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A socio-technical framework for assessing the viability of carbon capture and storage technology

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ABSTRACT

Carbon capture and storage (CCS) is seen as a key technology to tackle climate change. The principal idea of CCS is to remove carbon from the flue gases arising from burning fuels for electricity generation or industrial applications and to store the carbon in geological formations to prevent it from entering the atmosphere. Policy makers in several countries are supportive of the technology, but a number of uncertainties hamper its further development and deployment. The paper makes three related contributions to the literatures on socio-technical systems and technology assessment: 1) It systematically develops an interdisciplinary framework to assess the main uncertainties of CCS innovation. These include technical, economic, financial, political and societal issues. 2) It identifies important linkages between these uncertainties. 3) It develops qualitative and quantitative indicators for assessing these uncertainties. This framework aims to help decision making on CCS by private and public actors and is designed to be applicable to a wider range of low carbon technologies. The paper is based on a systematic review of the social science literature on CCS and on insights from innovation studies, as well as on interviews about assessment of new technologies with experts from a range of organisations and sectors.

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1. Introduction

Carbon capture and storage (CCS) is today often considered a crucial technology in the long term carbon abatement strategies of many countries and international organisations [1]. The idea of carbon capture is straightforward: to remove carbon dioxide from the flue gases from burning fossil fuels in power plants or industrial applications and to store the carbon underground. Thereby the carbon is prevented from entering into the atmosphere and contributing to climate change. Possible applications mainly exist in the power sector, refineries, synthetic fuel production, blast furnaces, cement kilns, ammonia plants as well as combined heat and power plants [2]. Carbon capture and storage principally consists of three parts: 1) capturing the carbon at the power plant or industrial application; 2) transporting it to appropriate storage sites and 3) storing the carbon underground.

There are different technical ways of capturing the carbon from point sources such as power stations: pre-combustion, oxyfuel-combustion and post-combustion [3]. In pre-combustion, carbon is removed from the fuel before it is burned. To do this, the fuel is gasified and the carbon dioxide chemically separated out. In oxyfuel-combustion, fossil fuels are burned in almost pure oxygen rather than air. This produces almost pure carbon dioxide and water vapour from which the carbon can be relatively easily be removed. In post-combustion, the carbon is removed from the flue gas after the fossil fuel has been burned. This can be done using a number of different chemical solvents. Potentially 90% or more of the carbon emitted by burning coal in a power plant could be removed.

The transport of carbon typically entails using dedicated pipeline infrastructures connecting the point sources to storage locations. For the storage of carbon, a number of different options are explored: the use of saline aquifers, depleted oil and gas fields or old coal mines. Because of limited public acceptability, CCS advocates currently primarily focus on the potential of offshore storage sites. The whole CCS chain therefore involves a variety of actors: equipment suppliers producing the capture equipment, utility companies or industrial players like cement kilns which need to integrate the capture equipment onto their site, pipeline network operators and oil and gas companies with offshore expertise who might take charge of the injection into oil and gas fields.

Today the technology is used in a few applications worldwide mainly for enhanced oil recovery. As many countries around the world currently generate a high proportion of electricity from fossil fuels (mainly coal and gas) and their use is predicted to continue for a long time, CCS is believed to be a crucial technology to reduce carbon emissions from the use of fossil fuels. The International Energy Agency believes that the use of CCS in power generation could result in the cumulative capture and storage of some 79 Gt of CO_2 between 2010 and 2050 [2]. The UK government also sees carbon capture and storage as a key part of its strategy to reduce carbon emissions by 80% by 2050 and supports a number of demonstration plants [4].

However, whilst CCS is entering a phase of demonstration of large scale integrated systems in various locations around the world [5], there are still significant uncertainties in technical, economic, political and financial and other dimensions of CCS. This creates challenges for those actors who want to see CCS technology developed and deployed. For example, this is a problem for policy makers designing policy for CCS as well as broader energy and climate change mitigation. This is crucial as CCS will need government support to be part of the mitigation mix [6,7]. Such policy support should be as well informed as possible. The UK government has stated an intention of making CCS mandatory after it has been proven viable [8]. Uncertainty is also problematic for businesses that need to take decisions in terms of investment choices [9,10]. This highlights the need for a framework for analysing and assessing such uncertainties for CCS.

The challenge for both analysts and practitioners is to assess how the current uncertainties could come to be reduced, managed or adapted to, and how technological viability could come about through innovation processes. This paper makes a contribution by developing a socio-technical assessment framework that identifies key uncertainties of future CCS development and deployment, linkages between different uncertainties, as well as qualitative and quantitative indicators for assessing these uncertainties. The framework aims to support research and ultimately systematic decision making on CCS by private and public actors. The technology assessment (TA) literature has shown the pitfalls of trying to predict technology futures [11], and the framework developed here has the more limited ambition of identifying and guiding the analysis of key uncertain dimensions of possible CCS futures. The framework also draws on innovation studies, in particular the notion of socio-technical systems [12–14], to analyse the full range of technical, economic, political, etc. uncertainties and their interactions.

A growing social science literature on CCS has developed over recent years which points to a number of important uncertainties around the development of CCS. Our paper systematically reviews this literature and also draws on broader insights from innovation studies that have shed light on the development of technologies more generally. From these starting points – the policy problem and the insights from literature — the research questions guiding the analysis in this paper are:

1. What are the main uncertainties with regard to future CCS development?
2. How are the different uncertainties inter-related?
3. How can they be assessed (quantitatively or qualitatively)?

This paper draws on a research project funded by the UK Energy Research Centre. The project will provide an independent analysis of the uncertainties of CCS viability in the UK from now until 2030, and an assessment framework that can be used by practitioners, as well as more generalisable insights about technology assessment. The contributing researchers span science, engineering, politics and innovation studies, as well as law and financial markets. This paper is the key output of the first stage of the project.

The next section of the paper will provide a brief review of the limited existing social science literature on CCS innovation, and the third section will introduce theory on technology assessment and socio-technical systems needed for the analysis. The fourth section will outline the methodology used. Section 5 provides the key insights from our analysis and Section 6 concludes.