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Working Paper

The innovation impact of EU emission trading: findings of company case studies in the German power sector

Working paper sustainability and innovation, No. S2/2010

Provided in cooperation with:
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Suggested citation: Rogge, Karoline S.; Schneider, Malte; Hoffmann, Volker H. (2010) : The innovation impact of EU emission trading: findings of company case studies in the German power sector, Working paper sustainability and innovation, No. S2/2010, urn:nbn:de:0011-n-1191395 , http://hdl.handle.net/10419/30029

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Working Paper Sustainability and Innovation
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Malte Schneider
Volker H. Hoffmann

The innovation impact of EU emission trading – Findings of company case studies in the German Power Sector

Fraunhofer
ISI

Abstract

This paper provides a comprehensive analysis of how the European Emission Trading System (EU ETS) as the core climate policy instrument of the European Union has impacted innovation. Towards this end, we investigate the impact of the EU ETS on research, development, and demonstration (RD&D), adoption, and organizational change. In doing so, we pay particular attention to the relative influences of context factors (policy mix, market factors, public acceptance) as well as firm characteristics (value chain position, technology portfolio, size, vision). Empirically, our analysis is based on multiple case studies with 19 power generators, technology providers, and project developers in the German power sector which we conducted from June 2008 until June 2009. We find that the innovation impact of the EU ETS has remained limited so far because of the scheme's initial lack in stringency and predictability and the relatively greater importance of context factors. Additionally, the impact varies tremendously across technologies, firms, and innovation dimensions, and is most pronounced for RD&D on carbon capture technologies and corporate procedural change. Our analysis suggests that the EU ETS by itself may not provide sufficient incentives for fundamental changes in corporate climate innovation activities at a level adequate for reaching political long-term targets. Based on the study's findings, we derive a set of policy and research recommendations.

Key words

EU ETS, emission trading, innovation, technological change, adoption, diffusion, organizational change, power sector

Table of contents

Page

1 Introduction

Despite the setback in Copenhagen (UNFCCC, 2009), the delicate global negotiations for a successor of the Kyoto Protocol (UNFCCC, 1997) as well as the implementation of a variety of climate policies around the world (IEA, 2009a) reveal an increasing political will to limit climate change (UNFCCC, 1992). In a pioneering move, in 2005 the European Union introduced the world's largest multi-country greenhouse gas emission trading system, the EU ETS, representing the cornerstone of its climate policy (EU, 2003). The main advantage of this cap-and-trade scheme going back to the seminal work of Dales (1968) is its static efficiency: by establishing a price for greenhouse gas (GHG) emissions and granting participating companies flexibility in their choice of compliance strategies, the instrument promises the cost-minimal achievement of its emission cap (Tietenberg, 1985, Baumol and Oates, 1988). In addition, by establishing a price for carbon such a trading scheme is expected to generate dynamic incentives for the development and diffusion of low carbon technologies (for an overview, see Fischer, 2005). In line with this theory-based economic reasoning regarding the superiority of economic instruments for spurring innovation (Jaffe et al., 2002, Requate, 2005, Vollebergh, 2007, Popp et al., 2009), a number of other countries are in the process of implementing their own emission trading schemes. However, the actual implementation of the EU ETS has cast doubts over its capacity for triggering innovation, although this may be its most important property for achieving the required deep greenhouse gas emission cuts (IPCC, 2007b). Therefore, this article sets out to improve the understanding of the innovation impact of the EU ETS.

The existing literature on the innovation impact of the EU ETS can be differentiated into those studies trying to anticipate the scheme's impact and those conducting ex-post evaluations. Regarding the former, based on theoretical and empirical evidence from US trading schemes for SO_2, NO_x and lead (for an overview, see Hansjürgens, 2006), Gagelmann and Frondel (2005) conclude that the innovation impact of the EU ETS in its pilot phase from 2005-07 is likely to be limited. As main reasons for this they identify the generous initial allocation of EU ETS allowances as well as the linking with the project-based Kyoto Mechanisms Joint Implementation (JI) and Clean Development Mechanism (CDM) without upper limits (EU, 2004), and the distribution of allowances free-of-charge. Schleich and Betz (2005) arrive at a similar conclusion by discussing the potential innovation relevance of EU ETS design choices. These innovation-specific studies are complemented by broader analyses on the economic implications of the design of the EU ETS (e.g. Egenhofer et al., 2006, Ellerman and Joskow, 2008). For example, two innovation-relevant aspects of the EU ETS having been analyzed are the distortionary incentives arising from the treatment of new entrants and closures as well as the short trading phases and resulting investment uncertainties (Neuhoff et al., 2006, Ahman et al., 2007, Ellermann, 2008, Hoffmann et al., 2008). It thus comes as no surprise that the rare ex-post evidence indicates a rather limited actual innovation impact of the EU ETS, particularly on research and development and long-term portfolio decisions (Hoffmann, 2007, Cames, 2008). However, these early studies do not cover all aspects relevant for such an analysis (del Río González, 2009) and do not consider the more stringent second trading phase (2008-12) and the ambitious revision of the EU ETS post-2012 (Schleich et al., 2009).

Against this background, it is the aim of this paper to provide a comprehensive analysis of how the EU ETS has impacted innovation and whether it does so at a level adequate for reaching the long-term political targets required for a decarbonization of the economy. In doing so, we address several of the research recommendations brought forward for studying the determinants of environmental technological change (del Río González, 2009). We build our research framework on environmental economics and innovation studies (Fagerberg and Verspagen, 2009) and extend the existing studies in four respects: First, we distinguish innovation into the three dimensions of research, development and demonstration (RD&D), adoption, and organizational change, and address interactions between them. Second, we include not only regulated entities in our analysis, but also corporate actors from other value chain positions relevant for innovation outcomes (Pavitt, 1984). Third, we specifically address firm heterogeneity to understand how the innovation impact of the EU ETS differs according to firm characteristics, such as a firm's technology portfolio. Fourth, we also explicitly address the role of context factors to account for the multitude of determinants of corporate innovation activities (see e.g. del Río González, 2005, Horbach, 2008, OECD, 2007).

We limit our study to the power sector because it constitutes by far the largest share of CO_2 emissions covered by the scheme (EU, 2005). The power sector is also the largest contributor to CO_2 emissions in the rest of the world and thus plays a key role in future innovation and emission reductions (IEA, 2009b). Furthermore, we confine our analysis to Germany as it exhibits a fairly diversified mix of power generation technologies and is characterized by significant capacity renewal needs (IEA, 2007, Platts, 2008). We base our analysis on multiple company case studies because such a methodological approach enables us to uncover the complex effects and causal links relevant for corporate innovation decision making (Yin, 2002).

This paper is organized as follows. Section 2 presents the research framework, section 3 describes the case study methodology, and section 4 presents our findings on the impact of the EU ETS on RD&D, adoption, and organizational change. Finally, section 5 discusses them and section 6 concludes with research and policy recommendations.

2 Research framework

We build our conceptualization of innovation on the Oslo Manual and focus on innovations new to the firm (OECD, 2005). In line with neoclassical (Requate, 2005) and evolutionary studies (Oltra and Saint Jean, 2005), we differentiate innovation into research and adoption and add organizational change as third innovation dimension (Christensen and Rosenbloom, 1995, Edquist, 1997, Armbruster et al., 2008). Regarding *research, development, and demonstration* (RD&D), 'research' stands for basic laboratory research, 'development' consists of testing the new technology at a small scale in pilot projects, and 'demonstration' refers to the first larger-scale implementation of the technology. We conceptualize *adoption* as companies' investments in state-of-the-art technologies. It encompasses both investments in new installations and retrofits of existing ones, thereby determining the diffusion of commercially available technologies. Finally, *organizational change* consists of procedural change, structural change, and vision change. We are particularly interested in activities contributing to a reduction of GHG emissions and refer to them as *corporate climate innovation activities*.

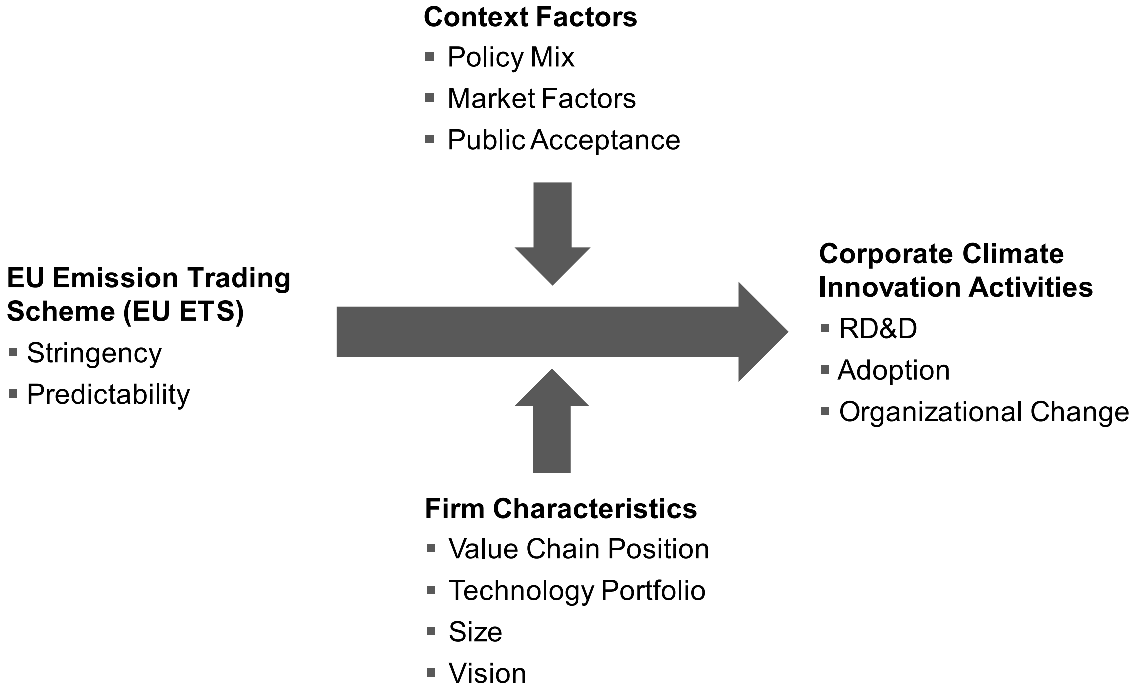
Since the recent literature has pointed out that a policy's design features may be more influential for innovation than the instrument type (Kemp and Pontoglio, 2008, Vollebergh, 2007), we do not merely consider the EU ETS' carbon price and thus its nature as a market-based instrument. Instead, we focus on two design features that have previously been identified as important: stringency (Frondel et al., 2007, 2008) and predictability (Jänicke et al., 2000, Hoffmann et al., 2008). *Stringency* measures the necessary monetary effort in a given firm for complying with the environmental requirements of the policy instrument EU ETS (Bernauer et al., 2006). One element of the stringency of the EU ETS is its cap and the corresponding market price for CO_2. In addition, its specific policy details, such as the share of auctioning, the rules governing the allocation of allowances free of charge, or the share of CDM/JI credits allowed for compliance, also determine its overall stringency (Betz et al., 2006). *Predictability* captures the degree of certainty associated with a policy instrument and its future development. This concerns the instrument's overall direction, detailed rules, and timing. Since the EU ETS operates in relatively short trading phases (3 and 5 years) with specific policy details as elaborated in the National Allocation Plans of Member States (Schleich et al., 2009), the scheme is associated with large regulatory uncertainty (Hoffmann et al., 2008, 2009). Predictability is particularly relevant for sectors with long-lived capital-intensive investments, such as the power sector.

Since corporate innovation activities depend on a variety of firm-external and firm-internal factors (Rehfeld et al., 2007, del Río González, 2009), we also include context factors and firm characteristics in our research framework. *Context factors* cover, first, the *policy mix*, which is constituted by the main policies other than the one under investigation. In our research case, important other policies include renewables support schemes (particularly the German feed-in-tariffs), the nuclear phase-out law, and R&D subsidies (IEA, 2007). The policy mix also incorporates long-term climate policy targets at the UN, EU, and national level, as well as the project-based Kyoto Mechanisms CDM and JI. Second, context factors include *market factors* such as prices, market structure, and demand as established innovation determinants (e. g. Newell et al., 1999). For the power sector, these market factors include, for example, equipment prices, fuel prices and security of supply concerns, particularly for gas. Finally, *public acceptance* of technologies and thus their legitimacy can be an influential context factor (Hekkert et al., 2007).

By including *firm characteristics*, we explicitly acknowledge the heterogeneity of corporate actors and their strategies (Barney, 1991). First, as the power sector is a supplier-dominated sector (Pavitt, 1984) we pay particular attention to firms' *value chain position* (Mazzanti and Zoboli, 2006). We thus study both power generators as actors directly regulated by the EU ETS and technology providers. Second, we follow Christensen and Rosenbloom (1995) by including a company's *technology portfolio* because the type and share of technologies in a company's portfolio determines its technological capabilities and its exposure to the EU ETS. Third, we take account of company *size*, which may predetermine a company's scope and patterns of action. Finally, our framework encompasses a company's general strategic proactivity and its capability of establishing a shared long-term *vision* (Hart, 1995). Vision also alludes to the recognition that collective frames may have to be broken in order to do things fundamentally differently (Kaplan and Tripsas, 2008).

Figure 1 summarizes our research framework for investigating the innovation impact of the EU ETS subject to the influence of context factors and the varying characteristics of firms.

Figure 1: Research framework for studying the innovation impact of the EU ETS



3 Method

In order to empirically analyze how companies are changing their innovation activities in response to the EU ETS, we chose a multiple case study approach as it is particularly appropriate for studying complex contemporary phenomena (Eisenhardt, 1989, Yin, 2002).

3.1 Sample selection

In selecting our cases, the goal was not to design a statistically representative sample, but to allow for analytic generalizations about the innovation impact of the EU ETS. Such an analytic generalization of findings requires their literal and theoretical *replication,* which is facilitated by the application of theoretical sampling (Yin, 2002). This implies that, on the one hand, our theoretical sample includes at least two comparable companies so as to ensure the ability of finding similar results with different cases, i.e. *literal replication*. For example, we choose at least two technology providers with comparable firm characteristics, such as their technology portfolio and size (third column of Table 1). On the other hand, by choosing firms with different firm characteristics we allow for *theoretical replication*, i.e. the identification of contrasting results but for predictable reasons. For example, we interviewed both diversified and specialized technology providers (second column in Table 1).

Table 1: Overview of case studies

Value Chain Position	Other Characteristics	Cases	Interviews
Power Generator (PG)	Large	3	34
	Medium-sized	4	
Technology Provider (TP)	Large (with varying degrees of diversification)	3	20
	Chemical process technology (for CCS)	3	
	Biogas	2	
	Wind	2	
Project Developer (PD)	Diversified incumbents	2	7
Total		**19**	**61**

In order to generate a broad sample with a high level of variation, we incorporated both large incumbents and smaller corporate actors. We also included companies active in established (e.g. coal, gas) as well as in emerging power generation technologies (e.g. wind, biogas). These differences in firm characteristics are an important attribute of our sample as this allows the capturing of the diversity and heterogeneity of corporate innovation responses to the EU ETS. Finally, in order to triangulate our findings we also enclosed two project developers, leading to a total of 19 companies.

3.2 Data collection

We conducted our case studies between June 2008 and June 2009, at a time when the regulatory details for phase 2 were determined and information about the review of the EU ETS directive post-2012 was publicly available (EU, 2008c, 2008a). As part of each company case study, we compiled a detailed background analysis of archival data, such as annual reports and media coverage, which were used to construct customized interview guides. This second source of evidence later enabled us to triangulate interview results to ensure construct validity. Depending on the organizational setup of companies, we conducted between 1 and 7 interviews to cover all functions relevant for innovation – technology, strategy, sales, and climate policy. This led to a total of 61 interviewed experts, or approximately 3 interviewees per case. Interviews were conducted face to face on the company site, with the exception of 5 phone interviews. On average, they lasted 70 minutes. As the innovation strategy constitutes a particularly confidential element of a company's strategy we did not record the interviews, but at least two researchers were present at each interview who individually took detailed notes that were then aggregated to a common interview protocol. In addition, we agreed to conceal the identity of our case companies and disguise any connection between statements and individual companies. Finally, in order to ensure the reliability of our study, we used a standardized electronic case study database to facilitate the repetition of the operations of our study.

3.3 Data analysis

In our analysis, we used the software Atlas.ti and proceeded in four steps. First, based on the initial research framework two of the interviewing researchers developed a common code list with clear definitions of categories. This code list was refined when coding the first case interviews. In a second step, one researcher coded the interview transcripts. Third, based on this code work both researchers identified where the EU ETS had a strong, mixed, or negligible impact on corporate innovation activities. In analyzing these impacts, different elements of the framework were causally interlinked. Finally, the researchers refined their code list in order to understand in greater detail the issues touched upon by their preliminary findings. Based on this final code list, the second researcher recoded all interview transcripts in order to confirm and further refine earlier findings. Throughout the data analysis process, we applied pattern-matching and addressed rival explanations to enhance the internal validity of our results (Yin, 2002).

4 Results

Below, we present the EU ETS' main effects on the three innovation dimensions RD&D (4.1), adoption (4.2), and organizational change (4.3) and explain the influence of the most important context factors and firm characteristics. We support our findings with exemplary quotes in the text as well as in summary tables.

4.1 Impact on research, development, and demonstration

4.1.1 RD&D on CO_2 capture technologies

We find that the EU ETS has led to a significant intensification of RD&D activities on CO_2 capture technologies (CCS). While laboratory research on CCS had already been conducted by large diversified technology providers in the nineties, the introduction of the EU ETS triggered a strong increase in corporate CCS research, demonstrated by the initiation of pilot projects and plans for demonstration projects. This is illustrated by one power generator: *“Emission trading is quite clearly the driver for R&D in CCS."* As a consequence, private funding of CCS RD&D has risen significantly, with the largest share originating from large power generators. While companies pinpoint their initial spike in engagement to the EU ETS, the prospect of its continuation is what maintains it at a high level. Additionally, the prospect of full auctioning in the EU ETS from 2013 onwards seems to have further facilitated power generators’ interest, as illustrated by one technology provider: *“The fear of 100% auctioning after 2012 has led to sharply increased interest from utilities".*

Apart from the EU ETS, a number of *context factors* seem important for the observed developments. First and foremost, the prospects of stringent long-term climate policy and debates about the introduction of command and control measures, such as performance standards for thermal power plants, are further spurring EU ETS triggered large-scale corporate RD&D activities as they indicate that CCS will be a must-have technology. Furthermore, RD&D on CCS is supported by public research funds which have also recently increased. The lack of public acceptance for coal is another driver, yet companies are also struggling with potential public resistance against CCS. This is explained by one technology provider*: "A big uncertainty is whether CCS will gain political acceptance in the future, but for utilities the lack of acceptance for coal-fired power plants – their image problem – is an important reason to put money into CCS R&D".* Thus despite this uncertainty incumbents are pursuing CCS RD&D to be able to further rely on coal as their core business, as illustrated by one power generator: *“Coal is dead without CCS, [..] [We conduct] CCS research, since otherwise no long-term use of coal is possible due to the climate issue."* By now, these research activities are taken very seriously as they are seen as important for ensuring companies’ future competitiveness.

Regarding *firm characteristics*, companies’ choice of which technological CCS routes to pursue at which intensity is influenced by their technology portfolio, i.e.

the underlying core strategies and competencies. [1] For example, power generators' RD&D intensities appear especially large if the replacement need and thus the age of their coal plants and share of coal in their portfolio is high, as described by one such generator: "*[We have] not done much yet [..] the pressure on us is less because of our relatively new coal-fired power plants*" . Yet regardless of their portfolio composition, postcombustion appeals to all coal-based power generators alike due to its suitability for retrofitting and its flexibility. While the efforts of power generators are to a large extent driven by the EU ETS, technology providers' increased RD&D activities are typically driven by their customers' needs, illustrating the trickledown effect of the EU ETS through the value chain. For them, core strategies and competencies again determine their choice of CCS routes. For example, technology providers creating a major part of their added value through boilers strategically chose the oxyfuel route which implies the sale of boilers, while others predominantly chose IGCC. This was, as explained by a project developer, in order *"to push [the sale of] their gas turbines"*. Finally, the involvement of power generators in CCS RD&D partnerships with technology providers appears more intense than is usually the case. Moreover, for all three technological CCS routes new RD&D cooperations have been formed with technology providers of the chemical industry.

4.1.2 RD&D on coal efficiency

Our case studies reveal that the EU ETS has accelerated previously ongoing incremental RD&D activities focusing on new materials to increase the energy efficiency of new coal plants up to 50% and beyond ('50+'). The first main reason for this acceleration is the CO_2 price, while the second is the efficiency losses that would occur if CCS was installed in the future. This is illustrated by one power generator: *"To take such a risk to go from 46% to 50% is alone not such a big incentive in terms of fuel savings - that is doubled by the fact that the [prices for] CO_2 emissions are taken into account [..] the leverage is even greater if I then go in the direction of CO_2 capture and storage."*

That is, regarding *context factors*, fuel prices and corresponding fuel cost savings remain a prime motivation for RD&D on coal efficiency, but are now supplemented. In addition, the lack of public acceptance for new coal plants appears to further augment the coal efficiency RD&D engagement of large incum-

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[1] The three main routes are postcombustion, integrated gasification combined cycle (IGCC), and oxyfuel.

bents, as well as the perceived security of supply of coal. Of course, this line of research has also been benefiting from public RD&D funding, particularly at early stages.

Regarding *firm characteristics*, all large power generators, as well as technology providers with a big share of coal technologies in their portfolio, have been active in coal efficiency RD&D. Firm-internal reasons for an investment in '50+' RD&D also include the German engineering mentality to strive for the best technological solutions.

4.1.3 RD&D on gas efficiency

The EU ETS' impact on incremental RD&D activities on gas technologies that aim for higher efficiency appears to be positive but relatively small. This strikingly low importance of the EU ETS can be explained by the high share of the fuel price relative to the CO_2 price, as elucidated by one technology provider: *"Emissions trading is driving investments [in gas power plants] [..] The driver for innovation is however the gas price [..] not the ETS".*

This means that *context factors*, and here in particular the relatively high gas prices dominate gas efficiency RD&D. In addition, technology providers continue to invest large amounts of money into this line of research due to fierce competition, as gas turbines represent a high value core product. This is illustrated by one technology provider: *"Efficiency is a need to have [issue], a lot of work is being done here [..], but it is not because of emission trading - one must have at least as much as the competitors, otherwise you do not get a contract."*

Regarding *firm characteristics*, the players active in gas efficiency RD&D are again predominantly large incumbents with gas technologies in their core portfolio. The major share of investment continues to be made by technology providers.

4.1.4 RD&D on wind turbines

Our analysis shows that the EU ETS has a very limited and only indirect impact on the ongoing rapid incremental innovation activities for wind power[2], resulting from learning effects due to the increased adoption of wind turbines (see 4.2.4).

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[2] Currently, wind RD&D activities are primarily aiming at output maximization, cost minimization, reliability improvement, grid management and offshore commercialization.

The EU ETS contributes to this with the outlook that wind energy is on the verge of becoming competitive through rising electricity prices and decreased attractiveness of investments in fossil-based power generation. However, currently this does not seem to affect wind RD&D, as illustrated by one technology provider: *“Climate policy does not play a role in technical innovation [for wind power plants], but turbine development is driven by markets and feed-in tariffs."*

That is, *context factors* are clearly the most relevant drivers for RD&D on wind turbines. Here, public support mechanisms for renewables such as the German feed-in law with its degressive tariff structure and comparable policies in other countries continue to be the underlying prime motivation for wind RD&D because they result in a large demand for wind turbines and stable market growth. These RD&D activities are further supported by high public acceptance rates and long-term climate policy prospects. Finally, there is no general pattern of *firm characteristics* which further explains the negligible innovation impact of the EU ETS for wind RD&D.[3]

Table 2: Key findings and exemplary quotes regarding RD&D

Key findings on RD&D impact of EU ETS *and exemplary quotes*
EU ETS strongly increased **CCS RD&D** activities of large-scale incumbents. ▪ *“The commercialization of CCS – pilot and demonstration projects – is conditional upon the operationalization of the EU ETS; otherwise neither power generators nor technology providers would get heavily involved.” [TP]* ▪ *“The only reason you do [CCS R&D] is because avoiding CO_2 represents a value and you can say that from a certain CO_2 price upwards, the additional consumption of resources [coal, money] is worth it.” [PG]*
Coal efficiency RD&D accelerated due to EU ETS and CCS efficiency losses. ▪ *“To be able to do this CO_2 separation, [..] [it is] extremely important to have the highest possible efficiency. This is why CO_2 trading is a really important point.” [PG]* ▪ *“The 700°C technology would have probably happened even without emissions trading. Lignite drying, on the other hand [..] would probably not have been pushed as hard without the EU ETS. Compensating the efficiency losses of CCS is now the next step.” [PG]*
EU ETS only marginally adds to fuel prices and fierce competition which remain the main drivers for **gas efficiency RD&D**. ▪ *“Gas only profits additionally from ETS, ETS is not the trigger for R&D!” [TP]* ▪ *“So far, efficiency increases [have] been linked to fuel prices, now CO_2 is added as a new factor […] [but] gas is already quite advanced [..] the R&D budget is very high because there has already been a lot of stiff competition.” [TP]*

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[3] By and large, this low indirect impact of the EU ETS on wind RD&D is exemplary for RD&D activities for other renewables. A similar argument also holds for nuclear power generation technologies.

Direct EU ETS impact on **RD&D for wind and other renewables** negligible, but indirect contribution to acceleration of technological progress through increased adoption.

- *"The CO_2-price is too low to determine the course, but we are watching it." [TP]*
- *"The decision to say that renewable energies make up a significant share of generation – in our portfolio – then automatically leads to everything to do with research and development receiving higher priority." [PG]*

4.2 Impact on adoption

4.2.1 Adoption of new coal power plants

Regarding the adoption of new coal plants, the role of the EU ETS has changed significantly due to the switch from very favourable gratis allocation rules to full auctioning of EU allowances beginning in 2013. Initially, the generous coal benchmarks and standard load factors have functioned as quasi-subsidy leading to a temporary increase in planned coal plants (see e.g. Ellermann, 2008). This attractiveness of new coal even improved further due to the 'guaranteed' free-of-charge allocation for 14 years, leading to a rush of getting plants operational by 2012. [4] As one power generator highlighted: *"In 2005 every power plant was profitable thanks to the free allocation."* However, with the announcement of full auctioning in 2008 these subsidy effects vanished, making coal less profitable and intensifying site-specific engineering efforts, as illustrated by another power generator: *"The introduction of 100% auctioning exercises [..] pressure on the coal projects, but no project is completely called into question because of auctioning."*

The main reasons for the ongoing cancellations of some planned coal plants seem to be *context factors.* The prime cancellation reason appears to be market factors, particularly the significant increase of equipment prices, rendering some projects unprofitable. Another important withdrawal reason is the lack of public acceptance for coal plants in Germany, as pointed out by one power generator: *"To communicate coal is like squaring the circle"*. In addition, these anti-coal protests and resulting image problems together with the EU ETS support the planning of new coal plants as capture-ready, a trend that is also driven by restrictive governmental approval conditions. However, the perceived security of

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[4] The EU Commission prohibited the application of the so-called 14-year rule in its decision on Germany's second allocation plan on November 29, 2006 (EU, 2006).

supply and the favourable coal-to-gas price ratio remain strong drivers for preferring new coal over new gas plants.

Regarding *firm characteristics*, we find that companies with large shares of coal in their portfolio tend to stick to their core competency, as explained by one coal-only power generator: *“Diversification is rather uninteresting for us: what we are good at is burning coal.”* In contrast, power generators with gas-dominated or gas-only portfolios – being driven by regulatory and market uncertainties – favour investments in coal so as to diversify their portfolio: *"We want to have coal [in our portfolio], even against the trend" [PG].*

4.2.2 Adoption of new gas power plants

We find that the incentives the EU ETS generates seem hitherto often insufficient for ultimately deciding in favor of new gas plants. As one power generator explained: *"Emissions trading is relevant but not essential for the decision to fuel with coal or gas."*

The main reason for this smaller than expected impact of the EU ETS on new gas plants lies in the domain of *context factors*. Compared to the relatively moderate CO_2-prices, high gas prices combined with security of supply concerns are often perceived as more important. This is illustrated by one power generator: *"Without a long-term contract, the political dependency on gas from one country is too high",* and supplemented by one technology provider: *"The assumed gas price has a greater influence than the CO_2 price."* Regarding *firm characteristics*, we only find that power generators with decentralized generation and low-carbon visions are less reluctant to invest in new gas.

4.2.3 Adoption of coal plant retrofits

We find that the EU ETS contributes to an increase in retrofit activities, particularly for older coal plants which can be traced back to CO_2 prices and specific allocation rules. One power generator clarified: *"The ETS has set a strong trigger to review the topics [...] [retrofit measures] have become cost effective through the ETS".*

However, *context factors* such as fuel costs and electricity prices remain very relevant for retrofits: *"Efficiency has always been important independent of CO_2, but the incentives of the EU ETS strengthen the fuel cost basis."* Further motivations for lifetime extensions are the current lack of public acceptance for constructing new coal plants (see 4.2.1), regulatory uncertainties of the EU ETS, and the political and technological uncertainties associated with CCS (see 4.1.1). We did not notice striking differences due to *firm characteristics* aside from the straightforward relevance of power plant portfolios.

4.2.4 Portfolio shift towards renewables

While its overall impact on individual projects has so far been limited as other factors tend to be more important, the EU ETS is contributing to a strategic adjustment of power generators' target portfolios towards diversification and more specifically towards renewables. As one power generator said: *"This target portfolio [...] would definitely look different if there were no cost burdens from* CO_2 *certificates."* Another power generator explained the close link between the EU ETS and international climate policy: *"Now we are looking much more at the portfolio effect. [...] Both long-term climate policy and emissions trading have contributed to this [...], but without emissions trading and the price for* CO_2 *a company would not do that."*

However, this portfolio shift towards renewables would not have occured if there were no public support for renewables making investments in renewables profitable and low risk. Closely connected to this key *context factor* are the tremendous market growth prospects for renewables, particularly for wind. As one power generator explained: *"The one market [renewables] is growing, politically driven, at the expense of the other [fossil] market. There are several arguments in favour of engaging in the growth market."* The lack of public acceptance for coal and nuclear further supports this shift.

Regarding *firm characteristics*, almost all power generators reported an increase in portfolio thinking and renewables investment. The choice of renewable power generation technologies is mainly determined by geographic constraints, with smaller power generators being more bound to *"regional availabilities",* as put by one of them. Leadership and vision (see 4.3.2) were mentioned as very important for going forward with these investments, as explained by another power generator: *"[The wind investments are] rather driven by strategic considerations, but [the former CEO] would not have accepted wind power."*

Table 3: Key findings and exemplary quotes regarding adoption

Key findings on adoption impact of EU ETS *and exemplary quotes*
Initially, spike in planned large-scale **coal power plants** due to free allocation; decreased profitability due to 100% auctioning not as decisive for cancellations as increased equipment prices and lack of public acceptance. ▪ *“In 2004 [before the start of the EU ETS] and today [November 2008] the premises [for building our new coal-fired power station] were strongly driven by electricity supply shortages, in Phase 1, in contrast, they were profit-driven. [..] the [EU Comission’s] decision against the 14a rule almost overturned this.” [PG]* ▪ *“Decisive for the project termination [..] were [..] mainly [the increased] equipment prices, then market uncertainties, that is mainly coal prices and also CO_2 prices.” [PG]* ▪ *“Because of acceptance problems [we can see] coal investments are switching to countries where coal is approved, along the lines of: if necessary, I’ll locate my coal power station in Romania or even outside the ETS zone.” [TP]*
EU ETS impact on **gas adoption** weaker than expected due to comparatively high gas prices (relative to the CO_2 price) and problems in obtaining long-term gas contracts. ▪ *“ETS is generally a factor for the choice of fuel, but gas and equipment prices are even more important and more uncertain.” [PG]* ▪ *“We made the decision in favour of coal for two reasons: first it was […] more economic [than gas] and second, without a long-term contract, gas is politically too heavily dependent on one state.” [PG]*
EU ETS additional direct and indirect driver for **coal plant retrofits** due to increased profitability of lifetime extension and/or efficiency increases. ▪ *"The ETS has set a strong trigger to review the topics [...] [the retrofit measures] have become cost effective through the ETS". [PG]*
EU ETS and long-term climate policy indirectly contribute to **shift in future portfolio towards renewables** but investments would not materialize without public renewables support. ▪ *“There is a portfolio effect which comes about indirectly via climate policy and directly due to the internal target of CO_2 neutrality. On individual concrete projects, in contrast, climate policy has limited influence.” [PG]* ▪ *“Climate policy played a massive role in getting into renewables because when [..] looking at the portfolio structure and then the climate targets formulated around us in the order of 50% by 2030 or 80% by 2050, then as a company you have to find a role there somewhere. [..] Emission trading doesn’t go that far. But we can assume that policy makers will come up with some kind of instrument to implement these targets.” [PG]* ▪ *“The four main reasons for going into [offshore] wind are diversification, our renewal need, the CO2 costs of fossil fuels [..] and thus competetive prices for wind, and the EEG [German feed-in law]. Without the EEG payment for offshore we would not have invested in it – this is the same for all other utilities, too.” [PG]*

4.3 Impact on organizational change

As the impact of the EU ETS on organizational change mainly differs between value chain positions, in presenting our findings we distinguish between power generators and technology providers.

4.3.1 Procedural change

We find that the EU ETS has a strong impact on the business procedures of power generators but also on those of some technology providers, and as such has been changing companies' CO_2 culture. Companies have quickly integrated the new cost factor CO_2 in their routines, such as into investment appraisals or even employee suggestion systems. This routinization is illustrated by one power generator: *"CO_2 is now part of all investment appraisals. This alone has an impact."* We also find increased top management attention to CO_2 issues, particularly for power generators. This is illustrated by one power generator stating that *"the EU ETS [..] has now arrived at the board level."* Finally, while the procedural change started with operational issues, it has been continuously moving towards strategic issues, which is illustrated by another power generator: *"Operationally [the EU ETS] was of course immediately [integrated], but with regard to the generation strategy it took a certain time to be able to estimate [..] the scope and mode of action [..] of CO_2 certificate prices for an investment decision."*

Power generators have decentrally integrated the EU ETS in relevant business procedures*: "We have no specific person responsible for climate policy [...] Everyone plays his part [...] the issue of climate has been decentrally integrated into the company."* In contrast, for *technology providers* the business procedures most impacted by the EU ETS are those associated with sales, particularly for large diversified technology providers: *"Initially there was a staff position which [...] explored what CDM and EU ETS meant [for us] as suppliers, that is, where these mechanisms impact our customers".*

4.3.2 Vision change

We observe a change in companies' visions driven by long-term climate policy targets, including for renewables. However, the EU ETS and the support schemes for renewables as the operationalization of these targets are also contributing to these corporate vision changes.

Among *power generators*, strategic questions like the following are common: *"What does the instrumentalization of climate policy mean for [us]: how are we positioning ourselves in the future?"*. As a consequence, many power generators set long-term targets for renewables, CO_2 emission reductions, and energy efficiency improvements. These are typically oriented towards the EU's 2020 goals (EU, 2008b)[5] but are also driven by *"the feed-in law and the public [climate] discussion in general"*. That is, for such vision changes the EU ETS is just one aspect embedded in the larger landscape changes associated with climate change.

Regarding *technology providers*, we find that the extent of climate policy triggered vision changes depends – even more so than for power generators – on the carbon-intensity and diversification of their technology portfolio. For renewables, large diversified technology providers foresee these technologies as becoming equally important as their current fossil core business. This is best exemplified by wind power, for which the large players attempt to join the specialized technology providers in exploiting the booming market, while for wind specialists climate policy only further enhances their market visions. In contrast, for biogas specialists climate policy in the form of the CDM has influenced entry into new geographical markets, as stressed by one: *"We want to be present in the markets in South East Asia and Latin America. [..] without CDM [we would] never have thought of offering our own products in developing countries."* Finally, technology providers with CCS related know-how envisage a potential new market: *"The idea is to make CCS an independent business unit [...]. International competitors have similar visions."* Yet, for coal specialists we find that climate policy in its current form does not break the existing mental frame. Instead, these actors are driven by the growing coal business around the world.

4.3.3 Structural change

The impact of the EU ETS on structural change falls into two categories: the set-up of CDM/JI sourcing units, and the indirect contribution to the establishment of new business units for renewables resulting from climate policy triggered vision changes (see 4.3.2).

For *power generators*, the first structural change concerns all large power generators, and also a single medium-sized one, who established new business units for the sourcing of credits from the Clean Development Mechanism and Joint Implementation (CDM/JI) to reduce EU ETS compliance costs. As one power generator explained: "*[the shortage allocation in phase 2 is] a completely different lever, which no one predicted. We try to prevent the worst, [..] so a new*

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[5] A 20% reduction of CO_2 emissions, an increase in the share of renewable energies to 20%, and a 20% improvement of energy efficiency.

business unit CDM is being built up." Some large power generators see this engagement in CDM projects in developing countries as *“the head of the international expansion considerations"* since *"the project-based mechanisms allow us to get to know new markets more quickly" [PG].* Second, power generators which changed their vision regarding renewables have been adjusting their organizational structure accordingly by establishing new business units for renewables in which new competencies are being developed. These units are characterized by their own subculture and equipped with relatively large investment budgets (see 4.2.4). A technology provider explained these developments: *"All utillities [..] have established independent subsidiaries for renewables - with nice marketing names. [..] There is a different working environment in these subsidiaries, other people work there and the workforce is much younger, this is necessary as different know-how is required for renewable energies than was present in the utilities."* Similarly, one project developer reported: *"1 ½ years ago [2007] the utilities became restless [...] they headhunted colleagues, in the meantime they pay strategic prices, and push back the institutional investors.“*

Large, diversified *technology providers* whose vision changed towards renewables have also adjusted their organizational structures to reflect the ever increasing market potential of renewables. This can go so far as positioning renewables on the same organizational level as conventional power generation technologies.

Table 4: Key findings and exemplary quotes regarding organizational change

Key findings on organizational impact of EU ETS *and exemplary quotes*
EU ETS causes quick **changes in routines** within all power generators and to a lesser extent in technology providers with a diversified portfolio. ▪ *“There have been quite a few organizational changes due to the introduction of the EU ETS. [..] CO_2 is integrated in investment appraisals [..] It is also a price factor in suggestions for improvements, both for saving potentials and for determining premiums”. [PG]* ▪ *"At the beginning, CO_2 was located in the long-term research division [..] the more concrete it became, the more it went into the product areas." [TP]*
Interpretation of EU ETS and support for renewables as operationalization of overarching long-term targets drives **vision changes**. ▪ *"Until now, we have underutilized the opportunities [for renewables] which emerged from such a changed environment. [..] [We] coordinated corporate goals in agreement with EU targets.” [PG]* ▪ *“Two years ago CCS was not even mentioned in the annual strategy paper; last year it did get a mention, but only a weak one. This year, its share in the strategy paper has greatly increased. If policy pushes it even more, another quantum leap will take place. In a few years, CCS could account for at least 50% of turnover [..] – assuming demonstration plants are actually built in the future. At present, however, there is no doubt about this on the part of [power generators].” [TP]*

Vision changes are followed by **structural change towards renewables**, but EU ETS only plays a minor indirect role.

- *"[From 2007/8 on] there was a shift in perspective because people realized that there are problems with the market development and growth of traditional business and, on the other hand, that increased social and energy policy interest will definitely result in renewables playing a role in the long term and that even now they are already experiencing a shift towards core business, i.e. that you can earn good money with it." [PG]*
- *"Based on a strategic study our board authorized the set-up of a CDM sourcing team 1.5 years ago [spring 2007]. [..] The motivation for this is the generation of credits for EU ETS plants [..] We want to make full use of the 22% limit, because the [price] spread is still worth it [..] If climate continues to be an important topic, then we will extend our engagement." [PG]*
- *"After the restructuring, renewables are now on a par with oil/gas etc. – that was not formerly the case, they used to be somewhere behind power stations – the topic of climate has had an impact on the organization." [TP]*

5 Discussion

Our analysis suggests that the EU ETS by itself will not provide sufficient incentives for fundamental changes in corporate climate innovation activities at a scale appropriate for achieving longer-term GHG emission reduction needs as indicated by climate science (IPCC, 2007a). Instead, the optimal corporate decisions to reach near to medium targets, i.e. up to 2020, might not be optimal for reaching long-term targets because they lead to path-dependencies that render the required longer-term reductions extremely difficult and costly to achieve. In the following, we discuss our findings and derive policy recommendations.

5.1 Impact on different innovation dimensions

Our findings show that the innovation impact of the EU ETS varies tremendously across technologies and firms. As expected, the largest impact occurs among the most carbon-intensive technologies and among incumbents with large-scale coal power generation technologies in their portfolios. In contrast, the innovation impact of the EU ETS on low- or zero-carbon mitigation options tends to be very limited. In addition, the scheme scores very differently on our three innovation dimensions.

First, regarding *RD&D* we find the largest impact of the EU ETS for CCS and coal technologies being carried out by large incumbents in cooperation with chemical industry players. Our analysis highlights that companies' choices among the wide array of RD&D activities mainly depend on their core strategies and competencies and the expected market relevance. Second, for *adoption* decisions context factors, such as fuel prices, public acceptance, or renewables support, tend to be more decisive than the EU ETS. The only exception was the temporarily skyrocketed attractiveness of new coal plants resulting from fuel-specific free allocation. With today's prospect of full auctioning, in principle the EU ETS now favours the choice of less carbon-intensive fuels. Yet the CO_2 price level tends to be too low for leading companies to adopt new gas instead of new coal plants, and may also be insufficiently low to render CCS profitable. Third, regarding *organizational change*, we find that the EU ETS was the prime motivation for routine changes and the set up of JI/CDM business units of power generators. The EU ETS also brought climate change onto the agenda of top-management and may ultimately be contributing to the breaking of mental frames of incumbent power generators. However, the resulting observed vision changes for renewables are mainly driven by long-term climate targets whose credibility is significantly increased by operationalizing them through the EU ETS. Still, without the existence of feed-in tariffs these vision changes would not have led to the observed structural changes within incumbents.

These findings have important implications for policy makers. First, even with auctioning the adoption of new gas plants faces significant barriers which will only be overcome at relatively high CO_2 price levels. Second, technologies from emerging renewables regimes need to be promoted through policies other than the EU ETS. Finally, policy makers should increase their scenario-building efforts to produce and clearly communicate credible political visions of the power sector as these can constitute very important benchmarks for fundamentally changing corporate strategies.

5.2 Interactions between innovation dimensions

Our analysis reveals how feedback loops between the three innovation dimensions shape the impact of the EU ETS on technological change. Here, we focus on two interaction effects. First, the observed portfolio shift of most power generators towards renewable power generation technologies appears to be leading to a shift in their RD&D focus towards renewables as well. In a similar vein, such increased demand for low-carbon technologies is associated with higher production levels for technology providers and strengthened operation experiences, thereby accelerating learning curve effects and thus incremental innovations.

Second, for coal power plants in the short run the EU ETS triggered increase in lifetime extending retrofits opens up the opportunity to postpone the replacement of existing plants with more efficient new ones, yet may lead to a rise in emissons. In order that today's retrofits become environmentally beneficial in the long run, policy makers ought to strengthen the stringency of existing and envisaged climate policies. Subsequently, assuming that current political and technological uncertainties are solved rather soon, retrofitting today may lead to investments in more "radical" low-carbon technologies in later years.

5.3 Role of EU ETS design features

In general, our research confirms that a higher CO_2-price resulting from a tighter emission cap increases the EU ETS' impact on organizational change as well as RD&D and the adoption of low-carbon technologies. From this it follows that a generous limit on the use of CDM/JI credits, while increasing static efficiency, may reduce innovation incentives within the EU, particularly for RD&D on high-tech solutions.

Our findings also underline the relevance of EU ETS design details for innovation, which becomes particularly evident by the change in the impact of the EU ETS due to the foreseen shift from free allocation to 100% auctioning. The higher exposure of carbon-intensive power generators raises their attention and effort level and leads them to take the newly established CO_2 constraint more seriously. It also provides clear guidance for investment decisions, [6] yet allocation details appear to be most relevant for adoption decisions. Instead, the expected CO_2 price level, the size of future markets, and the scheme's predictability seem to matter most for RD&D decisions, illustrating the particularly prominent role of long-term climate policy.

Aside from full auctioning for the power sector the most straightforward policy advice for strong innovation incentives of the EU ETS is the credible political commitment to a long-term GHG reduction path in line with climate science, ideally at a global level. The reason for this is that these long-term climate targets guide corporate climate innovation activities as they are expected to be operationalized by policy instruments such as the EU ETS, for which the ambition level is contingent upon international post-2012 provisions.

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[6] Due to the temporary nature of free allocation rules, their predicted distortionary influence appears to be smaller than what may have otherwise been the case (Ahman et al., 2007, Ellermann, 2008).

5.4 Importance of context factors

Our analysis shows that so far context factors have often been more decisive for corporate climate innovation activities than the EU ETS itself, which is particularly evident for adoption decisions. For example, for new coal plants lack of *public acceptance* can be equally important as policy and market factors. The same is likely to be true for CCS, yet public information campaigns to build legitimacy for this pollution control technology seem inappropriately low considering the large private and public funding invested in capture technologies.

Perhaps most importantly, we find a mutual reinforcing effect of the EU ETS and other policies, particularly long term climate policy and associated targets, as well as renewables support mechanisms. With the introduction of full auctioning, these different elements of the *policy mix* are well aligned with climate mitigation, thus complementing each other and guiding the search of corporate actors (Hekkert et al., 2007). For example, while long-term climate policy is expected to provide the predictability that instruments such as the EU ETS are lacking, it is precisely these instruments which ultimately lead companies to adjust their strategies.

Therefore policy makers should strengthen their activities targeted at building legitimacy for low- or zero-carbon technologies, which may be particularly challenging for CCS. They should also strengthen and align all elements of the policy mix, e.g. by mainstreaming climate change into sectoral policies. Finally, efforts to reach an ambitious and credible international post-2012 climate agreement need to be increased.

6 Conclusion

We conclude that, in principle, the regulatory demand-pull of the EU ETS works, meaning that the trading scheme contributes to a change in corporate climate innovation activities across major parts of the value chain. We thus confirm that due to its establishment of a carbon price the EU ETS can serve as basic element in a climate policy portfolio (Fischer and Newell, 2008). However, while the introduction of full auctioning will generate undistorted carbon signals and the EU ETS' phase 3 cap will significantly contribute to the EU's efforts in reaching its 2020 targets, the EU ETS by itself is highly unlikely to lead to RD&D and adoption decisions in line with reaching the EU's proposed 2050 targets. Two examples supporting this are the limited impact of the EU ETS on renewables and demand-side energy savings. Here, complementary policies are needed to create attractive markets for renewables, particularly for technologies not yet competitive with conventional power generation technologies and for assisting companies in inventing viable business models promoting reductions in power consumption. More generally speaking, there is a need for complementing the pure carbon price incentives with long-term scenario-building efforts in order to start changing established mindsets of incumbents and create new corporate visions of the future.

Furthermore, we argue that through the EU ETS triggered changes in corporate routines companies in the power sector are better prepared for a tightening of climate policy in line with the 2°C target (UNFCCC, 2009). Nevertheless, while large incumbents are finally embracing the growing renewables market, thereby being faced with an internal clash of cultures, the majority of their investment is still earmarked to conventional technologies. It is therefore questionable whether the big players are moving quickly and proactively enough to become agents of change for the needed decarbonization of the power sector. Thus, keeping markets open and attracting new dynamic and innovative entrants seems to be essential.

Finally, if the EU ETS's stringency were further tightened to reflect the deep emission cuts indicated by climate science (IPCC, 2007b) we expect its innovation impact would increase. In such circumstances, the EU ETS as cornerstone of EU climate policy, complemented by other policies, may ultimately live up to its potential of guiding the decarbonization of the European power sector. As stressed before, a precondition for this may be the passing of an ambitious and credible long-term global climate treaty because cap-and-trade can be understood as the operationalization of these overarching mitigation targets. Such a treaty would increase the overall predictability for innovators. Furthermore, as technology providers innovate for the global market such an international agreement should cover all major power markets as these other regions would then be likely to follow suit in establishing markets for CO_2 reductions and thus raise the gains from RD&D activities.

Our results on the innovation impact of the EU ETS shed some light on what may be expected from emission trading schemes being negotiated in the rest of the world. Most prominently, the trading scheme being developed in the US based on the Waxman-Markey bill (ACES Act, 2009), while including some commendable features such as the foreseen long-term reduction path and high level of auctioning, is likely to have a relatively moderate impact on corporate climate innovation activities in the power sector. This is mainly because the foreseen inflow of CO_2 price reducing offset credits is too lenient for the scheme to ultimately have a decisive impact on adoption as well as RD&D decisions leading to the called for decarbonizing of the US power sector. Similarly, based on our analysis of the EU ETS, it is also unlikely that the proposed Australian carbon pollution reduction scheme (CPRS Bill, 2009) will be sufficient in promoting technological change up to levels required for a low carbon transformation of the Australian power sector due to the combination of a potentially lenient target, unlimited offsetting, and a rather low price cap.

Our study is not without limitations, however, and thus warrants future research. As we focused our analysis on the power sector, other studies will have to identify whether and how the innovation impact of the EU ETS differs across sectors. Additionally, all of our case companies were based in Germany – though often with international operations – so it might be useful to check whether companies with other home markets have reacted similarly to the EU ETS. Moreover, of the actors relevant for innovation in the power sector we only included power generators, technology providers, and project developers. While this value chain approach goes well beyond the standard of addressing the regulated entities only, the analysis could be extended to other actors, particularly to final power consumers, start-ups, and venture capitalists. Finally, while our qualitative approach enabled us to study the complex causal links and feedback loops of innovation processes in the power sector and how the EU ETS is impacting them, innovation surveys allowing for statistical generalizations should complement this analysis.

Acknowledgements

The authors wish to thank all companies for participating in our study and express our gratitude for the time our interviewees took to answer our questions and share their expertise with us. We are grateful to Vicki Duscha and Tobias Schmidt for their interview support. Research assistance by Franziska Borkel, Andrea Maute, Christine Gutekunst, Sara Ziegler, David Ta and Jürgen Weber is also acknowledged, as well as proofreading by Grace Goss-Durant and layout support by Brigitte Kallfaß.

This research was funded by the Volkswagen Foundation, the Ministry of the Environment of Baden-Württemberg and the ClimPol project within the Competence Center for Environment & Sustainability of the Swiss Federal Institute of Technology, whose support we gratefully acknowledge.

7 References

ACES Act, 2009. American Clean Energy and Security Act of 2009 (H.R. 2454). Passed by the House of Representatives (Waxman-Markey).

Ahman, M., Burtraw, D., Kruger, J. and Zetterberg, L., 2007. A Ten-Year Rule to guide the allocation of EU emission allowances. *Energy Policy*, 35 (3), 1718-1730.

Armbruster, H., Bikfalvi, A., Kinkel, S. and Lay, G., 2008. Organizational innovation: The challenge of measuring non-technical innovation in large-scale surveys. *Technovation*, 28 (10), 644-657.

Barney, J.B., 1991. Firm Resources and Sustained Competitive Advantage. *Journal of Management*, 17 (1), 99-120.

Baumol, W.J., Oates, W.E., 1988. The Theory of Environmental Policy. Cambridge UP, Cambridge.

Bernauer, T., Daniel, S.E., Seijas, J. and Seijas, K., 2006. Explaining Green Innovation - Ten Years after Porter's Win-Win Proposition: How to Study the Effects of Regulation on Corporate Environmental Innovation?, ETH Zürich, Zürich.

Betz, R., Rogge, K. and Schleich, J., 2006. EU emissions trading: an early analysis of national allocation plans for 2008–2012. *Climate Policy*, 6 (4), 361-394.

Cames, M., 2008. Emissions trading and innovation in the German electricity industry, Presentation at Berlin's Energy Days, Öko-Institut e.V., Berlin.

Christensen, C.M., Rosenbloom, R.S., 1995. Explaining the Attackers Advantage - Technological Paradigms, Organizational Dynamics, and the Value Network. *Research Policy*, 24 (2), 233-257.

CPRS Bill, 2009. Carbon Pollution Reduction Scheme - A Bill for an Act to reduce pollution caused by emissions of carbon dioxide and other greenhouse gases, and for other purposes, The Parliament of the Commonwealth of Australia, House of Representatives, Canberra.

Dales, J.H., 1968. Pollution, Property and Prices. An Essay in Policy-making and Economics. University of Toronto Press, Toronto.

del Río González, P., 2005. Analysing the Factors Influencing Clean Technology Adoption: A Study of the Spanish Pulp and Paper Industry. *Business Strategy and the Environment*, 14 (1), 20-37.

del Río González, P., 2009. The empirical analysis of the determinants for environmental technological change: A research agenda. *Ecological Economics*, 68 (13), 861-878.

Edquist, C., 1997. Systems of Innovation Approaches – Their Emergence and Characteristics, in: Edquist, Charles (Ed.) , Systems of Innovation: Technologies, Institutions and Characteristics, London, Washington, pp. 1-35.

Egenhofer, C., Fujiwara, N., Ahman, M. and Zetterberg, L., 2006. The EU Emissions Trading Scheme: Taking Stock and Looking Ahead, CEPS; CLIPORE, Brussels.

Eisenhardt, K.M., 1989. Building Theories from Case Study Research. *Academy of Management Review*, 14 (4), 532-550.

Ellerman, D., Joskow, P., 2008. The European Union's Emissions Trading System in perspective, Pew Center on Global Climate Change.

Ellermann, A.D., 2008. New entrant and closure provisions: How do they distort? *The Energy Journal*, 29 (Special Issue), 63-76.

EU, 2003. Directive 2003/87/EC of the European Parliament and the Council of 13 October 2003 Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community and Amending Council Directive 96/61/EC, 32-46.

EU, 2004. Directive 2004/101/EC of the European Parliament and the Council of 27 October 2004 amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanisms, 18-23.

EU, 2005. EU action against climate change: EU emission trading - an open scheme promoting global innovation, European Community, Brussels.

EU, 2006. Communication from the Commission to the Council and to the European Parliament on the assessment of national allocation plans for the allocation of greenhouse gas emission allowances in the second period of the EU Emissions Trading Scheme accompanying Commission Decisions of 29 November 2006 on the national allocation plans of Germany, Greece, Ireland, Latvia, Lithuania, Luxembourg, Malta, Slovakia, Sweden and the United Kingdom in accordance with Directive 2003/87/EC, Brussels.

EU, 2008a. Directive of the European Parliament and of the council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading system of the Community, 1-73.

EU, 2008b. Energy and Climate Change - Elements of the final compromise, European Union, Brussels.

EU, 2008c. Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading system of the Community, Commission of the European Communities, Brussels.

Fagerberg, J., Verspagen, B., 2009. Innovation studies—The emerging structure of a new scientific field. *Research Policy*, 38 (2), 218-233.

Fischer, C., 2005. Technical innovation and design choices for emissions trading and other climate policies, in: Hansjürgens, Bernd (Ed.) , Emissions Trading for Climate Policy - US and European Perspectives.

Fischer, C., Newell, R.G., 2008. Environmental and technology policies for climate mitigation. *Journal of Environmental Economics and Management*, 55 (2), 142-162.

Frondel, M., Horbach, J. and Rennings, K., 2008. What triggers environmental management and innovation? Empirical evidence for Germany. *Ecological Economics*, 66 (1), 153-160.

Frondel, M., Horbach, J. and Rennings, K., 2007. End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions Across OECD Countries. *Business Strategy and the Environment*, 16 (8), 571-584.

Gagelmann, F., Frondel, M., 2005. The Impact of Emission Trading on Innovation - Science Fiction or Reality? *European Environment*, 15 (4), 203-211.

Hansjürgens, B., 2006. Emissions Trading for Climate Policy - U.S. and European Perspectives. Cambridge University Press, Cambridge.

Hart, S.L., 1995. A Natural-Resource-Based View of the Firm. *Academy of Management Review*, 20 (4), 986-1014.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S. and Smits, R.E.H.M., 2007. Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change*, 74 (4), 413-432.

Hoffmann, V.H., 2007. EU ETS and Investment Decisions: The Case of the German Electricity Industry. *European Management Journal*, 25 (6), 464-474.

Hoffmann, V.H., Trautmann, T. and Hamprecht, J., 2009. Regulatory uncertainty: A reason to postpone investments? Not necessarily. *Journal of Management Studies*, 46 (7), 1227-1253.

Hoffmann, V.H., Trautmann, T. and Schneider, M., 2008. A taxonomy for regulatory uncertainty—application to the European Emission Trading Scheme. *Environmental Science & Policy*, 11 (8), 712-722.

Horbach, J., 2008. Determinants of environmental innovation - New evidence from German panel data sources. *Research Policy*, 37 (1), 163-173.

IEA, 2007. Energy Policies of IEA Countries: Germany 2007 Review. OECD/IEA, Paris.

IEA, 2009a. Addressing Climate Change - Policies and Measures. Online: http://www.iea.org/Textbase/pm/index_clim.html.

IEA, 2009b. World Energy Outlook 2008, IEA, Paris.

IPCC, 2007a. Climate Change 2007 - Synthesis Report, IPCC, Valencia.

IPCC, 2007b. Climate Change 2007 Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York.

Jaffe, A.B., Newell, R.G. and Stavins, R.N., 2002. Environmental policy and technological change. *Environmental & Resource Economics*, 22 (1-2), 41-69.

Jänicke, M., Blazejczak, J., Edler, D. and Hemmelskamp, J., 2000. Environmental Policy and Innovation: An International Comparison of Policy Frameworks and Innovation Effects, in: Hemmelskamp, J., K. Rennings and F. Leone (Eds.), Innovation-Oriented Environmental Regulation: Theoretical Approach and Empirical Analysis. Springer Verlag, Heidelberg.

Kaplan, S., Tripsas, M., 2008. Thinking about technology: Applying a cognitive lens to technical change. *Research Policy*, 37 (5), 790-805.

Kemp, R., Pontoglio, S., 2008. The innovation effects of environmental policy instruments - a typical case of the blind men and the elephant. Paper for DIME WP 2.5 Workshop on Empirical Analyses of Environmental Innovations, Fraunhofer ISI, January 17-18, 2008, Karlsruhe.

Mazzanti, M., Zoboli, R., 2006. Economic instruments and induced innovation: The European policies on end-of-life vehicles. *Ecological Economics*, 58 (2), 318-337.

Neuhoff, K., Martinez, K.K. and Sato, M., 2006. Allocation, incentives and distortions: The impact of EU ETS emissions allowance allocations to the electricity sector. *Climate Policy*, 6 (1), 73-91.

Newell, R.G., Jaffe, A.B. and Stavins, R.N., 1999. The induced innovation hypothesis and energy-saving technological change. *Quarterly Journal of Economics*, 114 (3), 941-975.

OECD, 2005. Oslo Manual: Guidelines for collecting and interpreting innovation data. 3rd edition. OECD, Paris.

OECD, 2007. Environmental Policy and Corporate Behaviour. Edward Elgar Publishing Limited, Edward Elgar Publishing, Inc., Cheltenham, Northampton.

Oltra, V., Saint Jean, M., 2005. Environmental innovation and clean technology: an evolutionary framework. *International Journal of Sustainable Development*, 8 (3), 153-172.

Pavitt, K., 1984. Sectoral patterns of technical change: Towards a taxonomy and a theory. *Research Policy*, 13 (6), 343-373.

Platts, 2008. Platts Database. The McGraw-Hill Company, London.

Popp, D., Newell, R.G. and Jaffe, A.B., 2009. Energy, the environment, and technological change, NBER, Cambridge.

Rehfeld, K.M., Rennings, K. and Ziegler, A., 2007. Integrated product policy and environmental product innovations: An empirical analysis. *Ecological Economics*, 61 (1), 91-100.

Requate, T., 2005. Dynamic incentives by environmental policy instruments - a survey. *Ecological Economics*, 54 (2-3), 175-195.

Schleich, J., Betz, R., 2005. Incentives for energy efficiency and innovation in the European Emission Trading System. *ECEE 2005 Summer Study - What works& who delivers? - Panel 7 New economic instruments*, 2005, 1495.

Schleich, J., Rogge, K. and Betz, R., 2009. Incentives for energy efficiency in the EU Emissions Trading Scheme. *Energy Efficiency*, 2 (1), 37-67.

Tietenberg, T.H., 1985. Emissions Trading. An exercise in reforming pollution policy. Resources for the Future, Washington D.C.

UNFCCC, 1992. United Nations Framework Convention on Climate Change, UN, New York.

UNFCCC, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change, UN, New York.

UNFCCC, 2009. Copenhagen Accord.

Vollebergh, H., 2007. Impacts of environmental policy instruments on technological change, OECD, Paris.

Yin, R.K., 2002. Case Study Research: Design and Methods. Sage Publications, London.

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Karlsruhe 2010