A Socio-Ecological Systems Analysis for Understanding Risk Institutions in Carbon Capture and Storage

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Abstract

Many scenario analyses in energy technology development disregard the importance of institutions and the interdependence of economic, technological, political and societal concerns and events. I propose a dynamic institutional systems framework to integrate the various concerns into a simultaneous analysis and demonstrate the frame with case analyses on the budding developments of Carbon Capture and Storage (CCS) technologies in Europe.

The framework combines cognitive institutionalism with the Socio-Ecological Systems (SES) framework. Institutions are the rules of the game in a society shaping human interactions; both formal rules, such as laws and regulations, but also informal institutions through traditions and practices. Cognitive science has recently started unfolding the evolution of collective mental models and how they change. Incremental change, institutional inertia and path dependency shape choices in energy systems. There is no guarantee that the process finds the institutions to support the technologically most advanced or environmentally most benign energy production systems. I look at the institutions in the SES subsystems of production systems, technology systems, governance systems and user systems and how they constrain and enable each other.

The paper is based on case studies of recent developments in Europe. In Finland, a retrofit demonstration capture project was cancelled fairly late into the process, with environmental impact assessments completed and positive. A combination of factors including company strategies, national climate plans and technological uncertainties forced the project off track. I interpret these factors as organizational and shared everyday practices or rules-in-use and deeper constitutional rules. The Finnish case is compared with other European experiences, mainly in Sweden, Norway and Germany. The uncertainties in CCS development are responded to in different ways in the different countries based on the institutional factors available.

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, I argue for a methodology from institutional economics in combination with a socio-ecological systems perspective. I present a first analysis from a case study in energy technology development. Carbon capture and storage (CCS) is often cited as one of or the key technology for sustainable energy production. Many projects in many countries have met surprising obstacles, and some are doubting whether the technology can meet the expectations at all. I analyze a cancelled power plant retrofit project from Finland with an eye on the institutions – shared rules, norms, strategies and classifications and the mental models formed by collections of such – that various actors hold.

The first research question is: how did these institutions affect the process over this particular power plant? The second is how to generalize on these issues: what are the common threads for institutions? To respond to the research questions, interview data is used to elicit the mental maps of the stakeholders. Mental model methods have used both direct and indirect elicitation techniques (Jones et al. 2011); direct referring to using various visualization techniques to establish a correspondence between the external cognitive map and the internal mental model, indirect to researcher extracting the mental model from text. In each method, maps consist of concepts (or variables) and relationships between them. Text data is coded into statements of form (concept -> relationship -> concept) and compiled into the map of the mental model (Carley & Palmqvist 1992).

For our research, there are two nested mental models that we try to construct from the data. The stakeholders operate at two levels that interact: first, their generic perception on what risk entails is one mental map. This constitutive mental model is operationalized into the specific CCS mental model and further into a case-specific model. Another issue that is especially interesting in risk models is handling uncertainty; this means assessment of the relationships for how uncertainty and probability are represented and how they compare to mental models where relationships represent certainty. Finally, the various mental models of stakeholders can be synthesized into a shared model of CCS risks, possibly the multi-step fuzzy cognitive mapping approach (Özesmi & Özesmi 2004) or a cognitive blending approach.

The research questions, when understood in light of this discussion, turns into subquestions:
(1a) What are the mental models of risk stakeholders use?
(1b) What are the mental models of CCS systems stakeholders use?
(1c) How are arguments about uncertainty made and what they are based on?
(1d) What are the risks of CCS technologies? Timescales? Scope?

Institutionalism and Socio-Ecological Systems

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 (Doyle & Ford 1998, 17-21). 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 referred to 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 (Byers 2011, 55). 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, too (Wynne xx), and suffers from blind sports in relation to detectability of certain types of risk (Kastenhofer 2011) or to so-called black swan events – low probability, high effect situations (Taleb 2007). This does not imply that ever more detailed evidence on risk factors is irrelevant; just that it is not complete without a more detailed understanding of risk.

So far, the research tradition on risk as mental model has focused on shortcomings and errors in lay perception of risk (Doyle & Ford 1998, 12). For example, the people’s understanding of radon radiation was found to be incomplete and incoherent (Bostrom et al. 1992, 98). Misconceptions such as confusing climate and weather or climate change and ozone depletion (Reynolds et al. 2010) are obviously important in public discourse, but this perspective ignores biases in experts’ mental models and ignores the time and effort required to gather information.

In reality, even experts' mental models are incomplete and vary considerably between experts. The science of modern risk analysis disagrees, as some have even gone as far as to state that the "only meaningful way to evaluate the riskiness of a technology is through probabilistic risk analysis" (Cohen 2003, 909). In this view, mental models would be knowledge gaps and over-generalizations (Atman et al. 1993). Even though risk analysis as a science that grew out of the concerns of the general public, this perspective ignores the between-persons weighing or risks (Hansson 2004). 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 (Metz et al. 2005), commercial or investment (Yang et al. 2008), political or regulatory (Blyth et al. 2007; Wilson et al. 2007) and social (van Alphen et al. 2007) risks are all relevant to the future of CCS. Currently, there is no consensus about costs, benefits, technology or regulation of CCS (Brunsting et al. 2011, 6382). These ongoing debates are based in risk concepts that are built on underlying mental models.

The mental models are difficult to observe, measure, and analyze. 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. (North 1990.) Norms of classification and categorization are important institutions in enabling communication (Kahnemann 2011, 74).

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 (Crawford & Ostrom 1995). 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).

Institutional methods range from loose qualitative analyses to game-theoretical treatments with explicit payoff matrices and the like (Crawford & Ostrom 1995. In this paper, we utilize a socio-ecological systems perspective as a classification and catalogue of institutions, and analyze the content of documents and thematic interviews through the lens of potentially interacting institutions with a qualitative content analysis procedure.

The perspective of Social-Ecological Systems has been developed in the context of common pool resources management (e.g. Berkes & Folke 2000), but it aims to be a more general framework. An SES consists of four main subsystems: the resource system, the resource unit system, the governance system, and the user system (Ostrom 2009), interacting with each other and the results or outcomes. This framework should be considered as a nested conceptual map, with each subsystem unraveling into a system on its own, with the level of detail growing into second and third tier variables (Ostrom 2007).

The system is divided into 4 subsystems, 2 background systems and the interactions between these systems and their evolution. The aim is to estimate system dynamics by answering three questions: 1) What patterns of interactions and outcomes are likely to result from the set of variables?, 2) What are the likely developments of the systems in the presence of a certain governance system? and 3) How robust and sustainable is the configuration to disturbances in the systems? (Ostrom 2007.) The system descriptions also have the benefit of letting the values of the outcomes be determined simultaneously with the probabilities, building the dialogue into the process, as has been suggested in policy advice documents (Davies 2007), instead of separating the science and the dialogue.

The background systems are the social setting and all related ecosystems. These systems set the problem and put it into a more general context. The social setting describes the framing of the problem, as well as the general background not connected to any individual actor or organization. It justifies the analysis and makes it understandable to the diverse set of interested parties or stakeholders. The setting may be called the consensus: the set of issues that are agreeable to all, and are used to feed the process. These include the governance setting (the set of possible institutional frameworks that are used), public perception of the issue, media perception of the issue, and the economic background. The references to a general public or general media opinion are included in the background when they cannot be appointed to any specific actor.

The related ecosystems include systems in which the current system is nested in. The SES is itself an eco(-social) system, and the related systems are similar conceptualizations. The SES framework is nested by design, and any SES can be conceptualized as part of a larger system – whether defined as geographically larger, or possibly larger in timeframe, or in some other sense.

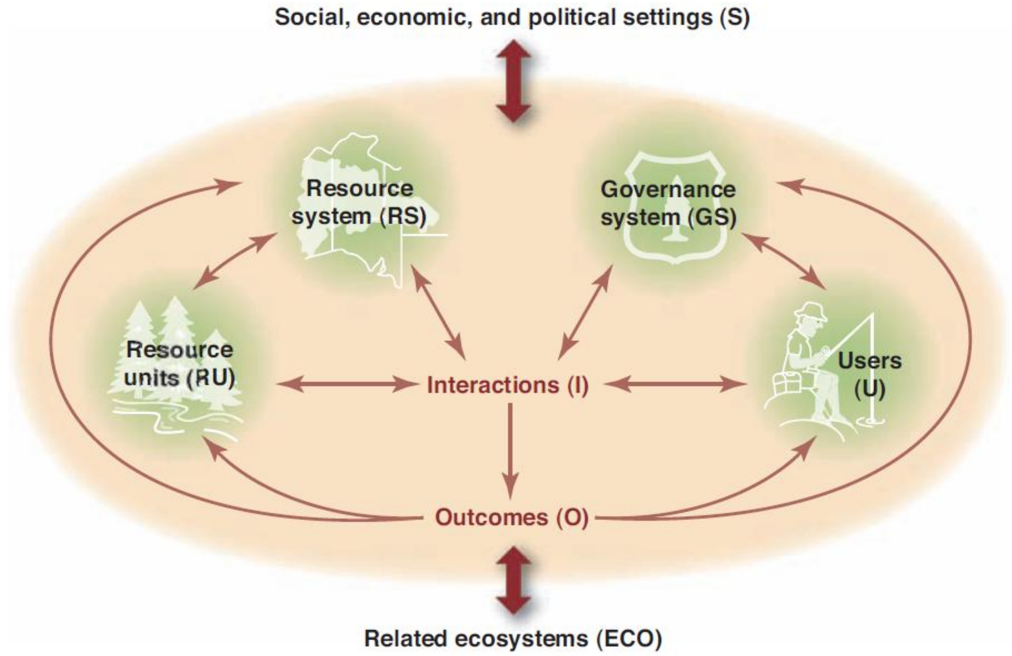


Figure 1. SESs from Ostrom 2009.

Vulnerability refers to both the external stresses and shocks SESs face as well the capacities to resist them, cope with them and recover from them (Luers et al. 2003, 256). Vulnerability refers to exposure, sensitivity and capacity of response. Exposure is the amount of stress from a particular source the system is facing; sensitivity is the level to which a particular source can change the system. For example, a person with low immunological defences is sensitive to disease, but not necessarily exposed to them, and thus not vulnerable. Capacity to react to the dynamic perturbations is the resilience of the system. (Gallopin 2006).

For the participants in the system, the goal is to maintain functionality of the system when facing external and internal disturbances. The ability to do this is called resilience (Walker et al. 2002). 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 (Holling 1996, 33). 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 (Turner et al. 2003, 8074). The systems perspective with resilience should enable risk analysis to respond to these challenges.

The SES in CCS development is facing many external challenges, and resilience or ability to switch between favourable 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 SES follow a pattern of path dependency (North 1990; Pierson 2000). 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 (xx, xx).

Carbon Capture and Storage in Finland

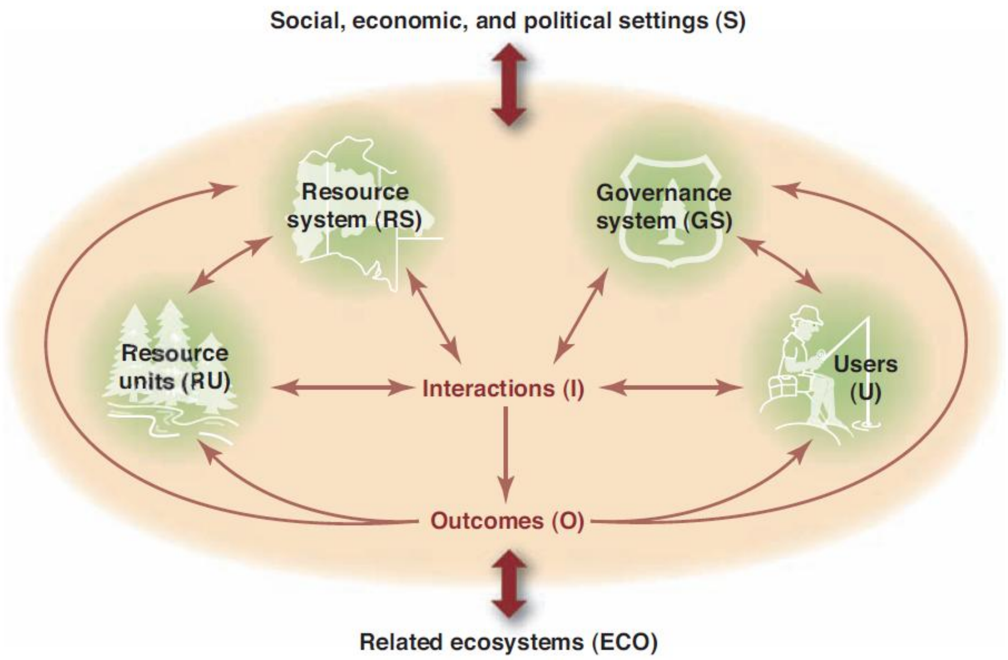
CCSis a budding technology, with few applications but grand forecasts for deployment in the fairly close future. In Europe, the European Union adopted a directive on geological storage of captured CO_2 in 2009 (Directive 2009/31/EC). As of February 2012, one member state, Spain, had fully managed to implement the directive into national law, as required (Armeni 2012). Finland has implemented the law with some reservations, namely by forbidding storage in Finland as impossible.

Finland is thys hardly a forerunner in CCS, but the short history of technology offers some interesting examples of the dynamics at play elsewhere, too. In what is becoming a common story for CCS, a large scale planned facility was cancelled fairly late into the planning process. The Finncap project was a joint project involving Fortum and Teollisuuden voima (TVO), two of the largest power companies in Finland. The aim was to retrofit a coal power plant in Meri-Pori with post-combustion capture technology provided by Siemens Energy, which would treat 50% of the plants flue gases at full capacity. Post-combustion methods simply treat the flue gases from plant with another filter, analogously to other flue gas treatments required for environmental reasons. The technology would

achieve a 90% reduction of CO_2 in treated flue gases, which would amount to 1,25 Mt of reduction of CO_2 emissions annually, an equivalent of 1,5% of Finland's CO_2 emissions (2007 levels).
The method would reduce power plant efficiency approximately 5% or 65 MW due to its energy consumption. The captured carbon dioxide would finally be pressurized and transported (1800-2000kms) for storage in the North Sea by Maersk. (Iso- Tryykäri, 2010.)

The publicized reason for the cancellation, as declared by Fortum, was technical and economic risks and changes in company strategy. Fortum wanted to concentrate on hydropower, renewables and combined heat and power. Further, the withdrawal of TVO from the project would further increase the financial risks involved as Fortum would now be solely responsible for the implementation and carry most of the risks. Following the change in corporate strategy the economic cost of the project and the financial risks involved were considered too large to carry out the project. (Fortum, 2010.)

Institutional Explanations for CCS Development in Finland



In my analysis, I have identified five examples of institutions that seem to have an effect on future argument beyond their logical form; in other words, they introduce path dependency to the development. I will discuss these six below.

1) CCS as an option vs. CCS as necessity

The first institution is a very basic one, in most texts and spoken language used simply as a quick introduction into the subject. The common way to start any argument on CCS is to present the grim reality of climate change, and then introduce CCS as either one possible tool in reducing emissions, or a necessary tool given the constraints of time.

2) Carbon market forecasts

The European Union Emission Trading Scheme (ETS) has not been without effect, but the current low prices are not great in stirring technology development for emissions reductions. The price will not stay the same, though, and all actors are acting upon some forecast emission price in their decisions. As the future of ETS is highly uncertain, actors are often working from rule-of-thumb assumptions instead of detailed forecasts, seemingly separating two ways to act on the uncertainty: either extrapolation from the current low (and falling) prices to a future with low prices, or using the initial macroeconomy models from ETS planning work, with assumptions of steady midrange forecasts. Whether starting with the more pessimistic or optimistic mental model of future carbon price, actors are not usually explicit in their argument. Debates on whether CCS can be commercially viable are too often empty of real content, as assumptions are not explicit, especially in policy discourse.

3) Directive on CCS mostly in the S

Storage is the most controversial issue in CCS with the general public. The worry about potential leakages, especially of the violent or explosive type that happen due with carbon dioxide naturally in some places, lead the European officials to focus heavily on onshore storage in the law-making. Issues such as export of CO_2 for storage are covered, and mainly banned. For Finland, a country with no storage options locally, but some nearby across the border in Russia, this was an element in banning storage in Finland and focusing on pipeline transport options. Legislating based on current foreseen technology can put technologies in development at risk: for example, using captured CO_2 for something else than storage, such as mineralization, starts at a disadvantage.

4) No local storage is possible

The impossibility of local storage led Finland to outright ban it in the legislation that implements the CCS directive. Bannign something on the grounds that it is impossible to do is a legislative oddity.

Still, such meaningless regulations can have effects beyond the regulation. Even if the law were to have no logical conclusions, it signals some kind of opposition to actors thinking about engaging in similar technologies. How likely would financial support for Finnish technology developers in a technology that is banned in Finland be? Still, none of the legislative or administrative authorities reports opposing CCS in any meaningful sense – the law appears to have been a safe play in unknown circumstances.

5) National strategy work

Despite their efforts the political risk was realized when the government was reluctant to support the project, as CCS has not been identified in the Finnish energy strategy as a tool for climate mitigation, which was published in 2008 as Fortum was conducting feasibility studies on the Finncap project (Iso- Tryykäri, 2010). The energy strategy focuses strongly on increasing the use of renewable energy and improving energy efficiency (TEM, 2008). The failure to obtain financial support from the government resulted in an increase in financial risk, as the profitability of the project decreased, weakening its financial viability compared to alternative investments.

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