International Journal of Greenhouse Gas Control xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

Mobilizing private funds for carbon capture and storage: An exploratory field study in the Netherlands

Mark Sanders[a,*], Sabine Fuss[b,c], Peter-Jan Engelen[a]

[a] Utrecht School of Economics, Utrecht University, Utrecht, The Netherlands
[b] Mercator Reseearch Institute on Global Commons and Climate Change (MCC), Berlin, Germany
[c] International Institute for Applied Systems Analysis, Ecosystems Services and Management Program, Laxenburg, Austria

ARTICLE INFO

Article history:
Received 1 March 2012
Received in revised form 17 May 2013
Accepted 9 September 2013
Available online xxx

Keywords:
Real options
Investment under uncertainty
Carbon capture and storage
Case studies
Structured interviews

ABSTRACT

Investors have typically been hesitant to commit resources to the decarbonization of energy production as CCS investments combine large up-front investment outlays, a long planning horizon, different sources of uncertainty and irreversibility of the capital expenditure. The real option literature offers a vast amount of models to handle investment decisions in such a context. This exploratory study conducts structured interviews with a number of investors in the Netherlands to understand how CCS investment decisions are actually made. The interviews were based on stylized, but realistic business cases in which important real option characteristics are deliberately embedded. Our objective was to analyze whether these options were recognized and whether the decisions of those investors are in line with real option theory. We find that real option models may predict outcomes more or less adequately at the macro level, but do not (fully) describe the micro level behavior of investors. We develop some tentative recommendations for policymakers who want to promote the private funding of CCS projects and formulate the outline for follow-up research to confirm the preliminary findings of this exploratory study.

1. Introduction

Carbon dioxide Capture and Storage (CCS) is generally considered an important if not indispensable tool in curbing global CO_2 emissions and keeping global temperature increases below the critical 2 °C threshold (EC, 2011; Gibbins and Chalmers, 2008; Odenberger and Johnsson, 2010). Several studies have also computed the required investments in CCS infrastructure and installations to achieve these emissions reductions and, although they differ in the details, it is clear that a massive challenge lies ahead (Bennaceur and Gielen, 2010; Chalmers and Gibbins, 2007; Gibbins and Chalmers, 2008; Heal and Kristrom, 2002; Oliver, 2008). Finally, the recent financial crisis clearly shows that crisis-struck government budgets leave little room for heavy public funding of this effort. If CCS is to play a significant and timely role in mitigating further climate change, the private sector will have to engage and public policy should be redirected toward mobilizing private sector funding to create the leverage needed to implement CCS at the desired scale.

The private sector, however, has its own investment logic. Private investors, corporations and banks all face hard budget constraints and will only commit financial resources if a sound business case can be made. They have to operate in a global and competitive environment and cannot afford too many loss-making projects or take excessive risks onto their balance sheets (Cassimon et al., 2003). Investing in CCS can only be considered if projects pass the test of commercial viability. It seems that the answer to this test is currently negative, as private firms are very hesitant to make the required large investments (The Economist, 2009). Golombek et al. (2011) review all major energy assessments with respect to the diffusion of CCS in Europe. In general, diffusion is found to occur either in the second half of this century and/or at relatively high carbon prices, even though the pictures is diverse and results across studies differ with respect to whether CCS is considered as a retrofit or green field investment. The authors find that substantially lower CCS costs would be necessary to make retrofitted CCS profitable. Furthermore, if the CO_2 price in 2030 would be much lower than US$90 (e.g., more in the area of today's ETS prices) then there will be no CCS green field investments either. Given the large up-front investment costs, the long planning horizon and different sources of uncertainty, companies are not making any investments in CCS. This situation of inertia is arguably the result of large, non-diversifiable and systemic uncertainties individual private firms face. What can policy makers do to overcome the thresholds and lock-ins? To answer such questions, we need to carefully investigate the actual investment decisions that the parties in the CCS chain face.

Recent advances in investment theory have allowed economists to analyze corporate investment decisions under uncertainty,

* Corresponding author. Tel.: +31 641243557; fax: +31 302537500.
E-mail address: m.w.j.l.sanders@uu.nl (M. Sanders).

1750-5836/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijggc.2013.09.015

which obviously is highly relevant for CCS. The application of theoretical insights of so-called real option models to CCS projects, however, is relatively rare in the literature and testing such theoretical investment decision models empirically has not been done. The reason is pretty mundane. Very little data can be gathered. CCS investments to date are typically not made without substantial government grants and subsidies. For instance, the European Union (EU) decided in 2007 to develop 12 flagship demonstration projects of CCS by 2015 (Gibbins and Chalmers, 2008). Operational projects on commercial scale are rare and, for those can be found, the data relevant for testing investment decision theory is typically confidential and not easily and freely available.[1]

To bridge this gap this exploratory study discusses three custom-made stylized cases of CCS projects presented during structured interviews to relevant private sector decision makers. The business cases were explicitly constructed to incorporate important 'real options' characteristics to assess whether decision makers would respond to their presence in way theory predicts. The study was aimed to confront actual decisions with decisions predicted by real option theory. As any real option behavior should come in a natural way, the research was deliberately designed in such a way that real option reasoning and models were not instructed to the decision-makers as not to lead them to the 'correct' decision. Instead the study examines if their usual decision rules would help them uncover and appreciate the planted real options. The cases were all designed to have a positive net present value (NPV) but for different reasons would not be likely to be accepted at first glance. These decision makers were then asked to reflect on these cases during a structured interview (Denzin and Lincoln, 2000; Lindlof and Taylor, 2010). The interviewing team went over the cases with the decision maker and eliminated one by one all bottlenecks in the case until the interviewee would indicate a positive final investment decision could be made. In going over the cases in this circular fashion the interviews allowed us to identify key impediments to CCS investments and test these against the variables real options theory would suggest being important to trigger the investment decision.

The article is organized as follows. In Section 2 we shortly discuss the relevant literature on investment decisions, real options and real options in CCS. This results in a taxonomy of relevant real options for CCS, presented in Section 3, that inspired our case studies. The general research methodology and construction of the stylized cases is described in Section 4. Section 5 discusses the results based on the data collected in the interviews we conducted. Section 6 concludes and sketches an agenda for further research.

2. Literature review: from investment decisions to real options to real options in CCS

Allocating resources through investment opportunities is traditionally evaluated using a net present value approach. The inherent limitations of such approach are well-documented. It assumes a now-or-never decision and assumes the decision maker to follow a rigid path once the investment decision is taken (Feinstein and Lander, 2002). In reality, in a competitive environment with uncertainty and change, projects will not crystallize in the same shape as the decision maker has initially envisioned (Cassimon et al., 2004). This is especially true with respect to climate change (Heal and Kristrom, 2002). During the lifetime of the project new information might arrive or certain sources of uncertainty might be resolved, making it valuable to adjust the project (Trigeorgis, 2000). The cost–benefit model cannot handle operational flexibilities such as delaying, scaling-up/down, shutting down/restarting or abandoning a project (Guerrero, 2007). Dixit and Pindyck (1994) stress the importance of timing an investment decision. This implies that decision makers in actual investment projects have the option to wait/postpone the final investment decision. And they may have good reasons to do so if additional relevant information can be expected to reveal itself over time. An investment decision is the right, not the obligation to commit resources and reap future rewards.[2] This gives most investment decisions an option character.[3]

This option character is valuable in an investment environment characterized by the simultaneous existence of uncertainty, irreversibility of investment and some freedom on the timing of the investment. In theory, taking into account the value of flexibility implies that a firm will invest only if the NPV of the project exceeds the value of keeping the option alive (i.e., not commit the resources). Similarly, a firm will only disinvest in a project if its NPV falls sufficiently below zero to warrant giving up the option to continue operations in the future.

Real options theory can thus explain the higher than expected hurdle rates that firms and investors typically apply when considering investment decisions. The decision makers interviewed during the course of this study do not represent an exception. It is, however, useful to first review the seminal real options literature, before going into the more specific applications to CCS and eventually develop a taxonomy to form the basis for the analysis of the interview results.

2.1. Real options theory

Options valuation and pricing models have originally been devised to value financial options (Black and Scholes, 1973). Arrow and Fisher (1974) were among the pioneers incorporating irreversibility and uncertainty into a model where decisions about environmental preservation need to be made. Henry (1974) investigates the so-called "irreversibility effect", i.e., the effect that decisions that previously appeared to be economical become unattractive when irreversibility is taken into account. Furthermore, his findings show that the irreversibility effect is enhanced by an increase in uncertainty. Although both articles touched upon the concept of irreversibility and uncertainty, it was not until the 1980s that real option modeling of decision making under uncertainty took off.

Different theoretical types of real options have been developed in the early literature, such as options to delay (McDonald and Siegel, 1986), scale options (Trigeorgis and Mason, 1987), and options to abandon (Myers and Majd, 1990). For instance, McDonald and Siegel (1986) consider an investment decision with sunk costs, where the value of the project and the investment costs are stochastic variables growing in time, while Majd and Pindyck (1987) develop a model in which sequential investments can be analyzed with the option to abandon the project midstream.

[1] For instance, CGI (2010) listed 328 (non-R&D) projects in CCS worldwide of which 80 involved integrated CCS of which a mere 9 had reached the operational stage.

[2] This strongly contrasts with traditional approaches that rely on the NPV-rule, such as Jorgenson's (1963) "per period marginal product equals per period rental cost" approach and the equivalent Tobin's (1969) q theory of investment. See e.g. Nickell (1978) and Abel (1983) for more details on the "user cost" and "Tobin's q" theories of investment, respectively.

[3] In general, an option can be defined as the right, but not the obligation, to buy (call-option) or sell (put-option) the underlying asset at an agreed price (strike price or exercise price) during a specific period (as in the case of American options) or at a predetermined expiration date (as in the case of European options). In contrast with financial options, real options refer to the application of the options concept to real physical investment opportunities.

Table 1
Value drivers of financial and real options and notation.

Symbol	Value of put (P) and call (C)	Financial options definition	Real options analogy
V	P(−), C(+)	Underlying asset price	Present (expected) value of cash flows
I	P(+), C(−)	Strike price	Investment costs
σ^2	P(+), C(+)	Volatility of underlying asset return	Volatility of underlying project return
T	P(+), C(+)	Time to maturity	Window of opportunity
r	P(−), C(+)	Risk free rate	Risk free rate
δ	P(+), C(−)	Amount of dividend payments	Opportunity cost of keeping option alive

What all these models have in common, is that they draw a parallel between the structure of financial options' pay-offs and the pay-offs a firm or investor can obtain from a real investment project. Consequently, the argument is made that fundamental value drivers of financial options are also relevant for the valuation of real investment projects. Table 1 gives an overview of the basic value drivers of financial options and the corresponding variables in real investment projects. We return below to the intuitions behind these value drivers.

The applications to natural resources have been vast in real options theory. Paddock et al. (1988), for example, focus on undeveloped oil reserves and found that, empirically, the real options valuation performs better than the traditional discounted cash flow (DCF) method. Brennan and Schwartz (1985) investigated whether and when it is optimal to take a copper mine into operation when the price of copper follows a stochastic process. Similarly, Pindyck (1980) used real options to compute the optimal exploitation strategy for an exhaustible resource, but in this case it is not only the future cash flow, but also the level of the resource reserve that can vary stochastically. More recent literature applied real option models to project and company valuation in different sectors, such as consumer electronics (Lint and Pennings, 2001), pharmaceutical R&D (Cassimon et al., 2011a), mobile payment innovations (Cassimon et al., 2011b) or even criminal behavior (Engelen, 2004). CCS investments have also been modeled recently using the real option approach. In the next section, we focus on the most important contributions on CCS, without making any claim for completeness.

2.2. Real options in CCS

Reinelt and Keith (2007) focused on the social cost of CO_2 price uncertainty, which is enhanced by investment irreversibility and alleviated by the competitiveness of technologies with relatively inexpensive carbon capture retrofit opportunities. Blyth and Yang (2007) concluded that potential jumps in the carbon price create uncertainty, raise the option value of investment and lead to the postponement of investments in CCS. Abadie and Chamorro (2008) conducted a real options analysis of investment in a capture unit, modeling the permit price as a Geometric Brownian Motion (GBM) and the electricity price as a Mean-Reverting (MR) process. They found that the current technological development and regulatory framework do not seem to encourage an early adoption of CCS and concluded that climate policies need to be more stringent.

Szolgayova et al. (2008) investigated the decision of a coal-fired power plant owner that considers replacing the expiring capacity with a new coal-fired power plant that can be retrofitted with a CCS module or with a biomass-fired power plant. The latter has the extra bonus of sequestering CO_2 during the fuel-generation process and can be adjusted to capture carbon as well. With respect to CO_2 price uncertainty, their analysis showed that even for moderately rising CO_2 prices, fluctuations frequently lead to investment into CCS, as the trigger level is exceeded more and more often – unless there is a price cap or safety valve capping the price below the investment threshold.

Fuss et al. (2009) presented a real options model where multiple options are evaluated simultaneously so that the effect of the individual options on each other is accounted for. Three typical technologies are included in the analysis: generation equipment based on fossil fuel, fossil fuel with carbon capture, and renewable energy, respectively. In this way, the transition from CO_2-intensive to CO_2-neutral electricity production in the face of rising but uncertain CO_2 prices can be analyzed. The authors also found that larger price uncertainty leads to postponing investment and higher cumulative CO_2 emissions. They showed that it is preferable to have climate change policies that are stable over a certain length of time and change abruptly. Less abrupt but more frequently changing policies are more detrimental to investment in CCS.

Recently, Heydari et al. (2010) have built an analytical real options model, where the plant owner may decide to invest in either full CCS or partial CCS retrofits given uncertain electricity, CO_2, and coal prices. They showed that for low enough price volatilities the investment region is dichotomous, which implies that for a given fuel price, retrofitting to the full CCS technology is optimal if the CO_2 price increases and vice versa if it decreases sufficiently. However, calibration with current market data indicated that retrofit is suboptimal.

3. A taxonomy of real options in CCS

The extant literature on investments under uncertainty distinguishes a number of typical real option formats. These will also be important in the analysis of the business cases and interviews in the following sections. Section 3.1 therefore establishes the basic real options types, while Section 3.2 will elaborate on this categorization of different real options types.

3.1. Categorization for CCS cases

The real option mostly considered in the seminal literature is a simple investment timing option. A second type of real option is an "operational flexibility option". The flexibility (at some additional cost) to scale up (expand), to scale down (contract), to stop and restart operations or to switch to other inputs or outputs in response to market and cost developments can be valued within a real option framework as well. A third type we distinguish is the "option to abandon" the project at salvage value, which is especially important for projects involving flexible multipurpose assets. Finally, there are "growth/compound options" which open up new options upon exercise. This type of option is important when investments are needed, e.g., to develop new technology or open up new markets. More finely grained taxonomies have been offered in the literature (see e.g., Trigeorgis, 2005 for further discussion) but our four types of real options generally cover most business opportunities. Table 2 summarizes the categories of real options most relevant for the CCS business cases covered in this article. In the following section, we will give an overview of the literature in this context.

Putting the literature review in Section 2.2 on CCS into the context of the categorization in Table 2, it immediately becomes clear that most options fall into the area of "operational" and "timing

Please cite this article in press as: Sanders, M., et al., Mobilizing private funds for carbon capture and storage: An exploratory field study in the Netherlands. Int. J. Greenhouse Gas Control (2013), http://dx.doi.org/10.1016/j.ijggc.2013.09.015

Table 2
Types of real options in this study.

Type	Description
Timing option	In the face of uncertainty, which gets resolved over time, there is an economic value of being flexible and of timing investments differently.
Operational option	Fluctuations in demand or input prices/availability make the option to suspend operations and resume at a later point in time valuable.
Option to abandon	Especially in the case of sequential decision-making, if there is an option to abandon a project, investments with a standard NPV < 0 could still be deemed attractive if the salvage value is high and the abandonment option is valued.
Growth option/compound option	Exercising the option of investing in an R&D or pilot project opens up new option(s) for the decision maker, e.g. turning a previously negative NPV of installing a plant positive.

options". Most of the papers analyze the impact of regulatory or market uncertainty on the timing of adoption of CCS investments. Many also consider the option value of building capture-ready installations in face of regulatory uncertainty. Some of the papers also include additional "post-investment" operational flexibility options. For instance, Szolgayova et al. (2008) consider the flexibility to turn the capture installation on and off in response to fluctuations in the carbon price. Both the energy penalty and the additional outlays in terms of operations and maintenance and transport and storage can thus be suspended if the economic trade-off changes due to volatility.

Abandonment options and growth options have not been the subject of the CCS real options literature to date. The reason for that might be that the installation of CCS equipment is typically not a mature business yet and even in the face of decreasing costs, big uncertainties remain about the potential of storage without leakage, the network externalities involved in building a pipeline infrastructure for transport and issues of social acceptance. However, the analysis of the cases and interviews will show that these options are also highly relevant for decision makers in practice if projects are structured accordingly. We feel this is an important gap to be filled in the CCS literature.

3.2. Formal comparison

A firm will postpone the final investment decision on a project when the value of waiting, as captured by the real option value C_0 exceeds the value of immediately investing $(V_0 - I_0)$,[4] with V_0 being the present value of all expected operating cash flows over the lifetime of the project and I_0 being the required (present value of) investment expenditure on the project:

$$\begin{cases} C_0 > V_0 - I_0 \rightarrow postpone \\ C_0 < V_0 - I_0 \rightarrow invest \quad now \end{cases} \tag{1}$$

Rearranging Eq. (1) gives further insight into what triggers immediate investment. Eq. (2) shows that the project should not only have a positive (present) value, but also that this value should exceed the value of waiting:

$$V_0 > I_0 + C_0 \tag{2}$$

[4] The value of immediate investment $(V_0 - I_0)$ is equivalent to an NPV calculation.

As a deferral option is equivalent to a call-option, the project is sensitive to the same six value drivers of any call option: the real option value increases with a higher underlying value, a longer time to maturity, a higher volatility of the asset return[5] or a higher risk-free rate, while it decreases with a higher exercise price or a higher opportunity cost (Hull, 2011). The threshold value $(I_0 + C_0)$ that triggers investment depends therefore on the time the decision can be delayed, the level of uncertainty over future cash flows, the project's cost of capital and the opportunity cost of waiting (Blyth et al., 2007). Reducing (perceived) uncertainty (e.g., access to more, better and reliable information on government policies, market developments, technological evolutions), increasing the opportunity cost of waiting (e.g., loss of first-mover advantages or a limited subsidy window) or staging investment outlays are ways to induce earlier investment.

Growth options exist when a project consists of separate sequential phases, in the sense that one phase is a prerequisite for the following phase. This is, for example, the case when a project is a pilot for a large-scale follow-up project. It is clear that this pilot project has option characteristics. The large-scale project can only be considered when the firm has indeed decided to execute the pilot phase, but investing in the pilot project does not commit the firm to invest in the follow-up project (Cassimon et al., 2011b). As such, the pilot project gives the firm the possibility to go on to the large-scale project. The investment cost of the large-scale project and the additional future cash flows are respectively the exercise price and the underlying asset of the growth option and drive the value of this growth option. This value should be taken into account when calculating the value of the pilot project, by *adding* it (C_0) to the conventionally calculated net present value $(V_0 - I_0)$ of the pilot phase:

$$(V_0 - I_0)^{phase1} + C_0^{phase2} > 0 \tag{3}$$

If the sum of the growth option and the net present value of the pilot phase is positive, the firm should invest in the pilot project as the entire project has enough upside potential to compensate for the (likely) initial losses in the pilot phase. In the other case the pilot project (and thus the entire project) should be rejected. When more than two phases are involved growth options can be valued as compound options (Cassimon et al., 2011a). The option value of the second phase includes in this case also the option values of the subsequent phases. The cost of the pilot phase can alternatively be considered as the premium to obtain the option. It is clear from Eq. (3) that investors should care about the value drivers of the growth option as well as the pilot project itself. That is, by the logic explained above, the lifetime of the option (+), the volatility of underlying cash flows *in the follow-up project* (+), the magnitude of the initial loss of the pilot phase (−) and the second stage investment costs (−) all affect the value of the entire project directly (Cassimon et al., 2004).

If market conditions deteriorate, management can also consider terminating and abandoning the project permanently. Having the option to realize a certain salvage value puts a floor to the potential losses of a project and thus adds value in comparison to the same project without this possibility. Management compares the project value as a going concern with the liquidation value the firm can realize upon termination of the project. This managerial decision

[5] The choice for a specific type of stochastic process in the case of the carbon price and its parameterization both have an influence on the option value and thus the optimal timing of the investment. Often a Geometric Brownian Motion (GBM) is selected in line with the shadow carbon price development accompanying most stabilization targets. A higher trend will obviously lead to earlier investment, while higher volatility will increase the option value and thus lead to later investment (see also Dixit and Pindyck, 1994 for a treatment of different stochastic processes and the impact of their parameters on the option value).

Please cite this article in press as: Sanders, M., et al., Mobilizing private funds for carbon capture and storage: An exploratory field study in the Netherlands. Int. J. Greenhouse Gas Control (2013), http://dx.doi.org/10.1016/j.ijggc.2013.09.015

Table 3
Overview of real option decision rules.

Real option type	Modeling type	Decision rule	References	Examples in the CCS literature
Option to delay	Call option	$\begin{cases} C_0 > V_0 - I_0 \rightarrow postpone \\ C_0 < V_0 - I_0 \rightarrow invest\ \ now \end{cases}$	McDonald and Siegel (1986), Ingersoll et al. (1992)	Abadie and Chamorro (2008), Fuss et al. (2008) and Zhou et al. (2010)
Growth option	Compound option	$(V_0 - I_0)^{phase1} + C_0^{phase2} > 0$	Cassimon et al. (2011a, 2011b), Pindyck (1988)	None
Option to abandon	Put option	$(V_0 - I_0) + P_0 > 0$	Myers and Majd (1990)	None
Option to shut down and restart	Call option	$(V_0 - I_0) + C_0 > 0$	Brennan and Schwartz (1985), Dixit (1989)	Szolgayova et al. (2008)

can be interpreted and valued as a "put option", the right to sell an asset at a predetermined price at or up to a predetermined point in time (Myers and Majd, 1990). When the value of continuing a project V_t (the expected present value of all remaining future cash flows) drops below its current liquidation value L_t, management should rationally terminate the project. The value of a project with an abandonment option is then given by:

$$(V_0 - I_0) + P_0, \tag{4}$$

with V_0 and I_0 as defined above and P_0 as the value of the put option. At each decision node, for instance every year, the firm has the possibility to reap the highest of V_t (receiving the present value of the remaining cash flows) and L_t (the level of the liquidation value at that moment): $\max(V_t, L_t)$. This makes clear that the value of a project in the presence of an option to abandon is directly linked to the (potentially uncertain) liquidation value of the project over time. This limits the downside potential of a project and thereby increases its value.

Operational options include options to expand, contract, suspend and resume operations and the option to switch inputs or outputs during operation (e.g., switching fuel). A shut down and restart option assumes that a project does not have to be operated permanently. Depending on the net revenues and (marginal) costs management can temporarily suspend operations and resume once net revenues cover the (variable) cost of operation. Management has the option to receive the project's net revenues minus the variable costs when the project is operated in a given year (Trigeorgis, 2000). The value of the project in any given year is thus:

$$\max(cf_t - vc_t, 0) \tag{5}$$

with cf_t that year's cash revenues and vc_t the variable costs of operation. The value of this call option, C_0, is equal to the risk-neutral discounted value of a sum of (5) over the lifetime of the project minus the project value without flexibility $(V_0 - I_0)$. From the equation we can see that the asset will be operated if and only if the revenue exceeds the variables costs. This limits the downside risk to the fixed costs and therefore the project value should respond positively to increasing volatility in variable costs and in operating cash flows. Intuitively, all else equal, in more volatile environments, the value of operational flexibility is higher. The option to scale up (expand) can be seen as a call option in a similar way as a growth option, while the option to scale down (contract) can be seen as a put option similar to an option to abandon. Table 3 summarizes the different option types and their corresponding investment decision rules.

4. Methodology and data collection

In the literature researchers typically tests the predictions of investment theory by deriving predictions on outcomes of decision processes and confronting these with (quantitative) data on observed investment behavior (e.g., Cassimon et al., 2003). By taking that approach, however, one tests if the models are able to predict the decision and design projects and policies to mobilize private funds. A drawback of that methodology is that it is hard to collect data on projects postponed or abandoned. In addition and more fundamentally, to show that one theory may explain an observed behavior is not the same as showing that such behavior follows that theory. This is why we took an alternative approach and decided to unravel the decision making process in a series of interviews with decision makers in the field. In a first wave of ten interviews we discussed investment decisions in CCS with investors and financiers in an open format.[6] From these interviews it was clear that basic NPV-calculations fall short of explaining actual investors' behavior. From our interviews we could conclude that uncertainty, irreversibilities and project specifics play a key role. The expected NPV should of course be positive, but this turned out to be a necessary, not a sufficient condition. We therefore turned to the more sophisticated real option models described above. These models aim to address several of the issues raised in the first round of interviews and we decided to test their predictive power in an exploratory study by carrying out a second round of six structured interviews. As this is an exploratory study sample size and representativeness were less of a concern. For these second interviews the interviewees were asked to select one of three business cases we prepared (see their description in detail below). These cases all had real options characteristics incorporated in them, but the option values were deliberately not calculated or mentioned explicitly. Instead the financial projections showed a positive expected NPV for all the projects and the real options were described implicitly in the business case documentation. The structure of the interview was then designed to uncover what steps an investor would have to take before getting from an incomplete and uncertain proposition containing somewhat hidden real options, to a final investment decision in which resources are committed. In analyzing the steps an investor took in evaluating these business cases, we uncovered if and to what extent they attached value to the real options that were embedded in the business cases. The structure of the interviews is shown in Appendix 1. In the remainder of this section we first describe the business cases and discuss explicitly what option(s) were embedded in these cases. The next section turns to the interviews and concludes.

4.1. Case descriptions

To measure key CCS investment triggers by means of structured interviews with managers three business cases have been formulated. They will be described shortly in this section.[7] It should be noted here that, although inspired on actual projects in CCS, these

[6] More information on the open format interviews can be found in Sanders (2010). A detailed discussion of those results is outside the confines of this paper, but it is available upon request from the authors.
[7] The elaborate description of these cases is presented in Sanders (2011) which is available upon request from the authors.

cases are purely hypothetical and written for research purposes only. As our first round of interviews has clearly indicated that the reputation of business partners is of great importance, the cases did use existing company names. The cases have been manipulated to serve our research purposes, however, and should in no way be regarded as an adequate description of projects currently being undertaken or considered by the companies mentioned in them. Interviewees were asked to select the case that was closest to their interest and usual business based on short descriptions presented in this section.

4.2. Business Case 1

The first case is about a startup project called Nano BV. NanoMembranes will develop retrofit membrane separation solutions for carbon capture at commercially viable scales for existing coal fired power generation. These membranes do not require expensive chemicals, high energy input or high maintenance and their operation does not interfere with running operations in the plant. These advantages make membranes a likely candidate for future market dominance. There are, however, some engineering challenges that remain. NanoMembranes is perfectly positioned to address these challenges and develop the industrial standard in the emerging retrofit market. We ask for €2.5 million in convertible loans to take our venture to the next stage.

Business Case 1 clearly targets the venture capitalists and private equity investors in the sample. As we had concluded from our first wave of interviews, they would be interested in smaller scale, high-risk technology start-up firms, where venture capital can help grow a new business into a mature market. The most important characteristic in this case is the growth potential. Obviously, an important growth option was therefore embedded in this business case. The proposed scaling up of the membrane technology carries significant technical and engineering risks, but if successful it was described to have the potential to become the industrial standard in a very large market for retrofit CCS on coal fired power plants.

Real option theory predicts that investors should care a lot about the uncertainty surrounding the potential future market as well as the costs of entering the next stage. It also predicts they should be triggered to engage in the project if the upside potential in the follow-up stages is high. Downside risks in the follow-up stages should play a limited role, as that downside risk does not affect the value of the option. This implies that higher mean-preserving spreads in the distribution of expected outcomes should increase the value of the first stage, everything else being equal. The length of time until a decision on moving toward the second stage needs to be taken, should affect the project value positively. Finally, a higher strike price of the second stage and the costs of moving into the full-scale market would reduce the value of the option. Real option theory predicts that investors' decisions should be driven by these aspects: investors should request information about it, should be willing to pay for such information and should delay or abandon the project if these variables affect the value of the pilot stage negatively.

4.3. Business Case 2

The second case is entitled Carbon Sara Shipping BV. Carbon Sara is a 1250 m^3 liquid gas tanker, equipped for transporting CO_2. With this new vessel Carbon Sara Shipping BV will provide CO_2 transportation services to an emerging market for carbon capture and storage in the Rotterdam Port area. The ship is under construction and will be funded by bank loan (€30 million) and equity provided by the controlling partner (€15 million) and commendatory partners (€10 million). Due to bank loan leverage and a high residual value of the ship if the venture fails, the project offers a projected IRR of 12% for equity holders, with little downward risk and big upside potential.

In business case 2 the technical and engineering risks are largely eliminated. Instead the shipping concept revolves around operational flexibility to handle market uncertainty. Shipping CO_2 is expensive relative to the alternative of transporting it to the storage sites by pipeline (Decarre et al., 2010; Schoots et al., 2011). These dedicated pipelines, however, lack the flexibility of shipping. Ships can be deployed on different shipping lanes and in the end can also be converted to shipping other industrial gasses or even liquids. This means costs are not fully irreversible in the project and can be recovered by switching source, sink or even market if things turn out unfavorable. Another important issue in this case is the uncertainty over the speed at which the complementary infrastructure will be built.

Real option theory predicts that investors should care a lot about the salvage value of the assets and should be triggered to engage in the project if the salvage value is high enough, limiting the downside risk. The presence of a (secure) abandonment option implies, however, that the value of the project responds asymmetrically to increases and decreases in the present value of cash flows. This implies that mean-preserving increasing spreads in expected present value should increase the value of the project, as would an increase in the planning horizon of the project. In theory the decision makers should value uncertainty less negatively as the salvage value increases and a valuable and realistic fall-back option exists.

4.4. Business Case 3

Finally, in the Maasvlakte CCS Project BV case, investors/asset developers are given the option to invest in a carbon capture, transport and storage facility on the Tweede Maasvlakte in Rotterdam, the Netherlands. This waste treatment facility will offer flue gas scrubbing services to two newly constructed coal fired power plants at this site. Contracts have been signed on future delivery of services. The project is subject to electricity price and CO_2 emission rights price risk. The newly formed Maasvlakte CCS Project C.V. now offers investors the opportunity to obtain a 20% equity share in the new venture. For equity investors the projected IRR is 7%.

For business case 3 the technical and engineering risks were also eliminated and operational flexibility was reduced to the operation of the plant. Capital costs are sunk completely as there is no salvage value over and beyond the scrapping value. Irreversibility thus plays a large role in this project. This project, however, is integrated from source to sink, such that few transactional risks and uncertainty over complementary infrastructure remain.

Real option theory predicts that investors in this project would care a lot about the volatility in variable costs and revenues (Chalmers et al., 2009; Cohen et al., 2010). The option to shut down and restart operations under (un)favorable price movements implies that the uncertainty over CO_2 prices and wholesale electricity prices affects the value of the project asymmetrically. Higher CO_2 prices and lower electricity prices increase the revenues and reduce the (opportunity) costs of operating the CCS installation, increasing the value of the project and vice versa. However, due to the stop/restart option the downside risk is limited and more uncertainty over electricity and CO_2 prices should increase the value of the operational flexibility (but also increase the value of the option to postpone) compared to a project without this option.

4.5. Survey technique

All participants in the structured interview round were selected on the basis of their expertise and involvement in investment decision-making. The interviews took at least two hours each, excluding time for preparation. The interviewees were approached through various channels, but all come from the professional network of the researchers and the CATO2-consortium. On the one hand, having interviewees from this network increased the response rate significantly; in fact, all requests for interviews were granted. On the other hand, questions might be raised about generalizing our conclusions to the entire population of investment decision makers. Our results should therefore be considered as indicative and tentative. Still the cases above were each discussed in-depth with at least two decision makers and these interviews reveal some interesting insights to which we turn below. To prepare the cases, two experts involved in developing a shipping concept and a pilot in CCS were interviewed with an open format in a preparatory round prior to a last wave of six interviews where the cases were discussed in a closed format (see Appendix 1). The results of both open and closed format interviews are reported below as the former already provided very useful and interesting insights.

The structure of the closed interviews was such that the interviewer would lead the interviewee from an initial rejection of the project to a final investment decision by providing all required additional information (hypothetical) and manipulating the various triggers and levers in the business cases to make them attractive enough to consider committing resources. For example, if the interviewee would indicate that the internal rate of return in the business case was the reason to reject, the interviewer would ask for a critical value to re-evaluate and then tell the interviewee to assume an additional subsidy would reduce capital costs in such a way that the critical level could be reached. In this way the business cases were evaluated step by step, allowing us to identify the main concerns for investors in order of importance.[8]

5. Results

5.1. Business case 1: NanoMembranes BV

Business case 1 was discussed in closed format with one private equity fund manager and one venture capital fund manager. From the interviews, we can conclude that early stage investors indeed see the option value of a new venture start-up and quickly zoom in on the relevant risk factors to value the growth potential. They tried to obtain additional information to reduce uncertainty as predicted by real options theory. In this case the key uncertainties were technological (scalability) and commercial viability and market dominance (will the retrofit market emerge and how competitive will membranes be within this market). They requested information on the technology and were looking for comfort on that front. They generally were more at ease with market uncertainty, although more information on competing options and total market size predictions was also requested.

As both interviewees indicated, investing in early stage ventures remains primarily an intuitive (group) decision, not a strictly financial computation. The venture capitalists and private equity firms have structures in place that aim to prevent "group-thinking" and are biased toward "decline" by the unanimous decision-making conventions. A project needs to fit well with the funds' area of expertise to allow the fund to "add value" to the project. A good match reduces the information and verification costs, especially on the market risk, and thereby increases the viability and attractiveness of the project to the investor (Sahlmann, 1990).

The interviewees recognized and asked for information to value the growth option and the venture capitalist explicitly discussed the option to "mothball" the venture, conditional on some fundamental uncertainties to be resolved. This option, however, was not spontaneously selected. Typically venture capital and private equity investors want to "close the deal". That is, they continue to request, collect and verify information until they can either abandon or take the project to the next stage. The timing option seems less relevant. From the general discussion of this case (and more so below) this has to do with the fact that the information on the case is costly to collect and will lose value over time. Another concern, particularly acute in venture capital and private equity funding, is competition. There are more investors looking for good prospects and the challenge is to quickly separate lemons from peaches and contract the latter quickly. That typically requires proceeding to the next, contractual, stage. So even if the project itself has a clear timing option, the marketability of the project implies that the option is not an exclusive right for the evaluator and thereby valued much less from the investor's viewpoint. Real option theory indeed predicts that a high level of opportunity cost of waiting (such as the probability that a competing private equity fund will contract the project in the mean time) will significantly reduce the timing option to defer the investment decision. The choice for a venture capitalist or private equity investor is in that sense closer to the traditional "now-or-never" type of investments that standard NPV calculations address.

5.2. Business case 2: Carbon Sara CV

Business case 2 was discussed in an open format with a new business developer at a company providing tank terminal capacity globally, and in a closed format with an international shipping company. From a real options perspective the open interview was perhaps more revealing than the structured interview on the case. In the open interview the importance of operational flexibility and multipurpose assets was clearly mentioned, whereas such considerations were not explicitly recognized in the closed interview. The information requested in the closed interview was all aimed at verifying that the project was well embedded in a chain where risks are minimized and engineering is optimized over the entire chain. The case was intended to be a potential stand-alone project in a world where such an (emerging) infrastructure is already being built, but it seems that this was too far from reality today to be seriously considered.

We can therefore not draw very strong conclusions on the validity of real option theory in general and for the shipping concept in CCS specifically on the basis of one closed interview. The discussion about the sizing of the ship right at the start made the interview highly hypothetical. In addition, the interviewee's day-to-day business was not to evaluate and decide on investment proposals but rather to develop such ideas for the consideration of the board. Naturally, this implied the interviewee was more focused on "making the case more realistic". Moreover, both interviewees are heavily involved in *CINTRA* (an actual project in developing a carbon transport and shipping concept in Rotterdam) and it is naturally hard to distance oneself from all the knowledge accumulated in that project when evaluating a hypothetical case that is close but different in many details. As such it could be expected the interviewee would not really explicitly appreciate the real options aspects in the business case introduced by the operational flexibility (in routing) and multipurpose asset (the ship).

A very interesting and unexpected outcome of the interview, however, is that family businesses offer an additional and unique source of funding for CCS. As these firms apply longer time horizons, longer depreciation schedules and lower hurdle rates for the IRR (e.g., Zellweger, 2007), these funds may well be effectively mobilized for CCS projects if designed to cater to these firms' preferences on risk (sharing). Family firms may well provide viable options to develop parts of the transport infrastructure. As the open

[8] The complete transcripts of the interviews are available in Sanders (2011).

Please cite this article in press as: Sanders, M., et al., Mobilizing private funds for carbon capture and storage: An exploratory field study in the Netherlands. Int. J. Greenhouse Gas Control (2013), http://dx.doi.org/10.1016/j.ijggc.2013.09.015

interview revealed, however, this would involve changing the design of stimulation policies (subsidize CAPEX not OPEX to avoid rapid depreciation schedules) and a rethinking of the European Trading Scheme (ETS) and the price uncertainty therein. Family businesses are typically relatively more conservative (Van Essen et al., 2011). As opposed to venture capitalists and private equity investors, these firms typically choose low-risk low-return long-run projects (Le Breton-Miller and Miller, 2006). Operating ships in a *CINTRA* type joint venture may well satisfy these criteria. In that case the operational flexibility or abandonment options are not very valuable. Instead this type of firms looks for long run stability, contracts on long run relationships and thereby eliminates these flexibilities. The family business thus gives up the option value and seems willing to pay for security in terms of lower returns. Of course, then the up- and downstream contracts become the focus of attention in this case. To bring out such contrasts sharper, however, one would have to discuss this case with a private equity or venture capital investor as well.

5.3. Business case 3: CCS Maasvlakte

Business case 3 was first discussed in open format with a new asset developer in an energy company and, subsequently, in closed format with three decision makers, one private equity investor, one new asset developer in a CCS project for an energy company and one CCS investment portfolio manager in a large oil company. We can conclude from the interviews on case 3 that asset developers and investors have a hard time imagining CCS as a mature business case. CCS is not considered a normal waste disposal service and all three had a hard time not seeing the energy producer involved. The interviewees engaged in the Rotterdam *ROAD* project (a demonstration project involving integrated capture, transport and storage in Rotterdam harbor), however, did confirm that the energy producer would operate the capture unit "as if" it were a stand-alone business unit. The capture unit will thus not be operated if market prices are unfavorable. By virtue of the subsidy, the assets can be written off in the first five years of the project, such that marginal cost and benefits drive the project after the subsidy expires. The case was built to reflect that situation right from the start and the people familiar with the *ROAD*-project therefore had less trouble imagining this as a stand-alone project.

The capture and storage installations give the operator an implicit option to operate the installation when prices are right. The price scenarios provided in the case then indicated how likely it is that these conditions will emerge. The interviewees recognized this option, but did not really respond in the way real options theory would predict (shut down and restart option). In fact, all interviewees found it hard to imagine investing such large amounts in an installation without a very high level of comfort (certainty) that the installation would be operated at full capacity. Corporate managers seem to suffer from the so-called disposition effect when they need to decide to terminate a project and thus keep the project alive too long (Statman and Sepe, 1989). The investors indicated not being able or willing to tie up such large amounts of capital in assets and have them sit idly by as "there are too many valuable alternatives, especially in oil and gas". Theory predicts the operational flexibility should be valued positively, but instead investors wanted the underlying uncertainty to be eliminated. The investors requested additional information and assurances, not to value the operational option but to try and avoid economic downtime. The investors seem not to be very pleased with the value created by a shutdown and restart option, although previous empirical research showed that financial markets seem to clearly value abandonment options (Berger et al., 1996). It seemed as if the interviewees do not wish to maximize flexibility, but rather minimize the need for flexibility.

Theory would also suggest that more uncertainty over CO_2 prices and electricity prices would cause the project to be shelved (timing option). Only the CCS investment portfolio manager gave that option some serious consideration. The CCS project manager in the energy company explicitly said that putting the project on hold was not a realistic option, whereas the private equity investor, as his colleague in case 1, did not even consider it explicitly.

In the open interview another real option (growth option) in *ROAD* was explicitly mentioned. *ROAD* itself is a first of a kind project and consequently strategic considerations and the option to apply the knowledge to a large future market are explicitly considered. This option was taken out of the business case developed for the closed interview. In the case study the technology was assumed to be mature, but decision makers subsequently had a hard time imagining CCS being at that stage of the life cycle already. Also, the CCS investment portfolio manager mentioned the "option" of proving with this project that offshore storage is safe, such that in future applications, cheaper, on-shore storage can be considered. CCS is clearly not yet at a stage at which investment projects are considered business-as-usual.

5.4. Discussion of our results

In conclusion the interviews have shown that the timing option is not considered to be very relevant. Investors do not seriously consider postponing investment decisions because much of the information needed to make such a decision is costly to obtain and verify and needs to be updated when a project is suspended. Real option models can in principle incorporate the high (opportunity) costs of keeping an option alive. If the cost to postpone the decision is too high, the value of the option to delay will drop to zero and investors might not want to postpone. In practical terms this implies that investors in CCS rarely delay an investment decision process to see how certain fundamental market uncertainty would resolve itself. Another reason is that investors believe most uncertainty will only be resolved when "you just start doing it". Moreover, subsidies and permits typically tend to be costly to obtain and have limited duration. Finally, especially venture capital and private equity investors have to compete in their market niches for good projects, whereas new business developers in large corporations point out that the firm always has good competing projects to consider. Consequently, investors may not have the luxury of considering delay. Under high uncertainty they will then reject, rather than postpone. Funds are not limited on the supply side, but competition for good opportunities implies resources are not left idle and tied up in options. Investors will quickly abandon a marginal project and invest very little in keeping such options alive.

The growth, abandon and operation options in the membranes, shipping and capture cases respectively were recognized, but did not always elicit a response that is fully in line with real options theory. The growth option in the membranes case was clearly realized by both investors. And despite the fact that the IRR was significantly below normal rates of return projections, both investors could be convinced to evaluate the project at (significantly higher) rates. Also their requests for information clearly focused on establishing more comfort and certainty over the future market size and the competitiveness of the technology in the future. Both directly affect the upside of the growth option, which drives the value of the growth option.

The abandonment option was not appreciated the way theory would predict as the interviewee in the shipping case was used to taking decisions and developing projects for a rather conservative family-owned firm. This type of investor does not want to buy a ship with leveraged equity and make a clean exit when times turn bad. To such investors a very explicit abandonment option signals a lack of commitment to the venture. Therefore it is weighed as a

Please cite this article in press as: Sanders, M., et al., Mobilizing private funds for carbon capture and storage: An exploratory field study in the Netherlands. Int. J. Greenhouse Gas Control (2013), http://dx.doi.org/10.1016/j.ijggc.2013.09.015

negative element, if at all. The case simply did not fit well with the priors of this interviewee. As a corollary, however, the interviewee also indicated that all risk would have to be reduced to counterparty risk by contracting on the business for longer terms "back-to-back".

Finally, the operational option present in the third case was also not really appreciated the way theory would predict. Corporate asset developers felt very uncomfortable with developing assets that may turn out to be idle, even if for very sound economic reasons. They request information in an effort to reduce this risk ex ante, rather than to value the operational flexibility as theory would predict. In follow-up contacts with the interviewees, they did indicate such calculations are made, but the combination of a very high capital costs and low internal rate of return in the case made "downtime" the most important (negative) value driver in the case.

6. Conclusions and further research

Before turning to our conclusions, a general caveat has to be made. Our study is based on eight interviews (six closed and two open formats) on three stylized business cases. Although sample size and representativeness are less of a concern in an exploratory study, it also indicates the limitations of our study. Readers should be careful in interpreting and generalizing the results beyond the scope of our study. But in spite of the obvious limitation in our set-up, we feel the results obtained during the structured interviews do allow us to draw some tentative conclusions and formulate non-trivial implications.

An obvious conclusion from the interviews is our stylized CCS projects were not considered a convincing business case to invest in, whatever the assumptions in the case were. Investors clearly have to go outside their comfort zone with regards to technological, market and political risk. And this, it seems, is a significant impediment to the mobilization of private funds for CCS. We might also conclude that there seems to be a mismatch between investment practice and (real options) theory. This does not imply that real option theory is not a valid and useful approach to investment projects. On the contrary, real option modeling can help investors in highly risky technologies with huge upfront costs to understand, capture and manage the true risks of the project and feel more comfortable with the project. Communicating the insights and value-added of real option models could be a first step in overcoming the hesitation of private investors. For instance, the value of an abandonment option and the operational flexibility option were not valued, or not nearly as much as theory would predict. Providing investors insights into dividing projects in stages and framing the business case in terms of new concepts such as abandoning, scaling up/down and temporarily shutting down operations might allow them to better understand the business case and facilitate a more transparent and confident decision making process. Researchers and business schools therefore need to reach out and make investors aware of real option thinking and how it can enhance their decision-making rules.

But given the current practice in investment decision-making we cannot rely exclusively on advanced investment models to inform the structuring of projects and policies. What models predict to be causes to delay a project, may in fact cause investors to simply be turned off. The timing option is typically of limited value if investors need to compete for good projects (as opposed to projects competing for available funds). In addition the often expensive information and verification cycles in an evaluation process require that waiting options are quickly realized (in the venture capital stage) or often they will not be realized at all. Information is costly to gather and verify and such investments are sunk in the evaluation process, reducing the attractiveness of suspending the evaluation process. At first sight this might seem to contrast with real option theory. Incorporating the opportunity cost of keeping the option alive by postponing the decision can explain investors' behavior quite nicely, however, but these costs are not easily quantified and this requires a careful evaluation of the project at hand. We can also conclude tentatively that the value of an abandonment option depends very much on the attitude and culture of the investor. Operational flexibility is valued, but not necessarily as much as theory would predict. Corporate asset development is not a highly speculative business in general and the option of shutting down very expensive equipment was not considered a big plus by our interviewees, even if not being able to shut it down would probably be considered even worse.

Our tentative results correspond with Barbose et al. (2008) in the sense that real options logic only imperfectly predicts our investors' attitudes and behavior and that enthusiasm for CCS investments is limited. First, the beliefs and preferences of investors might be very different from what models assume. Especially if the government has not been credible in honoring previous commitments, investors might attach a relatively low probability to a scenario where a carbon price is kept in place or where an existing price could be raised to further decarbonize the energy sector. Second, these probabilities might actually be partially endogenous, as corporate investors form strong interest groups, which might have an influence on the likelihood of stringent regulation.[9] Third, CCS might just be perceived as too uncertain a technology: high capital costs are typically cited as a disincentive to invest. Add to this the uncertainties related to the potential of transporting and storing the CO_2 safely for the long term (Nogues et al., 2012; Ramírez et al., 2010; Strachan et al., 2011) and the uncertainty connected with issues of liability, and the option to postpone such investment gains tremendous value. This, however, reflects itself in an unwillingness to even engage in costly verification procedures. At current CO_2 prices the option is so far "out of the money" that investors do not want to spend their time and efforts on keeping it alive. Finally, social acceptance plays a major role as well (Brunsting et al., 2011; Terwel et al., 2011; Wallquist et al., 2012). Firms do not operate in a social vacuum (Ashworth et al., 2010; de Best-Waldhober et al., 2009). Cases are known where citizens have resisted the storage on CO_2 close to their residences (e.g., Barendrecht in the Netherlands, Brandenburg in Germany) and scientific evidence on the safety of this process is discounted against reputational damages that result from irrational fears, lack of knowledge and failure to fully account for the consequences of the status quo. If investors take into account that a CCS project could be stopped due to such resistance, even if the science is sound and all financials look great, then the risk might be judged too high to sink resources in the first place.

Our final conclusion is that there is in principle no shortage of private capital to develop a CCS infrastructure and reduce CO_2 emissions significantly in that way. The challenge, however, is to mobilize these funds. For that purpose private investors first need well-contained and manageable projects. Designing such business cases, even stylized ones as in the course of our research, turned out to be quite an effort and despite efforts to provide complete proposals, the cases provoked many more questions and requests for further information. The heuristic process of actual investors is hard to capture in a model and therefore hard to predict. Several of the incorporated real options in our business cases were not recognized or explicitly considered irrelevant for reasons we had not anticipated. What this exercise has shown is that objective,

[9] In fact especially the VC and PE investors worried about this market not emerging (fast enough) or collapsing due to strong lobby from the sector.

verifiable information is a necessary but never sufficient condition, even to evaluate a project. Investors need to personally engage in the project and investment decisions are not taken based on a financial cost benefit calculation alone. CCS therefore needs sound business cases, credible champions to advocate them and good management to make them a success. One success will then breed another and create more tacit information that gives more investors the required levels of comfort to engage and continue the virtuous cycle. Policy makers and project developers should be aware of these considerations if they aim to mobilize market resources. And even then there are no guarantees or clear cut-off points. Mobilizing private investment funds is as much an art as it is a science.

Finally, there are several routes along which the research presented in this paper can be extended and improved. As our study had an exploratory nature, an obvious way would be to conduct a follow-up study with a larger, more representative sample. This can be done by discussing the cases with more investors in more different types of positions (e.g., bankers and investment bankers), and by extending the research to other countries. Such a follow-up study can confirm the conjectures made by this exploratory study and allow us to draw stronger conclusions. One could also extend the research by adding more cases to choose from and some refinements can be made to the cases in this study (e.g., technical specifications). Our exploratory study deliberately did not instruct the interviewees on real option theory as we wanted to confront their actual investment decisions with what real option theory would predict. Another extension would be to test what added value insights into real option modeling would have brought to investors. A research design with two groups of interviewees where one group of interviewees could be exposed to a short training in ROV concepts and the other group not, could shed more light on this by comparing the investment decisions of the instructed and the reference group when confronted with the same business cases. It would be also interesting to conduct an analysis such as this one when the investment project is not hypothetical. Stylized cases have the advantage of being able to manipulate the cases to investigate theoretical predictions in practice. Observing real investment evaluations, also failed ones, however, would complement this study a lot. A better understanding of real-life private investors' decision-making processes at the micro level is vital in shaping projects and policies to mobilize private funds for CCS.

Acknowledgements

This work has been conducted in the frame of the CATO-2 project. CATO-2 is the Dutch national research program on CO_2 Capture and Storage technology (CCS). The program is financially supported by the Dutch Government (Ministry of Economic Affairs) and the CATO-2 consortium parties. Sabine Fuss (IIASA) and Mark Sanders (UU) also acknowledge support from the FP7-funded PROSUITE project (grant agreement no.: 227078). We thank, without implicating in any way, Andrea Ramirez (Utrecht University) for useful comments on the research reports and earlier drafts and two anonymous referees.

Appendix 1. Structure of the structured interviews

1. Is the material presented in the case clear?
   [yes goto 3/no goto 2]
2. What needs further clarification?
   [open, respond and goto 1]

Appendix 1 (*Continued*)

3. Does the case present sufficient information for you to evaluate the project?
   [yes goto 5/no goto 4]
4. What information is missing?
   [open, respond and goto 3]
5. Based on the information in the case, would you:
   a. Reject the project [goto 6]
   b. Request more information [goto 8]
   c. Keep the option to proceed open but commit no further resources [goto 11]
   d. Proceed with the project to the next stage [goto 12]
   e. Commit the required resources to complete all stages/final stage. [goto END]
6. What is the most important variable that made you decide to reject?
   [code goto 7 or "other, nl:"[open], respond goto 5]
7. What would the critical value for that variable have to be for you to reconsider?
   [value, set value to answer and goto 5]
8. What information would you request?
   a. Technical Engineering Studies
   b. Legal and Permits
   c. Economic and Market Analysis
   d. Other, nl: [open]
   [goto 9]
9. Who would you request this information from?
   a. Own Staff
   b. Colleagues
   c. Consultants
   d. Other, nl.: [open]
   [goto 10]
10. What would you be willing to pay for this information?
    [value, provide requested information and goto 5]
11. When would you be prompted to reconsider the project?
    [open, prompt then goto 5]
12. Who would you have/want to involve in the next stage?
    [open, goto 13]
13. How essential is their commitment/input for the success of the project?
    [1.10; very to not at all, goto 14]
14. How will they be involved in the strategic decision making process?
    a. At the strategic decision making level (e.g., board members)
    b. In the execution of the project (e.g., engineers)
    c. In providing information (e.g., consultants)
    d. Other, nl: [open]
    [goto 15]
15. Who would ultimately decide on the project's next stage?
    a. Me
    b. Me with peers
    c. My superiors
    [goto 3 and read "next stage" for "the project"]

END

References

Abel, A., 1983. Optimal investment under uncertainty. Am. Econ. Rev. 72, 228–233.
Abadie, Chamorro, 2008. European CO_2 prices and carbon capture investments. Energy Econ. 30, 2992–3015.
Arrow, K., Fisher, A., 1974. Environmental preservation uncertainty, and irreversibility. Quart. J. Econ. 88, 312–319.
Ashworth, P., Boughen, N., Mayhew, M., Millar, F., 2010. From research to action: now we have to move on CCS communication. Int. J. Greenh. Gas Con. 4, 426–433.
Barbose, G., Wyser, R., Phadke, A., Goldman, C., 2008. Reading the Tea Leaves: How Utilities in the West Are Managing Carbon Regulatory Risk in their Resource Plans, Report LBNL-44E. Ernest Orlando Lawrence Berkeley National Laboratory, Available at http://eetd.lbl.gov/ea/EMS/EMS_pubs.html
Bennaceur, K., Gielen, D., 2010. Energy technology modelling of major carbon abatement options. Int. J. Greenh. Gas Con. 4, 309–315.
Berger, P., Ofek, E., Swary, I., 1996. Investor valuation of the abandonment option. J. Finan. Econ. 42, 257–287.
Black, F., Scholes, M., 1973. The pricing of options and corporate liabilities. J. Polit. Econ. 81, 637–659.
Blyth, W., Yang, M., Working Paper LTO/2007/WP 01, IEA 2007. Modeling Investment Risks and Uncertainties with Real Options Approach.
Blyth, W., Bradley, R., Bunn, D., Clarke, C., Wilson, T., Yang, M., 2007. Investment risks under uncertain climate change policy. Energy Policy 35, 5766–5773.
Brennan, M., Schwartz, E., 1985. Evaluating natural resource investments. J. Bus. 58, 135–157.

Brunsting, S., Upham, P., Dütschke, E., De Best Waldhober, M., Oltra, C., Desbarats, J., Riesch, H., Reiner, D., 2011. Communicating CCS: applying communications theory to public perceptions of carbon capture and storage. Int. J. Greenh. Gas Con. 5, 1651–1662.
Cassimon, D., Engelen, P.J., Meersman, H., Van Wouwe, M., 2003. Investment, uncertainty and irreversibility: evidence from Belgian accounting data. In: Butzen, Fuss (Eds.), Firms' Investment and Finance Decisions. Theory and Empirical Methodology. Edward Elgar, Cheltenham, UK, pp. 194–219.
Cassimon, D., Engelen, P.J., Thomassen, L., Van Wouwe, M., 2004. Valuing new drug applications using n-fold compound options. Res. Pol. 33, 41–51.
Cassimon, D., De Backer, M., Engelen, P.J., Van Wouwe, M., Yordanov, V., 2011a. Incorporating technical risk into a compound option model to value a pharma R&D licensing opportunity. Res. Pol. 40, 1200–1216.
Cassimon, D., Engelen, P.J., Yordanov, V., 2011b. Compound real option valuation with phase-specific volatility: a multi-phase mobile payments case study. Technovation 31, 240–255.
CGI, 2010. The Status of CCS Projects; Interim report 2010. Global CCS Institute, Canberra, Australia.
Chalmers, H., Gibbins, J., 2007. Initial evaluation of the impact of post-combustion capture of carbon dioxide on supercritical pulverised coal power plant part load performance. Fuel 86, 2109–2123.
Chalmers, H., Leach, M., Lucquiaud, M., Gibbins, J., 2009. Valuing flexible operation of power plants with CO_2 capture. En. Proced. 1, 4289–4296.
Cohen, S.M., Rochelle, G.T., Webber, M.E., 2010. Turning CO_2 capture on and off in response to electric grid demand: a baseline analysis of emissions and economics. J. Energy Resour. 132, 21003–21008.
de Best-Waldhober, M., Daamen, D., Faaij, A., 2009. Informed and uninformed public opinions on CO_2 capture and storage technologies in the Netherlands. Int. J. Greenh. Gas Con. 3, 322–332.
Decarre, S., Berthiaud, J., Butin, N., Guillaume-Combecave, J.-L., 2010. CO_2 maritime transportation. Int. J. Greenh. Gas Con. 4, 857–864.
Denzin, N.K., Lincoln, Y.S. (Eds.), 2000. Handbook of Qualitative Research. Sage, Thousand Oaks, CA.
Dixit, A., 1989. Entry and exit decisions under uncertainty. J. Pol. Econ., 620–638.
Dixit, A., Pindyck, R., 1994. Investment Under Uncertainty. Princeton University Press, Princeton.
EC, 2011. Energy Roadmap 2050, COM (2011) 885/2. European Commission, Brussels, Online at http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf
Engelen, P.J., 2004. Criminal behavior: a real option approach. With an application to restricting illegal insider trading. Eur. J. Law Econ. 17, 329–352.
Feinstein, S., Lander, D., 2002. A better understanding of why NPV undervalues managerial flexibility. Eng. Econ. 47, 418–435.
Fuss, S., Szolgayova, J., Obersteiner, M., Gusti, M., 2008. Investment under market and climate policy uncertainty. Appl. Energy 85, 708–721.
Fuss, S., Johannson, D., Szolgayova, J., Obersteiner, M., 2009. Impact of climate policy uncertainty on the adoption of electricity generating technologies. Energy Policy 37, 733–743.
Gibbins, J., Chalmers, H., 2008. Carbon capture and storage. Energy Policy 36, 4317–4322.
Golombek, R., Greaker, M., Kittelsen, S.A.C., Røgeberg, O., Roar Aune, F., 2011. Carbon capture and storage technologies in the European power market. Energy J. 32 (3), 209–237.
Guerrero, R., 2007. The case for real options made simple. J. Appl. Corp. Fin. 19, 38–49.
Heal, G., Kristrom, B., 2002. Uncertainty and climate change. Environ. Resour. Econ. 22, 3–39.
Henry, C., 1974. Investment decisions under uncertainty: the irreversibility effect. Am. Econ. Rev. 64, 1006–1012.
Heydari, S., Ovenden, N., Siddiqui, A., 2010. Real options analysis of investment in carbon capture and sequestration technology. Comput. Manag. Sci., http://dx.doi.org/10 1007/s10287-010-0124-5, Available online since June 2010.
Hull, J.C., 2011. Options, Futures, and Other Derivatives, 8th edn. Pearson, Upper Saddle River, NJ.
Jorgenson, D., 1963. Capital theory and investment behavior. Am. Econ. Rev. 53, 247–259.
Ingersoll Jr., J.E., Stephen, A., Ross, S.A., 1992. Waiting to invest: investment and uncertainty. J. Bus., 1–29.
Le Breton-Miller, I., Miller, D., 2006. Why do some family businesses out-compete? Governance, long-term orientations, and sustainable capability. Entrepreneurship Theory Pract. 30, 731–746.
Lint, O., Pennings, E., 2001. An option approach to the new product development process: a case study at Philips Electronics. R&D Manag. 31, 163–172.
Lindlof, T.R., Taylor, B.C., 2010. Qualitative Communication Research Methods, 3rd ed. Sage Publications, Thousand Oaks, CA.
Majd, S., Pindyck, R., 1987. Time to build, option value, and investment decisions. J. Finan. Econ. 18, 7–27.
McDonald, R., Siegel, D., 1986. The value of waiting to invest. Quart. J. Econ. 101, 707–723.
Myers, S., Majd, S., 1990. Abandonment value and project life. Adv. Futures Options Res. 4, 1–21.
Nickell, S., 1978. The Investment Decisions of Firms. Cambridge University Press, Cambridge.
Nogues, J.P., Court, B., Dobossy, M., Nordbotten, J.M., Celia, M.A., 2012. A methodology to estimate maximum probable leakage along old wells in a geological sequestration operation. Int. J. Greenh. Gas Con. 7, 39–47.
Odenberger, M., Johnsson, F., 2010. Pathways for the European electricity supply system to 2050—the role of CCS to meet stringent CO_2 reduction targets. Int. J. Greenh. Gas Con. 4, 327–340.
Oliver, T., 2008. Clean fossil-fuelled power generation. Energy Policy 36, 4310–4316.
Paddock, J., Siegel, D., Smith, J., 1988. Option valuation of claims on real assets: the case of offshore petroleum leases. Quart. J. Econ., 479–508.
Pindyck, R., 1980. Uncertainty and exhaustible resource markets. J. Pol. Econ. 88, 1203–1225.
Pindyck, R., 1988. Irreversible investment, capacity choice, and the value of the firm. Am. Econ. Rev. 79, 969–985.
Ramírez, A., Hagedoorn, S., Kramers, L., Wildenborg, T., Hendriks, C., 2010. Screening CO_2 storage options in The Netherlands. Int. J. Greenh. Gas Con. 4, 367–380.
Reinelt, P., Keith, D., 2007. Carbon capture retrofits and the cost of regulatory uncertainty. Energy J. 28, 101–127.
Sahlmann, W., 1990. The structure and governance of venture-capital organizations. J. Finan. Econ. 27, 473–521.
Sanders, M., 2010. Options for Investment in CCS Part A. Mimeo. CATO-2-WP2.2-D04A.
Sanders, M., 2011. Assessing private funding possibilities: Real Options for Investment in CCS Part B. Mimeo. CATO-2-WP2.2-D04B.
Schoots, K., Rivera-Tinoco, R., Verbong, G., van der Zwaan, B., 2011. Historical variation in the capital costs of natural gas, carbon dioxide and hydrogen pipelines and implications for future infrastructure. Int. J. Greenh. Gas Con. 5, 1614–1623.
Statman, M., Sepe, J., 1989. Project termination announcements and the market value of the firm. Finan. Manag. 18, 74–81.
Strachan, N., Hoefnagels, R., Ramírez, A., van den Broek, M., Fidje, A., Espegren, K., Seljom, P., Blesl, M., Kober, T., Grohnheit, P.E., 2011. CCS in the North Sea region: a comparison on the cost-effectiveness of storing CO_2 in the Utsira formation at regional and national scales. Int. J. Greenh. Gas Con. 5, 1517–1532.
Szolgayova, J., Fuss, S., Obersteiner, M., 2008. Assessing the effects of CO_2 price caps on electricity investments—a real options analysis. Energy Policy 36, 3974–3981.
Terwel, B.W., Harinck, F., Ellemers, N., Daamen, D.D.L., 2011. Going beyond the properties of CO_2 capture and storage (CCS) technology: how trust in stakeholders affects public acceptance of CCS. Int. J. Greenh. Gas Con. 5, 181–188.
Tobin, J., 1969. A general equilibrium approach to monetary theory. J Money Credit Bank 1, 15–29.
The Economist. Carbon capture and storage: Trouble in store, 7th of March, printed edition.
Trigeorgis, L., 2000. Real options and financial decision-making. Contemp. Finan. Dig., 5–42.
Trigeorgis, L., 2005. Making use of real options simple: an overview and applications in flexible/modular decision making. Eng. Econ. 50, 25–53.
Trigeorgis, L., Mason, S.P., 1987. Valuing managerial flexibility. Midland Corp. Finan. J 5, 14–21.
Van Essen, M., Carney, M., Gedajlovic, E., Heugens, P., Available at SSRN: http://ssrn.com/abstract=1837517 or http://dx.doi.org/10.2139/ssrn.1837517 2011. Do U.S. Publicly-Listed Family Firms Differ? Does it Matter? A meta-analysis.
Wallquist, L., L'Orange Seigo, S., Visschers, V.H.M., Siegrist, M., 2012. Public acceptance of CCS system elements: a conjoint measurement. Int. J. Greenh. Gas Con. 6, 77–83.
Zellweger, T., 2007. Time horizon, costs of equity capital, and generic investment strategies of firms. Fam. Bus. Rev. 20 (1), 1–15.
Zhou, W., Zhu, B., Fuss, S., Szolgayova, J., Obersteiner, M., Fei, W., 2010. Uncertainty modeling of CCS investment strategy in China's power sector. Appl. Energy 87, 2392–2400.

Please cite this article in press as: Sanders, M., et al., Mobilizing private funds for carbon capture and storage: An exploratory field study in the Netherlands. Int. J. Greenhouse Gas Control (2013), http://dx.doi.org/10.1016/j.ijggc.2013.09.015