Assurance offshore monitoring, a cross-disciplinary approach.

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We outline the approach chosen in an ongoing project, ACTOM[1], aiming to develop procedures for design and execution of appropriate, rigorous and cost-effective monitoring of offshore geological carbon storage (OGCS), aligning industrial, societal and regulative expectations with technological capabilities and limitations.

An interdisciplinary consortium applies methods to critically assess secure offshore CO_2 storage as this technology becomes implemented and upscaled internationally as a key greenhouse gas emissions reduction strategy. Reserving marine areas for subsea CO_2 storage raise new and difficult questions on policy and legal frameworks. International law, regional (like EU) and national regulations come into play in the CO_2 storage permit procedure, including preliminary Risk and Project Impact assessments, procedural requirements regarding stakeholder and public participation, and public access to information and integrated assessments. In the last 20 years, more strategic and holistic instruments for management of (sea) areas and resources have been developed, compared to the traditional license system.[2] Examples might be Marine Spatial Planning (MSP) requirements for opening marine areas for storage based on Strategic Environmental Assessments (SEA).[3]

Formulating appropriate monitoring programs, from either a regulatory or operator viewpoint, is very difficult to achieve without a properly quantified cost-benefit analysis of what that monitoring could achieve. In addition, communicating risks and uncertainties is a challenge for offshore storage projects, and tools assisting in dialogue with stakeholders, governments and public at large will be of value.

Currently, regulations require assurance of zero or minimal loss of storage integrity, but generally do not specify what constitutes acceptable assurance. Providing assurance of storage conformance with an acceptable standard is philosophically challenging. Whilst we seek evidence of absence (of leakage), that cannot be delivered by an absence of evidence. Any given monitoring observation has a finite relevance in both space and time. The question is therefore – what is a sufficient number and type of observations for assurance?

Transparency of decision-making, open and credible science technology, social, legal and ethical considerations are prerequisites for high public acceptance of new technologies.[4,5,6] The monitoring

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[1] https://actom.w.uib.no

[2] Schütz in Raphael J., Heffron; Little, Gavin F.M.(ed), "Renewable energy production in marine areas and coastal zone – the Norwegian model" in Delivering Energy Law and Policy in the EU and the US, Edinburgh University Press 2016.

[3] Directive 2001/42 EU on the assessment of the effects of certain plans and programmes on the environment.

[4] Funtowicz, S.O., and Ravetz, J.R. 1993. Science for the post-normal age. Futures, 25(7): 739-755.

programs will have a role in communicating risks and benefits for storage projects and assure against unjustified accusations for having adverse environmental effects, but cannot be seen in isolation from the multi-leveled Carbon Capture and Storage (CCS) management systems.

Evaluations of CO_2 storage monitoring techniques usually aim to determine the suitability to user-defined project scenario (e.g. IEAGHG monitoring selection tool[7]) or to assess the availability of sensors that can measure variables that are likely to fluctuate under a seepage scenario, or processes that are sensitive to CO_2-related stress. Less focus has been on how they perform relative to regulatory requirements, cost efficiency, and user friendliness.

We can use observations and models to characterise the natural variability of the marine system, or, the noise from which an anomalous signal must be detected. Here we focus on detecting changes in pH caused by CO2 seeps through the seafloor from unknown locations. The strength of the signal will be reduced very quickly away from the source and will be hidden within the natural pH variability.

We can use models to simulate hypothetical leak events thereby defining the monitoring target(s). We have algorithms that assess the cost-benefit of a range of anomaly criteria – i.e. a signal that would provoke a more concerted monitoring campaign and finally algorithms that can derive the optimal deployment strategy – i.e. where to monitor and when. The challenge is to collate these abilities into a coherent whole, which then allows the presentation of an evaluated monitoring system that can be judged against regulatory and societal expectations.

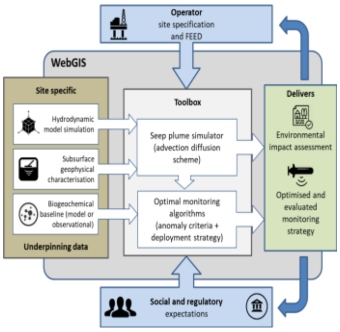

Figure 1: Conceptual sketch of the monitoring tool kit.

In the project, we establish a toolbox capable of simulating "what if" seep scenarios, as well as monitoring deployments, that can be used to deliver environmental impact assessments as required under the CCS and EIA directives[8]. As a result, recommended monitoring strategies could be delivered autonomously and be largely dependent on established generic operational marine simulation models, both factors reducing costs.

The overall framework that we use to connect the models and scenarios to society is *Responsible Research and Innovation (RRI)*[9]. In RRI societal actors work together during the whole research and innovation process (legitimacy) in order to better align both the process and its outcomes (control), with the values, needs and expectations of society (orientation). In accordance with the RRI approach researchers, citizens, policy makers, businesses and organizations will be engaged in discussions of how the CCUS monitoring innovation process and the outcomes best can be aligned with society's climate change mitigation objective in an iterative dialogue.

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[5] Funtowicz, S.O., and Ravetz, J.R. 1990. Uncertainty and quality in science for policy. Springer Science & Business Media. 231 p.

[6] Kloprogge, P., and van der Sluijs, J. P. 2006. The inclusion of stakeholder knowledge and perspectives in integrated assessment of climate change. Climatic Change, 75: 359–389.

[7] https://ieaghg.org/ccs-resources/monitoring-selection-tool

[8] Following inclusion of capture installations in EIA Directive (85/337/EEC), now repealed by Directive 2011/92/EU, environmental impact assessment has to be carried out in the capture permit process, cf. preamble CCS Directive sec. 27.

[9] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation