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The impact of the EU ETS on the sectoral innovation system for power generation technologies - Findings for Germany

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Abstract

This paper provides an overview of early changes in the sectoral innovation system for power generation technologies which have been triggered by the European Emission Trading Scheme (EU ETS). Based on a broad definition of the sector, our research analyses the impact of the EU ETS on the four building blocks 'knowledge and technologies', 'actors and networks', 'institutions' and 'demand' by combining two streams of literature, namely systems of innovation and environmental economics. Our analysis is based on 42 exploratory interviews with German and European experts in the field of the EU ETS, the power sector and technological innovation. We find that the EU ETS mainly affects the rate and direction of the technological change of power generation technologies within the large-scale, coal-based power generation technological regime to which carbon capture technologies are added as a new technological trajectory. While this impact can be interpreted as defensive behaviour of incumbents, the observed changes should not be underestimated. We argue that the EU ETS' impact on corporate CO_2 culture and routines may prepare the ground for the transition to a low carbon sectoral innovation system for power generation technologies.

Key words: EU emission trading scheme (EU ETS), innovation system, power sector

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1 Introduction

The European Emission Trading Scheme (EU ETS) is the European Union's core policy instrument to address greenhouse gas emission (GHG) reductions and to help fulfil the EU's Kyoto obligations (R&D spillovers and environmental externalities, see EU, 2003). It covers energy-intensive installations from a wide range of sectors and activities and aims at a cost-minimizing reduction of their GHG emissions. It also aims at the promotion of global innovation (EU, 2007), a goal which is shared with other emission trading schemes emerging around the world, but for which only limited empirical evidence exists. Hence, early empirical evidence on the innovation effects of the EU ETS could guide policy makers in the design of current and emerging trading schemes and regarding the role of emission trading in the overall climate policy regime. In this paper, we provide such an empirical analysis about the innovation effects of the EU ETS.

The seminal economic theory for the analysis of the innovation effects of environmental regulation is environmental economics (Jaffe et al., 2002; Requate, 2005). Based on experiences with US trading schemes, Gagelmann and Frondel (2005) explore the potential innovation effect of the EU ETS and conclude that, in its pilot phase (2005-07), it is likely to be limited. Schleich and Betz (2005) discuss which design options in the EU ETS (e.g. cap, gratis allocation rules) can be expected to be most relevant for innovation. For example, the treatment of new entrants and closures may cause distortionary investment effects (Ellermann, 2008). Yet, due to its recent implementation, ex-post evaluations of the actual innovation effects of the EU ETS are obviously limited (Cames, 2008). Also, while environmental economics studies provide valuable insights into the economic incentives and disincentives generated by environmental policy instruments and their specific design, in general, they have rigid assumptions and do not look at system changes and interdependencies, although such system changes are necessary to reach long-term emission reduction goals.

Such a systemic look at innovation is at the core of the innovation system literature, which focuses on the importance of actors, networks, institutions, cumulative learning processes between users and producers, as well as the importance of spatial and technological characteristics (Edquist, 2005). Within the innovation system literature, a variety of approaches exist that target different levels of analysis: nation states (Freeman, 1987; Lundvall, 1992; Nelson, 1993), sectors (Malerba, 2002, 2004, 2005), or technologies (Carlsson et al., 2002;

Carlsson and Stankiewicz, 1991). Studies analysing energy-related innovations within the innovation system framework – a need underlined by Sagar and Holdren (2002) – typically focus on renewable and alternative power generation technologies. The innovation system approaches applied by these energy-related studies vary, but studying the functions of emerging technological innovation systems within the technological innovation system framework has become prominent (Hekkert et al., 2007a; Hekkert et al., 2007b; Negro et al., 2007). However, the energy-related innovation system studies typically do not analyse the specific impact of environmental regulations on the innovation system and have been criticised for not generating practical enough policy advice (Bergek et al., 2008).

In this paper we combine these two literature streams for a more systemic evaluation of the innovation effect of the EU ETS. On the one hand, environmental economics allows a thorough understanding of the incentives generated by the trading scheme. On the other hand, we extend the scope of analysis to the innovation system thereby explicitly considering the underlying innovation processes. With this combined approach we aim to identify policy-triggered changes in the innovation system and explain how these changes came about (Walz and Schleich, 2008; Weber and Hemmelskamp, 2005).

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, 2007). 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, 2008). Our research thus analyses how the EU ETS has impacted the sectoral innovation system of power generation technologies, taking Germany as an example. We thereby provide an early systemic account of the actual innovation effects of the trading scheme from which we can derive policy recommendations.

This paper is organised as follows. Section 2 presents the research case and elaborates the chosen innovation system approach. Section 3 provides a brief overview of the sectoral innovation system of power generation technologies in Germany before the EU ETS. Section 4 describes the methodology of our analysis and section 5 presents our findings on the impact of the EU ETS on the innovation system. Finally, section 6 discusses our findings and concludes with policy and research recommendations.

2 Research case

In this section, we first provide some details about the EU ETS, then define the boundaries of our research case, and finally describe the specific innovation system approach chosen.

The EU ETS is a market-based climate policy instrument which went into operation in 2005. It applies directly to large emitters of greenhouse gases in all 27 EU Member States by requiring them to cover their GHG emissions with tradable EU allowances (EUA). The EU ETS is a flexible instrument rather than a command-and control regulation prescribing specific technologies or emission standards, because it is up to the individual firms how to achieve compliance (Hoffmann, 2007). In its first two trading phases (2005-2007, 2008-2012) allowances were predominantly allocated free-of-charge, and the rules governing this gratis allocation varied significantly among fuels, technologies and countries (Betz et al., 2006; DEHSt, 2005). The effects of these often distortionary allocation rules on the power sector were studied mostly on an ex-ante basis (Ahman and Holmgren, 2006; Burtraw et al., 2006; Martinez and Neuhoff, 2005; Neuhoff et al., 2006).

Four main design features of the EU ETS are relevant for the boundary setting of our analysis. First, on a *sectoral* level, we limit our analysis to the one sector which has the largest share of GHG emissions covered by the scheme – the power sector. Second, on a *technological* level, we include all power generation technologies also those not directly covered by the scheme such as renewables and nuclear because the EU ETS is characterized by technological openness. Third, on a *product* level, we place power generation technologies at the centre of the innovation system. This also reflects that innovation in the large capital equipment intensive power sector is – following Pavitt's (1984) taxonomy – supplier-driven, i.e. by technology providers. Thus, we define 'innovation' as consisting of both 'research, development and demonstration' (RD&D) in low-carbon power generation technologies which reduce greenhouse gas emissions, as well as the 'adoption' of these low-carbon technologies. [1] 'Adoption' includes the two innovation properties 'modernization', i.e. technological meas-

1 This simplifying distinction between development and adoption is in line with, e.g. Requate (2005) and Oltra and Saint Jean (2005), but by no means implies a subscription to a linear innovation process model on our part.

ures to reduce the CO_2 emissions of existing plants (e.g. retrofits), and 'investment in new plants', i.e. the construction of new plants which contribute to the reduction of the sector's CO_2 emissions. Finally, at a *national* level, we limit this study to one country due to the national differences in allocation rules from 2005-2012 (Matthes et al., 2005; Rogge and Linden, 2008) and the partial embeddedness of actors in national rather than European innovation system structures (Carlsson, 2006). We choose Germany because it is the EU Member State with the largest amount of emissions covered by the EU ETS (474 Mt/a in 2005), the largest share of planned EU power generation capacity (17%) and a multitude of providers of power generation technologies (EU, 2006; Platts, 2008).

As a consequence, we assume a sectoral perspective which enables us to study the impact of the trading scheme on all power generation technologies and thus on all technological regimes and niches relevant for the power sector. In doing so, we follow Malerba's definition of a sectoral system of innovation and production as being "composed of a set of new and established products [here: power generation technologies] for specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products" (Malerba, 2004, p. 16). As suggested by Malerba (2004), we assume a broad definition of the sector because such an aggregation level allows interdependencies, linkages and transformations to be identified within the sector of power generation technologies being impacted by the EU ETS.

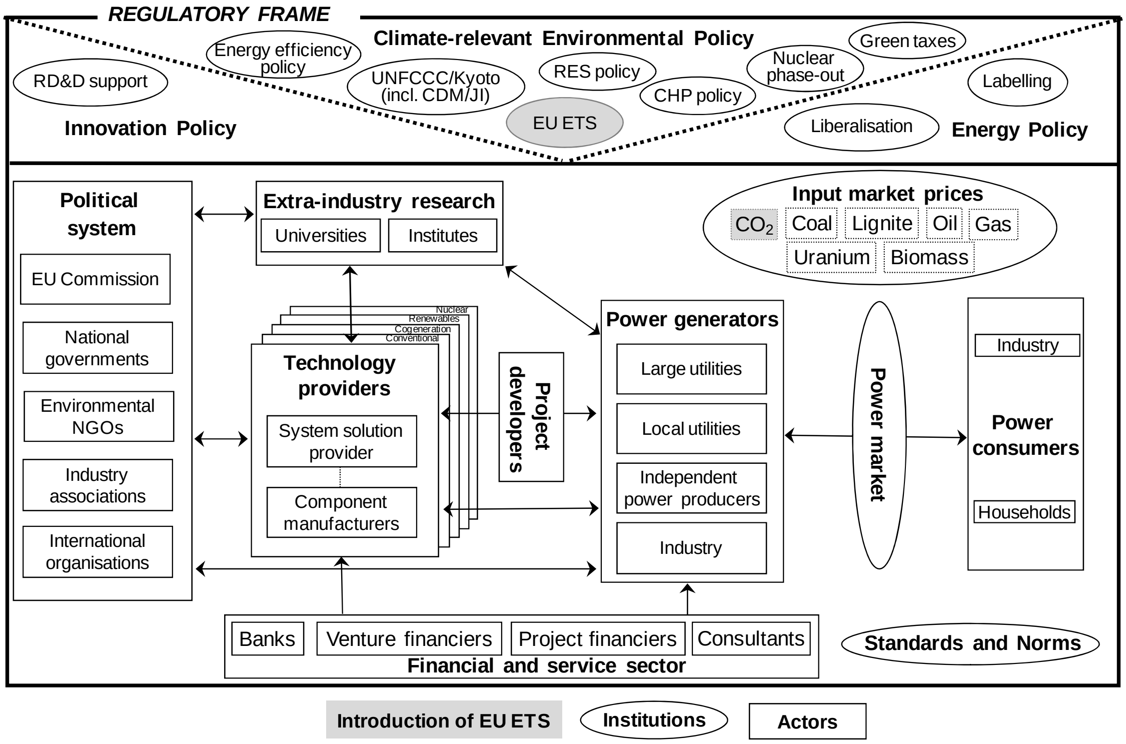
Building on Malerba (2002, 2004), we search for EU ETS triggered changes in the four building blocks of the sectoral innovation system: 'knowledge and technologies', 'actors and networks', 'institutions', and 'demand'. *'Knowledge and technologies'* captures that "sectoral systems differ in terms of technologies", that these "affect the nature, boundaries and organization of sectors" and that "sectors and technologies differ greatly in terms of the knowledge base and learning processes related to innovation" (Malerba, 2004, pp. 18f.). *'Actors and networks'* addresses that "a sector is composed of heterogeneous agents" (organisations and individuals) which "interact through processes of communication, exchange, cooperation, competition and command" and "are connected in various ways through market and non-market relationships" (Malerba, 2004, p. 18). *'Institutions'* includes "norms, routines, common habits, established practices, rules, laws, standards" which shape the "cognition, actions, and interactions of agents" (Malerba, 2004, p. 18). Finally*, 'demand'* is "composed of heterogeneous agents the interaction of which with producers is shaped by institutions" (Malerba, 2004, p. 27). 'Demand' "constitutes both a stimulus for innovation and a major constraint" (Malerba, 2004, p. 28).

3 Overview of the sectoral innovation system of power generation technologies

In this section, we present a brief overview of the German sectoral innovation system of power generation technologies before the implementation of the EU ETS (IEA, 2007; Kaloudis and Pedersen, 2008) to provide the background for our analysis of changes caused after the incorporation of the EU ETS as a new institutional element (see generic mapping in Figure 1).

'Actors and Networks': As can be seen in Figure 1, the key actor groups within the innovation system are technology providers, power generators and extra-industry research, as well as actors from the political system, the financial and services sectors and power consumers. Technological development is mainly accomplished by technology providers and their suppliers – typically aiming at the global market – and on a basic level also by extra-industry research. The four large power generators (RWE, Vattenfall, E.ON and EnBW) as well as a multitude of smaller ones (e.g. local utilities and industry) not only constitute the demand for new technologies but are also important partners of technology providers for pilot and demonstration plants (e.g. risks and costs sharing), especially for large-scale projects. Aside from such contributions to standard setting (i.e. reference plants), power generators also play a role in incremental innovations through user-producer-linkages. Apart from these activities, if RD&D departments exist, these typically focus on market research for new technologies. Private RD&D spending in both actor groups has recently recuperated from the low levels linked with liberalization and consolidation of the market. Networks take different forms, and national as well as European associations play a central role in connecting the actors, for instance through working groups, conferences and research projects. Apart from self-organised links (e.g. project-based, formal cooperation agreements, funding of university chairs), RD&D support schemes also contribute to networks (e.g. Corretec, EU Framework Programme). Governmental actors from all levels set the framework conditions for innovation, with local agencies being especially relevant for diffusion by specifying approval conditions. Finally, international organisations such as the International Energy Agency are important players for informing the actors in the innovation system (e.g. through IEA, 2008).

Figure 1: The sectoral innovation system of power generation technologies



Source: Adjusted and extended from Kuhlmann and Arnold (2001)

'Knowledge and Technologies': The sectoral innovation system of power generation technologies encompasses several technological innovation systems which can be broadly grouped into those for conventional, renewable and nuclear power generation technologies, with cogeneration applicable to the former two (see technological layers in Figure 1). Depending on the technology, the boundaries of these technological innovation systems are broader than those of the sectoral innovation system, e.g. for cogeneration, which is also used in industrial sectors. Also, the technologies in the sectoral innovation system have varying degrees of maturity, as the sectoral system not only includes established or emerging technological regimes, such as coal or wind, but also niches, such as fuel cells. (Markard and Truffer, 2008, Smith et al., 2005). For conventional power generation technologies, an important technological trajectory concerns energy efficiency improvements driven by fuel prices. Another priority area is RD&D within emergent renewable technological regimes and niches, with the most important drivers being public support programmes and future market prospects. Centralized electricity generation and long-distance transmission constitutes the dominant sector regime, although this is increasingly being challenged by the diffusion of wind and other renewable, distributed power generation technologies.

In general, this large technical system (Markard and Truffer, 2006) tends to evolve relatively slowly because of the long lifetimes of power generation equipment from 20 up to 90 years (IEA, 2008) and because several of the steps necessary for system change take a long time to implement, e.g. extending the power grid, or investing in new production facilities for new technologies.

'Institutions': Power generation technologies are a major constituent of energy infrastructure systems which are not only affected by the 'double externality' problem (R&D spillovers and environmental externalities, see Rennings (2000), Jaffe et al. (2005)), but also by natural monopolies (e.g. power grid). As a consequence of this so-called triple regulatory challenge (Walz, 2007), a high density and variety of German and European policies are in place to address these challenges as illustrated in the regulatory frame in Figure 1. Within this frame we already indicated the EU ETS as a new institutional element among other existing policy instruments addressing environmental externalities. Recently, liberalization efforts across Europe, albeit at different speeds, are among the most fundamental institutional changes which have not only led to a concentration among power generators and the establishment of a German network regulator in 2005 (IEA, 2007), but also to changes in corporate routines (see e.g. Markard andTruffer, 2006).

'Demand': The market for power generation technologies is global in nature, with the German demand constituting just a small fraction of the total. Of the 613 GW of power generation capacity currently under construction worldwide and expected to be operational by 2015, only one quarter is situated in OECD countries (IEA, 2008). In Germany, capacity was 124 GW in 2006 and 11.5 GW power plant capacity will be commissioned by 2012 (5.8 GW hard coal, 2.8 GW lignite, 2.4 GW gas, others 0.5 GW) with an additional 23 GW being planned (Matthes and Ziesing, 2008). Approximately half the existing power plant capacities need to be replaced by 2030 (BMU and BMWT, 2006). Renewables are predicted to grow by more than 30 GW by 2020 (Matthes andZiesing, 2008). Global cumulative investment needs for the power sector in 2007-2030 are estimated at US$13.6 trillion (in 2007$), with approximately half of this for generation, and again half of the latter (48%) for renewables (especially hydro and wind) (IEA, 2008). However, not too long ago, demand was meagre, leading to a consolidation of technology providers. Despite this, Germany remains one of the countries with a strong base of power generation technology providers, with the largest non-EU competition coming from Japan and the US. In recent years, costs for power plants have increased drastically and the sector has experienced supply chain constraints (IEA, 2008). Finally, after falling during the 1990s, electricity prices have increased again (IEA, 2008).

4 Methodology

To map the impact of the EU ETS on the sectoral innovation system of power generation technologies we adopted an inductive approach because of the novelty of the policy instrument under study (Eisenhardt, 1989, Yin, 2002).

Data sampling and collection: The empirical analysis is based on 42 interviews with German and European experts about the sectoral innovation system of power generation technologies. In order to ensure comprehensive coverage, we followed three simultaneous strategies when selecting interviewees (see Table 1). First, interviewees represent all the major stakeholders of the sectoral innovation system of power generation technologies (see corresponding boxes in Figure 1). Second, overall, interviewees cover the three categories of sectoral, technological and national experts. A third selection strategy was the even distribution of interviewees' expertise in the areas of EU ETS, the power sector and technological innovation. Our semi-structured interviews lasted between 40 minutes and 3 hours, totalling approximately 85 hours. Interview guides were adjusted for each interviewee in order to tailor the questions to the interviewee's individual area of expertise and to adopt the set of questions to findings from earlier interviews. If permitted, interviews were recorded, while in all other cases detailed notes were taken. Interviews were conducted face-to-face (with the exception of five phone interviews) and were held between December 2006 and April 2009. We deliberately chose a long time span in order to be able to better capture the dynamics in the system and identify which effects of the EU ETS were of a temporary nature and which outlasted the periodic changes in the regulatory details. In order to triangulate our findings, we analysed publicly available documents and used this documentary information to tailor our interview guides. In addition, we also conducted 15 informal talks with experts in the fields of the EU ETS, the power sector and the financial sector. These talks usually took place at climate conferences and carbon trade fairs, such as the CarbonExpo in Cologne in May 2008.

Table 1: Overview of interviewed experts

Interviewee classification					
... according to actor groups		… according to expertise *			
Power generators	7	Sectoral	Power generation (PG)	30	
Technology providers	9	Technological	Conventional PG	22	
Academia & research institutes	4		Renewables & cogeneration	17	
Governmental authorities	6	Geographical	Germany	33	
Consultancies & project developers	5		Europe	18	
Associations & intern. organisations	11	Functional	EU ETS	26	
			Innovation	20	
Total number of interviewees	*42*		** multiple assignments possible*		

Data analysis: Interviews were transcribed and coded using the software Atlas.ti. The code list was initially developed based on three exemplary interviews using open coding, and then refined and reorganised during a coding test with one interview in Atlas.ti. The updated code list was tested on five more interviews from which the final code list was developed which was then used to code all the interviews (Strauss and Corbin, 1998). After coding, the cross-interview analysis was conducted by applying software-based queries on the innovation properties and the link to the EU ETS and its design features. The queries also evaluated the relevance of other policy instruments (such as international long-term climate policy, or feed-in tariffs) and additional context factors (e.g. fuel prices) as well as firm characteristics (e.g. portfolio, firm size). Queries covered all meaningful combinations of codes, and redundancies were built in so as to confirm or reject patterns in the data. The findings were cross-checked, e.g. through plausibility checks across actor groups and through comparison with the literature. Contradictory findings were subject to careful scrutiny. The explanations for these contradictions were typically found to be reasons such as regime membership (conventional vs. renewables), firm-characteristics (e.g. portfolio) or timing of the interview (e.g. changes in EU ETS) and were integrated into our results. The findings were subsequently organised according to the building blocks of the sectoral innovation system and condensed to show the major impacts of the EU ETS.

5 Results

In this chapter we present our findings on how the EU ETS – as a new element within the building block 'institutions' – has impacted the sectoral innovation system for power generation technologies in the first years after its implementation. In doing so, we always highlight those elements within the innovation system's building blocks which are affected most by the EU ETS (for additional supporting quotes see the Annex).

5.1 Impact of the EU ETS on 'knowledge and technologies'

Regarding the impact of the EU ETS on 'knowledge and technologies', we find that the emphasis on CO_2-free technologies increased in four main areas. First, the EU ETS seems to have accelerated the innovation process in general and thus positively affects the rate of technological change as explained by a power generator: *"There is a general acceleration effect – everything that has been done up to now needs to be done in a compressed manner."* Similarly, one expert of a technology provider observed that *"At the moment several technology leaps seem to be taking place simultaneously [..] Things used to be more sequential."* This acceleration apparently affects both the diffusion of existing technologies as well as RD&D on new technologies, and is particularly relevant within the technological regime of coal-fired power plants.

Second, the most prominent effect of the EU ETS on 'knowledge and technologies' is the mainstreaming of RD&D on carbon capture and storage (CCS). As a technology provider remarked: *"The impact of emission trading on R&D is visible in CCS. [..] Internally, the topic of CCS has moved from being an exotic side issue to a main focus."* Clearly, CCS as a technological mitigation route has witnessed a very dynamic development over the last 5 years with the EU ETS as the main driver, even though long-term climate policy is also an important driver for carbon capture technologies. However, the operalization of long-term targets by the EU ETS appears to have led to a significant scaling-up of earlier technology push efforts. Another technology provider stated that *"Climate policy as a whole is the driver for CCS [..] but the EU ETS is what companies can feel, it brings monetary effects into businesses, goes down well with management. Ultimately, therefore, the EU ETS can be seen as the main driver. Because climate protection has been talked about for 20 to 30 years, but nothing happens in businesses as a result of soapbox oratory."* In addition, the prospects of an extension of stringent climate policies outside Europe together with a continued demand for coal-fired power plants signify a large potential market for carbon capture technologies and are thus also driving RD&D efforts. These efforts concern both components and the interplay of new processes in the overall system.

Third, the EU ETS contributes directly to energy efficiency RD&D of large fossil fuel-fired power plants because CO_2 prices represent an add-on to fuel prices. One technology provider described this supplementary nature of the EU ETS: *“Efficiency was always on the agenda as optimization projects, but the EU ETS reinforces these tendencies.”* The higher the expected long-term CO_2 price, the higher the incentives to further increase the efficiency level, which is especially relevant for coal-fired power plants. The strength of the impact of the EU ETS on coal is illustrated by another technology provider: *“in addition to the saved fuel costs comes proportionately almost one hundred percent saved costs of CO_2 emissions as well, and that means that the optimal plant design of a coal-fired plant clearly changes”*. The EU ETS thereby reinforces ongoing RD&D activities along the existing technological trajectory which focus on materials (e.g. 700°C power plant) and components. Because of the associated savings in fuel costs, these RD&D efforts in energy efficiency improvements are viewed as a low-risk option. Finally, losses in a plant’s energy efficiency level due to CCS serve as an additional driver for increased efforts in efficiency improvements.

Fourth, the EU ETS appears to indirectly benefit RD&D on renewables. One technology provider stated that they *“are carrying out more projects on renewables and new energies; [..] the EU ETS reinforces these tendencies.”* For the case of wind, another technology provider added *“Turbine development is driven by markets and feed-in tariffs.”* In other words, the EU ETS complements existing favourable framework conditions for renewables, among others by increasing power prices and thus the competitiveness of renewable energy technologies. However, in itself, it does not appear to significantly affect the RD&D on renewables. Instead, public support measures such as the German feed-in-tariffs remain the main driver for RD&D on renewables.

5.2 Impact of the EU ETS on ‘actors and networks’

In the first years after its implementation, the actors affected most by the EU ETS were corporate actors, while extra-industry research or innovation policy departments were less impacted. First, the EU ETS not only impacts power generators as actors directly subject to the regulation, but also contributes to driving technology providers’ product portfolios towards technologies helping to combat CO_2 emissions. One power generator association illustrated that the regulatory pull (Rennings, 2000) trickles backwards along the value chain from users of power generation technologies to producers:*"Utilities need to put pressure on technology providers to provide low carbon solutions, and utilities themselves are pressured by the carbon constraint, that is the CO_2 price".* Therefore, to start with, technology providers, especially large diversified ones, analysed how the EU ETS affects their customers and thus future demand. As one technology provider explained: *"It was very important to brief our marketing dept. because the EU ETS is nothing else for the customers than just [..] another monetary variable [..] for life-cycle cost calculations"*. Consequently, the units of technology providers most affected by and active in the procedural integration of the EU ETS are marketing and sales. However, as technology providers tend to develop their products for a global market, they not only look at the EU ETS but also at the prospect of continued CO_2-reduction policies in an increasing number of countries.

Second, power generators and technology providers alike have significantly increased their RD&D spending; this is especially evident for larger players. For example, one power generator said that their *"R&D budget has tripled since 2001"*. This seems to mark the end of the trend of declining RD&D budgets in times of liberalization, but CO_2 is only one of the factors involved in the recovery of RD&D spending as explained by one technology provider: *"a few years ago funds were generally cut back, because times were difficult. It became necessary to raise them again - CO_2 played a significant role here among other issues."* This increase is happening regardless of the uncertainty companies face due to the lack of a binding political commitment about future global climate policy targets, as illustrated by one technology provider: *"Actually we already know what international savings would be necessary for some sensible burden sharing [-50%, -80%] [..], even if some people do not want to know. We take the [targets] seriously [..], otherwise the whole thing is just a farce."*

Third, different actors in the innovation system react very differently to the EU ETS. These differences appear to be mainly routed in regime membership and firm characteristics. For actors affiliated with the large-scale coal technology regime, the EU ETS presents a serious threat leading, among others, to a significant level of CCS RD&D. However, proponents of the alternative, decentralized, renewables technological regimes reported a lower innovation impact of the EU ETS. This is illustrated by a power generator focused on renewables: *"The EU ETS [..] only causes a power price increase, but it does not guide investments. [..] In this regard, for example, feed-in-tariffs or the cogeneration law* *are much more successful."* Firm characteristics such as a firm's technology portfolio can also lead to variations in expert statements. For example, a technology provider specialized in coal power plants explained that they *"have not made detailed analyses of NAPs, but that would be sensible for firms with two products in order to decide where to concentrate resources"*, thereby illustrating why large diversified technology providers have apparently made the biggest efforts to analyse the EU ETS and its impact on demand.

Regarding networks, we could not identify any relevant effects of the EU ETS on innovation networks in general or on existing networks for energy efficiency. However, we did observe a strong effect for RD&D linkages regarding carbon capture technologies (CCS). We identify an increased involvement of large utilities in CCS projects with technology providers, both in terms of funding and human resources. Mostly project-specific cooperation was established between large utilities and technology providers in order to make those technological CCS route(s) commercially available which best fit their portfolio. The involvement of utilities in CCS projects seems to be more pronounced than in other areas, such as energy efficiency projects, as illustrated in an interview with a technology provider: *"In CCS a joint development is taking place between technology providers and power generators, and that is rare. [..] The cooperation is fundamentally different."* Large utilities were also said to be funding a much larger share of the associated costs for the pilot projects as one technology provider reported: *"The utilities are providing the most money, and we are developing the technology for capture"*. This apparently differs from other RD&D projects where most private funds tend to be contributed by the technology providers themselves. An important reason for the financial involvement of large utilities with coal in their portfolios is the strategic urgency attributed to getting CCS commercially ready. RD&D activities are pursued to ensure their future competitiveness in a carbon-constrained world, and here the EU ETS plays a crucial role.

We also find the inclusion of sector-external technological capabilities. One technology provider pinpoints the *"absolutely essential focus [..] on the oil and gas firms"*. Also, new links are being forged to technology providers from the chemical industry which is illustrated by another technology provider: *"A few years ago, power generators were an unknown customer segment [..] but with the EU ETS our technologies and know how are in demand"*. These new linkages extend the scope of the sectoral innovation system. Finally, RD&D on CCS now appears to be very competitive and is taken very seriously by technology providers and large utilities alike, as illustrated by one technology provider: CCS *“is true competition – in the meantime. This says a lot about the state of affairs because if there were an open exchange [among technology providers], then that would mean the topic need not be taken seriously.”*

5.3 Impact of the EU ETS on ‘institutions’

Our interviews reveal that the impact of the EU ETS – as a new institutional element of the innovation system – on the building block ‘institutions’ is most pronounced for corporate institutions, while other institutions so far seem to be less affected. This corporate institutional change occurs regarding the corporate CO_2 culture in general and innovation routines in particular. These changes are apparent in all power generators, while for technology providers they appear to be most pronounced for diversified system solution providers with close proximity to the regulated actors.

First, we observe a shift in corporate attitudes towards climate change. To a large degree, this change in thinking across departments can be traced back to the EU ETS, whose operationalization brought with it not only a price for CO_2 but also the awareness that policy makers might actually become more serious about tackling climate change and thus that ‘business as usual’ may no longer be a sustainable option. This is illustrated by one technology provider: *"Now people are slowly realizing that if emission trading with real money is already politically feasible today, then it could actually happen that the climate change problem will be taken seriously tomorrow. [..] And if that were the case, then CO_2 emissions would really have to be reduced!”* This change in thinking especially concerns top management involvement regarding climate change challenges, mainly because of the scheme’s effect on core business decisions, such as making new investments. In some instances, there appears to have been certain thresholds that had to be crossed before top management took the EU ETS and CO_2 seriously – such as the forced shutdown of a power plant due to too high CO_2 costs, the EUA price reaching 30 Euros, or the announcement of 100% auctioning. One power generator explained this involvement of top management: *“The issue of CO_2 has reached the board members [..] now they have all understood it. [..] it has a considerable effect on investment costs and [..] may mean that the investment decision crashes.”*

Second, the EU ETS has been incorporated into the most relevant business structures and procedures, leading to an increased distribution of CO_2 expertise across the organisation. For example, one technology provider explained that *“The CO_2 issue has grown rapidly, now there is at least one person in every* *department dealing with CO_2 at least on a part-time basis."* Similarly, one power generator reported: *"We [had to] then look and see where CO_2 occurs and if there are existing processes where we just have to integrate CO_2 in parallel."* While the level and intensity of coordination of this distributed CO_2 expertise varies among organisations, apparently both larger and smaller power generators subject to the EU ETS now perceive the scheme and how to deal with it as standard procedure, as illustrated by one power generator: *"The EU ETS is now standard, but the effort for integration was considerable."* This change was accomplished in an astonishingly short period of time.

Third, the incorporation of the EU ETS into business procedures includes its integration into corporate innovation routines (see Becker, 2008; Nelson and Winter, 1982). These routines – in the sense of abstract activity patterns (Winter, 1995) – have evolved over a longer period of time and changes to them may be key to understanding the innovation impact of the EU ETS. One example for such routine changes are investment decision making routines which now incorporate the impact of CO_2 prices and gratis allocation rules. This may affect adoption decisions, e.g. regarding the decision to build a plant, or the choice of fuel and efficiency level, as well as cause adjustments in the envisaged portfolio mix. For the latter point, one power generator explained: *"The discussion up to now was very much related to single projects, and that of course leads to cost comparisons, the plant must be cost-effective. [..] Only now are people beginning to think, how should I actually evaluate my portfolio?"* Another example for routine changes is the impact of the EU ETS on RD&D strategy formation. Here the EU ETS in combination with expectations of long-term climate policies is causing corporate actors to work towards a decarbonization of their portfolio. The EU ETS and its 2013-2020 proposal (EU, 2008) have played a significant role in generating the required trust of corporate actors, especially technology providers, in the long-term value of CO_2 reductions as illustrated by one technology provider: *"The long-term innovation impact of the EU ETS depends on the level of trust in the continuation of the instrument. The announcements in the EU Directive [proposal] regarding CCS [..] and the acceptance of JI/CDM post 2012 were positive [..]. These statements firmly establish the [innovation] road map."*

5.4 Impact of the EU ETS on 'demand'

The introduction of the EU ETS has led to a number of changes relevant for the 'demand' of power generation technologies. First, in Germany it was possible to observe a spike of interest in getting new plants operational by 2012. One reason is that the gratis allocation of EUA functions as a subsidy for new plants which can greatly improve the profitability of new plants (see e.g. Ahman and Holmgren, 2006). Another reason is the German allocation rule of guaranteeing an unchanged level of gratis allocation (i.e. a compliance factor of 1) for 14 years for plants becoming operational up to 2012. This 14-year-rule worked as a strong incentive for many investors – including investors other than the big incumbents – to get new plants operational by then, but was later abolished by the EU Commission (EU, 2006). With both of these EU ETS design features gone, the profitability of new power plants appears to be more difficult to establish, therefore reducing the initial spike of new investments. This development is summarized by one power generator: *"Prior to 2001, there were cost saving programs in power plants. [..] In 2005 every power plant was economically viable on account of the gratis allocation.[..] [New coal power stations] did very well under the 14-year rule, then they sank."*

Second, while the EU ETS incentivizes switching to fuels with lower carbon intensities and cogeneration, these incentives were often not decisive for investment decisions; other factors are more relevant. Regarding fuel switching to gas, the uniformity of allocation rules across fuels and technologies favours fuels with lower CO_2 intensities (Schleich et al., 2008). In addition, if the uniform level of gratis allocation is high, then there is said to be an even stronger incentive to choose gas over coal. However, EUA prices would need to be much higher to overcome high gas prices and security of supply concerns, as illustrated by one power generator: *"The CO_2 price would have to be 60-70 €/ t CO_2 to make gas profitable.[..] Gas is also out of the question because of the unavailability of long-term gas contracts"*. Regarding cogeneration: While the uncertainty associated with the continuation of beneficial cogeneration allocation rules in the EU ETS beyond 2012 appears to be detrimental to cogeneration investments, other important reasons exist for greater interest in new cogeneration power plants. These include the revised and extended cogeneration support law, indicated political commitment to an increased cogeneration share and an improvement in the public acceptance of planned new power plants. As another power generator explained: *"Cogeneration now plays a larger role in ongoing projects, among others because of the cogeneration law compensation and the hoped for cogeneration bonus in emission trading."* However, for large plants, some power generators reported problems in identifying sufficiently large demand for the heat generated.

Third, new coal power plants are being planned as CCS-ready. This development appears to be not only driven by the EU ETS but by authorities making CCS-readiness a precondition for granting a construction permit. Power generators purchase the option to add CCS post-combustion to their plants when it becomes commercially available and economically attractive, i.e. when CO_2 prices are sufficiently high. Also, CCS-readiness can help overcome public acceptance issues associated with the construction of new coal-fired power plants. This is illustrated by one power generator: *"The new block will be CCS-ready. The planning for this started together with the first protests against the power plant [2007]. [..] The block will also be CCS-ready because CCS is already an approval condition for [another] power plant"*.

Fourth, the EU ETS indirectly contributes to the diffusion of renewables and a growing attractiveness of nuclear power generation technologies. We have observed an intensification of utilities' investments in renewables over the last few years. Clearly, the CO_2 price and the associated effect on power prices have improved the competitiveness of investments in renewables when compared to fossil power generation. However, this appears to be only relevant for long-term prospects while current engagement is more due to generous and relatively stable feed-in-tariffs. This is illustrated by one power generator: *"In our future portfolio, renewables play a greater role, but that is only flanked by CO_2, the main driver is the German Renewable Energies Act. [..] Renewables are now a big topic in all the big companies."* Other contributing factors are general climate and resource concerns as well as public renewables goals, supplemented by the maturing of an industry (esp. wind), growth prospects and image reasons. One project developer explained this new strategy of power generators: *"1½-2 years ago the utilities became anxious that they were not part of the wind boom [2006/07]. [..] As the institutional investors showed them how to put together a large portfolio, they became nervous [..] They are headhunting colleagues, paying strategic prices in Europe and outdoing others."* Similarly, one technology provider said that the *"utilities in Germany have been fast asleep during the last few years"* and *"are now trying to secure their profits via off shore"*. The impact differs for nuclear power where a growing attractiveness can be observed across Europe due to climate policy (IEA, 2008). One technology provider explained these revival prospects and their limited relevance for German actors: *"We are observing a certain renaissance of nuclear energy. [..] In Germany this is more or less a non-topic today, [..] [it] will only be dug out and dusted off if things get really serious."*

Finally, we have observed an incremental increase in the optimal efficiency level of new and existing plants, especially coal-fired ones. The reason is the increased profitability of energy efficiency improvements which in the past were mostly driven by the rationale of saving fuel costs and are now supplemented by the new cost factor of CO_2. This is summarized by one power generator: *“CO_2 is only one point among many and of course it influences the investment appraisal, [..] but all that really means is that [..] one simply goes a step further, but that is not a fundamental paradigm change, for increasing efficiency was always important to us and now the EU ETS is yet another incentive to go a bit further”*. Regarding new plants, there are also other reasons for higher energy efficiency levels such as public acceptance concerns about coal-fired power plants and user preferences for technological sophistication, a remnant of the pre-liberalization era. Regarding modernization activities, we find confirmations of the greater profitability of energy efficiency improvement measures. As another power generator explained: *“The potential for improving efficiency in the generation system is well known, it is only a question of whether it is profitable. [..] Emission trading has set a strong trigger to review the topics and it now appears clear that some measures have become profitable”*. However, there are examples of modernization activities simply aiming to extend the lifetime of existing plants. This is the case because higher power prices and public acceptance problems for new coal-fired power plants make this an economically attractive but environmentally doubtful option to which the EU ETS indirectly contributes.

In summary, despite the EU ETS changing the framework conditions of the power sector, its impact on demand has remained limited so far as other factors have been more decisive for investment decision making. However, this situation could change with the increasing stringency and predictability of the EU ETS. One technology provider alluded to the importance of stringency: *“We do think that CO_2 will become relevant, but in the first phase it was not yet relevant, we know why... as for the second phase, let's wait and see”*.

6 Discussion and conclusion

This paper provides an early analysis of the impact of the EU ETS on the sectoral innovation system for power generation technologies by conducting a systemic evaluation of the innovation impact of this market-based climate policy instrument.

Regarding *'knowledge and technologies'*, the innovation process has accelerated in the large-scale coal power generation technological regime along the two trajectories 'energy efficiency' and 'carbon capture'. While the impact of the EU ETS on the former is of an incremental nature, the EU ETS was fundamental in establishing the new technological trajectory of CCS. As no significant developments can be observed in the emerging renewable regimes and niches triggered by the EU ETS, we argue that the scheme does not seriously challenge the current sectoral regime of large-scale centralised power generation.

Regarding *'actors and networks'*, we find that corporate actors embedded in the large-scale fossil-fuel based power generation technological regime, i.e. power generators and technology providers (especially large incumbents) are reacting to the EU ETS, while its influence on other actors is rather low. The main impact of the EU ETS on networks so far concerns the RD&D network for carbon capture technologies which is not only characterized by new linkages to companies from the oil and gas as well as chemical industry, but also by a particularly intense involvement of power generators.

Regarding *'institutions',* we find that the EU ETS has led to the mainstreaming of CO_2 across organisational units, its integration into corporate routines and – perhaps most importantly – a change in thinking regarding carbon constraints and top management's attention to its strategic importance. We argue that these corporate institutional changes of firms' CO_2 culture should not be overlooked as they prepare the ground for the transition to a low carbon sectoral innovation system for power generation technologies.

However, regarding *'demand',* the direct impact of the EU ETS remains limited so far, mainly because of its lack of stringency and predictability and the relatively greater importance of other factors. Yet, the scheme indirectly contributes to an increased demand of power generators for renewable power generation technologies, particularly wind, thereby positively contributing to the development of the emerging technological wind regime with potential repercussions for the dominant sector regime.

Summing up, our research indicates that, on a sectoral scale, the EU ETS affects the rate and direction of the technological change of power generation technologies with the main impact within the large-scale coal power generation technological regime. The EU ETS needs to be understood as only one, albeit important, instrument within the integrated climate and innovation policy mix needed to orient all the elements of the sectoral innovation system of power generation technologies along an ambitious low carbon path. For example, the impact of the EU ETS on renewables or university research has been limited so far, but feed-in-tariffs are driving the diffusion of and RD&D on renewables, while public support schemes for basic research on low-carbon technologies are promoting RD&D activities of universities and research institutes within a low carbon sectoral innovation system. Also, our interviews indicate that such a coordinated policy mix may benefit from a closer linking of environmental, energy and innovation policy departments so as to better align the variety of regulatory measures.

If sufficiently stringent and predictable, emission trading can be a powerful tool in the policy mix. Two design features appear important for this: the emissions cap and the mode of allocation. Regarding the former, if the expected future CO_2 price path is not sufficiently high, it will hamper both the diffusion of existing and the RD&D on new low carbon technologies. As a consequence, low CO_2 prices can be expected to be detrimental for innovation. In the same vein, predictability is vital, as strategic decisions, especially those regarding RD&D, seem to be driven by expectations of the ongoing long-term existence of a stringent monetary carbon constraint, not only in Europe, but also in other regions of the world. Here, the actual implementation of the EU ETS matters as this generates trust in the seriousness of policy makers about tackling climate change. Regarding the latter, our research indicates that the mode of allocation and especially expectations of future allocation rules play an important role in adoption decisions and thus care needs to be taken when designing them to avoid distortions. However, factors other than the EU ETS are often more important for strategic decisions about new power plants. With the decision for full auctioning, a simple and predictable carbon signal has been given which together with more ambitious emission caps can be expected to contribute to supporting the market for low carbon technologies.

Finally, our research has implications for the international Post-2012 climate agreement because significantly large future product markets for power generation technologies are essential for low carbon innovations, and especially for RD&D activities of technology providers. A stringent and predictable climate regime implies the existence of such markets as it will need to be operationalized with demand-pull policies such as emission trading. In order to make the most of this regulatory pull effect, an international Post-2012 climate agreement should generate markets for low carbon technologies in the growth regions of the world, particularly China and India.

We envisage three areas of future research. *First,* since our innovation system analysis identified the relevance of corporate actors, our research should be extended by in-depth case studies of power generators and technology providers. This should examine technological and firm-level differences as these appear to have high explanatory value. *Second,* in order to specify the extent of the innovation effects of the EU ETS, researchers should conduct a survey of companies regulated by the EU ETS and of technology providers, ideally in several countries. At a later point in time this question should then be addressed by econometric analyses using indicators such as patents. *Third,* our research indicates that the combination of the systems of innovation literature with environmental economics is a fruitful endeavour for policy evaluation studies and should also be applied to other regulations or/and other innovation system approaches.

This study is not without limitations. At the time of the interviews, the EU ETS had only been in place for a short period of time, so that our analysis can only provide an early snapshot of its impact on the sectoral innovation system and it may be worthwhile to repeat it at a later stage. As we only studied the case of Germany, although the EU ETS applies across Europe, our findings should be compared with results from other countries. Finally, our approach could be applied to other sectors covered by the EU ETS so as to highlight sector-specific differences in the impact of the EU ETS on innovation systems. In spite of these shortcomings, our analysis gives important first insights into the actual innovation effects of the EU ETS in the power sector and thus provides a valuable foundation for policy makers designing emission trading.

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8 Annex

Table A-1: Impact of the EU ETS on 'knowledge & technologies'

Examplary quotes for key observations regarding the impact of the EU ETS on 'knowledge and technologies'
K&T1. EUA scarcity accelerating innovation process ▪ "There is a general acceleration effect – everything that has been done up to now needs to be done in a compressed manner. If something becomes more expensive, you always need to speed up your activities". [PG] ▪ "The EU ETS acclerates investments in new and in existing plants - factor in 10 years for bringing forward investments. The reason for this are allocation shortages". [TP] ▪ "At the moment several technology leaps seem to be taking place simultaneously: 2 to 3 technology leaps in one, things used to be more sequential." [TP]
K&T2. Mainstreaming of Carbon Capture and Storage Technologies (CCS) ▪ "The impact of emission trading on R&D is visible in CCS. [..] Internally, the topic of CCS has moved from being an exotic side issue to a main focus. It was said: CO_2, climate change is an important subject, it's not going to go away, it needs dealing with. If you assume that fossil energies [..] will still play an important role at least for the next 30 years, then you can either say: why does the climate concern us, or one tackles the matter. [..] This means that the subject must be taken seriously and the technologies have to be developed. If you see a market for it, then that gives a considerable impetus. [..] Emission trading gave impetus to the whole affair. There was suddenly a topic in the room [CO_2], which did not used to be there." [TP] ▪ "The topic of CCS has developed in the last years from one for absolute nutcases into one which is totally in today. Ten years ago I was laughed at when I mentioned this possibility. Five years ago I gave [..] a lecture, [..] and colleagues [from a large utility] objected, saying [..] it was completely ridiculous and totally absurd and so on. Today they are interested in it themselves." [TP] ▪ "Climate policy as a whole is the driver for CCS [..] but the EU ETS is what companies can feel, it brings monetary effects into businesses, goes down well with management. Ultimately, therefore, the EU ETS can be seen as the main driver [..]. Because climate protection has been talked about for 20 to 30 years, but nothing happens in businesses as a result of soapbox oratory." [TP] ▪ "All large power plant component suppliers are active in CCS". [TP] ▪ "Post-combustion technology protects investments in existing plants. That's why we are conducting research in this area." [PG] ▪ "The ambition is to reduce the efficiency loss from 10% to 5-6% or less, [..] for CCS is actually counterproductive: 46% lignite, 36% after post-combustion, that doesn't make anybody really happy." [TP]
K&T3. Additional driver for higher efficiency levels (materials, components) ▪ "Efficiency was always on the agenda as optimization projects, but the EU ETS reinforces these tendencies." [TP] ▪ "More energy-efficient power stations are never a mistake" [..] "Producing in a resource-friendly way is an old topic [for R&D], now the emphasis is more on climate-friendliness: how can CO_2 be avoided in fossil power plants". [..] "CO_2 is not that important in [our] research into renewables, it is a separate technology path, a new energy source". [PG] ▪ For steam power plants the influence is much greater and the reason is, what was the monetary value till now of an efficiency increase in a steam-powered plant? That is essentially the discounted value of the future saving in coal, and coal is not that expensive, but coal has proportionately more carbon and thus more CO_2 emissions, which means that in addition to the saved fuel costs comes proportionately almost one hundred percent saved costs of CO_2 emissions as well, and that means that the optimal plant design of a coal-fired plant clearly changes. [..] A power station isn't designed to realize the best available technology, but the most economic technology, and at present a higher degree of efficiency is more economical.[..] There are still some incremental measures I could carry out - here we are no longer talking about the component level, but the level of the whole plant [..] - there is still some scope when designing the plant, [e.g.] another preheating stage in the steam process and slightly better cooling in the cooling tower, which all mean additional investment and improve the degree of efficiency incrementally. [..] And now it appears that there is a new optimal design with a greater efficiency. This is also reflected in what is presently being invested, in what projects are currently being discussed, not only in Germany.[..] And that is independent of how the allocation is made." [TP] ▪ "The great advantage of increasing efficiency is that R&D is also advantageous if CCS does not arrive - then the power plant with the highest efficiency is the one most likely to be approved". [TP]
K&T4. Indirectly benefiting renewables ▪ "We are carrying out more projects on renewables and new energies; these are really future-oriented projects. The EU ETS reinforces these tendencies." [TP] ▪ "[Wind] Turbine development is driven by markets and feed-in tariffs. [..] The price for CO_2 allowances is essential, and must be guaranteed for the long term, at least 15 years, otherwise it cannot be a replacement for the feed-in tariff." [TP] ▪ "The one lives on [fossil power plants], renewables are added, [..] not because of increasing prices for coal or oil, they would have to rise much more, but because of public renewables support such as feed-in tariffs." [TP] ▪ "ETS and CDM/JI have no direct effect on our business [wind] but the long-term climate policy does: for the last 2 years there has been a veritable hype for renewables. [..] Due to the low production costs (6-7 cent /kWh) and the market price development for conventionally produced electricity, wind energy will be accepted on its own strengths – it will become interesting in any case". [TP] ▪ "Emission trading will ultimately lead to an increase in electricity prices and that leads to the situation that renewable energies, which generally have higher production costs, will become more competitive." [Association] ▪ "There is considerable dynamics in the renewables, which is simply driven – very indirectly – by the fact that states confronted with internationally legally binding CO_2 reductions are able politically to enforce production quotas. [..] my hypothesis is that the promotion of renewables is politically very stable, despite scarce funds. And that has consequences for us implicitly, that we say we have to consider where there are possibilites for us, and how does that fit in with our business, and our competences and strengths – a typical portfolio question. [..] the question of innovation can then follow [..]. [Within this] really big movement, the EU ETS is only a small impulse. Although I would claim it is no coincidence that we [perceive] a change in awareness in the discussion, also in the public one. I believe that the fact that we have a system that gives CO_2 a monetary value has a strong influence." [TP]

Table A-2: Impact of the EU ETS on ’actors and networks’

Exemplary quotes for key observations regarding the impact of the EU ETS on ‘actors and networks’
A1. Regulatory-pull from EU ETS to power generators to technology providers ▪ “Utilities need to put pressure on technology providers to provide low carbon solutions, and utilities themselves are pressured by the carbon constraint, that is the CO_2 price.” [Association] ▪ “First of all, it was very important to brief our marketing dept. because the EU ETS is nothing else for the customers than just a further planning condition .. just another monetary variable [..] for life-cycle cost calculations with certain time horizons, which then leads to funny effects on the market, to last minute panics and that has to be grasped in detail, that is important for the marketing people [..] that they understand how this influences our clients' decisions. [..] [The allocation rules in the MS affect the outlay on the marketing side and for business planning. [..] That is so to speak another plausibility factor [for the market forecast].” [TP] ▪ "The coordination of information regarding CO_2 in general and the EU ETS in particular is for the most part carried out by the marketing dept. The angle here is more where you can sell something, what are the sales and framework conditions.” [TP] ▪ “The fact is a supplier can be driven by clients, that is to say, a project that is being seriously considered sets things in motion, that is quite clear and it immediately gets management listening if there is a customer around. Of course, there must be an underlying perspective, but as long as I talk about topics without any real projects in the background, nothing much will happen. The [first CCS] projects [..] have provoked a great deal of discussion [..] Once a customer is on the brink of a project, then things will immediately be taken very, very seriously at all levels and move from this preliminary perspective into a real development world” [TP] ▪ “The green idea is already fully adapted, is certainly a sales argument and thus naturally an internal development argument”. [TP] ▪ “In general terms, technology providers’ strategy is aligned with providing low carbon technology, whether for power stations or grids - this is what is driving their programs” [Association]
A2. Contribution to increased RD&D spending, especially of larger players ▪ “According to statistics of the Donors' Association, there have been sharp cutbacks in R&D spending since the liberalization of the markets. A change in attitude may be taking place now, but in general utilities still assume that technology providers are the ones that ought to invest in innovation.“ [Government] ▪ “R&D expenditures have increased for the following reason: a few years ago funds were generally cut back, because times were difficult. It became necessary to raise them again - CO_2 played a significant role here among other issues.” [TP] ▪ “Our R&D budget has tripled since 2001. [..] One of the cost drivers were the machines for the renewables. [..] But research on renewables is a bit of a 'fig-leaf'. [..] Substituting coal-fired plants by renewables is not a research topic.” [PG] ▪ “1.5 years ago [two large utilities] announced that they will spend € 1 billion on building a CCS 400 MW plant. You cannot say that there was a price signal from the EU ETS, but you could say that there is some sort of carbon signal coming out of it - that clearly needs to be developed.” [Association] ▪ “How vehemently some relevant pilot project budgets are set up, which then rapidly expand to the tune of millions in such a [large] company - or are these always just placebo affairs? [..] thanks to emissions trading and [..] demand, e.g. by turbine buyers [..], the course will be set differently and more relevant funds will be provided, in order to drive developments forward.” [Consultancy] ▪ “Actually we already know what international savings would be necessary for some sensible burden sharing to reach a 450 ppm path, at least realistically. The question is not so new, even if some people do not want to know. We take the [targets] seriously. We calculate them in scenarios, that is what one must reckon with, otherwise the whole thing is just a farce. We calculate with minus 50 per cent, minus 80 per cent and the immediate consequence is that there will be massive structural changes”. [TP]
A.3 Heterogeneity of actors and evaluation of impact of EU ETS ▪ „The EU ETS [..] only causes a power price increase, but it does not guide investments. [..] In this regard, for example, feed-in-tariffs or the cogeneration law are much more successful.” [Renewables and CHP specialized PG] ▪ “In particular against the background of Kyoto – but also CO_2 allowances, load optimization, and efficiency – research [CCS and increasing efficiency] is important again in order to maintain business in the future too.” [Coal-specialized PG ▪ “As long as there is or we believe there is a large demand for coal in the mid term – a time horizon of 15 years – we are well positioned.[..] The coal market is a gigantic, huge complex, internally consistent, the CO_2 price would really have to be very high in order to curb carbon” [..] “Our strategy is to take the business on board and finish it [..] – [it is] running very well. We are not positioned to think in advance in 20-year time periods, nobody has time for that today.” [Coal-specialized TP] ▪ "We have not made detailed analyses of NAPs, but that would be sensible for firms with two products in order to decide where to concentrate resources. [..] For us, CO_2 was never a big topic internally, as the large power suppliers all have highly qualified engineers and can calculate everything for themselves and based on that then set the framework conditions for the plant producers. We usually get finished tenders from power generators which specify [..] what is required of the components.“ [Specialized TP] ▪ “We are not developing new technology, it must be available on the market. If we do something, it tends to be demonstration plants. At the moment, however, only one fuel cell project is running. [..] We participate in a [local] innovation fund [as a financial backer], that should promote projects to advance climate protection.” [Medium sized PG]

N1. Increased involvement of large utilities and true competition regarding RD&D on CCS

- “In CCS a joint development is taking place between technology providers and power generators, and that is rare. [..] The cooperation is fundamentally different with CCS [..] Utilities want to build up skills [engineering know-how]. [..] R&D together with utilities used to be very difficult, you had to beg and plead to be allowed to test a [component] in a plant, now they have understood that CCS will be imposed on them by politicians and then became very pro-active, they are suddenly very committed - e.g. at ZEP.” [TP]
- “CCS is an exception: utilities are collaborating here with plant constructors because we are still in the pilot phase and the enterprises have different needs and are therefore pushing different technologies.” [Research institute]
- “In the case of CO_2 capture, [the formation of partnerships] is driven by the operators' side today, because the search is on for solutions to being able to continue to produce electricity reliably, but simultaneously meeting the set environmental goals.” [Association]
- “The utilities are providing the most money [for CCS research], and we [as technology providers] are developing the technology for capture.” [TP]
- "For the utilities much of what is called innovation is petty cash and marketing. [..] At the technology level, actually only market research is conducted, because you want to know the potentials of the technologies; the only exception is perhaps CCS, but in this case the utilties see themselves as forced to develop positions – but the technologies themselves, even CCS, are being developed by the system providers and not the operators." [Association]
- “For energy suppliers, the lack of acceptance of coal-fired plants and their image problem is an important reason to invest money in CCS R&D. [..] We [technology providers] used to further develop a component step-by-step and paid for it ourselves, the plant constructor bore the risk.” [TP]
- “The customer has a completely different reaction [to CCS-RD&D] than to just increasing energy efficiency”. [TP]
- “[Acting] pro-actively is always better than being dragged into things. [..] Diversification is not that interesting for us: what we can do is burn coal. [..] We want to concentrate on our main business area. [..] Post-combustion technology represents a protection of investments for existing plants. That is why we are researching in this field”. [PG]
- “I would say that universities play hardly any role [in capture technology]. The absolutely essential focus is on the oil and gas firms, and now increasingly even the RWEs and E.ONs and Vattenfalls of this world. [..] It will happen via positioning and ultimately tackling demonstration projects” [TP]
- “A few years ago, power generators were an unknown customer segment [..] but with the EU ETS our technologies and know how are in demand, [..] If the demonstration plants are going to be built, then this could easily make up 50% of our sales. [..] It is a big chance for us”. [TP]
- “[CCS] is true competition – in the meantime. This says a lot about the state of affairs because if there were an open exchange [among technology providers], then that would mean the topic need not be taken seriously.” [TP]
- “Each of the large energy suppliers has selected a technology and is pursuing it exclusively, i.e. without other utilities, in order to secure the knowledge for themselves.” [TP]
- “The clients ask [..]: can you do oxy-fuel later, and what about a CO_2 scrubber? In one tender we were the selected bidder, but we didn’t have a scrubber – that is a problem, a market disadvantage, and you have to react strategically; there was a R&D meeting [..], and now we are building a [..] test plant, among other things. [..] The customers were the main driver, because [without CCS readiness] they would no longer receive the permits.” [TP]
- “Actually the really big topic for us [for the product portfolio] is definitely CCS, because that really brings far-reaching changes in the whole plant, the components, even up to the business models, one can think relatively far if you go through it step-by-step” [TP]

Table A-3: Impact of the EU ETS on 'institutions'

Examplary quotes for key observations regarding the impact of the EU ETS on 'institutions'

C1. Change in thinking, including top management involvement

- "The fact that emission trading has come into operation and has brought about real trading with real money, many colleagues are amazed at how it came about. [..] Many people thought that it would come to nothing, and it cannot work and so on, but it is now simply a fact and functions and is here and here to stay. And that has created a lot of confidence that we will continue to have to deal with something like this and that is influential." [TP].
- "There has already been a change in thinking caused by a real price being put on emissions, and this change in thinking should not be underestimated." [Association]
- "Now people are slowly realizing that if emission trading with real money is already politically feasible today, then it could actually happen that the climate change problem will be taken seriously tomorrow. [..] And if that were the case, then CO_2 emissions would really have to be reduced as too little has been done so far .. then it would no longer be possible to avoid a solution like [CCS]. And the idea .. is spreading more and more, [..] and it can be increasingly observed even at management level that people have understood it, okay, what are the possibilities to reduce CO_2 on a really large scale? It no longer helps if I suggest we should somehow increase efficiency by 0.3 percentage points ... that is business as usual, that is no real help. It is still important, I don't want to imply otherwise but it bypasses the main issue [..] climate change is here to stay ". [TP]
- "There is a recognition that the industry needs to move to a low carbon generating fleet." [19:12] [Association]
- "That climate change is a problem has been known for a long time. [..] things like the EU ETS are just tightening the screws". [TP]
- "The reason the ETS has had no impact is because the certificates are allocated for free [..]. Now, with the prospect of 100% auctioning in 2013, something is starting to shift at the utilities". [TP]
- "Some board members really start to flounder when the subject of CO_2 is involved. The issue of CO_2 has reached the board members in any case, [..] now they have all understood it. That is [..] its effect on the investment account, simply that it has a considerable effect on investment costs and at the same time may mean that the investment decision crashes if there is any doubt." [PG]
- "In the power and oil sector, the EU ETS was always located with the CEO or very far up the board hierarchy; the very important discussions were always strategic ones". [Research institute]
- "In the meantime, emission trading is an issue at every board meeting; above all now that the new allocation is at stake. If you telephone with the persons responsible for emission trading in a company, these people are really under pressure in the enterprises. Above all for new plants and capacity expansions: how many emission allowances will they get, or whether the capacity expansion will be recognized, and if yes, to what extent – that is what the board wants to know." [Government]
- "Climate change is deeply rooted in top management". [TP]
- "For one and a half years [mid 2006] we have had a CO_2 product manager in high places [in corporate headquarters]." [TP]

C2. Distribution across organization

- "The CO_2 issue has grown rapidly, now there is at least one person in every department dealing with CO_2 at least on a part-time basis." [..] "Twice a year a CO_2 workshop takes place which brings everyone together." [TP]
- "We [had to] then look and see where CO_2 occurs and if there are existing processes where we just have to integrate CO_2 in parallel: it is an issue for fuel purchasing, it was a subject for trade and it is now, with a view to innovation and technology, of course an essential contribution to investment analysis." [..] "Weekly telephone conferences are held with all the CO_2 experts in the company" [PG]
- "The EU ETS is now standard, but the effort for integration was considerable. [..] There is no explicit CO_2 coordinator." [PG]
- „After the decision to introduce the EU ETS, the preparation [for] and actual implementation [of the EU ETS] was a high-priority topic for [us], regarding which many, actually all business units were involved. More and more it has also been integrated in the whole generation strategy". [PG]

C3. Integration into corporate innovation routines

- "The discussion up to now was very much related to single projects, and that of course leads to cost comparisons, the plant must be cost-effective. [..] Only now are people beginning to think, how should I actually evaluate my portfolio? Under the current German NAP [notified 2008-12] I would build more coal-fired plants first if I were looking at individual plants or projects. [..] But from an energy management viewpoint, I can only warn against this, you shouldn't [..] cultivate a monoculture - but you have to be able to explain this strategically." [PG]
- "In 2007 expectations of partial free allocation dropped to full auctioning. [..] Today we are assuming auctioning only – we have already forgotten the time of free allocation. [..] The [differentiated] gratis allocation brought coal an advantage, this is all different now." [PG]
- "Public utilities conduct sensitivity analyses with different CO_2 prices. This leads to fluctuating decisions, because many plant designers cannot bring themselves to carry out a clear profitability analysis for their project, because it does not exist" [Association]
- "There is a price of carbon that determines where the investment goes – and not [anymore] so much the allocation methodology because the future prospect is for auctioning". [Association]
- "The long-term innovation impact of the EU ETS depends on the level of trust in the continuation of the instrument. The announcements in the EU Directive [proposal] regarding CCS [..] and the acceptance of JI/CDM post 2012 were positive, even if there is no international follow-up agreement. These statements firmly establish the [innovation] road map, because it emerges from this that the EU ETS will stay, climate protection is still important – and is so for the long term." [TP]
- "[What matters is that] we have gained a certain degree of confidence in the fact that in the future saving CO_2 will be worth money. This is only very indirectly related with today's emissions trading. [..] Only due to the confidence that this will continue, and not only in the EU, but also because it is clear that something is being done worldwide in several places, and [..] ultimately, the fact that emission trading has really implemented the whole thing operatively and brought about real trade with real money." [TP]

Table A-4: Impact of the EU ETS on 'demand'

Exemplary quotes for key observations regarding the impact of the EU ETS on 'demand'

D1. Temporary spike in pre2012 interest

- "Prior to 2001, there were cost saving programs in power plants". [..] In 2005 every power plant was economically viable on account of the gratis allocation. In Phase 1 [our newly built power station] was yield-driven, before that it was capacity-driven and now is so again. [..] [New coal power stations] did very well under the 14-year rule, then they sank. [..] With a lot of skill we've managed to turn them around economically." [PG]
- "We wanted to build a large-scale power station. The fundamental decision to build a new power plant was encouraged by the 14-year rule, [..] as the new plant would have been able to operate from 2013 for 14 years without certificates." [PG]
- "The CO_2 gratis allocation is important for the investment decision, very much so." [..] "With decreasing CO_2 allocation, the present value of the investment decreases and, at some point, economic efficiency is no longer given. And that can be attributed to CO_2 alone, to the CO_2 allocation." [..] "The man behind building the new power station who actually has to overcome this "building decision" obstacle, only sees that the CO_2 allocation is sinking, he doesn't like that at all." [PG]
- "For the first Energy Summit in April 2006 we had a long list of power plants with a performance of 19,759 MW which were scheduled to go on the grid between 2006 and 2012. This year [December 2007], the list had completely melted away. Today we have indications of plants, or plants currently being built with a total performance of approx. 12,000 MW [..] and this is definitely connected with the fact that emission trading for the second trading period was more restrictive than utilities imagined, and that no one knows how things will continue in the third trading period." [Government]

D2. New plants: Incentives for fuel switching and cogeneration, but not decisive

- "Emission trading creates advantages [for gas] [..] but this is not sufficient." [PG]
- "We decided on coal for two reasons: first of all it is somewhat cheaper, and secondly without a long-term contract, the political dependency on one state is too high with gas." [PG]
- "The CO_2 price would have to be 60-70 €/ t CO_2 to make gas profitable.[..] Gas is also out of the question because of the unavailability of long-term gas contracts". [PG]
- "Due to the fact that the present allocation rules give too strong incentives for gas power stations – because no gas-fired power plant runs for 7,500 hours – the fuel mix is naturally being very strongly directed towards gas" [PG]
- "Naturally the choice of fuel depends heavily on whether there is a fuel-dependent benchmark or not" [..] "The fuel incentive is banal. [..] This is always indirect: the allocation decision is for the next five years [..], what really counts is the estimate of what the following allocation periods will bring and they will never be coal-friendlier again, that's the simple prognosis." [TP]
- "German energy suppliers would not shift from coal to gas on their own, this is caused by the EU ETS and the tight coal benchmark. [..] Investments in gas are driven by the EU ETS, innovation on the other hand by the gas price. For steam plants, the EU ETS tends to curb investments, but spurs innovations". [TP]
- "How much of each fuel do we already have in our portfolio? [As the majority is gas:] We also want to include coal, even against the trend" [..] "The price assumption models up to 2030 are all nonsense. [..] It is ridiculous to base business decisions on them, one must diversify." [..] "What use are 27 scenarios [when considering investment plans] – in the end, one is so uncertain that they are no longer relevant for the decision, ultimately, it is only important that one wants to remain in the generation business. [..] For the technology / fuel decision one does use scenarios for orientation purposes, but every project can be made to fit". [PG]
- "[Regarding new cogeneration plants] even favorable rules are not enough compared to long-term uncertainty associated with the EU ETS". [Association]
- "Cogeneration now plays a larger role in on-going projects, among others because of the KWKG [cogeneration law] compensation and the hoped for cogeneration bonus in emission trading." [..] "The 2000 KWKG did not bother anyone, but today one tries to use heat, the incentive has grown considerably stronger." [PG]

D3. New plants: coal-fired plants planned as CCS-ready

- "The plants are already planned to be capture-ready, so that this can be implemented later." [Association]
- "The new block will be CCS-ready. The planning for this started together with the first protests against the power plant [2007]. [..] The block will also be CCS-ready because CCS is already an approval condition for [another] power plant, and we are assuming that [our] approval will be exactly the same." [PG]
- "If the price of CO_2 is high enough, all the old power plants will be replaced – the new ones must however be capture-ready – that would be a boom for us. The second boom would be CCS retrofitting." [TP]

D4. Indirect contribution to the diffusion of renewables and nuclear (but latter not (yet) in Germany)

- "1 ½ - 2 years ago the utilities became anxious that they were not part of the wind (energy) boom [2006/07]. [..] As the institutional investors showed them how to put together a large portfolio, they became nervous [..] They are headhunting colleagues, paying strategic prices in Europe and outdoing others - utilities have almost limitless funds on their balance sheet. [..] They also think more in the mid term context than institutional investors, who tend to want to cash in after 2-3 years." [Project developer]
- "In our future portfolio, renewables play a greater role, but that is only flanked by CO_2, the main driver is the German renewable energies act [..] Renewables are now a big topic in all the big companies. [..] Due to the ETS there is a greater willingness to take the risk [with offshore wind]." [PG]
- "The utilities in Germany have been fast asleep during the last few years. As the [on shore wind] market has closed down they are now trying to secure their profits via off shore. The German utilities did not take renewables seriously and are only now realizing how relevant they are. [..]. Foreign utilities were much more active here." [TP]
- "Through the CO_2 price it is foreseeable that renewable power generation will become a competitive alternative. The higher the CO_2 price, the greater the incentive or pressure. In reaction to the EU ETS there is a tencency of power generators to focus on low carbon technologies." [Government]
- "All utilities [..] have founded separate subsidiaries for renewables – with nice marketing names. The working climate is different in these subsidiaries, a different type of people work there and the workforce is much younger; this is necessary as different know-how is required for renewable energies." [TP]
- "Wind has the greatest volume of the 2020 target of 20% renewables. Renewables should be rapidly built up. The shift is innovative, wind was previously a hobby, now it has a generation identity and is a new business area with a new culture. [..] The trigger [for this] however is not climate policy (except for perhaps the fixed payment of the Renewable Energy Act), the triggers are much more individual persons who were able to drive an idea forwards. [..] Climate policy was important as an argument." [PG]
- "We are observing a certain renaissance of nuclear energy. [..] In Germany this is more or less a non-topic today, there is nothing [no new plants] on the agenda. That will only be dug out and dusted off if things get really serious." [TP]

D5. Rise in profitability of measures improving energy efficiency (modernization & plant design)

- "CO_2 is only one point among many and of course it influences the investment appraisal, [..] but all that really means is that [..] one simply goes a step further, but that is not a fundamental paradigm change, for increasing efficiency was always important to us and now the EU ETS is yet another incentive to go a bit further" [PG]
- "Efficiency [in a coal-fired power plant] is basically driven two thirds by fuel and then one third by emission trading, [..] because this is the [..] structure of the CO_2 price to fuel price at the moment. [..] Then maybe you can tinker a little with the plant design [..] I am going to wangle one percent point more efficiency out of it [..] but this is not only driven by emissions trading, I also save a little bit of fuel in doing so, so that is a double effect. [..] In principle, emissions trading improves efficiency, there is a greater focus on the variable costs". [PG]
- "In Europe only state-of-the-art efficient power stations are installed anyway, of course the level of efficiency will be forced upwards by the EU ETS." [TP]
- "According to the German licensing law, a power plant must be state-of-the-art. [..] In times of monopoly, the main question was: who has the best plant, you showed your technical muscle, today the question is, who has the cheapest plant." [Company, PG]
- "Due to the lack of public acceptance for coal-fired power stations in Germany, an operator building a new coal-fired power plant has to build a very efficient one. But to some extent you can also see a shift to other countries taking place, e.g. Poland, Romania and Albania." [TP]
- "When building a new plant [..], the newest technology would be used anyway [..], because primary energy will become more expensive in the future. Emission trading does not play a role here. However, it means that the economic viability of new technologies increases – the numbers are better with additional CO_2 costs." [PG]
- "The subject of efficiency, that is, how much efficiency can I expect or how far am I prepared to go – that is usually at the expense of availability [..]. If, for example, I do not expect a high CO_2 price, I would say forget the few efficiency points, I'll go for availability, but if I am expecting a higher price then I would say, okay" [PG]
- "After taking the fuel decision [one asks oneself]: how are we going to write the tender, how do we want the plant designed?" [..] "Independent of allocation mechanisms, increased efficiency gets an additional monetary value through the saved CO_2 emissions and their price forecast" [TP]
- "The potential for improving efficiency in the generation system is well known, it is only a question of whether it is profitable. [..] Emission trading has set a strong trigger to review the topics and it now appears clear that some measures have become profitable". [PG]
- "There are other cases where the influence was very much greater and where it did make sense to understand beforehand that, aha! there is a new market heading for us: the modernization of steam turbines, [..], especially against the background of the old plant rule [Malus Rule] [..] to [..] overcome the efficiency threshold." [TP]
- "The EU ETS is already affecting investment behaviour, e.g. in countries with benchmarking allocation. [..] For old plants, under-allocation acts as a punishment for inefficiency which is why efficiency measures are being conducted in existing plants [..] the customers are beating a path to our door" [TP]
- "This retrofit was not driven by climate policy, but by economic considerations. The core question was: Can we still earn money with this block? For how long? [..] CO_2 and fuel costs pull in the same direction for improving efficiency, it is the same thing - CO_2 only reinforces the effect of the [saved] fuel costs." [PG]

D6. Summing up: Direct impact on demand limited so far

- "Emission trading as an instrument did not really catch on in the market in the past. The steering effect of emission trading has been relatively weak." [Association]
- "The first trading period was not exactly a big success". [TP]
- "We do think that CO_2 willl become relevant, but in the first phase it was not yet relevant, we know why... as for the second phase, let's wait and see". [TP]

9 List of Abbreviations

CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
EU ETS	EU Emission Trading Scheme
EUA	European Allowance Units
GHG	Greenhouse gas emissions
PG	Power generator
R&D	Research and Development
RD&D	Research, Demonstration and Development
TP	Technology Provider

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