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Stakeholder perceptions on carbon capture and storage technologies in Finland- economic, technological, political and societal uncertainties

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Abstract

Success of individual CCS projects as well as integration of CCS into larger energy systems depend on institutional and organizational support from a variety of contexts. We map stakeholder perceptions from an institutional perspective and present a framework for identifying path dependencies, challenges and opportunities in the dynamic development of the social, political and economic setting around CCS technologies. The analysis is based on data collected on two Finnish CCS demonstration projects; a cancelled retro-fit project for a coal-fired power plant and a recently developed method for mineralizing CO_2 into stable calcium carbonate. Our goal is to examine which uncertainties are considered most significant and most likely to affect the development and employment of CCS technologies.

Keywords: Carbon Capture and Storage; risk governance; institutional analysis

1. Introduction

Understanding how technologies develop from the laboratory through various trials and pilot phases into a commercial, sustainable technology requires a more detailed understanding of the institutions involved and the system in which they interact. In this paper, we present a methodology from institutional economics in combination with a socio-ecological systems perspective. We present a first analysis from

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two case studies in energy technology development. Carbon capture and storage (CCS) is often cited as one of or the key technologies for sustainable energy production [1]. Many projects in different countries have met surprising obstacles, and there are doubts on whether the technology can meet the expectations. We analyze a cancelled power plant retrofit project from Finland and a new method for mineral carbonation using steel making slags, with an eye on the institutions – shared rules, norms, strategies and classifications and the mental models formed by collections of such – which various actors hold and use.

Individual projects and the integration of CCS into larger energy systems both depend on institutional and organizational support from a variety of contexts. We map stakeholder perceptions of various experts from an institutional perspective and present a framework for identifying path dependencies, challenges and opportunities in the dynamic development of the social, political and economic setting around CCS technologies.

The two applications were chosen for the study as they represent the CCS technologies with most potential in Finland under the current circumstances as well as two CCS technologies in very different phases in their development and maturity. The combination of these cases gives us a comprehensive outlook on the variety and significance of different uncertainties relevant to countries located relatively far from geological storage sites since there are differences regarding the significance and magnitude of a variety of uncertainties for each of the applications. This research is part of the project "Risk governance of carbon capture and storage (RICCS)" conducted in co- operation with Aalto University and Helsinki University and funded by the Academy of Finland.

2. Understanding risk as mental models of complex institutions

The analysis is based on two case studies, with material including scientific and media publications together with expert and stakeholder interviews. Interviews were conducted with stakeholders from a variety of organizations and perspectives, reflecting the holistic and integrative approach in the paper. The material was analyzed from the perspective of mental models reflecting rules or institutions that are used to justify actions.

The evolution of an energy system is dependent on how the interacting experts from a variety of fields understand the interdependencies of the various uncertainties over the developments. Humans understand uncertainties and risk through mental models. Mental models are relatively enduring and accessible but limited internal conceptual representations of an external system whose structure maintains the perceived structure of that system [2]. These mental models are characterized by inherent imperfections in the representation, both within the model and in comparing the various models and their outcomes and attempting to integrate them.

The uncertainties and risks are harmful potential or uncertain real-world phenomena, but this reality cannot be completely or accurately reduced to a collection of facts and principles, as the popular image of science suggests [3].The basic model of scientific risk analysis based on expected value calculations from probability and potential damage is a mental model. This model is an incomplete representation, as technologies are extensive, open-ended technical-social systems where local behavior is not driven by any overall rationality [4], but suffers from blind sports in relation to detectability of certain types of risk [5] or to so-called black swan events – low probability, high effect situations [6]. For CCS in particular, there have been calls for an integrative analysis [7][8].

So far, the research tradition on risk as mental model has focused on shortcomings and errors in lay perception of risk [2]. Misconceptions about CCS in the public sphere [9] are obviously important in risk governance, but in reality, even experts' mental models are incomplete and vary considerably between experts. The future development of CCS is a complex entanglement of political, financial, technical and social features, and experts in these fields start with different model of risk.

There is a range of scientific traditions that deal with future uncertainty in relation to CCS. Technical [1], commercial or investment [10], political or regulatory [11][12] and social [13] risks are all relevant to the future of CCS. Currently, there is no consensus about costs, benefits, technology or regulation of CCS [14]. These ongoing debates are based in risk concepts that are built on underlying mental models.

In this paper, we draw upon the tools from institutional economics and look at the mental models underlying the forecasts and uncertainties as institutions. Institutions are shared strategies, norms and rules that shape human interaction. Conventions, codes of behavior and organizational practices are institutions, but so are formal laws. Institutions can act as constraints – limiting what is acceptable, potentially even defining punishments for deviation – but they can act to enable as well, for example by creating a common language for a purpose. [15] Norms of classification and categorization are important institutions in enabling communication [16].

Sometimes the institutions can be in explicit, linguistic or even algorithmic form, but just as often they are hidden in natural language. Empirical institutional research is to uncover the rules used in particular settings. This entails the use qualitative methods to find the institutions from the natural language uttering and actions [17]. In this paper, we draw loosely upon the grammar of institutions model, where every institution is defined in terms of the attributes limiting who the institutions concerns, a deontic (may, must, must not), and an action, along with limiting conditions and possibly punishment for deviation (for formal rules).

The models of risk held by the stakeholders can be analyzed from the perspective of capacity to incorporate surprising events. The ability to do this is called resilience [18]. There are two types of resilience: the ability to return to an equilibrium state after disturbance, also called engineering resilience, and the ability to absorb disturbance before moving the system into another far-from-equilibrium state or stability domain, called ecological resilience [19]. The engineering variety of resilience operates in CCS at the level of individual technological designs, but the whole domain is in a constant state of change.

Conventional risk concepts operate within the domain of engineering resilience. Risk-hazard and dose-response models have been criticized for ignoring the ways in which systems amplify or attenuate the impacts of hazards, ignoring the distinctions between exposed subsystems and components, as well the role of social structures in shaping response [20]. The systems perspective with resilience should enable risk analysis to respond to these challenges.

The development is facing many external challenges, and resilience or ability to switch between favorable states of development is crucial. The trajectory can conceptualized as chains of events that happen in and between subsystems and that affect other subsystems. Changes in one system can cause non-reversible changes in another - the events in the follow a pattern of path dependency [15]. Path dependent events are events with the following properties: specific patterns of timing and sequence matter; a wide range of social outcomes may be possible; large consequences may result from relatively small or contingent events; particular courses of action, once introduced, can be almost impossible to reverse; and consequently, political development is punctuated by critical moments or junctures that shape the basic contours of social life.

3. Carbon capture and storage technologies in Finland

Finland is a county that has very few geological formations for CO_2 storage, with very limited potential and the occurrence of saline aquifers is unlikely. Therefore geological storage would have to be based abroad, the nearest potential storage sites that can be legally utilized (EU has ruled out storage outside Europe [21]) are located underneath the North Sea or in the Barents Sea area. This means that any CO_2 would have to be transported over long distances by ship or pipeline. Ships would be the most feasible option in the demonstration phase, many of the largest Finnish point sources of CO_2 are located in coastal areas and ships are a cost effective option for the transportation of small amounts of CO_2. Another possibility would be to build a pipeline along the Bothnian coast leading to Barents sea in the North, but such pipeline would have expensive initial investment and would require large volumes of CO_2 in order to make sense in economic terms, making it unfeasible for the demonstration phase. [22]

Finland has significant CO_2 emissions from bioenergy, so there is existing potential for implementing CCS with biomass. The use of bio- CCS would lead to negative CO_2 emissions as it would effectively remove carbon from the carbon cycle [22]. However, as the EU ETS does not recognize emissions from non- fossil fuels, there are no financial incentives to implement bio- CCS for the moment.

Due to near lack of domestic storage sites, mineral carbonation (also known as carbon mineralization) presents an interesting storage option. In the carbonation process, captured CO_2 is fixed into mineral form for long term storage. These minerals are thermodynamically stable and useful for other applications (e.g. road construction), thus there is no need for monitoring. Carbonation of industrial solid waste such as steelmaking slags to produce precipitated calcium carbonate (PCC) for paper industry is a good example of mineral carbonation [23].

3.1 Post- combustion capture at coal- fired power plant with storage abroad

Despite being cancelled in 2010, the plan to implement a post- combustion capture technology at a power plant in western Finland is the only demonstration phase project planned in the country so far. The purpose was to reduce carbon emissions from the power plant by treating 50% (at full operating capacity) of the flue gases using an amino acid salt- based post- combustion technology. The use of this method would achieve a 90% reduction in the CO_2 content of the treated flue gases, amounting to a total reduction in CO_2 emissions of 1.25 Mt annually. This would be equal to 1,5% of the total annual Finnish CO_2 emissions based on 2007 levels [24]. The use of the method would lead to increased energy consumption, thus reducing the efficiency of the plant by 65 MW or approximately 5%.The captured CO2 would be pressurized into liquid form and transported to a storage site off the coast of Denmark in tankers similar to what is currently used for transport of petroleum and petrochemicals, with capacity for transporting up to 20 000 m^3. A depleted oil field off- shore was selected as a storage site since it would mean the geology on site would be well known and had some existing infrastructure which could be used, such as wells, and there was the possibility to cover some of the cost of the demonstration project using enhanced oil recovery (EOR). It was also estimated that an off- shore site would minimize any potential problems with acceptability.

Environmental impact assessment (EIA) indicated that the capture phase would not contain significant risk on the environment nor does it contain other risks exceeding those of a standard power plant or other industrial operation. Transportation and handling as well as intermediate storage would be conducted according to the highest industry standards; therefore the results of the EIA seemed very promising. According to company surveys conducted on the inhabitants of the municipality where the power plant is based, the level of acceptance was high. People had a positive attitude toward the implementation of CCS on the plant, mainly because of the creation of new jobs in the area both in the building phase and later in permanent maintenance and logistics. Total investment costs for the project were estimated at 500 million euros. Although financial support from the European Union seemed likely, significant investment would still be necessary from the companies involved and the national government was reluctant to offer financial support. The costs were too high for some of the partners and in 2010, they started pulling out of the project, which was eventually cancelled. The largest partner also implemented changes in company strategy which meant that coal- based power generation was no longer the focus of their operation.

3.2 Mineral carbonation in steel production using steel- making slags

The process for fixing CO_2 with mineral carbonation using steel making slags is a relatively new application in the early stages of scaling- up. Steel manufacture is one of the largest sources of CO_2 emissions and the largest individual source of CO_2 in Finland. Steel making by- products and waste, such as steel converter and blast furnace slags naturally contain a high level of calcium and could therefore be used in carbonation. In this process ammonium salt solution, such as ammonium acetate, ammonium nitrate or ammonium chloride is used to extract calcium from steel slag, followed by bubbling CO_2 through this solution in order to precipitate pure calcium carbonate. As well as providing a use for steel making by- product or waste, the process results in marketable precipitated calcium carbonate (PCC) which is high quality. PCC could be used as a coating material in paper production, for instance, where it would partially replace PCC specifically manufactured for this purpose and reduce the CO_2 emissions caused by the burning of limestone.

Preliminary feasibility studies show that mineral carbonation using steel making slags has economic potential. Most mineral carbonation processes require high temperatures and pressure as well as significant amounts of chemicals and minerals, which is the main reason for high cost. Experiments show that carbonation using steel making slags takes place in low temperatures and normal atmospheric pressure. A small amount of residual slag would be left of the process to be treated, but the solvent is mainly recyclable in the process and minimizes chemical consumption. The costs of the process would be recovered through the sales of the end- product as well as possible CO_2 allowances. Scaling up to industrial level would be necessary to confirm the initial economic and technical results as well as provide more accurate measurements. Potential for the method in terms of climate abatement is limited, both by the amount of slag created in the steel making process and the demand for PCC.

4. Stakeholder perceptions on CCS technologies in Finland

Stakeholder interviews place emphasis on economic and political uncertainties as most significant in determining the success of CCS implementation in Finland. Both case studies revealed the importance of national political support and institutions which support the implementation of the technological application. Weak political support, the lack of government financial support and low emission prices as well as the difficulty to predict future emission permit prices were considered the largest obstacles.

The currently low prices of the European Union Emission Trading Scheme (ETS) do not give sufficient incentive for technology development. Since future price development is highly uncertain, actors tend to use simple assumptions for predicting future price, either by extrapolating from the current low prices to a future with low prices, or using the initial ETS macroeconomic models, with assumptions of midrange forecasts. Whether the actors hold a more pessimistic or optimistic mental model for the future carbon price, they are generally not explicit in their arguments. Estimates on commercial viability of CCS are also generally not based on explicit assumptions, particularly in policy discourse.

Storage is the most controversial issue in CCS with the general public. The possibility of leakages and the potentially catastrophic consequences of large eruptions have led European legislation to focus on legislating onshore storage and to ban export of CO_2 for storage outside the EU. Although Finland has no geological storage sites (some do exist near the border in Russia), legislation to implement the directive was issued and storage was banned in Finland. Banning something on the grounds that it is impossible to do is a legislative oddity, but it can be considered to have additional effects as a signal to actors who are considering engaging in similar applications. How likely would it be to gain financial or political support for a technology that is banned in Finland? Still, none of the legislative or administrative authorities reports neither opposition nor support towards CCS and the law appears to have been more of a safeguard in unknown circumstances. As the current legislation is based on predictions of main technological applications, the development of other applications could be distorted. Since mineral carbonation applications have largely been determined unviable, institutions to support their development are largely missing.

Typical in discussions about CCS is to introduce the grim reality of climate change, followed by the presentation of CCS as a possibility to reduce emissions or a simple necessity considering time and other limitations. To the steel industry, for instance, it seems that CCS may be the only way to reduce CO_2 emissions further as other known measures are already implemented. In the Finnish discussion of climate abatement, both environmental organizations as well as the government focus their attention on renewables. The government does not see CCS among Finnish climate abatement measures and it is missing from the Finnish energy strategy. In the political context CCS is discussed as an option, rather than a necessity.

In the assessment of uncertainties for CCS applications, a variety of uncertainties need to be analyzed in order for the assessment to represent the reality. An example of a model of risk that separates one aspect from others is environmental impact assessment. Considerable amount of work can go into an assessment that holds other things in society constant, when more often, they are not. For the power plant case in Finland, an EIA was completed just in time for the project to be cancelled. No matter how exact calculations were made on known factors, the EIA risk model has very little resilience, as the document does not address the real-life unknowns.

5. Conclusions

In this paper, we have presented a first analysis of CCS in Finland, based on a comprehensive risk governance framework. At this stage, the results have to be considered as preliminary, but we hope to have presented enough material to demonstrate the usability of a socio-technical framework that borrows from institutional economics.

The next step following these analyses is a more systematic approach that collects the information into systematic scenarios. Scenarios have been criticized for being technologically deterministic [8] and naïve, and the aim here is to find a method that is able to go beyond these problems. Quite often, CCS scenarios are still either blueprints, describing how the technology can succeed, or wishful enactments creating futures, either for use by stakeholders or for communicating to the wider community. Our aim is to build scenarios that do the opposite: find potential problems before they occur. The goal is not to analyze technologies and their limitations and possibilities, but the social dynamics that are at work.

The goal here was a short demonstration of the kinds of path dependencies and institutional inertias that can make or break individual projects, including large commercial scale projects that are far into the planning process. Once finalized, the scenario methodology should serve to help not only social scientists understand energy system developments but potentially also individual project managers and technology developers who wish to avoid social, economic and political issues.

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