Paper to be presented at the

35th DRUID Celebration Conference 2013, Barcelona, Spain, June 17-19

Climate Innovation ? The Case of the Central German Chemical Industry

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Abstract

Climate change, including its possible causes and consequences, is one of the most controversial and intensely discussed topics of our time. However, European businesses presently are less affected by the direct effects of climate change than by its indirect consequences. One central issue that arises in this context is the change in demands imposed by businesses? operational environment.

This article contributes to the environmental innovation literature by providing a comprehensive evolutionary framework which allows an analysis of the drivers, determinants and outcomes of climate innovations implemented by companies. In this context, the prime issue is how the perception of climate change affects corporate innovation processes. Firstly, we consider the new demands imposed on the company by its stakeholders. Secondly, we discuss the innovative reactions to these impulses. Finally, we highlight the functions and relevance of certain internal and external determinants in the innovative process.

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1. Introduction

The possible causes and consequences of climate change are some of the most controversial and intensely discussed topics of our time. Today, European enterprises are more affected by the indirect consequences of climate change than by its direct effects such as extreme weather events. Some of these indirect consequences for industries arise from society's perception of climate change, and by new demands imposed on companies by their operating environment. In order to adapt to these new or changing stakeholder demands, a firm might react with innovative activities. These innovations may differ, depending on the group demanding them, the business objectives and external factors.

Theoretical contributions to the subject of innovative reactions to climate change by enterprises are as yet rather scarce and most concentrate on the impact of the European emissions trading system (EU ETS). Even before the introduction of the EU ETS, Betz (2003) estimated the transaction costs of this new instrument to firms as well as the competitive impact it would have. However, the innovative response gained only rather limited interest in this work. In the course of their literature review of emission trading schemes in the USA, Gagelmann and Frondel (2005) report that they expect only moderate impacts on innovation as a result of the EU ETS. Oberndorfer and Rennings (2007) compare various theoretical studies and also conclude that the EU ETS will have a negligible effect on innovation. In the case of the energy and industry sectors, Schleich, Rogge, and Betz (2009) expect the EU ETS to stimulate only limited improvements in efficiency.

Up to this point, empirical research has focused on the influence of the EU ETS on innovative reactions in various sectors or countries. Results from these studies differ with regard to the impact of the EU ETS. Furthermore, other drivers in the context of climate change are usually not described. First empirical inquiries investigate the influence of the EU ETS on corporate investment decisions (see, e. g., Hoffmann 2007) or focus on the impact of innovation on the German energy sector (see, e. g., Rogge, Schneider, and Hoffmann 2011). In the same line of research, Rogge, Schleich, et al. (2011) explore the impact on innovation of the EU ETS in the German paper industry and find that it hardly influences innovation activities, in contrast to common market factors. In a study of the Italian paper industry, Pontoglio (2010:87) found that "wait and see" was a frequently adopted strategy in the paper industry during the first phase of the EU ETS. Investigating the chemical industry in Portugal, Tomás, Ribeiro, et al. (2010) simulated the impact of the EU ETS on unit costs and found only a limited impact. Again, in this study, the innovation impact is not considered. Conducting a literature study, Kemp and Pontoglio (2011) find that the influence of market-based environmental policy instruments (e. g. emissions trading) on innovation is far weaker than generally assumed.

This study contributes to the existing body of research on environmental innovation by investigating whether businesses respond with innovation to the demands imposed on them by their corporate environment and by perceptions of climate change. These demands include, in particular, the EU ETS, but also market changes and requests from civil society. Therefore, the research objective of this study is to analyze the innovative behavior and formation processes with its drivers, determinants, sources and outcomes at the corporate level. In doing so, the extent and form of this innovative reaction is of central interest to this work.

Energy intensive industries' branches are doubly affected by the indirect consequences of climate change. This is the case not only because of the direct pressure imposed on these industries but also because of the increased energy prices passed on from the energy providers, or market prices in general. The consequences are increased energy costs as well as cost risks at company level. This study is therefore characterized by in-depth analysis of the innovation processes and outcomes in an energy intensive and regionally agglomerated industry - the chemical industry in Central Germany.

2. Theory of climate innovations

The theoretical framework used here to analyze drivers and determinants of climate innovation at the corporate level is described in detail by Ehrenfeld (2012). In the following section, a short representation of this framework is outlined. As a theoretical basis for this analysis, the evolutionary or, to be exact, Neo-Schumpetrian theory seems well-suited because of its explicitly dynamic conception. Contrary to the neo-classical theory, it is not based on perfect and complete markets, complete information, full rationality or a static equilibrium. In addition, it allows for a consideration of exogenous as well as endogenous drivers of evolutionary change.

In line with the OECD's Oslo Manual (OECD 2005:46), innovation is defined here as "implementing something new or significantly improved". According to this definition, an innovation is understood to be new to the individual firm but not necessarily to specific sectors, regions or markets. Furthermore, four types of innovation are distinguished: product, process, organizational and marketing innovations. Product innovation refers mainly to new goods, process innovations to new production methods and organizational innovations are considered changes e. g. in the workflow or internal knowledge processing of the firm. Marketing innovations include changes in product packaging and advertising (see, e. g., OECD 2005:29; 47-52). Consequently, the term “climate innovation” denotes all kinds of innovations which result in the direct or indirect avoidance of greenhouse gases, whether intended or not (Ehrenfeld 2012:11).

Climate change drives corporate innovations through various channels. In this context, “drivers” are pressures exerted on the firm by individuals or groups that affect the company’s performance or are affected by the company’s actions (stakeholders) to implement climate innovations. Perhaps the best known driver related to climate change and external to the firm is a certain form of regulation stemming from governmental bodies: the European emissions trading system. The EU ETS was introduced in 2005 to create monetary incentives in order to mitigate industrial CO_2-emissions and to foster more energy- and carbon-efficient technologies by imposing market based prices on CO_2-emissions (see, e. g., Schleich, Rogge, and Betz 2009:38). The industrial sector most affected by the ETS in the first and second trading period was energy suppliers who passed on the costs of carbon allowances to their customers in the form of rising energy prices.

Besides regulation, gaining a competitive edge is claimed to be the most important driver in the environmental innovation literature. Consequently, achieving cost savings is considered a driver of innovations. High resource consumption, especially energy resources, is considered a sign of inefficient production. So, revising the company’s production processes and reducing input costs leads to higher productivity and thereby to comparative advantage and increased market shares (see, e. g., Frondel, Horbach, and Rennings 2007:573ff.). On the other hand, an increased sensitivity among customers towards sustainable issues, including climate issues, can drive the demand for environmentally friendly products. Creating additional customer value, e. g. better product quality or energy savings, is intended to reinforce the demand for these products. Markets can thus act as a second important external driver of climate innovations.

Finally, the quest for institutional legitimacy (see, e. g., Bansal and Roth 2000) is considered an external driver for climate innovations. Civil society demands certain behavior from the firms consistent with a certain set of values and (informal) norms. Particular pressure can be exerted by the media (also in its interaction with local communities and scientific institutions) or special interest groups like NGOs. A positive image is said to help a corporation in accessing financial resources as well as in raising employee morale and goodwill. But even more, a negative image can affect the reputation of a firm and public opinion towards it, right up to the unpleasant development of a regulatory environment for these firms or declining shareholder values (see, e. g., Buysse and Verbeke 2003:461).

As opposed to social norms, which are external to the firm, managerial motivation is internal to the corporation (see, e. g., Bansal and Roth 2000). After all, managers are also members of society and are therefore also influenced by the media and public opinion. In line with civil values, the very commitment of management towards climate and environmental issues in general is considered an important internal driver for climate innovations.

Innovations arise from different sources – both internal and external to the firm. From inside the firm, research and development (R&D) as well as "learning by doing" are considered the prime internal sources of innovation. Cooperation achieves connection and transfer of knowledge as well as risk sharing among the partners of the R&D process. As far as outside sources are concerned, firms often obtain innovative resources from other firms or public research organizations. This process is then called "adaption" or "diffusion" (OECD 2005:36; 57).

Apart from the four types of innovation (see above, p. 3), Ehrenfeld (2012:21f.) distinguishes three classes of climate innovations: congruent, unintended and insubstantial. "Congruent" climate innovations occur when the innovation genuinely aims to reduce greenhouse gases (GHG) and performs this task. The result of "unintended" climate innovations is indeed the reduction of GHG, but the incentive is motivated by something other than climate issues (usually cost aspects). Finally, "insubstantial" innovations are themselves irrelevant to GHG emissions. These are mainly marketing innovations and attempts to improve the firm's image in relation to climate issues. These kinds of innovations are a case of what is commonly called "greenwashing".

In contrast to drivers, determinants of the innovative process do not exert pressure on the firm to innovate but have a fostering, hindering or steering effect on the innovation process simply because of their existence or properties (Ehrenfeld 2012:23). In this connection, determinants can be internal to the firm (the company's characteristics), external (from the corporate environment), or properties of the inventions to be introduced. In the case of determinants internal to the firm, the current knowledge base and technology portfolio of the firm constitute the basis for new innovations. Closely linked to the actual portfolio is the absorptive capacity of a firm, because this determines the firm's ability to absorb knowledge from outside and to gain a sustainable competitive advantage (see, e. g., Cohen and Levinthal 1990; Cohen and Levinthal 1989). So, the fit between old and new elements in the portfolio also affects their value to the enterprise. This has two effects: on the one hand, iterated innovations along the same technology path lead to learned effects and competitively relevant specialization. On the other hand, path dependencies can lead to a "lock-in" and may isolate the firm from new technologies (see, e. g., David 2000). Other impediments in this connection are the general inertia of organizations themselves as well as the "not invented here" syndrome (see, e. g., Fagerberg 2005:11).

The question of whether the size of a firm governs its environmental innovation cannot be answered conclusively (see, e. g., Wagner 2007:1596, but Frondel, Horbach, and Rennings 2007). It is often said in this regard that large firms are more likely to produce environmentally friendly mass products whereas smaller firms concentrate on niche markets. On the one hand, larger firms are often slow to respond, especially if they hold a large market share. On the other hand, larger corporations are financially better suited to the risks of R&D processes and have standardized information processes (often including environmental management systems), leading to a higher degree of concentrated technological competency and better utilities for transferring knowledge between single firms. Furthermore, larger firms are more visible and therefore more subject to public and media interest regarding environmental issues. In this regard, the position in the value chain has a similar effect. The closer the firm's position to the end consumer, the greater the influence on the firm of the end customer's demands for environmentally friendly products or processes.

Any innovation contains elements of uncertainty from various sources (e. g. sales and buying markets, payback time, technological progress), exerting a restraining effect on its genesis (see, e. g., Dosi 1988:222). In the case of resource saving innovations, future resource prices are an additional source of uncertainty. Moreover, high acquisition costs will certainly inhibit innovation. One property particular to environmental innovations impedes their emergence: while their diffusion is beneficial to other competitors and, above all, to the society in its entirety, this situation discourages firms from investing and innovating because private returns on environmental R&D are significantly less than their social return (see, e. g., Rennings 2000:325).

Governmental funding can act as an encouraging external determinant for the development of innovation (see, e. g., Jaffe, Newell, and Stavins 2003:474). The main forms of funding are tax incentives, direct subsidies and grants. Another external determinant is market structure. The larger the sales market, the larger the uptake potential for innovations. Conversely, monopolistic market structures protect large market-dominating firms and act as a barrier to new, smaller firms wishing to enter the market. However, there are great differences between the industrial sectors.

Finally, cooperation and networking activities not only act as a source of innovation (see p. 4), but can also influence a firm's environmentally innovative behavior through some kind of transmission of environmental values. So, in the course of interaction the members of the network influence each other's state of information and decisions. In this connection the relevance of spatial proximity to other firms or institutions is a hotly debated factor in the intended or unintended spillover of knowledge. A greater degree of proximity to relevant knowledge sources is said to help knowledge to spill over and thereby facilitate innovation (see, e. g., Audretsch 1998). However, other forms of closeness, such as social or organizational proximity, are often regarded as at least as important as spatial proximity (see, e. g., Boschma 2005).

3. The Central German chemical triangle

The chemical industry has a very long history in Central Germany. During the 1840s, the first chemical enterprises producing sodium carbonate (soda) emerged in the region. Since 1893, chlorine and caustic soda have been produced on a large scale (in a very energy intensive process) around Bitterfeld-Wolfen. Agfa built a large dye factory near Wolfen in 1895 (the "Farbenfabrik") and a film factory (the "Filmfabrik") in the same place in 1909 (see, e. g., Löhnert and Gill 2000:124). In 1916, the Leuna works were founded near Halle/Saale as a subsidiary company of BASF for the production of ammonia and methanol. Further major chemical firms were founded as branches of West German enterprises and expanded in the Halle-Leipzig region in the 1920s and 1930s (see, e. g., Hackenholz 2007:155ff.).

These foundations were primarily tied to some favorable location factors. One very important factor in this connection and a core advantage of this region for this purpose was proximity to the brown coal deposits used to generate electrical power at low cost (see, e. g., Stranges 2000:179). Other important site factors were the proximity to water from the Saale and Mulde rivers as well as mineral salt deposits for the production of chlorine (see, e. g., Hackenholz 2007:152f.). The result was that the area of Bitterfeld-Wolfen became the nucleus of the large chemical industry in Central Germany (see, e. g., Sattler 2005:131f.; Brenke, Eickelpasch, et al. 1998:141ff.).

After 1933, the East German chemical industry became strategically important, driven by self-sufficiency efforts in preparation for World War II. Synthetic rubber, "gasoline from coal", nitric acid (for blasting explosives) and synthetic fibers were the most sought after materials. In response to this demand, the Buna works were founded in Schkopau in 1936 for the manufacture of synthetic rubber as a raw material, e. g. for the production of tyres. By the end of World War II, more than 80 percent of synthetic rubber and 50 percent of German chlorine came from this region (Bathelt 2009:368; Hackenholz 2007:166).

After World War II, the chemical enterprises were occupied by Soviet troops. Parts of the industry were disassembled, others were collectivized and restructured in accordance with the planning principles of the Soviet Union (see, e. g., Hackenholz 2007:166ff.; Karlsch 2000:375ff.). The expectation was that the chemical industry would develop as a growth engine for postwar reconstruction and for future economic growth. Production capacities based on domestic coal as a main energy source, and the petro chemical industry based on oil and gas imports from the Soviet Union were expedited. In 1988, between 310,000 and 340,000 people were employed in the East German chemical industry (Bathelt 2009:369). Around 40 to 50 percent of these people were employed in Bitterfeld-Wolfen, Buna and Leuna (Derlien, Faupel, and Nieters 1999:4; Bathelt 1997:126).

In addition to this reliance on brown coal, inefficient technologies and a dramatic under-investment in environmental technologies led inter alia to severe environmental problems (see, e. g., Christ 2005:385ff.). The consequences were massive dust emissions as well as poor water quality. This situation led to severe health problems among the population and to the labeling of Bitterfeld as the dirtiest town in Europe (Derlien, Faupel, and Nieters 1999:3f.). At this time, roughly a third of manufacturing plants were more than 50 years old (Bathelt 2009:369). In addition, because of the enormous economic pressure, these plants were operated at the load limit leading to disproportionate emissions. Furthermore, the pits left by lignite mining were filled with production residues leading to dangerous pollution of soil which posed a potential and resistant hazard (Derlien, Faupel, and Nieters 1999:4).

After German reunification, the East German chemical industry experienced a severe decline (see, e. g., Kind 2005:7f.). The reason for this was a combination of factors including inefficient technologies, the loss of traditional export markets in Eastern Europe as well as the inability to achieve international competitiveness. The striking consequences of this situation were dramatic closures and a decrease in employment by almost 90 percent after 1990. Since then, a radical restructuring has occurred in the East German chemical industry (see, e. g., Bathelt 2009; Bathelt forthcoming).

Today, the Central German chemistry triangle is organized mainly into chemical parks which have an area of more than 5,500 ha located in three federal states. Altogether, there are about 600 companies with circa 27,000 employees (ChemLog 2009:11f.). There are six park sites, located in Bitterfeld-Wolfen, Leuna, Schkopau (near Halle/Saale), Böhlen, Zeitz and Schwarzheide (see, e. g., Germany Trade and Invest 2011; isw 2011; isw 2010): Bitterfeld-Wolfen's chemical industrial profile is characterized by the production of chlorine, phosphor, dyestuffs as well as fine and specialty chemicals. In Leuna there are more than 20 large and medium-sized enterprises including a refinery. The goods produced range from technical gases to caprolactam (a raw material for synthetic fiber manufacture). In addition, there are infrastructure facilities at the Leuna chemical site such as power generation and supply, water supply and disposal, fire brigade, and telecommunications shared by all the enterprises.

The Schkopau site is dominated by the plastics processing industry and includes about 15 firms. In Böhlen, there is a "cracker" which generates ethylene and propylene from naphtha. This facility is the beginning of the value chain for plastics processing. In the chemical and industrial park at Zeitz, a wide range of chemical products are made by about 50 enterprises: from adipic acid, a raw material for polyester fiber production, to specialty waxes for the paper and cosmetics industries. At the BASF site in Schwarzheide, more than 20 plants produce polyurethane base products and systems, engineering plastics, crop-protection agents, water-based coatings and refining chemicals. While the sites of Böhlen are in Saxony and the sites of Schwarzheide are in Brandenburg, the sites of Bitterfeld-Wolfen, Leuna, Schkopau and Zeitz are located in Saxony-Anhalt.

The chemical industry in Saxony-Anhalt takes the largest share of the East German chemical industry's turnover (32 percent in 2010) and a share of just under four percent of the total turnover of the German chemical industry. Also, 30 percent of the chemical workers employed in East Germany, four percent of all employees in the German chemical industry, work here. There are 114 predominantly medium-sized chemical enterprises (each with at least 20 employees). Of these firms, 90 percent have fewer than 250 employees. The dominant sector in Saxony-Anhalt's chemical production is basic chemical products, which account for around 60 percent of the revenue share. Within the manufacturing sector in

Saxony-Anhalt, the turnover of the chemical industry is the second largest, after the food industry (VCI 2011).

In this study we concentrated on the Central German chemical industry - more precisely, on the chemical industry that is located in Saxony-Anhalt. This region was selected for various reasons. Firstly, apart from metal production, the chemical industry is the largest industrial energy consumer in Germany (see, e. g., Sayğın and Patel 2009). In addition, the production of basic chemicals is the industry branch with the largest power consumption in Germany (Rohde 2011). The chemical industry includes, inter alia, some very energy-intensive sub-sectors such as ethylene production, synthesis of chlorine and ammonia synthesis, but also some areas which can help to improve resource efficiency in the downstream stages of the value chain. In recent years the chemical industry has reduced its consumption of resources and has been characterized by a high proportion of environmental innovations (see, e. g., Rave 2010).

Secondly, the chemical industry is traditionally an essential industry sector in East Germany, but has experienced a new resurgence and growth since German reunification in 1990. From 1991 to 2009, expenditure in Saxony-Anhalt's fixed chemical capital was realized to the amount of 7.9 billion euros. This corresponds to 45 percent of the investment in all six East German federal states together (VCI 2011). One consequence of this is that a similar state of technology can be assumed to exist in all these enterprises.

Thirdly, besides its common location in East Germany, a core characteristic of the Central German chemical industry is its high geographical concentration and proximity to scientific institutions in this region. Most of the chemical industry in Central Germany is located in Saxony-Anhalt (see figure 1). The consequence of this spatial and sectoral concentration could be an increased transmission of knowledge or spillovers between the firms or an increased incidence of cooperation. This may be true for innovations in general but also for climate innovations in particular. Finally, because of the energy intensity of the chemical industry, one could expect similar problems among the enterprises. This commonality could be an additional incentive or opportunity to work together in this particular area.

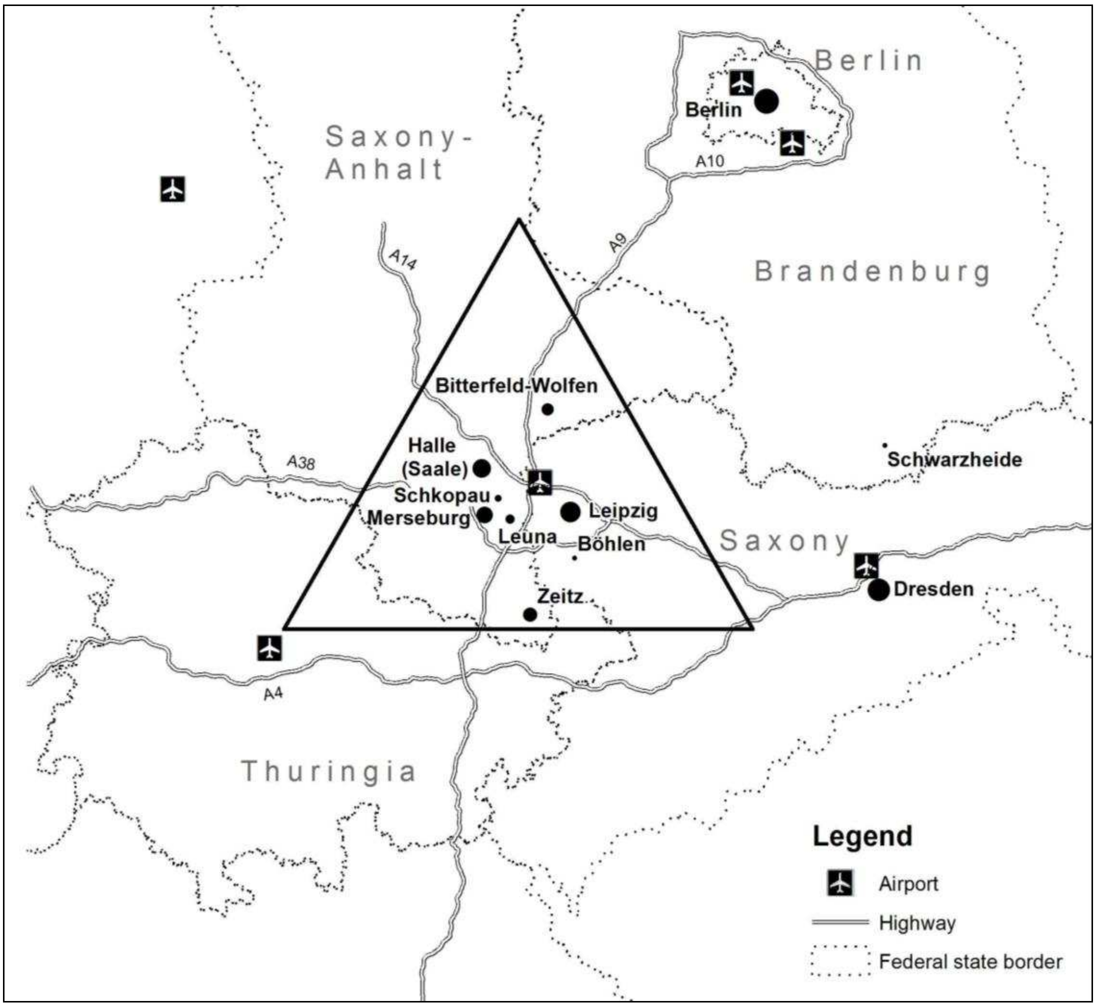

Figure 1: The Central German chemistry triangle. Source: Own illustration.

4. Data and methods

The corporate innovation processes analyzed here are complex, relatively novel and still evolving. Furthermore, we want to explore structures and patterns in these processes. As the case study method is particularly suited to in-depth analysis of complex contemporary phenomena (Yin 2009:18), we use this approach and focus on qualitative data in this study (Yin 2009; Eisenhardt and Graebner 2007; Eisenhardt 1989).

The case study denotes a research strategy which aims at "understanding the dynamics present within single settings" (Eisenhardt 1989:534). This sort of inquiry can involve either single or multiple cases. Compared to econometric analysis or broad quantitative surveys, this approach is especially appropriate when questions of causality and details of the organizational process are the subject of investigation. The disadvantage is that the results are relatively specific; statistical generalizations cannot be made based on case studies. Nevertheless, by appropriate selection of the cases using a multiple case study design, analytical findings can to a certain extent be generalized. The predictive ability can be stabilized by cases delivering similar results in terms of the relevant connections as well as by contrasting cases if they lead to different results for predictable reasons. In doing so, multiple-case designs are aimed to build general explanations that fit each of the individual cases, even though the cases vary in detail.

As innovations are both strategic contemporary processes and characterized by their complexity, the multiple case study approach appears suitable for investigations in this research field (see, e. g., Jaffe and Palmer 1997:614; Porter 1991:99; Dosi 1990). Furthermore, contrary to an econometric approach, the specifics of the innovation context are captured (Kemp and Pontoglio 2011:28). In particular, case studies are used by representatives of evolutionary economics to gain empirical support as the predictive power of available statistical data is often too limited to answer evolutionary questions such as the genesis and development processes of innovations (Nill 2009:25; Bünstorf 2002; Pavitt 1984).

From the theoretical framework outlined in section 2, we developed a common interview guide for the semi-structured interviews. We operationalized the single elements of this framework in order to generate open questions (see, e. g., Kvale 2008:60ff.; Gläser and Laudel 2006:138ff.). In addition, a supportive brainstorming session was conducted with five fellow economics researchers with different thematic backgrounds to enrich this first version of the interview guide. Subsequently, working in a small group, we checked and discussed whether the wording of the questions appeared suitable for capturing the elements of the theory, in order to ensure construct validity (Yin 2009:41ff.; Gibbs 2007:93ff.; Mayring 2010:117). Finally, the interview guide was arranged in four sections, containing thirty-two possible questions in total (see Appendix, p. 36).

The operationalization (see table 1) as well as the questions about the innovative results of the process were taken rather straightforwardly from the theory. The central question we asked was which climate relevant innovations had been introduced. In order to cover further query options, we addressed the four innovation types (product, process, organizational and marketing) separately. Furthermore, we questioned expectations and achievement of the innovations introduced as well as the potential of future innovations. As described above, in connection with the perceptions of climate change, buying and sales markets, the EU ETS and the pressure from civil society are seen as the main drivers of climate innovations. For this reason, we posed questions on the requests from ecology groups, on the perceived importance of the EU ETS to the enterprise and on the impact of pure cost pressure. In addition, we asked how these incentives had changed over time and which important drivers had not been addressed.

Operationalization	
Innovation type	New products; Change of production processes; Organizational innovations; Marketing innovations; Expectations; Potential for the future
Drivers	Customer requests; Claims of civil society; Importance of these claims; Cost pressure; Meaning of emissions trading; Previously undisclosed factors; Change in these incentives over time
Sources	R&D; Patenting/pass-on; Obtaining from outside; Cooperation
Corporate determinants	Management attitude; Marketing adjustment; Considerations in the decision making process; Facilitating factors; Funding; Inhibiting factors; Fit to current technology and products; Demands on suppliers; Evaluation of new ideas from outside; Utilization

Table 1: Operationalization. Source: Own illustration.

Regarding the sources, we posed questions on where the inventions which had been introduced had originated. In this category we differentiated between own R&D, the role of cooperation and what had been obtained from outside the corporation (for capturing adoption). Finally, we asked questions about the factors that had been particularly important during the introduction of these innovations. To this end, we interrogated the position of top level management towards climate issues or energy efficiency, the attitude of corporate marketing in this regard and the reflections during the decision-making process before introduction of the innovation. We then asked in a general sense what it was that had made the innovation easier to introduce (including funding) and what had hampered this process. In order capture the current knowledge base as well as the absorptive capacity (see p. 5), we elicited information on the fit between former technology and products and the innovations as well as how new ideas were evaluated and utilized in the enterprise.

The firms for this study were selected using a theoretical sampling approach (see, e. g., Eisenhardt and Graebner 2007:27). Working from a company profile database,[1] all

[1] Bureau van Dijk: markus database. markus.bvdep.com/.

manufactures of chemical products in Saxony-Anhalt were selected, according to Code C20 of the German classification of economic activities (Klassifikation der Wirtschaftszweige, Ausgabe 2008 - WZ2008). We obtained the address, a contact name and a contact phone number for every firm from the database. At the beginning of September 2011 a covering letter was sent to the selected firms. This letter contained a short presentation of the research purpose and a request for an interview (see Appendix, p. 35). These initial interview requests were reinforced by an extensive telephone campaign. Finally, 22 interview dates were scheduled in the time frame from mid-September to the end of November 2011.

Of the 22 firms at which interviews were conducted, five were small firms (fewer than 50 employees), 11 were medium sized enterprises (50 to 250 employees) and six were large companies (more than 250 employees). Three firms had taken part in the EU ETS since 2005 and three will join the system in 2013. The remaining 16 companies are not expected to take part in the foreseeable future. The selected cases thus offer a good range in terms of firm size and participation in the EU ETS, bringing diversity and variety to the data.

The empirical material of the study was then collected from semi-structured guideline interviews with experts (see Meuser and Nagel 2009; Gläser and Laudel 2006). In general, experts are persons who possess special knowledge within an interesting field of action and although they may not necessarily be the only ones to have this knowledge, it is not accessible to everyone (Meuser and Nagel 2009:18). In the case of this study, experts are assumed to have extensive knowledge of their enterprise and its processes, including innovations, investments and the reasoning and reflection that have led to these. At least one representative from each firm was interviewed. As a rule, this was the general manager, the site manager or the head of the technology or energy management. Only in two cases did members of the environmental protection department take part in an interview. In four cases, more than one person from a firm participated in the interview.

All interviews were conducted in German in face-to-face meetings. In most cases we were allowed to record the interview, and the interview was then conducted by a single researcher. The content of the interview was digitally recorded while notes were taken simultaneously by the interviewer. This was done with the signed consent of the interviewee. However, five participants refused permission to be recorded. In these cases, a minute keeper accompanied the interviewer. After each of these interviews, a common interview protocol was generated for subsequent evaluation. In addition, at the end of each interview appointment we gathered and verified some general firm properties such as size and participation in the EU ETS by means of a short questionnaire (see Appendix, p. 38).

Each interview took between half an hour and two and a half hours. The average effective length of the recorded interviews was 61 minutes. The recorded interviews were transcribed[2] in their entirety and verbatim (see Appendix, p. 39). In doing so, simple transcription rules were followed (see, e. g., Kvale 2008:96; Kuckartz 2010:44f.). The resulting, very readable, transcripts of the interviews made up more than 330 pages.

The interview data were subsequently analyzed using qualitative content analysis (see Krippendorff 2004; Gibbs 2007; Mayring 2010; Mayring 2000) to sift out the commonalities, patterns and types but also the interpretations, differences and singularities. Qualitative content analysis is a procedure which extracts information from the text, converts this information into a suitable format, and processes it separately from the original text (Gläser and Laudel 2006:191ff.).

In the first step, we derived an initial category system from the interview guide. This system was used as a search grid for the transcripts, assigning the relevant interview sections to appropriate categories (see, e. g., Saldaña 2009:3; 70ff.). Gibbs (2007:38ff.; 144) calls this procedure "thematic coding".[3] In the course of this coding, the causalities mentioned by the interviewees were captured as well as some expressive quotes. During this process, the category system was treated as dynamic and open. When some important information that did not fit into the category system appeared in a text, the system was modified. This included the re-definition of existing categories as well as the creation of new categories, but with no deletions. The result was a hierarchical category system (see, e. g., Saldaña 2009:8ff.). During the development of the category system, a codebook was kept to retain coding consistency and to allow for traceability of the coding (see, e. g., Gibbs 2007:41; Mayring 2010:106f.). This codebook contains the label of each category, its definition, an example and the applied coding rules (see Appendix, p. 41).

In the next step, we sorted the material according to content, checked for redundancies and inconsistencies, and collected scattered information for each case. In addition, we compressed the material by paraphrasing. In this way we derived a structured information base by

[2] We want to thank Kristin Geyer and Lars Werner for their assistance with the transcription. This task was performed using the free software F4 v.3.1 (http://www.audiotranskription.de/ english/f4.htm).
[3] The labeling was carried out using the commercial MAXQDA 10 (http://www.maxqda.com/). The free Weft QDA (www.pressure.to/qda/) was discovered too late for this study.

extracting the relevant information, but significantly reducing the size of the material. Hereafter we worked with the extracted material but always kept the references to the raw data in the form of time codes or paragraph numbers so that it was possible at any time to control whether content decisions were in line with the original text. Contrary to other approaches (see, e. g., Meuser and Nagel 2009; Gläser and Laudel 2006), we first developed the category system and then paraphrased the material, because we did not want to lose any information before the category system was complete and sound.

The cases were then "reconstructed" (Flick 2007:49; Gläser and Laudel 2006:214); in other words, they were analyzed in terms of the reported causal relationships. First, we analyzed the manifestations and types of innovation introduced by the firms as well as the related drivers. Then we investigated the interviewees' statements on the determinants in the innovative processes as well as the source of the inventions. After the single cases had been completed, a cross-case analysis was conducted to work out common occurrences of characteristics and relationships between the single cases (see, e. g., Yin 2009:136ff.; Krippendorff 2004:50ff.; Kelle and Kluge 2010:83ff.) and to identify differences and singularities. For this task, the code relations matrix (see Appendix, p. 45), which shows the overlapping of the codes in the categorized interview sections, proved quite useful.

Finally, in order to improve reliability we conducted a re-test on the material (see, e. g., Gibbs 2007:99f.; Mayring 2010:117). The interview transcripts were assessed a second time by different analysts. Subsequently, the results were discussed, and the differences addressed. There was general consensus between the investigators on most of the analysis. Furthermore, to triangulate the interview material in order to increase validity, we compared the statements from the interviews to company reports and press releases about and from the interviewed firms (see, e. g., Flick 2007:40ff.; Gibbs 2007:94ff.). For this purpose, an internet inquiry was conducted.

In the following section we outline the main results of the interviews. For the purpose of this analysis the names of persons and corporations were substituted or avoided to preserve the anonymity of the persons interviewed. In the same way, details about production techniques which would allow conclusions to be made about a particular enterprise were avoided as far as possible.

5. Findings

Although the chemical firms in this study are very heterogeneous in size, structure, products and processes, some characteristic patterns in the various types of innovation can be identified. Below, we present the results of our investigations of the types of climate innovation: process innovations (section 5.1, table 2), product innovations (section 5.2, table 3), organizational innovations (section 5.3, table 4) and marketing innovations (section 5.4, table 5). We explain the observed influence of the relevant drivers, external and internal determinants and address sources and outputs. The observations are illustrated by vivid quotes from the transcribed interviews. These quotes were translated into English from the German transcripts and are printed in italics.

5.1. Process innovations

In the interviews it became clear that issues related to climate change are practically never seen in isolation, but always within the overarching theme of "sustainability". This topic includes the use of resources such as energy, renewables, water and raw materials in general, but also questions of toxicology and industrial safety. From the organizational perspective, the topic "climate change" is often dealt with by the department of technology or energy, but also by the departments responsible for industrial security, environment and quality.

While not the most frequently mentioned, the driver termed as most important for process innovations in general is compliance with the operating permit of the facility. Compliance with certain *"hard"* environmental legal limits for the firms' emissions of certain substances into the environment has top priority at these enterprises. The regulations are regularly monitored and enforced by audits. Offending against the operating permit results in the firm falling *"out of the game quite rapidly"*.

At almost every firm in this study, process innovations which related to the improvement of energy efficiency over the last years were reported. Most frequently, the driver indicated as central to this form of innovation is energy costs (*"to be honest"*). The enterprises experienced continuously rising energy prices in the past and expect further price increases *"clearly above the overall average inflation rate"* over the next few years. In addition, the enterprises expect the topic of sustainability to become increasingly important in the future. The main reason for energy costs being the main driver in this case lies in the energy-intensive nature of the chemical industry and rests on the importance of energy for the raw materials and the developmental stage of the enterprise.

For small, research intense firms, enterprises that are *"on the way into the market"* or firms with a very varied choice of products, energy issues seem to be less important than for large corporations with well defined and established products. For single production facilities in multi-corporate groups the pressure from group headquarters to work more and more efficiently plays an important role in this connection. But the sheer availability of new components and the overall perceived social pressure because *"awareness has changed"*, as well as the perceived political stance towards sustainability has exerted some pressure on the corporate decision makers to invest in new and more energy efficient equipment. Sometimes the sole technical self-conception was termed a driver for more environmentally friendly behavior: "primarily we produce [our main product] at a high technical level and so environmental issues are simply a must, there is no choice".

The most frequently observed form of technical energy related process innovations is the introduction of new, more energy efficient technical or energy saving components like heat exchangers, electric motors and pumps. In particular, use of frequency converters has increased over the last years. These devices allow enterprises to control the speed of engines and thus to regulate energy consumption. Such devices are preferably used for replacement or are installed when constructing new facilities. However, retrofitting these parts is often technically difficult or unprofitable. But even seemingly minor moves like introducing more frequent cleaning cycles for the heat exchangers to achieve a better heat flow also have an effect on energy efficiency. On the other hand, enterprises increasingly try to *"sensitize"* or *"educate"* their staff towards more a responsible use of energy and the avoidance of unnecessary consumption: *"If I do not need the* equipment *..., it must be turned off"*.

Most ideas for general process improvements come from within the firms, either directly from the staff or from other branches of their group. Intra-group cooperation is therefore considered an important source of innovation for enterprises which are group subsidiaries and are mostly regarded as more important than local cooperation. Part of the reason for this is that these enterprises are mostly purely production sites.

Strategy development and R&D is undertaken at the company headquarters which are not located in East Germany. This does not mean that some ideas for improvements are not developed and passed on to the headquarters by the local sites. Sometimes, enterprises have departments for process engineering, or classic R&D departments, which also take care of production processes. In order to implement process improvements, enterprises mostly need new components. But even if the processes themselves are left unchanged, component changes and renewals have a great impact on energy consumption.

Thus equipment matters have been extremely important for energy efficiency innovations in the past years. For this reason, the main source of innovation was external to the firms in the form of component supplies. This was often connected to strong cooperation between the enterprises and their equipment suppliers. In the field of technology the enterprises maintain in part very close collaborations with these suppliers in plant construction or modification. Solutions for a certain application or improvements are sometimes developed by the enterprise and then built by an external supplier to its specifications.

Technical progress among equipment suppliers and falling prices has been labeled as supportive for the increasing use of energy efficient equipment. Frequency-controlled drives are now considered *"almost standard"* for new devices. Also termed supportive for the diffusion of new energy efficient motors is legal regulation in the form of, e. g., the EU ecodesign requirements for electric motors simply because "there is nothing else to buy. You do this quite automatically". This may hold as an example of the "weak" version of the Porter hypothesis (see Porter and van der Linde 1995a; 1995b): "stricter regulation leads to more innovation" (see, e. g., Kemp and Pontoglio 2011:33), because the regulation fosters the installation of new devices in the facility. Whether the related "strong" version of the Porter hypothesis ("stricter regulation enhances business performance") holds here is difficult to determine because of the costs of energy which themselves exert an incentive to pay attention to energy efficiency and the relatively higher price of these motors.

The move towards energy efficiency is not limited to electrical energy. Steam, gas, hot water and compressed air also play a crucial role in chemical facilities; compressed air is known as the most expensive form of energy in the chemical industry. Energy efficiency in this regard includes the whole processing chain e. g. from the generation of steam to the reduction of steam consumption; from questions of co-generation of heat and power, to losses of heat and steam itself during its transport in pipes, to the extent of consumption itself: *"here we have thousands of tiny adjusting screws"*. But packaging is also an area where progress has been made in the saving of raw materials and energy. Increased action has been taken to encourage the use of reusable packaging or to reduce the amount of packaging material, e. g. reducing the thickness of packing foils without loss of tear resistance. This is supported by advances in the material properties of these foils.

As far as transport processes are concerned, it is often said that a system of pipe bridges installed at a chemical park saves on transport by road or by rail. A pipe bridge system which moves raw materials in pipes between firms is a characteristic feature of some chemical park designs. Though this is not a current innovation, it is mentioned here because it assists daily in CO_2 emission reduction by design. On the other hand, raw materials as well as finished products are often transported by truck or train. Transport by train is believed to be the more energy efficient and is furthermore said to have the added advantage of being the safest way to transport dangerous goods.

Some enterprises have tried to shift transport from road to rail, but have experienced some difficulties with German Railways, because of slow delivery times and the inflexibility of the railway service provider. At times, the development even went backwards, because a part of the railway track used by the enterprise was shut down. Transport by truck has experienced some logistical improvements to save fuel and time and therefore costs. This includes achieving a larger time frame for delivery and consequent route optimization as well as better use of space in the vehicles, leading to a reduction in transport demands. Another strategy to reduce (mostly dangerous) transport is to integrate the production of some important intermediate products into the production portfolio of the enterprise, leading to insourcing.

Governmental support is seen as beneficial for the introduction of new technology, especially in the form of tax benefits for investments, according to the German Investment Premium Law (Investitionszulagengesetz; InvZulG). The intention of this law is to promote investment in the five East German states in the form of the acquisition of new equipment or new, moveable assets in general. In this connection it is regrettable that this kind of subsidy will end in 2014 and has decreased since 2010 by 5%, effectively by 2.5% a year. Other forms of grant are called upon only occasionally, because *"a good project has to work even* without *subsidies"*. A hindrance here is the related administrative burdens and the time restrictions involved: *"You can* only spend the time once. Either I write a great application ... or I use the time to work with my customers and earn my own money as a result."

Other, internal factors promoting innovation include the qualification, expertise, training, responsibility and motivation of the workforce together with flat hierarchies, short decision methods, active participation of the employees, and technical competence of upper management. This holds for process innovations in general, but is especially true for energy efficiency related innovations. A well trained and motivated staff itself also acts as a constant source of ideas for future process improvements: *"most things come from our own people"*. In this connection, the future supply of good, qualified young people is sometimes seen as a problem.

In the interviews, Saxony-Anhalt was labeled as a *"very convenient location"*, which is interpreted as a factor conductive to innovation. Firstly, the region is associated with a population which in general accepts the existence of the chemical industry in this area. The region is seen as a *"traditional chemical environment"*. In Saxony-Anhalt *"there has always* been a chemical industry here*"* and *"you can't wipe* out 120 years of history". This does not mean that the chemical industry had a positive image in the GDR, in particular when it came to environmental issues: "That was really bad". At that time, Bitterfeld was labeled as "Europe's dirtiest town". But this has changed since the German reunification. In this context, the German turnaround was termed *"also partly an env*ironmental movement, especially *around here"*. Since then the chemical industry has also made considerable efforts to improve its image and to *"get ahead"* regarding sustainability issues in particular.

Another reason for its acceptance is the interdependency between the industry, the region and its population. The industry pays business taxes to the communes and the population finds work in the industry: *"Most people around here* depend directly or indirectly on the chemical industry". Secondly, there is relatively little difficulty with the approval by authorities of the federal state, even regarding duration of approval procedures. The enterprises foster good cooperation with the local authorities, too. This is sometimes seen as "soft support", but is in practice more valuable than some monetary grant.

As a factor which encourages innovative process or as a source of innovation, local cooperation is not regarded as particularly important. Some enterprises engage in very little or even no local cooperation at all, or the interaction is only *"one part of many"*. Often, local involvement is limited to the utilization of infrastructure and technical services or the exchange of material in the chemical parks. The enterprises also cooperate with the local universities of applied sciences and research institutes. This is often carried out on a project-related base. In contrast, cooperation with suppliers of components and raw materials is seen as more important. Exchange of ideas related to energy improvements and sustainability indeed takes place on a local basis. But since the product groups differ greatly between the enterprises, the potential effects of exchange remain quite limited. In regard to exchange of experience, certain associations like the Association of the Chemical Industry (VCI) and the North-Eastern Chemical Associations (Nordostchemie) play an important role.

In the conception of the EU ETS its second aim, beyond the reduction of greenhouse gases, is to spur on innovation (see, e. g., Hoffmann 2007:465). As far as the effect of the EU ETS on process innovation is concerned, our results in a way support the conclusions drawn by Hoffmann (2007) on corporate investment decisions in the electricity industry: the EU ETS seems to provide incentive for "small-scale investments with short amortization times". Indeed, in the case of the chemical industry this happens as a result of increased energy prices as only a few enterprises interviewed are subject to the EU ETS: *"Emissions trading* is brand new to us. But less directly, and rather through the suppliers, i.e. the suppliers of energy, i.e. electricit*y and high pressure steam..."*.

In this connection, it was repeatedly pointed out that the rising electricity prices of the last few years are at least in part caused by the passing on to the consumer of the allowance prices by German energy providers: *"the*y [the electricity providers] had already added this by the time they received the allowances at no cost. So, we actual*ly pay for this already"* (for this issue cf. also Zachmann and Hirschhausen 2008). But the volatility of the prices and the uncertainty of future energy price development is also an incentive: *"I do not know what my* energy costs will be tomorrow. And so I would rather make sure that I take *measures today."* The result is an increased use of more energy-efficient technology and the topic of energy efficiency becomes even more of a focus of management as an increasingly important cost driver.

For enterprises which have to take part in the ETS, this system has an additional, direct effect which is in first line perceived as administrative effort, and uncertainty about regulatory details, new technical efforts in monitoring as well as cost and risk aspects of the allowances. Small businesses in particular see a considerable burden in the ETS because of the administrative effort, but sometimes also because of the requested technical consequences: *"The improvements need to be paid* for, and the money for these improvements has to be *earned."* On this occasion, it became clear that the ratio of administrative effort on the part of the businesses to the profit "for the climate" is often seen as critical: *"[Our view is that] the* expenditure we have to incur here has absolutely no relation to the effects that we have on the *world climate"*.

Furthermore, the political asymmetry between the EU and some emerging economic regions such as China but also the USA was a main source of criticism of the system in particular, but also of the sustainability approach taken in the EU in general. Those emerging countries have neither a regulation such as the EU ETS nor the energy prices of Germany, but are in (fairly strong) competition with the companies here. As a consequence, strong competitive disadvantages are anticipated by the resident companies:

"I myself have some doubts ─ I must say in all honesty: as long as we do not succeed in establishing a binding concept of sustainability, especially in emerging economic regions ─ China, India, some Latin American countries ─ I am speaking again with regard to chemistry ─ we suffer enormous competitive disadvantages with an excessive sustainability policy. The most perfect sustainability is not of any use if we cease to exist, because then we can no longer sel*l our products."*

Here the problem is seen to lie less in the direct effects of the higher energy prices than in the relative asymmetry between the energy prices in Germany and those in other countries: *"Basically I have nothing against high electricity prices* ─ if they apply to everyone and do *not cause distortion"*. In this context, the EU ETS or the high energy prices were not so much perceived as a hindrance to a specific kind of innovation, but more as an obstacle to the competitive fitness of European or German enterprises in general: *"... [E]special*ly in the field of chemistry. Energy prices ─ the rise! We are no longer competitive in Germany. One *hundred percent."* This factor especially is viewed with suspicion when it comes to competition for establishing new enterprises in the region. Occasionally, the system was also labeled as a driver for a particular type of organizational innovation in this connection: for the relocation of parts of the value chain ("carbon leakage"). This can happen both within multi-corporate enterprises as well as through mechanisms of international competition and selection for single enterprises. However, apart from competitive issues, environmental claims in principal are seen as positive.

The perceptions of the European Union regulation for the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)[4] follow a similar trend. This regulation requires companies manufacturing or importing more than a certain quantity of chemical

[4] See Regulation (EC) No 1907/2006 of The European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

substances into the European Union to register these substances with the European Chemicals Agency (ECHA). According to the persons interviewed, REACH causes *"significant administrative burden and costs"*, because the substances have to be laboratory analyzed and the registration is costly and complex. To add to this, there is no equivalent of this regulation outside the EU, and the resulting asymmetry is perceived as a competitive disadvantage for EU businesses, weakening the resource base for innovation. Again, this is regarded not so much as an argument against the REACH regulation itself, but more as a demand for similar rules for other countries outside the EU. However, it was not uncommon that some new products were canceled because of the costs that would have been necessary to register them.

Process innovations

Characteristics	Sensitizing the staff; Energy efficient/saving equipment; Minimizing loss of other forms of energy; Packaging; Transport
Main Drivers	Compliance with operating permit; Energy costs; Perceived social pressure (weak); technical self-conception (weak)
Sources	R&D; Equipment suppliers; Cooperation with suppliers; Intra-group cooperation
External determinants	Price of equipment; Availability of components; Regulation; Properties of German railways; Governmental funding; Acceptance of chemical industry in the region; Local cooperation (weak); Administrative effort and political asymmetry (EU ETS, REACH)
Internal determinants	Firm size; Very young enterprise; Product flexibility; Multi-corporate enterprise; Properties and competence of workforce
Expectations	Cost saving; Improve image
Economic results	Goals usually met

Table 2: Process innovations. Source: Own illustration.

5.2. Product innovations

The most important drivers of product innovation in this study were certain customer demands, customer orders, and the need to gain a competitive advantage. This was regularly referred to as *"the market"*: *"Even here, competition is the main drive*r. ... Higher performance, lower energy consumption, perhaps, too, and then being better than the competitors, these are the driver*s."* Requests in terms of climate issues were seldom made directly to the enterprise and, if they were, then these demands were considered as part of the *"product performance"* : *"... [T]here*, more and more themes arise such as sustainability, *improvement of the material situation and reduction of emissions."* Another aspect is energy efficiency issues related to the product, but only if the product has an impact on the customer's energy consumption: *"The custom*er, of course, thinks the same way: save energy and pass these requirements on to us. We have then translated this into product *characteristics."*

In most cases, however, direct climate aspects were near non-existent: *"I can*not say that I have now experienced anything on the sales side that has something to do with climate *change"*. Mostly, other quite ordinary product properties were considered far more important instead. For instance, the price of the product was labeled the most important property after the basic product characteristics and quality: *"The client primarily wants the best price..."* but *"in the same* vein, the product*'s qualities have to be right"*. In this connection, toxicity and products being free of solvents were also labeled as core issues. However, sometimes the interviewees found it hard to separate and evaluate the actual incentives: *"It is difficult to* judge whether customers buy our product because of low power consumption ─ only one of several reasons".

In principal, sustainable production is rated positively by customers: *"In general, the* requirements are such that companies always want to have more of it*"*. At the same time, there appears to be no additional willingness to pay for this product feature: *"just because it's* a renewable resource, no one wil*l pay anything"*. This is considered an obstacle to products which are produced in a CO_2 saving way, and also to sustainable products in general. The situation becomes even more complex when familiar features of similar, well established products are changed in this connection with the result that the sustainable products are then considered inferior to the conventional ones: *"Then the customer has to adjust and get* involved. At the moment their acceptance is very, very reluctant*."* Regarding sustainable issues, the statement of one interviewee sums up the current situation: "So I guess that the road leads this way, but more slowly than I would say the press and research projects suggest *in principle"*.

Thus proactive action towards products with CO_2 saving or sustainable properties as a core feature is observed only sporadically. However, some enterprises see in the chemical industry a realistic future market for sustainable products: *"Yes, we expect a real market advantage with our products"*. These enterprises also understand that the market is not ready yet: *"In* two, three, four years, this issue is going to *be acute"* but want to press ahead offensively despite this: *"Su*stainability, yes, this is still relatively far away. But we do not want to wait until the time *is here ... but take a leading role."*

One reason for the perceived irrelevance of their products in regard to climate issues could be the position of the enterprise in the value chain. Most of the enterprises are producers of raw materials and basic chemicals and are therefore *"quite far away from the market"*. Their products have a very wide range for further processing. Further climate relevant innovations are not uncommonly reported from downstream stages in the value chain: *"Our pr*ocessors make things out of our products which are then used to save energy."

The situation is slightly different for enterprises which are in a supply relationship with the renewable energy industry or with industry branches which manufacture products which have experienced increased demand as a result of the German Energy Savings Act (Energieeinsparungsgesetz - EnEG), e. g. the whole value chain of building insulation material. For these enterprises, the demand for their products has either risen in the last years or they have been asked for new products or to modify and optimize some of their previous products to meet new claims: *"... [S]o it is quite a growth spurt for us now just because of the* energy efficiency guidelines for new buildings, as well as renovations of old buildings, has brought new growth to *our products"*. Of course, the introduction of new products leads in turn to modification or renewal of production processes. Again, the development of this branch of industry is thus influenced by legal regulations ─ another clue to the "soft" version of the Porter hypothesis.

Product innovations often come from internal R&D, where the development is often directed towards application-oriented development and close to non-fundamental research. This holds true especially for medium-sized companies: *"Medium*-sized companies have to do research in order to stay ahead, particularly with such niche products, though this is a huge cost factor *for them"*. Sometimes, too, application-oriented journals or suggestions from salespeople provide the impulse for ideas for new products. Not uncommonly, precursors to new products are developed when projects cooperate with regional research institutes.

In contrast, some enterprises do no product development at all, because they are pure production facilities ─ especially when they are part of a larger group of corporations.

Consequently, patent activity is also very heterogeneous between the enterprises. Some have patented every product that leaves their firm: *"So today no* more products that are not protected by own patents leave the building*"*. Others produce only innovations which cannot be patented (mainly application-oriented research) and therefore try to protect their knowledge by keeping their processes confidential.

Product innovations

Characteristics	Product characteristics
Main Drivers	Customer demand or ideas; Gaining competitive advantage
Sources	Mainly internal: R&D; Application oriented development
External determinants	No additional willingness to pay vs. increasing demand for sustainable products
Internal determinants	Flexibility of product portfolio; Attitude of management; Expectation of market development; Position in value chain; Supply relationship to renewable energy industry or energy saving material manufacturers; Suggestions from salespeople; Project cooperation; Multi-corporate enterprises
Expectations	Sell new products
Economic results	Goals mostly reached

Table 3: Product innovations. Source: Own illustration.

5.3. Organizational innovations

The most frequently observed climate innovation at enterprise level was the introduction of environmental management systems or energy management systems. Most of the enterprises in this study had such systems in place or were currently working on the introduction of such systems. Often these management systems are certified according to the ISO 14001 and EMAS for environmental management systems and the ISO 16001 (specifically the DIN EN ISO 50001 starting from April 2012) for energy management systems. As another climate-related innovation, some of these systems have been extended recently to capture the carbon footprint of the enterprise.

Multi-corporate enterprises often have larger internal reporting and controlling systems into which these subsystems have been integrated. In such cases the systems have mostly been introduced to the enterprise by the headquarters of the group, because in larger companies such systems often belong to the controlling standard. The single enterprise then provides data to its headquarters. Groups also often conduct internal audits at their branches and compare the individual business units. Such audits then serve to build up internal pressure: *"... [T]hen* you see the charts and the one for whom the bar reflects the highest value, will be trying not *to be there again in the next year or in the few years ahead"*. It is usually easier to introduce changes in the structures of larger corporate groups because the necessary expertise for the operation already exists and synergy effects between the various business units can be exploited. Furthermore, the public's interest in large corporations plays a more important role with respect to their image than in smaller enterprises.

There are various incentives at the corporate level for the introduction of such systems. Firstly, these systems raise awareness of the disproportionate use of resources, especially energy, and therefore encourage the discovery of potential resource savings. This is especially helpful for energy-intensive industries. The data collected are then used as a starting point for considerations in modifying production processes and raising the energy efficiency of these processes, preferably in a short payback time.

These certifications are in part specifically requested by certain customers in order to prove the origin of their intermediate products. In particular, large customers who themselves have such systems and capture the values of their suppliers in these systems request such certification. In some cases these customers have committed themselves to purchasing goods or services only from certified suppliers. In the last years the demand for certification is said to have increased: *"If you want to be* a top supplier, you need this". In some cases it has been reported that customers have also requested the carbon footprint of the goods from their suppliers.

Conversely, such a certificate is seen as a signal to the customer: *"This is a*n act of faith. *That'*s psychology! The factory is al*l right."* In general, however, certification is quite rarely actively used for marketing or image purposes. It seems to be more of a prerequisite in certain business relationships. The same applies even more to the carbon footprint as some enterprises calculate this value, but do not make a great deal of fuss about it: *"We have the* data here. If we are asked for it, then we will provide it. And then we also have a comparison. But we will not offer this pro*actively."* Sometimes, certification or calculation of the carbon footprint even belongs to the self-image of an enterprise ─ to be *"authentique"*: *"I can*not make a product which claims to be good for the environment and at the same time act as an energy waster. That does not fit, you know." The demand for certification is then often passed on to the enterprise's own suppliers, but this is also not seen as something new, but as a simple progression from quality management.

An important motivation for the introduction of an energy management system and an associated certification by ISO 16001 is the tax incentives which are involved (*"to get the appropriate refunds"*). For example, the German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz - EEG) requires certification of the "ascertained and assessed energy consumption and the potential for energy savings" if it is to limit the EEG surcharge (§41 (1) 2 EEG 2012). In addition, as it appears, from 2013 on the tax cap in the German ecotax (see §55 Energiesteuergesetz - EnergieStG and §10 Stromsteuergesetz - StromStG) will require a certification "in accordance with international standards (EN 16001, ISO 50001)" (see BMWi and BMU 2010:12).

This is compared to the cost of implementation and certification combined with a considerable administrative burden. In a few cases, the administrative burden was so severe for these small companies that the system was cancelled again a few years after its introduction. Some interviewees were rather glad that certification had not proved very important to their customers up to that point because of these administrative burdens but also because of the measurement technology that would be required, but which was as yet not installed: *"Environmental* certification does not play a big role and I would be happy if it *would stay that way, because that's always quite an e*ffort for us to effect such certification".

Other organizational innovations relating to climate issues which were reported were an increased exchange of experience about energy issues within associations or local companies (see above, p. 22) and the introduction at firms of internal groups for collecting ideas on energy efficiency as part of the employee suggestion system or as own projects: *"... [A]nd not* only in the places where there is really a great deal of energy consumption, but also down to the smallest office".

Organizational innovations

Characteristics	Introduction or extension of EMS and certification (ISO 14001/EMAS; ISO 16001/50001); Calculation of carbon footprint; Information exchange with other enterprises; Introduction of firms' internal groups for gathering energy efficiency ideas
Main Drivers	Energy/Resource costs; Customer demand; Tax incentives
Sources	Mainly external suppliers
External determinants	Regulation; Cost of implementation and certification
Internal determinants	Multi-corporate enterprise; Firm size; Competence of staff; Attitude of management
Expectations	Raise awareness of resource consumption and discover potential for improvements; Improve image
Economic results	Results mainly positive

Table 4: Organizational innovations. Source: Own illustration.

5.4. Marketing innovations

Marketing innovations with regard to climate issues were not often observed within this study. More often, the subject of climate change was considered as irrelevant for marketing purposes – especially in international businesses: "No chance. If you go to a customer in America and say, look, we do everything well and have saved 5,000 tons of CO_2, then he will say, well, you did fine, but if the underlying price is not right, then you can go home again". At best, such efforts are focused on sustainability or environmental issues in general, but not on climate change alone: "Maybe we do not do green advertising ... [but seek] acceptance. Acceptance in the population. Acceptance of the policy. Acceptance for the group. A question of image." Some efforts are also undertaken to present the enterprise as "progressive" and "clean", as well as supporting perceptions of the quality of the products. Often, environmental issues do not matter at all in marketing: "I do not think that the issue of environmental marketing is relevant to us, at least not yet. So, it is not advertised with environmental objectives or environmentally friendly production in mind, but our product is selling because of quality and price, and in part because of availability."

This may be the case because some of the enterprises are only production facilities and do not conduct their own marketing: *"Basically*: marketing is not done here. That is done by the *[group headquarters]."* In addition, this is closely associated with the position in the value chain; many companies in the study are at the beginning of the value chain (see above, p. 26). Furthermore, currently there seems to be little interest in sustainability as a core product feature. This may also be because of the position in the value chain, where the enterprise's customers are also towards the beginning of this chain. According to the assessment of many interviewees, the topic of sustainability and climate change will become more important in the future, but not as soon as some might expect and certainly not now (see above, p. 26).

Environmental certification is partly used for marketing purposes. But again, this is more a basic prerequisite of certain customers (see above, p. 29). Some enterprises are prepared to use the carbon footprint, for instance, for marketing purposes in the future, but do not use it currently (see above, p. 29). Sometimes, environmental issues are considered to be part of the self-concept and the value chain they are part of, but this is not used very actively for marketing purposes: *"Sustainability. Sustainability is a business philosophy. A large part of* our product goes to industry branches whose products are increasingly presented as environmental*ly friendly"* (see also above, p. 29). In part, the sustainability topic is seen simply as too outdated to use in marketing: "You have this commitment to sustainability in any modern chemical company today. This is something that is simply normal behavior in our western world."

Marketing innovations

Characteristics	Mostly focused on sustainability in general (not climate alone)
Main Drivers	Desire for acceptance; Sales expectations
Sources	Internal developments; Service providers
External determinants	Interest in sustainable product properties
Internal determinants	Multi-corporate enterprise; Attitude of management; Position in value chain
Expectations	Improve image; Increase sales; Support perception of quality of products
Economic results	Results mainly positive

Table 5: Marketing innovations. Source: Own illustration.

6. Summary and outlook

In this article, we reveal the results of a multiple case study carried out in the Central German Chemistry triangle in order to analyze the indirect impact of climate change on corporate innovation processes. For this study, we conducted guideline-based expert interviews at 22 enterprises and evaluated the results using the methods of qualitative content analysis.

Summing up, we come to the conclusion that energy efficiency and resource saving innovations exist in very different forms in the enterprises consulted. Mainly, these are incremental or small innovations such as energy efficiency drives, which fit into the general production setting of the facility. Very often, these innovations are driven by cost aspects or by regulation. However, they show the character more of the continuing development of energy and material efficient production processes, thereby adding to the progress in the reduction of greenhouse gases. In contrast, completely new and disruptive innovations were not observed. In a way, climate process innovations are part of the chemical industry’s regular business, simply because of the energy intensive nature of this industry and the large share of energy costs in total costs.

Customer requests are the most important incentive for product innovations but these customer demands were seldom targeted directly at climate issues. The increasing introduction or extension of environmental energy management systems, or energy management systems in combination with certification could be referred to as the main organizational innovation. Cost aspects, tax incentives and practical reasons for the management of larger corporations can be seen as the main incentives here. Finally, as far as marketing innovation is concerned, it has to be said that climate issues do not appear to play a very important part in this regard.

During the analysis of the innovative processes at the enterprises included in this study it also became clear that localized spillovers only have a minor effect on innovations. The main reason for this is the heterogeneity of the enterprises in regard to their production processes as well as some limits on disclosure of corporate process information. Compared to this, the spillover effects in multi-corporate groups, for instance, are much stronger. However, in the area of general energy efficiency some exchange has been observed.

The political asymmetry regarding instruments such as the EU ETS or REACH between the EU and emerging countries like China is considered a major problem for these enterprises. This is mainly because of the higher costs and the perceived associated distortion of competition. However, this is not regarded as grounds for cancelling some of the European legislation but rather as a reason for moving towards an adjustment and the introduction of similar regulation in emerging countries, which would also have a positive influence on the environment.

As in any other empirical study, this work is not without its limitations. One constraint may be the limited regional coverage of the study as it covers only the chemical industry. In addition, the study is limited to Central Germany. Further research into climate innovations is therefore recommended for other regions or countries and in other energy intensive or innovative industry sectors. The drivers, determinants and considerations derived from this study have revealed some patterns in the area of tension between climate change and innovation which might indeed also be the situation in other enterprises. However, compared to other parts of the chemical industry in Germany the results of this study may be somewhat distorted, because the facilities in the region studied are relatively new and so the scope for energy efficiency related innovation may be rather limited.

Finally, one could question for statistical generalizability of the results. Case study research designs in general do not allow for statistical generalization. The focus of this qualitative study was the exploration of the complex mechanics of the innovative process and the associated causal interrelationships. Starting from the patterns and causalities assessed here, the primary aim of this study was to expand and generalize elements of theory (analytic generalization), but not to count frequencies (statistical generalization). Larger, complementary innovation surveys could allow for statistical generalizations and therefore support this analysis.

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