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Master's Thesis in Sociology, 30 higher education credits

The Social Dynamics of Expectations in the Development of Mitigation Technologies: a Study on the ' Rise and Fall' of Vattenfall's Carbon Capture and Storage Project

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Abstract

The ’sociology of expectations’ has revealed the importance of expectations in technological development processes. Yet little research in this field has focused on Carbon Capture and Storage (CCS). The Swedish state-owned utility Vattenfall became a widely recognized leader in the research and development (R&D) of CCS, until it cancelled its CCS R&D in 2014. The aim of this paper is to generate a sociological understanding of the ’rise and fall’ of Vattenfall’s CCS project. It does so by analyzing the project’s embedded social and political issues in general, and the social dynamics of expectations in particular. The analysis focuses on Vattenfall’s ’expectation statements’ on CCS in publicly released texts on the CCS project from 2000–2016. It employs an interpretative ’discourse analysis’ inspired by works within Science and Technology Studies (STS) to analyze the embedded scripts in these expectation statements and the narratives that Vattenfall employed in its ’expectation work’ on CCS. The results show that ’hype-disappointment dynamics’ and ’promise-requirement dynamics’ played an important role in the ’rise and fall’ of the project. They also show how CCS was used as a ’political device’ to legitimize and deflect criticism from Vattenfall’s coal and lignite operations.

Keywords: *expectations, hype-disappointment dynamics, promise-requirement dynamics, sociology of expectations, Carbon Capture and Storage (CCS), Vattenfall, Science and Technology Studies (STS)*

1. Introduction

The escalating urgency that surrounds the climate change issue has given rise to a host of novel mitigation technologies – and reconfigurations of old technologies in new forms. One of the most prominent mitigation technologies is Carbon Dioxide Capture and Storage (CCS). CCS is based on the idea of 1) separating, 'cleaning' and compressing the waste CO_2 that is produced by large point sources (>0.1Mt CO_2/year), such as fossil fuel power plants and heavy industry plants, 2) transporting the CO_2 to a permanent storage site (e.g. via pipelines, cargo ships or trains) and 3) injecting it into certain geological formations at least 800 meters underground with an impermeable layer of cap rock above it[1] (IPCC, 2005). These storage conditions (theoretically) traps the CO_2 underground indefinitely. Thus, CCS is not one single technology, but consists of a range of technologies. To complicate matters further, the capture-part of the equation itself consists of three main technological contenders – pre-combustion, post-combustion and oxyfuel combustion. Multiple technological options have also been investigated for the transportation, storage and monitoring of the CO_2. As Russell et al. (2012: 660) have argued, "the shape of CCS is not yet settled: neither what the system as a whole consists of[…] nor particular components and connections between them".

The main goal of CCS is thus to capture the majority of the CO_2 emissions that are produced by fossil fuel-dependent industries and to store them underground indefinitely. The central promise of CCS has been said to be that it is "the only technology that squares the circle of continued reliance on fossil fuels with climate change mitigation" (Markusson & Shackley, 2012: 36).

The research and development (R&D) of CCS generated substantial academic attention from scholars from across the social sciences during the 2000's and the early 2010's (for overviews, see e.g. Meadowcroft & Langhelle, 2009; Markusson et al., 2012), but interest has subsided dramatically in recent years. The sudden abandonment of research on CCS left several knowledge gaps in its wake. The majority of the social science research on CCS thus far has taken the form of studies on the 'public perception' of CCS, or so-called 'acceptance studies', where different publics' knowledge of and willingness to accept CCS is gauged (see e.g. Markusson et al., 2012; Russell et al., 2012). However, as Russell et al. (2012) argues, "there are crucial social issues embedded in the apparently technical questions they [CCS developers and advocates] are preoccupied with[…]

[1] These storage sites include saline aquifers, declining or depleted oil and gas fields and unmineable coal seams. Apart from such "geo-sequestration" options, there have also been investigations into the "solid storage" of CO_2 through chemical reactions with alkaline/alkaline-earth oxides that produces mineral carbonates, as well as offshore deep ocean storage (i.e. injecting the CO_2 into oceans at depths exceeding 1000 meters). Because of the latter two proposals' potentially detrimental ecological effects and uncertain international legal status (cf. IPCC, 2005: 38ff), they are generally no longer considered feasible.

These issues go way beyond those of public ’perception’ and acceptance that social scientists are usually called in to address” (Russell et al., 2012: 666). Works within the fields of Science and Technology Studies (STS) and the philosophy and sociology of technology have long drawn attention to the embedded social and political issues in technological development processes. For instance, Sundqvist argues that ”Technological projects are developed for solving social problems, and should be understood as political devices embedded in social interests and sociopolitical decision processes for overcoming these problems” (2012: 69). CCS projects should consequently also be understood as political devices, since their primary goal is to help solve the social, or ’socio-environmental’, problem of climate change. However, there has been a lack of STS-inspired research on CCS development processes which has focused on these embedded political and social issues. This paper aims at providing such an analysis and filling this knowledge gap. More specifically, the paper will examine the social dynamics of expectations in CCS development processes – an area which has been undertheorized in previous research. It will take the Swedish state-owned energy utility Vattenfall’s high-profile CCS project as its case. In-depth analyses of Vattenfall’s CCS project have been similarly lacking from previous research (however, for a historical overview, see Hansson, 2008).

Vattenfall became a widely recognized leader in the development of coal/lignite power production with CCS from the middle of the 2000’s until the company announced that it had cancelled its R&D on CCS on 6 May 2014 (Vattenfall, 2014). The company was especially prominent in the R&D of the oxyfuel capture technology, which became somewhat of a ’flagship’ technology for the company. Vattenfall’s CCS project was closely interconnected with the company’s politically controversial expansion into Germany (see Hansson, 2008; Högselius, 2009). This paper will therefore focus on Vattenfall’s CCS-related activities in Germany. Vattenfall acquired significant coal and lignite assets in Germany between 1999 and 2002 (Hansson, 2008; Högselius, 2009). Prior to the expansion into Germany, Vattenfall’s ’energy mix’ had largely consisted of ’clean’ hydropower and nuclear power assets in Sweden. Thus, Vattenfall’s acquisitions of German lignite mines and power plants were, and have remained, controversial. Critics argued that it was inappropriate for a Swedish state-owned energy utility to go into the environmentally harmful business of lignite mining and power generation in Germany, and that this decision was irreconcilable with Sweden’s energy and climate policies and the companies state-mandated sustainability goals (see e.g. Hansson, 2008: 263ff). It was in this politically precarious context that CCS emerged as a possible solution to Vattenfall’s lignite conundrum.

2. Purpose and research questions

This paper aims at generating an understanding of the social dynamics that contributed to the ’rise and fall’ of Vattenfall’s CCS project and the projects’s embedded social and political issues. In order to do so, it will employ theories and concepts from the sociology of expectations literature, which focuses on the importance of *expectations, visions* and *promises* in technological development processes. These concepts are all related and overlap to a certain extent. Technological *expectations* have influentially been defined as ”real-time representations of future technological situations and capabilities” (Borup et al., 2006: 286). Technological *visions* and *promises* similarly represent future technological situations and capabilities in ’real-time’, but ”emphasize to a higher degree their enacting and subjectively normative character. They stress that expectations are wishful enactments of a desired future” (Borup et al., 2006: 286). The latter point is crucial, since it is this wishful enactment of a desired future that lends expectations, visions and promises their *performative* character, as we will return to below. More specifically, the paper will employ the notions of ’hype-disappointment dynamics’ and ’promise-requirement dynamics’ in order to analyze the social dynamics of expectations in Vattenfall’s CCS project.

The paper will investigate Vattenfall’s production of expectations and visions on the CCS technology, and its simultaneous production of expectations and visions on the society which would ’receive’ the technology. In other words, it will investigate Vattenfall’s production of the CCS technology alongside its production of political visions – or Vattenfall’s ’mutual shaping’ of technology and society. In doing so, the paper hopes to shed light on the embedded social and political issues in Vattenfall’s CCS project.

The purpose of the paper is to fill two knowledge gaps. Firstly, it aims at showing how Vattenfall’s CCS project can be understood as a political device ”embedded in social interests and sociopolitical decision processes” (Sundqvist, 2012: 69). As mentioned above, STS-approaches to CCS development processes have been missing from much of the previous research. Secondly, the paper aims at showing how the social dynamics of the expectations that Vattenfall generated in its CCS project contributed to the ’rise and fall’ of the project. There have been no in-depth analyses on Vattenfall’s CCS project. Not only is the case interesting from a STS perspective, it is also of utmost societal relevance because of Vattenfall’s state-owned nature.

The paper will critically examine the following research questions:

1) What expectations and visions of CCS and the society which would ’receive’ the technology did Vattenfall generate in its CCS project?
2) How did the social and technical expectations that Vattenfall generated in its CCS project contribute to the ’rise and fall’ of the project?
3) In what way(s) can Vattenfall’s CCS project be understood as a ’political device’?

3. Theoretical perspectives: the sociology of expectations

The sociology of expectations developed from van Lente’s (1993) introduction of the concept of expectations as a key driver of technological change (van Lente & Bakker, 2010). The literature largely focuses on the importance of *collective* expectations – i.e. widely shared and publicly communicated expectations – in technological development and innovation processes. These collective expectations are important since ”they stimulate, steer and coordinate action of actors” (van Lente & Bakker, 2010: 694) under the inherent conditions of uncertainty in technological development processes (Budde & Konrad, 2013). Actors that are engaged in technology development have to rely on *imaginings*, *expectations* and *visions* about the future (of the technology), rather than on robust knowledge of the ’actual’ future when deciding about e.g. what strategies to adopt (e.g. Budde & Konrad, 2013). Borup et al. therefore argues that ”Novel technologies and fundamental changes in scientific principle do not substantively pre-exist themselves, except and only in terms of the imaginings, expectations and visions that have shaped their potential” (2006: 285).

Technological expectations have influentially been defined as ”real-time representations of future technological situations and capabilities” (Borup et al., 2006: 286). However, since ’non-technological’ expectations, e.g. ”expectations concerning the future socio-economic environment or the institutional framework conditions can have a major influence on the technological innovation itself” (Budde & Konrad, 2013: 4), this paper will employ a wider definition of expectations. For the purposes of this paper, expectations will therefore be defined as ”real time representations of future situations” (Budde & Konrad, 2013: 4).

The sociology of expectations has been characterized as the study of ”how the future is mobilised in real time to marshal resources, coordinate activities and manage uncertainty” (Brown & Michael, 2003: 2). This mobilization of the future into the present through the medium of expectations and visions also entail powerful political and moral dimensions, since *other* possible futures are discounted or excluded in this process. Berkhout comments in relation to this that:

> […] to give them force, visions of the future tend to be 'moralised', in the sense of being encoded and decoded as either utopias or dystopias. This is because the possible effects of different visions are socially distributed (there will be winners and losers), and because one way of enrolling actors to a particular vision is to attach it to positive moral values, or to visualise the negative consequences of not pursuing it (Berkhout, 2006: 300)

Budde and Konrad also argue that power relationships play an important role in the shaping of expectations and visions of the future, since ”actors try to ’colonize the future’ by articulating expectations corresponding to a future desirable from their perspective” (2013: 6). In the context of expectations as *resources* for actors (see van Lente, 1993) which shapes and are shaped by power relations, it has also been emphasized that ”Different groups construct the same expectation differently amongst themselves and to others. Scientists, for example, may acknowledge caveats behind closed doors but downplay them in front of investors” (Porter & Randalls, 2014: 2; see also Brown & Michael, 2003). Budde and Konrad also write that several studies have shown that ”actors may consciously stimulate or even inflate expectations about a technology they have stakes in” (2013: 6).

So far in our discussion, expectations may come across simply as rhetorical resources that can be employed by actors in the (discursive) struggle to shape the future. However, the literature emphasizes that expectations should be seen as *actants* in their own right. Elaborating on this point, van Lente points out that ”the [expectation] statement itself alters social reality: it creates, reinforces, or destroys a social connection, or *linkage*. It is a ’speech act’” (1993: 190). Expectations are therefore viewed as *performative* – i.e. as doing something, as demanding action (van Lente, 1993), as acting upon the world (Porter & Randalls, 2014) – rather than simply as (passive, descriptive) ”representations of something that does not (yet) exist” (van Lente, 1993: 190). Borup et al. further this argument by stating that ”expectations are 'constitutive' or 'performative' […] in attracting the interest of necessary allies […] and in defining roles and in building mutually binding obligations and agendas” (2006: 289). Expectations can therefore be said to contain a *script* (Akrich, 1992), i.e. ”explicit or implicit messages and guidelines ’built in’ in artefacts” (van Lente, 1993: 191), or ”a description of the future situation and a concomitant distribution of roles for selves, others and technologies” (van Lente & Bakker, 2010: 694). Porter and Randalls argue that ”expectations have material and discursive effects. They act on the world. Inscribed in texts, bodies, machines and actions they help steer present futures or take on a life of their own” (2014: 2). In other words, expectations contribute to the shaping of the future – not just ideologically or discursively, but also in *material* senses – through their performativity and the scripts they contain.

However, critics have argued that collective expectations do not necessarily or automatically produce the envisioned future. Berkhout (2006), for instance, argues that expectations or visions about the future should be seen as ’bids’ about what the future might be like, which coexist with a multitude of other expectation bids. Whether a bid will be successful in realizing some version of its envisaged future depends on its ability to enroll ’adherents and advocates’ to actualize the bid (Berkhout, 2006). Furthermore, Berkhout (2006) argues that in the rare cases where expectations actually succeed in materializing at all, they often do so in a radically modified version of the original vision. Similarly, Pollock and Williams argue that ”we cannot presume stable trajectories and the continuation of existing sets of expectations” (2010: 529) during the development of novel technologies. Later entries into the literature have therefore often emphasized that collective expectations ”act as *provisional*, and in that sense *tentative*, but forceful assumptions on the future potential and requirements of an emerging technology” (Budde & Konrad, 2013: 2, my emphases) which requires a network of actors to continuously *perform* the vision in order for it to have a chance of materializing (see e.g. van Lente, 2012).

For these reasons, it is often emphasized that expectations and visions of the future are usually *contested*, and that expectations are *dynamic* – i.e. they evolve and change over time. To analyze the social dynamics of expectations, this paper will employ two more specific notions from the sociology of expectations literature – promise-requirement dynamics and hype-disappointment dynamics.

3.1. ***Promise-requirement dynamics***

The concept ’promise-requirement dynamics’ describes the phenomenon whereby promising ideas, innovations or innovation fields turn into requirements through performative expectation statements (’speech acts’). These expectation statements create linkages in actor-networks (e.g. in the form of binding obligations and scripted roles), and gain ’forcefulness’ by being taken up in agendas. Promises can in these cases be said to be *translated* into requirements (van Lente, 1993). An example of this might be if a CEO of a technology company publicly announces that a technology that the company is working on is expected to be operational and ready for market introduction by 2020. This expectation statement (or *promise*) would then be translated into a *requirement* for the company’s technologists to deliver on the CEO’s promise (given that the promise related to issues that were already on the company’s agenda).

Furthermore, van Lente and Rip state that ”Technological promises function as a yardstick for the present and as a signpost for the future. The implication for the dynamics of concrete developments is that what starts as an ’option’ can be labeled a technical ’promise,’ and may subsequently function as a ’requirement’ to be achieved, and a ’necessity’ for technologists to work on, and for others to support" (1998: 216). They underline that these dynamics are part of a social process that is not autonomous, deterministic or irreversible – but something which is actively constructed and performed by the involved actors (van Lente & Rip, 1998: 216).

3.2. *Hype-disappointment dynamics*

The notion of 'hype-disappointment cycles' or 'dynamics' relates to the process whereby "Initial enthusiasm produces hype, elevating expectations, before relapsing when that hype is revealed to be unjustified, with hope consequently recycled into new expectations or old expectations rebuilt in new ways" (Porter and Randalls , 2014: 2). It has been suggested by several papers that high initial expectations are necessary in order to attract the attention and interest that is required to enroll actors and mobilize resources for an innovation project (e.g. Borup et al., 2006; Brown & Michael, 2003; Geels & Smit, 2000). Furthermore, it has been shown that technologists and scientists may strategically use exaggerated expectations – in the sense that they may downplay the many contingencies, uncertainties and risks that may hinder the realization of the project – as a strategic resource in order to attract allies and funding for their projects (Brown & Michael, 2003; Geels & Smit, 2000). As Borup et al. puts it, "Early technological expectations are in many cases technologically deterministic, downplaying the many organizational and cultural factors on which a technology's future may depend" (2006: 290). Disappointments are therefore seen as likely in the evolving social dynamics of expectations.

4. Previous research

Previous 'expectation studies' have shown that expectations play an important role in establishing and governing new scientific and technological fields in areas as diverse as membrane technology (van Lente & Rip, 1998), neural computing (Guice, 1999), gene therapy (Martin, 2001), pharmacogenomics (Hedgecoe & Martin, 2003) and nanotechnology (Selin, 2006). Similarly, research focusing on hype-disappointment dynamics (e.g. Brown and Michael, 2003; Geels & Smit, 2000) and promise-requirement dynamics (e.g. van Lente, 1993; van Lente & Rip, 1998) has shown that these dynamics play an important role in the development and evolution of scientific and technological fields and projects. These studies have all drawn attention to the critical role that collective expectations play in legitimizing emerging technologies, in mobilizing funds and attention from other actors and in reducing the inherent uncertainty that decision-makers face in technological development processes. Furthermore, they highlight the critical role of expectations and visions in garnering support for vulnerable nascent technologies – especially in the initial phase when e.g. proof of concept, prototypes and hard results do not (yet) exist (Selin, 2008). This is often done through the production of ’promising stories’ about the emerging technology (Selin, 2008). These stories will be a focal point for the analysis in this paper, as we will return to below.

’Expectation studies’ on CCS have thus far been sparse, with a few exceptions. Hansson (2012), for instance, shows how the production of techno-economic models and scientific scenarios on CCS is influenced by expectations and, in turn, influences expectations. The article shows how methodological issues in the scenario literature has led to problematic results regarding the future of CCS – especially concerning its estimated cost (Hansson, 2012: 78ff). Hansson (2012) argues that these issues have resulted in inflated expectations regarding the feasibility of CCS as a mitigation technology. The article shows how the scenario literature’s issues, in turn, have influenced the energy industry’s high expectations on CCS and the high expectations on CCS that are presented in policy documents (Hansson, 2012).

Hansson argues that because CCS is commonly seen as the only technology which could potentially ’square the circle’ of continued fossil fuel exploitation with mitigation, ”…CCS is constructed as essential and the methodological restrictions and simplifications are justified [in the scenarios and models]. Managing the remaining real problems with CCS, which are almost entirely framed as non-technical, is consequently described as a collective societal responsibility” (Hansson, 2012: 87). This, Hansson (2012) argues, is the reason why politicians and publics must be supplied with scientifically produced knowledge on CCS according to the scenario literature. But, as Hansson (2012) shows, this knowledge has vital flaws. While the article provides valuable knowledge that will be employed in the analysis of Vattenfall’s CCS project, its research object differs from this paper’s.

Russell et al. (2012) outlines a social science research agenda on CCS demonstration activities by showing how concepts and theories generated within STS and the sociology of expectations can be fruitfully applied to CCS demonstration activities. For instance, they discuss the ways in which demonstrations can be interpreted as theatre – as a performance which creates ”a story of the technology in use, often tightly scripted to achieve the desired naturalistic depiction” (Russell et al., 2012: 656). They also discuss the ways in which demonstration events play into the negotiation and (potential) closure of the meaning of the technology, or ”the political and discursive contest between competing interpretations of the available technological options, so that a particular envelope becomes taken for granted as the essence of the technology” (Russell et al., 2012: 657).

With regard to the sociology of expectations, Russell et al. argues that ”To date, CCS consists to a large extent of visions: there is a relevant knowledge base, there is experience of component technologies as used in other applications […] but there is little experience of anything like a complete CCS system” (2012: 660). The production and enactment of collective expectations and visions is therefore seen as vital in order for the technology to be able to materialize. Russell et al. (2012) argues that demonstrations play a central role in the generation of visions on CCS – particularly visions of full-scale, commercial versions of the technology. Furthermore, CCS demonstrations play an important role ”in filling out and confronting visions with reality, as well as in promoting and developing the visions” (Russell et al., 2012: 660). Similar to what previous research in the sociology of expectations has shown, they argue that (overly high) expectations introduces new problems for the developers and advocates of CCS, since CCS demonstrations may backfire and ’punch holes’ in the visions (Russell et al., 2012: 660).

Russell and colleagues' article, like Hansson's, provides valuable knowledge which will be used in this paper's analysis. However, the article covers a (partially) different research object than the one this paper is interested in exploring.

5. Design and method

In order to analyze Vattenfall's ’mutual shaping' of technology and society, the paper will adopt an interpretative and constructivist approach, inspired by previous works in the STS field generally (see e.g. Law, 2015) and the ’sociology of expectations' more specifically. STS has close ties to ’grounded theory', in that it has a strong focus on empiricism (see e.g. Clarke & Leigh Star, 2008). The analysis in this paper will also have a strong empirical focus, and, much like grounded theory, I have employed an abductive approach (see Clarke & Leigh Star, 2008: 117).

The paper will use a qualitative case study design with Vattenfall's CCS project acting as the case. The contextual conditions are in this case very relevant to the phenomenon that is being studied – i.e. Vattenfall's production and communication of collective expectations and visions on CCS – and the boundaries between the phenomenon and the context are entangled and unclear, which makes a case study design suitable for the study (see Yin, 2008).

The case study will take the form of a discourse analysis – discourse here understood as ”assemblages of language, motive, and meaning, moving toward mutually understood *modus vivendi*–ways of (inter)acting” (Clarke & Leigh Star, 2008: 116). As Clarke and Leigh Star point out, this definition of discourse ”include commitments that stem from work and material contingencies” (2008: 116). In other words, it highlights the heterogenous ways in which discourses are embedded in, and stem from *collective, material action* (see Clarke & Leigh Star, 2008). STS-approaches are particularly well known for paying attention to both material and symbolic practices and the ways in which they mutually shape one another (see e.g. Law, 2015), which is why this version of a discourse analysis was chosen for the study.

The paper has followed the methodological pointers laid out by van Lente (1993), who argues that the analyst should focus on gathering and analyzing ’expectation statements’, i.e. statements that contain (collectively held) expectations which are uttered in public or written down. Since ”statements, by their nature, are made *explicitly*”, they are therefore ”public and […] accessible, for actors and analysts” (van Lente, 1993: 33). Furthermore, expectation statements ”refer to *shared* orientations, or are shared themselves” (van Lente, 1993: 33). Shared or collective expectations are the type of expectations that are of interest here, since *private* expectations ”can only become effective as far as they are linked to shared expectations” (van Lente, 1993: 33).

Expectations commonly take the form of ’stories’, or ’narratives’ (cf. Selin, 2008). As Law notes, narratives, and the tropes (figures of speech and metaphors) on which they draw, carry political and social agendas (2015: 6). Special attention was therefore payed to the stories/narratives that Vattenfall produced and employed in its ’expectation work’ on CCS.

The analysis was carried out in three steps. First, expectation statements and stories/narratives were identified through an inductive reading of the material. Second, these expectation statements and stories/narratives were analyzed with the help of the theoretical framework laid out in part 3. Lastly, Vattenfall’s collective expectations on the CCS project were analyzed to see if transitions and transformations of particular note could be identified. This resulted in a chronological, descriptive – or ’de-scriptive’ (Akrich, 1992) – ’re-telling’ of Vattenfall’s original narrative constructions, or ’plot’ (cf. van Lente, 1993: 179), on CCS, which will be presented in part 7.

5.1. *Material*

The material for this paper consists of publicly released texts in which Vattenfall disseminates and projects its expectations and visions on CCS into the ’public sphere’. These texts include Vattenfall’s various reports, its R&D Magazine and its press releases on CCS. To complement these texts, I have also gathered and analyzed scientific reports and articles that were produced within Vattenfall’s CCS project. This was done in order to access more in-depth technological expectations on CCS. Finally, I have also analyzed more overtly political documents, such as the report *Curbing Climate Change* (2006), in which Vattenfall presents its vision for a global ’adaptive burden-sharing model’ and a global CO_2 emissions trading system.

The material that I have analyzed was produced between 1997 and 2016. However, CCS is barely mentioned in the material before 2000. Because of this, I decided to start the analysis with the year 2000. I also decided to limit the materials to texts that were produced by Vattenfall and the actors that it enrolled into its CCS project. I would have liked to include texts that were produced in the CCS networks in which Vattenfall participated (e.g. the EU Framework Programmes that Vattenfall participated in). I would also have liked to interview engineers and/or scientists who worked on the project to access more ’informal expectations’ on the project (see van Lente, 1993). But including this material would have been unmanageable for the scope of this paper. Nevertheless, the analysis of the material led to a situation in which I felt that I had reached a point of ’data saturation’, or ’theoretical sufficiency’ (see e.g. Marshall & Rossman, 2011: 220).

6. Ethics

Because the paper’s material consists of publicly released documents, there are no clear ethical issues (cf. Marshall & Rossman, 2011: 162). The ’criterion of the protection of the individual’ (see e.g. Swedish Research Council, 2011) isn’t easily applicable since the study does not have any informants. Furthermore, the paper does not deal with individual persons, but with Vattenfall as an institution. The paper therefore does not contain any names of individual employees, for example. However, the paper will unavoidably reference the names of the authors of the scientific papers that have been analyzed. But since these papers have all been published in books or journals, using the authors’ names should be unproblematic from an ethical standpoint. The most problematic texts from an ethical point is a PowerPoint on CCS (Strömberg, 2003) and a paper from a symposium on CCS (Strömberg, 2001), for which I have not acquired express permission from the author. However, both of these texts are also publicly available through the National Energy Technology Laboratory (NETL) and Chalmers University of Technology, respectively.

In this case, the ’research criterion’ (see e.g. Swedish Research Council, 2011) in my view outweighs the ethical concerns that might be raised. The research criterion mandates critical inquiry into the business of powerful actors such as Vattenfall. This is especially true since Vattenfall is a state-owned company, which is ultimately owned by the Swedish people.

7. Results

In this part, the results of the study will be presented. As mentioned above, Vattenfall’s CCS project was closely interconnected with the company’s expansion into the German coal and lignite markets, wherefore the analysis will focus on Vattenfall's CCS-related activities in Germany. The reading of the material revealed three broad periods, or 'phases' in Vattenfall's CCS project. The phases should not, however, be seen as anything other than heuristics to help develop an understanding of Vattenfall's CCS activities. The analysis will be structured according to these three phases, which will be presented below.

7.1. *Phase 1: 2000-2002. CCS is identified as a promising opportunity.*

The first CCS 'project group' was formed at Vattenfall Research & Development in 2000, at which time Vattenfall had begun its expansion into Germany. In one of the few mentions of CCS in the material from 2000, Vattenfall states that "In the long term, [CCS] has considerable potential. *From this perspective, coal could be considered to be a sustainable fuel.* Vattenfall intends to follow and actively participate in developments to separate and store carbon dioxide on a commercial basis in order to minimize the impact of fossil fuels on the climate" (Annual Report, 2000: 22, my emphasis). Already at this early stage, it is (tentatively) expected that coal could become a 'sustainable fuel' through the development and deployment of CCS.

In 2001, Vattenfall began conducting R&D on CCS for coal-fired power plants in collaboration with "universities, industrial colleagues and other professional organizations, such as Linde AG and others" (Strömberg, 2001: 60). The project was given the working name the 'CO_2 demo project' (Strömberg, 2001). The ultimate goal of the project was to "build a 250 MW lignite-fired plant with zero emissions on German ground in [the] future" (Strömberg, 2001: 60). The research that was conducted by Vattenfall and its partners focused on assessing the different capture options (post-combustion, pre-combustion, chemical looping combustion and oxyfuel combustion) with regard to their potential, costs and consequences compared to other emission reduction options (Strömberg, 2001: 60). These 'other options' were identified as a) improving fossil fuel plant efficiency by replacing old plants with new ones, b) changing fuels from coal to natural gas and c) R(D)&D of "truly sustainable energy sources", i.e. wind, solar, biofuels and hydropower (Strömberg, 2001: 58–59). It was stated that in the "short term these [other] options are the only ones available" (Strömberg, 2001: 59), but in the "slightly longer term", CCS is "very promising" (Ibid.). The perceived advantaged of CCS, compared to the other mitigation options, was that it could create a "possibility of using coal as a fuel and still showing concern for the environment" and that it could "create an option for using an energy source which is found all over the world, is relatively cheap, does not have the obvious security problem of oil and gas and […] is so plentiful that it will last for several hundred years" (Strömberg, 2001: 63). Furthermore, it was stated that ”The potential is great, and there is considerable industrial experience. The present cost is high, estimated at 50 €/ton of CO_2 a few years ago, but this is still lower than for most renewables. Research and development of CO_2 capture and storage might bring down costs considerably. At present the total cost is estimated at 30–35 €/ton of CO_2” (Strömberg, 2001: 59). By now, Vattenfall had clearly identified CCS as a promising opportunity for the company, and expectations on the technology were already high. These high expectations likely helped enroll the aforementioned academic and industrial actors into its CCS project.

The above paragraph highlights three expectations: 1) that the estimated *total* cost (i.e. capture, transport and storage) would be around 30–35 €/ton, 2) that CCS would allow for coal power to become ’environmentally friendly’, and 3) that there is ’considerable industrial experience’, which implies that the development of the technology was seen as more surmountable than the development of wholly ’new’ technologies (cf. Strömberg, 2001). Previous research has highlighted that the latter is a recurring argument and expectation amongst CCS advocates, even though most industry experience stem from the use of ’component technologies’ in other industrial applications – *not* of anything like a full ’CCS chain’ (see Hansson, 2012; Russell et al., 2012). The ’stabilization’ of what components to use in the ’CCS chain’ and problems relating to their ’integration’ into a ’unified technology’ (cf. Russell et al., 2012) would be one of Vattenfall’s primary issues.

Expectations were especially high for the oxyfuel technology. The cost of capturing and transforming the CO_2 to liquid form was expected to be 10-13 €/ton of CO_2 for an oxyfuel power plant on the scale of Vattenfall’s Lippendorf (865 MW) power plant (Strömberg, 2001: 63). Furthermore, it was expected that a plant on this scale could be made into a true ’zero emission plant’ with ”virtually no CO_2 emissions, no sulphur emissions, and considerably reduced NOx emissions”, and that the investment cost could be less than for a conventional power plant (Strömberg, 2001: 63). The oxyfuel process therefore seemed to be the most favorable and cost-effective of the CO_2 capture technologies, in Vattenfall’s view (Strömberg, 2001: 63). The high expectations regarding the potential of the oxyfuel technology led to a continued focus on this particular capture option.

Vattenfall began conducting laboratory experiments on the oxyfuel capture process together with researchers at Chalmers University of Technology in 2002 (Vattenfall, 2016a). Vattenfall also conducted a feasibility study on a commercial-scale 865 MW oxyfuel power plant. The results indicated that ”O_2/CO_2 [oxyfuel] combustion is a realistic and a near future option for CO_2

reductions in the power sector with an avoidance cost of approximately $8 per tonne CO_2 excluding transportation and injection costs" (Andersson et al. 2003: 1056).

However, Vattenfall emphasized that CCS was not a replacement for other mitigation technologies. Instead, it was viewed as a technology which might ”buy some time for the development of as yet unknown [sustainable] energy sources, which are necessary" (Strömberg, 2001: 59). It was, however, seen as a promising means of achieving the drastic emissions reductions that the company, Europe and the world would need in order to mitigate climate change (Strömberg, 2001; Annual Report, 2001). In sociology of expectations terms, the identification of CCS as a promising opportunity and the launch of the CCS R&D project made sure that CCS was taken up in a local agenda – in this case, finding a cost-effective means of reducing the environmental impact of the company's new coal and lignite power generation assets (cf. Strömberg, 2001; Annual Report 2001; 2002).

7.2. *Phase 2: 2003–2009. CCS is hyped and promises are translated into requirements.*

In 2003, Vattenfall introduced its CCS R&D project more officially to the general public (CSR Report, 2003). The project had now been rebranded 'the CO_2 free power plant'. Vattenfall stated that the project aimed at ”developing a coal combustion power plant with in principle no CO_2 emissions" and that ”the project will end with the construction and testing of a 250 MW electricity demonstration plant in 2010, with the aim of developing a commercial concept during the later half of the next decade [the 2010's]" (CSR Report, 2003: 15). This performative expectation statement – that the project will end with the construction of a demonstration plant – functioned as a means of translating the 'promise' of CCS into a concrete 'requirement' for the engineers and technologist that Vattenfall had enrolled into its CCS project to work on (cf. van Lente & Rip, 1998).

Vattenfall continued focusing its CCS efforts on the oxyfuel process. The main opportunities with oxyfuel, in Vattenfall's view, were that the technology is based on existing boiler and steam cycle technology – which, according to Vattenfall, could take advantage of ongoing (as of 2003) R&D projects on how to increase the efficiency of conventional power plants, such as the AD700 project (Strömberg, 2003: 22). Furthermore, the technology was expected to allow for the 'co-capture' of CO_2 and other pollutants, which would effectively result in a 'near zero emission power plant' and reduce the cost of flue gas treatment (Strömberg, 2003: 22). The oxyfuel process was also expected to benefit from 'next generation' boiler designs, such as compact Pulverized Fuel boilers and Circulating Fluidized Bed boilers (Strömberg, 2003: 22). All things considered, this meant that the oxyfuel technology was expected to be significantly cheaper with regard to both the total and the variable Cost of Electricity (COE) compared to both post-combustion and pre-combustion technologies (Strömberg, 2003). These statements highlight the fact that Vattenfall's expectations were contingent upon the success of developments that lay partly outside of its own immediate CCS project, such as the AD700 project. These contingencies were downplayed in Vattenfall's 'expectation work', however.

A number of 'challenges' with the oxyfuel process were also outlined. Vattenfall identified potential problems with the possibility and cost of a scale-up of the component technologies that would be necessary in order for the oxyfuel process to work and potential problems with the integration of these technologies into the overall oxyfuel 'CCS chain' (see Strömberg, 2003). These issues again underline the contingencies in Vattenfall's CCS project.

Vattenfall also identified more specific issues, e.g. regarding the design of the CO_2 compression train. The exact specifications of the compression train was seen as dependent on what CO_2 impurity level that was acceptable (Andersson et al., 2003; Strömberg, 2003). This, furthermore, depended on the intended end use of the CO_2 – e.g. geological storage, Enhanced Oil Recovery (EOR) or other industrial purposes (Strömberg, 2003). In this context, it was stated that "Requirements on CO_2 purity from transport, storage [and] environmental perspective is generally unexplored" and that the "Behaviour of CO_2 with impurities at high pressures (supercritical) is not well known (solubility etc.)" (Strömberg, 2003: 25). These statements shine a light on the project's close interconnections with political, legal and scientific issues. Legal frameworks that regulated the acceptable impurity level for safe geological storage, for example, would have to be developed simultaneously as the technical development of CCS progressed. This, furthermore, called for a (scientific) knowledge production on the behaviour of CO_2 with impurities under supercritical conditions. The complex interconnections between these social, political, scientific and technical issues highlights why CCS projects such as Vattenfall's should be interpreted as emerging 'sociotechnical systems' which exhibit varying degrees of (technical and organizational) 'integration' (cf. Russell et al., 2012: 658ff).

Another example of the CCS project's close ties to political and legal issues is Vattenfall's expectations on the EU's Emissions Trading System (ETS). Already before the formal implementation of the ETS in 2005, Vattenfall expected it to be a crucial market mechanism for making CCS cost-efficient and financially attractive as a mitigation option (Annual Report, 2003: 31; Annual Report, 2004: 31; Strömberg, 2003). The key issue for Vattenfall was to ensure a high enough price on carbon credits. In Vattenfall's view, this would create an incentive for CCS, since the marginal cost of producing electricity *with* CCS would then be lower than producing electricity *without* CCS, even when accounting for the so-called 'energy penalty' that CCS incurs (cf. Strömberg, 2003; Jordal et al., 2005). This argument is also repeated in Vattenfall's report *Curbing Climate Change* (2006), in which it proposes a *global* emissions trading system in order to overcome the perceived shortcomings of the ETS. The report also includes a proposal for an 'adaptive global burden-sharing model', in which 'developed countries' would be subject to an emissions cap, while 'developing countries' would be allowed to emit unrestricted amounts of CO_2 until they reach a certain 'GDP threshold', at which point they too would be subject to emission restrictions (Curbing Climate Change, 2006). Vattenfall's intense lobbying of the political proposals it presented in the report (see Hansson, 2008) again underscores the CCS project's close ties to political and social issues, and the many contingencies – technical, social, political and financial – that needed to be overcome before CCS could be 'integrated' into a functioning sociotechnical system. Different parts of these issues were also R&D'd in the numerous networks and projects on CCS that Vattenfall was participating in – e.g. the EU Framework Programmes ENCAP and CO_2 SINK, and within the EU's Zero Emissions Platform (ZEP) (see e.g. Daniel & Heiskanen, 2006).

An important step towards the 'integration' of CCS as a sociotechnical system came in 2005, when Vattenfall decided to build the planned CCS pilot plant (CSR Report, 2005: 23). In May 2006, work began on the construction of Vattenfall's 30 MW oxyfuel CCS pilot plant at the Schwarze Pumpe power plant. The pilot plant was designed to "provide […] knowledge on one potential layout of the [oxyfuel] process. However several alternative process solutions are possible. The pilot plant has some flexibility in providing opportunities […] to later on test alternative process designs and process components" (Strömberg et al., 2009: 589). The materialization of the pilot plant represented an emerging 'stabilization' of Vattenfall's oxyfuel CCS technology, even though it still allowed for the testing of different 'configurations' of the nascent technology (cf. Russell et al., 2012: 658).

The pilot plant was officially inaugurated on September 9, 2008. During the years it was operational, tests and measurements were done on e.g. different burner geometry, the combustion characteristics of lignite under oxyfuel conditions and on how variations in fuel quality affected the oxyfuel process (Strömberg et al., 2009: 588; Annual Report, 2009: 21). The first test results from the pilot project were encouraging, with Vattenfall stating that "The pilot project shows that the technology works as intended, and the result has exceeded expectations. The share of carbon dioxide that is captured is currently more than 90%" (Annual Report, 2009: 21; see also Strömberg et al., 2009). Given the promising results from the pilot plant, Vattenfall stated that it believed that CCS ”will become a reality and that the technology will be commercially viable by 2020” (CSR Report, 2009: 13). CCS was now beginning to be seen as *indispensable* in combatting climate change and in reaching the EU’s emission targets (see e.g. CSR Report, 2005) and the commercialization of CCS was expected to be imminent (e.g. CSR Report, 2009: 13).

However, Vattenfall had begun planning as if CCS would inevitably become a reality even before the pilot plant was inaugurated. Vattenfall stated that the new hard coal power plant that it was planning on building in Moorburg and the planned new 675 MW generation unit at the Boxberg power plant, would both be ”ready to be retro-fitted with Carbon Capture Storage technology *when [CCS is] commercialized*” (CSR Report, 2007: 18, my emphasis). In other words, the continued expansion of its coal and lignite assets were *prospectively* legitimized with reference to the expectation of CCS’s impending materialization and commercialization. Simultaneously, the expectation of CCS’s impending commercialization was used to *retrospectively* legitimize its past acquisitions, i.e. its expansion into the German coal and lignite markets (Hansson, 2008).

In the midst of all the optimism that surrounded the CCS project, clouds were beginning to form on the horizon. In 2009, public protests on CCS broke out in Germany (e.g. Voosen, 2010). The protests mainly focused on the storage of CO_2 and its associated risks and were sparked as a consequence of Vattenfall’s decision to investigate the potential for storage in geological formations under the towns of Beeskow and Neutrebbin in eastern Germany. The protests grew and became a national issue during Germany’s national elections in the summer of 2009, which prompted politicians at the federal level to delay the planned transposition of the EC’s CCS Directive into national law (Shogenova et al., 2014; Voosen, 2010). This would soon turn into a considerable problem for Vattenfall.

7.3. *Phase 3: 2010–2016. Hype turns into disappointment.*

In 2010, Vattenfall started to imply that it was uncertain whether its investments in CCS would continue. Vattenfall stated that ”Provided that research and investments continue, it is estimated that CCS can be operating commercially by around […] 2020 at the earliest” (Annual Report, 2010: 37). The expectation in 2003 had been that a demonstration plant could be built by 2010, and that a commercial plant could be built in the later half of the 2010’s (CSR Report, 2003), and in 2007, Vattenfall had stated that its goal was to present ”a commercial concept for CCS at coal-fired power-plants by 2020 *at the latest*” (CSR Report, 2007: 12, my emphasis). Just one year earlier, Vattenfall stated that ”we plan to begin demonstrating [CCS] on a large scale by 2015” (CSR

Report, 2009: 1). The pushed-back schedule again suggests that CCS was hyped, and that crucial contingencies and uncertainties were downplayed in the early ’expectation work’ of Vattenfall. Simultaneously, however, the company emphasized that the test program at the Schwarze Pumpe pilot plant had been ”successful and given the anticipated results”, and that the ”function and processes of oxyfuel technology have been fully verified” (Annual Report, 2010: 62).

The major (socio)technical issues that Vattenfall was faced with was to ”reduce energy consumption in the separation process, which significantly lowers the plant’s efficiency” and to ”hold down the investment costs for CCS technology” (Annual Report, 2010: 37). To overcome these issues, Vattenfall stated that it was ”collaborating with numerous stakeholders to develop the necessary social, legal and financial conditions” for CCS. In other words, Vattenfall needed to shape the society which would ’receive’ the technology, while continuing the work of shaping the CCS technology. More specifically, it had to try and shape that society’s ’legal, social and financial’ dimensions in order for CCS to be able to materialize. Without a ’mutual shaping’ of these ’social’ and ’political’ dimensions of the technology, it simply would not work.

The future of Vattenfall’s CCS project now hinged on the materialization of a full-scale demonstration plant at the Jänschwalde power plant, which would allow Vattenfall to ”evaluate [the] commercial conditions” of its CCS technology (Annual Report, 2010: 37). Vattenfall had by this time received a €180 million grant from the European Energy Programme for Recovery (EEPR) as partial funding for the demonstration plant, which carried an estimated price tag of €1.5 billion (Annual Report, 2010: 62). However, the conditions for the construction of the demonstration plant were seen as uncertain, largely due to the ’legal, social and financial’ issues mentioned above. Without a full-scale demonstration plant with which Vattenfall could showcase the feasibility of the technology, it would be hard for the company to continue its CCS R&D. And without CCS, the company’s investments in coal and lignite power generation would look even more unsustainable from an environmental perspective. As Vattenfall itself put it, ”[t]he future of coal depends on CCS” (Annual Report, 2010: 20).

The stakes were thus high for Vattenfall. One of the main concerns for Vattenfall was that Germany had not yet transposed the EC’s so-called ’CCS Directive’ into national law (Annual Report, 2010: 62). As mentioned above, this delay was prompted by public protest – not least in the regions in which CO_2 storage projects were being planned (see e.g. Shogenova et al., 2014; Voosen, 2010). The CCS Directive provides a legal framework for the ’environmentally safe geological storage of carbon dioxide’ during the entirety of the storage period and designates closure and post-closure obligations for the operator, among other things (EC, 2016). The directive had to be transposed into national law by all EU member states by 25 June 2011 at the latest (EC, 2016). However, the German government had not done this by 2010, which made the legal status of CO_2 storage uncertain – which, in turn, rendered the future of Vattenfall's projected €1.5 billion investment in the Jänschwalde CCS demonstration plant uncertain. Vattenfall nevertheless held out hope that Germany would implement the directive before the EC's 25 June 2011 deadline. However, the Bundestag (German Parliament) took until 7 July 2011 to adopt a new CCS Act (Lang, 2011). The proposed CCS Act included a clause which made it possible for Germany's federal states to designate which areas were and were not allowed to use for CCS pilot projects – a clause which was heavily criticized by Vattenfall and the state of Brandenburg, who wanted a ”uniform nationwide law” (Lang, 2011). The bill consequently failed to acquire the necessary support in the Bundesrat (Federal Council), which led to a mediation procedure in which the parties tried to find a compromise (Lang, 2011; Annual Report, 2011: 18). After two failed attempts at such a compromise, Vattenfall announced that it was cancelling its plans for the CCS demonstration plant in Jänschwalde on 5 December 2011 (Vattenfall, 2011). It cited the ”ongoing impasse in German CCS law” (Vattenfall, 2011) as its reason for the cancellation, and claimed that there was ”insufficient will in German federal politics to implement the European directive so that a CCS demonstration project in Germany could be possible” (Vattenfall, 2011). The hype that Vattenfall had built around its CCS project was now decidedly turning into disappointment.

Despite the cancellation of the demonstration plant and the concurrent ’dramatical decrease’ of its CCS R&D budget (Annual Report, 2011: 42), Vattenfall stated that it would continue its R&D efforts on CCS. It would especially focus on the R&D of CO_2 storage (Annual Report, 2011: 23). It stated that ”Hopefully, the long development horizon for CCS and storage tests on an R&D scale will facilitate the public dialogue and lead to greater acceptance of storage among the general public in time for future investments” (Annual Report, 2011: 42). Presumably, the reason why Vattenfall chose to focus on CO_2 storage was that this part of the ’CCS chain’ had failed to develop in step with the oxyfuel capture technology – especially with regard to social and political issues. The belated focus on public dialogue and the fostering of public acceptance which followed (cf. Annual Report, 2011; Daniels & Heiskanen, 2006) highlights the fact that Vattenfall failed to predict that there would be public skepticism and protest towards CO_2 storage.

After the reduction of its CCS R&D program, Vattenfall stressed that it would not ”make any lifetime-extending investments in existing [coal-fired] plants” or build ”any new coal-fired power plants until a political framework is in place for [CCS]” (Annual Report, 2011: 6) after the aforementioned Moorburg and Boxberg power plants, which were already under construction, were completed. Vattenfall also underlined that CCS ”must be fully developed and commercially viable” (Ibid.) before any lifetime-extending investments would be carried out or any new coal/ lignite-fired power plants would be built. Finally, it emphasized that ”Should the political situation change on this issue [CCS], Vattenfall is far advanced in its development, but until then, our CCS work is being conducted on a smaller scale” (Annual Report, 2011: 6).

Vattenfall's R&D priorities were consequently shifted away from CCS, which had been the ”largest programme area in the Group” (Annual Report, 2010: 62) just one year earlier. The company instead focused its R&D efforts on offshore wind power, 'smart grids', on ”increasing the flexibility of existing heat and hydro power plants” (Annual Report, 2011: 42) and on the co-firing of fossil fuels with biomass as means of reducing the company's 'CO_2 exposure' (Ibid.).

Vattenfall announced that it had cancelled its CCS R&D program on 6 May 2014 (Vattenfall, 2014). Instead, the company would focus on ”efficient” R&D that could contribute to Vattenfall's business ”now and in the future” (Ibid.). In October 2014, the company announced that it had started to ”look into various alternatives for a new ownership structure for the lignite operations in Germany” (Annual and Sustainability Report, 2014: 9) in order to be able to ”transform the production portfolio towards lower CO_2-emitting sources and more renewables” (Ibid.).

In 2015, Vattenfall announced that it was initiating a sale of its lignite operations. The bidding process started on 22 September 2015 (Annual and Sustainability Report, 2015: 44). Eventually, the only bidder that remained in the process was a consortium of two actors – Czech energy company EPH and its 'financial partner' PPF Investments (Vattenfall, 2016b). Despite the vocal critique of EPH's environmental and economical record that erupted in the Swedish media, Vattenfall was given a green light to sell its lignite assets to EPH by the Swedish government in July 2016 (Vattenfall, 2016c). At the time of writing (September 2016), the sale is still in the process of being completed.

8. Concluding discussion

This paper has shown that Vattenfall produced a wide variety of expectations and visions on CCS. During the first phase, these expectations centered around the cost of the technology, the timetable for when it could be commercialized and its potential as a mitigation technology. While all of these issues involve social and political aspects, the expectations were presented in a more or less purely techno-economic, or technologically deterministic fashion (cf. part 7.1.). Vattenfall soon began viewing the oxyfuel process as the most promising of the capture technology contenders, and focused most of its R&D efforts on this technology. Vattenfall's high initial expectations arguably helped enroll its academic and industrial partners into the CCS project. They also helped CCS to be taken up in a local agenda – i.e. the realization of a ’cost-effective’ means of managing the ’externalities’ its newly acquired coal- and lignite-fired power plants produced. These findings match the results of previous expectation studies well (see e.g. van Lente & Rip, 1998).

Vattenfall also launched the vision of CCS as a technology which would allow for ’zero emissions’, or ’CO_2-free’, power plants during the first phase (Andersson et al., 2003; Strömberg, 2001). This vision was continuously reproduced during the second phase too.

During the second phase, Vattenfall’s expectations on CCS in general, and the oxyfuel process in particular, rose markedly. Vattenfall now expected the oxyfuel process to be considerably cheaper than post-combustion and pre-combustion technologies (Strömberg, 2003), and it was seen as ”the most promising for early commercialization” (CSR Report, 2009: 12). The oxyfuel process was also expected to allow for a ’(near) zero emission power plant’ – not just with regard to CO_2, but other pollutants too (Strömberg, 2003). In hindsight, it is clear that Vattenfall hyped its CCS project, and that this (technologically deterministic) hyping downplayed the many uncertainties and contingencies that would have to be overcome in order for CCS to materialize. Nevertheless, the materialization of full-scale CCS and the commercialization of the technology was beginning to be viewed as imminent during this phase (see part 7.2.).

The second phase also saw translations of ’promises’ into ’requirements’. The work that Vattenfall’s technologists put into meeting these ’requirements’ played a vital role in the materialization of the Schwarze Pumpe pilot plant. It could be argued that these ’promise-requirements conversions’ led to the emergence of a ’prospective structure’ – i.e. a ”not-yet-existing structure that is to be filled in with agency” (van Lente & Rip, 1998: 225), which ”is made up of links which can be found in texts. In subsequent actions and reactions, the structure is filled in, modified, reshuffled – and becomes social structure, in its various forms, i.e. emphatically including new technological artifacts” (Ibid.). The pilot plant can be seen as an emerging ’integration’ of Vattenfall’s oxyfuel process into a ’fully formed’ sociotechnical system, while simultaneously leaving room for trying out different ’configurations’ of the technology. An alternative interpretation is that the pilot plant itself was an emerging social structure, which retained some of the characteristics of a ’prospective structure’ (cf. van Lente & Rip, 1998).

During the third phase, Vattenfall’s expectations on CCS began turning into disappointment as they were confronted with reality. The expectation on when CCS would be commercialized was pushed back to ”2020 at the earliest” (Annual Report, 2010: 37). This was largely explained with reference to the uncertainty regarding the feasibility of investing €1.5 billion in the Jänschwalde demonstration plant under the risky and uncertain legal, political and social conditions in Germany (see part 7.3.). Vattenfall's expectations decidedly turned into disappointment when Germany did not adopt a uniform, nation-wide legal framework on CO_2 storage within an acceptable timeframe for Vattenfall. This led Vattenfall to cancel its planned investment in the Jänschwalde demonstration plant. It nevertheless carried on with its CCS R&D, but on a much more modest scale. This pattern aligns almost perfectly with the so-called 'hype-disappointment cycle' (see e.g. Porter & Randalls, 2014). Vattenfall cancelled its CCS R&D project in May 2014 and decided to sell its lignite assets in Germany in the fall of 2015. In my opinion, it is reasonable to assume that the failure of the CCS project made Vattenfall's coal and lignite operations (even more) unviable, since CCS was Vattenfall's only way of legitimizing its coal/lignite operations from an environmental perspective. CCS was also a way of 'ensuring' (to some extent) the future cost-efficiency of coal and lignite power production in *Energiewende*-Germany.

The analysis has also pointed toward the 'narratives', or 'stories' (Law, 2015; Selin, 2008) that Vattenfall employed in its 'expectation work' on CCS. A recurring narrative in the material is the scripting of CCS as a kind of technological 'savior' for the climate change issue. In this narrative, the consequences of *not* developing and deploying CCS are (implicitly) encoded as dystopic. For instance, Vattenfall stated that ”The risks of CCS are very small in comparison to the risks of not going for CCS” (CSR Report, 2007: 13). Furthermore, Vattenfall stated that ”If we do not take control of our emissions, we will be forced to make drastic changes to the conditions under which we – and more so our children and grandchildren – live” (Annual Report, 2004: 3). In this moralized narrative (cf. Berkhout, 2006), CCS implicitly becomes a means of assuring that 'we' and 'our children and grandchildren' do not have to suffer drastically changed life-conditions.

Another recurring narrative is that of CCS as an 'inevitability' if we are to reach ambitious climate stabilization targets (see also Hansson, 2008; 2012). For instance, Vattenfall stated that the EU's goal of reducing Europe's CO_2 emissions by 60-80 percent by 2050 ”can hardy be reached without the carbon capture and storage technology” (CSR Report, 2005: 28). At the same time, however, Vattenfall repeatedly emphasize that ”CCS is not a substitute for renewable energy sources” (CSR Report, 2009: 13), but one technology among a range of necessary mitigation technologies.

As we have seen, expectations played an important role in the 'rise' of the CCS project. I will here argue that expectations were equally important in the 'fall' of the project. As the analysis indicated, the CCS project did not necessarily fail because the oxyfuel technology itself failed. In fact, it seems to have performed above expectations at the Schwarze Pumpe pilot plant (Annual

Report, 2009: 21; Strömberg et al., 2009). Instead, much of Vattenfall's problems stemmed from its focus on *technical* expectations and techno-economic considerations and its lack of focus on overcoming the (embedded) social and political issues of the project. This allowed the complex sociopolitical reality in Germany to 'punch holes' in Vattenfall's expectations and visions of CCS (cf. Russell et al., 2012) – e.g. through the public protests against CO_2 storage that erupted and the consequent legal impasse around the transposition of the CCS Directive (see Shogenova et al., 2014; Voosen, 2010). This issue is also manifested by the general lack of *social* expectations and visions in the material for this paper. It seems that Vattenfall's failure largely consisted in it not being able to 'integrate' the *social* and *political* dimensions of CCS into a 'fully formed' *sociotechnical* system. Perhaps Vattenfall didn't spend enough time producing forceful 'expectation bids' (Berkhout, 2006) and visions of the society which would 'receive' the technology in order to convince the German public of CCS's perceived virtues?

Furthermore, Vattenfall suffered from a 'failure of imagination' with regard to its inability to predict the emergence of widespread public skepticism and protest towards CO_2 storage. As mentioned in part 7.3., this led to a belated focus on public dialogue and a lack of public participation measures at early stages of the project (cf. Daniels & Heiskanen, 2006). Ironically, Vattenfall could learn a thing or two from itself in this context, e.g. by reviewing its involvement in the preemptive public participation efforts on nuclear waste management in Sweden – even though these measures were problematic in many other respects (see e.g. Elam & Sundqvist, 2006).

Finally, I will discuss how Vattenfall's CCS project can be understood as a 'political device'. Firstly, it is obvious that the development of CCS lay in Vattenfall's sociopolitical interest as a state-owned company which has 'corporate social responsibility' embedded into its governing documents, which nevertheless decided to invest in German coal and lignite. As this paper has shown, Vattenfall quickly identified CCS as a promising opportunity after these acquisitions. This was likely because CCS represented a potential solution to Vattenfall's lignite conundrum, since it could function as a way of reducing its CO_2 emissions and of deflecting the criticism that was aimed against it for its dubious environmental behaviour. Hansson (2008: 247) has in this context argued that CCS was seen as a 'saving angel' by Vattenfall's Board of Directors.

Thus, CCS was a 'political device' in that it acted as a means of legitimizing Vattenfall's coal and lignite assets (cf. Hansson, 2008: 247). Vattenfall used its expectation on the 'ever-imminent' materialization of CCS as resource to *retrospectively* legitimize its initial coal/lignite acquisitions, and to *prospectively* legitimize the expansion of its coal/lignite assets. However, as soon as reality 'punched holes' in this expectation (cf. Russell et al., 2012), Vattenfall had to retract its earlier

’promise’ that Moorburg and Boxberg would be ’capture ready’, and instead promise that Moorburg and Boxberg would be the last power plants/generation units the company would build that would not be equipped with CCS (Annual Report, 2011: 6).

Lastly, CCS can function as a ’political device’ in that it is a way of keeping coal and lignite on the political agenda in the current context of increasingly ambitious climate targets. CCS can function as a means for incumbent energy companies to ’cling on’ to their market positions in this context, since CCS is a ’regime-led’ innovation, rather than a radical, disruptive innovation that has been developed in ’niches’ (see e.g. Winskel, 2012). CCS can therefore be viewed as a tool for incumbent energy companies to safeguard the industry’s ’status quo’, simultaneously as it allows them to ’colonize the future’ (cf. Hansson, 2012).

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