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Optimal investment strategies in power generation assets: The role of technological choice and existing portfolios in the deployment of low-carbon technologies

Wilko Rohlfs [a,*], Reinhard Madlener [b,1]

[a] Institute of Heat and Mass Transfer, School of Mechanical Engineering, RWTH Aachen University, Augustinerbach 6, 52056 Aachen, Germany
[b] Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics/E.ON Energy Research Center, RWTH Aachen University, Mathieustrasse 10, 52074 Aachen, Germany

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ABSTRACT

In this paper we identify optimal strategies for investment in power generation units. The economic value of the investment options is driven by a technology-specific combination of several underlying prices, such as the price of fuel, electricity, and CO_2. The correlation between those underlyings allows investors to diversify and thus reduce the overall risk by holding a portfolio of different technologies. This yields an investor-dependent strategy for the deployment of new energy generation units. The modeling framework developed is based on stochastic real options analysis that enables to account for the additional value of waiting, which arises from uncertain commodity price development. In the presentation, we increase the model's complexity stepwise, in order to depict the influences of various aspects, as for instance the interaction of technologies, value of waiting, or modification of an existing power plant portfolio. Including the value of waiting in the decision process does not only delay the investment but also leads to an asymmetric risk distribution, which features a much lower probability for losses. In addition, the results where the value of waiting has been incorporated are more robust with respect to a variation of the discount rate compared to the results gained with the classical net present value model. Finally, we investigate the required market conditions needed for the deployment of carbon capture and storage (CCS) technologies. We find that a carbon dioxide price of 35 €/t_{CO_2} and an electricity price of 70 €/MW_h are required in the year 2015 in order to reach a probability of at least 50% for the deployment of CCS in 2020.

1. Introduction

Carbon capture and storage (CCS) is seen by many international organizations (IEA, 2010; World Energy Council, 2007), the European Commission (2011a) and also by many energy modelers (e.g. Nitsch et al., 2010) to play a major role in reducing carbon dioxide emissions.

In the literature, CCS technologies are evaluated from different perspectives and by various methods. Life cycle analyses (LCA), for instance, aim to identify overall environmental consequences of technologies by examining all impacts from cradle to grave. In Pehnt and Henkel (2009), for example, the environmental impact of the post-combustion, pre-combution, and oxy-combustion carbon capture processes was examined, revealing a clear benefit of the pre-combustion technology compared to post-combustion. Similar results were obtained by Zapp et al. (2012). However, most of the LCA studies remain silent about the technology's economic value.

In contrast, studies such as Davison (2007) compare the specific cost of different technologies for capturing carbon dioxide (post-combustion, pre-combustion, and oxy-combustion) with those of conventional power generation plants. Typically, as a result, the cost of electricity generation, the cost of carbon capture and compression, and the cost of avoided emissions are presented. Studies with similar intention have been presented, among others, by Hammond et al. (2011) and the IEA (2005). Caused by different underlying assumptions in such cost studies (discount rate, expected life-time, operating hours, etc.), a comparison of the results is rather difficult or even infeasible. Strong criticism has thus been raised e.g. by Rubin (2012), not only with respect to the different assumptions made, but also according to the inconsistent

* Corresponding author. Tel.: +49 241 80 97 428; fax: +49 241 80 92 143.
E-mail addresses: rohlfs@wsa.rwth-aachen.de (W. Rohlfs), RMadlener@eonerc.rwth-aachen.de (R. Madlener).
[1] Tel.: +49 241 80 49 820; fax: +49 241 80 49 829.

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definitions of important characteristic numbers, such as the cost of CO_2 avoided, captured, or abated.

Thus, even though a plethora of economic studies compare conventional and CCS power generation technologies, they usually do not aim at predicting the technology's potential in light of interactions with other available technologies. Due to the strong interest in CCS and its potential deployment, many studies deal with the question of when this technology will become available for commercial use (for a review, see Rubin et al., 2012). To address this question, technology roadmaps and deployment scenarios have often been developed by governmental (US Department of Energy, 2010; European Commission, 2011b) as well as non-governmental organizations (CSLF, 2009; Nitsch et al., 2010; EPRI, 2011). Such roadmaps or scenarios, if gained from engineering-economic energy models, typically aim at a mathematical representation of the entire energy system, e.g. electricity supply, consumption and storage, making assumptions about population growth or technological change. Most of those models are based on general equilibrium or linear optimization approaches, aiming at a cost-minimized energy mix. However, those models do not usually account adequately for effects, such as commodity price uncertainty or technical and regulatory uncertainty, which may lead to a substantial difference between the price level at which CCS becomes economically viable and the price level at which an investor will take the decision to build a CCS power plant. Hence, in our study, the possible deployment of CCS as well as the required market conditions for the latter are investigated from an investor's point of view, taking especially commodity price uncertainty into account.

In recent years, investors in power generation assets have been confronted with the problem of an increasing commodity price volatility, rapid technical change, and regulatory uncertainty, which render the decision more and more risky. As a consequence, those stochastic model approaches and their application to the energy sector have flourished that support decision-makers with background information about optimal investment strategies. Reinelt and Keith (2007), for instance, investigate the cost of regulatory uncertainty in carbon capture retrofit investments, based on a two-dimensional model (volatile natural gas price, uncertain carbon regulation) for different coal-fired power plants using Bellman's Principle of Optimality (Bellman, 1957). However, such a separated comparison of alternative investment options is insufficient and remains silent about both the optimal timing of investment and the optimal technology mix.

Real options (RO) models (Black and Scholes, 1973; Dixit and Pindyck, 1994) are attractive in this respect, as they allow these points to be explicitly addresses by accounting for the value of waiting or postponement of the investment (McDonald and Siegel, 1986). Therefore, it is not too surprising that in recent years RO models have been increasingly applied in the energy literature also (see Westner and Madlener, 2012, for an overview), even though most applications have only dealt with one or two technologies and a single stochastic variable at a time (typically, some input fuel or the electricity price, or the difference between the two – the "spread"). In Blyth et al. (2007), different technologies (coal- and gas-fired power plants with and without CCS) are compared to each other. In their study, uncertainty is represented as an anticipated price shock. In addition, the carbon price follows a geometric Brownian motion. Conducting a pairwise comparison of the different technologies, the authors draw a regime map which indicates zones of investing and waiting in dependence on the carbon price and the gas/coal price ratio. Correlations between the price for gas and for carbon dioxide emission allowances is accounted for in Yang et al. (2008). The authors focused on risk premia required in a market with additional uncertainties in climate policy. These risk premia were calculated as the difference between the results of the RO model and the results of an NPV model. Other studies of multi-dimensional real options in the energy sector were conducted by Siddiqui and Fleten (2008) (two-dimensional model) and Gahungu and Smeers (2009) (multi-dimensional model). Applying RO models, Fleten et al. (2007) find that the optimal investment in decentralized renewable power generation will be delayed, waiting for higher prices if an RO model with stochastic electricity prices is applied compared to the break-even price using an NPV model.

Contrary to many existing models, which evaluate multiple options independently from each other, simultaneous evaluations of several different technologies at once are performed in Reinelt and Keith (2007) as well as in Fortin et al. (2008). In Reinelt and Keith (2007), an investor is given the flexibility to build different types of power plants, to retrofit an existing plant, or to keep the existing technology. Therein, the decision process depends on a four-dimensional state vector, covering the power plant type, its age as well as the price of gas and the price of carbon dioxide. In Fortin et al. (2008), coal-fired power plants with and without CCS, and a wind farm are compared with each other over a long time horizon (150 years). The study reveals under CO_2 price uncertainty the transition from conventional to CCS plants and subsequently to wind farms.

In a former study by the authors (Rohlfs and Madlener, 2013a), the influence of carbon capture readiness was investigated by a stochastic NPV model with an endogenous, time- and technology-dependent discount rate. With this model, the value of carbon capture readiness was found to be small, and the option of replacing older power plants – including a premature shut-down – with a new CCS power plant turned out to be the preferred choice in the majority of investigated scenarios.

The original contribution of this paper is threefold: First, the development of a model is presented, which allows the probability of investing in a specific technology in the future to be estimated, thereby accounting for various aspects. This includes the effect of technology-specific risk emerging from a technology-specific combination of commodity prices (e.g. price of electricity, fuel, and carbon dioxide allowances), the effect of exogenously prescribed technical innovation/learning as well as the effect of multiple existing and concurring technologies. Still another effect included is the above-mentioned value of waiting. Finally, the model accounts for the influence of an investor's existing power plant portfolio on the investment decision. The second original contribution of this paper is the analysis of the influence of the previously mentioned effects by a stepwise increase of the model's complexity, while retaining the value of the underlying parameters. The third contribution is the application of the model for identifying market conditions (e.g. bounds for the price of electricity and carbon dioxide allowances) for which the deployment of CCS will become highly probable in the near future.

The remainder of this paper is structured as follows. Section 2 introduces the modeling framework, Section 3 reports on the underlying data and assumptions used, Section 4 presents the results, and Section 5 concludes.

2. Problem analysis and modeling approach

Investors in the electricity supply industry are spoilt for choice of deciding from one of various available technologies when investing in new power generation units. Both the fuel type (hard-coal, lignite or gas-fired) and also the possible implementation of carbon mitigation technologies allow a variety of technological options. Due to the capital intensity and the long life-time of new power generation units, single investment decisions (in a new power plant and thus in a portfolio modification) have a strategic character and may have strong implications on the investor's future performance.