

Working Paper

Emissions Trading Scheme and Investments under uncertainty in the power sector*.

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Abstract

Environmental regulation can strongly affect the investment decisions of Electricity players. This short paper illustrates, by adopting a Real Option approach, how "hysteresis" can emerge from the main utilities capital budgeting process, thus strongly impacting the efficacy of European Union Emission Trading Scheme on technological innovation, emissions reduction and energy price dynamics.

JEL Classification: D81, G31, Q42

Keywords: Irreversible investments, Real Options, Kyoto agreement, Tradable Permits

** The views expressed in this paper are those of the authors and do not necessarily reflect the official position of the company they work for.*

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Introduction

The strategy put in place by the European Union to fulfil the goals set in Kyoto aims to provide the power sector with an incentive to switch from high polluting technologies to more environmental friendly ones. The Emission Trading Scheme (ETS), by attaching an economic value to environmental externalities, creates a market for CO₂ emissions. In this market the price of carbon will equal the lowest marginal abatement cost; thus encouraging power utilities to shift towards a lower carbon intense fuel mix. In this context, carbon driven shifts are due to variations in the merit order of the different power plants, using different fuels with different emissions coefficients.

Focusing on the Italian market, we analyse how the European Union Allowances (EUAs) price puts an operator of the power sector in the condition of becoming indifferent on whether to run a coal fired steam power plant or a Combined Cycle Gas Turbine (CCGT). The theoretical switching price between the two technologies is the CO₂ price at which gas becomes more cost-effective than coal.

Our analysis shows that this threshold price can vary significantly depending on both the decision rule that will be adopted by power players, and the way in which national authorities will implement the scheme. In particular, by applying a Real option framework, we highlight that when the managerial flexibility, embedded in the option to switch from coal to gas, is taken into account the EUA price that triggers the technological shift rises significantly, thus affecting the likelihood to reach the target fixed in Kyoto. Conclusions will be drawn on:

- 1) The evolution of the generation mix due to new investments and plants repowerings
- 2) The likelihood to reach the objectives set by the Environmental Legislation under the current regulatory framework
- 3) The expected impacts on future competition and electricity prices

EU Emission Trading Scheme

Since January 1st 2005 a cap and trade scheme, the EU-ETS, has been introduced in the EU to reduce the overall level of CO₂ emissions. The new regulatory framework has an impact on nearly 5.000 energy and industrial plants representing something like 50% out of total EU-15 emissions. The ETS can be considered the most important tool adopted at EU level to fulfil the targets fixed in Kyoto, namely an 8% reduction of GHGs emissions from the 1990 level. Figure one shows how the EU target has been shared among member states within the EU burden sharing agreement¹.

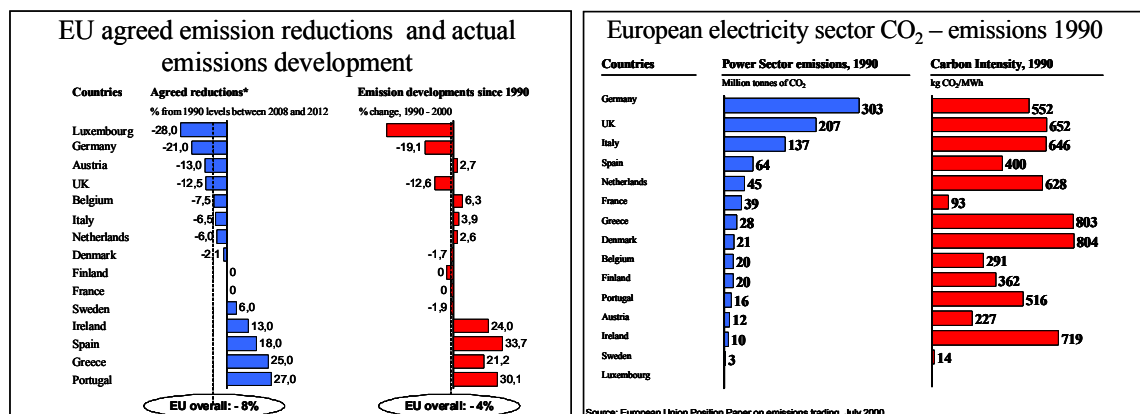
In order to achieve the desired environmental effect, the scheme allows to trade CO₂ emissions in the market as a commodity (they can be bought, sold, traded and banked for future use), the maximum amount of CO₂² that can be emitted in a given country (the cap) during the period within which the EU-ETS will be in force (commitment period) is fixed ex-ante. Once the cap is fixed emission rights are allocated to the regulated sectors. It is clear that, in order to make the EU-ETS effective, a shortfall of permits within each commitment period is essential. Namely a shortfall in permits allocated creates a permits price and therefore stimulates a cut in emissions. In this context, operators that are able to reduce their emissions at lower costs will do so and sell any excess of emission permits; conversely, those that have relatively high abatement costs will purchase tradable permits in order to meet their targets³.

¹ The Burden Sharing Agreement is a legally binding agreement that sets individual emissions targets for each Member State within EU

² The mechanisms is based on the Kyoto Protocol's system for the accounting of targets. Under this system, the amount to which national authorities must reduce its emissions over the commitment period (2005-2012) is divided into units. A greenhouse emission reduction unit is equal to a tonne of carbon dioxide equivalent (t-CO₂e).

³ The theoretical price of emissions allowances is the marginal cost of abatement, therefore the mechanism allows the economy to attain its abatement target in a cost-effective way.

Figure 1: 1990 Emission Level and EU targets



The EU-ETS is centrally managed by the DG Environment of the European Commission⁴ while, at national level, member governments are responsible for implementing the scheme. The details of the national level allocations for each period are published in the National Allocation Plans (NAPs) which determine:

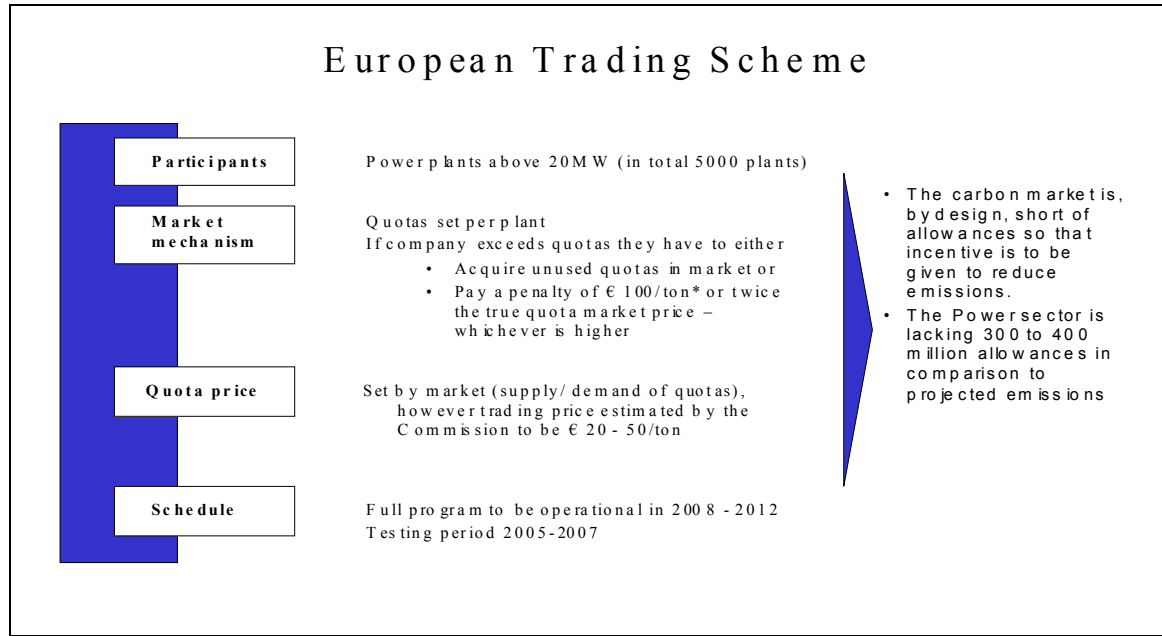
1. The proportion of the country's emissions to be covered by the scheme;
2. The total number of EUAs ("polluting rights") to be issued;
3. The industrial sectors covered by the scheme;
4. The proportion of EUAs given to companies for free versus the number auctioned;
5. The size of the New Entrant Reserve;
6. The extent of permitted use of Kyoto mechanisms by companies to meet emission targets (possibility to bank permits, possibility to use CDM, and JI).

Free quotas of EUAs are issued in accordance with the emissions track record ("Grandfathering principle"). Every year, emissions are calculated per plant, and each firm has to own an equivalent amount of allowances. Accounts are settled per plant and if an installation exceeds its quotas it has either to acquire unused quotas

⁴ The most important European documents concerning the EtS are the directive 2003/87/EC and the Communication of the Commission COM(2005) 703 final

on the market or to pay a 40/ton penalty⁵ (or twice the current EUA market price – whichever is higher).

Figure 2: The European Trading Scheme



The EU ETS will be implemented in two stages: during the testing period (2005-2007), already in force, at least 95% out of the allowances were allocated charge free and the use of other Kyoto mechanisms was limited, during the second phase (2008-2012), corresponding to the first commitment period of the Kyoto protocol, the percentage of free allowances will be reduced as it is shown in table 1. The negotiation to set up the emission cap for the Second phase of the scheme (2008-2012) have already started and that the new NAPs should be submitted to the Commission not later than June 30th 2006.

⁵ In phase II the penalty will rise to 100€/ton

Table 1: The EU-ETS Phase I and Phase II

| Feature | Phase 1 | Phase 2 |
|---|--|--|
| Proportion of country's emissions to be covered by the scheme | 45% | 45% |
| Total number of European Union Allowances (EUAs) to be issued. | 6,572mt/CO ₂ | 6% reduction required to meet Kyoto obligation |
| Sectors covered by the scheme | Power generators; Oil refineries and coke ovens; Building materials (glass, cement clinker & lime production, brick and tile manufacture, ceramic products); Iron & steel production; Pulp & paper | Expansion of sectors covered to include: Refineries, Iron and Steel (Offshore), Cement, Chemicals, Lime, Food and Drink, Ceramics, Aluminium, Glass & Mineral Wool, Services, Pulp and paper, Generators, Downstream Gas Possibly aviation |
| Proportion of EUAs given to companies for free | Vast majority of permits were allocated free | Up to 10% may be auctioned/sold |
| Size of the New Entrant Reserve | 182mt/CO ₂ | No guidance issued |
| The extent of permitted use of Kyoto mechanisms by companies to meet emission targets | Unlimited use of CERs | Limited use of CERs and ERUs |

Source: Citigroup (2006)

Policy options and the role of the power sector in the EU environmental strategy

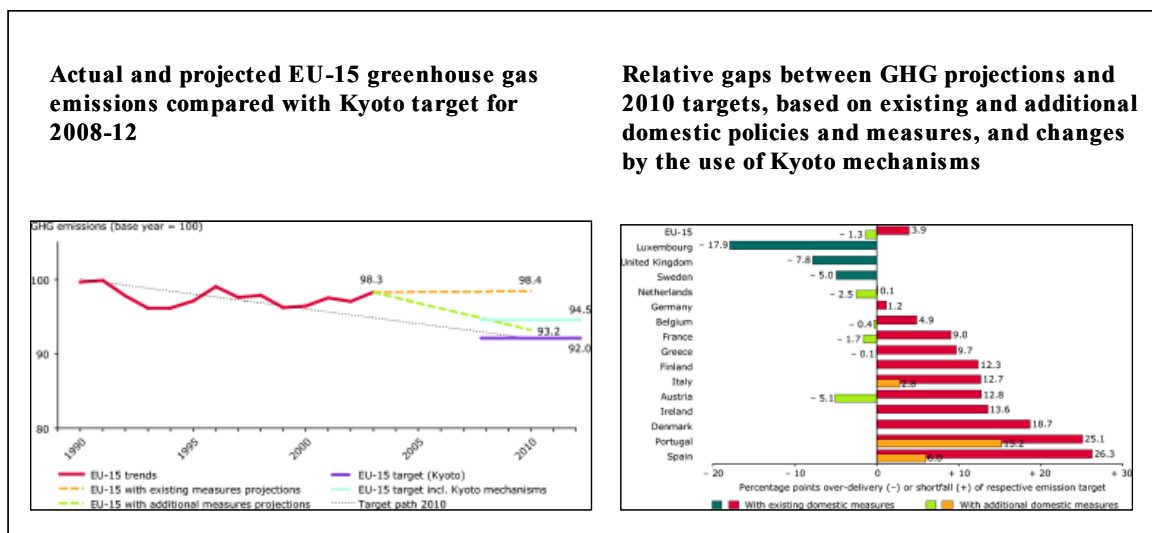
As we have highlighted in the previous section, the EU-ETS is the most important tool adopted by EU in order to fulfill its obligation within the Kyoto framework. However, it has to be noticed, that the agreements reached with the Kyoto protocol in terms of emission reductions are binding only for signatory Party (Countries), while by adopting the ETS, EU Member States have decided to partially swap national obligations to private companies making carbon dioxide emissions relevant to European investors. In particular, under the EU-ETS, the industrial and the power sectors will consistently contribute to the obligation of their national governments.

As a result the possibility to achieve the required emission reduction will strongly depend on two factors:

1. The way in which the EU-ETS will be implemented at national level;
2. How the regulated sectors will react to the new regulatory framework.

For what concerns the first issue, the projections of the European Energy Agency (EEA 2005) with respect to the aggregate level of GHG emissions in the EU-15 in 2010, show that the adoption of the EU-ETS, and the use of the other Kyoto mechanisms, will enable the EU-15 to reach its Kyoto target, however this result relies on over-delivery by some Member States. In particular emissions in Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Spain are all projected to be significantly above their commitments (figure 3). Thus in these Countries a further effort will be required in order to compile with the targets fixed within the EU burden sharing agreement.

Figure 3: Progresses toward the achievement of the Kyoto targets in EU-15



For what concerns the role played by regulated sectors, it has to be noticed that during the testing period of the ETS the power sector is forecasted to carry on the greater part of the costs related with the implementation of the scheme (table 2). Indeed if the overall ETS market, within the period (2005-2007) is forecasted to be

slightly short of about 120M/ton of CO₂, the power sector alone is estimated to be 400M/ton short while the industrial sector to be long of about 300M/ton of CO₂⁶.

Table 2: Forecast of the position of Phase One of the ETS (EU-15)

| Year | Power Sector | | Industry | | Total | |
|----------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| | Emissions M/ton | Allocation M/ton | Emissions M/ton | Allocation M/ton | Emissions M/ton | Allocation M/ton |
| 2005 | 1,272 | 1,237 | 770 | 872 | 2,042 | 2,109 |
| 2006 | 1,362* | 1,194 | 770** | 877 | 2,132 | 2,071 |
| 2007 | 1,411* | 1,187 | 770** | 872 | 2,181 | 2,059 |
| Phase I | 4,044 | 3,617 | 2,311 | 2,622 | 6,355 | 6,239 |

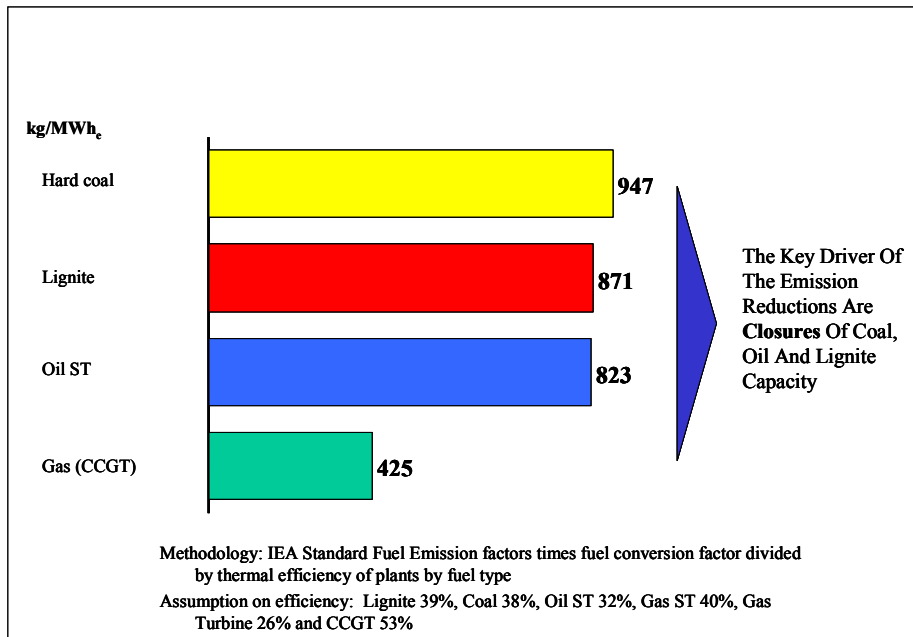
Source: Fortis, Point Carbon

* Forecasts from E-Simulate simulations

** Assumption status quo for Industry

The table above clearly highlights the pivotal role played by the power sector within the context of EU-15 strategy. Therefore the possibility to achieve the targets fixed in Kyoto will strongly depend on how this sector will react to the new regulatory framework and in particular on whether the ETS will succeed in encouraging a technological shift from high polluting technologies to environmental friendly ones. Considering that, to date, the European economy strongly relies on fossil fuels for the production of electricity, the key driver of emission reduction will be the closure of power plants running on high polluting fuels, such as lignite, oil and coal, and the adoption of gas fired plant and in particular of CCGTs (figure 4).

⁶ Source Fortis bank (2006) A. This estimation do not take into account new entrant reserves (NERs), potential banking from phase one to phase two and potential inflow from certified emission reduction units (CERs)

Figure 4: Specific CO₂ emissions from fossil fuel generation

The Italian NAP

In order to comply with its Kyoto obligation, Italy should reduce its emissions by 6.5% from the 1990 level, this will imply a reduction of 69 MT of CO₂ per year from the 2001 level. The Italian ETS strategy for the first commitment period (2005-2007) was inspired by 3 main pillars:

- Italy is a country with high energy efficiency and low energy intensity compared to other European countries (the ratio between CO₂ emissions and GDP is equal to 0,13 for Italy vs. 0,18 EU average according to IEA). This means that the marginal cost of domestic abatements is higher than in other European countries. The Italian Nap underlines that this result is even more striking because of the national position about nuclear energy;
- The national energy security must be ensured, therefore the incidence of imports on total energy consumed should be reduced;
- The competitiveness of the Italian firm should be guaranteed. For the

sake of this goal Italian firms are supposed to use credits from JI and CDM projects in material way in order to comply with the EU directive.

If we analyse the structure of the NAP in detail we can see that, under the existing regulation and with respect to the Business as Usual (BaU) level⁷, the overall ETS sectors are estimated to be short of 18.6 Mt of CO₂ per year, while the power sector alone is estimated to be short of 27.8 Mt of CO₂⁸. Therefore, it is clear that the power sector plays a critical role within the Italian emission reduction strategy, indeed to date the contribution of the energy sector to the ETS target is equal to the 151%.

Table 3: The role of the power sector in the Italian NAP

| Unit | Year | 2005 | 2006 | 2007 |
|------------------------------|---|--------|--------|--------|
| <i>MtCO₂/year</i> | Total Allowances | 221.79 | 224.87 | 219.81 |
| <i>MtCO₂/year</i> | Share of allowances issued to the power sector | 59% | 60% | 58% |
| <i>MtCO₂/year</i> | ETS Business as Usual (BaU) forecast – NAP | 239.96 | 240.57 | 241.64 |
| <i>MtCO₂/year</i> | Energy sector BaU forecast – NAP | 159.44 | 158.75 | 158.47 |
| <i>MtCO₂/year</i> | ETS shortfall - NAP figures | 18.17 | 15.70 | 21.83 |
| <i>MtCO₂/year</i> | Energy sector shortfall - NAP figures | 28.36 | 24.94 | 30.06 |
| % | Total shortfall | 7.57% | 6.53% | 9.03% |
| % | Energy sector share of total shortfall | 156% | 159% | 138% |

However it has to be stressed that, the Italian Nap for the first commitment period assigns a marginal role to the EU-ETS, indeed the contribution to the Kyoto target of the EU-ETS within the period 2005-2008 is only the 28% (table 4). Thus, considering that the sectors covered by the scheme account for nearly the 50% of the total emissions, the cap level does not appear to be in line with the Kyoto targets⁹.

⁷ Emission level that would have occurred in the absence of the scheme

⁸ Average over the period 2005-2007

⁹ EEA (2005)

Table 4: Italian target under the Kyoto protocol

| Kyoto target (2012) | Emission level (1990) | Emission level (2001) | Emission reduction per year ETS average (2005-2007) | Emission reduction per year ETS average (2005-2007) | Emission Reduction Required to meet the Kyoto Target |
|------------------------------|------------------------------|------------------------------|--|--|---|
| <i>MtCO₂/year</i> | <i>MtCO₂/year</i> | <i>MtCO₂/year</i> | <i>MtCO₂/year</i> | <i>%</i> | <i>MtCO₂/year</i> |
| 403 | 431 | 470 | 18.57 | 28% | 66 |

As far as plant by plant allocation is concerned for the energy sector the following criteria has been adopted:

- Electricity: expected production;
- Heat: historical emissions;
- Heat and Electricity: historical production.

Due to the deep change which is going to affect the Italian energy sector (shift to CCGT technology) it has been chosen to allocate allowances on the basis of the expected production. Allocation rules are based on plant capacity and on forecasts by technology mix (combination of technology and fuel type) of both hours of operation and specific emissions factors.

Moving forward, if we consider that, the negotiations to set up the emission cap for the Second Phase of the scheme (2008-2012) have already started and that the new NAPs should be submitted to the Commission not later than June 30th 2006, it is important that power players, national authorities and organizations are thoroughly prepared for the negotiations on an EU level and for the national implementation. In particular in the next months the Italian government will have to undertake a series of decisions that will affect the possibility to comply with its obligations under the Kyoto protocol:

1. which quota of the overall Kyoto target should be achieved by making use of the ETS scheme;
2. within the ETS quota which role will be played by the power sector;
3. the extent of permitted use of Kyoto mechanisms to meet emission targets.

These decisions will strongly influence the strategic behaviour of power players in both the short and the long run. For what concerns the short run, the weight of the reduction imposed will affect the production mix, while in the long run it will impact the investment strategies. The success of the strategies implemented at national level will also depend on the decision rule that power sector operators will adopt in order to determine the optimal timing to switch toward more environmental friendly technologies.

Power utilities strategic behaviour: why do real options make sense?

After the implementation of the ETS, several contributions have been focused on the impact of the new regulatory framework on power utilities strategic behaviour and the problem has been analyzed under different perspectives.

Some authors have focused on the short run effect of the ETS, thus in all these models the possibility to switch from one technology to another depends on the existence of extra production capacity that gives to the operators some flexibility in selecting the most cost-effective production mix. Thus power players are assumed to lower the output of coal plants and increase the output of CCGT technologies as soon as the spark spread equals the dark spread¹⁰. Fuel switching can also take place through cross-border import and export of electricity. In this case the switch is obtained by lowering the output of carbon intensive generation in country A, and increasing the output of generation with a lower carbon intensity in country B and adjusting the import/export balance between A and B accordingly¹¹.

While in the short run operators have only the ability to adjust the production mix, in the medium and long run there is also the possibility to undertake new investments to shift towards a less carbon intensive technology. The long term investment strategy can be selected by adopting different decision rules. The classical approach

¹⁰ Dark and spark spread represent the theoretical margin for a power plant. If the spark/dark spread is positive, then the price of the power is higher than that of the fuel and the spread is profitable. If the spread is negative, the power is priced at less than the cost of fuel and is not profitable. Dark and spark spread identify the operative margin of coal and gas fired plants respectively

¹¹ Fortis Bank (2006)

is based on the assumption that power players will decide the optimal strategy on the basis of a Net Present Value (NPV) approach¹². According to this methodology the decision to switch from a given technology to another should be undertaken whenever the present value profits generated by less polluting technology exceeds the present profits value of the more carbon intensive one. However this approach fails in taking uncertainty, irreversibility, and managerial flexibility into account, leading to wrong estimates on the overall value of the opportunity to invest in projects enabling to reduce the CO₂ emissions level. Considering that investments in the power sector are irreversible decisions with long-term consequences, to be undertaken under different uncertainties (e.g. fuel costs, output prices and emissions trading costs, etc.), a Real Option-based approach (ROA) fits the problem better than the conventional NPV approach¹³.

According to the ROA, when an agent decides to undertake an irreversible investment, it gives up the option of waiting for new information that might affect the attractiveness or the timing of the investment. The option value, which is destroyed by undertaking the investment decision, is an opportunity cost that must be taken into account in calculating the overall value of the investment. Thus in order to render optimal the project implementation at a given point in time, the present value of the stream of benefits expected to be generated must exceed the costs incurred in order to implement the project itself by an amount equal to the value of keeping the deferral option alive. As a result, by analysing the problem faced by power sector operators with a real option framework we can observe a relevant change of perspective. Real options theory predicts that switching conditions will be different because economic agents will try to exploit at best the managerial flexibility they have.

When analysing the impact of the ETS scheme on the power sector, we will distinguish, for the sake of simplicity, two different cases: one describing the problem of incumbents, and another for new entrants.

¹² See De Leyva and Lekander (2003)

¹³ See also Laurikka and Pirilä (2005) and Burkhardt (2004)

The incumbent is the owner of a switch option; he has the right, but not the obligation, to undertake an investment in order to switch from the currently used technology to a less polluting one by leveraging its Brownfield. Usually, switching options are complex portfolios of put and call options and Incumbents might switch among different modes of production more than once during the operating life of the plant. Nevertheless, it has to be noticed that in the power sector switching from one technology to another involves high investment costs and, therefore, the possibility that an operator will switch more than once is unlikely. For this reason, following Dixit and Pindyck (1994), we will only take into account the possibility of a single switch. This assumption will allow us to consider the option to switch as a simple call option giving to its owner the possibility to exchange a risky asset, the currently used technology, with another, the new adopted technology.

On the other hand the new entrant is the owner of an option to wait, giving him the right, but not the obligation, to enter the market with one of the currently available technologies. The technological choice and the timing of the investment will be based on the merit order of the different technologies.

The model and the switching conditions

Our model examines how ETS will influence the short and long run strategic behaviour of the power utilities operating in the Italian market. In particular we want to determine the EUA price that makes a power company indifferent on running a 38% efficiency coal fired steam or a 53% efficiency CCGT. The theoretical switching price between the two technologies is the EUA value at which gas becomes more cost-effective than coal. The analysis performed will show how this threshold value changes depending on both the decision-rule that is adopted by the operators and the way in which national authorities will implement the scheme, thus influencing the effectiveness of the ETS.

The CO₂ quota each technology can emit has been calculated making different hypothesis about the cap imposed to the regulated sectors in the Italian NAP for

phase II. In particular we have considered three scenarios as it is shown in the table below.

Table 5: Scenario Hypotheses

| Scenario | Incidence of ETS on the fulfillment of Kyoto's target | Delta Incidence vs. 2005-2007 of Power sector on the fulfillment of ETS goals | Share of CERs and ERUs allowed (%) | 4. Reduction after 2012 (% of the reduction until 2012 each five years after 2012) |
|----------------|---|---|------------------------------------|--|
| <i>Base</i> | 45% | -10% | 12% | 33% |
| <i>Tight</i> | 50% | 0% | 6% | 33% |
| <i>Relaxed</i> | 40% | -10% | 20% | 33% |

Each scenario encloses hypotheses concerning the incidence of the ETS scheme on the Italian emission reduction strategy (table 5 column 1), the incidence of the power sector within the ETS framework¹⁴ (table 5 column 2) and the share of other Kyoto mechanisms to be used in order to achieve the targets fixed in the NAP (table 5 column 3). Moreover we have assumed that the ETS will continue after 2012, and that after 2012 a further 33% reduction from this baseline will be required each five years.

For what concerns the base case we have assumed that the contribution to the Kyoto target of the ETS scheme will be proportional to the contribution of the regulated sectors to total emissions. Moreover the Italian government will help private companies to reach their targets by making use of other Kyoto mechanisms up to a 12% of total required reductions. Finally, in line with the trends observed during the first commitment period, the contribution to the ETS of the power sector will decrease by 10% from the 2007 level.

In the tight scenario we assume that the ETS will contribute to the Kyoto target for the 50%, that the use other Kyoto mechanisms will be halved with respect to the

¹⁴ The delta incidence of the power sector is calculated with respect to the power sector contribution under the current NAP (table4)

base case, and that the power sector contribution to the ETS will remain unchanged with respect to the testing period (2005-2007). Finally, in the relaxed scenario we assume that the possibility to use other Kyoto mechanisms will grow up to 20% and that the contribution of the ETS to the Kyoto target will be the 40%.

Carbon is introduced in the model as a production input, thus each technology will be affected by the ETS proportionally to its emission level. Therefore the costs incurred by the different technologies, as a consequence of the implementation of the ETS, will depend on the number of full load-equivalent running hours and on their emission coefficients (figure 4).

For what concerns each technology number of full-load equivalent running hours per year, in line with the current market structure, we assumed 5500 hours for CCGT and 7600 hours for Coal. This means that the Coal fired steam is our base-load technology (i.e. the technology with lower marginal production costs), while the CCGT is the price setter. The electricity market price, in every hour of the day, is fixed by the operating technology that has the higher marginal production cost. According to these assumptions, only the price setter technology, CCGT, is able to fully discharge to end-users the costs incurred to compile with the targets fixed in the NAP.

$$P_{e,t} = \lambda P_{gas,t} + \Delta OC_{CCGT,t} + X_t + K_{CCGT} + \mathcal{G}$$

Where:

P_e = electricity price

P_{gas} = price of fuel

λ = percentage of the increase in fuel price that is discharged to end-users

ΔOC_{CCGT} = increase in operating costs due to the implementation of the ETS scheme

X_t = Spark spread

K_{CCGT} = other operating costs

\mathcal{G} = stochastic term

Considering that the two technologies run for a different number of full-load equivalent hours they face different electricity prices. The price faced by the coal

fired steam is assumed to be a deterministic function of the electricity price for the CCGT technology, specifically it is 7% lower in every operating year.

The number of free allowances, expressed in full load equivalent running hours, allocated to each technology in every operating year are enclosed in the table below.

Table 6: number of

| Year | 2008-2012 | After 2012 |
|-------------------------|------------------|---|
| CCGT | 5500 hours | 5500 hours |
| Coal Fired Steam | 6742 hours | 33% of the reduction until 2012 each five years |

According with the allocation rule provided in the Italian NAP for the period 2005-2007, the CCGT technology will receive a number of allowances equivalent to 5500 hours during the whole time horizon considered in the model. As a consequence the coal fired steam technology will have to carry on the whole cost associated with the implementation of the ETS.

Moreover, in line with the moral suasion carried-on by the Regulatory Authorities, we assumed that power sector operators would not include entirely EUA costs in their marginal costs for pricing purposes. In other words, according to the economic theory of perfect competition, the power player should include the opportunity cost of using their allowances (which can be sold on the market) when calculating the marginal cost of producing each MWh. Under such arrangement power prices would reflect the entire cost of EUA thus transferring to the end-users that are notoriously price inelastic the costs of ETS. The surge of power prices due to this CO₂ component has been observed in many European countries.

On the contrary, under imperfect competition pricing strategies becomes less predictable. In particular for Italy it is much less evident the impact of EUA on power prices. In particular, if only the cost of emissions net of allowances is taken into account we could get to a totally different picture. If we consider the case of a system where the price setter technology is CCGT, if we give to combined cycles

enough allowance to cover their emissions under standard production regime we could expect no impact on power prices.

The model analyses the incumbent and the new entrant optimal strategies, independently and will be solved under two different assumptions about the use of free allowances made by power sector operators. In the first case (oligopolistic pricing rule scenario), in line with what happens in the Italian markets, we assume that free allowances will be used as a production input. In this setting only the increase in marginal costs faced by the price setter, as a consequence of the implementation of the scheme, comes into electricity prices. In the second case (competitive pricing rule scenario), in line with what happens in EU countries characterized by an higher level of competition, we will relax this assumption allowing power sector operators to use allowances for speculative purposes. Thus the cost of CO₂ will be fully discharged to end-consumer also in the case in which allowances are granted to the installation.

With respect to the incumbent, we assumed this operator is running a 38% efficiency Coal fired steam power plant in the mid of its operating life. Due to the new regulatory framework the incumbent is the owner of a switch option from this technology to a CCGT by reusing the site and part of the existing infrastructures. The choice to switch might be undertaken on the basis of different decision rules.

In the short run the condition that makes the operator indifferent between the two technologies is the EUA price that equates dark and spark spread. In this case we only consider shifts in plants utilization not involving additional investments¹⁵.

¹⁵ Some insights could be obtained by a simple analytical exercise. If we assume for the sake of simplicity:

$$(A1) \text{Dark Spread} = P_{\text{baseload}} - OC_{\text{coal}} - EUA * EMI_{\text{coal}}$$

$$(A2) \text{Spark Spread} = P_{\text{mid-merit}} - OC_{\text{gas}} - EUA * EMI_{\text{gas}}$$

Where coal plants produce baseload (about 7.500 equivalent running hours per year) while CCGTs operate mid-merit (about 5.500 equivalent running hours).

By relying on the following additional definitions and assumptions:

$$(A3) \text{EMI} = \text{Emissions(ton/MWh)} * \text{Net of Allowances Factor} = \gamma_i \delta_i \quad i = \text{coal, gas. } \delta \in [0,1]. \text{Allowances Gas} = \text{Emissions} \rightarrow \delta_{\text{gas}} = 0;$$

In analysing the medium run switching condition we have calculated the EUA's threshold level in both the static and the dynamic cases.

$$(1) \sum_{t=0}^{t=14} \frac{B_{i,t} - OC_{i,t} - \Delta OC(q_{i,t}, EUA^*)}{(1+r)^t} = \sum_{t=0}^{t=26} \frac{B_{j,t} - I_{j,t} - OC_{j,t} - \Delta OC(q_{j,t}, EUA^*)}{(1+r)^t} \Rightarrow$$

$$OPV_c = NPV_g$$

$$(2) \sum_{t=0}^{t=15} \frac{B_{i,t} - OC_{coal,t} - \Delta OC(q_{i,t}, EUA^*)}{(1+r)^t} + F(X) = \sum_{t=0}^{t=26} \frac{B_{j,t} - I_{j,t} - OC_{j,t} - \Delta OC(q_{i,t}, EUA^*)}{(1+r)^t} \Rightarrow$$

$$OPV_{coal} + \text{Option to switch} = NPV_{CCGT}$$

Where

$i = \text{coal}, j = \text{ccgt}$

$B_{i,t}$ = benefits generated by the project i at time t

$OC_{i,t}$ = operating costs to the net of emission costs

$q_{i,t}$ = quantity of EUA sold or bought in the market

$I_{j,t}$ = repowering cost incurred to convert the plant (70% of the Greenfield investment)

r = discount factor

$F(X)$ = value of the switch option

OPV_{coal} = Operating NPV coal

The static condition, equation 1, holds if, and only if, we assume that there is not uncertainty surrounding the outcome of the investment: namely, if both fuel and EUA prices will stay constant over the operating life of the two plants. In this case the price of EUA making the incumbent indifferent on the two technologies is the

$$(A4) P_{baseload} = \alpha P_{mid-merit} + \theta_1 \text{ e } P_{mid-merit} = \beta OC_{gas} + \theta_2 \text{ with } \theta_1 \text{ and } \theta_2 \text{ random walk;}$$

A4 is quite a radical linearization of the dynamics of the power market, but it seems to be quite reasonable for our purposes.

We can then write-down the standard indifference condition between coal and gas as follows:

$$(A5) \text{Dark Spread} = \text{Spark Spread} = \alpha \beta OC_{gas} - OC_{coal} - EUA^* Emi_{coal} = \beta OC_{gas} - OC_{gas}$$

By deriving the expression for EUA^* obtained in (A5) with respect to OC_{Coal} and OC_{gas} , we easily obtain the elasticity of EUA threshold price versus the price of gas and coal:

$$(A6) \eta_{EUA/coal} = - \frac{1}{\gamma_{Coal} \delta_{Coal}} \frac{OC_{coal}}{EUA}$$

$$(A7) \eta_{EUA/gas} = \frac{(\alpha \beta - \beta + 1) OC_{gas}}{\gamma_{coal} \delta_{coal} EUA}$$

one that equates the operating NPV of the pre-existing Coal plant to the NPV of the new built CCGT.

In calculating the dynamic switching condition, equation 2, the uncertainty surrounding the investment is taken into account by applying the Real Option Methodology. According to the ROA theory, in order to render the switch optimal, the NPV of the new built CCGT, given the EUA price, must be high enough to offset the opportunity cost of killing the option.

The parameters used in order to calculate the value of the switch option are shown in table 8. Based on the approach of Dixit and Pindyck, the savings that the operator can achieve by adopting a CCGT technology gives the underlying of the option, while, the strike is the difference of the operating expenses the switch will imply. The volatility of the option has been calculated through a Montecarlo simulation performed on the underlying of the option. In performing the simulation we have assumed that the fuel prices and the EUA price would evolve stochastically over time with volatility respectively equal to 37% for gas, 8% for coal and 20% for EUA¹⁶. The table below encloses the correlations within variables.

Table 7: Correlation factors

| Correlation factors | | | | |
|---------------------|--------|--------|-------|--------|
| | Coal | Oil | Eua | Energy |
| Coal | 1.000 | | | |
| Oil | -0.031 | 1.000 | | |
| Eua | 0.260 | 0.174 | 1.000 | |
| Energy | 0.231 | -0.032 | 0.148 | 1.000 |

Table 8: Option to switch

| | |
|-----------------------|---|
| Underlying | PV of the difference between the two technologies emission costs + PV of the difference between the two technologies OPEX costs |
| Strike | Investment costs to build a CCGT on the Brownfield of an existing coal plant (80% Greenfield investment) + PV of the difference between gas and coal fuel costs |
| Volatility | 15% Volatility of the underlying resulting from the Montecarlo simulation |
| Free risk rate | 3% |

¹⁶ More information about the methodology used to perform the simulation are enclosed in the appendix

| | |
|-------------------------|--|
| Dividends | 0% |
| Time to maturity | 15 (remaining operating life of the coal fired steam technology) |

For what concerns the new entrant, the switching condition for the static and the dynamic cases are shown in equation 3 and 4 respectively.

$$(3) \sum_{t=0}^{t=30} \frac{Bc_{i,t} - I_{i,t} - OC_{i,t} - \Delta OC(q_{i,t}, EUA^*)}{(1+r)^t} = \frac{B_{j,t} - I_{j,t} - OC_{j,t} - \Delta OC(q_{i,t}, EUA^*)}{(1+r)^t} \Rightarrow NPV_{Coal} = NPV_{CCGT}$$

$$(4) \sum_{t=0}^{t=30} \frac{Bc_{i,t} - I_{i,t} - OC_{i,t} - \Delta OC(q_{i,t}, EUA^*)}{(1+r)^t} - F(Y_{coal}) = \frac{B_{j,t} - I_{j,t} - OC_{j,t} - \Delta OC(q_{i,t}, EUA^*)}{(1+r)^t} - F(Y_{CCGT}) \Rightarrow$$

$$NPV_{coal} - \text{Option to wait coal} = NPV_{CCGT} - \text{Option to wait CCGT}$$

Where:

$$I_{i,t} = \text{Greenfield investment}$$

$$F(Y_{Coal}) = \text{value of the option to wait to build up a coal fired steam generator}$$

$$F(Y_{CCGT}) = \text{value of the option to wait to build up a CCGT generator}$$

According to ROA, a new entrant will decide to come into the market today and adopt a CCGT technology if, and only if, the EUA price is high enough to compensate both, the difference in expected benefits between the two technologies and the opportunity cost of waiting for additional information inflows. Namely, when the NPV of a coal fired steam minus the option to wait will be equal to the NPV of a CCGT minus the corresponding deferral option. The parameters used to calculate the value of the option to wait for the two technological alternatives are enclosed in table 2.

Table 2: Option to wait

| Parameters | CCGT | Coal Fired Steam |
|-------------------------|---|---|
| Underlying | PV of the net benefits | PV of the net benefits |
| Strike | PV of the investment costs | PV of the investment costs |
| Volatility | 15% Volatility of the underlying resulting from Montecarlo simulation | 17% Volatility of the underlying resulting from Montecarlo simulation |
| Free risk rate | 3% | 3% |
| Dividends | 0% | 0% |
| Time to maturity | 5 (expiration of governmental authorization) | 5 (expiration of governmental authorization) |

Simulations

The main results of the analysis for the base case under both the oligopolistic and the competitive pricing rule scenarios are shown in figure 3 and 4, respectively illustrating the switching conditions for the incumbent and the new entrant (see also table 9 and 10). By analysing the two charts we can get some insights about how the effectiveness of the Italian NAP will depend by both gas prices and the decision rule adopted by power players. First of all under current gas and EUA prices and regardless of the decision rule that will be adopted, power utilities have no incentive to move towards less carbon intensive technologies. Indeed, currently observed EUA prices (the red line) are well below the threshold level and, as a consequence, reaching EU targets looks quite unlikely under the current scenario unless either the price of EUA increases or the price of gas falls.

In addition, if we take a look to the situation faced by the incumbent, we can also notice that if the decision to switch were undertaken relying on a ROA-based decision rule (yellow line in figure 3) the value of the EUA triggering a technological shift would grow up to more than 200% in comparison with the static case (pink line), making the likelihood to reach EU targets even smaller.

The situation faced by the new entrant is more complex: the expectation of an increase in EUA prices could encourage this operator to adopt a CCGT technology, even if the current level of market prices does not provide additional incentives. Indeed, in the case of a new entrant, the adoption of a ROA based decision rule (the blue line in figure 4) would slightly lower the EUA price that makes an operator indifferent between the two technologies. The rationale behind this result is the following: considering that only the installation running on Coal has to face an additional cost due to the implementation of the ETS, the adoption of this technology rises the uncertainty faced by the operator. As a result the EUA price required to adopt the more environmental friendly technology is lower.

Comparing the oligopolistic and the competitive pricing rule scenarios, we can see that under the oligopolistic pricing rule, the price of EUA that triggers a technological switch in the medium run tends to be lower, while it is slightly higher in the short run.

Table 9: Incumbent EUA*

| Dark= Spark Spread | Gas Price €/MWh | CO2 as a component of marginal cost: full cost of CO2 into electricity Price (Competitive Pricing) | Extra cost of CO2 into electricity price (Oligopolistic Pricing) |
|--------------------------------------|-----------------|--|--|
| | | EUA* (€/t) | EUA* (€/t) |
| | 30 | 6.54 | 8.33 |
| | 40 | 68.41 | 87.06 |
| | 50 | 130.41 | 165.97 |
| | 60 | 192.41 | 244.89 |
| | 70 | 254.42 | 323.80 |
| NPVgas= OPV coal | Gas Price €/MWh | EUA* (€/t) | EUA* (€/t) |
| | 30 | 8.49 | 7.49 |
| | 40 | 102.27 | 89.97 |
| | 50 | 196.27 | 170.87 |
| | 60 | 290.27 | 251.77 |
| | 70 | 384.27 | 332.67 |
| NPV gas = OPVcoal- Option to switchl | Gas Price €/MWh | EUA* (€/t) | EUA* (€/t) |
| | 30 | 211.18 | 126.95 |
| | 40 | 397.72 | 249.44 |
| | 50 | 620.71 | 389.92 |
| | 60 | 843.96 | 530.66 |
| | 70 | 1,067.40 | 671.57 |

Figure 3: Incumbent EUA*

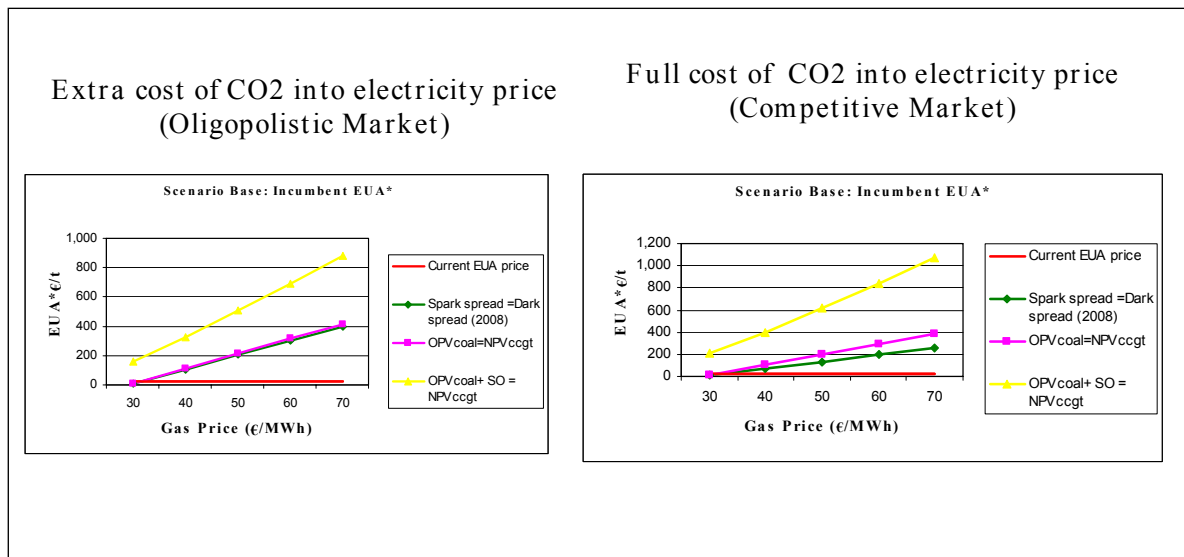
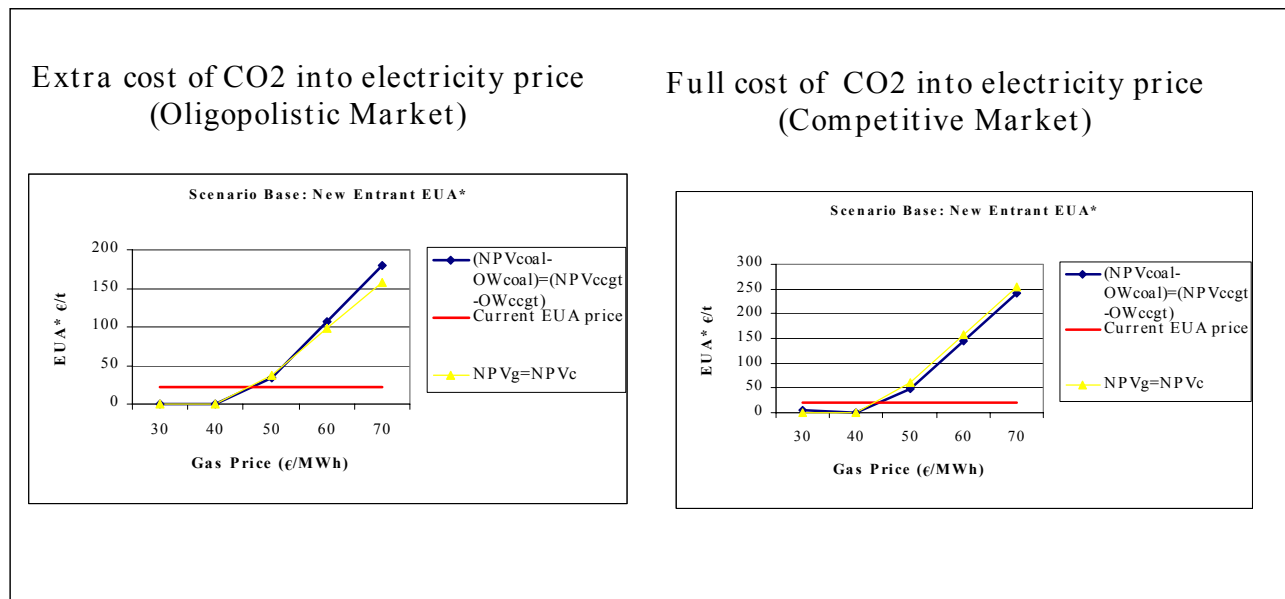


Table 10: New entrant EUA

| | | CO2 as a component of marginal cost: full cost of CO2 into electricity Price (Competitive Pricing) | Extra cost of CO2 into electricity price (Oligopolistic Pricing) |
|-----------------------|-----------------|--|--|
| | Gas Price €/MWh | EUA* (€/t) | EUA* (€/t) |
| NPVgas= NPV coal | 30 | 0.00 | 0.00 |
| | 40 | 0.00 | 0.00 |
| | 50 | 61.71 | 38.10 |
| | 60 | 158.09 | 97.61 |
| | 70 | 254.47 | 157.12 |
| NPVgas+SW= NOVcoal+SW | 30 | 0.00 | 0.00 |
| | 40 | 0.00 | 0.00 |
| | 50 | 48.17 | 24.84 |
| | 60 | 144.97 | 84.71 |
| | 70 | 241.36 | 144.60 |

Figure 4: New Entrant EUA*



Turning on the expected impact of the ETS on electricity prices, we also tried to forecast the impact of the ETS scheme on end-users. In order to perform this calculation we fixed the gas price at its current level, 50 €/MWh, and we calculated the impact on electricity prices by assuming that the additional costs due to the implementation of the ETS would be a completely pass-through only for the price setter (CCGT). Given that the CCGT technology does not face any incremental cost due the implementation of the ETS, none increase in electricity price will be associated with the implementation of the scheme in the oligopolistic pricing rule scenario. The result changes completely in the competitive pricing rule scenario as it is shown in the table below.

Figure 5: Expected impact on electricity price

Impacts on Electricity Prices

Current Gas Price: 50 (€/MWh)

| Switching Condition | EUA* (€/t) | EUA* (€/MWh) | Increase in Electricity Price (%) |
|-----------------------------|---------------|-----------------|---|
| Dark=Spark Spread | 130 | 58.44 | 70% |
| OPVcoal=NPVccgt | 196 | 87.95 | 106% |
| OPVcoal+Op. Switcht=NPVccgt | 621 | 278.15 | 335% |

- The increase in Electricity prices, paid by end-users, would be significant, but not associate with any environmental benefit
- In the event the players take a decision in accordance with a ROA criterion, the impact on Electricity prices could be more than three times in size (70% vs. 335%)

The above analysis shows that the Italian NAP, as implemented in the testing period (2005-2007), does not help the economy to reach the required emission reductions. However, given that only the price setter is able to completely discharge to end-consumers the incremental production cost, under the current framework, there will be no impact on electricity prices due to the implementation of the ETS. Therefore

increases in electricity prices are due to factors external to the implementation of the ETS (such as increases in fuel prices).

Moreover the comparison between the two alternative pricing rules, enables to highlight other important features of the Italian strategy with respect to who has to carry on the costs associated to the ETS. The oligopolistic pricing rule, indeed, protect end-users and penalizes power operators which production mix highly relies on coal (i.e. this operators face higher production costs that is not able to pass through electricity prices). The adoption of a competitive pricing rule however would have a completely different effect. Indeed in this case the implementation of the ETS would represent a cost only for consumers, while power sector operators would benefit from the higher electricity prices regardless of their emission levels. Indeed under the competitive pricing rule the EUA price that triggers the technological switch, in the medium and long term, tends to be higher (figure 3 and 4). This result implies that also high carbon intensive technologies can benefit from the increase in electricity prices due to the implementation of the new regulatory framework, lowering the likelihood of a technological switch (table 11).

Table 11: The welfare effect of the introduction of different pricing rules on the Italian ETS with respect to: end-users, power players and environment

| | End-users | Power Players | Environment |
|----------------------------|------------|---------------|-------------------|
| Competitive pricing rule | ↓ ————— | ↑ | Negligible |
| Oligopolistic pricing rule | ↑ | ↓ | Negligible |

Comparing the results of the base case with the other scenarios, tight and relaxed) we can get more insights about how the decisions of the Italian authorities will affect power players (figure 5 and 6).

Figure 5: Incumbent Scenario's Results: Switching Conditions Comparison

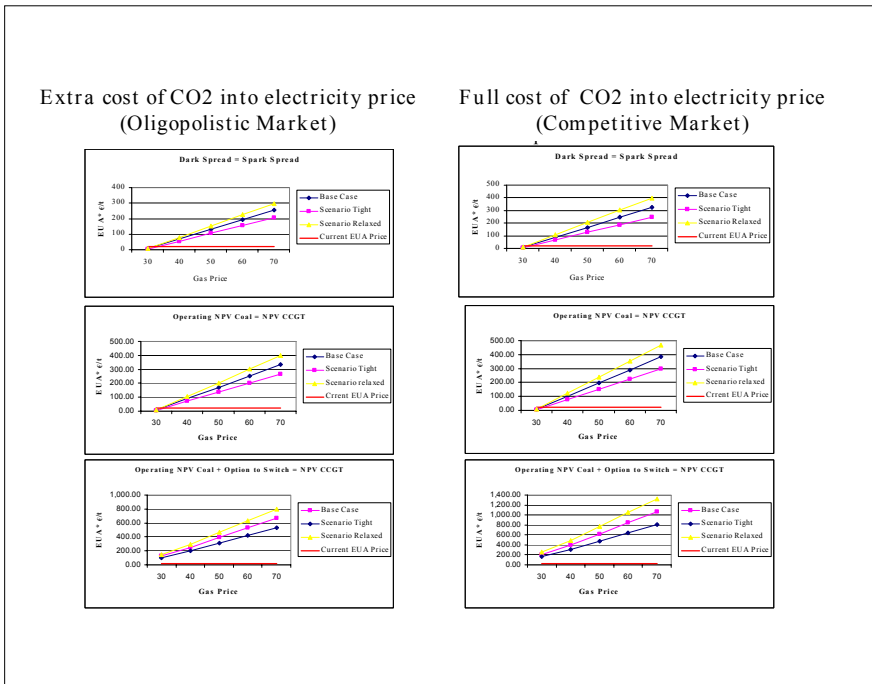


Figure 6: New entrant Scenario's Results

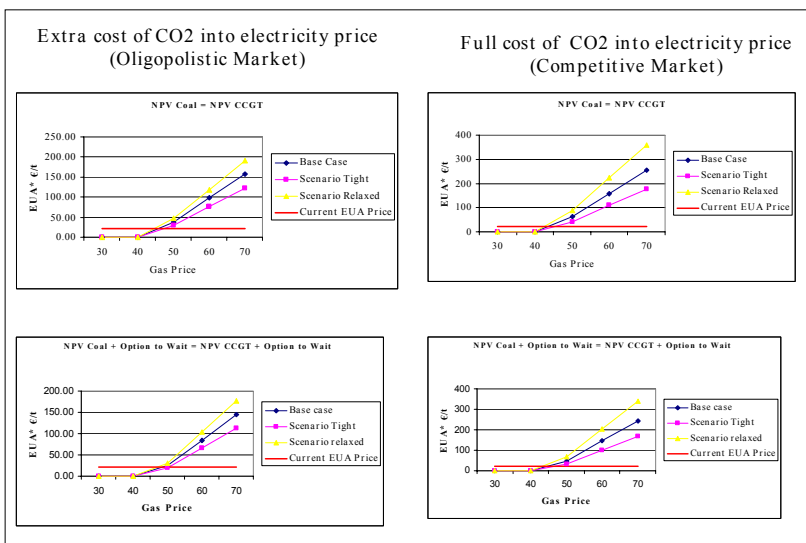
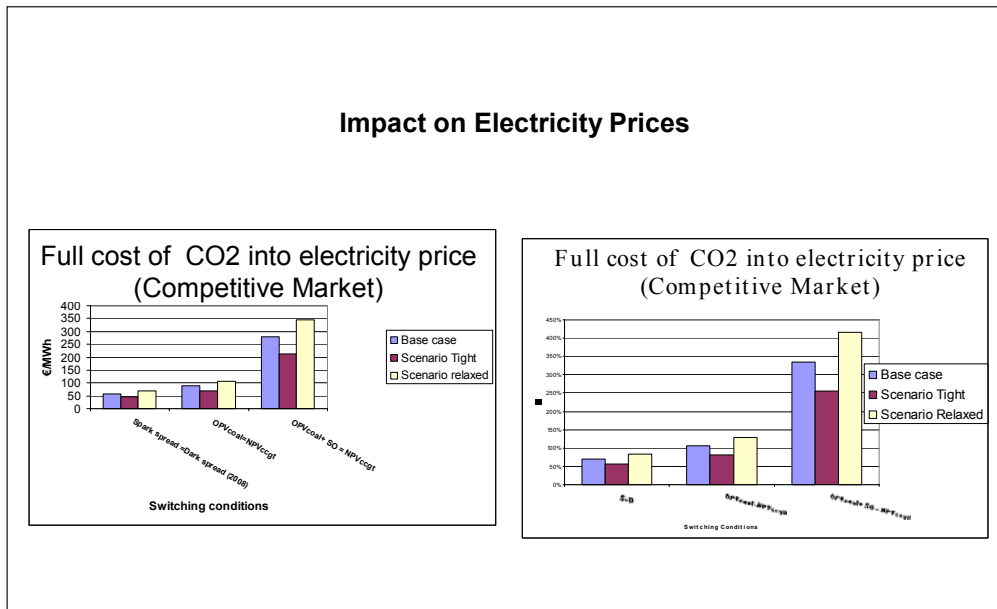


Figure 7: Impact on electricity prices under the competitive pricing rule

As shown in the figure 6 and 7, in all the scenarios, a stronger cap will lower the EUA price threshold level. In the oligopolistic pricing rule scenario this will result in higher production costs faced by power sector operators, while in the competitive pricing rule scenario will imply higher electricity prices for end-users (figure 7).

Given the current market conditions for what concerns fuel and EUA prices, and considering that in the Italian market an oligopolistic pricing rule has been adopted, the most likely scenario appears the one in which power utilities production costs go up without any material impact on the environment, making the ETS completely ineffective. Moreover given that a technological switch appears implausible, regardless of the pricing rule that will be adopted, a strategy that imposes strong obligations to power sector operators doesn't seem to be optimal.

Finally, our results tell also something about the strategy followed by the Italian government that seems to have chosen to postpone the abatement of emissions inside the country and to heavily rely on the mechanisms provided by the Kyoto

Protocol (CDM, JI) to meet its obligations. However such a choice is clearly sub optimal because it imposes an extra cost on power sector operators that is not associated to any environmental benefit. In this context the new regulatory framework would represent a social cost that does not generate any social benefits.

Conclusions

The simple simulation analysis discussed above, clearly demonstrates how relevant can be taking into account uncertainty when dealing with regulation matters in capital-intensive industries. The behaviours of the utilities, the impact on power prices and finally the success of regulation in improving the environment, have to be drastically revised when Real Option valuation framework replaces Net Present Value techniques.

We believe that further research work should be carried on in this direction in order to optimise the policy design for the next commitment period of the European Trading Scheme.

Even if our results could be refined in many important aspects (e.g. more detailed analysis of the stochastic properties of EUA prices and of their correlation with Oil and Electricity prices, strategic analysis of the interdependency of the option values for Incumbents and New Entrant with a game-theoretic approach) our results show the risk of getting an inappropriate vision on the operators incentives and strategies when uncertainty it is not properly treated.

We would like then to conclude this short paper, by stressing once more, how important it is for Regulations to rely on modelling schemes that allow overcoming the risk of imposing a social cost not generating “enough” environmental benefits.

References

Burkhardt (2004), *Real options valuation in emissions trading and control*, Presentation in the 2nd “Business and Emissions Trading” Workshop in Wittenberg, Germany, 3-5.11.2004.

Citigroup (2006), *Socially Responsible Investment: Permit Poker, The environment: Citigroup business initiatives*, 5 may
<<http://www.citigroup.com/citigroup/environment/index.htm>>

Copeland and Antikarov (2001), *Real Options: a practitioner's guide*, New York, Texere LLC

De Leyva and Lekander (2003), *Climate change for Europe's Utilities*, in «McKinsey Quarterly», n. 1, pp. 120-130.

Directive 2003/87/CE “Direttiva 2003/87/CE del 13 ottobre 2003 che istituisce un sistema per lo scambio di quote di emissioni dei gas a effetto serra nella Comunità e che modifica la direttiva 96/61/CE del Consiglio”

Dixit and Pindyck (1994), *Investment under uncertainty*, Princeton, Princeton University Press

European Commission (2005), *Further guidance on allocation plans for the 2008 to 2012 trading period of the EU Emission Trading Scheme*, COM(2005) 703 final

European Energy Agency (2005), *The European environment - State and outlook 2005*, State of Environment report No 1/2005

European Parliament and Council, *Establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC*, directive 2003/87/EC

Fortis Bank (2006), “Fortis Bank (2006), *ETS Phase One Forecast - Flat to Slightly Short*, Energy & Environmental Markets: Special Report ,(19 May)

Fortis Bank (2006), “Fortis Bank (2006), *Fuel Fundamentals in the Carbon Market '05*, Energy & Environmental Markets: Special Report ,(25 January)

Fortis Bank (2006), *Emission reduction potential by fuel switching in the EU power sector*, Energy & Environmental Markets: Special Report (25 April)

Laurikka and Pirilä (2005), *Investment Appraisal of Heat and Power Plants within an Emission Trading Scheme*, Helsinki University of technology, http://www.tkk.fi/Yksikot/Energiatalous/INVIS_Final_Report.pdf

Maloney and Brady, (1988), *Capital Turnover and Marketable Pollution Rights*, Journal of Law and Economics 31(4), pp. 203-226

Nelson and Tietenberg (1993), *Differential Environmental Regulation: Effect on Electric Utility Capital Turnover and Emissions*, Review of Economic Statistics, 75 (2), pp. 368-373

Appendix I: Data sources and volatility estimation

The volatility used to calculate the value of the options has been estimated through a Montecarlo simulation performed on the underlying of each option.¹⁷ This approach allow us to estimate this parameter as a function of the stochastic component of the underlying. For the purposes of our analysis we have identified four sources of uncertainty: energy price, gas price, coal price, and EUA price. We have assumed this variables to evolve over time following a simple stochastic process of the form depicted in the following equation

$$P_{i,t} = P_{i,t-1} + \sigma_i dz_i \quad \text{For } i = \{\text{energy, coal, oil, EUA}\}$$

Where:

$$dz = \varepsilon \sqrt{dt} \text{ and } \varepsilon \sim N(0,1)$$

$P_{i,t}$ = price of the variable i at time t

σ_i = variance of the variable i

The variance of each variable and the correlation among variables has been estimated on the basis of historical data (table A). The price of oil has been taken as a proxy for the price of gas. This choice has been made since the two variables result strictly correlated in the European market because of international agreements between producers¹⁸. Table B encloses the results of the analysis.

¹⁷ One of the most difficult challenges in applying the ROA approach is the estimation of the parameters required to calculate the value of the options. Indeed the volatility of the project under analysis is not simply the sum of the volatility of inputs and outputs used in the production process

¹⁸ However it has to be noticed that this assumption could partially bias the results and that further investigation would be needed in order to model more correctly the relationship between the two variables.

Table A: Data

| | Coal (TFS) | Oil | EUA | Energy |
|---------------------------|--------------------|------------------|-----------------|---------------|
| Source | Bloomberg | Bloomberg | Fortis | IPEX |
| DATE/Unity Measure | in USD / MT | \$/barrel | Euro/ton | €/MWh |
| 24-Jun-2005 | 60.35 | 59.12 | 23.20 | 60.47 |
| 1-Jul-2005 | 61.10 | 58.25 | 24.76 | 64.12 |
| 8-Jul-2005 | 63.20 | 59.96 | 28.55 | 64.37 |
| 15-Jul-2005 | 64.33 | 59.09 | 28.00 | 66.59 |
| 22-Jul-2005 | 63.23 | 57.46 | 21.80 | 67.54 |
| 29-Jul-2005 | 60.93 | 59.56 | 21.04 | 67.90 |
| 5-Aug-2005 | 58.53 | 61.60 | 20.43 | 58.12 |
| 12-Aug-2005 | 57.10 | 64.91 | 21.95 | 54.34 |
| 19-Aug-2005 | 59.95 | 64.84 | 22.07 | 52.04 |
| 26-Aug-2005 | 59.60 | 66.42 | 22.81 | 55.41 |
| 2-Sep-2005 | 58.25 | 68.60 | 23.76 | 62.89 |
| 9-Sep-2005 | 58.18 | 64.77 | 24.18 | 61.58 |
| 16-Sep-2005 | 58.68 | 63.86 | 22.19 | 61.20 |
| 23-Sep-2005 | 57.08 | 66.22 | 22.00 | 64.50 |
| 30-Sep-2005 | 55.33 | 66.05 | 22.29 | 63.05 |
| 7-Oct-2005 | 54.78 | 63.07 | 23.44 | 64.56 |
| 14-Oct-2005 | 54.45 | 63.03 | 23.17 | 62.35 |
| 21-Oct-2005 | 54.33 | 62.33 | 22.45 | 63.05 |
| 28-Oct-2005 | 54.15 | 61.15 | 21.65 | 61.58 |
| 4-Nov-2005 | 51.83 | 60.34 | 21.34 | 53.51 |
| 11-Nov-2005 | 51.33 | 58.69 | 22.73 | 60.70 |
| 18-Nov-2005 | 50.50 | 57.01 | 22.56 | 63.66 |
| 25-Nov-2005 | 50.68 | 59.13 | 21.22 | 67.30 |
| 2-Dec-2005 | 51.18 | 57.79 | 20.10 | 68.75 |
| 9-Dec-2005 | 51.43 | 59.82 | 21.51 | 66.33 |
| 16-Dec-2005 | 52.20 | 60.31 | 21.42 | 68.91 |
| 23-Dec-2005 | 52.20 | 58.12 | 20.76 | 66.49 |
| 30-Dec-2005 | 52.28 | 59.84 | 21.06 | 59.15 |
| 6-Jan-2006 | 52.95 | 94.19 | 22.34 | 65.24 |
| 13-Jan-2006 | 53.18 | 63.73 | 22.85 | 72.26 |
| 20-Jan-2006 | 54.58 | 79.01 | 24.53 | 73.19 |
| 27-Jan-2006 | 57.43 | 67.01 | 25.20 | 78.35 |
| 3-Feb-2006 | 60.45 | 66.58 | 26.33 | 79.87 |
| 10-Feb-2006 | 59.40 | 63.04 | 25.98 | 81.94 |
| 17-Feb-2006 | 61.45 | 59.36 | 26.00 | 80.35 |
| 24-Feb-2006 | 61.23 | 64.88 | 26.44 | 82.82 |

Table B: volatility

| | Coal | Oil | EUA | Energy |
|------------------------------|-------------|------------|------------|---------------|
| Annualized volatility | 8% | 37% | 20% | 20% |

Table C: correlation matrix

| | Coal | Oil | EUA | Energy |
|--------|--------|--------|-------|--------|
| Coal | 1.000 | | | |
| Oil | -0.031 | 1.000 | | |
| EUA | 0.260 | 0.174 | 1.000 | |
| ENERGY | 0.231 | -0.032 | 0.148 | 1.000 |

On the basis of this results and of the assumptions illustrated in equation 1, we have run a Montecarlo simulations (5000 trials) on the base scenario The output of the simulations has been used to calculate the volatility of each option as it is shown in the equation below:

$$\sigma_J = \sqrt{\frac{1}{N-1} \sum_{n=0}^N \left(\ln \left(\frac{S_{j,n}}{S_j} \right) - \ln \left(\frac{\bar{S}_j}{S_j} \right) \right)^2} \quad \text{For } J= \{1,2,3\} \text{ and for } N = 5000$$

Where

N= number of trials

$S_{j,n}$ = value of the underlying of the option j in the nth trial of the simulation

S_j = value of the underlying of the option in the static case (i.e. before the simulation)

\bar{S}_j = average of the underlying of the option j over the 5000 trials

σ_J = volatility of the option j

The results of the calculations are shown in table D.

Table D: Estimated volatility¹⁹

| | Volatility |
|---------------------|------------|
| Option to switch | 15% |
| Option to wait CCGT | 15% |
| Option to wait Coal | 17% |

¹⁹ We have performed two different simulations one for the competitive pricing scenario and the other for the oligopolistic pricing scenario. The results with respect to the volatility of the underlyings doesn't change.