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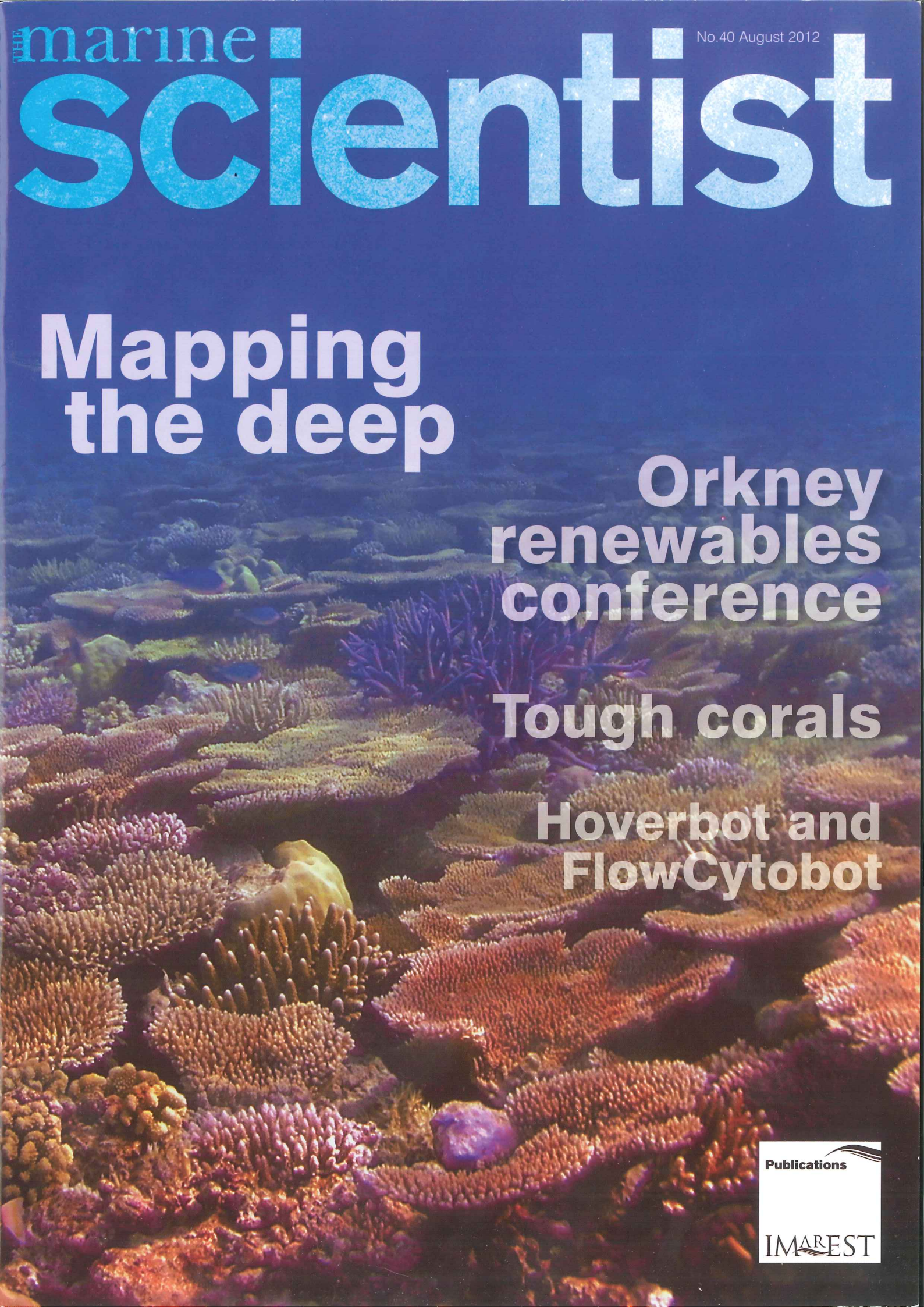
Mapping the deep

Orkney renewables conference

Tough corals

Hoverbot and FlowCytobot



Publications

IMAREST

Investigating the impact of sub-seabed CO_2 storage on marine ecosystems

As the world faces the consequences of rising anthropogenic carbon dioxide entering the atmosphere and ultimately the ocean, a growing arsenal of adaptation and mitigation strategies are being investigated. Carbon dioxide capture and storage (CCS) is regarded as a useful way of removing CO_2 at source, transporting it and storing it at depth underground, in saline aquifers or depleted hydrocarbon reservoirs beneath the seabed. But will there be any impacts in the marine environment above these sites? **Anja Reitz,** describes how one EC- funded project hopes to find the answers.

At the European and international level, carbon dioxide capture and storage (CCS) is considered as a key technology for the reduction of CO_2 emissions from power plants and other industrial facilities. Accordingly, the European Commission promotes the implementation of CCS in Europe at industrial scale by supporting selected demonstration projects. Several European states (the Netherlands, United Kingdom, Norway, and Italy) aim to store CO_2 below the seabed to implement the EU directive on geological storage of CO_2. However, little is known about the short-term and long-term impacts of sub-seabed CO_2 storage on marine ecosystems even though CO_2 has been stored on industrial scale since 1996 (Sleipner) in the Norwegian North Sea and since 2008 (Snøhvit) in the Barents Sea.

Project aim

As a consequence of this lack of knowledge, the EC is supporting the *ECO*$_2$ project- Sub-seabed CO_2 storage: Impact on Marine Ecosystems. The aim of *ECO*$_2$ is to evaluate the likelihood of leakage, the possible impacts on marine ecosystems, and associated economic and legal issues. A framework of best environmental practices to guide the management of offshore CO_2 injection and storage will be the final result of the project. Accordingly, the project actively contributes to the implementation of the EU directive on "Geological Storage of CO_2" for the marine realm. *ECO*$_2$ will establish a comprehensive monitoring concept for storage sites comprising innovative techniques capable of detecting different modes and levels of leakage, including that of pre-cursors. Field studies at operational and prospective CO_2 storage sites (Sleipner, Snøhvit, B3 field) will be supported and complemented by laboratory experiments and numerical simulations at natural CO_2 seeps (Mediterranean Sea, North Sea, Barents Sea). *ECO*$_2$ is a large scale integrating collaborative research project within the FP7 work programme, 'The Ocean of Tomorrow'. The consortium consists of 27 partners from nine European countries (Germany, Norway, United Kingdom, Italy, the Netherlands, Poland, Belgium, Sweden, and France). The project is coordinated by the GEOMAR | Helmholtz Centre for Ocean Research Kiel, Germany. The entire lifetime of *ECO*$_2$ is from 1st May 2011 to 30th April 2015.

Progress

The investigations of the project cover a wide range of approaches from basic marine research to ocean governance. Hence, the work is divided into different work packages (WP) which are cross-cut by some themes (CCT) to support information flow, strengthen cooperation across the work packages, and integrating and evaluating the results of the individual work packages.

The basic marine research component of *ECO*$_2$ will (i) con-

Map indicating operated and prospective CO_2 storage sites (purple stars) and natural CO_2 seeps (pink starts); SDJ=Salt Dome Juist. (GEOMAR).

duct geophysical acquisition, modelling, and hydro-acoustic monitoring to specify the range of performance and efficiency of sub-seabed geological CO_2 storage, (ii) determine the chemical composition of reservoir fluids at existing storage sites and natural seeps supported by laboratory studies focussing on CO_2-induced mobilisation of toxic metals and the ability of CO_2-hydrate formation to seal leaks, (iii) carry out process studies and model simulations to underpin risk and impact assessments of potential leakage from CO_2 storage in the overlying water, and (iv) determine the biological impacts and risks associated with CO_2 leakage by controlled exposure experiments or in-situ observations at natural seeps.

Research expeditions

During the 2011 field campaign at Sleipner with RV *G.O. Sars* and RV *Alkor*, a characterisation of the subsurface architecture above the Utsira storage formation was carried out by means of 3D seismic interpretations and attribute analyses. The stratigraphy above the storage site is rather simple with no prominent folding or faulting, however, numerous fluid flow structures such as chimneys or shallow gas accumulations were identified at different stratigraphic units.

Measurements of gas concentrations in bottom waters above the Sleipner CO_2 storage site were carried out by a novel sampling system, in which seawater is pumped directly into a membrane inlet mass spectrometer. The measured pCO_2 data did not show any increased levels in the vicinity of the sub-surface CO_2 plume. Sub-seabed storage site samples were taken to (i) conduct baseline studies of spatial scaling of diversity of bacterial and meiofaunal communities, (ii) to investigate microbiology studies, and (iii) to set up laboratory experiments. Based on the results of 2011 the 2012 research expeditions will advance the knowledge gained in 2011, particularly, about the fluid and gas composition at Sleipner, the ability to discover minor leaks, and the detection of pre-cursers. Japanese colleagues from the Kyushu group will participate in the 2012 RV *James Cook* research cruise where Japanese developed sensors will be deployed.

At Snøhvit, stratigraphic boundaries of the storage overburden, faults, gas chimneys, shallow gas accumulations, and bottom-simulating reflectors were identified by means of conventional 3D seismic data analyses. Geological models of the whole overburden were established based on the integration of 3D seismic and well log data. To assess the sealing or leaking potential of faults tentative leakage scenarios were proposed. Sev-

WP1	Integrity of the sedimentary cover
WP2	Fluid and gas flux across the seabed
WP3	Fate of emitted CO_2
WP4	Impact of leakage on ecosystems
WP5	Risk assessment, economic & legal studies
WP6	Public perception
WP7	Coordination & Data Management

CCT1	Monitoring techniques & strategies
CCT2	Numerical modelling
CCT3	International collaboration
CCT4	Best environmental practices

Scientific work structure. (GEOMAR)

eral preliminary CO_2 leakage scenarios were simulated with a two-phase flow model considering an intact and a damaged sedimentary cover.

East of Panarea Island, numerous, previously unknown, CO_2 bubble flares were mapped. Monitoring was conducted by the deployment of a lander equipped with an acoustic doppler current profiler, a storage CTD, and a CO_2 sensor and by the deployment of an eddy correlation instrumentation, allowing estimation of benthic heat and oxygen fluxes. Additionally, air-sea CO_2-exchange surveys were done to estimate gas transfer rates, high resolution temperature profiling was conducted to determine bubble plume dynamics, and gas bubble sampling and analyses at different distance levels to the seafloor were performed to determine bubble dissolution parameters. Suitable sampling sites were identified around the Panarea seep site to assess the impact on benthic bacteria and meiofaunal community diversity, structure and functioning caused by long-term CO_2 leakage. First results revealed that the chosen seep sites accommodate atypical nematode communities characterized by a low diversity and a high dominance of the genus *Microlaimus*, whereas the reference site accommodates a typically highly diverse sandy sediment community. In order to evaluate the intensity and the impact of viral production and decay on prokaryotes along the CO_2 gradient and to quantify the fraction of lysogenic prokaryotes

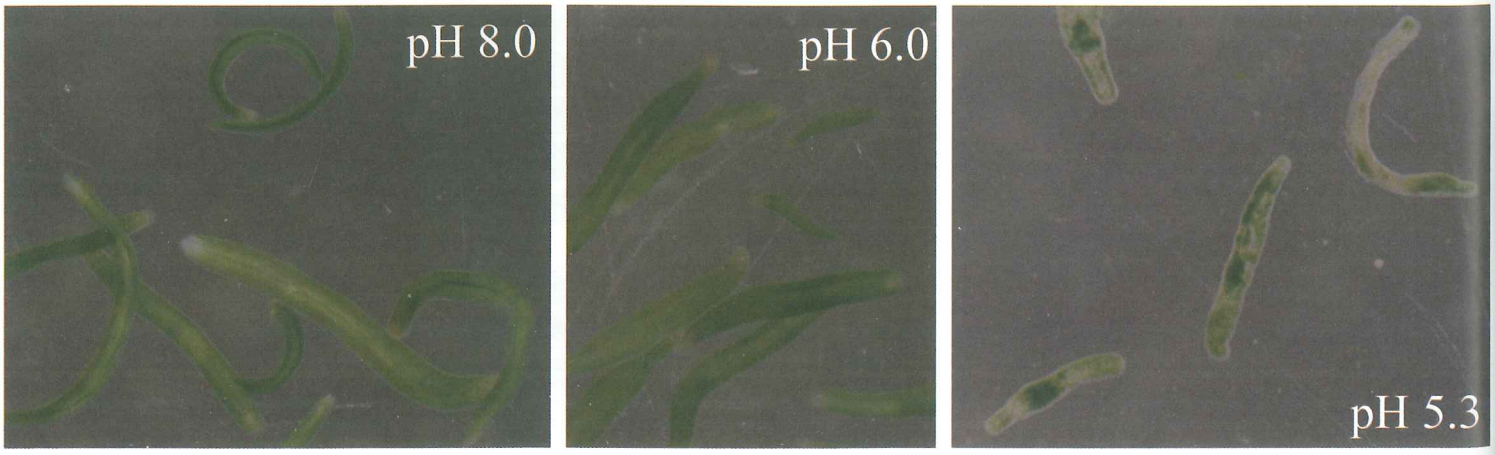
Experimental setup to study infauna bivalve communities. (Frank Melzner, GEOMAR)

under CO_2 exposure an experimental set up was constructed.

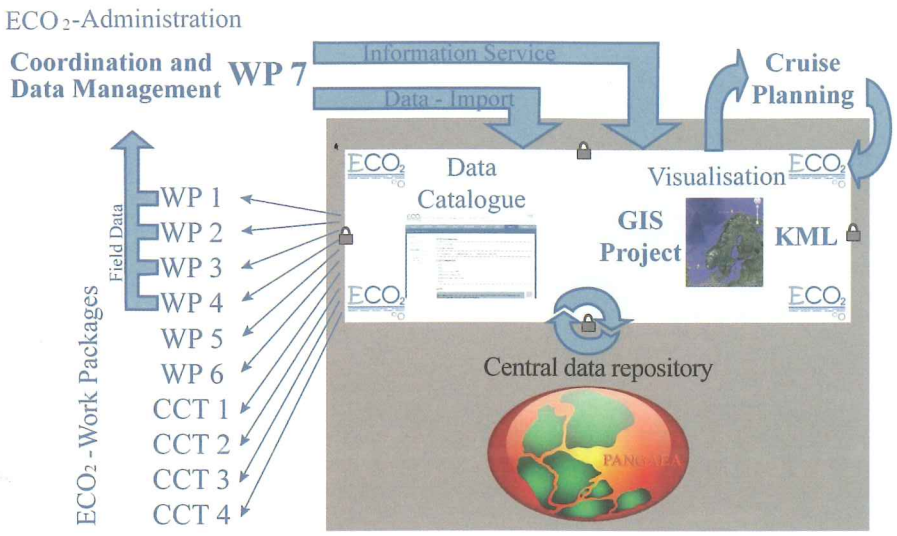
The work carried out at the Juist Salt Dome, in the German North Sea, regarding fluid and gas fluxes across the seabed highlighted the importance of considering natural variations in CO_2 for establishing baselines around sub-seafloor storage at similarly shallow sites. The obtained patterns in bacterial and meiofaunal community structure suggest that they may serve as a baseline for comparison of active phases of CO_2 emission. At the Jan Mayen vent fields a tool for the collection of gas was successfully tested. CO_2-rich plume samples as well as background seawater samples were taken for the study of macrofaunal community diversity and the food web.

Experiments to quantify

To quantify the impact of CO_2 leakage on vulnerable species, epibenthic echinoderm species, in this case sea urchin, were tested in a simulated CO_2 leakage experiment regarding their suitability as CO_2 indicator organisms. First results have shown that no mortality was encountered but strongly reduced feeding activity was indicated. Further, sea urchin larvae tolerate a wide range of pCO_2 but from 2000 μatm pCO_2 on abnormality and mortality increases. Additionally, sensitivity of sandy infauna bivalve communities to CO_2 stress is currently tested. First results indicate that at pCO_2 of 10-20,000 μatm high bivalve mortality is coupled to intensive shell dissolution. Conspicuously, the bivalves leave the sediment prior to death and accumulate on the sediment surface. Infaunal brittlestar was chronically exposed to elevated pCO_2, resulting in a reduced metabolic rate and scope for regeneration and enhanced protein metabolism. A photosymbiotic, non-calcifying and autotrophic acoel worm was investigated regarding the impact of extreme pCO_2 increase. The worm is resistant to high pCO_2 levels up to 54000 μatm, however, some sub-lethal bleaching was observed when seawater is saturated by CO_2 (up to 270000 μatm pCO_2). To study the biological uptake of toxic and heavy metals under high CO_2 conditions a mesocosm experiment was carried in the Oslofjord at Solbergstrand using three test species (*Brissopsis lyrifera, Nereis virens, Mytilus edulis*). The reference sediment was collected in a clean part of the outer Olsofjord and the naturally heavy metal-contami-



The impact of elevated CO_2 on the acoel worm Symsagittifera roscoffensis. (courtesy: Sam Dupont)



ECO_2 Data management Concept. (GEOMAR)

nated sediment was collected in the inner part of the Oslofjord.

All data generated within the framework of the project will be transferred to a secure ECO_2 database at the PANGAEA data repository. Furthermore, a KML file for Google Earth was compiled including all *ECO_2* and external data sets available to support planning of upcoming research cruises. Currently, the project data management team is establishing a geographic information system (GIS) for the study site Sleipner.

Assessing the risk, economic and legal factors, and public perception

Within *ECO_2* the environmental risks associated with CCS and how these risks may impact on the financial, legal, and political considerations surrounding the future geological storage will be elaborated. Initially, agreement was reached on what information is needed to carry out an Environmental Risk Analysis (ERA) and which leakage scenarios should be considered in *ECO_2*, were identified. Regarding the assessment of impact of environmental risk upon financial considerations, the existing modelling framework was extended to cover long-time perspectives. In early 2012, the first briefing paper for potential stakeholders was completed focussing on *ECO_2* fieldwork activities.

The public perception assessment group is investigating trust and context as two important factors influencing the configuration of public perception patterns. They composed a compendium and analysis of the key theoretical approaches employed to date in studies of public perception of CCS. The document is entitled 'Carbon Capture and Storage Public Perception Factors: Literature Review and Open Issues'. Furthermore, a publication regarding the potential contribution of literature on environmental values to the CCS debate has been produced. An interview protocol was developed and the first pilot interviews have been held in Scotland and Italy in March 2012. An informal collaboration with the UK NERC-funded QICS project (CO_2 release into sediments) enabled video recording during a public meeting held by the QICS project.

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