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Development of leakage scenarios in the RISCS project

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SEVENTH FRAMEWORK PROGRAMME

Outline

- Set of credible CO_2 impact scenarios for a range of near-surface reference environments
- Plausible leakage fluxes and areas
- Summary

Scenario

"A plausible description of the potential evolution of a system according to the nature of the features, events and processes that might act within and upon it."

Scenarios are hypothetical situations, not predictions

Plausible:

- Consistent with fundamental physical / chemical / biological principles and laws
- Probability not agreed to be so low as to be of no concern to anyone

Reference Environments

- Illustrative environments
- Both the 'marine' and 'terrestrial' environments
- Basis for discussion and communication
- Help structure discussions
- Environments together cover representative range of receptor classes
- “Receptor classes” = things that could be affected (people, animals, resources etc)

Aspects of Scenarios

- Kinds of environment

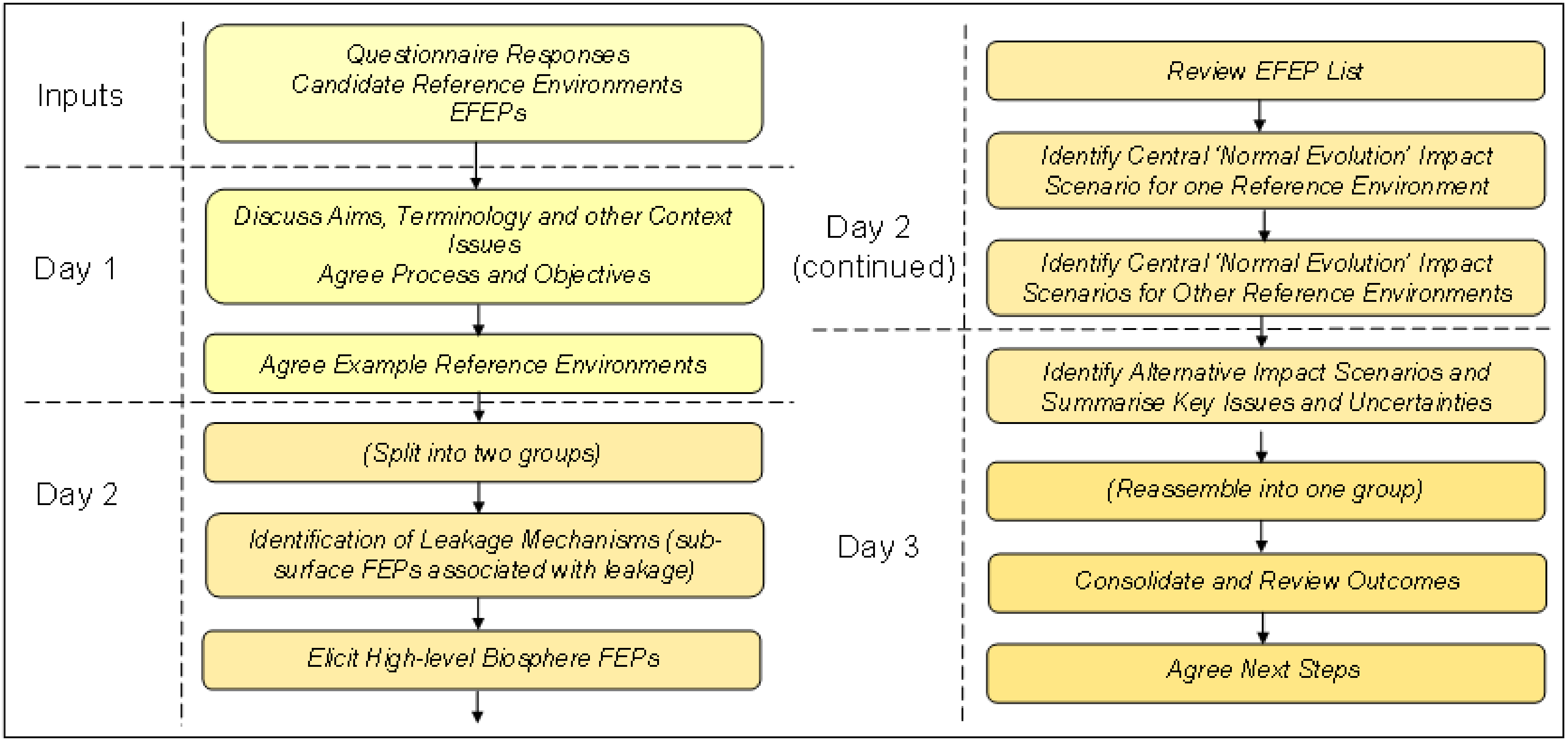
- Patterns of leakage (point source, alignments of point sources, diffuse etc)

- Things that could be affected (“receptor classes”)

- Initially simple descriptions

- Expect will become more complex later in the project

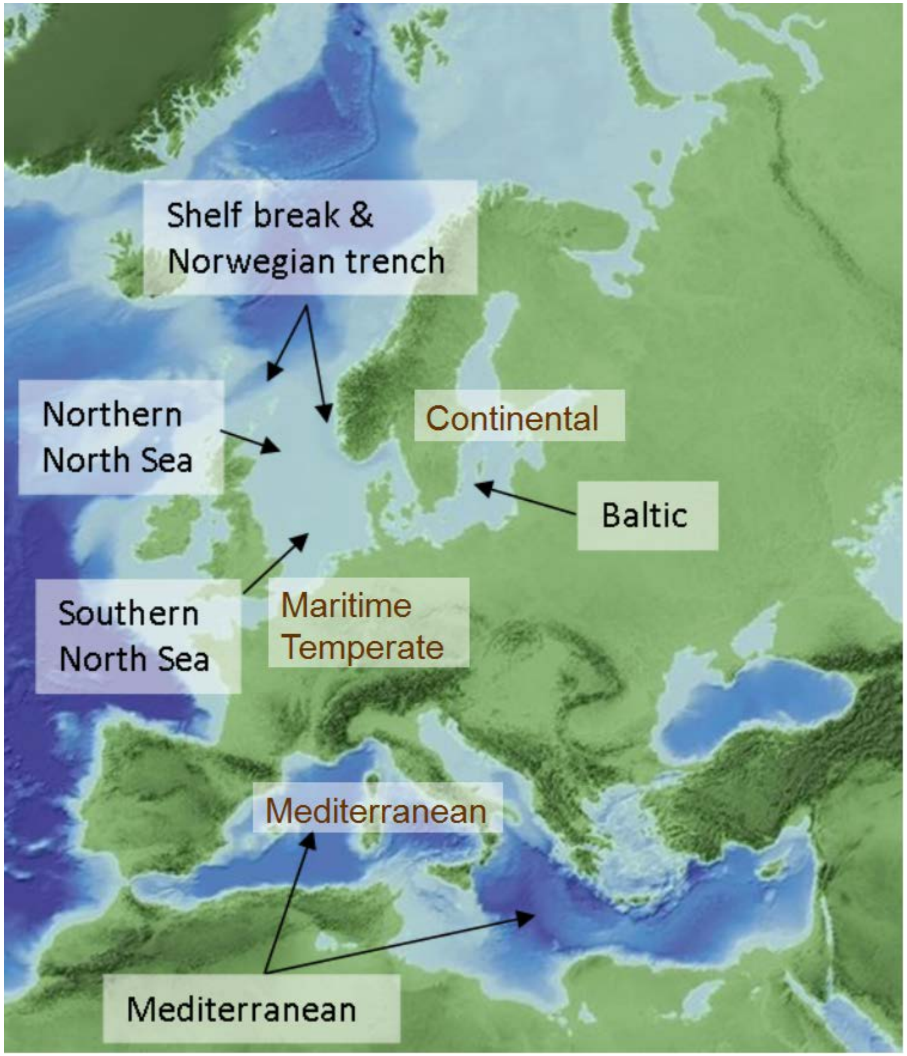
Scenario Definition Process



Structured expert discussions

Reference Environments

- Identify a range of European ***environment types (not specific sites)***
- CO_2 could feasibly be stored in the kinds of environment
- Aim to ensure that all relevant processes influencing potential impacts / safety are represented to some degree across one or more of the environments



*Recognize impossibility of investigating **explicitly** all environments that occur and processes that might affect them*

Marine Reference Environments

Cool, temperate, deep	Continental shelf remote from shoreline, water depth > 60 m, typically > 100 m. Not Arctic but bottom water ~5˚C. e.g. northern North Sea, or to the west of Norway.
Cool, temperate, shallow	Land is relatively close and the water depth ~ 10s of m. Temperature varies: ~ 4˚C - ~15˚C. e.g. southern North Sea.
Warm, shallow	Land is relatively close and the water depth ~ 10s of m. Temperature is a minimum of 5˚C at the seabed and varies from ~ 6˚C to ~ 25 ˚C, at the sea surface. e.g. Adriatic Sea.
Low salinity	Land is relatively close and the water depth ~ 10s of m. Water salinity lower than that of open ocean water. e.g. the Baltic Sea.

Terrestrial Reference Environments

Maritime Temperate	Representative of a northern central European, cool climate (e.g. UK and the Netherlands).
Continental	Climate associated with northern (but not Arctic) European continental land mass countries.
Mediterranean	Representative of warmer, more arid, southern European climates.
Generic Urban	Specifically designed to explore potential impacts on humans should a storage system be located close to a large urban centre.

Scenarios

Both ***marine*** and ***terrestrial*** environments:

normal evolution scenario is containment (for comparison with leakage scenarios)

'What-if' alternative evolution scenarios for leakage consider potential impacts via:

- Direct release of CO_2 to the atmosphere (***terrestrial*** environments)
- Localised (point-source) short- or longer- term emissions to near-surface soils or to aquifers (***terrestrial***); to sediments and the water column (***marine***)
- Diffuse (linear or over a wide area) emissions to the same systems
- Release to a ***terrestrial*** urban environment

Scenarios noted but **not** considered in detail include:

- *Displacement of saline formation water due to storage activities* (outside scope)
- *Impacts through inadvertent human intrusion into the facility* (a lower priority);
- *scenarios related to leakage as a result of seismic activity* (considered sufficiently encompassed by primary 'what-if' scenarios)

Illustrating Fluxes and Areas

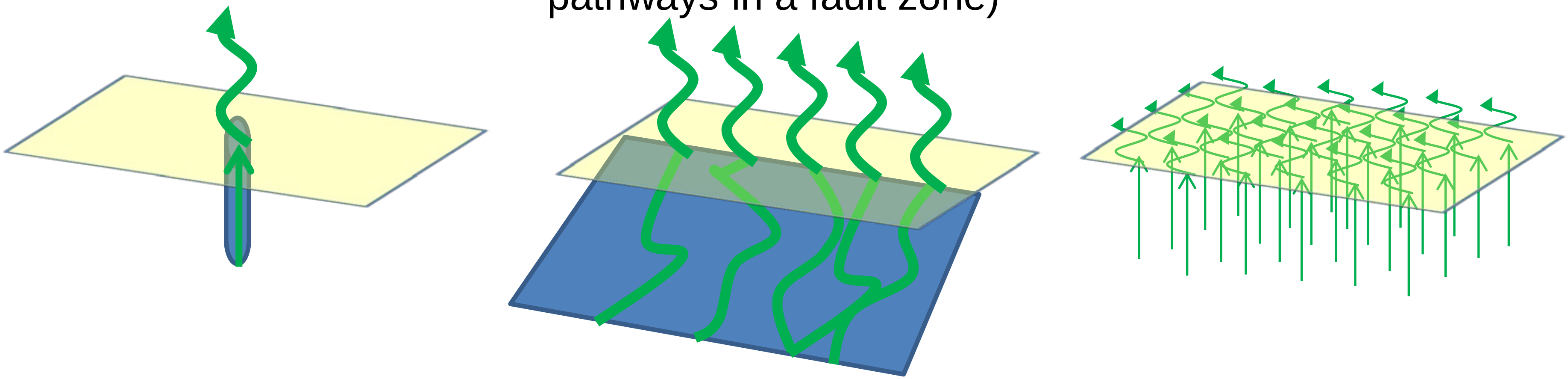
- Impact scenarios should include plausible CO_2 fluxes to the near-surface environment and areas over which fluxes might feasibly occur, should CO_2 leak unexpectedly
- ‘Near-surface environment’ means features associated with things that could be affected, e.g. shallow aquifers, land surface, lake/sea bed
- Leaks from pipelines and other infrastructure not a RISCS focus, but impacts would be qualitatively similar to short-duration localised leakage from failed boreholes, which are covered
- Fluxes and areas for leakage scenarios would depend on site-specific characteristics – no absolute, generic “worst case”
- Focus here on ***illustrative plausible*** fluxes and areas

Plausible Fluxes and Areas

Fluxes = Quantity of CO_2 per unit area per unit time

Various leakage patterns can be envisaged, e.g.

Point source (e.g. leaking well)	Arrays of point sources (e.g. multiple linear pathways in a fault zone)	Diffuse leakage (unclear how could occur)



- Given CO_2 storage would not be permitted if significant probability of leakage fluxes and areas inherently unlikely
- "Plausible" means does not violate fundamental physical / chemical principles / laws and all parties agree to be conceivable

Leakage Risk

$$\text{Risk} = \underbrace{\text{Probability of Leak*}}_{} \times \underbrace{\text{Consequence}^{\#}}_{}$$

- Usually cannot estimate numerically from prior knowledge
- Expert judgment needed (subjective)

- Subjective:
  - consequences of interest
  - mapping to numerical scale
- Context-dependent

*Due to some phenomenon
e.g. well seal failure, earthquake-related faulting etc

#Consequence of intial concern is flux and area, RISCS assesses subsequent consequences

Low Leakage Risk

Low Risk = Low Leak Probability x Low Consequence

Or

Low Risk = High Leak Probability x Very Low Consequence

Or

Low Risk = Very Low Leak Probability x High Consequence

- Many people most concerned about the third case, even though low risk
- Aim to ***illustrate*** the sorts of consequences that could arise for a range of fluxes

Approach

- Literature review by Quintessa (focus on natural sites where CO_2 emitted, observations and simulations from other projects)
- Augmented by simulation of leakage from a marine storage site by SINTEF (Grimstad, 2011) – illustrates key factors to be considered

Terrestrial & Marine Environments

- CO_2 dispersion ("spreading") different in shallow solid geosphere
  - Terrestrial environments water saturated & unsaturated zones
  - Marine environments (almost) always water-saturated

- Terrestrial sites (not water-saturated) – evidence from natural sites & experiments that pore space becomes CO_2-saturated at relatively low fluxes (e.g. at Latera where CO_2 fluxes > c.5 x 10^{-4} to c.8 x 10^{-4} mol m^{-2} s^{-1}, (c. 1900 – 3000 g m^{-2} d^{-1}) soil is >95% CO_2-saturated - Beaubien et al. 2008)

- Greater fluxes can be envisaged for leakage scenarios (e.g. open borehole) – but the maximum CO_2 saturation of the soil would still be 100% - *qualitative* effect of higher fluxes presumably similar to lower fluxes (could extrapolate from lower flux cases to higher flux cases)

- Marine sites (& lake / river terrestrial sites) – need sufficiently high CO_2 flux to displace water to achieve CO_2-saturation of sediment / rock pore space

Use of Natural CO_2 Releases

- Few (if any) are really similar to CO_2 storage sites
- Inconsistencies between different kinds of natural site (e.g. highest fluxes reported for diffuse leakage higher than for point-source fluxes)
- Highlight problem with reporting of seepage type (point, linear arrays of point sources, linear, diffuse etc) and “averaging” effect of areas, e.g.
  - No clear definition of “diffuse seepage” (many small point sources within a wide area, or uniform flux over a wide area?)
  - Areas over which CO_2 actually seeps often not reported precisely
- Fewer well-studied offshore sites than on-shore sites

But

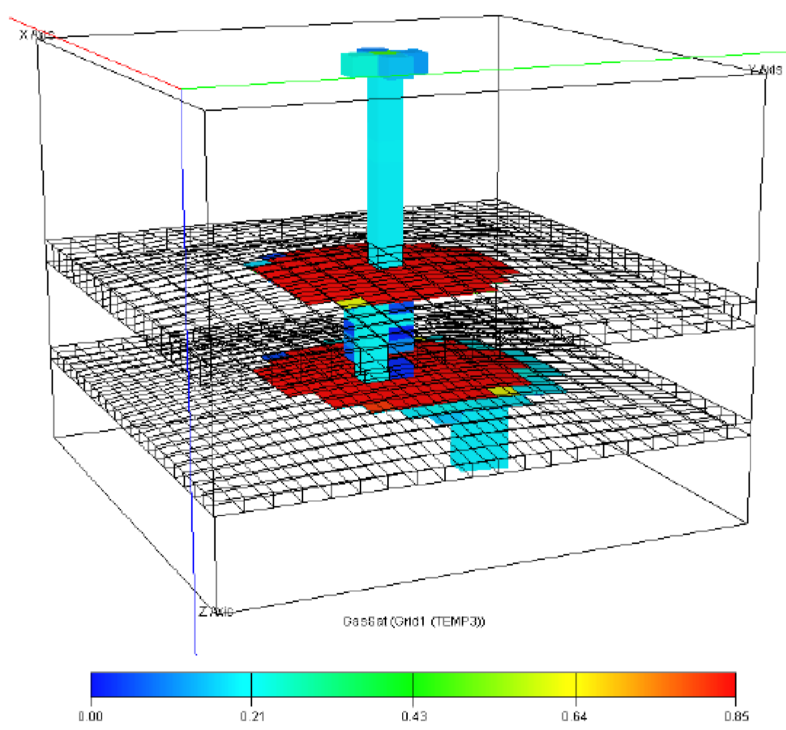
- natural releases *illustrate* certain fluxes and areas that are *plausible*

Example flux / area illustrations

Scenario	Illustrative Flux		Illustrative Area of Leakage	
	Flux (mol m^{-2} s^{-1})	Justification	Area (m^2)	Justification
Normal Evolution Scenario	2.5E-6 =9.5 g m^{-2} d^{-1}	Mean natural flux for Ketzin (Pilz et al. 2011), near minimum natural flux in IPCC (2005).	N.A.	N.A.
Direct release to atmosphere, via a well (high flux for a relatively short time – e.g. days)	2E+5 =750 t m^{-2} d^{-1}	Modelled open borehole flux (Aines et al., 2009). Similar to peak flux in blowout of natural CO_2 at Sheep Mountain, Colorado (Kuuskraa and Godec, 2007).	0.03	Typical well area (180 mm diameter). =22.5 tonnes/day
Localized release to soil through wells / faults / fractures, leading to high CO_2 concentrations near surface	5E-4 =1900 g m^{-2} d^{-1}	Consistent with maintaining near-100% CO_2 saturation of soil, based on modelling (Oldenburg et al., (2003) and observations at natural seeps (e.g. Latera, Italy - see Beaubien et al. 2008).	5 vents of 6m diameter within 50,000 m^2	Frequency similar to vents in Little Grand Wash Fault Zone, Utah (Allis et al. 2005). Diameter similar to natural seeps of Latera, Panarea and Laacher See (e.g. Beaubien et al. 2008; Lombardi, 2010; Gal et al., 2011).

Sintef's Modelling

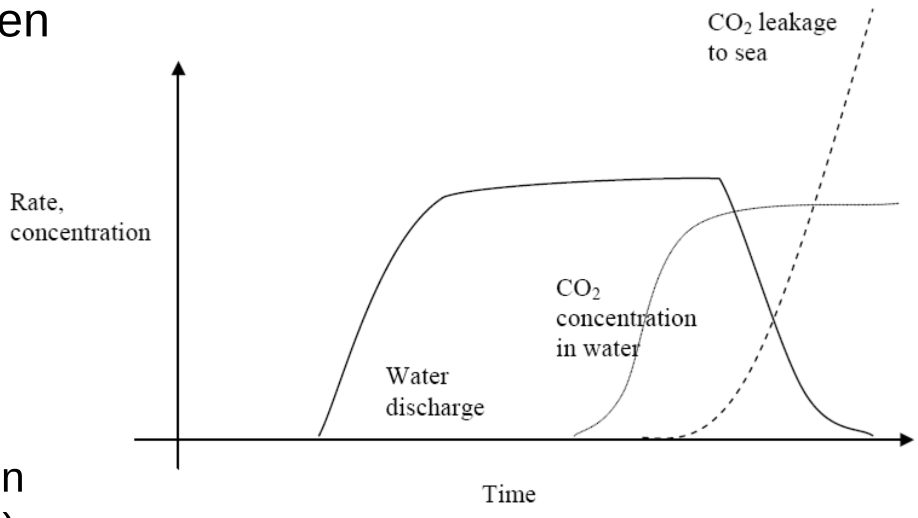
- Simulated CO_2 in deep sub-seabed reservoir overlain by primary cap rock, with top 950 m below sea level
- 3 aquifers separated by two secondary seals lie above cap rock
- Seabed 100 m below sea surface
- Cap rock leaks CO_2 over 50 m x 50 m
- Many simulations, each with leak area placed randomly
- CO_2 fluxes through leaking cell 1.87 to 580 tonnes / day
- CO_2 able to accumulate beneath each secondary seal and leak through permeable area, 50 m x 50 m, in centre of each
- Simulated leak continued unless a specified period elapsed after any of CO_2 accumulation reaches 4000 m^3. Assumed larger CO_2 accumulation detected and mitigated



After Grimstad (2011)

Sintef's Results

- Leakage too small to be detected or reach surface during first 50 years
- Where free CO_2 reached seabed, rate increased with increasing delay between leak recognition and start of mitigation
- Among simulations in which the CO_2 reached the seabed, maximum mean flux was 80 gm^{-2} day^{-1} over c.200 m x c.200 m (area based on analogue)
- Simulated water displacement by leaking CO_2 showed:
  - relatively long period (3 - 5 months) when displaced water (no dissolved / free CO_2) arrives at seabed
  - later, shorter period (1-2 months) when water with dissolved CO_2 would arrive at the seabed (no free CO_2)
  - then longer period of free CO_2 discharge from seabed



After Grimstad (2011)

Summary

•All leakage improbable at a well-chosen and operated CO_2 storage site

•***Illustrate*** a range of low-likelihood higher leakage flux scenarios

- basis for designing monitoring plans
- basis for designing mitigation plans
- a communication tool

•Provide a context for the discussion of project results

•Don't present "worst-case" leakage fluxes and areas because these will be very site-specific, but:

- provide a context for the discussion of project results
- identify issues to be considered in order to specify "worst case" at an actual site