 | 9,346 | 5,785 | 7,299 |

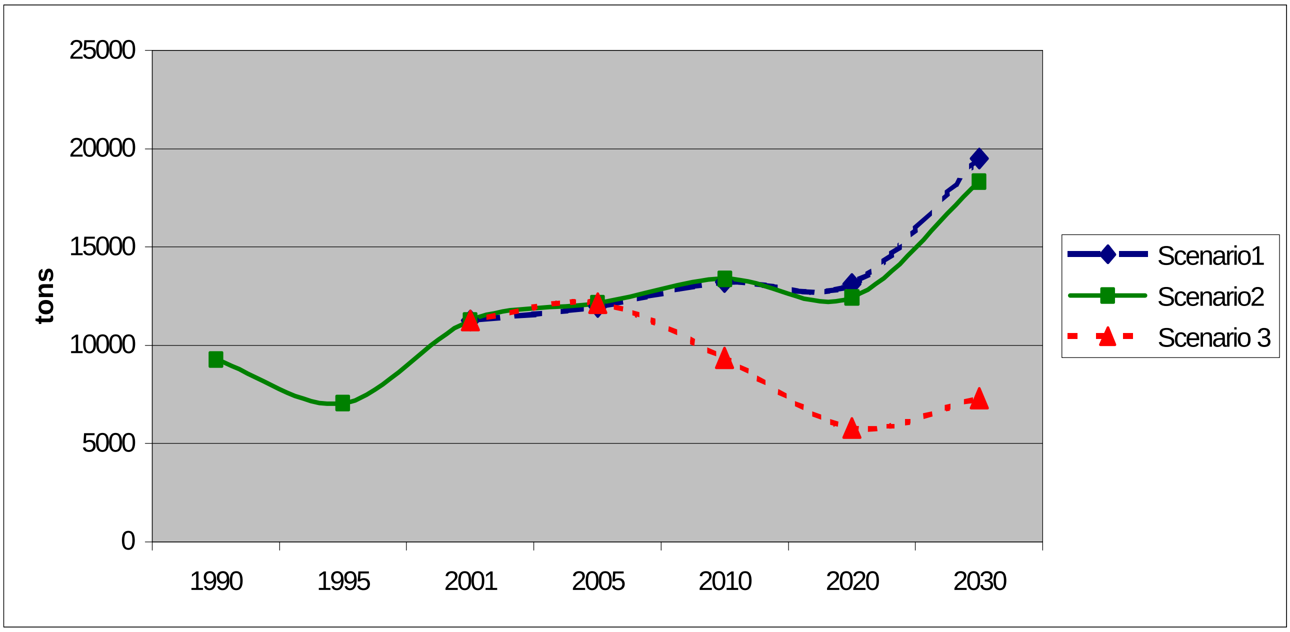



**Figure V.1-2 Projections of $NO_x$ emissions for the analyzed expansion scenarios**

Results of the IMPACTS analysis show an increase in levels of emitted nitrogen oxides across the first two analyzed scenarios. $NO_x$ emissions are decreasing solely in the third scenario which has restrictions on greenhouse gas emissions. Scenario 1 and 2 $NO_x$ emissions for 2010 almost double in relation to 1995. The same values are 42 to 44 percent higher than in 1990.

## Particles

Particles include those solid, liquid or gaseous elements (at process temperature and pressure) which are expected to turn into particulate matter once they reach the temperature and pressure of the natural environment. Emission projections for these pollutants can be seen in Table V.1-4 and Figure V.1-3.

**Table V.1-4 Projections of particles emissions for the analyzed expansion scenarios**

| | *1990* | *1995* | *Future Emissions (tons)* | | | | |
|---|---|---|---|---|---|---|---|
| | | | **2001** | **2005** | **2010** | **2020** | **2030** |
| ***Emissions*** | 2,031 | 1,342 | | | | | |
| ***Scenario1*** | | | 1,063 | 1,034 | 1,059 | 790 | 1,531 |
| ***Scenario2*** | | | 1,063 | 1,052 | 1,073 | 763 | 1,265 |
| ***Scenario 3*** | | | 1,063 | 1,052 | 805 | 252 | 284 |

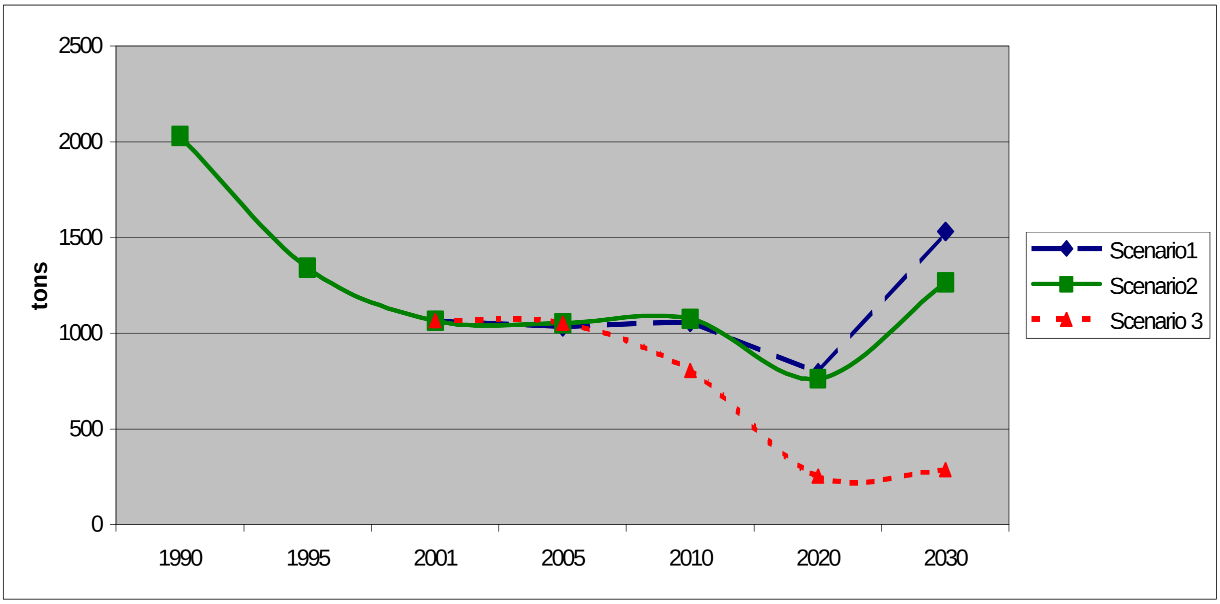



**Figure V.1-3 Projections of particle emissions for the analyzed expansion scenarios**

Emission values for particles remain around 1,000 tons for scenarios 1 and 2 until 2010 when they start to fall due to the decommissioning of existing thermal power plants. The notable rise in emissions of particles witnessed around 2020 can be attributed to the entry of new coal fired thermal power plants into production. Nevertheless, emission levels for particulate matter are low in comparison with other pollutants. Thus, it can be concluded that particles will have a predominantly local environmental impact in the future.

## Carbon Dioxide ($CO_2$)

Carbon dioxide emissions are generated mostly by combustion processes. Since a feasible technology to control $CO_2$ emissions does not exist, mitigation strategies are restricted to fuel substitution, use of efficient technologies, or the increase in the number of $CO_2$ sinks.

Table V.1-5 and Figure V.1-4 show $CO_2$ emissions from the three expansion scenarios. The third scenario has the lowest levels of $CO_2$ emissions since it was designed for that purpose in order for Croatia to be able to meet obligations from Kyoto.

**Table V.1-5 Projections of $CO_2$ emissions for the analyzed expansion scenarios**

| | *1990* | *1995* | *Future Emissions (kilotons)* | | | | |
|---|---|---|---|---|---|---|---|
| | | | **2001** | **2005** | **2010** | **2020** | **2030** |
| ***Emissions*** | 3,749 | 2,692 | | | | | |
| ***Scenario1*** | | | 5,173 | 5,645 | 6,419 | 7,808 | 12,729 |
| ***Scenario2*** | | | 5,173 | 5,735 | 6,510 | 7,444 | 11,557 |
| ***Scenario 3*** | | | 5,173 | 5,735 | 4,368 | 2,872 | 3,792 |

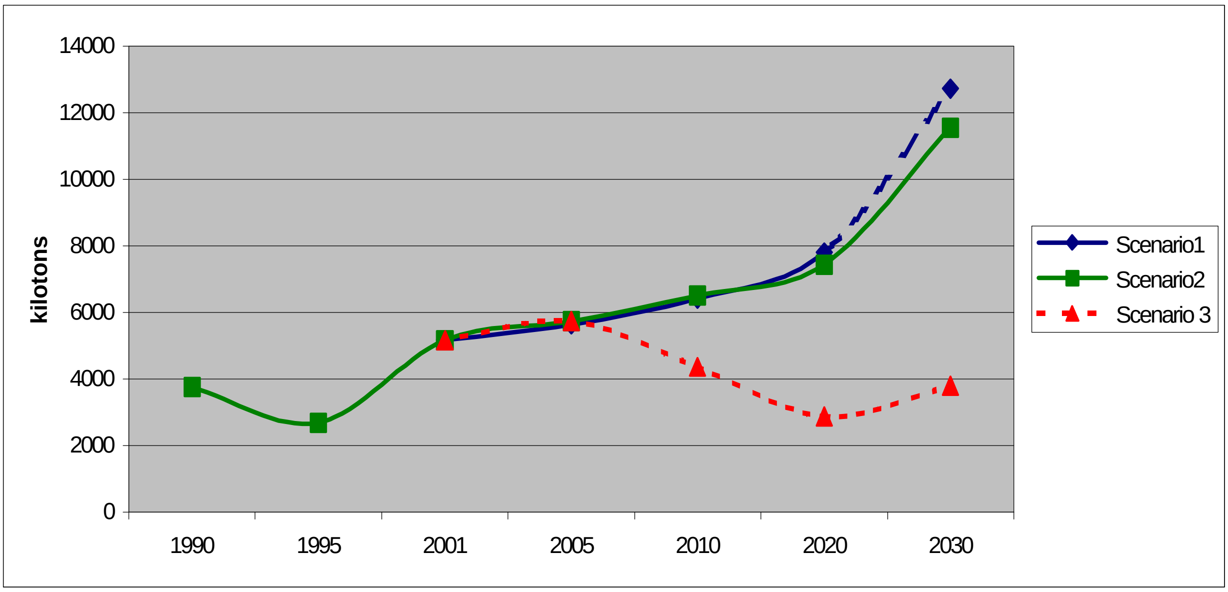



**Figure V.1-4 Projections of $CO_2$ emissions for the analyzed expansion scenarios**

Emissions of carbon dioxide increase for scenarios 1 and 2 reaching ca. 6,5 million tons in 2010 which is 1,7 times the emission in 1990. A notable increase in $CO_2$ emissions resulting from the entry of coal fired thermal power plants[2] can be observed after 2010. Emissions reach 12,7 million tons in 2030 for the first scenario (3,7 times the 1990 emission levels), and 11,5 million tons in 2030 for scenario 2.

Should emissions from coal fired thermal power plants owned by the Croatian Electric Utility Company outside the territory of the Republic of Croatia be added to 1990 emission levels, the reference emission level for Kyoto would rise to 7,5 million tons of $CO_2$. In this case scenarios 1 and 2 would conform to Kyoto obligations until 2010. However, emission levels after 2010 would be higher than permitted.

The electric sector expansion scenario that maintains $CO_2$ emission levels at 95 percent of the Kyoto Protocol reference year emission levels (should the reference year be between 1985 and 1990) is scenario 3. This scenario has the lowest $CO_2$ emission levels, and the lowest emissions in general. The scenario excludes the construction of coal fired thermal power plants, preferring the construction of hydro power plants and three 600 MW nuclear power plants which is highly unrealistic.

As it was previously mentioned in this report, power plants owned by the Croatian Electric Utility Company (HEP) are responsible for 14 to 25 percent of the Croatian $CO_2$ emissions which is considerably lower than the emissions from plants owned by Electric Utility Com-

---

[2] Scenario 1: One 480 MW coal fired plant in 2011 and 2021; and a 330 MW plant in 2027.
Scenario 2: One 480 MW coal fired plant in 2011 and in 2022.

panies of many European countries. Hence, if the Republic of Croatia wishes to conform to emission reductions agreed in Kyoto, the solution will have to be found outside the electricity production sector. The problem of $CO_2$ emissions and the role of the electricity production sector should be further examined and elaborated in order to be able to draft an adequate greenhouse gas abatement strategy.

**Comparison with other countries**

It is interesting to compare emissions from plants owned by HEP and plants owned by the Electric Utility Companies in other countries. Data concerning electric sector emissions for 1990 was available. Since then, EU countries reduced their $SO_2$ emissions by ca. 35 percent, $NO_x$ emissions by ca. 10 percent and $CO_2$ emissions by ca. 5 percent (total national emission levels). Figure V.1-5 displays a comparison between the three elaborated Croatian electric sector expansion scenarios, emissions from HEP plants in 1990 and 1995, and the emissions from the electric sectors of selected European countries. The values represent emissions per MWh of electricity delivered to the consumers.

Figure V.1-5 shows that Croatian $SO_2$ emission levels are far below the European average for each of the analyzed scenarios. It is estimated that European $SO_2$ emission levels will be reduced by an additional 60 percent until 2010, but the analyzed scenarios show that Croatian emission levels would also decrease. Croatian $NO_x$ emissions are also below European average and it is expected that they would reach average values even with a 40 percent decrease in European $NO_x$ emissions until 2010.

Croatian $CO_2$ emissions would reach levels planned in Europe for 2010 according to the Kyoto Protocol (92 percent of 1990 $CO_2$ emissions). After 2010, $CO_2$ emissions rise for scenarios 1 and 2 exceeding levels agreed in Kyoto.

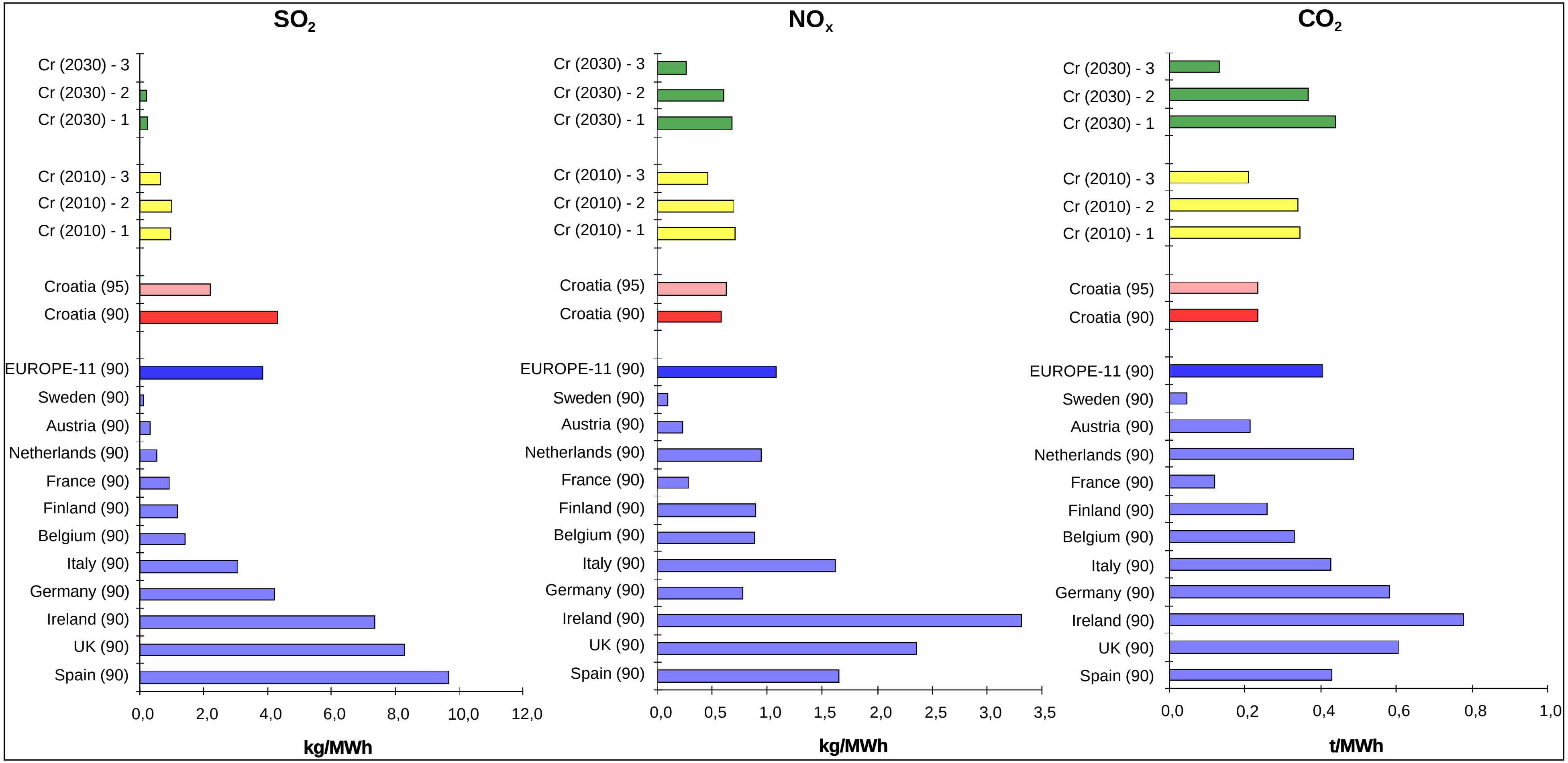



**Figure V.1-5 Electric sector emissions of SO2, NOx and CO2 for Croatia and selected European countries**

## V.2 COSTS

The cost analysis also focused on two major pollutants resulting from combustion processes in coal fired thermal power plants: sulfur dioxide ($SO_2$) and particulate matter.

Croatian legislation and relevant international treaties and conventions impose restrictions on emissions of all major pollutants including $SO_2$ and particulate matter. As it was already mentioned earlier in this report, pollution from heavy metals, waste and other pollutants, as well as noise, water, visual and other environmental impacts will be the subject of project- oriented environmental impact assessments.

It is expected that future coal fired thermal power plants will be equipped with pollution control technologies in order to be able to meet Croatian and international environmental standards and regulations. They will be fitted with electrostatic precipitators for the control of particulate matter and with wet scrubbers for $SO_2$ control. These pollution control technologies will entail certain capital and operational costs. It is important to quantify these costs in order to be able to weigh the costs and benefits of pollution abatement associated with each electric sector expansion scenario.

Combining data from ELECTRIC and IMPACTS modules, capital, operational and cumulative costs associated with the implementation of selected pollution control technologies were calculated. The calculations were performed for each coal fired thermal power plant individually, as well as for the entire electric system for the planning period. Costs were subsequently discounted in order for them to be comparable. For the purpose of this analysis, the costs were discounted to January 1st 2001. An 8 percent discount rate was applied to all calculations.

Plant-specific capital and O&M pollution control costs which were used for performing cost calculations with ENPEP IMPACTS are given in Table V.2-1.

**Table V.2-1 Plant-specific capital and O&M costs of pollution control technologies.**

| | PLO II | | C330 | | C480 | |
|---|---|---|---|---|---|---|
| | Part. ESP | $SO_2$ WS | Part. ESP | $SO_2$ WS | Part. ESP | $SO_2$ WS |
| ***Capital costs*** | | | | | | |
| ***US$/kW*** | 137 | 224 | 99 | 138 | 90 | 110 |
| ***US$/GJ*** | 1,3847 | 2,2634 | 1,4035 | 1,9552 | 1,3076 | 1,5968 |
| ***O&M*** | | | | | | |
| ***US$/kW (y-fix)*** | 0,09 | 0,99 | 0,07 | 0,63 | 0,06 | 0,51 |
| ***US$/MWh*** | 0,52 | 0,27 | 0,37 | 0,19 | 0,36 | 0,19 |
| ***US$/GJ*** | 0,0572 | 0,1446 | 0,0575 | 0,1314 | 0,0568 | 0,1126 |

## Particulate Matter Control Costs

Based on the above parameters, discounted cumulative costs for abatement of particulate matter were calculated using IMPACTS module of ENPEP. The results are presented in the figure below.

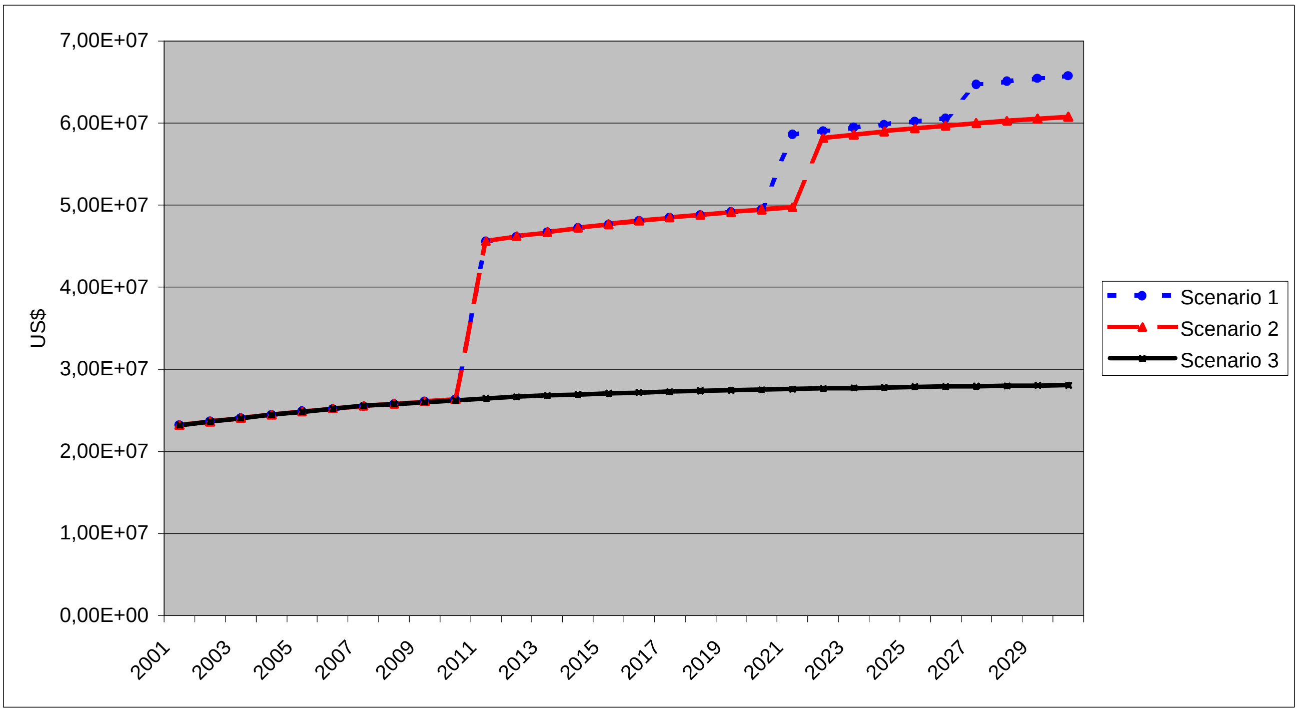



**Figure V.2-1 Discounted cumulative abatement costs for particulate matter.**

Scenario 1 shows three sharp increases in particulate matter control costs (2011, 2021 and 2027) which correspond to the entry of new candidate coal plants with particulate matter control technologies. The peaks are the result of capital costs sustained for the purchase and installation of the electrostatic precipitators. Scenario 2 has two cost peaks corresponding to capital costs sustained from the entry into production of two candidate plants in 2011 and 2022. Scenario 3, on the other hand, shows only capital costs associated with Plomin II TPP (US$ 22,7 million). The slow but steady cost increase across the planning period can be attributed solely to O&M costs for the Plomin II electrostatic precipitator.

Scenario 1 also has the highest value of avoided particulate emissions resulting from three coal fired thermal facilities in the planning period (Table V.2-2). Monetary values per ton of avoided pollution range from US$ 38 for the lowest emission scenario, to US$ 40 for the scenario with the largest number of coal fired facilities and highest emission values.

**Table V.2-2 Total avoided particle emissions and NPV for particulate matter control technology.**

| | Total avoided emissions (tons) | NET PRESENT VALUE | |
|---|---|---|---|
| | | Undiscounted emissions | Discounted emissions |
| | | US$/ton of part. avoided | US$/ton of part. avoided |
| ***Scenario 1*** | 4,997,083.0 | 10,2 | 40,1 |
| ***Scenario 2*** | 4,590,284.5 | 10,2 | 38,5 |
| ***Scenario 3*** | 1,346,294.9 | 16,0 | 38,4 |

## SO$_2$ Control Costs

Figure V2.-2 presents discounted cumulative costs for $SO_2$ abatement calculated with IMPACTS.

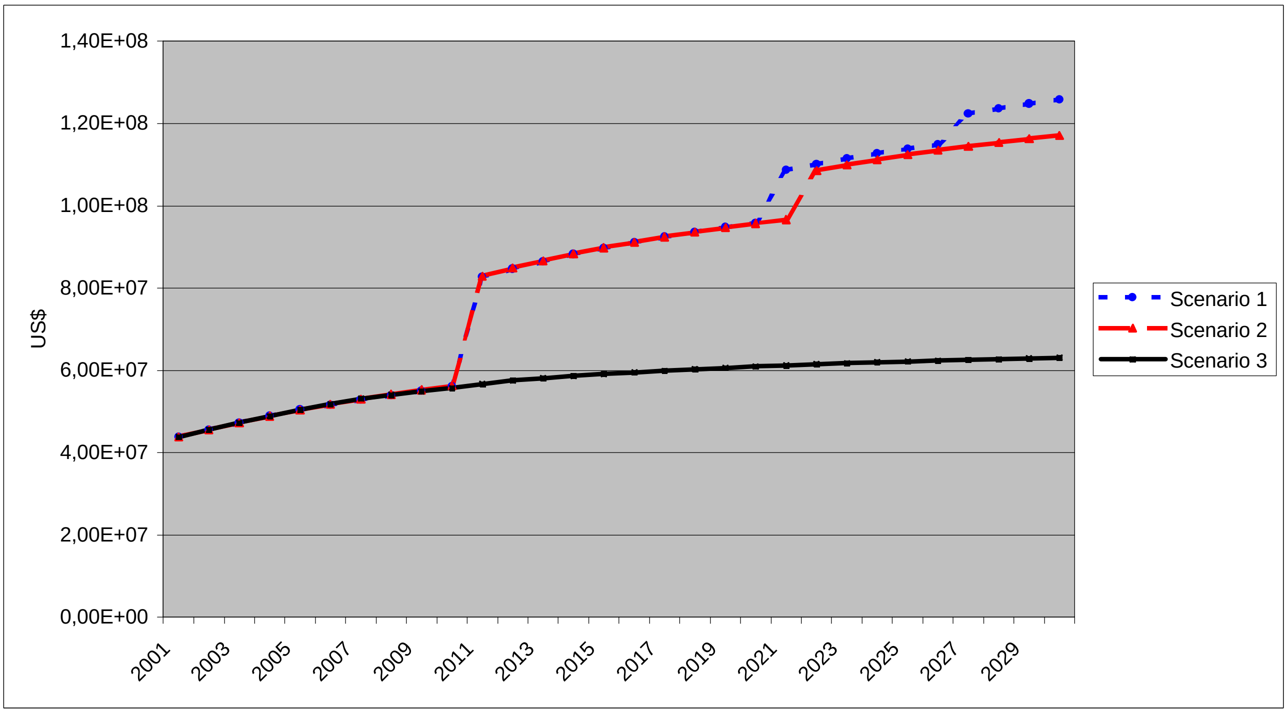



**Figure V.2-2 Discounted cumulative $SO_2$ abatement costs.**

Sulfur dioxide abatement costs show the same tendencies and properties as do costs associated with particulate matter albeit with different values. Total avoided particle emissions and NPV of $SO_2$ control technology are shown in Table V.2-3.

**Table V.2-3 Total avoided particle emissions and NPV for $SO_2$ control technology.**

| | | ***NET PRESENT VALUE*** | |
|---|---|---|---|
| | ***Total avoided emissions (tons)*** | ***Undiscounted emissions*** | ***Discounted emissions*** |
| | | US$/ton of $SO_2$ avoided | US$/ton of $SO_2$ avoided |
| ***Scenario 1*** | 903,341.8 | 89,8 | 354,8 |
| ***Scenario 2*** | 829,826.4 | 89,8 | 340,6 |
| ***Scenario 3*** | 243,550.9 | 166,6 | 400,9 |

# VI CONCLUSION

Results of this draft study show that, in order to meet projected electricity demand, the Croatian electric sector will need an additional 3500 3700 MW in new electricity production facilities (assuming that existing facilities remain in operation for the remainder of their life-cycle and that facilities currently under construction enter into production as planned).

Assuming higher permitted $CO_2$ emission levels, the first new plant to enter into the production system after 2001 should be a combined cycle gas power plant of 300 MW net output power. IMPACTS shows that gas power plants entail low pollution abatement costs (as far as particulate matter and $SO_2$ are concerned), and low emissions. The second preferable plant in the system is also a combined cycle gas power plant of 300 MW net output power entering in 2006 or 2007 depending on whether or not hydro power plants would be built (scenario 2). In general, natural gas as an energy source for electricity production is proven preferable over coal in environmental and economic analyses. The security of supply of adequate quantities of natural gas and the construction of an adequate transport and distribution system remain key questions when analyzing the future role of natural gas. The processes of demonopolization and liberalization of gas markets are likely to favor the utilization of natural gas for electricity production.

The retirement schedule of existing coal fired thermal power plants excludes the construction of new coal facilities before 2011 (scenarios 1 and 2). The construction of a coal fired thermal power plant of 480 MW net output power is needed in 2011 to meet an increase in demand caused by the retirement of existing plants. Analyzing the structure of production facilities in scenario 2, it is obvious that natural gas and hydro power are the preferred energy sources for electricity production. These sources are proven as most appropriate as far as emissions and abatement costs are concerned as can be seen from the conducted analysis using ENPEP IMPACTS.

A diversification of energy sources for electricity production is preferable and maintained in scenarios 1 and 2. The foreseen structure of utilized sources does not jeopardize the security of supply. In the period between 2010 and 2015, after the retirement of coal fired thermal power plants, a substitute energy source has to be found.

In this respect, scenario 1 offers the construction of a 480 MW coal fired plant and two 300 MW gas fired plants equipped with pollution control technologies, while scenario 2 foresees the construction of a 480 MW coal plant fitted with pollution control technologies, a hydro power plant and a 300 MW gas fired facility. The result is a steady decrease in $SO_2$ and particle emissions, and an increase in $NO_x$ and $CO_2$ emissions for both scenarios. These results have been obtained without taking into account the application of denox control technologies. Preliminary calculations suggest that the Second $NO_x$ Reduction Protocol will call for a 23 percent reduction of $NO_x$ emissions in relation to 1990. Croatia s probable ascession to the Protocol will call for an overall reduction of $NO_x$ emissions. The electric sector will, thus, also need to take action by applying control technologies or planning measures aimed at emissions reductions.

Results of the economic analysis of pollution prevention prefer scenario 2 because of its higher share of hydropower which has no associated pollution control costs. Results would probably differ considerably should economic calculations try to quantify externalities and impacts such as land-take, population relocation and other local impacts associated with the construction of hydropower facilities.

Scenario 3 foresees the construction of two hydro facilities and a nuclear power plant in the 2010 2015 period. This scenario shows the lowest emission levels and costs of pollution prevention. However, should the costs of radioactive waste transport, short-term and long-term storage be taken into account, the economic analysis would differ from the one obtained through ENPEP IMPACTS. The question of capital costs for the construction of nuclear power plants and the very fact that scenario 3 presumes the construction of three 600 MW nuclear plants in a 30-year planning period, makes it a very improbable course of action despite its environmental and pollution abatement cost benefits.

As far as the period beyond 2011 is concerned, all the scenarios predict a specific dynamism and structure of the Croatian electric sector. Nonetheless, the reliability of the predictions decreases with time as it is very probable that the input parameters will significantly change in such a long period. Today it is very difficult to predict the order and magnitude of that change.