The Clean-Development-Mechanism, Stochastic Permit Prices and Energy Investments

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Abstract

In this paper we evaluate the simultaneous impact of two emission permit classes with stochastically evolving prices on energy investments. We consider permits that are allocated and auctioned inside the EU (EUA) and secondary Certified Emission Reductions permits (sCER), which are resold primary CER from the CDM. One price taking firm subject to emission regulation has the choice to invest in a wind power plant, a gas power plant or can choose do to nothing. An investment in either plant type is considered to be irreversible. When investing in the gas plant the investor also has to consider the future development of emission prices. We use Monte-Carlo simulation to generate price paths for the emission permits, which serve as an input for a recursive optimization problem. We find that allowing the usage of offset permits in the present policy framework leads to a significantly lower probability of an investment into wind power taking place. If the quota of sCER permits is doubled, the decrease in the investment probability into wind is more than proportional. Decoupling the price processes does not significantly alter the results. Since the CDM has been under a lot of criticism over the years, recently especially concerning its baseline-methodology and a subsequent over-supply of emission permits, policy makers should be careful in constructing new offset mechanisms without properly understanding the impact on investment behavior.

JEL-Classification: C63,Q47

Keywords: Energy Investment, Uncertainty, Clean Development Mechanism, Climate Change

1 Introduction and literature review

Negotiations to reach a legally binding international agreement to combat climate change are on stalemate and proposals to postpone the final deadline to reach an agreement to 2015 have been put forward [1]. However, despite of the slow pace of international negotiations, several countries are planning to set up their own Emission Trading Schemes (ETS) in the near future. These include Australia, China and Korea [2]. Thus, the question of how these markets will interact with each other and how the flexible Kyoto-Mechanisms will continue to function in such a setting is of great importance. Currently, the flexible Mechanisms include the Clean Development Mechanism (CDM) and the Joint Implementation Mechanism (JI). A program that is likely to join their ranks in the foreseeable future is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD).

Uncertainty about a future climate change agreement and the way ETS markets are going to interact will have a major influence on future profit stream of energy companies. Furthermore, investment in the energy sector is generally considered as irreversible. Combining uncertainty and irreversibility with the possibility of waiting for new information to make a better informed decision, renders this problem suitable for a real-options analysis framework. After the original development of financial options valuation by Black and Scholes (1973) and Merton (1973), their techniques were adopted for real-investments in the physical sense by Myers (1977). Dixit and Pindyck (1994) and Trigeoris (1996) provide a good overview with numerous examples. One of the first adoptions to the energy sector was undertaken by Herbelot (1992). Analyzing the decision of a coal-power plant owner to install a scrubber to fulfill sulfur emissions limits, he finds that the net present value (NPV) increases substantially when the owner can decide flexibly when to start investing, due to the value of additional information. Insley (2003) investigates the same problem and finds that the low level of emission prices since 1993 led to few investment decision in favor of scrubbers, while the preferred method of compliance was switching to a low-sulfur coal type. The option to halt construction at any point played pivotal role in the investment decision. Yang et al. (2008) investigate the impact of uncertain emission prices on the risk associated with investing either into a coal, gas or nuclear plant. They find that the degree of the investment risk caused by uncertain permit prices depends to a large degree on the merit-order of energy pro-

[1] http://www.environmental-finance.com/news/view/1995

[2] http://www.environmental-finance.com/news/view/1995

duction, being lowest when gas or nuclear plants are first. Furthermore, including the possibility of price shocks, policy makers should try to let them happen as seldom as possible since investment will stagnate while waiting for new information on prices to be revealed. In contrast, Fuss et al. (2009) consider the case when a company can invest into a fossil, a carbon-capture and storage (CCS) module, and/or a renewable power plant. The owner is flexible with respect to the timing of investment and permit prices evolve stochastically. They find that when evaluating these options simultaneously, the option to retrofit the fossil plant with CCS leads to a postponement of the investment into renewable energy. Also, when considering the timing of climate policy they find that longer periods between jumps in prices lead to less emissions. Fuss et al. (2010) consider the impact of options on emission permits that are derived from REDD on energy investments. They find that REDD options may leave investment in carbon capture and storage technology (CCS) unaffected if they are priced as derivatives of CO_2 permits, since this would ensure a high enough price. However, one should not forget that CCS will remain a non-viable technology option for the medium-term future, and testing has even been banned in some countries [3].

Studies that investigate the impact of the CDM on power investments in the developed world are largely absent in the literature, and if the issue is mentioned no quantitative evaluation is carried out [4]. Most studies that investigate the CDM look at the impact it has had in developing countries. However, as mentioned before new ETS markets are emerging world wide and without an overarching structure of a global climate agreement, more CDM like mechanisms will emerge in time to connect those markets. Without a good understanding of how these mechanisms influence the investment decisions of energy companies, it is not clear ex-ante that they will help to transform the energy infrastructure and strengthen sustainable development, which are the two foremost goals of the flexible mechanisms[5].

[3] http://www.n-tv.de/politik/Wie-ein-Ausweg-zur-Sackgasse-wurde-article4376091.html

[4] See for example (Blanco and Rodrigues, 2008, p.1517):"However, the low price of CERs and ERUs (Emission Reduction Units) on the EU ETS market can play an indirect negative role on wind energy and other technologies since their inflow to the EU ETS market further reduces the allowance prices in Europe and with them the little incentive that remains to invest in-house. An industry obliged to cut its emissions would prefer to import cheap JI or CDM credits instead of buying EU ETS credits or adapting its production process.".

[5] http://cdm.unfccc.int/about/index.html

The contribution of this paper is to analyze the impact that the simultaneous availability of the two permit classes with differing price developments has on an energy investor. We find that allowing the usage of offset permits in the present policy framework leads to a significantly lower probability of an investment wind power. If the quota of sCER permits is doubled, the decrease in the investment probability into wind is more than proportional. Decoupling the price processes does not significantly alter the results. These findings imply that policy makers should take great care in the design of offset mechanisms, in order for them not to lead to actually more emissions on a global scale. Also, since energy investment is long lived once the investment into gas has taken place it will take a long time before renewables could actually replace a fossil powered infrastructure. We do not consider various renewable energy policies[6] in our model. However, it is clear from our results that there will be a continued need for support of renewables, if it is the pronounced political will to achieve a high penetration of renewable energy sources in the market. Current emission prices and their likely evolution over time do not seem a sufficient incentive to achieve this goal.

The paper is organized as follows: Section 2 introduces briefly the most important background issues, the CDM, the carbon market and the behavior of emission prices analyzed in the literature. In Section 3 the model is described, including the price-processes of the two permit classes. Section 4 contains the data information used in the model, concerning energy markets and the different types of power plants. In Section 5 we present the results of our model, section 6 concludes.

[6]For example: Direct subsidies, portfolio target etc.

2 A short history of the CDM and the carbon market

2.1 The CDM

The CDM gives developed countries flexibility in achieving their emission targets and should lower their compliance cost, since abatement activities carried out in developing countries are considerably cheaper (Castro, 2010; Bakker et al., 2011). The CDM operates as follows: Companies can invest into projects in developing countries, receiving the emission saved due to their involvement as emission permits. These can be used in their regional ETS to fulfill their own abatement requirements or can be re-sold in the market. Projects should only fall under the CDM if they would not have been carried out without CDM support, and additional emission savings are generated due to the CDM involvement (Zavodov, 2010). This is known as the additionality criterion. CDM projects do not need to have a technology transfer component. A study by Seres et al. (2009) finds that about 36% of all CDM projects have a technology transfer component. There is a limit on how many CDM permits can be used for abatement in the European ETS. This limit is set at 13,4% of the total of allowed emissions for Phase II, which runs from 2008-2012 (Kossoy and Ambrosi, 2010).

The CDM has been subject to a variety of criticism over the years. One main line of criticism concerns the additionality criterion, since often projects that would have gone ahead without the CDM were reported in such a way to make it CDM conform (Wara, 2008; Bakker et al., 2011). This in turn led to an oversupply of CDM credits and consequently depressed emission prices. Other criticism concerns its actual contribution to sustainable development, the lack of technology transfer, the distribution of projects world wide (95% in Asia and Latin America), and the level of transaction cost involved in getting a project approved (Bakker et al., 2011). How and if these criticisms will be incorporated into a post-2012 climate change agreement is not clear at the moment. However,"...the CDM will last well into the post-Kyoto phase, since the majority of projects already approved will lead to the issuance of CERs (*permits*) for many years to come" (Klepper, 2011, p.696)

2.2 The Carbon Market

The carbon market is largely dominated by European ETS transactions, being currently the only large scale mandatory ETS market in operation worldwide. The overall volume and the importance of the CDM have been growing steadily, coming to a halt in 2009 due to the uncertainty over a new climate change agreement. With a total value of 141.9 $ billion dollars in 2010, the European ETS represented 82% of the market volume and the CDM 14% (Linacre et al., 2011). There are two asset classes pertaining to the CDM. The first is primary Certified Emission Reductions (pCER). These are credits that are obtained directly from projects. The second class, secondary Certified Emission Reductions (sCER), are resold pCER. The main difference between the two pertains to delivery risk. sCER do not have a delivery risk, since they have been delivered already. However, this is a major issue with pCER. Regulations concerning what projects are CDM eligible change frequently and might discontinue an already existing permit flow (Bakker et al., 2011; Klepper, 2011). Therefore, it is uncertain if pCER will eventually be generated from a project. Despite the fact that they have already been delivered, the delivery risk of pCER does carry on to sCER in that without a constant stream of new permits from CDM projects, the market will eventually become illiquid thus influencing the sCER price (Linacre et al., 2011; Mansanet-Bataller et al., 2011).

2.3 Emission Prices

One European Emission Allowances (EUA) and one sCER can be used to abate the same amount of CO_2. Therefore, they should theoretically have the same value. However, this is not the case. Since the CDM became operational in 2007 and the establishment of its different asset classes in the market, a spread existed between sCER and EUA allowance prices. Mansanet-Bataller et al. (2011) investigate the drivers of this spread. They find the following factors to be the most influential: Linking the CDM with other ETS, the EUA price, the financial crisis, and the volume of EUA and sCER traded. Linking with other ETS markets is an important issue since demand for the CDM would increase, thereby decreasing the reliance of CDM projects on the European ETS market. With the current import quota, liquidity is limited on the market. It will increase if CDM permits can be used in other markets as well, which would reduce the spread since there is less of a risk of not being able to sell an sCER latter. The spread is also driven by the EUA-Price since this sets effectively the upper limit for sCER prices. Since industrial production was significantly lowered during the financial crisis, less emissions where produced and consequently also less permits required. This led to a significant over-supply of EUA and this brought the sCER and EUA price closer together. The volume of trading points to the fact, "...that the EUA-sCER spread maybe used as a 'speculative' instrument by rational investors and market participants on the EU ETS, who are able to trade simultaneously EUAs and sCERs when the price difference is large enough to justify the arbitrage activities" (Mansanet-Bataller et al., 2011, p.1067).

3 Model Description

3.1 Price-processes

In our model we will focus on the impact of EUA and sCER on energy investments. We exclude pCER from our analysis for three reasons: First of all, there is no common pCER price since each project has an individual risk class and therefore an individual price (Mansanet-Bataller et al., 2011). This would force us to include a stochastic process for every project type, which would render the model intractable. Secondly, including pCER would also imply that we would have to include the decision to invest into a CDM project. We will not pursue this modeling approach, since there are many firms in the market that are not able to develop CDM projects, but are subject to emission limits and rely on the sCER market. Finally, pCER transactions do not play a significant role in the current market situation and are unlikely to play a major role within the next five years.

We assume that prices for EUA and sCER allowances follow stochastic processes. For EUA prices we follow current results in the literature that attempt to model their price development (Yang et al., 2008; Fuss et al., 2008, 2009, 2010), by assuming the price development to follow a geometric Brownian motion (GBM) with a positive trend. The basic reason for using GBM to model the price process, is that it is generally expected that prices for allowances will reach a higher long-term price than the current one, despite possible price reductions from time to time. The goal of a long-term higher price stems from clearly formulated political will to achieve a relatively carbon free economy in the long-term in order to limit severe consequences of global warming.

The price process for EUA allowances is described by the following equation:

$$dP_t = \mu^c P_t dt + \sigma P_t dW_t^P \quad (1)$$

μ^c is the drift parameter, σ is the volatility parameter and dW_t^P is the increment of a Wiener process. In accordance with the literature we assume a 5% trend for the EUA price process (Yang et al., 2008; Fuss et al., 2008, 2009, 2010).

We assume that the sCER price also follows a GBM with a positive trend. This is the current standard in the literature for sCER and sCER like permits (Yang et al., 2010; Fuss et al., 2010). For sCER prices we assume a 2% trend. As argued above, the price for EUA and sCER permits are driven by similar factors and sCER prices are strongly influenced by EUA prices since the EU ETS is the main market for sCER currently. Furthermore, there is still a large amount of untapped projects at cost similar to current projects (Castro, 2010; Bakker et al., 2011). This implies that over the medium to long term prices will increase, but most likely at a slower rate than those of EUA markets in which the amount of permits is constantly decreased. Also, there will be new demand for sCER credits from other ETS markets, decoupling the influence of the EU ETS market on sCER prices. The most recent example of this is Australia, which expects most of the allowances during the first years of its ETS to be covered by CDM credits (Fogarty, 2011). It can be expected that the regulations on new ETS markets will tighten slower than on the EU ETS markets. Therefore, the price increase of those permits is likely to be slower than in the EU ETS market, which will impact the price behavior of sCER. Linking to other ETS markets also implies greater liquidity in the CDM market since more sellers and buyers enter the market (Mansanet-Bataller et al., 2011). Following the argument above, limited liquidity is one of the most important factors influencing the price process of pCER and sCER allowances. Combining this with the argument that there is still a large reservoir of untapped CDM projects, decoupling from the EU ETS, greater demand and increased liquidity we expect that this will overall lead to a slower price increase of sCER than for the EUA. The price process for sCER permits is described by the following equation:

$$dP_t = \mu^c Q_t dt + \sigma Q_t dW_t^Q \quad (2)$$

μ^c is the drift parameter, σ is the volatility parameter and dW_t^Q the increment of a Wiener process.

We expect dW_t^P and dW_t^Q to be correlated. The correlation parameter is denoted by ρ. EUA prices have a positive influence on sCER price (Mansanet-Bataller et al., 2011). The intuition is as follows: An increase in the price of EUA will increase interest in buying sCER allowances due to their now relative lower price, assuming that the quota for sCER allowances has not been reached yet. This will drive up the sCER price and therefore we expect the correlation to be positive.

Electricity and gas prices evolve deterministically and are assumed to be constant[7]. This assumption is made to reduce modeling complexity significantly and to put the focus on the effect of allowance prices on power plant investments, the foremost topic of this paper. Including a stochastic evolving electricity price would not result in any significant knowledge gain, as both forms of power generation are similarly affected. Relative certainty of electricity prices can be justified by the long-term nature of contracts prevalent in the industry. If energy prices were to follow a stochastic process, a mean-reverting process would be most adequate (Laurikka and Koljonen, 2006; Fuss et al., 2008).

We do not consider technological progress in our paper since both power plants types are mature technologies which we assume to experience similar speed of technological improvement in the long-term, which leaves the overall investment decision unaffected.

3.2 Profit function and investment options

Companies can either build a gas power plant, a wind power plant, both, or choose to do nothing. Capital used for the construction of one type of plant cannot be used for the construction of the other or resold, thereby making the investment irreversible. If the gas-plant is built a company needs to comply with emission regulations, and we assume that this will be done by buying emission permits. The abatement requirement can be fulfilled by either buying EUA or acquiring sCER. As described above, there is a maximum limit imposed on the amount of sCER that can be used for abatement. The wind power plant is emission free. We assume that if emission permits need to be purchased, a company will use the maximum quota of sCER since they are cheaper, and buy EUA to fulfill the rest. The profit function is then defined as follows:

[7] In recent years technological advances such as fracking have led to a drastic increase in the supply of gas. For example, the US has become a net exporter of natural gas where only a few years ago it was a net importer. We therefore believe that the assumption of long-term stable prices is justified.

Profit Function:

$$\Pi(x_t, a_t, P_t^P, P_t^Q) = q^e(x_t)P^e - q^g(x_t)P^g - OC(x_t) - c(a_t) \\ -(1-\alpha)q^P(x_t)P_t^P - \alpha\, q^Q(x_t)P_t^Q \tag{3}$$

- x_t = State the system is currently in at time t [8]
- a_t = Action chosen at point t [9]
- q_e, P_e = Quantity and price of electricity
- q_g, P_g = Quantity and price of gas
- OC = Operating and maintenance cost
- $c(a_t)$ = One-Time Investment cost depending on the action chosen
- q^P, P^P = Price and quantity of EUA permits purchased
- q^Q, P^Q = Price and quantity of sCER permits purchased
- $\alpha \in [0,1]$ = Maximum fraction of sCER that can be used to reduce emissions

The time horizon of the model is 80 years. This time horizon has been chosen, since the average operating life-time of a gas power plant is about 30 years and for a Onshore wind power plant 25 years (IEA, 2010).

The company knows that prices for EUA and sCER evolve stochastically from a known starting value and therefore its problem is to determine the optimal time when to invest into a power plant. In order to analyze this, we use the following Bellman equation solved recursively:

$$V_t(x_t, P_t^P, P_t^Q) = \max_{a_t \in A_t(x_t)} \{\pi(x_t, a_t, P_t^P, P_t^Q) \\ +e^{-r}E[V_{t+1}(x_{t+1}, P_{t+1}^P, P_{t+1}^Q)|P_t^P, P_t^Q]\} \tag{4}$$

The first part of the equation is the immediate revenue stream a company obtains when investing into any of the two power plants or both at the same time. $A_t(x_t)$

[8] No plant operating, gas plant, wind power plant

[9] No Investment, build gas plant, build wind power plant, build wind and gas power plant

is the set of feasible actions for a given state x_t and r [10]. The second part is the continuation value. For the simulation of future EUA and sCDM allowance prices we follow (Fuss et al., 2008) in using Monte Carlo Simulations.

4 Data

Table 1: Electricity Generating Cost

	CCGT	Onshore Wind
Electricity price	70 €	70 €
Generation Capacity (MW)	480	45
Capital cost (overnight cost) (US$/kW)	1,068.00	2,348.00
Fuel Cost (US$ /MWh)	61,12	0
O&M (US$ /MWh)	4.48	21.92
CO_2 emissions (tCO_2/MWh)	0,33	0
Load Factor	85%	26%

Source: IEA (2010)

4.1 Power Plant Data

In table 1 costs and CO_2 emissions of the different power plants are listed. These are derived from "Projected Costs of Generating Electrity - 2010" (IEA, 2010). We compare a Combined Cylce Gas Turbine (CCGT) with an Onshore wind power plant, since gas is likely to remain more competitive than coal and nuclear power given current events and costs (Kaplan, 2008). We choose not to consider large offshore wind power plants since there is currently too little information available on their cost structure which certainly will experience steep learning curves. In contrast, onshore wind power has already profited from significant learning effect and is considered a mature technology. We follow Fuss et al. (2010) in assuming that operation & maintenance cost (O&M) as well as capital cost are deterministic. The load factor is the average yearly usage of the full capacity of the power plant. Capital cost can be considered as overnight cost, which are the cost that would apply if the plant could be constructed overnight. Using overnight costs [11] for two different

[10]For example, if a gas plant has already been built $A_t(x_t)$ compromises the following actions: Do nothing, or build a wind power plant.

[11]The overnight cost therefore excludes escalation in equipment, labor, and commodity prices that could occur during the time a plant is under construction. It also excludes the financing charges, often referred to as interest during construction (IDC), incurred while the plant is being built". (Kaplan, 2008, p.696)

Table 2: Price Process Data

	EUA	sCER
Trend	5%	2%
Volatility	30%	30%
Starting Price	10.30 €	7.03 €
Discount Rate	5%	5%
Correlation sCER-EUA	0.3-0.7	

types of plants is a valid assumption, if the lead time does not differ substantially which is the case for wind and gas power (IEA, 2010; Kettunen et al., 2011). We base our assumption of the electricity price on the average of EEX for the last year, which is around 70 €.

4.2 Permit Prices and volatility

Permit prices are subject to great uncertainties due to the influence of climate policy which is subject to frequent changes. Also, due to the relatively short existence of permit markets, especially in the case of CDM permits, there is no long-term data available (Fuss et al., 2010). We take current future prices of EUA and sCER as a point of departure [12]. In accordance with current literature and modelling, we assume that the trend of the EUA price is 5% and the volatility 30% (Fuss et al., 2010; Kettunen et al., 2011). As argued above, we assume the price trend to be 2%. For the sCER price we assume the same volatility as for the EUA price process, due to the strong dependence of sCER on the EUA market. We assume the discount rate to be 5%, which is in accordance with the literature on power investment (Kaplan, 2008; IEA, 2010). As mentioned above, we assume that the sCER and EUA price process are correlated. Chevallier (2011) tests for correlation in a multivariate GARCH Model. He finds correlations ranging from 0.01-0.9. However, most of the correlation values lie within the 0.3-0.7 range, which is also the range which we will test for in our model.

[12] EUA:10,30 €; sCER:7,03 €Data from http://www.eex.com Date: 28.10.2011

5 Results

5.1 Price Paths

The Figures below represent a sample of 5 price paths generated with our model for EUA. We include only a fraction of the price paths generated in the actual simulation in order for the reader to get a impression of the behavior of the price paths. The horizontal axis represents the time dimension, the vertical indicates the price. Price paths for sCER evolve in a similar fashion.

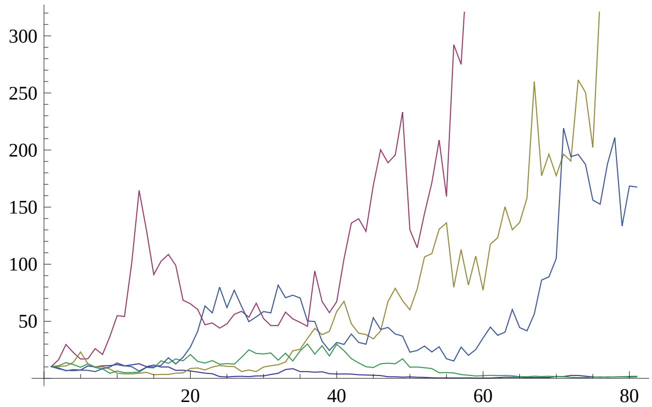

Figure 1: Price Process EUA/sCER

5.2 Policy Scenarios

In this section, we discuss the results of our model in three different policy scenarios. We ran the model according to the specification above and simulated 10,000 different emission price paths. This number of simulations has proven sufficient in order for the results to change in a insignificant fashion if we re-run the model.

In scenario 1 we assume that there will be no significant change in the regulatory environment. The EU leaves the quota of how many CDM credits can be used at roughly 15%. The EU ETS market also remains the dominant carbon market in the world, which means that the degree of correlation between the two prices also remains high [13]. In the second scenario, we assume that the regulation concerning the amount of CDM permits is loosened by increasing the quota to 30% and the EU ETS market still remains the main global carbon market and the correlation of

[13]We assume a value of $\rho = 0.5$

sCER and EUA stays at 0.5. One policy scenario in which the quota would increase is if new offset mechanisms such as REDD would be introduced into the market. In order not to reduce the CDM market to a level that would leave it illiquid it is possible that policy makers would add a REDD allowance quota on top of the CDM quota. This reasoning implies that REDD allowances will exhibit the same behavior as CDM allowances, which is taken as an assumption here since no data on the value of REDD permits is available. In our third scenario we assume that new carbon markets emerge world-wide in which the CDM can also be used for abatement, reducing the correlation to 0.3. The quota of allowed offset permits remains at 15%. In all simulations presented below the volatility was set at 30%. In order to ensure robustness of the results, we also tested for volatilities of 0%, 5% and 15%. Changing the volatilities did not alter the qualitative results significantly. In all the figures below, we compare the case where no sCER can be purchased to the different scenarios above. Therefore, the case when power plant operators can only buy EUA permits is our baseline case. The no-sCER line is purple in all the graphs below, the line which includes the opportunity to purchase sCER credits is blue.

The reader should keep in mind that the figures shown below are best interpreted as probability distributions. For example, when at a certain point in time 3,000 price paths lead to a positive decision to invest into wind power this implies that there is a 30% chance that the owner will decide to invest into a wind power plant in that year, with 10,000 different price paths simulated. In all graphs below, the horizontal axis represents the time dimension, whereas the vertical axis stands for the number of price paths simulated.

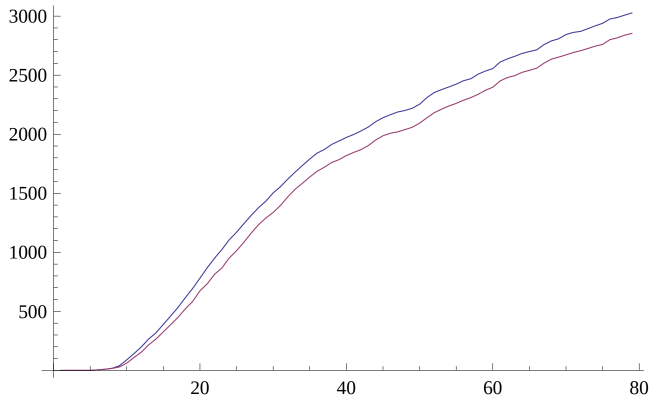

Figure 2: Scenario 1, Correlation = 0.5, sCER Quota:15%

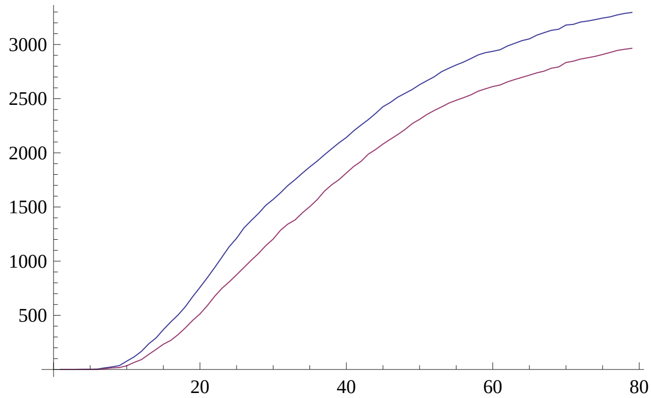

Figure 3: Scenario 2, Correlation = 0.5, sCER Quota:30%

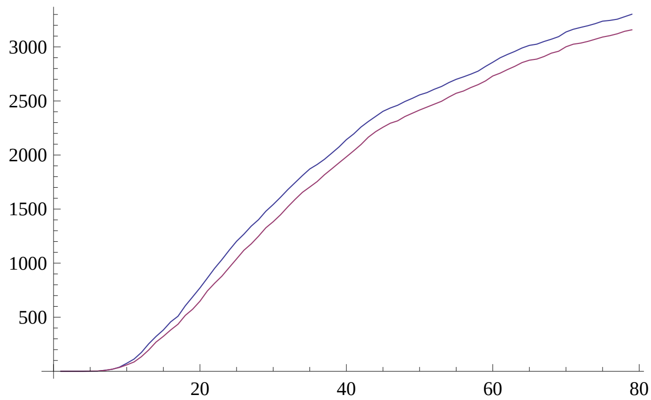

Figure 4: Scenario 3, Correlation = 0.3, sCER Quota:15%

In Scenario 1 we can observe that allowing sCER permits for abatement reduces the probability to invest in a wind power plant by about 5-20% over time, as compared the case when no sCER are available. The slowly increasing divergence of investment as we approach the end of our time horizon, stems from the fact that as EUA prices increase over time, sCER can reduce the cost of emission permits relatively more than in earlier time periods. The reader should keep in mind that the uncertainty surrounding the time-path of emission prices increases with the passage of time, and therefore very long-term results are by the nature of our model also very uncertain. As compared to scenario 1 we observe in scenario 2 that the doubling of the quota leads to a more than proportional decrease of the probability of investment in wind-power. The opportunity to use sCER permits for abatement leads to a decrease in the probability of investment in wind in the range of 10-50% over time. Figure 3 indicates that when the sCER permit quota is kept at a similar level to the current one, but the dependence of the CDM on the EU ETS market is reduced, results are similar to the ones observed in scenario 1. The decrease in the probability of investing into wind power ranges from 5%-15% over time.

What we can observe from the figures above in general is that the incentive to invest into wind energy in either scenario remains low over time.[14]. Since we have not included the diverse set of renewable policies which are used in many countries to boost investment, this is not surprising. We have chosen not to consider these policies in our model since each type of support requires a different modeling approach, which would increase the complexity of our model without increasing the insight concerning the impact of different permit classes. What our model shows however is that wind power will need continued support in order to remain competitive. Considering that wind power is considered the most mature and cost competitive of all renewable energy forms at the moment (IEA, 2010), this implies an even stronger need for support for solar and other renewable energy types if they are to become competitive. As mentioned above, there is no technological progress component in our model. We do not include this since it is likely that technological progress will affect both technology types to a similar degree, therefore leaving the effect of the different permit classes unchanged.

Concerning the effect on the investment probability into wind power, the results indicate that allowing abatement via sCER permits has a negative impact. If the regulatory environment remains similar to the one in place today, the probability of investment is reduced by up to 20%. If a quota of how many sCER can be used

[14]By low we mean that the probability of investment remains below 25% over time

for abatement is doubled, the probability of investment is lowered by up to 50%. Decoupling the the sCER price-process from the EUA process does not significantly change the results of the current policy environment, the decrease in invest is up to 15%. These numbers should be treated carefully though. We assume two stochastic price processes which represent a best guess of a the future based on previous modeling approaches in the literature and the current political situation. Therefore, the general direction of the effect should be taken as the main result of our simulations, not specific results for each year. The effect of allowing abatement via sCER is negative for wind power and increases more than proportional if the quota is increased. Reducing the correlation of the increments of the two price processes does not alter the status quo results significantly, thus the overall effect on investment is still negative.

5.3 Critical Investment Price

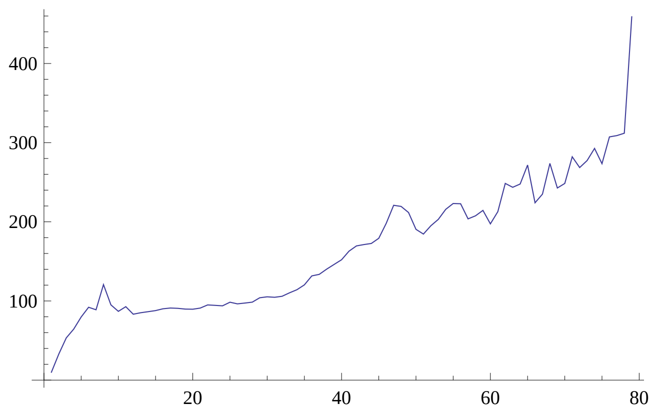

Figure 5: Development of critical investment price for wind power plant given that a gas power plant has been built

The figure above depicts the development of the critical EUA price, above which investment into a wind power plant becomes profitable once a gas plant is installed in scenario 1. We choose this comparison since in all scenarios a gas plant is installed before a wind-power plant. Therefore, this is the correct setup in order to determine the value of a real option to invest into wind energy. The price increases steeply until year 6 [15], remains stable with minor deviations until year 35, when it starts increasing again. The steep increase towards the end of the time horizon stems from

[15]The price in year 6 is 92€

the fact that in order for a wind power plant to be more profitable over a short period of time as compared to a gas power plant, the EUA price must be very high. Therefore, results towards the end of the time horizon should be treated carefully. Results from the other scenarios concerning the critical price are similar. Therefore, we limit our analysis to scenario 1. This graph implies that from a policy perspective it is worthwhile to increase the EUA price early on if a high market penetration of renewable energy is a policy goal. If policymakers wait, the price necessary to induce investment into wind energy is likely to increase quickly within a short period of time, requiring drastic action which is unlikely to be political feasible. As mentioned above we have not included various forms of renewable support policy. However, in the case of Germany these subsidies are phased out and considering our results it is unlikely that the current EUA price provides sufficient incentives for further substantial renewable investment to take place.

6 Conclusion

In this paper a real-option framework was presented in order to identify the simultaneous effect of several emission permit classes on investment in the energy sector. This question will become more important as carbon markets mature and more financial and risk-management tools become available over the next years. The maturing of the market will stem from two main influences: First of all, more obligatory ETS will emerge world-wide moving actors further along the learning curve of what tools they need and how such markets operate. Secondly, more offset mechanisms such as REDD are likely to emerge. Connecting those offset mechanisms with a variety of separate carbon markets worldwide, without impacting investments into renewable energy negatively will be a major task for regulators and policy makers.

In our model we considered the two main permit classes in the currently only obligatory ETS world wide, the EU ETS. In the EU ETS energy producers can trade and buy emission permits that are allocated or auctioned by the EU and national governments (EUA), or use the flexible Kyoto mechanisms to achieve the required emission reductions. In our model we focused on the currently most influential permit class originating from the Clean Development Mechanisms (CDM), secondary Certified Emission Reductions (sCER). These are resold primary CER which are obtained by investing in projects in developing countries that save emissions due to the investors involvement. Together, the EUA and sCER make up more than 95% of the EU ETS market. The permit prices follow stochastic processes which are taken as exogenous by the price taking firm. Both price processes behave according to a gemotric brownian motion with a positive trend. The main difference lies in the smaller trend of the sCER process. The increments of the Wiener process of the two price-processes are positively correlated.

We simulated three scenarios: First of all, a business-as-usual scenario in which regulation and the interdependence of the two permit classes stay the same. Secondly, a scenario in which more offset permits can be used in order fulfill abatement requirements. Finally, we consider a scenario in which new ETS markets emerge worldwide which changes the relationship between the two permit classes. Our results indicate that wind power is currently and for the foreseeable future not competitive as compared to gas power, even if gas power plants need to buy emission permits. What is not included in our model are the diverse set of policies that support renewable energy worldwide. Therefore, the result that wind power is currently not competitive is not surprising. However, they do show that these support mechanisms will have to remain in place for the time being if it is the formulated political will to increase the share of renewable energy production.

Concerning the influence of offset permits, we find a negative influence of sCER on the investment probability in wind power plants. The probability of investing in a wind power plant is reduced by 5-15% in scenarios 1 and 3. In scenario 2 the reduction lies between 10-50%. However, it should be kept in mind that the level of uncertainty is large towards the end due to the stochastic nature of the permit prices, and results stemming from this part should be treated cautiously. Furthermore, since our model represents a best guess of the future development of permit prices based on previous results in the literature and the current political situation, it is the general direction which is the main result. Numbers for specific years should be treated with caution.

We also calculated the critical investment price above which a wind power plant was installed, given that a gas power plant has already been built. This setup fits our model since gas power plants are always installed before wind power plants. Therefore we are able to determine the value of the real option to invest into a wind power plant. Our findings suggest that the critical price quickly increases to a high level, remains stable a long-period and then increases again. For policymakers this implies that an early on increase in the EUA price is very effective, whereas waiting to increase the price would required drastic changes. The steep increase in the end is a purely technical result since in order for a wind power plant to be more profitable than a gas power plant towards the end of the time period, a gas power plant needs to be highly unprofitable. This happens only when the EUA price is very high.

Allowing abatment via sCER permits has a negative effect on investment in wind power plants. Considering that other forms of renewable energy are even more expensive in their cost structures, this result implies a general negative effect of sCER on all renewable energy investments. This will lock the energy sector in a fossil fuel state since investment once undertaken is irreversible and long-lived. As explained above, a variety of criticism surrounds the CDM currently especially concerning its methodology for business-as-usual cases, which has caused a significant over supply of credits so far. Considering that it is likely to lead to more emissions in developed countries, while it is debatable if it reduces emissions in developing countries, policy makers should thread more carefully when considering creating new offset mechanisms and linking them to ETS. A foremost goal should be to secure that reductions in developing countries are not subject to leakage into other sectors thereby making them sustainable, and to create a methodology for baseline scenarios that puts an end to the oversupply of offset permits.

Several extensions of the model presented here are interesting for future research. First of all, since we only consider a price taking firm, it would be interesting to look at a market in which the company can influence either the price of permits or the allocation by the government, thus endogenizing the price development of emission permits. Furthermore, one should consider a firm that can purchase sCER but can also directly invest into CDM projects, thereby obtaining pCER. Also, if data are available on new offset mechanisms, it will be interesting to see how they influence each other and the investment behavior. Finally, it would be interesting to look at the impact of offset mechanisms if a company already has a a portfolio of power plants.

References

S. Bakker, C. Haug, H. Van Asselt, J. Gupta, and R. Saïdi. The future of the CDM: same same, but differentiated? *Climate Policy*, 11(1):752–767, January 2011. ISSN 14693062.

F. Black and M. Scholes. The pricing of options and coporate liabilites. *The Journal of Political Economy*, 81(3):637–654, 1973.

M. I. Blanco and G. Rodrigues. Can the future EU ETS support wind energy investments? *Energy Policy*, 36(4):1509–1520, April 2008. ISSN 03014215. doi: 10.1016/j.enpol.2007.12.025. URL `http://linkinghub.elsevier.com/retrieve/pii/S0301421507005770`.

P. Castro. Climate Change Mitigation in Advanced Developing Countries: Empirical Analysis of the Low-Hanging Fruit Issue in the Current CDM. Technical Report 54, Working Paper Series, University of Zurich, 2010.

J. Chevallier. Anticipating correlations between EUAs and CERs : a Dynamic Conditional Correlation GARCH model. *Economics Bulletin*, 31(1):255–272, 2011.

A. Dixit and R. Pindyck. *Investment Under Uncertainty*. Princeton University Press, New Jersey, 1994.

D. Fogarty. Analysis: Australia CO2 plan puts carbon pricing back on tracke, 2011. URL `http://www.reuters.com/article/2011/07/11/us-carbon-global-idUSTRE76A27B20110711`.

S. Fuss, J. Szolgayova, M. Obersteiner, and M. Gusti. Investment under market and climate policy uncertainty. *Applied Energy*, 85:708–721, 2008.

S. Fuss, D. Johansson, J. Szolgayova, and M. Obersteiner. Impact of climate policy uncertainty on the adoption of electricity generating technologies. *Energy Policy*, 37(2):733–743, February 2009. ISSN 03014215.

S. Fuss, J. Szolgayova, A. Golub, and M. Obersteiner. Options on low-cost abatement and investment in the energy sector: new perspectives on REDD. *Environment and Development Economics*, (June 2010):1–19, October 2010. ISSN 1355-770X.

O. Herbelot. *Option Valuation of Flexible Investments: The Case of Environmental Investments in the Electric Power Industry*. Phd thesis, MIT, 1992.

IEA. Projected Costs of Generating Electricity - 2010 Edition. Technical report, IEA, 2010.

M. C. Insley. On the option to invest in pollution control under a regime of tradable emissions allowances. *Canadian Journal of Economics*, 36(4):860–883, November 2003. ISSN 0008-4085.

S. Kaplan. Power Plants :. Technical report, CRS Report For Congress, 2008.

Janne Kettunen, Derek W Bunn, and William Blyth. Investment Propensities under Carbon Policy Uncertainty. *Energy Journal*, 32, 2011.

G. Klepper. The future of the European Emission Trading System and the Clean Development Mechanism in a post-Kyoto world. *Energy Economics*, 33(4):687–698, July 2011. ISSN 01409883.

Alexandre Kossoy and Philippe Ambrosi. State And Trends of the Carbon Market 2010. Technical report, World Bank, Washington, 2010.

H. Laurikka and T. Koljonen. Emissions trading and investment decisions in the power sector—a case study in Finland. *Energy Policy*, 34(9):1063–1074, June 2006. ISSN 03014215.

Nicolas Linacre, Alexandre Kossoy, and Philippe Ambrosi. State And Trends Of the Carbon Market 2011. Technical Report June, World Bank, Washington, 2011.

M. Mansanet-Bataller, J. Chevallier, M. Hervé-Mignucci, and E. Alberola. EUA and sCER phase II price drivers: Unveiling the reasons for the existence of the EUA–sCER spread. *Energy Policy*, 39(3), March 2011. ISSN 03014215.

R. Merton. Theory of rational option pricing. *The Bell Journal of Economics and Management Science*, 4(1):141–183, 1973.

S.C. Myers. The determinants of corporate borrowing. *Journal of Financial Economics*, 5:147–175, 1977.

S. Seres, E. Haites, and K. Murphy. Analysis of technology transfer in CDM projects: An update. *Energy Policy*, 37(11):4919–4926, November 2009. ISSN 03014215.

L. Trigeoris. *Real Options, Managerial Flexibility and Strategy in Resource Allocations.* MIT Press, Cambridge, MA, 1996.

M. Wara. Measuring the Clean Development Mechanism's Performance and Potential. *UCLA Law Review*, 55:1759, 2008.

M. Yang, W. Blyth, R. Bradley, D. Bunn, C. Clarke, and T. Wilson. Evaluating the power investment options with uncertainty in climate policy. *Energy Economics*, 30:1933 – 1950, 2008.

Ming Yang, François Nguyen, Philippine De T'Serclaes, and Barbara Buchner. Wind farm investment risks under uncertain CDM benefit in China. *Energy Policy*, 38 (3):1436–1447, March 2010. ISSN 03014215. doi: 10.1016/j.enpol.2009.11.024. URL http://linkinghub.elsevier.com/retrieve/pii/S0301421509008544.

K. Zavodov. Renewable energy investment and the clean development mechanism. *Energy Policy*, pages 1–9, August 2010. ISSN 03014215.