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COST-EFFECTIVENESS OF POWER PLANTS IN EASTERN EUROPE

An approach for estimating the cost-effectiveness of existing, retrofitted and new power plants

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Framework of the study

This paper describes a methodological study that is conducted in the framework of the project 'CO_2 emission reduction strategies for Eastern Europe', commissioned by the Dutch Ministry of Economic Affairs (project number 7124). Since CO_2 emissions are largely dependent on energy consumption and supply mix, an extensive study into the current situation and possible future developments in the energy sector in Central European countries has been started. Energy demand projections, energy supply, and energy technologies are researched.

The presented method concerns the identification of the cost-effectiveness of lifetime extension of existing power plants which can currently be observed in Central European countries. The method will be used in the country studies for the Czech Republic, Slovakia, Poland, and Hungary using the Linear Programming model EFOM-ENV/GAMS.

CONTENTS

1. INTRODUCTION

In many Western European countries, power plants are replaced or retrofitted after 25 or 30 years; just continuing the operation of an old plant hardly occurs, in most cases because it is considered to be uneconomic. This implies that in many cases operating an old plant in the Western situation is more expensive than building a new one. In some cases, retrofitting the old plant is the least-cost option.

In Eastern Europe very old (power) plants are kept in operation 'as long as possible'. Thirty to forty years is no exception. In the discussion on explanations of the different Eastern European practice, two arguments are often heard. The first argument concerns limited availability of financial resources in Eastern Europe as an explanation for the current lifetime extension of old, existing power plants. This argument is popular among Western European experts being their view or judgement of the situation. The second argument, advocated mostly by Eastern European experts, is that it is cheaper or more cost-effective to continue operating old, existing power plants instead of building new ones.

This paper will shed some light on the validity of both arguments. First, a summary of national cost-effectiveness analysis such as applied by EFOM-ENV/GAMS will be given. Second, potential arguments pro and contra operating old plants will be summarized and discussed in terms of national cost-benefit analysis. Third, a set of modelling assumptions for appliance in EFOM-ENV/GAMS for the programme 'CO_2 reduction strategies for Eastern Europe' will be presented and discussed. Finally, some case results will be shown and preliminary conclusions will be drawn on the topic of lifetime extension of existing power plants.

2. NATIONAL COST-EFFECTIVENESS ANALYSIS

The following types of costs are considered in cost-effectiveness analysis on a national level such as applied in EFOM-ENV/GAMS [1]:

- Investment costs [Dfl/kW]
- Fixed costs for Operating & Maintenance [Dfl/kW/y]
- Variable costs for Operating & Maintenance [Dfl/GJ_{output}]
- Fuel costs [Dfl/GJ_{input}]

The number of operation hours influences the effectiveness of the investment and fixed O&M costs; a relatively high operation time results in relatively low costs per GJ production. Furthermore the conversion efficiency acts upon the fuel costs.

In order to be able to compare costs to be made in different time periods, all costs are discounted by a fixed discount rate to a certain base year (Present Value method). The result of this discounting is that costs in the future are of less value than costs occurring in the present. In fact the Present Value of fixed and variable costs for O&M, fuel etc. can be substantially lower than the actual fixed and variable costs figures. For example, using a discount rate of 5%, the 1990 Present Value of 100 Dfl spent in 2010 is only 38 Dfl. The formulas used for calculation are presented in the Appendix.

An investment in the cost-effectiveness studies is converted by the annuity method into yearly costs including real interest. The effect of the use of this method is that investments have a relatively high Present Value, which implies a high contribution to the total discounted system costs. Future yearly costs such as fuel costs and O&M costs, which are calculated without interest, have a relatively low Present Value and thus a low contribution to the total discounted system costs.

Two interpretations of this method are possible since the discount rate is equal to the interest rate. First, the investment costs have a high Present Value compared with future yearly costs because they have to be paid in advance. The difference is caused by the timing of costs, modelled by the discount rate. Second, investment costs that have to be covered by an interest-bearing loan, which are paid in future years, have the same high Present Value as investment costs in the first case due to the interest payments. This interpretation, most close to the calculation method and situation of capital scarceness in Eastern Europe, will be followed in explaining case results in the paper, although of course the other interpretation is also valid.

Since the total discounted costs are minimized in cost-effectiveness analysis using Linear Programming, the use of a high discount rate implies a low 'attractiveness' of investments and a high 'attractiveness' of yearly costs. A high discount rate represents a situation with high barriers for investments, consisting of e.g. high perceived risks, high interest rates due to capital scarcity etc.

3. OLD, NEW, AND RETROFITTED PLANTS

Positive and negative influences on costs of existing and new energy conversion plants are summarized in table 3.1 below. The left column presents the additional costs of building a new plant compared with continuation of the operation of the 'old' plant. These costs consist of the investment and accompanying interest (see point 1 and 2 in the left column). These additional costs from the point of view of the new plant are of course benefits from the standpoint of the old plant.

Continuing the operation of an old plant will be attractive if these benefits are larger than the additional costs of the worse operation of the old plant, compared with the new plant. The factors playing a role in the operation of the plant are stated in the right column of table 3.1.

Obviously, if the lifetime of a plant is extended without doing a thorough update, the utility of a plant will degenerate: as well the operation time as the (relative) efficiency will decrease (see point 1 and 2). This is often observed in Eastern Europe. For instance: the efficiency of some old coal fired electricity plants is 33%, while a new one can attain an efficiency of 42%. Furthermore, additional fixed Maintenance costs will be needed, for replacing old or broken parts such as burners, piping, etc. (point 3). These costs are only considered in specific plant studies but not in cost-effectiveness studies on a national level of aggregation.

Apart from the low operation time due to forced outages, financial losses of the consumer can be caused by frequent drop out of production. In other words, the security of supply (point 4) is not guaranteed. However, this is difficult to express in monetary terms. Furthermore, it must be noticed that a low operation time is not only a symptom of degenerated functioning of a plant. From 1988 up to now, the electricity demand has dropped tremendously due to the economic transition from a centrally planned system to a more market oriented economy. Therefore, a huge overcapacity exists nowadays. Thus, the costs of lack of security of supply are difficult to estimate, but probably small due to present overcapacity, and are neglected here.

Table 3.1 *Advantages and disadvantages of old and new plants*

ADVANTAGES	OLD PLANTS	*DISADVANTAGES*
1 Investment costs		Efficiency affects fuel costs 1
2 Interest		Forced outages affect operation time 2
		Replacement of parts affects fixed 3 Maintenance costs
		Security of supply 4
		Pollution and safety impacts 5
DISADVANTAGES	NEW PLANTS	*ADVANTAGES*

Setting pollution reduction targets and safety standards can cause considerable additional costs for operating an old plant. Often new plants are optimally designed for reaching higher standards, while old plants can be upgraded only by replacing essential parts of the equipment or by adding end-of-pipe technologies, which are costly. The costs of safety measures are neglected here, because they are plant specific and difficult to estimate. The costs of pollution mitigation are well known for some pollutants, but for reasons of simplicity, they are neglected here too. However, in the EFOM-ENV/GAMS model specific abatement technologies, their investment and operation costs, and emissions from old plants are considered in detail. But in the Reference case, without an emission reduction target, the least-cost solution will not include abatement technologies, nor let clean fuels prevail above polluting fuels, unless these fuels are cheaper.

An intermediate option, in between continuing the operation of the old plant and building a new one, is retrofitting the old plant, herewith improving efficiency, security, and availability of the plant. However, this takes additional costs, and in most cases the standards of a new plant will still not be reached.

4. ASSUMPTIONS

In general technical data such as efficiency, fuel type, and also operation time are available for plants in Eastern Europe. However cost data of energy technologies and accompanying information are in general hardly available. This is in many cases limiting the accuracy and reliability of results of the cost-benefit analyses, in particular with respect to the comparison of old, retrofitted and new plants.

Available cost data are the (Western European) investment costs and O&M costs of new plants. The key question is whether it is possible to estimate with these costs of a new plant the missing cost data of old and retrofitted plants, such that on a national (not plant) level sensible indications can be given about opportunities for types of technologies in terms of retrofitting, doing nothing, or investing. In table 4.1 costs assumptions are made on the basis of the new costs data and results will be presented later.

The investment costs of an old plant are considered to be zero, since major changes are not made to an old plant. It is assumed that investments for the old plant have been paid off, or financial commitments for a certain time period, which can not be withdrawn, have already been made. However, it is expected that maintenance costs are higher than maintenance costs for a new plant. Assume that O&M costs consist of 50% labour costs and 50% material costs. Suppose that the additional forced outages are due to technological problems which are repaired at costs equal to material costs during 'normal' maintenance and no additional personnel costs are calculated. This way, additional maintenance costs are seen as 'business-as-usual' material costs due to additional forced outages (see the formula in footnote 1 of table 4.1). Furthermore, additional forced outages reduce the effectiveness of the fixed O&M costs (in terms of O&M costs per GJ production). However, it must be noticed that in most cases a major part of the total additional costs are due to additional fuel use of the old plant. Additional costs for security of supply and safety measures are neglected.

Costs for retrofitting an old plant are supposed to be equal to the investment costs of a new installation, assuming that the plant is retrofitted by 'replacing it part by part', which adds up to total replacement over the complete lifetime. It is assumed, since costs occur in bits year by year, that no interest is paid. The cost advantage compared with the new plant consists of not paying the real interest, which is a considerable expenditure (5% interest over 25 year amounts to 77% interest additional to 100% investment costs). The complete investment cost seems a huge expenditure, but on a yearly basis it only doubles or triples the O&M costs, depending on the plant type.

It seems disputable whether the lifetime of an old plant can be extended technically for another 25 years. However, in the present approach the length of the lifetime extension of an old plant is only important with respect to the calculation of the additional O&M costs and the comparability of the cases. Since investment costs are zero, the cost-effectiveness is independent of the chosen lifetime. Moreover, the goal of applying this method in EFOM-ENV/GAMS, using increasing fuel price projections, is to investigate whether economic explanations can be found for a limited lifetime (extension) of old plants.

The discounted costs per unit of produced electricity is, as in EFOM-ENV/GAMS, indicator for the attractiveness or cost-effectiveness of an option and options are ranked accordingly. Note that the electricity production costs (not purchase price) are discounted.

Table 4.1 *Typical examples of costs calculations for new, old, and retrofitted coal and gas fired power plants*

		New	Old	Retrofit
Gas plant				
Assumptions				
Investments	[Dfl/kW]	1467	0	0
Availability	[fraction]	0.8	0.7	0.8
O&M costs	[Dfl/y]	73.0	92.0[1]	132.0[2]
Efficiency	[fraction]	0.47	0.35	0.40
Fuel price	[Dfl/GJ]	8.0	8.0	8.0
Lifetime	[year]	25	25	25
Interest/Disc. rate	[%]	5	5	5
Results for 1 kW				
Disc. investment costs	[Dfl]	1467	0	0
Disc. O&M costs	[Dfl]	1034	1292	1861
Disc. fuel costs	[Dfl]	6052	7111	7111
Disc. elec. costs	[Dfl/GJ]	13.56	15.23	14.23
Ranking		1	3	2
Coal plant				
Assumptions				
Investments	[Dfl/kW]	1780	0	0
Availability	[fraction]	0.8	0.7	0.8
O&M costs	[Dfl/y]	53.0	67.0[1]	125.0[2]
Efficiency	[fraction]	0.42	0.33	0.37
Fuel price	[Dfl/GJ]	3.0	3.0	3.0
Lifetime	[year]	25	25	25
Interest/Disc. rate	[%]	5	5	5
Results for 1 kW				
Disc. investment costs	[Dfl]	1780	0	0
Disc. O&M costs	[Dfl]	753	941	1756
Disc. fuel costs	[Dfl]	2540	2828	2883
Disc. elec. costs	[Dfl/GJ]	8.04	6.83	7.36
Ranking		3	1	2

[1] $O\&M_O = O\&M_N + 0.5 \times O\&M_N \times (Avai_N - Avai_O) / (1 - Avai_N)$

[2] $O\&M_R = O\&M_N + Inv_N / Lifetime$

5. CASE RESULTS

In figure 5.1 the discounted costs per GJ electricity production, average over the complete lifetime, are presented for the new, old, and retrofitted plants as a function of the fuel price (constant over the lifetime). The coal fired and gas fired plant costs are estimated according to the modelling assumptions as presented in the previous paragraphs.

At 5% discount and interest rate and current prices (solid circles) coal fired power stations are generating cheaper electricity than gas fired plants, due to the low coal price. At high fuel prices the new plants tend to be more attractive than retrofit and old plants due to the higher efficiency that results in substantial costs savings on the high fuel costs share in the total costs. This applies for both coal and gas fired plants, but doubling the fuel price results for the gas fired plant in a much larger increase in the fuel costs share in the total costs than for the coal fired plant, due to the currently much lower coal price. Note the different fuel price scales on the X-axes. Nevertheless, the cross-point of new and old plants lies for the gas plant at a slightly lower fuel price due to differences in O&M costs, investment costs, and efficiency. But, clearly, the key factor is the fuel price.

It must be noted that often gas fired plants are used for electricity generation during peak-hours. Therefore, the operation time is relatively low, which has an upward influence on the specific electricity production costs of especially new plants.

Since the retrofitted plant with respect to the costs and efficiency is in between the old and new plant, the ranking of attractiveness of the retrofitted plant is also intermediate. Again, a high fuel price is in favour of the efficient retrofitted plant and against the old plant.

The two graphs in the lower part of figure 5.1 show the discounted electricity production costs for similar plants at equal fuel prices, but at a discount and interest rate of 12%, as proposed by many Eastern European energy experts. Since a higher discount rate is favourable for a high variable costs share in the total costs and negative for a high investment costs share in the total costs, the solid line of the new plant (the only case including interest-bearing loans) lies relatively higher than at a 5% interest and discount rate, being less attractive. Note that the retrofitted gas plant is the most attractive option at 12% discount rate and current prices. However, the relative proportion between discounted electricity costs of old and retrofitted plants is not affected by the discount rate. This is once more illustrated in figure 5.2.

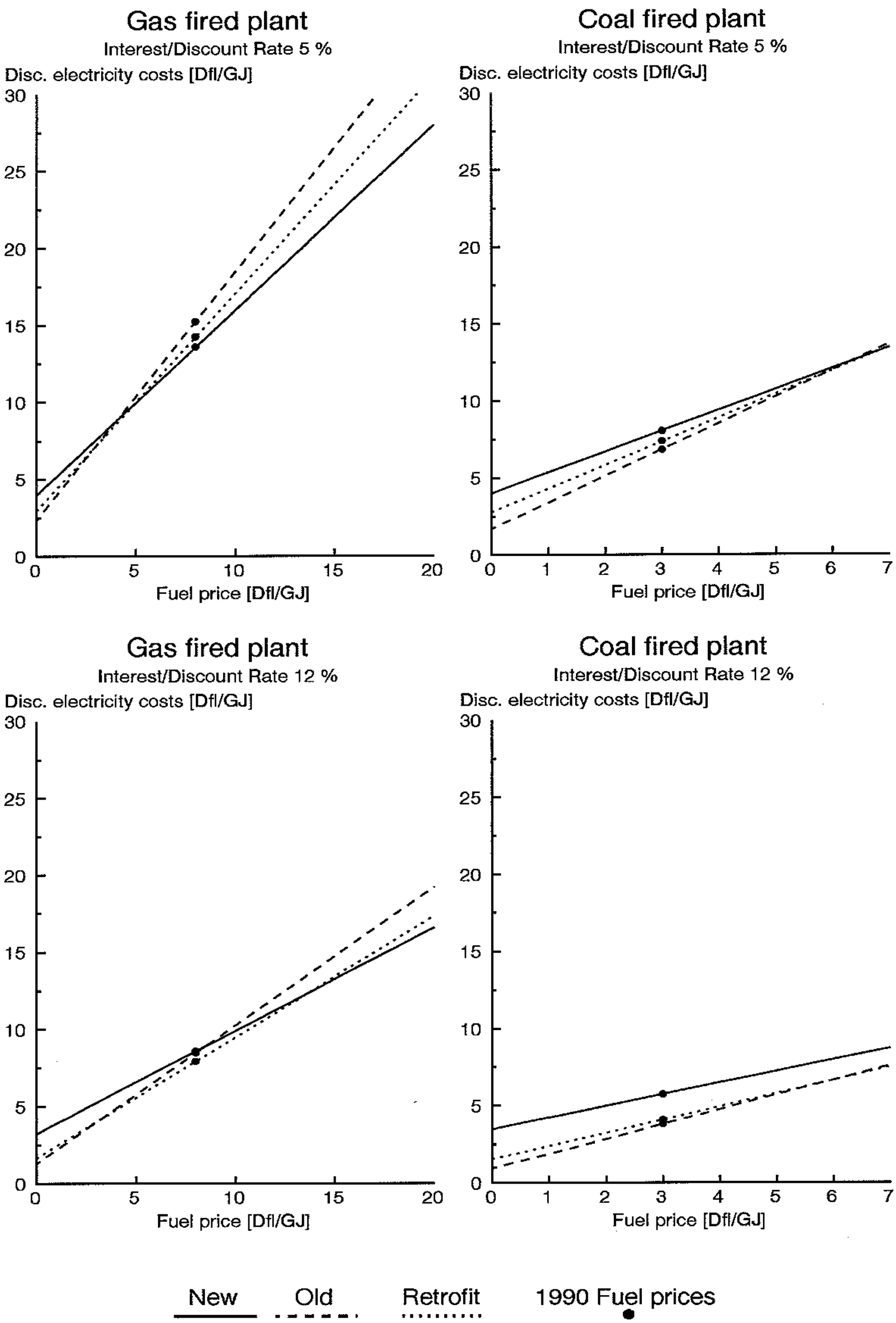

Figure 5.1 *Discounted electricity production costs of old, new, and retrofitted gas fired and coal fired power stations as a function of the fuel price, using 5% and 12% discount rate*

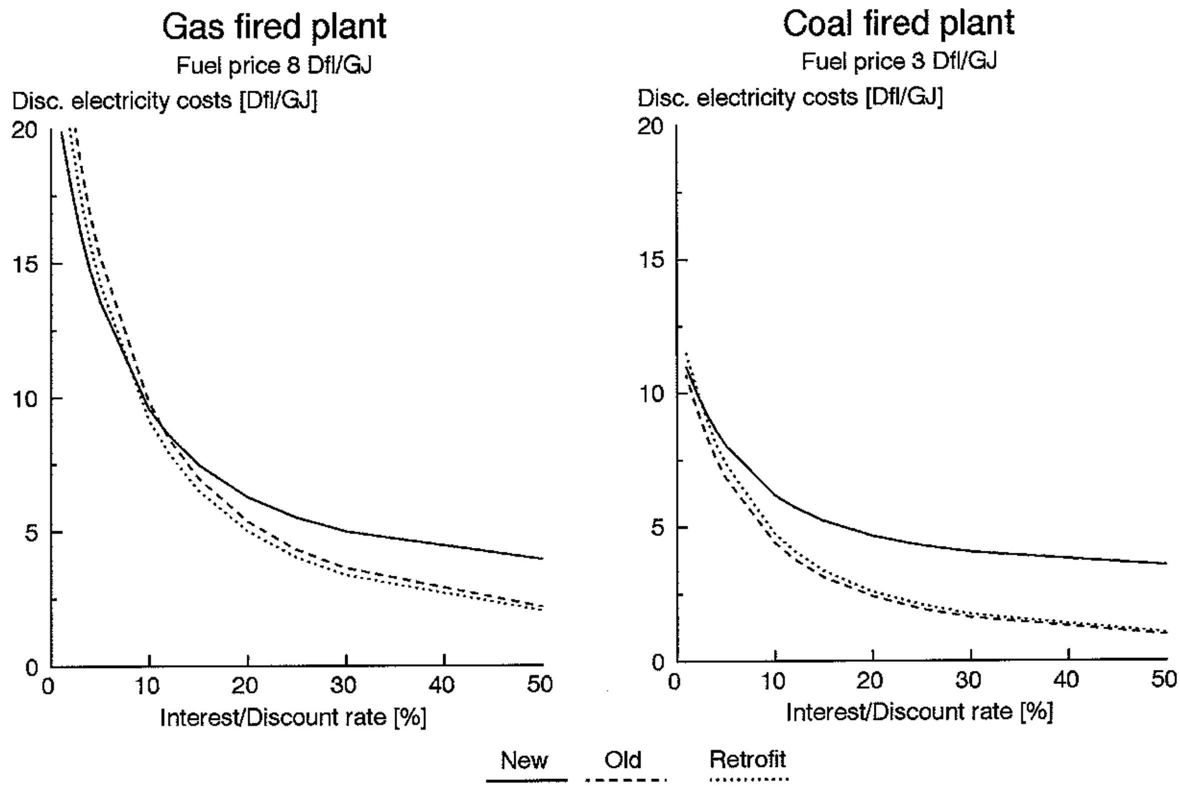

Figure 5.2 *Discounted electricity production costs of old, new, and retrofitted gas fired and coal fired power stations as a function of the interest and discount rate, using approximately current fuel prices*

The new coal plant is at the complete given range of fuel prices more expensive than the other options. This is correct, assuming that the application of a discount and real interest rate of 12% over a period of 25 years is correct. Currently, a real discount and interest rate of 12% is reality in Eastern Europe, and probably will be for the next few years. Capital scarcity is a fact, and interest-bearing loans are expensive and risky. Thus, at these low prices and for the short term, the continuing operation of old plants can be justified. However, longer term scenarios can include a strong improvement of the economic situation within years, which implies that the real interest and discount rates will drop to around 5%. So, longer term analysis with models such as EFOM-ENV/GAMS use interest and discount rates around that value. Consequently, national costs optimization can clearly illustrate whether old plants can be run, replaced, or retrofitted cost-effectively in the year 2000, at projected fuel prices.

6. CONCLUSIONS

Currently, a discount and real interest rate of 12% is reality in Eastern Europe due to capital scarcity caused by the poor economic situation. Making investments at 12% interest/discount rate in coal fired plants, which have to be compensated by fuel costs, are not attractive at current low coal prices. Even retrofitting existing coal plants seems not attractive at current coal prices; least cost option is to continue to operate old inefficient coal plants. However, due to the currently higher gas price retrofitting gas fired plants could be an attractive option. Unfortunately, gas fired plants are uncommon in Eastern Europe. Furthermore, the present overcapacity gives opportunity for stopping the production (temporarily) of the highest costs old plants. Thus, decisions on continuation of production, retrofit, or replacement are made for the less expensive plants, which diminishes the attractiveness of retrofit and replacement of plants.

These conclusions are only valid for the short term. On the longer term a strong improvement of the economic situation can be expected, which implies that the real interest and discount rates will drop. Longer term models such as EFOM-ENV/GAMS have to use an interest and discount rate lower than 12%. At 5% real interest rate/discount rate, the old coal fired plant is still the most attractive, but at higher (future) coal prices retrofit or even new plants will become more attractive. The new gas fired plant is the most attractive option among the gas fired plants.

Of course, these conclusions are general indications derived from two cases, without taking into account all features of the complete energy system, e.g. load duration curves, pollution, and safety standards, which can have a considerable effect on the attractiveness of an option. This will be investigated in more detail by EFOM-ENV/GAMS studies in the programme 'CO_2 reduction strategies for Eastern Europe'.

The key decision factors in determining the cost-effectiveness of old, retrofitted, and new electricity plants are:

- interest and discount rate (capital scarcity),
- fuel prices (efficiency),
- existing overcapacity,
- emission reduction and abatement technology,
- type of technology (investment/variable costs ratio).

Note that the high O&M costs and low operation time of old and retrofitted plants are uncertain but of less importance. The key factors mentioned above are very well known (physical parameters such as the efficiency and overcapacity) or addressed in publications of institutes and governments.

The here proposed modelling methodology for old, retrofitted, and new electricity plants contributes a necessary element to the proper assessment, such as made by models as EFOM-ENV/GAMS, of national level cost-optimal strategies for preparing national policies with respect to energy and environment.

It can be concluded that results of the case studies indicate that continuation of old, inefficient (coal fired) power plants in Eastern European countries can be cost-effective given the present specific circumstances in these countries.

REFERENCES

[1] M. van den Broek, F. van Oostvoorn, T. van Harmelen, and W. van Arkel: *The EC energy and environment model EFOM-ENV specified in GAMS, The case of the Netherlands.* Petten, ECN-C--92-003.

[2] M. Beeldman and J. Solinski: *Economic costs of electricity production in Poland.* Petten, ECN-C--94-009.

APPENDIX A. EFOM-ENV/GAMS FORMULAS

Yearly investment costs = Capacity x Investment costs per kW x Annuity

$$\text{Annuity} = \frac{\text{Interest rate}}{1 - (1 + \text{Interest rate})^{-\text{lifetime}}}$$

$$\text{Discount factor} = (1 + \text{Discount rate})^{-t}$$

Operation hours = Availability x 8760 hours

Production = Capacity x Operation hours

Fuel costs = (Production/Efficiency) x Fuel price

Emissions = (Production/Efficiency) x Emission factor