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The Impact of Climate Policy on Heat and Power Capacity Investment Decisions

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Abstract

Climate policy has become a major source of uncertainty in energy investments. This paper explores how different instruments of climate policy, such as emissions trading and taxes, affect heat and power capacity investment decisions. I start here with an analysis on the role of climate policy instruments in an investment decision process. Secondly, I examine how climate policy instruments affect the key components of a quantitative investment appraisal and how flexibility can help to cope with those impacts. Flexibility characteristics of some existing heat and power generation technologies are discussed. I find that climate policy increases the value of flexibility in energy investments. There are structural differences in flexibility between heat and power generation technologies. Whereas some technologies provide managerial flexibility through the option to alter operating scale and through the option to switch between fuels or products, others provide passive flexibility (robustness).

Keywords: Investment, heat and power generation, climate policy instruments, flexibility

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1 Introduction

Climate policy and the regulation of greenhouse gas (GHG) emissions have become a new factor affecting strategy and investment decisions. Heat and power producers are among those facing the largest changes due to their high emission intensity (emissions / turnover).

Globally, 4,800 GW of new electric capacity and investments of about 4.6 trillion USD are projected to be required until 2030 (IEA 2004). In addition, other final energy use in residential, services, industrial and agricultural sectors is expected to grow by 16,000 TWh (37%)[1] until 2030 (our own calculation based on IEA 2004), implying an increasing demand for heat only plants. All in all, it is recognized that "*increased investment in the energy sector, from both public and private sources, is necessary"* (EDC 2004). Also, large numbers of power plants will change hands as a result of *acquisition processes* in deregulated markets.

The economic lifetime of an investment in heat and power capacity typically ranges from 20-40 years (OECD NEA/IEA 1998). During the lifetime, various policy instruments intended to regulate GHG emissions can influence the cash flows of the plant and thus its viability. Such instruments can range from problem-specific tradable emission permits[2] to more general policy instruments, such as taxation (fuel tax, emission tax) and subsidies (investment subsidy, fixed feed-in tariff)[3].

Climate change related decision-making is essentially a sequential process under uncertainty (IPCC 2001). The development of climate science, climate policy goals and business-as-usual emissions is uncertain for an investor ("how big should the emissions reduction cake be?"). Moreover, the negotiation results between various parties, i.e. countries, sectors, and companies, create uncertainty ("how big is our piece of the emissions reduction cake?").

Assuming that the future of the energy sector is to a significant extent "carbon-constrained" - which seems to be the case, in Europe in particular - any investment or valuation should take into account the financial impacts of climate change mitigation (e.g. Vrolijk 2002; de Leyva and Lekander 2003; IEA 2003b). The European Union Emissions Trading Scheme (EU ETS) will be one of the key climate policy instruments until 2012 (EC 2003). In the medium-term, European utilities are likely to consider abatement options based on traditional technologies, and be keen on emissions trading due to the high long-term technological uncertainty (Söderholm and Strömberg 2003).

Climate policy instruments are often overlapping, i.e. the introduction of a new instrument (e.g. tradable permits) causes a need to change the earlier instruments (e.g. taxation). In most European countries several climate policy instruments are likely to co-exist in the future for many reasons. First, the structure of climate pol-

[1] Includes petrochemical feedstocks.
[2] In this paper, I apply the term *tradable emission permit* as a generic concept including emission *credits* (e.g. within the project-based Kyoto mechanisms) and emission *allowances* (e.g. within the EU ETS).
[3] For a good overview of climate policy instruments, see IPCC (2001).

icy instruments is already very heterogeneous in many countries (Vrolijk 2002; OECD/EEA 2003). Second, the United Nations Framework Convention on Climate Change (UNFCCC), the EU ETS, and the plans for tradable green certificate systems in several countries will enhance the role of currently less influential market-based climate policy instruments in the coming years. Third, climate policy instruments have complementary goals, which implies that they would not replace each other completely (Johnstone 2003). Finally, a policy mix consisting of several instruments can help to reduce abatement cost uncertainty, overcome technology market failures and increase behavioural responsiveness (Johnstone 2003).

It is, therefore, important for individual enterprises and/or investors to understand the logic of how different climate policy instruments affect their investment decisions, in order to recognize the structural differences between investment alternatives regarding climate policy instruments, and to be able to make informed predictions about the impacts of climate policy. At present, companies are not always fully informed about the quality of information and application of decision-support technologies (IPCC 2001).

This paper explores the mechanisms through which climate policy instruments affect heat and power capacity investment decisions. First, I analyze the role of climate policy instruments in an investment decision process. Second, I examine how climate policy instruments affect the key components of a quantitative investment appraisal and how flexibility can help to cope with those impacts. Flexibility characteristics of some existing heat and power generation technologies are discussed and compared.

2 Investment decision process

Three kinds of factors affect strategic decision processes such as investments: (1) organization's operating environment (e.g. uncertainty and complexity), (2) organizational conditions (e.g. internal power structure, past performance, past strategies and the extent of organizational slack) and (3) decision-specific factors (e.g. impetus for the decision, the urgency associated with the decision, the degree of outcome uncertainty, and the extent of resource commitment) (Rajagopalan et al. 1993). Environmental factors are macro level variables: they are equal to all investment decisions within the observed investment environment. Organizational and decision-specific factors influence at micro level and vary between decisions.

The growing importance of climate policy instruments is reflected in all three categories (Figure 1). Climate policy changes stochastic environmental factors, such as electricity market price, fuel prices and allowance market price[4]. Organizations perceive these future changes differently. This implies not only differences in price forecasts, but also, more profoundly, differences in perceptions of the problem character: some managers and board members believe that climate policy is "here to stay", whereas others expect it to be "a short-term fashion". The differ-

[4] This classification assumes that the investor cannot exert market power.

ent perceptions most likely result from diverse evaluations and beliefs regarding both the scientific foundation of climate change research[5] and the expected reactions of governments and companies.

Decision-specific factors are linked to location-specific risks, e.g. whether certain climate policy instruments, such as investment subsidies or emission credits, are relevant in a specific investment context. Within the EU ETS, allocation of free emission allowances can also depend on the situation on the planned site: e.g. whether the investment is considered a new entrant or a modification of an existing installation. Climate policy can also change other decision-specific factors affecting the process, such as heat demand and price. Some fuels, such as biomass, have more location-specific prices than others, such as coal. Climate policy is likely to improve the availability of bio-fuels for energy generation.

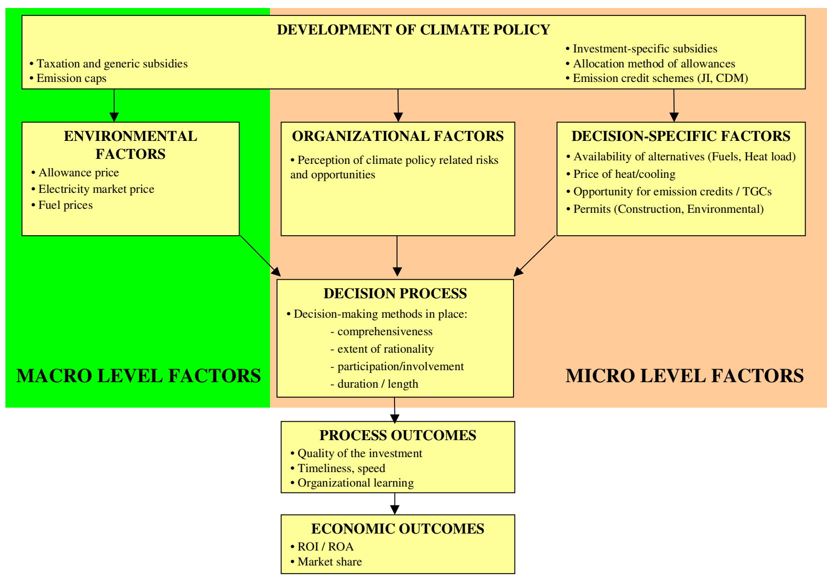

Fig. 1. Climate policy instruments in the investment decision process (modified from Rajagopalan et al. 1993).

The resulting decision process characteristics, such as the duration of the process and the degree of rationality, help determine process outcomes, such as the timeliness of the decision and the extent of organizational learning. Process characteristics as well as process outcomes influence economic outcomes.

Decision processes involving evaluation of capital expenditure typically consist of at least four steps: (1) Identification of spending proposals; (2) Quantitative analysis of the incremental cash flows; (3) Qualitative issues which cannot be fit-

[5] This is well illustrated by the existence of industrial organizations like the Global Climate Coalition and the Business Environmental Leadership Council in the US. See also Innovest (2003).

ted into the cash-flow calculus; and (4) Making the decision (Shank 1996). The importance of the identification of values and objectives as generators of creative alternatives for phase 1 has also been highlighted (Keeney 1994; Clemen and Reilly 2001). In this paper I assume, for simplicity, that decision-makers aim at maximizing their long-term financial performance without taking into account any other objectives they might have.

Decision processes vary according to their extent of *rationality* and *comprehensiveness*. Human behaviour in organizations is intentionally rational, but only boundedly so, which means that human decision-making is non-optimizing in practice (Simon 1997; Selten 2002). An organizational decision is therefore deemed rational if it is orientated towards the organization's goals (Simon 1997). Three types of rationality have been proposed as drivers of investments in energy capacity: (1) economic viability, (2) understanding of the business model of the investment, and its fit to the corporate strategy, and (3) the impact on the operational performance (Sandoff 2003). Comprehensiveness has been defined as the extent to which organizations attempt to be exhaustive or inclusive in making and integrating strategic decisions (Fredrickson and Mitchell 1984). In heat and power capacity planning, comprehensiveness has been pursued through large energy models in order to overcome the deficiencies of individual techniques, such as optimization, simulation and decision analysis. This "model synthesis" has been criticized as an elusive and ultimately impractical objective (Ku 1995). In line with this argument, for example, the record of US model-based energy forecasting yields evidence that the models have given biased estimates (Laitner et al. 2003).

The results of energy models, such as energy prices, have been used as inputs in the strategic investment appraisal. Standard approaches to strategic investment appraisal include quantitative methods such as payback, internal rate of return (IRR), return on investment (ROI), and discounted cash-flow (DCF) methods. In addition to these, an expanded DCF-based framework and a number of other analytical techniques, such as strategic cost management (SCM), the multi-attribute decision model (MADM), value analysis, the analytical hierarchy model, and the uncertainty method, have been developed in literature[6].

Perhaps the most important complement to the standard approaches is the *real option theory* and its applications, which have been strengthened by a substantial body of research during the last two decades[7]. The key reason for this interest has been the notion that standard approaches are inadequate in that they cannot properly capture management's flexibility to adapt and revise later decisions in response to market developments. Standard approaches are based on *"decisioneering"*, which assumes that the future is probabilistic and an optimal course of action can be found by comparing payoffs in scenarios (Lessard and Miller 2001). The standard approaches implicitly assume "expected scenarios" of cash flows and presume management's passive commitment to the selected operating strategies.

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[6] For a review, see Adler (2000).

[7] For an overview, see e.g. Trigeorgis (1995) or Schwartz and Trigeorgis (2001).

The proponents of real options or *"managerial approaches"* assume the future indeterminate, where outcomes are not only difficult to assess but depend on exogenous events or endogenous processes that can lead to multiple possible future states (Lessard and Miller 2001). Hence, the standard approaches should be extended to take the value of new information into account by modelling flexibility for contingency (Ku 1995; Trigeorgis 1995). Two kinds of flexibility can be identified corresponding to two ways of responding to uncertainty: *active* flexibility, a state of readiness such as the ability to react to change, and *passive* flexibility (often referred to as „robustness") as a state of being, such as a resistance or an immunity to change (Ku 1995).

A key impact of the real option theory in the context of this paper is that it opens up a new perspective to the evaluation of an investment appraisal. The traditional valuation tools do not work well, if there is a high uncertainty about the future and options available (Amram and Kulatilaka 1999). Climate policy has significantly increased uncertainty in the business environment through the value of tradable emission permits, the number of free emission allowances, and the impacts on subsidies and taxation. This results in a higher value for flexibility. The decision context and various energy technologies hold characteristics that need to be taken into account in order to end up in (organizationally) rational decision outcomes.

3 Quantitative investment appraisal

A quantitative investment appraisal can be broken down into sub-problems from the Net Present Value (NPV) framework: the initial investment, the annual cash flows and the discount rate. I will go through them one by one and discuss the role of climate policy instruments in each case. The following analysis is limited to financial implications.

3.1 Initial investment

The initial investment cost (I_c) of a plant with an output capacity P_{out} is given by

$$I_c = P_{out} \cdot i_c = P_{unit} \cdot n \cdot i_c(P_{unit}, t) \qquad (1)$$

with P_{unit} being the characteristic unit size (in MW) of the technology in question; n the number of units required to generate P_{out}; and i_c the specific investment cost (in €/kW) for a given level of P_{unit} at time period t. P_{unit} differs significantly between technologies: in particular, nuclear and coal plants tend to have large unit sizes, whereas renewable energy plants have small unit sizes. Typical unit sizes range from 455 - 1460 MW_e for nuclear power, 120 - 800 MW_e for coal and 250 - 750 MW_e for a combined cycle gas turbine (OECD NEA/IEA 1998). The average wind turbine size in the largest single market in Germany was 1.4 MW in 2002 (EurObserv'ER 2003).

The specific investment costs i_c for energy production technologies vary by technology, and typically show fairly strong economies of scale. i_c also tends to decrease in time as a result of technological innovation, if quality requirements remain the same. This is generally modelled in a formulation, in which each doubling of experience (e.g. cumulative capacity) reduces i_c by a certain percentage called the *learning rate*. Importantly, both changes in experience and learning rates differ by technology (McDonald and Schrattenholzer 2001).

Climate policy can affect the rate of experience accumulation for technologies and thus change i_c. Additionally, climate policy may change any regional investment subsidies available for different technologies. Let us denote this investment subsidy as a percentage (k) of the total investment. Then the effective specific investment cost i_{eff} at time t for the investor is[8]:

$$i_{eff,t} = (1-k_t)\cdot i_{c,t} = (1-k_t)\cdot i_{c,o}\cdot(1-r\frac{\ln(\frac{C_t}{C_o})}{\ln 2}) \tag{2}$$

with ic,t being the specific investment cost at time t, r being the learning rate, and Ct being the experience measure (e.g. the cumulative capacity) at time t. Combining Equations 1 and 2, we get:

$$I_{c,t} = P_{unit}\cdot n\cdot(1-k_t)\cdot i_{c,o}\cdot(1-r\frac{\ln(\frac{C_t}{C_o})}{\ln 2}) \tag{3}$$

Equations 1 to 3 formalize the concept of *modularity*: in an uncertain environment, modularity enables the operator to implement the investment in several phases, i.e. it provides an *option to staged investment* (e.g. Dixit and Pindyck 1994, p. 51-55; IEA 2003a, p. 29). In addition, each investor also has an *option to wait*: either to invest in one of available alternatives or to postpone and to wait for more favourable conditions (e.g. McDonald and Siegel 1986). An exception might be a situation in which the existing thermal capacity is running out (e.g. in a district heating system). Combined, these two options seem to create a situation, whereby a higher uncertainty delays capacity additions, but also makes those additions larger when they do occur (Pindyck 2001; Kort et al. 2004).

3.2 Annual cash flows

When the regulator applies economic climate policy instruments, cash flows of energy projects during a period can be simplified as follows:

[8] Equation 2 is deterministic. See Murto (2003) for a stochastic case.

$$R - C = P_{tot} \sum Sx + R_{f,CO2} - C_f$$
$$= P_{tot} \sum \left[\alpha\eta(\gamma) \frac{\gamma}{\gamma+1} p_e + \eta(\gamma) \frac{1}{\gamma+1} p_h + r_{CO2} - \mu c_v - c_{CO2} \right] \cdot x + R_{f,CO2} - C_f \tag{4}$$

with R being the revenue (in €) and C the total cost (in €). P_{tot} denotes the thermal capacity of the plant and S the *spark spread* i.e. the difference between the unit price of energy and the variable production cost of the plant (in €/MWh_{th}). x denotes the number of full-load operating hours during the period. $R_{f,CO2}$ (in €) is the corresponding climate-policy related fixed revenue, such as the value of free emission allowances, and C_f is the corresponding fixed cost (in €). p_e is the average market price of electricity (in €/MWh_e), γ is the *power-to-heat ratio* and $\eta(\gamma)$ is the thermal efficiency of the plant for a given power-to-heat ratio. α is the *production profile factor* of the technology in question during the period: if the technology can systematically benefit from output price fluctuations during the period, then the production profile factor exceeds one ($\alpha > 1$) and vice versa[9]. The price of heat delivered is denoted by p_h (in €/MWh_h).

Revenue per unit from any climate-policy related products, such as tradable green certificates, is given by r_{CO2} (in €/MWh_{th}) and c_{CO2} is the climate-policy related variable cost (in €/MWh_{th}), such as an emission tax or the market price of a surrendered emission allowance. c_v is the average "normal" variable cost including fuel costs (in €/MWh_{th}).

Corresponding to α, μ is the *consumption profile factor*. If the technology can systematically benefit from fuel price fluctuations during the period, then the consumption profile factor undercuts one ($\mu < 1$) and vice versa.

There is no multiplier for r_{CO2} or for c_{CO2} in Equation 4. Tradable emission permit markets do not have a similar basis for a systematic daily and monthly price fluctuation as compared to the electricity market, since compliance is required only on an annual basis[10]. In power exchanges, the market needs to be settled every hour.

Variables of Equation 4 may all be affected by climate policy. I will first take a look at revenues and then move to the cost side.

Market price of energy products (p_e, p_h): Economic theory suggests that market price of energy products will increase due to emissions trading or taxes. This results from increased production costs in utilities (see below), which are reflected in output prices. The effect is similar in heat production. Heat suppliers are even more likely to transfer increased production costs into prices due to the monopolistic character of the business.

In the power sector, theory and studies suggest that the price increase in p_e reflects the emission factor of the power plant on the margin, which often is a condensing power plant due to the merit order of technologies. For this reason, the

[9] Note that α is not necessarily constant in time.
[10] Note that prices can still fluctuate systematically for other reasons.

projected price increases can be significant. It has been projected that the EU ETS can raise wholesale power prices from 15% to 60% (de Leyva and Lekander 2003; Ernst&Young 2004; Reinaud 2003).

Combined heat and power (CHP) extraction plants with simultaneous excess capacity in heat production have a *switching option* due to *product flexibility*. This means that during a period of high power prices, a CHP extraction plant can produce more power and shift the corresponding heat production into heat only plants and vice versa. Thus the switching option due to product flexibility is reflected in the operator's ability to optimize the power-to-heat ratio (γ) between [γ_{min}, γ_{max}] in Equation 4. Backpressure plants do not typically have this option: the power-to-heat ratio is constant.

Revenue from climate policy related products (r_{CO2}): Investments can gain additional revenues due to new climate policy instruments in several forms:

- Tradable green certificates: in some countries, such as the Netherlands and Sweden, national trading schemes for green certificates have been established.
- Higher feed-in tariffs or tax subsidies for green electricity are used in many countries, such as Germany and Austria.
- GHG emission reduction credits: heat and power capacity investments in one of the signatory states of the Kyoto Protocol may obtain additional financing through joint implementation (JI). A host country approval is always required, and in the EU countries, a JI project affecting installations within the EU ETS may be implemented only, if an equal amount of allowances is cancelled from the registry of the host country (EC 2004). In the developing countries investments complying with the relevant rules and modalities and with approval from a host country may similarly obtain additional financing through the clean development mechanism (CDM).

Fixed revenues related to climate policy ($R_{f,CO2}$): Within the EU ETS, utilities obtain at least 95% of the emission allowances for the period 2005-2007 and at least 90% for the period 2008-2012 free of charge. In an investment analysis, this asset transfer may be considered a fixed - but uncertain - annual cash in-flow for the plant. The transfer is linked to a simultaneous *obligation* to surrender emission allowances during the same period, i.e. R_{CO2} is linked to the introduction of c_{CO2}. Free allowances are obtained regardless of whether the plant is used during *that* period or not. The fixed revenue for *subsequent* periods may change due to the selected operating strategy in the *preceding* periods, i.e. $R_{CO2,\ t+j}$ may depend on x_t, with j being, for example, between 1 and 5 periods.

Full-load operating hours (x): of a technology depend on the characteristics of demand and the technology in question. Operators of thermal plants have an *option to alter their operating scale* if the market turns out to be unfavourable, i.e. if the spark spread S is negative, the plant can be turned down taking into account the physical constraints, such as lead times, and switching costs (McDonald and Siegel 1985; Tseng and Barz 2002). This implies that:

$$R - C = P_{tot} \sum MAX \left[Sx - C_{sw,u}, -C_{sw,d}\right] + R_{f,CO2} - C_f \quad (5)$$

where $C_{sw,u}$ and $C_{sw,d}$ are the (potential) switching costs in start-up and shutdown (in €/MW). Power plants that rely on flowing resources (e.g. wind and run-of-river hydro power) or base load plants with heavy initial investments and low fuel costs (e.g. nuclear power) also have this option, but its value is negligible: in normal circumstances the optimal decision is to run the plant as much as possible. For wind and run-of-river hydro power plants, the number of operating hours is a stochastic variable depending on weather conditions and technical availability – not on managerial judgment.

Conventional variable cost (c_v): In thermal power plants, fuel costs constitute the bulk of the variable costs. Climate policy instruments can indirectly change fuel prices. The magnitude of this impact is not necessarily defined within the fuel market context only, since coordination with the tradable emission permit market might occur (Hagem and Mæstad 2002; Holtsmark 2003). It has been estimated that the producer price of coal would decrease by 7-10% and the price of oil by 2 % within an (unreachable) 100% implementation[11] of the Kyoto Protocol (Holtsmark and Mæstad 2002). Most analysts project an increase in natural gas prices due to the EU ETS (e.g. Ernst & Young 2004; de Leyva and Lekander 2003; Reinaud, 2003).

Many thermal heat and power producers have a *switching option* due to *process flexibility*. They are able to burn two or more different fuels and switch between them, or ex-post conversions are relatively straightforward and inexpensive (Kulatilaka 1993; Söderholm 2000). For this reason, Equation 5 can be modified as follows for multi-fuel plants:

$$R - C = P_{tot} \sum MAX \left[MAX_f (S_f x - C_{sw,f}) - C_{sw,u}, -C_{sw,d}\right] + R_{f,CO2} - C_f \quad (6)$$

with $MAX_f (S_f x - C_{sw,f})$ referring to the opportunity of the producer to optimize the operating cost through fuel selection taking into account the potential related switching costs ($C_{sw,f}$).

Climate policy related variable costs (c_{CO2}): Similarly to revenues, climate policy related costs potentially accrue in many forms, such as in taxes and in the value of surrendered allowances. Emissions are determined by the energy output, the emission factors of the fuels used and the heat rate of the plant[12]. Emission factors can generally be considered constant in a long-term investment analysis, although some uncertainty concerning global warming potentials (GWPs) of different greenhouse gases, for example, can be taken into account.

[11] Including the United States and Australia.

[12] Methane and nitrous oxide emissions are also affected by the combustion technology in question.

Hoff and Herig (1996) point out that *"the decision to build any polluting generation source includes the plant owner's decision to give a valuable option to the government. The option gives the government the right (but not the obligation) to change emission standards or impose externality costs (i.e. environmental taxes) associated with environmental damages at any time."* In fact, this option applies for all plants, not only for directly polluting plants. In the context of climate policy, it is, however, more likely that the government will raise standards for emission intensive plants.

In terms of Equation 4, having an emission free plant 1) *determines* c_{CO2} *to zero* and 2) gives the holder of the plant an *opportunity for climate-policy related revenues* (r_{CO2}) for the entire lifetime of the plant. Interestingly, the option hold back consisting of having a less emission-intensive plant is comparable to the notion of "robustness" or passive flexibility (see Chapter 2 or Ku 1995). A robust investment can also be regarded as an *"insurance investment"*. An insurance investment reduces exposure to uncertainty, but with a cost or "insurance premium" (Amram and Kulatilaka 1999).

Fixed costs (C_f): Some climate policy instruments will increase the fixed costs of power plant investments through *transaction costs*. For example, in order to obtain climate policy related revenues from JI and the CDM, companies need to pay for preparations up-front (i.e. r_{CO2} increases C_f). These costs are not strongly dependent on project size (e.g. Fichtner et al. 2003; Krey 2004). Empirical data on 15 Indian CDM projects suggest transaction costs ranging from USD 60,000 to USD 480,000 (without monitoring and verification) (Krey 2004). The Prototype Carbon Fund (2003) reports transaction costs of USD 265,000 for JI and CDM projects (without verification). It is estimated that even with simplified procedures and modalities the annual value of emission reduction must exceed USD 180,000 in order to keep the relative transaction cost at a sustainable level (CDCF 2004).

Within the EU ETS, installations are also subject to annual monitoring and verification. This will similarly cause additional transaction costs.

3.3 Discount rate

In standard financial theory, a dollar today is worth more than a dollar tomorrow. This implies that the future expected payoffs should be discounted by the rate of return offered by comparable investment alternatives, i.e. the opportunity cost of capital. In practical applications, the opportunity cost of capital is often either the cost of equity or the after-tax weighted average cost of capital (WACC), which additionally takes into account the cost of debt and the marginal corporate tax rate.

The cost of equity has been commonly estimated through the Capital Asset Pricing Model (CAPM) by Sharpe (1964) and Lintner (1965)[13]. The model suggests that in a market equilibrium, the value-weight asset market portfolio is

[13] CAPM has been a simple and attractive tool for practitioners, although model tests have shown it to be insufficient. Beta has been found unable to explain average returns alone (see e.g. Fama and French 1993; Wang 2003).

mean-variance efficient. This implies, firstly, that beta (β), the slope in the regression of a security's return on the market return, is the only risk needed to explain expected return. Secondly, there is a positive expected premium for β risk. Beta measures the systematic risk of the asset and it can be estimated as the co-variance of the asset value with the value of the market portfolio divided by the variance of the market portfolio.

According to many authors (e.g. Beaver et al. 1970; Ismail and Kim 1989; Young et al. 1991) the volatility of a company's earnings or cash flows compared to the volatility of the overall economy-wide earnings/cash-flows, its *accounting/cash flow beta*, is an applicable concept for predicting stock betas. If the annual cash flows between different technologies differ and have low mutual correlations, their stock betas should consequently be different as well. In oil projects, a high volatility in oil prices has been empirically found to be associated with a higher cost of capital (IEA 2003a, p. 53).

Risk sources of annual cash flows of various energy technologies differ significantly (IEA 2003b). For example, cash flows of thermal power plants depend on spark spreads, whereas those of hydropower and wind power mainly depend on electricity prices and hydrological / meteorological conditions. In addition, fuel prices do not correlate fully.

In the evaluation of heat and power capacity investments, a single discount rate (with a potential sensitivity analysis) is often selected for *all* investment alternatives, implying that they share the same systematic risk (e.g. OECD NEA/IEA 1998). If discount rates differ, high discount rates are typically used for new technologies, due to their inherent uncertainty (IPCC 2001).

Taking into account the discussion above, the existing practices may turn out to be too simplified. As different technologies have different characteristic emission factors, climate policy and, in particular, the market-based instruments seem to modify the risk related to annual cash flows. However, it is not self-evident what exactly the impact is on discount rates for different technologies. GHG-emission-free power plants, such as renewable energy and nuclear plants, are insured against changes in climate policy related *costs*, whereas plants using fossil fuels remain either fully or partly exposed to climate policy risks. However, even renewable energy plants remain exposed to climate-policy-related volatility in *revenues*.

3.4 Comparison of technologies

As discussed above, energy production technologies provide different kinds of flexibility regarding the financial impacts due to climate policy instruments. These are roughly summarized in **Table 1**.

Thermal power investments provide an option to alter the operating scale, if the market conditions turn out to be poor. Multi-fired power plants have an option to switch between fuels, whereas CHP extraction plants can provide an option to switch between products. The rate up to which a technology is insured against changes in climate policy related *costs* is reflected through the relative emission factor (in $kgCO_2$/MWh) of the plant. Fossil fuels remain either fully or partly exposed to climate policy cost risk.

Table 1. Flexibility regarding climate policy: comparison of technologies (+ = option available/significant).

Source of flexibility		Technology								
		Thermal plants						Other		
		Multi-fired	CHP extraction	Coal	Gas	Oil	Biomass	Hydro with reservoir	Hydro (run-off-river), wind	Nuclear
Active flexibility	Option to wait	+	+	+	+	+	+	+	+	+
	Option to alter operating scale	+	+	+	+	+	+	+	-	-
	Option to switch between fuels	+	-	-	-	-	-	-	-	-
	Option to switch between products	-	+	-	-	-	-	-	-	-
Passive flexibility	Robustness to changes in climate policy related costs[1]	Fuel (mix)-dependent	Fuel (mix)-dependent	0%	40%	17%	100%	100 %	100 %	100 %

[1]Defined as the relative emission intensity of the fuel (Coal = 0 %)

4 Discussion and conclusions

This paper has explored the impact of climate policy instruments on heat and power capacity investment decisions. Climate policy changes environmental, organizational and decision-specific factors in capacity investment decision processes. The quantitative investment appraisal is modified through an influence on the initial investment, the annual cash flows and, potentially, the discount rate. Climate policy increases uncertainty in the business environment and, as a consequence, the value of flexibility, which is not fully captured with standard methods of quantitative investment appraisal.

Heat and power generation technologies show significant structural differences in flexibility to stochastic changes in climate policy instruments. Whereas some technologies provide managerial flexibility through the options to alter operating scale and to switch between fuels or products, others provide passive flexibility (robustness).

Managerial flexibility can be taken into account in the investment decision process through a real options analysis using partial differential equations, dynamic programming or simulation (Amram and Kulatilaka 1999). Robustness, on the other hand, either creates upside potential in annual cash flows or provides insurance against the downside risk. In many cases, there are multiple, interactive options *and* robustness present in the investment problem, which requires a joint valuation of different sources of flexibility.

This setting is interesting for the quantitative investment appraisal that is more or less comprehensively applied in all investment decision processes. While it is obvious that the value of climate policy related robustness depends on the prospects of climate policy, we may ask how large the climate policy related uncertainty must be in order to compensate for (in many cases) higher investment costs on the one hand, and worse managerial flexibility (in comparison to thermal plants) on the other hand. Also, the value of robustness can, in some circumstances, be reduced by the risk of windfall taxation: if it is perceived that some technologies receive sudden increased profits "without effort", the regulator may pursue "not to distort the market" and to prohibit this phenomenon through an additional tax. From the flexibility perspective, biomass-fired co-generation projects with a multi-fuel option seem ideal, since they provide both robustness (if the emission factor of the fuel-mix is significantly lower than with fossil fuels only) and managerial flexibility.

References

Adler RW (2000) Strategic Investment Decision Appraisal Techniques: The Old and the New. Business Horizons, November-December

Amram M, Kulatilaka N (1999) Real Options – Managing Strategic Investment in an Uncertain World. Harvard Business School Press, Boston, Massachusetts

Beaver W, Kettler P, Scholes M (1970) The association between market determined and accounting determined risk measures. The Accounting Review 45, October: 654-682

CDCF (Community Development Carbon Fund) (2004) Annual Report 2004

Clemen RT, Reilly T (2001) Making Hard Decisions with DecisionTools®. Duxbury. Pacific Grove.

de Leyva E, Lekander PA (2003) Climate change for Europe's utilities. The McKinsey Quarterly. New York

Dixit AK, Pindyck RS (1994) Investment under uncertainty. Princeton University Press, Princeton, New Jersey

EC (European Commission) (2003) Directive of the European Parliament and of the Coun1cil establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

EC (European Commission) (2004) Directive of the European Parliament and of the Council amending the Directive establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanisms.

EDC (Energy for Development Conference) (2004) Chairman's conclusions. December 12 - 14, Noordwijk

Ernst&Young (2004) Press release 17.06.2004
EurObserv'ER (2003) Wind Energy Barometer
Fama EF, French KR (1993) Common risk factors in the returns on stocks and bonds, Journal of Financial Economics 33: 3-56
Fama EF, French KR (1997) Industry costs of equity, Journal of Financial Economics 43: 153-193
Fichtner W, Graehl S, Rentz O (2003) The impact of private investor's transaction costs on the cost effectiveness of project-based Kyoto mechanisms. Climate Policy No. 3: 189-235
Fredrickson JW, Mitchell TR (1984) Strategic Decision Processes: Comprehensiveness and Performance in an Industry with an Unstable Environment. Academy of Management Journal 27 (2): 399-423
Hagem C, Mæstad, O (2002) Market power in the market for greenhouse gas emission permits – the interplay with the fossil fuel markets. CICERO working paper 2002-08
Hoff TE, Herig C (1996) Strategic Planning in Electric Utilities: Using Renewable Energy Technologies as Risk Management Tools. 58th Annual Meeting of the American Power Conference. Chicago, Illinois, USA
Holtsmark B, Mæstad O (2002) Emission trading under the Kyoto Protocol – effects on fossil fuel markets under alternative regimes. Energy Policy, 30: 207-218
Holtsmark B (2003) Russian Behaviour in the market for permits under the Kyoto Protocol. Climate Policy, 3: 399-415
IEA (International Energy Agency) (2001a) Natural Gas Information 2001. Paris
IEA (International Energy Agency) (2001b) Coal Information 2001. Paris
IEA (International Energy Agency) (2003a) World Energy Investment Outlook 2003. Paris
IEA (International Energy Agency) (2003b) Power Generation Investment in Electricity Markets. Paris
IEA (International Energy Agency) (2004) World Energy Outlook 2004. Paris
Innovest (2003) Carbon Finance and the Global Equity Markets. Carbon Disclosure Project 2003. Innovest Strategic Value Advisors
IPCC (Intergovernmental Panel on Climate Change) (2001) Third Assessment Report - Climate Change 2001: Mitigation. EarthPrint.com
Ismail BE, Kim MK (1989) On the Association of Cash Flow Variables with Market Risk: Further Evidence. The Accounting Review, 64, January: 125-136
Johnstone N. (2003) The Use of Tradable Permits in Combination with Other Policy Instruments: a Scoping Paper. ENV/EPOC/WPNEP(2002)28. OECD
Keeney RL (1994) Creativity in Decision Making with Value-Focused Thinking. Sloan Management Review, Summer: 33-41
Kort P, Murto P, Pawlina G (2004) The Value of Flexibility in Sequencing Irreversible Investment. Working Paper, September
Krey M (2004) Transaction costs of unilateral CDM projects in India – results from an empirical survey. Energy Policy (In press)
Ku A (1995) Modelling Uncertainty in Electricity Capacity Planning. Ph.D. thesis, London Business School
Kulatilaka (1993) The Value of Flexibility: The Case of a Dual-Fuel Industrial Steam Boiler, Financial Management 22 (3): 271-280
Laitner JA, DeCanio SJ, Koomey JG, Sanstad AH (2003) Room for improvement: increasing the value of energy modelling for policy analysis. Utilities policy, 11: 87-94
Lessard D, Miller R (2001) Mapping and Facing the Landscape of Risks. In Lessard, D. (2001) Strategic Management of Large Engineering Projects: Shaping Institutions, Risks and Governance. MIT Press. Cambridge, MA, USA

Lintner J (1965) The Valuation of Risk Assets and the Selection of Risky Investments in Stock Portfolios and Capital Budgets, Review of Economics and Statistics 47: 13-37

McDonald A, Schrattenholzer L (2001) Learning rates for energy technologies. Energy Policy, 29: 255-261

McDonald RL, Siegel DR (1985) Investment and the Valuation of Firms when there is an option to shut down. International Economic Review. Volume 26, Issue 2, June: 331-349

McDonald RL, Siegel DR (1986) The value of waiting to invest. The Quarterly journal of Economics, Vol. 101, Issue 4, November: 707-728

Murto P (2003) Timing of investment under technological and revenue related uncertainties, Systems Analysis Laboratory Research Report E 11. Helsinki University of Technology

OECD NEA/IEA (Nuclear Energy Agency/International Energy Agency) (1998) Projected Costs of Generating Electricity – Update 1998. Paris

OECD/EEA (2003) Database on economic instruments and voluntary approaches used in environmental policy and natural resources management. http://www1.oecd.org /scripts/env/ecoInst/

PCF (Prototype Carbon Fund) (2003) PCF Annual Report 2002 www.prototypecarbon fund.org

Pindyck RS (2001) Irreversibility, uncertainty and investment. In Schwartz, E.S., Trigeorgis L (2001) Real Options and Investment under Uncertainty – Classical Readings and Recent Contributions. The MIT Press. Cambridge, Massachusetts

Rajagopalan N, Rasheed MA, Datta DK (1993) Strategic Decision Processes: Critical Review and Future Directions. Journal of Management, 19(2): 349-384

Reinaud J (2003) Emissions trading and its possible impacts on investment decisions in the power sector. IEA information paper. Paris

Sandoff A (2003) Teoretiskt ramverk för analys av aktörernas drivkrafter för investeringar. In Rydén B (ed) Nordleden – Slutrapport för etapp 2. Gothenburg (In Swedish)

Schwartz E Trigeorgis L (2001): Real options and investment under uncertainty: classical readings and recent contributions. MIT press., Cambridge, Massachusetts

Selten R (2002) What is Bounded Rationality? in Gigerenzer, G., Selten, R. (ed) Bounded Rationality – the Adaptive Toolbox. Dahlem Workshop Reports. The MIT Press, Massachusetts

Shank JK (1996) Analysing technology investments – from NPV to Strategic Cost Management (SCM). Management Accounting Research 7: 185-97

Sharpe WF (1964) Capital Asset Prices: A Theory of Market Equilibrium under Conditions of Risk. Journal of Finance 19: 425-442

Simon HA (1997) Administrative behavior – a study of decision-making processes in administrative organizations. Fourth Edition. Free Press, New York

Söderholm P (2000) Fuel flexibility in the West European power sector. Resources Policy 26: 157-170

Söderholm P, Strömberg L (2003) A utility-eye view of the CO2 compliance decision process in the European power-sector. Applied Energy, 75: 183-192

Trigeorgis L (1995) Real options: an overview in Trigeorgis L (ed.) Real options in capital investment – models, strategies and applications. Praeger, Westport, Connecticut

Tseng C, Barz G (2002) Short-term generation asset valuation: a real options approach. Operations Research, 50(2), March-April: 297-310

Vrolijk C (ed) (2002) Climate Change and Power – Economic Instruments for European Electricity. Earthscan Publications Ltd, London, p. 300

Wang, K.Q. (2003) Asset pricing with conditioning information: a new test. Journal of Finance, 58(1): 161-196

Young SD, Berry MA, Harvey DW, Page JR (1991) Macroeconomic Forces, Systematic Risk, and Financial Variables: an Empirical Investigation. The Journal of Financial and Quantitative Analysis, 26(4): 559-564