Impact Assessment of Greenhouse Gas Trading on Electricity Production Industry

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Abstract
Electricity markets constitute an important and rapidly developing research field in the area of energy economics. Deregulation and other organizational advances in international level have boosted electricity markets allowing customers to choose their provider and new producers to compete Public Power Companies. Within the frame of electricity market deregulation, energy related enterprises ought to be one step ahead of competition. Furthermore, emerging electricity generation technologies as well as technologies based on renewable energy sources progressively become attractive investment alternatives. CO2 trading and Kyoto protocol's targets on the other hand impose new standards on the financial aspects of power generation thus altering the environmental planning of private energy-related industry. The experience gathered till now, is not sufficient to derive safe conclusions regarding the efficiency and applicability of electricity production within the frame of the above mentioned advances. A computational tool is presented that models different investment options based on older and new emerging power production technologies. This model investigates important economic aspects as well. Electricity demand and prices of fuels fluctuate in ranges characterized by numerical uncertainty and this is dealt with appropriate stochastic numerical techniques. The same stands for the emissions trading allowance prices which contribute significantly to both cost and revenues through a highly volatile pattern. Finding the contribution of emissions trading to the expenses and revenues of the electricity sector is the primary objective of the model. Additionally, a comparison between the different electricity production technologies in terms of financial efficiency is presented. The different investment options analyzed, lead to interesting conclusions which might affect State policy interventions as well as potential private investment strategies.

Keywords: Greenhouse gas, Emissions Trading, Electricity Production, Investment Strategy.

Nomenclature

Symbol	Definition	Symbol	Definition
Pe	Electricity Selling Price (€/MWh$_e$)	P_{max}	Maximum load of Installed Capacity (MW$_{el}$)
P_f	Fuel Cost (€/MWh$_f$)	$S(t)$	Power averaged algebraic cash-flow (€/MWh)
e_f	Emissions Factor (kgCO_2/MWh$_f$)	dt	Time differential (day)
n	Thermal Efficiency Factor (%)	CF	Algebraic balance of annual Cash-Flow (€/year)
C_f	Fixed Costs (€/year)	i	Interest Rate (%)
Ψ	Variable Costs (€/MWh$_e$)	NPV	Net Present Value (€/year)
N	Annual CO2 allowances (tn)	n	Operational Life Time (years)
P_{CO2}	CO_2 allowance price (€/tn)	I	Initial Investment Cost (€)

1. INTRODUCTION

The electricity sectors of many countries have faced numerous changes in their structure and their business environment during the last years. Deregulation processes, and compliance with Kyoto Protocol related directives have modified private investment strategies. One of the mechanisms allowing individual industries to meet their targets is the emissions trading markets, such as the EU Emissions Trading System (EU-ETS) where the owner of emission allowances may trade them at the current price that is settled by the laws of demand and supply. This mechanism is of high importance for renewable as well as for conventional energy projects, as it may constitute a new revenue stream that will improve their financial yield [1]. Therefore, the production cost minimisation policies should be augmented by strategic and careful fuel selection.
The present study attempts to organize the above mentioned considerations in a computational model whose objectives are: (a) to simulate, correlate and forecast the variables under uncertainty including fuel prices, electricity prices as well as the greenhouse gas allowances, (b) to compare investment options (namely: lignite, coal and natural gas based technologies) for an electricity production company assuming that it operates in a fully deregulated system, (c) to analyse the cost and revenue structure of the optimal investment option and identify the share of greenhouse gas allowances. A major milestone of the study was the stochastic correlation of the variables. In order to accomplish the above milestones and objectives, some advanced computational techniques had to be implemented, to overcome the difficulties arising from nonlinear interaction of the various stochastic variables.

2. RELATED STUDIES

The financial engineering community is mainly based on traditional deterministic Discounted Cash Flow (DCF) methods for dealing with investment problems. In the field of Power Generation investments, even recently, traditional cash-flow analyses were used to address electricity production structure and its investment portfolio [2]. One could discriminate two separate classes of models investigating power sector investment options: (i) those dealing with policy interventions and suggesting State-originating power licensing procedures like in [3], and (ii) those who suggest investment options for private energy-related businesses [4,5]. The present study should likely be classified to the second (ii) category of financial modelling. The uncertainties arising from climate changes is a scientific area of interest gaining increasing focus during recent years [6,7]. These studies address the major issues of emissions trading that emerge in parallel with severe climate changes. Despite of their excellent analyses, the CO2 trading costs-revenues are not calculated. The present study addresses and compares the most interesting investment options that could potentially be realized in the Greek power sector.

3. METHODOLOGY: AN OVERVIEW OF THE MODEL

The starting point of the study is a potential investor willing to become a power producer in the range of 300MWel. A comparison of the most interesting investment options for a 30 year operational time horizon is performed. A "random walk" procedure is used in order to forecast the future electricity prices in a hypothetical fully deregulated electricity market in Greece. The same stands for fuel prices as well as for the CO_2 allowance prices. Appropriate Stochastic Differential Equations (SDEs) of either Geometric Brownian Motion (GBM) or Mean Reverting (MR) type, depending on the stochastic variable [3,4,5] are numerically solved using an Euler–Marujama type solver. All the stochastic variables are further simulated with a Monte Carlo sub-routine which is embedded in the model's forecasting solver. The forecasted variables are then processed by the Net Present Value (NPV) algorithm:
The **annual** cash-flow of a power plant is calculated assuming a full-load annual operation (dt is assumed to be equal to 1 day interval):

$$CF = P_{max} \int S(t)dt - C_f \quad (1)$$

Within the context of EU ETS implementation the algebraic balance of the daily cash-flows is calculated by subtracting the operational expenses of the power plant (fuel costs, CO2 costs, maintenance and other variable costs) from the electricity sales incomes to the national grid:

$$S(t) = p_e(t) - \frac{p_f(t)}{n} - \frac{e_f}{n} p_{CO_2}(t) - \psi(t) \quad (2)$$

Considering equation 1 as the integral balance of daily cash-flows for a whole year, then its full formulation considering also equation 2 becomes:

$$CF = P_{max} \int \left(p_e - \frac{p_f}{n} - \frac{e_f}{n} p_{CO_2} - \psi \right) dt - C_f \quad (3)$$

In the present study, three different scenarios of CO2 allowances have been considered:

- No Free allowances after the year 2012.
- No Free allowances after the year 2020. For the period 2012-2020, free allowances are assumed to decrease linearly till they vanish.
- CO2 allowance price always equals to zero.

The next step is to transform the annual cash flows (of the next 30 years) in present values. By summing up the present values of annual cash-flows, the NPV of the project is calculated and hence a comparison with the initial Investment Costs can be performed:

$$NPV = \sum_{1}^{n} CF \cdot \frac{1}{(1+i)^n} - I \quad (4)$$

According to the traditional Discounted Cash-Flow method a positive NPV implies a profitable project while a negative NPV implies a non profitable project: (NPV>0 →profitable projects).

4. RESULTS

The forecasting of the stochastic variables is presented in the following graph (Figure 1).

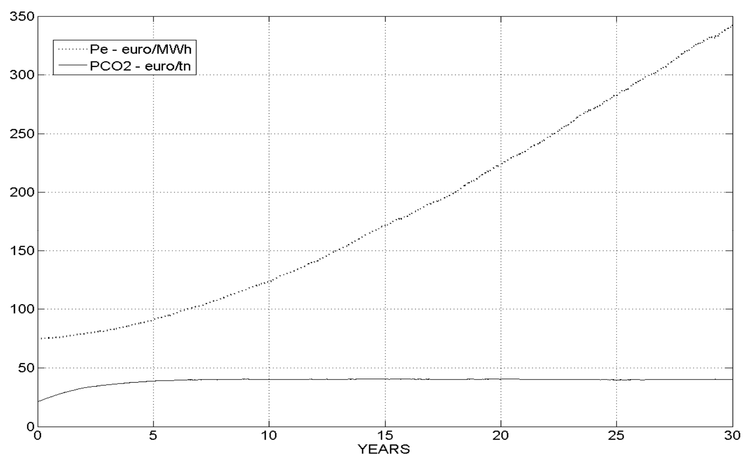

Figure 1. Forecasting of electricity and CO2 allowances prices

The predicted electricity prices have an increasing trend due to the type of the forecasting method used (reverting to a monotonically increasing mean). The CO2 allowance prices on the other hand are reverting to a constant mean average which is in line with its historical value. The fuel prices have been forecasted by solving the same type of SDEs according to the mathematical model described in the previous chapter and based on their historical data. This completes the reconstitution of the future field of stochastic variables and consequently, the expected NPV for each candidate power production technology may now be calculated. It is noted that a full load operational life time of 30 years has been assumed. The comparison of the different technologies in terms of financial efficiency (using the NPV criterion) is presented in the histograms of Figure 2.

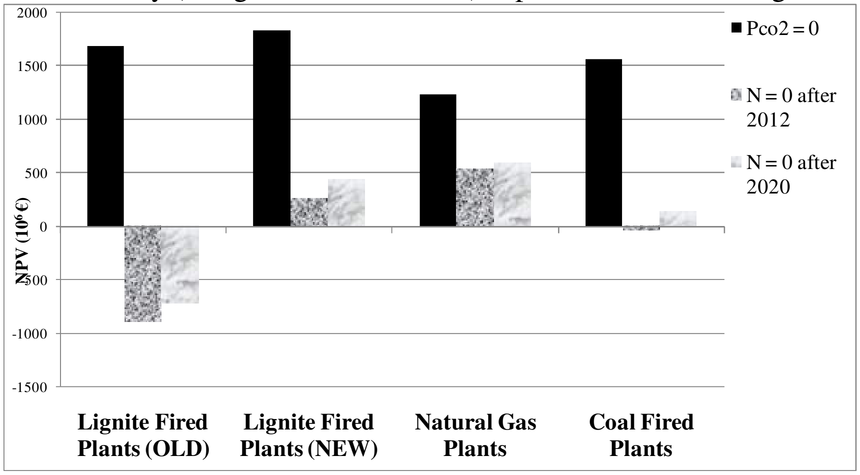

Figure 2. Comparison of NPV for the different electricity production technologies

It is noted that the scenarios involving EU ETS are characterized by the condition "CO2 allowance prices >0" and are represented by "marble and granite" columns. The NPVs of all the plant types have been also calculated for the hypothetical case of non-implementation of the EU ETS (PCO2=0, solid black columns). As can be seen, the consideration of natural-gas-fired plants is the most interesting investment strategy in terms of financial efficiency for all the scenarios involving EU ETS. The natural-gas-fired plants are characterized by higher electricity production efficiency as well as by lower emission factors thus leading to higher incomes per input fuel and significantly lower CO2 emissions. The gains from the lower CO2 expenses and high electricity production efficiency overbalance the need for new expensive infrastructure and expensive fuel thus making natural gas technology the one with the higher future prospects. The expected NPVs for the lignite-fired and coal-fired power plants are unacceptably low unless new solid fuel combustion technologies are implemented. The lignite-fired plants appear to be more profitable only in the hypothetical case of non-implementation of the EU ETS (solid black columns) due to significantly lower expected fuel costs which have been determined by the fuel prices' historical data. According to the new EU directives however, the implementation of the EU ETS will soon alter this status. The CO2 expenses are expected to rise, leaving fewer chances to lignite-fueled plants to survive in the deregulated energy market arena. Furthermore, some recent expert views imply that lignite prices will actually rise too, due to progressively harder winning efforts since the lignite reserves have already entered their depletion phase. If this is the case, then the lignite-fired plants may not be considered for the next decades' energy portfolio. In Figure 3 the decomposition of the incomes and expenses is presented for the gas (upper graph) and new lignite (lower graph) fired plants. No free allowances after the year 2012 have been assumed being in line with the purpose of the present article. As can be seen in Figure 3, the fuel expenses constitute a dominating cost-factor for the gas plants while the costs due to the emissions trading are significantly low. The lignite plants appear with a reverse cost structure (i.e. high CO2 expenses and low fuel costs) which explains the graph of Figure 2 and the comparison of EU-ETS (involving or not) scenarios. The remaining cost factors (fixed operational costs, variable operational costs etc.) are low for both plant types thus being insignificant for potential cost-killing policy. It is noted that the higher reliability of gas-plants lead to slightly higher incomes compared with the incomes of the statistically unreliable lignite-plants.

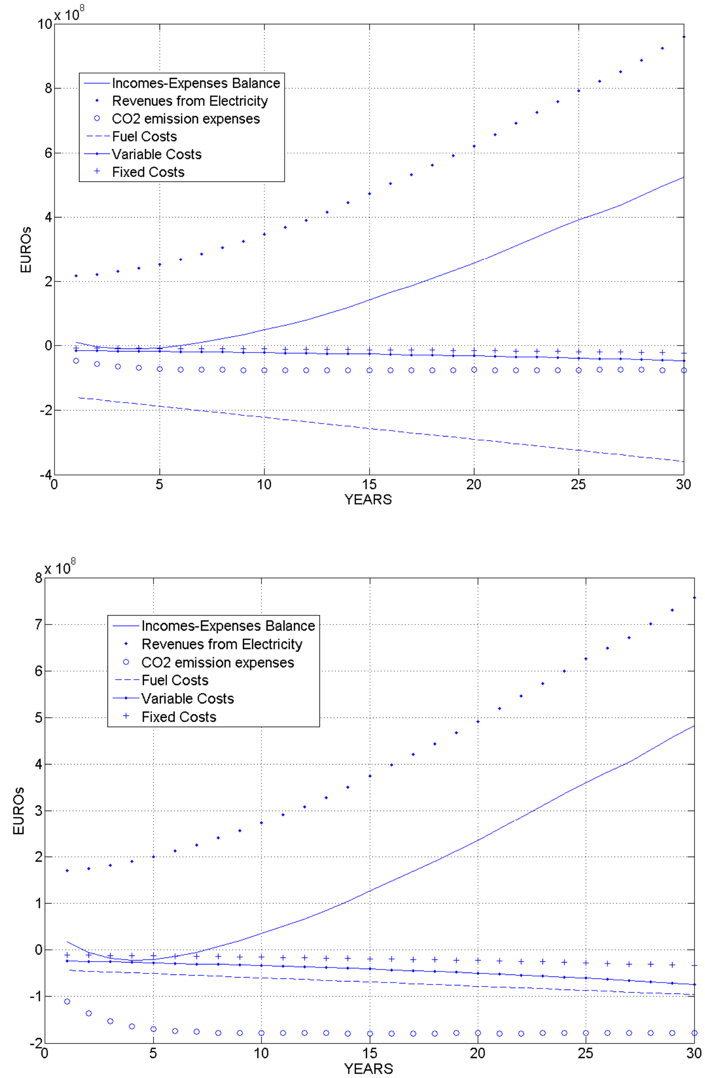

Figure 3. Structure of incomes and expenses for a natural-gas (up) and new lignite (down) plant

5. SENSITIVITY ANALYSIS

Although the model is robust to most of the key variables, it is significantly influenced by the changes of interest rate which is one of the most important parameters judging the efficiency of a business plan. For this reason a sensitivity analysis of the project's NPV has been performed as a function of interest rates in the vicinity of 8% which is the value assumed for the basic model runs. The scenario selected is based on a MR type forecasting of the CO2 allowance and electricity prices with a correlation factor equal to 0,5. The sensitivity analysis is presented in Figure 4.

- Obviously the highest interest rates produce lower NPVs. It is noted that the assumption of higher rates leads to decreasing annual algebraic balances of cash-flows thus making NPV to converge asymptotically to the initial investment costs especially in the case of high negative differences between predicted incomes and expenses (Old lignite fired plants).
- The Natural Gas fired plants always constitute the most profitable investment strategy but are significantly influenced by the interest rates changes (steeper negative slopes). This is a consequence of the higher fuel prices predicted for natural gas compared to the other fuel prices.

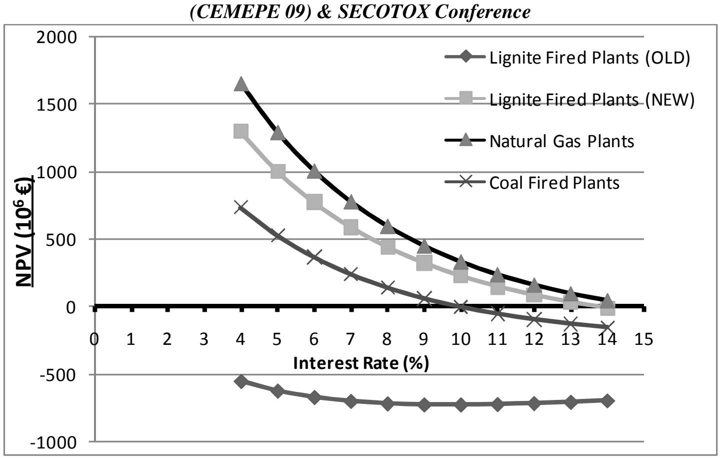

Figure 4. Sensitivity Analysis for the case of N= 0 after 2030

6. CONCLUTIONS

In the present article some of the most common technologies used for electricity production are compared in terms of financial efficiency within the frame of EU ETS and assuming a deregulated power production market. The natural gas fired plants are far more economical due to their lower CO2 emissions and higher electricity production efficiency. In other words, the new technologies of these plants lead to higher revenues and simultaneously significantly lower expenses. Concerning a potential investor willing to become a power producer in the level of 300 MWel, a new natural gas fired plant might be an investment priority, provided that CO2 allowances are not freely allocated. The State Power Company has already selected natural gas as the strategic fuel for the next decades aiming to replace the rapidly depleting lignite reserves. The results of the study might address potential private investments but additional options should be investigated too in order to build a clear and integrated view of the future: plants based on renewable energy sources, and wider capacity ranges (50-500MWel) could be investigated. The algorithm that has been created can easily produce such results since it is fully parameterized. The results of the study might be a reference for any private energy related enterprise willing to engage in the energy market while complying with the rapidly changing conditions and environmental constraints that rule this competitive business arena.

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