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Assessing the risks, costs, legal framework and public perception of offshore CCS

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ECO_2 Project - Sub-seabed CO_2 Storage: Impact on Marine Ecosystems
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Contents

Introduction

By Kristin Hamann, German Marine Research Consortium

Information about the technical aspects and processes of carbon dioxide capture and storage (CCS) is readily accessible. Websites and brochures – by NGOs, companies and governmental authorities – offer comprehensible explanations about the CCS procedure. This briefing paper serves the purpose to inform about aspects which have been less covered, but are crucial when it comes to the question of implementation: The societal concerns in offshore carbon dioxide capture and storage.

The topic of CCS has been on the EU agenda since initial steps were taken to foster this technology in 2005 with the creation of the Zero Emissions Platform (ZEP). The adoption of the EU Strategic Energy Technology Plan (SET-Plan) in 2007 and the CCS-Directive in 2009 were further crucial steps for the development of a CCS policy in Europe. The NER300 funding scheme was designed to give that policy an operational level by supporting CCS demonstration projects in Europe. To date, however, no CCS project has been funded under the scheme. Certainly many reasons could be identified why no CCS projects have really taken-off, but one core problem remains, namely that the commercial viability of projects is still not guaranteed. In March 2013 the European Commission published a Communication which concludes that CCS in Europe has not advanced the way it was estimated in 2007. To further promote the development and application of CCS, Chris Davies MEP published a report in autumn this year. So the debate about the future role of CCS in Europe is ongoing.

For the foreseeable future, Europe will continue to depend on fossil fuels as an energy source. Proponents of CCS argue that this technology should therefore be employed as a supportive measure to reduce emissions and help to reach the EU's 2050 CO_2 emission reduction targets. In contrast, critics point out that CCS may in fact serve to perpetuate the use of power plants with high emission rates, rather than promoting investments in renewable energy production. The case of CCS (offshore or onshore) is certainly controversial.

This briefing paper provides an overview of the research being conducted in the ECO_2 project surrounding societal concerns about offshore CCS. The overall goal of ECO_2 is to investigate the likelihood of leakage from sub-seabed storage sites and its possible short- and long-term impacts. The project addresses this issue both in terms of impacts on the marine ecosystem as well as related risk assessment, economic, legal and societal dimensions. In addition, the project will develop a comprehensive monitoring concept for storage sites in order to enhance the methods employed for different scenarios of CO_2 leakage. The ultimate objective of the project is to establish a framework of best environmental practices to guide the management of offshore CO_2 injection and storage.

To date, two briefing papers have been published. The first paper introduced fieldwork activities at Sleipner and Snøhvit and presented the scientific basis for offshore CCS. The second addressed the potential impacts of CO_2 leakage from sub-surface storage on seabed biology. This third paper now seeks to inform about current research into the societal dimensions of applying this technology.

The first part of the paper covers the research done to assess the risks, the legal frameworks and economic implications of offshore CCS. The article entitled ***"Understanding the level of risk associated with CO_2 storage sites***" explains the methods of how the risk of a potential leakage is estimated. These methods serve both to gain an enhanced understanding of the potential impact on the environment and to support a comprehensive approach to address public concerns. This is followed by a contribution on the different European and international regulatory instruments. Entitled ***"The regulatory framework of sub-seabed CCS"***, this article compares leakage acceptance in the various pertinent international and European legal instruments and analyses the challenges arising out of different applications and transpositions of EU law instruments. Such considerations of potential leakage invariably also raise questions related to the economic costs and benefits of offshore CCS. The article entitled ***"Economic Implications of CO_2 leakage risks"*** concerns itself with the micro- and macroeconomic dimensions of these costs.

Section two presents research in ECO_2 on the public perception of offshore CCS. The first article in this section is entitled ***"CCS Policy Perspectives and the Public Perception of CO_2 Geological Storage"*** and argues that the identification of potential CO_2 storage fields needs to cover not only geological considerations and technical aspects, but also place the same degree of importance on the social characteristics of the area in question. The article sheds light on the main reasons why the public may or may not be opposed to CCS and provides some thought-provoking impulses on how to improve the public's engagement with CCS. The second article, entitled "***Investigating offshore CO_2 storage from the perspective of the people"***, introduces the innovative research approach used in the ECO_2 project for the study of both the emotional and the rational aspects of public perception of the geological storage of CO_2. For the first time an in-depth exploration of cultural factors throws new light on the dynamics of public questioning of CCS implementation.

Finally, as a concrete contribution to the public understanding of CCS, a general glossary of CCS terms was developed. Entitled ***"A Glossary for the ECO_2 project: "The Language of CCS – definitions and explanations"***, the glossary is targeted at both expert and lay communities. Although only a few months old, the glossary has already been adopted as a reference guide by other projects and initiatives.

Before turning to the content of the contribution, a summary of the work performed so far in ECO_2 embeds this briefing paper in the overall project context.

Progress in ECO_2 …

… work performed until now

The scientists of the ECO_2 project have carried out risk analyses at the sub-seabed storage sites Sleipner, Snøhvit in the North Sea and Barents Sea and a proposed site called B3 field in the Baltic Sea. The selected sites cover most geological settings likely to be used for CO_2 storage. Factors like CO_2 leakage pathways and seep locations from current and potential storage sites and their impact on marine ecosystems have and will continue to be assessed by sophisticated monitoring techniques. Furthermore, effects of leakage of CO_2 through the sediment are investigated at natural analogues and the impact on benthic organisms is studied through experiments.

To facilitate their investigations, ECO_2 project members have set up mesocosm facilities, laboratory experiments, field work, numerical modelling tools and interfaces. In addition, 22 marine science expeditions to offshore storage and seepage sites were conducted for studies and data collection. During these cruises, the researchers employed and advanced a range of cutting-edge monitoring technology and techniques. So far, scientists did not detect any CO_2 anomalies in waters above the investigated CO_2 storage sites.

The environmental risks of CCS and its financial, legal and political implications have been elucidated and field data stored in a project database. Project findings are disseminated via the project website, press releases, articles, parliamentary briefings and more. Particular mention goes to the CCS glossary produced by Kelvin Boot (Plymouth Marine Lab) for ECO_2 “The language of CCS” (available at the ECO_2 webpage at www.eco2-project.eu)

ECO_2 has attracted the attention of groups from Australia and Japan that are involved in sub-seabed CO_2 storage initiatives. Successful project outcomes will provide an in-depth environmental risk assessment and monitoring strategy for sub-seabed storage sites.

Finally, a best environmental practice guide will be created from ECO_2 project results for sustainable sub-seabed CO_2 storage. This will support the European Commission, national policymakers and CCS stakeholders in decision making and cost estimations.

Aquatic Eddy Correlation lander deployed at Bottaro © McGinnis/PaCO2 cruise

Understanding the level of risk associated with CO_2 storage sites

By Sharnie Finnerty, Det Norske Veritas (DNV GL Group), UK

Understanding Risk

Carbon Capture and Storage (CCS) has been highlighted as one of the key technologies that can facilitate a transition to a more carbon neutral world. However, balancing the global environmental benefits of reducing CO_2 emissions against potential, though unlikely, local environmental impacts is a political and economic decision as much as it is a scientific one.

Although permanent containment is the ultimate objective of any carbon capture storage site, it is necessary to understand the probability of a release and its adverse consequences on the marine environment in order to establish the risk. Risks associated with properly managed CCS projects are expected to be very low although the perceived risk by society may be higher.

Therefore, in developing a risk-based approach it is necessary to ensure a robust traceable and transparent methodology is applied that gives credibility and assurance to the proper management of the residual risks.

Risk Assessment

Background

In order to apply a risk-based approach DNV have proposed the following steps in conducting its assessment:

1. Scenario identification;
2. Applying a 'propensity to leak' factor;
3. Assessing the consequences; and
4. Evaluating the risk.

1. Scenario Identification:

In order to understand the potential risks associated with a particular CCS site it is necessary to identify and understand potential leakage scenarios. Each CCS site is unique and plausible leakage scenarios should be site specific. However, in order to be able to conduct some speculative modelling within ECO_2 a number of generic leakage scenarios have been identified:

- Leakage from abandoned wells
- Leakage via fracture
- Catastrophic blowout

2. 'Propensity to Leak' factor:

In order to identify a 'propensity to leak' factor (PTL) for various leakage scenarios DNV has developed a Bayesian Net approach which applies the concept of discretized conditional probability. It isolates the main risk drivers in a high-level probabilistic format. This approach accommodates for several relationships between uncertain variables and allows expression of probabilities to consistently influence the top level risk indicators.

Figure 1 illustrates how a Bayesian Net calculation model for propensity to leak might look. The node-edge structure defines

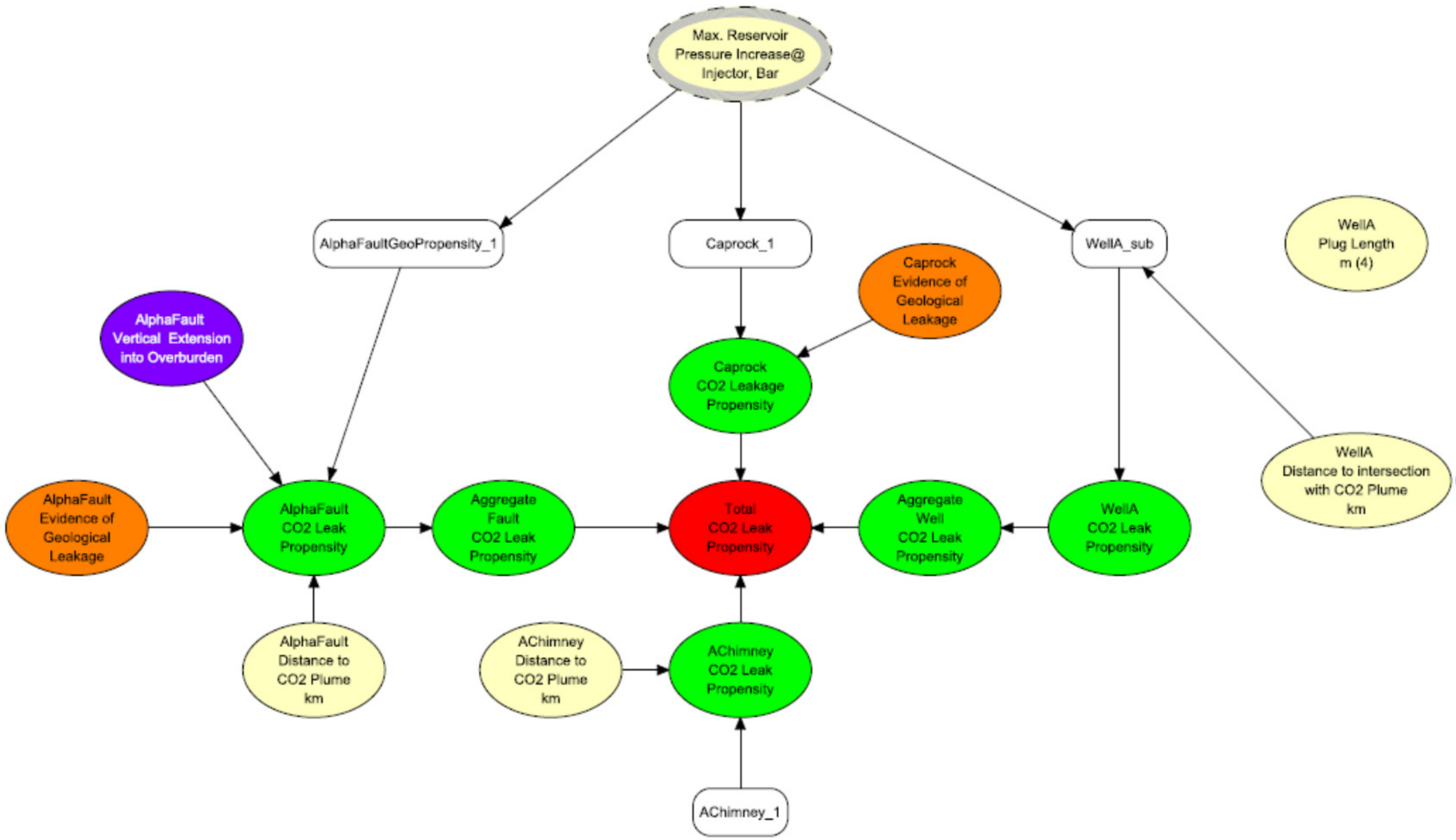


Figure 1: Example of Bayesian Net for calculating Propensity to Leak for a specific storage site

the parameter dependence relationships, while correlation tables and Bayesian discrete probability formulas define how probabilities are calculated for all downstream nodes. Using the Bayesian format allows for imperfect or ambiguous evidence to be represented, and at the same time, the structure establishes a formal means for updating evidence for new and improved knowledge concerning actual parameter influence and relations. These features are mentioned here specifically because they are not accommodated by traditional probability models, e.g. fault trees, barrier models or Monte Carlo models.

3. Assessing the consequences:

In order to assess the consequences of CO_2 leakage on marine fauna, DNV has applied a two-stranded approach which ensures that the impacts on an individual species (refered to as valued ecological components (VEC)) and a community level are investigated and assessed (see Figure 2). In general, the approach is dependent on modelled CO_2 concentrations at a given location or location(s) and data on effects for different CO_2 concentrations.

Valued Ecological Components (VEC):

For the purposes of the ECO_2 project, VECs are defined as species protected by international law, such as, for example OSPAR, EU Habitats Directive, IUCN Red List, etc. The identification of VEC's will be applied at a benthic species level and include:

- Resource mapping to identify the location and presence of VECs.
- Determining the impact of a leakage on VECs using the results of existing effects studies.
- Establishing the level of the impact on species and populations by using consequence tables based on the results of laboratory tests performed in WP4, from literature or other relevant data sources.

Community consequences:

Indices are widely used to assess the health of the macrobenthic community and to detect changes due to anthropogenic influences. Standardised monitoring regimes, for example, in the European Water Framework Directive (WFD) in coastal areas relate species patterns to environmental conditions. Many of the European Member States' WFD tools include the Azti Marine Biotic Index (AMBI) which has been tested extensively on various pressures but not yet with a CO_2 gradient. According to the developers of AMBI, it could be applied in offshore areas as long as species in the index are present.

DNV propose to:

Test extensive field databases on a CO_2 pressure gradient to determine whether AMBI picks up effects from CO_2 (other proposed indices can be tested at the same time, such as Indicator Species Index (ISI)).

If CO_2 pressure is identified, DNV will enhance and modify the equation for the purposes of a CO_2 tool, by feeding in CO_2 sensitivity scores from the lab and literature studies.

In parallel to the above, we will investigate possible indices for meio and nano benthos.

If the existing indices do not pick up CO_2 pressure, DNV will test datasets of macrobenthic datasets on a pH pressure gradient with the AMBI.

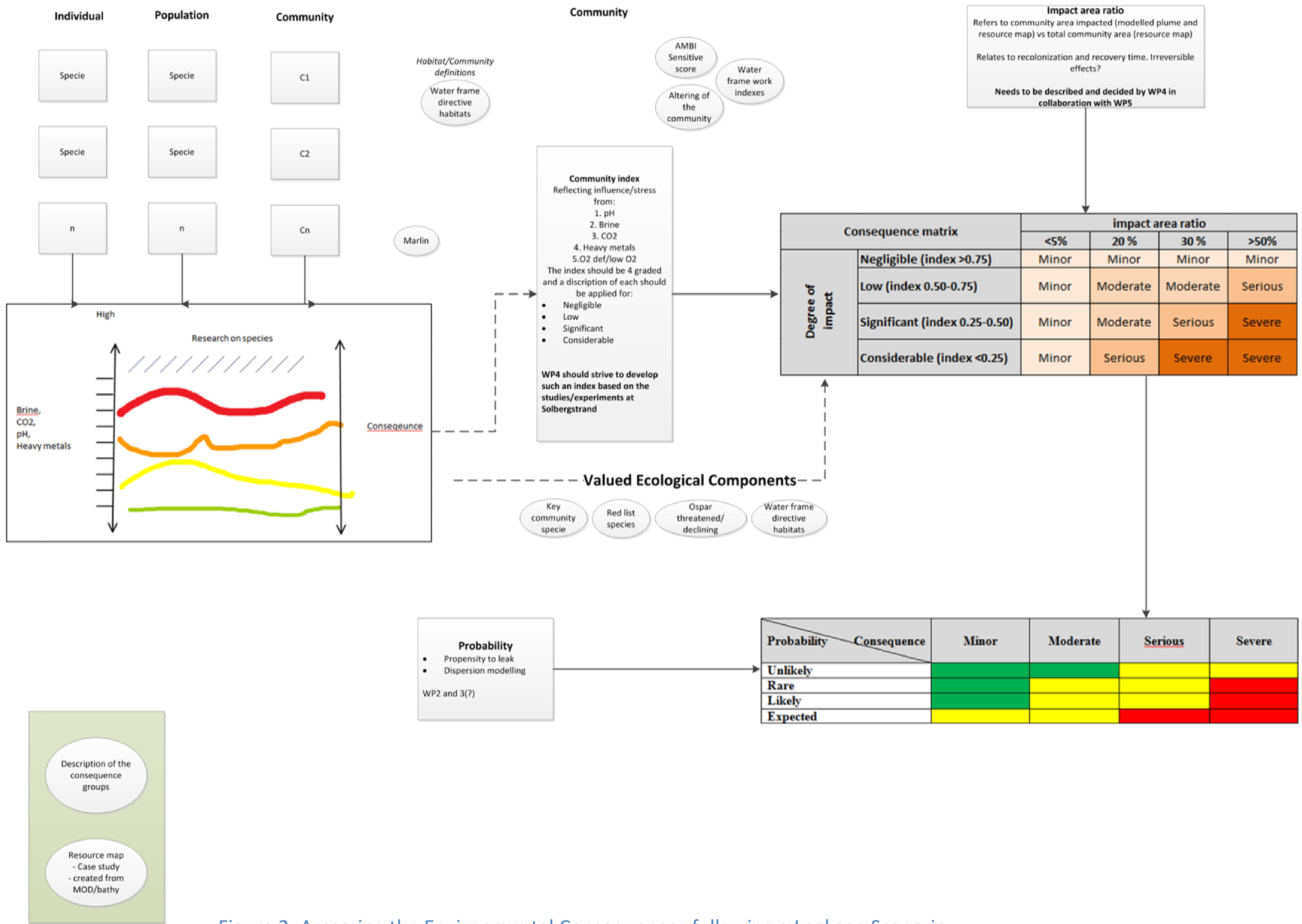


Figure 2: Assessing the Environmental Consequences following a Leakage Scenario

4. Evaluating the risk:

For the purposes of the ECO_2 project risk is defined as the *PTL x Consequence*. Therefore, once a PTL is calculated for a given leakage scenario and a resultant consequence level applied, an associated level of risk can be determined.

Risk evaluation may be qualitative, semi-qualitative or quantitative. Quantitative risk analysis implies that there is sufficient data and knowledge, e.g. statistical empirical evidence to quantify with a reasonable degree of accuracy the probability that a hazard occurs and the severity of any associated consequences. Although certain risks particular to CCS may be quantifiable, many risk scenarios will not be readily quantifiable due to lack of statistical data or quantitative risk indicators.

Therefore, a qualitative or semi-quantitative risk analysis will be applied using a risk matrix approach.

Links to other research fields:

As part of WP5, DNV have been collaborating with the Netherlands Organisation for Applied Scientific Research (TNO), Kiel Institute for the World Economy, Netherlands Energy Research Centre (ECN), University of Edinburgh, University of Sapienza Rome, University of Trier, University of Southampton, and the German Marine Research Consortium (KDM) with the aim of developing a number of legal, economic and public perception consequence assessment criteria that can be applied as part of the overall risk assessment. The criteria (if feasible) will be qualitative, high level and generic so they can be applied to the majority of CCS storage sites.

The regulatory framework of sub-seabed CCS

By Aleke Stöfen, University of Trier, Germany and Viktor Weber, University of Southampton, UK

Introduction

Due to its nature, marine CCS is located at the intersection of different regulatory approaches. Any assessment of the pertinent legal requirements must necessarily focus on how risks and potentially adverse consequences of marine CCS are integrated and addressed in international and European legislation. The following paper presents the results of an analysis of different regulatory developments that have taken place in the context of the London Protocol, the OSPAR Convention and the CCS-Directive. Scientific findings collected by the relevant WPs of the ECO_2 project have provided direct input for the evaluation of the legal standards. Also, different societal aspects of sub-seabed CCS and also its terminology that have been examined in WP 5, are important aspects of the study.

The international dimension of sub-seabed CCS

The 1996 London Protocol

The London Protocol to the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (LP) was concluded in 1996 and entered into force in 2006. It replaced the London Convention for those states that have ratified the LP. The list of parties to the Protocol includes some of the EU Member States, but not the EU itself. While the scope the London Convention does not include the sea-bed, the situation is different under the London Protocol (cf. Art. 1 (7) LP). The LP follows a permit approach according to which the dumping of substances listed in Annex 1 to the LP requires a permit that must meet the permission conditions as outlined in Annex 2 to the LP and ought to comply with the general obligations contained in the LP such as the duty to apply a precautionary approach.

Despite initial controversies on certain elements such as the purity of CO_2-streams and the risks associated with leakage, the LP was amended in 2006 to include marine CCS. Correspondingly, a new waste category was added to the list contained in Annex 1. According to the provisions of Annex 2, the permit procedure ought to be based on risk assessment guidance documents developed to guide national authorities in evaluating applications for dumping of wastes (referred to as the Framework for Risk Assessment and Management (FRAM) and the CO_2 Specific Guidelines). Even though these guidance documents are not legally binding, they serve as a general risk assessment framework and determine the CCS- terminology in the LP.

OSPAR Convention (North-East Atlantic)

The OSPAR Convention (to which both the EU and some EU Member States are parties) plays a particular role in regulating marine CCS since it is the first regional seas convention in which marine CCS, as a potential source of pollution, has been included. It sets obligatory marine environmental protection standards that primarily address the prevention of pollution. In fulfilling their obligations, the Contracting Parties need to let themselves be guided by the precautionary and the polluter-pays-principles. These principles automatically address the risks associated with CCS-activities. In 2007, the Contracting Parties adopted amendments to Annex II and III of the OSPAR Convention to provide a legal basis for marine CCS. According to Art. 3 (2) (f) Annex II OSPAR Convention, the disposal of carbon dioxide streams from carbon dioxide capture processes for storage is permissible, provided that: [...] *they are intended to be retained in these formations permanently and will not lead to significant adverse consequences for the marine environment, human health and other legitimate uses of the maritime area.* However, the provision concerned does not clearly define the permanence condition or the meaning of the term "significant adverse consequences".

In 2007, the Contracting Parties adopted OSPAR Decision 2007/2 on the Storage of Carbon Dioxide Streams in Geological Formations and the Risk Assessment and Management Framework (OSPAR FRAM) in order to provide generic guidance to the Contracting Parties in implementing and interpreting the provisions of the Convention and its Annexes.

The regulatory framework of sub-seabed CCS in the European Union

The EU CCS Directive

The CCS Directive has been adopted as part of the "Climate and Energy Package" in order to provide a common legal framework for CCS in the European Union. Key mechanisms of the CCS Directive are the permit approach and the transfer of liability to the competent authority after a period defined by the Directive in order to ensure compliance with the provisions of the Directive as well as safe geological storage. With a view to the aim of permanent storage, one of the central elements of the regulatory framework established by the CCS Directive is the definition of leakage of CO_2 as "any release of CO_2 from the storage complex" (Art. 3 (5) CCS Directive). Bearing in mind that the storage complex comprises the storage site and the surrounding geological formations, the determination of a case where leakage has occurred is difficult to establish. The leakage of CO_2 from the storage complex would in a strict interpretation of this provision already occur, if any of the stored CO_2 would be released from the storage complex. This standard constitutes an extreme application of the precautionary principle that is based on a "zero-risk approach".[1]

According to Art. 12 CCS Directive, the CO_2 stream that will be inserted at the storage site must fulfil a "purity" test. For the purpose of disposing CO_2, the stream "shall consist overwhelmingly of carbon dioxide." As in the case of the LP and OSPAR Convention, the use of "overwhelmingly" has been criticized as being too vague and failing to provide a concrete threshold in the form of a minimum content of CO_2 or a ceiling for pollutants contained in the CO_2-stream.

Whereas "leakage" constitutes any release of CO_2, "significant irregularities" may occur in relation to the injection or storage process or the complex in general. Should any irregularities or leakage be observed, so-called corrective measures are to be taken. However, no specific provisions exist that would characterize the measures concerned;

[1] The precautionary principle is a legally-binding principle in EU law (Art.191 (2) Treaty on the Functioning of the European Union).

the competent authority is thus given a wide discretion of when to act and what measures to apply.

With a view to the overall review of the CCS Directive by 31 March 2015, it is suggested that certain aspects such as the definition of the terms "leakage" and "significant irregularities" should be amended in order to increase legal certainty.

Consequences assessment criteria for legal considerations in the context of the definition of leakage

The precautionary principle, as a common denominator of the LP, OSPAR Convention and CCS Directive, guides the implementation of the necessary measures to be taken under the different regulatory regimes. While the legal consequences of applying this principle differ among the various instruments, it is justified to conclude that its application in a marine CCS context entails a risk assessment and management framework in which the scientific uncertainties associated with long-term storage on the one hand and possible negative impacts of CCS on the other are addressed. In all that, a detailed assessment of the different regulatory regimes shows that acceptance of leakage is the highest within the context of the LP and the lowest under the regime established by the CCS Directive. This assessment is directly linked to other ECO_2 WPs that help to understand what risks and consequences of sub-seabed CCS are socially acceptable, or do not cause significant adverse consequences for the marine environment respectively.

Instrument	Definition of leakage	Notes	Acceptance of leakage
CCS-Directive	Significant irregularity: "any irregularity in the injection or storage operations or in the condition of the storage complex itself, which implies the risk of leakage or risk to the environment or human health" (Art.3 (17) CCS-Directive). Leakage: "any release of CO_2 from the storage complex" (Art.3 (5) CCS-Directive).	• "Zero leakage" • Strict application of the precautionary principle • In case of leakage: Liability and emissions, or release of CO_2 from the storage site to the water column, shall be included as emission sources for the respective installation under the EU ETS Directive	Low
OSPAR-Convention	No definition of leakage in the OSPAR-Convention, but: "adverse consequences" and "permanence" requirements. OSPAR FRAM: "leakage is the escape of that CO_2 stream from the storage formation into overlying formations, the water column and the atmosphere."	• Threshold of adverse consequences and permanence requirement • Role of scientific results of ECO2	
London Protocol	Leakage "in respect of carbon storage, the escape of CO_2 from the storage formation in the water column and the atmosphere." (as outlined in the Risk Assessment and Management Framework for CO_2 Sequestration in Sub-seabed Geological Structures (FRAM)).	• Non-binding	High

The potential liability of offshore CCS in the European Union and its Member States

The risk of leakage demands an examination of the different supranational (e.g. CCS Directive and Environmental Liability Directive (ELD)) and national liability provisions that may be applicable to offshore CCS. Although not EU Member States, Norway, Iceland and Lichtenstein are also bound by the provisions of the CCS Directive by virtue of the amendment[2] of the EEA Agreement[3]. The research undertaken within ECO_2 has shown that significant differences exist amongst the Member States of the EU in the implementation of the CCS Directive. For example, in Germany the operator is to retain liability for 40 years before its transfer to the competent authority, while in France the period before the liability can be transferred is 30 years. In the United Kingdom the requirement is 20 years. The differences in the implementation may become problematic when CCS is developed beyond the experimental stage.

The implementation of the ELD is particularly varying across the Member States as well as its application.[4] These differences may create a number of challenges, such as: which private or public bodies may be held liable as 'operators', the application of the monitoring provisions and its costs, and definitions in relation to damage to the marine environment. Regarding the definitions, the project seeks to provide guidelines, on the basis of the scientific results, in a form similar to that used in the offshore oil and gas industry. The definitions are to be applied to leakage scenarios.

Complications may arise where damage is caused outside the jurisdictional areas of the state in which the CCS operation is carried out. The Rome II[5] regulation governs this within the European Union. How this regulation will apply when the damage occurs in another Member State or a non-EU Member State will be further explored. The rules governing the answer to these questions are to be linked to leakage scenarios to provide examples for their application.

Conclusion

The study has demonstrated that a regulatory framework of CCS activities has been established in which the potential risks associated of marine CCS were integrated. A common denominator of all instruments concerned is that they are based on a permit approach. Even though the risk assessment procedures that underlie that approach vary significantly regarding their degree of detail and legal value, they, again, largely follow a similar approach. As regards regulation on the EU level, certain concepts are still to be clarified, and the implementation of European law in the Member States varies.

[2] OJ L 270, 4.10.2012, p. 38
[3] OJ L 1, 3.1.1994, p. 3
[4] BIO Intelligence Service (2013), Implementation challenges and obstacles of the Environmental Liability Directive, Final report prepared for European Commission – DG Environment. In collaboration with Stevens & Bolton LLP.
[5] Regulation (EC) No 864/2007, OJ L 199, 31.7.2007, p.40.

Economic implications of CO_2 leakage risks

By Daiju Narita, Kiel Institute for the World Economy, Germany and Bob Van der Zwaan, Netherlands Energy Research Centre

The Kiel Institute for the World Economy (IfW) and the Energy Research Centre of the Netherlands (ECN) are investigating the economic implications of carbon dioxide (CO_2) leakage risks. These represent the potential social cost of CCS given uncertainty about the potential for leakage. The two groups are conducting the analysis on different, but complementary aspects of economic implications. IfW is focusing on the microeconomic aspects, including the costs and benefits of CCS and its leakage risks that have a bearing on the regulation of CCS operations and, in turn, the decision making of potential CCS operators. ECN is examining the implications of CCS and CO_2 leakage risks on the macroeconomic level. In cost-benefit assessments, the value at risk strongly depends on particular factors such as risk aversion and discount rates, and the analyses shed light on different aspects of the implications of leakage risks by employing different analytical approaches. Irrespective of modelling frameworks, leakage risks increase the costs of CCS: CO_2 leaks from CO_2 storage reservoirs, if the gas is eventually transported to the atmosphere, thus increasing the atmospheric CO_2 concentrations and exacerbating climate change. At the same time, leaks may also cause harm to local ecosystems on the sea floor. Both types of effects can be regarded as the social cost of CCS.

The IfW analysis focuses on economic decisions about a single representative CCS project by formulating an economic model based on the real options (RO) framework. The RO framework is essentially an application of the concept of financial options to decision problems of “real” investment – financial analysis has methodologies to evaluate the effects of risk on investment, and its use can offer useful insights on the leakage risks of CCS as well. A key idea in the RO concept is the combined effect of uncertainty and irreversibility of decisions: with irreversibility of initial investment, uncertainty in future returns tends to induce a CCS operator to delay the start of CCS operation and to wait until the carbon price is sufficiently high to compensate for potential unfavourable developments in the future. In the context of CCS operations, this effect becomes more complex when leakage comes into play. Our RO model can capture these features. A common feature that has emerged from the real option studies is that an RO analysis and an analysis based on the standard net present value (NPV) evaluation yield significantly different results and implications for a wide range of cases.

Scientific research on CO_2 storage has identified a nuanced view on the different types of leakage that may occur in the course of a CCS activity. There are at least three distinct types of leakage that one should be concerned with and which may have different economic implications:

First, leakage may occur in the early phase of a CCS project. This could happen partly because there may be geological aspects such as cracks in the storage formation that have not been identified in the exploratory phase of the project. Such surprises may happen and the probability for such events can be influenced by the amount of resources devoted to a proper investigation of the storage site. It can also happen that due to human errors, the operation of the project fails and a CO_2 blowout may take place. Such an event can be influenced by the care that is taken in the operation of the CCS project which translates into the cost of running the CCS facility.

The second type of leakage could be related to the capacity of a storage site. A storage site has some maximum capacity for storing CO_2 which then determines the lifetime of the CCS project. There is a possibility that, as the capacity of the storage sites is reached, there is a build-up of pressure with subsequent leakage. In this case the operator of a CCS storage site needs to decide how much physical capacity of a particular site she would like to use if the likelihood of leakage increases as the amount of CO_2 stored reaches its maximum. This decision may also influence the timing of the start of the project depending on the development of the rewards for CCS activities over time.

Finally, there is a possibility that CO_2 may leak to the surface or into higher geological layers even after a CCS project on a storage site has been finished. This type of leakage influences the timing and the operation of a storage site only indirectly through the potential liability for an operator, if indeed she can be held liable.

So far, the IfW has built a basic model that takes into account the above factors of possible leakage pathways and performed an initial calculation by using representative numbers of parameters that would fall into the likely range of parameter values for a typical CCS project. We will complete our analysis by further conducting an extensive sensitivity analysis after a calibration with scientific estimates drawn from other components of research under the ECO_2 project.

In contrast to IfW's microeconomic approach, ECN has made substantial progress with evaluating and understanding the macroeconomics of CO_2 leakage phenomena as associated with CCS for the very long run. A focus on the very long run offers valuable insights for macroeconomic assessment of CCS, as the long-term nature of climate change makes CO_2 leaks even in a far-distant future relevant in determining stringency of the current climate policy. ECN has substantial experience with energy and macroeconomic modelling, both with bottom-up and top-down global energy-environment-economy models. In the first phase of the ECO_2 project, ECN extended the DEMETER model (an economy-energy-environment model in Economics) to cover very long-time perspectives in order to prepare for its remaining work for ECO_2. This was an essential step in the work that needs to be performed by ECN as its contribution to WP5 and CCT2. This work is now being followed up by undertaking further new modelling work, and by inspecting what scenarios are to be investigated and what outcomes from the natural scientific WPs will serve as input for these WP5 and CCT2 activities focusing on potential CO_2 leakage effects and their impact as a result of sub-seabed CO_2 storage.

CCS policy perspectives and the public perception of CO_2 geological storage

By Simon Shackley, Leslie Mabon, University of Edinburgh, UK and Samuela Vercelli, University of Rome Sapienza, Italy

Summary of Main Points

The issue of public perceptions of CCS has risen in importance since proposed CCS projects at Barendrecht (Netherlands), Beeskow (Germany) and Greenville (USA) stumbled in large part due to public opposition. Some claim that offshore CO_2 storage will be of no (or minimal) concern to the public, but this ignores the infamous Brent Spar, the legacy of the Gulf of Mexico drilling disaster, controversies over offshore renewables development, the necessary onshore infrastructure and the importance of values which do not correspond with land/sea boundaries.

We review what is known about public perceptions of CCS and provide recommendations to governments and developers on how to better engage with publics for more resilient decision making in terms of both process and outcome. We suggest that in addition to geological and technical aspects, the social characteristics of an area need to be considered as this will influence the receptivity (and possible local resistance) to a CCS project – this is, we believe, just as applicable to projects with offshore storage as with onshore storage.

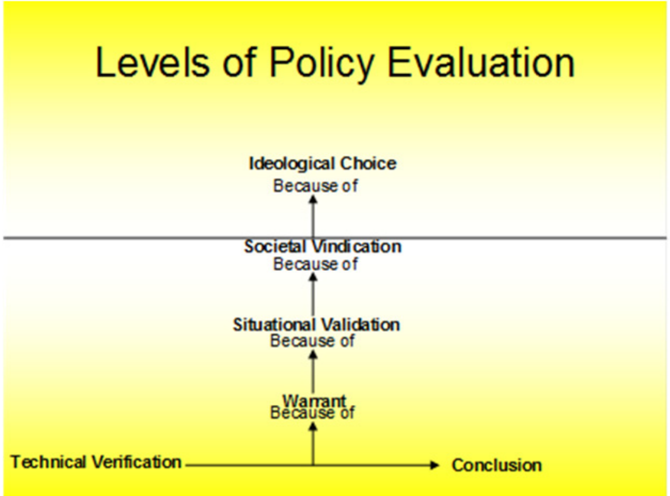
Overview of Findings on Public Perceptions

There is no single reason for public opposition to CCS, but the following can be identified:

- Preference among some people for decentralised and/or renewable energy sources rather than the continuation of centralised coal- and gas-based systems like CCS, and for energy efficiency or behavioural change as opposed to technological 'fixes';
- Objection to the continued extraction of coal – not just in terms of CO_2 emissions, but also potential negative effects from extraction such as effects on landscape, pollution, and risks to those working in extraction;
- Perception of CCS as inefficient due to energy penalties in deployment. Some also perceive the storage of CO_2 in rock formations as a wasteful use of a potential resource, preferring research into CO_2 usage;
- Suspicion of CCS becoming a convenient rationale to justify construction of new coal power plants. The use of captured CO_2 for enhanced oil recovery (EOR) may only serve to enhance these concerns about CCS perpetuating a fossil fuel economy.

However, not all CCS projects have resulted in public controversy. Examples of successful engagement include the planned Futuregen project in the USA (which did not, however, proceed due to funding changes); and the on-going Decatur (Ilinois) project utilising CO_2 from fermentation. Reasons for success may include the following:

- Provision of new employment opportunities in areas of industrial decline and high unemployment, especially if CCS draws on skills already present within the community;
- History of fossil fuel/hydrocarbon industry in area. For example, many of the companies likely to be involved in offshore CO_2 storage in north-east Scotland are known to local communities as 'good and trusted' employers (who pay well) through a long history of generally safe involvement in the oil and gas industry;
- Invitations to members of the public in early project consultations may likewise alleviate criticism that decisions have been made prior to consultation rounds.



Public evaluation of CCS

It is important to note that very few of the factors mentioned in Section 2 are influenced by whether or not the project in question utilises onshore or offshore storage. As we now explain, whilst it is true that offshore CCS may reduce the potential for public concerns over some of the issues seen with onshore CCS, many people's views are informed by much wider factors than the location of the storage site.

Based on the theory of political scientist Frank Fischer, we suggest publics' evaluation of CCS may take place on four levels. The first of these is *technical verification* – the technical aspects of CCS and CO_2 geological storage. The second is *situational validation* – whether the proposed location of the development is an appropriate site for CCS. The third is *social vindication* – whether CCS is an appropriate part of society's energy policies. The fourth and final of these is *ideological choice* – whether energy decisions like CCS are consistent with people's ideological beliefs.

In addition to these four levels, a further source of opposition relates to procedural conduct and effective project management – in essence, due process. If processes for participation are not effectively designed or implemented, publics may distrust the developer's ability to listen and respond to public concerns. Opposition may also arise if publics get the impression that participation in an engagement process is unlikely to have any real effect on the outcome of the project, or if people get the impression that scientists involved in CCS research have vested interests in the development of plans and policies in support of widespread implementation.

Improving Public Engagement on CCS

Trying to persuade the public to accept a proposed development can be counter-productive while improving decision making processes to include public participation and developing mechanisms to ensure proper project manage-ment will increase public trust and support. What the public expect is to have their concerns and feelings heard and taken seriously, and for a due process to consider different opinions before coming to a decision. Having said that, compensation for host communities in the form of financial recompense or infrastructure may – if managed carefully – help to engender support for CCS.

It is important for developers to attempt to understand early-on the reasons why publics and stakeholders actually form their opinions on CCS and to address and engage with the issues raised. Communication of the science behind climate change and CCS, and attempts to dispel any 'myths' about the safety of CCS, are unlikely to be effective on their own if it is issues of fairness, justice or values that are driving publics' concerns. Processes such as social site characterisation can help to understand this context (http://oceanrep.geomar.de/20601/) It may also be useful to imagine, develop and document systematically, broad-based rationales for CCS – for example energy security, reducing pollution and so on – that extend beyond narrow climate change mitigation.

There is a balance to strike between the possibility of making tangible changes to the project as a result of dialogue, versus the realities of decision making (physical limitations to storage sites, complexity of political processes, etc.). Starting engagement early whilst many of the project details are still open for discussion, but at the same time being clear from the outset about what participation can and cannot hope to achieve, would be a real advance on current practice.

Investigating offshore CO_2 storage from the perspective of the people

By Samuela Vercelli, University of Rome Sapienza, Italy and Simon Shackley, Leslie Mabon, University of Edinburgh, UK

Industry and policy makers often report the experience of people becoming "emotional" in relation to the introduction of a new technology and, related to this, the difficulty in understanding public opposition to projects. It is an issue which challenges social research in the field of CCS and has been studied by many authors up to now.[6] Most of these studies, to understand what people and stakeholders think about CCS, have focussed on the rational evaluation of the proposed technologies, and on the discussion of arguments proposed by researchers and/or external experts. To learn about the wider and deeper reasons that motivate different reactions by the public, the work on public perception in the ECO_2 project has experimented with a different approach, which gives voice to the arguments raised by members of the public themselves and considers both the rational and the emotional components of the technology's perception.

The approach taken in the ECO_2 project differs in two main regards. First, the investigation of public perception is based on what the people involved in the study themselves think of as relevant. Without prompting the content in any way, we asked people about their thoughts concerning the geological storage of CO_2, using free association interview techniques. The aim is to avoid bias arising from the researcher asking questions about things that they themselves think are important. Second, the analysis of the answers takes both rational and emotional dimensions into account, by applying approaches called Emotional Text Analysis and Voice Centred Relational Model.

The main advantages of this approach include:

- The development of a more in-depth understanding of the specific point of view of the public; this is different from what can be learned through surveys or highly-structured interviews, which give information about *what* people think, but cannot explain the reasons *why* people hold these perceptions.
- An understanding of the emotional dimensions related to CCS can build a fuller picture of different stakeholders' and publics' perspectives. These new insights can help stakeholders, including members of the public, to better communicate and understand each other.
- Raising awareness about the emotional and cultural area to which CCS 'belongs', can help find a common ground where a fruitful discussion on CO_2 geological storage can take place.

[6] for a brief overview see http://oceanrep.geomar.de/20270/

Areas of interest resulting from ECO_2 interviews and working hypothesis to date

The following topics arise from the cultural dimensions that have found expression in the words of members of the public in Italy and Scotland. What they told us is not only characteristic of their individual perspective but, what's more, of the social context they belong to. The kind of analysis conducted on the interviews' texts allows for the identification of typical ways of relating to the topic, in the specific social context under study. Although we interviewed individuals, the outcomes pertain to the realm of culture, which is a social and shared dimension. Thus our work consists of detecting the cultural models that exist, at a certain point in time, in the societal context under study. We present them here. What remains to be investigated is the quantification of the relevance of each of these cultural areas in the general population.

1. People's relationship with the energy sector

It seems to be very difficult for the publics that we have studied to make the connection between the energy they use each day and the technological/ political/economic/ scientific system that makes energy available. Knowledge and awareness are fragmented, making it all the more difficult to introduce a new and complex element, like CCS, into the picture. The concept of "energy" appears so abstract that the relationship between energy decisions and public demand appears to be lost. It is as if the fact that certain technologies are being deployed to ensure supply, to keep up with the energy each one uses every day, was not part of anyone's personal lifestyle and decision making.

2. Due process for decision making and implementation

People feel excluded from decision making processes: the feeling is that decisions on energy issues are taken "up there", in some remote context that the average person feels excluded from and feels they have no power upon. CCS falls under this category.

Public engagement activities, as a tool for participation to decision making, emerge as yet another confusing experience as they are often perceived as having little actual effect on policy. Business as usual processes for making and reviewing decisions appear to have come to a critical stage where change is now needed – it sounds like a call for action.

Figure 1: Direct interaction within an appropriate format could help professionals better understand people's perspectives on energy issues

3. Reasons for CCS as part of energy roadmaps

The possible role of CCS in the energy system and in the economic and industrial system overall is unclear to people. Many questions were posed by interviewees: compatibility with other industrial sectors, potential conflict with other uses of the subsurface or the marine environment, cost, energy penalty, impact on the cost of electricity, and impact on the development of renewables. In addition, more clarity is needed on why CCS should be integrated into the energy mix at a time of high energy prices, economic crises and an increasing need for energy independence.

Figure 2: Public engagement activities need to have a clear recognition of their role in decision making processes

4. Long-term perspective

The longer-term implications of CO_2 storage were raised in the interviews, not only in terms of management and liability, but also more generally with regard to the long-term implications of the energy decisions our society makes. What might be the impact of CCS on future generations? How will the decisions we make today affect the future landscape, climate, and energy supply? These questions are relevant for any technology, however, CCS (like nuclear) makes the connection with our long-term future much more evident due to the long timescales involved with storage. The need to include consideration of events that might happen far into the future is probably just as much a challenge for the single citizen as it is for policy makers.

5. Nature and climate change

A strong theme emerges in the ECO2 interviews concerning how CO_2 storage relates to the context of humans' relationship with nature. Does CCS make sense within a respectful approach to natural resources or is it yet another way of creating human-made and out of control situations? Can CCS really help to tackle climate change or might it paradoxically exacerbate it? This emerges as a strong emotional dimension: people are uncertain about whether to put faith in the contribution of this technology to tackle adverse climate events or whether to fear it could become yet another problem. People are now all too aware of the 'law of unintended consequences' and of claimed-for 'good intentions' that go wrong. There is increased awareness about the fact that our choices will have certain consequences on the environment, including climate, but the connection between decisions and consequences is far from being clear.

Figure 3: Bringing people in one room to work together on the impact of sustainable energy technologies

Next Steps

The next steps of the research involve the feedback of the above mentioned areas of interest to members of public, together with an information package that addresses the questions raised. These new activities will allow us to further progress our understanding of the emotional and rational factors affecting the way people think and feel about CCS.

A glossary for the ECO_2 project: "The language of CCS – definitions and explanations"

By Kelvin Boot, Plymouth Marine Laboratory, UK

One of the objectives of the "ECO_2 – sub-seabed CO_2 Storage: Impact on marine Ecosystems" project is *"to standardise commonly used terms and concepts in CCS (carbon dioxide capture and storage) research to facilitate effective communication"*. This objective was included within the Public Perception Work Package 6 and has been met through the production of a glossary of words and terms frequently encountered within the CO_2 storage literature and used within the CCS community: "The Language of CCS – definitions and explanations".

The Need

The need for such a glossary is a reflection of the relative youth of the technologies involved in CCS (the lexicon of CCS is still evolving and maturing), the complexity and breadth of the science involved and the involvement of necessary but non-scientific stakeholders who bring their own 'language' to the CCS table.

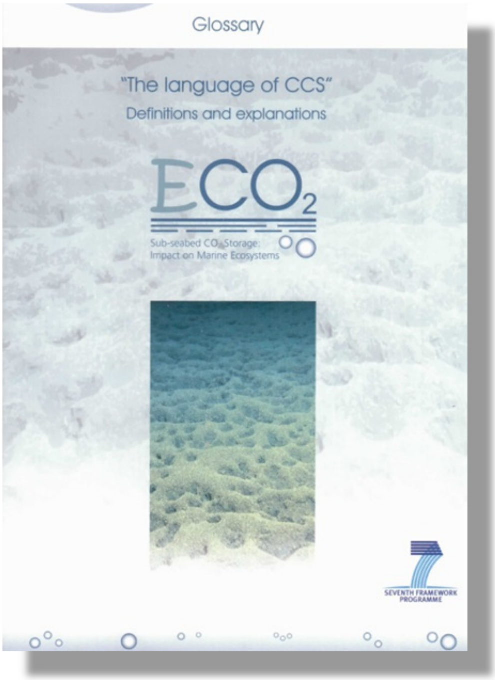
Perception of a technology has some relationship with the words used to name or describe it. However, terminology can be so specialised that it can alienate interest and understanding from the lay public, a concern when the technology becomes an issue for public debate. Also, some specialist terms can become so familiar and misused that they lose their original, more precise meanings, leading to misunderstanding and confusion. Additionally, when working across a multi-disciplinary field like CCS, even the technical experts might find difficulty in understanding the 'jargon' of their colleagues from different disciplines, while the non-scientist might find the language impossible to disentangle to find appropriate, helpful, definitions of terms.

A further and very important complication is that despite English being widely used as the accepted language of CCS, interpretations still vary from country to country, even within the English speaking world. An example might be the word carbon which is often preferred to carbon dioxide, i.e. carbon capture and storage as opposed to carbon dioxide capture and storage. Perhaps the non-scientific person might understand carbon to be a chemical element, yet it still conjures up images of lumps of coal or charcoal, perhaps diamond, rather than an element in combination with oxygen to form the gas carbon dioxide which is actually captured.

The Glossary – 'The language of CCS – definitions and explanations' – takes all of these challenges into consideration and has been collated and edited to support, both within and outside the scientific community, a process of sharing, discussion and clarification of terms that some of us use every day but of which others, particularly the general public, have no knowledge. Its primary intent was to provide a standardised set of definitions of the terms that are frequently used when CCS is being discussed.

The Glossary

The Glossary is inevitably an amalgamation of the ideas and work of many people, organisations and previous projects. Many partial glossaries, some merely clones of others, exist in a range of documents and on a large number of websites and these have proved a fruitful source of definitions. However, definitions of words and phrases can differ depending upon the particular interest of the document or website and the organisation which created them. Where these are similar they have been amalgamated into a single definition, our recommended definition. However, occasionally the same word can have two quite different meanings where there is a particular 'subject 'angle' on a definition that differs significantly between disciplines. Legal definitions were considered non-negotiable as they have become embedded in various pieces of legislation globally. Further while many definitions are relevant throughout the entire CCS process, the emphasis is very much towards the storage, and especially sub-seabed storage of CO_2, rather than the capture of CO_2 – this reflects the focus of the ECO_2 Project.



Consult the Glossary online:
www.eco2-project.eu/info-material.html

The process

A key function of the Glossary is to provide a document that could and would be used by everyone within the ECO_2 Project, but also in other projects and beyond into the wider community, as such it was essential to gain a consensus agreement across a wide range of potential users. The ECO_2 Project, because of its multi-disciplinary composition, provided an ideal sample of the CCS community, including a wide range of science disciplines, industry, legal, policy, social acceptance and other stakeholder interests. The first stage filter of potential terms for inclusion, and refinement of definitions was carried out amongst the participants of ECO_2 WP6. This proved to be a very thorough process resulting in much discussion at a fine level of detail. Following on from this initial appraisal, a second version was sent out to a wider stakeholder group of ECO_2 participants including Advisory Board members, again there was some detailed discussion to ensure a consistent agreement.

Of particular interest were discussions surrounding some of the most basic concepts and terms, terms that one would imagine were already commonly agreed, but actually were still open for debate. Even CCS itself fell into this category: is it carbon or carbon dioxide that is being captured; is it being stored, disposed of or sequestered? As key to the whole string of processes and an overall descriptor of the technology it was deemed necessary to provide some discussion on the definition of CCS within the introduction to the Glossary.

What next?

As with any attempt at a glossary for an emerging topic area 'The language of CCS' will need updating as the technology and the processes develop. Already, since its publication on the ECO_2 website and in hard copy, the Glossary has attracted some very helpful criticisms. Some terms which had been overlooked have been drawn to the attention of the authors, while minor changes to the nuance of a few definitions have also been suggested – these are noted and will be included in a revised version of the Glossary.

An interactive version of the Glossary, which allows cross-referencing between and within definitions, has now been completed and will be accessible via the ECO_2 website. The next development will be the collation and production of an updated Glossary, including the various suggestions and amendments so far received, as well as additional terminology which might have arisen since the publication of the first edition. To this end all participants in the ECO_2 Project will be contacted to garner their thoughts and criticisms. One suggestion, already received from a number of readers and which will be acted upon, is the inclusion of graphics and other images and more links to sources that will illustrate and help with explaining definitions.

Whilst the Glossary was intended largely for use by ECO_2 Project partners it was always hoped that because of its comprehensive nature, it would be useful beyond the ECO_2 Project and indeed this has been the case with at least two other projects, QICS (Quantifying and Monitoring Potential Ecosystem Impacts of Geological Storage) and RISCS (Research into Safety in CO_2 Storage), adopting it as a standard. It is to be hoped that as the Glossary develops, more projects will embrace its definitions.

ECO_2 Notes …

… upcoming research expeditions in 2014

For the third year of the project (2014), which is already the synthesis phase of ECO_2, three cruises are planned in the summer. During the data generating phase of the project (2011-2013), we conducted 22 research expeditions. The majority of the expeditions targeted the area at and around the CO_2 storage site Sleipner and the natural CO_2 seepage site Panarea. The table below shows that these sites will be the target of the 2014 cruises as well.

Time	Expeditions Name	Study Site
05 – 21 May 2014	RV Poseidon POS469	Sleipner / North Sea
16 May – 3 June 2014	Small Boat	Panarea
not yet scheduled	Small Boat	Panarea

… upcoming project meetings in 2014

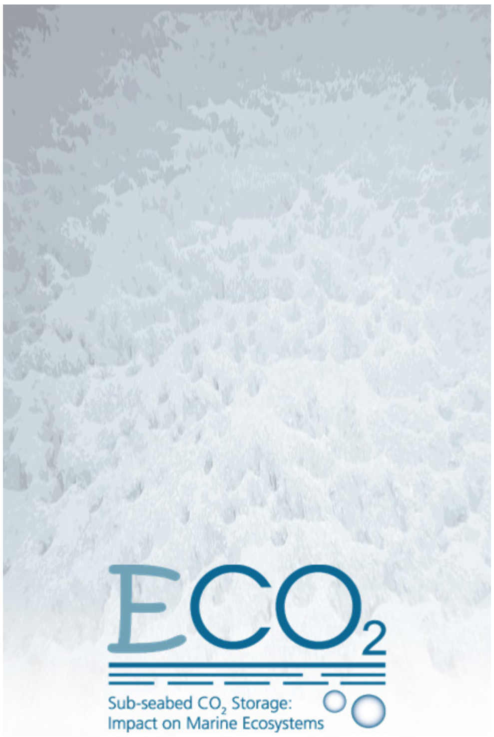
Workshop on 'Monitoring Techniques and Strategies in ECO_2', 2^{nd} June 2014 on Salina, Italy

Workshop on 'Public Perception', 2^{nd} June 2014 on Salina, Italy

PhD and PostDoc Workshop, 2^{nd} June 2014 on Salina, Italy

3^{rd} annual ECO2 Meeting, 2 – 6 June 2014 on Salina, Italy

The meeting will bring all 27 project partners and the members of the external advisory boards (Scientific Advisory Board and Stakeholder Dialogue Board) together.



www.eco2-project.eu

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