ESTIMATION OF EXTERNAL COSTS OF ELECTRICITY GENERATION USING EXTERNE MODEL

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ABSTRACT

The external costs of electricity generation can be characterised by the resulting social and environmental impacts. The most significant impacts are the air pollutions impact on health, built in environment, crops, forests, agricultural areas and on global warming. The primary impact considered is the air pollution's effect on human health. The monetised value of the health impact, the external costs are calculated for two regional coal power plants, the effects are examined on the EU level with the ExternE methodology.

INTRODUCTION

External costs of electricity refer to the costs of damage imposed on society and the environment by an electricity generation chain, but not accounted for in the market price of electricity. Electricity generation impacts include effects of air pollution on health, buildings, crops, forests and global warming; occupational disease and accidents; and reduced amenity from visual intrusion or emissions of noise. Effects of air pollution on human health are the most significant among them. The equivalent monetary value of health damage, i.e. external cost, is calculated here for two types of fossil fired power plants, located in Croatia, with the analysis covering Croatian- and European-wide scope of effects.

METHOD DESCRIPTION

Because of their diverse character, electricity generation impacts are expressed in a common measure, so called external costs. External costs can be calculated using the so called impact pathway methodology, which relates to the sequence of events linking a "burden" to an "impact", and subsequent valuation. The impact pathway methodology consists of the following steps: (i) quantification of emissions, (ii) calculation of the associated ambient concentration increase by means of atmospheric dispersion and transport models, (iii) estimation of physical impacts using various exposure-response functions, and (iv) finally monetary evaluation of damages. The tool used to assess external costs caused by power plant operation is the EcoSense software (EcoSense,1997).

Focus of this analysis is put on the effects of ambient air pollution on human health, as one of the priority impacts of electricity generation. Since air pollutants are transported over large distances, crossing national borders, their impacts are quantified both for population in Croatia and for the whole of Europe. Europe is mapped onto a grid comprised of 100x100 km sized cells, i.e. receptors. Long-range transport and dispersion of pollutants is assessed by a Lagrangian trajectory model, which examines incoming trajectories of air parcels arriving from different directions to the receptor point. The outputs from the model are atmospheric concentrations and deposition of emitted species and secondary pollutants in each grid cell.

Incremental air pollution attributable to power generation is a mixture of pollutants emitted from stack (particulate matter, sulphur dioxide, nitrogen oxides) and those formed subsequently in chemical reactions in the atmosphere (sulphate and nitrate particles, and troposphere ozone). Both primary and secondary pollutants cause certain health effects, mostly connected to respiratory and circulation problems. Quantitative relationships have been established linking air pollution with health endpoints (Table 1). Acute effects occur on the same day as increases in air pollution or very soon thereafter, while chronic effects are delayed and develop as a result of long-term exposure. More susceptible to symptoms are older people and those who suffer from respiratory diseases, e.g. asthmatics.

Increased air pollution can not really cause 'additional' deaths; it can only reduce life expectancy. Length of life lost in cases of acute mortality is likely to be short - a few weeks or months. If mortality is caused by chronic illness, life reduction is considered to be several years. Here is the example of how additional mortality and restricted activity days can be calculated based on the given exposure-response functions:

Mortality (number of cases) = exposure-response factor/100 × baseline mortality × population of the observed area × pollutant concentration increase ($\mu g/m^3$).

Restricted activity days (number of days) = exposure-response factor/100 × population of the observed area × percentage of adults × pollutant concentration increase ($\mu g/m^3$).

Table 1. Summary of exposure-response functions and monetary values

Impact Category	Monetary value (ECU)(1)	Pollutant	Exposure-response factor (2)
Acute mortality (3) (expected life reduction: 9 months)	155.000	PM_{10} and nitrates $PM_{2,5}$ and sulfates SO_2	0,040% 0,068% 0,072%
Chronic mortality (3, 4) (expected life reduction: 12 years)	83.000	PM_{10} and nitrates $PM_{2,5}$ and sulfates	0,390% 0,640%
Hospital admissions, respiratory problems	7.870	PM_{10} and nitrates $PM_{2,5}$ and sulfates SO_2	$2,07\times10^{-6}$ $3,46\times10^{-6}$ $2,04\times10^{-6}$
Hospital admissions, cerebrovascular problems	7.870	PM_{10} and nitrates $PM_{2,5}$ and sulfates	$5,04\times10^{-6}$ $8,04\times10^{-6}$
Restricted activity days (4)	75	PM_{10} and nitrates $PM_{2,5}$ and sulfates	0,025 0,042

(1) mortality values given at a discount rate of 3%, based on years of life lost; 1 ECU = 1,25 US$ (1999).
(2) slope of the exposure-response function is expressed in percentage change in annual mortality rate per unit of pollutant concentration increase (% change per $\mu g/m^3$) for mortality, while in number of events per person per $\mu g/m^3$ for morbidity.
(3) baseline mortality in Croatia is 11 per 1000.
(4) age group 14-65, in Croatia 68% of total population.

Source: ExternE, 1997

Mortality impacts can be valued based on the willingness to pay (WTP) for reduction of the risk of death, or on the willingness to accept compensation (WTA) for an increase in risk. One year of life lost is estimated at 98.000 ECU, if no discounting is applied. If the discount rate is set to 3%, which is recommended for environmental damage valuation, money loss in case of acute death is 155.000 ECU, while 83.000 ECU if a fatal outcome is caused by a chronic illness. Morbidity impacts are valued based on medical treatment cost and lost wages.

Application of the Impact Pathway Method on Croatia

The aim of the analysis made here was to estimate costs of health damages through air pollution caused by two possible power generation technologies in Croatia in the near future: coal and natural gas fired facilities. Hypothetical power plants, one coal and one gas combined cycle (CC) unit, are assumed to comply with current domestic emission standards (Službeni list 140/1999), so the emission rates equal the upper emission limits. Both power plants are same in size, 350 MW net capacities. Their emission data are given in *Table 2*.

Table 2 Emission rates of the analyzed power plants

Emissions	Coal fired		Natural gas fired	
	mg/m^3	g/kWh	mg/m^3	g/kWh
Particulates	50	0,15	0	0
SO_2	400	1,21	0	0
NO_x	650	1,97	100	0,52
CO_2	2,84E+5	862	0,66E+5	344

It was observed how each of those two power plants, if placed at a certain location in Croatia, would affect (a) population in Croatia, and (b) the whole of Europe. Power plants were moved across the country to check how the external costs vary with location. To determine the health impacts on population in Croatia only, grid cells belonging to Croatia were isolated in the matrix of results. The total affected population in Croatia is 4.8 million, while in the whole of Europe around 540 million. Spatial distribution of primary and secondary pollutant concentrations, combined with population distribution and the appropriate exposure-response functions is used to calculate health impacts on the population in Croatia and Europe and the associated external costs due to operation of the observed two power plants.

After examining several locations, possible for future power plants, a range of external costs was obtained. Results are shown in Table 3. More detailed description of the method and the results can be found in (Feretić, 1999).

Table 3. External costs: summary of results

	Coal fired facility	Gas fired facility
Scope: Croatia only (4,8 million)	mUS$/kWh	mUS$/kWh
Particulates	0,29 – 0,33	0
SO_2 (including sulphates)	0,59 – 0,93	0
NO_x (including nitrates)	0,63 – 1,96	0,18 – 0,54
Total*	***1,51 – 3,22***	***0,18 – 0,54***
Scope: Europe (540 million)	mUS$/kWh	mUS$/kWh
Particulates	1,99 – 2,95	0
SO_2 (including sulphates)	13,93 – 15,72	0
NO_x (including nitrates)	23,59 – 28,10	6,91 – 8,16
Total*	***39,51 – 46,77***	***6,91 – 8,16***

• health damages due to troposphere
• ozone (precursor: NO_x) not included.

The obtained external costs comprise only health impacts due to airborne emissions (particulates, SO_2, NO_x). Impacts of ground-level ozone, which is caused by NO_x, and of global warming, caused by greenhouse gases, are not included. Due to lack of reliable ozone models, external costs of NO_x via ozone are set to the uniform value of 1.500 ECU per ton of NO_x for the whole of Europe. External costs of global warming are subject to large uncertainties, so they vary from 3,8 to 139 ECU per ton of CO_2. The geometrical mean value was taken as the best estimate for global warming damages: 29 ECU/t.

External costs of power generation in fossil fuelled power plants are obtained as the sum of (i) airborne emissions damages, which are site specific, (ii) ground-level ozone damages that are for now considered uniform for the whole of Europe, and (iii) global warming damages that are considered uniform in the whole moderate climate zone. Those numbers are given in Table 4.

Table 4. Cases depending on the level of external costs included in optimization

External cost (mUSD/kWh)		Case name
coal gas nuclear	3,22 0,54 0,1	External cost Croatia
coal: 46,77 + 3,69* gas: 8,16 + 0,98* nuclear	50,46 9,14 0,1	External cost Europe (including ozone damage)
coal: 46,77 + 3,69* + 30,05** gas: 8,161 + 0,98* + 12,47** nuclear***	80,51 21,61 0,1	External cost Europe-total (including ozone and global warming damage)

* due to troposphere ozone, ** due to global warming, *** based on Rabl et al., 1996

External costs can be included in power system expansion planning, i.e. selection of the optimal future capacity mix. They can be added to production costs of candidate generation units and in that way incorporated into the optimization goal function. Such exercise was conducted in the following analysis. The aim was to find the capacity mix with the lowest annual production costs, which still complies with the given requirements.

The effect of external costs on the optimal expansion plan

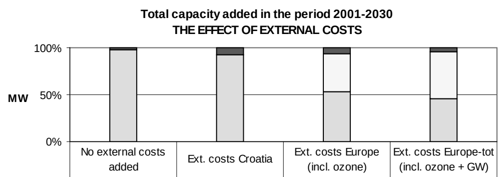
On the basis of electricity consumption forecast and scheduled retirements of the existing power plants, projections of the needed new generating capacities have been made [5]. It turned out that additional capacity of 4500 MW will have to be installed in the period 2001-2030. Fossil-fired (coal and natural gas) and nuclear power plants, together with several hydroelectric facilities, are chosen as candidates for system expansion. All candidate power plants are designed to comply with current environmental standards in Croatia. Coal units will be equipped with electrostatic precipitators for particulates removal and with wet scrubbers for desulphurisation. Low-NO_x combustion measures will be applied to reduce NO_x emissions to the allowable levels. The existing power plants will not be equipped with any additional emission abatement devices before they are retired.

Annual production costs are obtained as a sum of level fixed costs (comprised of annual capital cost recovery and yearly fixed maintenance cost) and annual variable costs (comprised of fuel cost and variable maintenance cost).

In the selection process of the optimal capacity mix in the following 30-year period four cases were observed, each with different external cost value added to direct costs of expansion candidates. In the first case no external costs were added, so the optimization was conducted based on direct costs only. In the second case, called *Ext. costs Croatia,* the calculation was made with the external cost for Croatia, as given in Table 3, which means that only damages within Croatia are taken into account. The upper value in the range was chosen following the conservative approach. The third case incorporated the external costs for the whole of Europe, plus the average ozone damage for Europe (*Ext. costs Europe*). In the fourth case, *Ext. costs Europe–tot*, the external costs from case 3 were increased by the value of global warming damages. The list of cases and the attached external costs is given in Table 4.

It has to be stressed that external costs are added only to candidate and not the existing units, because the purpose of this analysis was to examine the influence of external costs on resource selection and not on power system operation. Therefore, once the optimal capacity mix is determined, it is assumed that facilities are dispatched according to their direct costs, i.e. the economic loading order. In other words, external costs here are not meant to be imposed on any party, neither the producer nor the customer, and therefore should not affect the price of electricity.

The optimal capacity mixes in those four cases are shown in Figure 1, as cumulative values for the entire planning period. In all cases it is supposed that natural gas availability is unlimited.



	No external costs added	Ext. costs Croatia	Ext. costs Europe (incl. ozone)	Ext. costs Europe-tot (incl. ozone + GW)
HYDRO	83	326	286	180
NUCLEAR	0	0	1800	2400
GAS	4440	4140	2340	2140
COAL	0	0	0	0

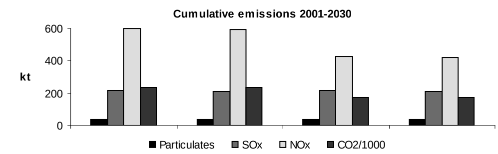


Figure 1. Total added capacity by fuel, depending on the external cost level

If no external costs are added, the optimal capacity mix consists only of gas CC power plants, since they have the lowest direct costs. Adding the external costs for Croatia would not affect the optimal solution much; because gas fired power plants would still have the lowest total costs. However, if the value of external costs is high enough, optimal expansion plan does get strongly affected. That happens in the third and fourth case, where European-level external costs are added. In the third case, where no global damages were included, three nuclear units enter the optimal capacity mix, whereas in the fourth case, where the global warming damages are also included in the cost function, optimal solution involves even four nuclear units.

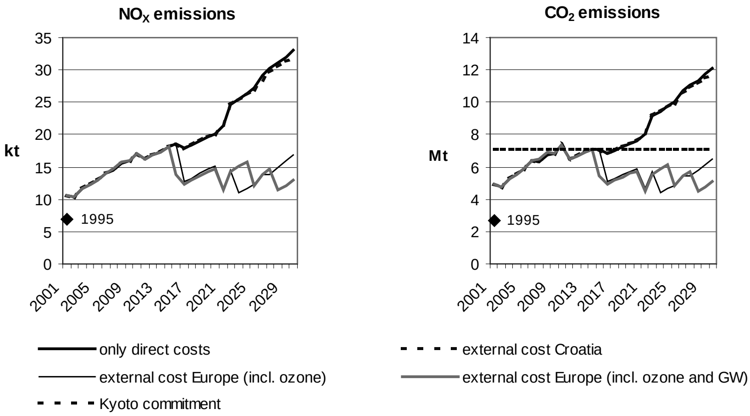


Figure 2. Emissions of NO_x and CO_2 in the observed period

The structure of new capacities is reflected on emission levels, as shown in Figure 2. If there are no nuclear facilities installed, emission follows an upward trend. Emissions of NO_x in the year 2001 are expected to be 10 kilo tonnes. During the observed period they would triple if only gas facilities are built. Only if more nuclear units are deployed, NO_x emissions could be kept at low levels, around 20-30% percent higher than today. Emissions of SO_2 and particulates in all of the observed cases are expected to drop to negligible amounts till the year 2030, because no coal or oil units are added.

An additional very important consequence is that CO_2 emissions are decreasing as well, although no direct measures to reduce CO_2 are applied. Croatian commitment in Kyoto is to start reducing total country's CO_2 emissions so that the average value in the period 2008-2012 is 5% lower than in 1990, and that the emissions are kept at that level afterwards. The corresponding requirement for the power sector is to reduce CO_2 emissions to 7,1 million tonnes per year. The average CO_2 emission in the period 2008-2012 would be around 6,8 Mt/year. This value is similar in all cases since bigger differences occur only in the second half of the planning period, due to the retirement of the existing units. Although the value is below the Kyoto limit, the rising emission trend suggests the goal of long-term reduction would not be met. Only the case with large share of nuclear power could keep CO_2 emissions below the Kyoto limit in the long run.

CONCLUSIONS

This paper is one of the first attempts to evaluate electricity externalities in Croatian power system, therefore the focus was put on priority impacts. Those are health effects of air pollution caused by coal and gas fired facilities, candidates for construction in the following 30 years. It has to be stressed that external costs of coal power plants can be lowered by further reducing their emissions, i.e. by applying more efficient abatement technologies already available on the market. Of course, that would induce some additional direct costs.

The results show that damages linked to coal power plants are much larger than those linked to gas fired facilities, since the latter are responsible only for NO_x emission and nitrates. The largest share in the damage costs accounts for mortality effects. The highest damages are attributable to particulate matter, on the local level directly while on the regional level in the form of sulfates and nitrates. Health damages highly depend on the number of people affected – that is why damages within Croatian borders are much lower than on the European scale.

When incorporated into electricity system expansion planning, the external costs that include only the population within Croatia do not significantly influence the optimal capacity mix, but the European-wide external costs do so in a great deal. In the latter case, the competitiveness of gas units is reduced in favor of nuclear units. It is very important to define geographical scope within which the impacts should be internalized, since that can seriously influence decision making in the country of emissions origin.

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