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Geological uncertainty and investment risk in CO_2-enhanced oil recovery

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Abstract

CO_2-enhanced oil recovery (CO_2-EOR) has the potential to combine the environmental benefits of greenhouse gas emission reduction and the optimal use of natural resources. In economic simulations, CO_2-EOR is generally approached in a classical way, with fixed parameters and limited flexibility. We propose a more realistic approach that combines realistic investment decision making with geological and techno-economic uncertainties. A cluster of seven active oil fields in the North Sea is simulated using a newly developed software tool, allowing to assess when EOR technology replaces primary production. CO_2 can be delivered from different onshore locations via ship or pipeline. The introduction of near-realistic investment geological and economic risks in CO_2-EOR projections will allow for in-depth assessment of CO_2-EOR at the level of the North-Sea Basis, as well as of individual potential projects.

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Keywords: CO_2-EOR, geological storage, techno-economic simulation, North Sea

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1. Introduction

A lack of a viable business case for CO_2 capture and storage (CCS) causes delay in private investments, and hampers its wide-scale deployment. CO_2-enhanced oil recovery (CO_2-EOR) is often proposed as a promising candidate business case, in which the costs for capture, transport and storage of CO_2 would be offset by the additional revenues from increased oil production. Such claims are based on traditional investment decision schemes that neglect the geological reality of reservoir uncertainties. For European North Sea oil fields, those neglected uncertainties and the offshore operation risk are important parameters in project decisions for off-shore oil production platforms. The aim of this study is to provide the optimal investment choice and timing for a CO_2-EOR project, acknowledging the risks encountered in real-world projects.

2. Methodology

2.1. PSS IV simulator

For tackling the issue of geological uncertainty in this context, a new computer tool is developed, starting from version three of the PSS simulator that is designed for traditional CO_2 capture and storage schemes in on-shore settings [1,2]. PSS III includes a realistic investment decision module and a methodology to deal with both geological and economic uncertainties. The new PSS IV simulator for CO_2-EOR is based on this methodology with a Real Options Analysis (ROA) approach in a Monte-Carlo iteration, to investigate the influence of different stochastic parameters such as CO_2 and oil market price. ROA includes the consequences of an investment choice, such as having the option to abandon a project to reduce losses. Investment decisions are taken from a company or investor's point of view, and for these decisions there is a spatial and a time dimension. Contrary to conventional economic (CCS) simulations, the principle of perfect foresight is abandoned. Each project decision by the simulator will be made based on its own future projections, with information as it can be available at that time. Actual future parameter values may be different, but are only revealed when simulation reaches that future point in time. This provides a considerably more realistic investment risk assessment over the conventional methodology.

The new PSS IV simulator will approach a cluster of oil fields owned by a single company, with active primary oil production. For PSS IV it is possible to apply CO_2-EOR technology along the lifespan of each field individually. With EOR operational, an oil field's life time can be extended because of higher oil revenues. A project stop can also be applied when this should be an economic option, and it is possible to stop oil production and continue with CO_2 geological storage (CGS).

2.2. The EOR value chain and simulation

The EOR value chain is a subsequent series of operations (Figure 1). A continuous stream of compressed CO_2 is delivered from an onshore source or hub. From that point, two transport modes are available: pipeline or ship. Each mode has practical and financial advantages and disadvantages. Pipeline transport involves a trunk line to an oil field cluster, and pipelines to individual oil fields. This transport mode has a high investment cost and is not very flexible towards capacity and location, but a continuous supply of CO_2 can be guaranteed from the transport side. Ship transport is more difficult to organize and guarantee continuous supply. Liquefied CO_2 can be transported with one or more ships towards a temporary offshore storage ship, from where it is injected into the reservoir. Alternatively, two or more ships take turns in supply and temporary storage for injection. Although ship transport is more prone to mechanical failure and dependent on meteorological conditions, the flexibility and low investment cost could favor this option for CO_2-EOR in the North Sea. At the injection site, the existing oil production equipment is extended with a compressor, heater, injection wells, and a treatment plant for separation of the produced oil and CO_2.

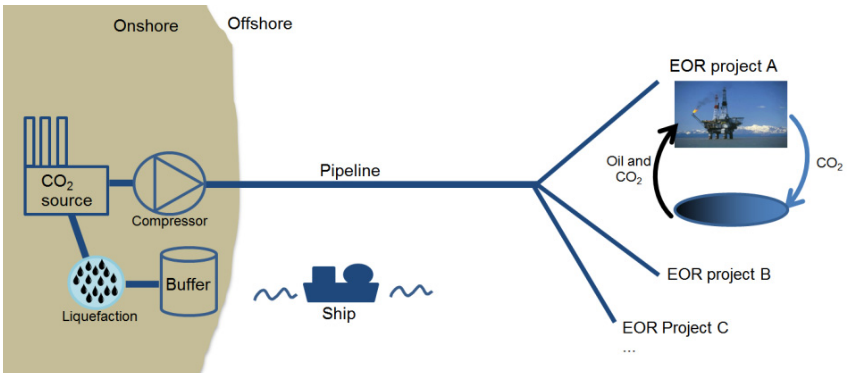

Fig. 1. Simplified presentation of the CO_2-EOR value chain. An onshore industrial facility produces CO2 which is captured and transported via ship or pipeline towards an offshore oil field cluster. Here, EOR can be applied to the different fields individually.

An analysis was made on how the EOR process can be simulated. For oil production (primary and EOR), a lognormal production curve is chosen. To simulate realistic geological uncertainties, the mode (time of maximum yearly oil production) and scale factor (oil in place, OIP) parameters are treated as stochastic (Figure 2). A next important parameter for EOR performance is the CO_2 recycling ratio, which determines the amount of CO_2 that is produced again after breakthrough at the production well. This CO_2 is separated and re-injected. In PSS IV, the amount of new CO_2 supplied is assumed to be constant. Thus, after breakthrough, the amount of injected CO_2 will rise gradually.

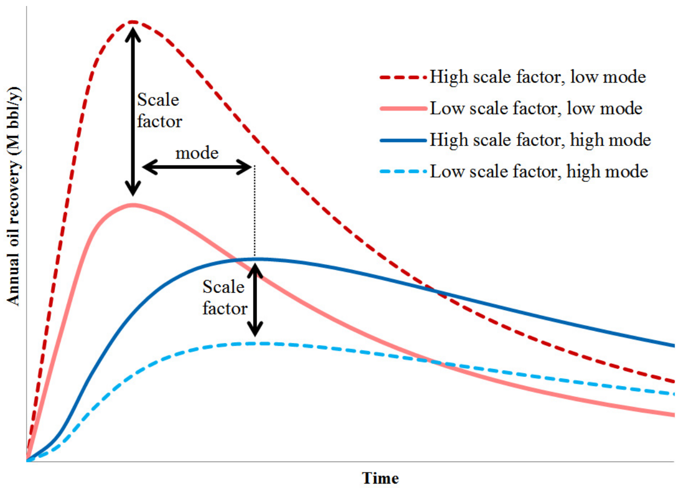

Fig. 2. Stochastic variation of the oil production curve. A lognormal distribution is chosen to fit real production data. To include geological uncertainties, the curve's scale factor (oil in place, OIP) and mode (time of maximum yearly production) can be varied stochastically. The stochastic behavior of the scale factor reflects the uncertainty on the available oil, while the variation of the mode reflects the uncertainty on reservoir behavior, such as production speed as a function of reservoir permeability.

PSS IV also includes parameters on processes that are often neglected in CO_2-EOR simulations, such as the amount of primary oil that is additionally recovered if EOR operation extends beyond the original primary decommissioning time, the amount of primary oil that is now produced using a more expensive production technique (EOR), and the part of the decommissioning cost that is saved by postponing the decommissioning of an oil field (due to the effect of discounting) (Figure 3).

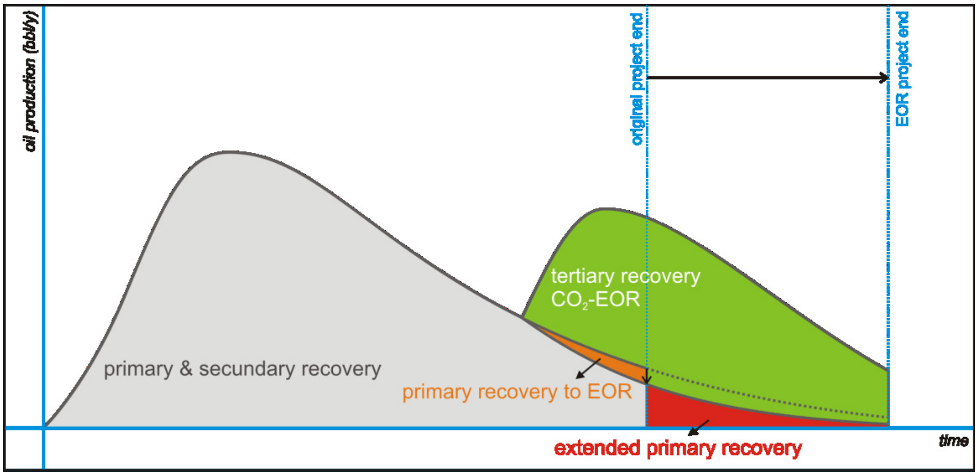

Fig. 3. Generic presentation of an oil field's primary (grey) and EOR (green) production simulation in PSS IV. Production parameters that are often neglected are the extra amount of oil from primary production by extending the field's lifetime (red), and the amount of primary oil that is produced by a more expensive method, EOR (orange).

2.3. North Sea case study

A generic case study for the North Sea was built using data from three active fields: Claymore, Fulmar and Forties. These data were used to create a realistic cluster of 7 oil fields in the North Sea that can be suitable for CO_2-EOR (Figure 4). Mean, standard deviation and amplitude of primary production are derived from available production data. EOR performance, CO_2 requirement and various cost data are taken from literature (e.g. [3,4,5]). An oil price and CO_2 tax scenario are developed with both parameter averages rising towards 130 €/t and 140 €/bbl respectively in 2050 [6,7]. The simulation timeframe is 2020-2050, being a realistic expectation for the commercial introduction of CCS, and by extension of the introduction of CO_2-EOR in the North Sea Region.

CO_2 supply is assumed to be available from four industrial areas around the North Sea, which were chosen based on their CO_2 production and availability of data. A CO_2 supply versus cost curve is constructed for each industrial area based on actual data and assumptions based on fuel type emissions. These locations supply CO_2 via pipeline or ship to the oil fields. Using an advanced routing algorithm for transport cost calculations, PSS IV will find the most optimal CO_2 supply chain for the oil field cluster.

3. Results and discussion

In a first stage, a preliminary version of the decision support tool without geological uncertainty was completed to identify important parameters, knowledge gaps and pitfalls. Results confirm published numbers and conclusions on the profitability of CO_2-EOR [4,8], and there is an important influence of the "economies of scale": a significant amount of CO_2 use and EOR operation is needed to create a profitable business. The turnover point lies between 1 and 5 $MtCO_2$/y, depending on EOR performance and transport distance. Smaller scale projects are never profitable. A sensitivity analysis revealed the oil price as the most sensitive parameter with respect to project profitability, and second the CO_2 emission tax (or ETS price). Still, even at low oil and CO_2 prices EOR can be profitable.

At the time of writing, an alpha version (experimental status) of the new PSS IV for CO_2-EOR is finished and first results indicate that the software is stable and is producing realistic overall results. Preliminary results show that oil fields in the cluster are being fitted with EOR technology, but when and where EOR is activated is strongly influenced by the stochastic oil and CO_2 market price, as well as the reservoir's oil recovery potential.

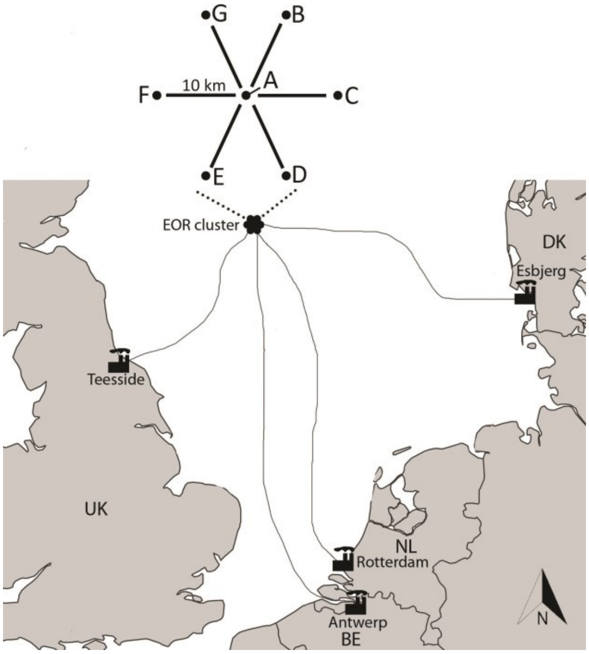

Fig. 4. Map of the North Sea case study. CO_2 can be supplied from four sources around the North Sea: Antwerp, Teeside, Esbjerg and Rotterdam. A fictive but realistic cluster of 7 active oil fields in the North Sea is assumed to be available for CO_2-EOR operation.

The EOR operation in PSS IV will need to be calibrated to allow for a realistic timing of the application of EOR. It is expected that in some cases, due to how the effect of discounting is currently taken into account, that the application of EOR would be favored in the first years of an oil field production, because early returns have a higher value and negative effects of early EOR operation, at reservoir level, are not fully taken into account. Also, the first application of transport by ship will likely need additional calibration to allow for realistic long-distance transport costs compared to pipeline transport, also to fully accredit the economic advantage of additional project flexibility offered by ship transport.

4. Conclusions

The goal of this study is to make a realistic assessment of potential CO_2-EOR projects in the North Sea in order to help making well-founded investment and policy decisions. As geological uncertainty is often neglected in these kind of calculations, a new simulation tool, PSS IV, is created to make realistic forecasts on potential EOR fields.

PSS IV provides realistic investment decisions, combined with EOR field operation simulation. Issues to be resolved are the calibration of the EOR performance and ship transport cost. First results already appear to be realible, and will be confirmed and detailed further in the coming months. Expectations are that more realistic geological uncertainty and project risk will have a significant influence on both overall project cost, project planning and timing. These new simulations will for the first time provide near-realistic insights into the cost-benefit balance of EOR projects in an offshore European context. This may help to provide realistic outlooks for EOR, as well as stimulate demonstration and full-scale projects.

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