

Geotechnical challenges resulting from legal requirements for off-shore CO₂ storage in the German EEZ

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Mainly relevant:

- > EU CO₂ Storage, Directive 2009/31/EG
- > EU GHG Emissions Monitoring Regulation (EU) 601/2012 & Implementing Regulation 2018/2066
- > German CO₂ Storage law (KSpG), under advanced amendment, offshore storage in EEZ

Others :

- > international maritime conventions
- > international and various national laws and regulations ± related to CCS
(Proelß & Westmark 2022, 2023)
- > technical guidelines

Technical guidelines are legally non-binding, however regulations could refer to such, e.g.

- ISO 27914:2017 geological storage, under advanced review
- ISO/TR 27923:2022 Injection operations, infrastructure, and monitoring
- CEN initiated work 2024 on CCU/S; CEN standards are binding for member states:
 - CO₂ streams and quality
 - pipeline and vessel transportation
 - storage, utilization
 - and accounting

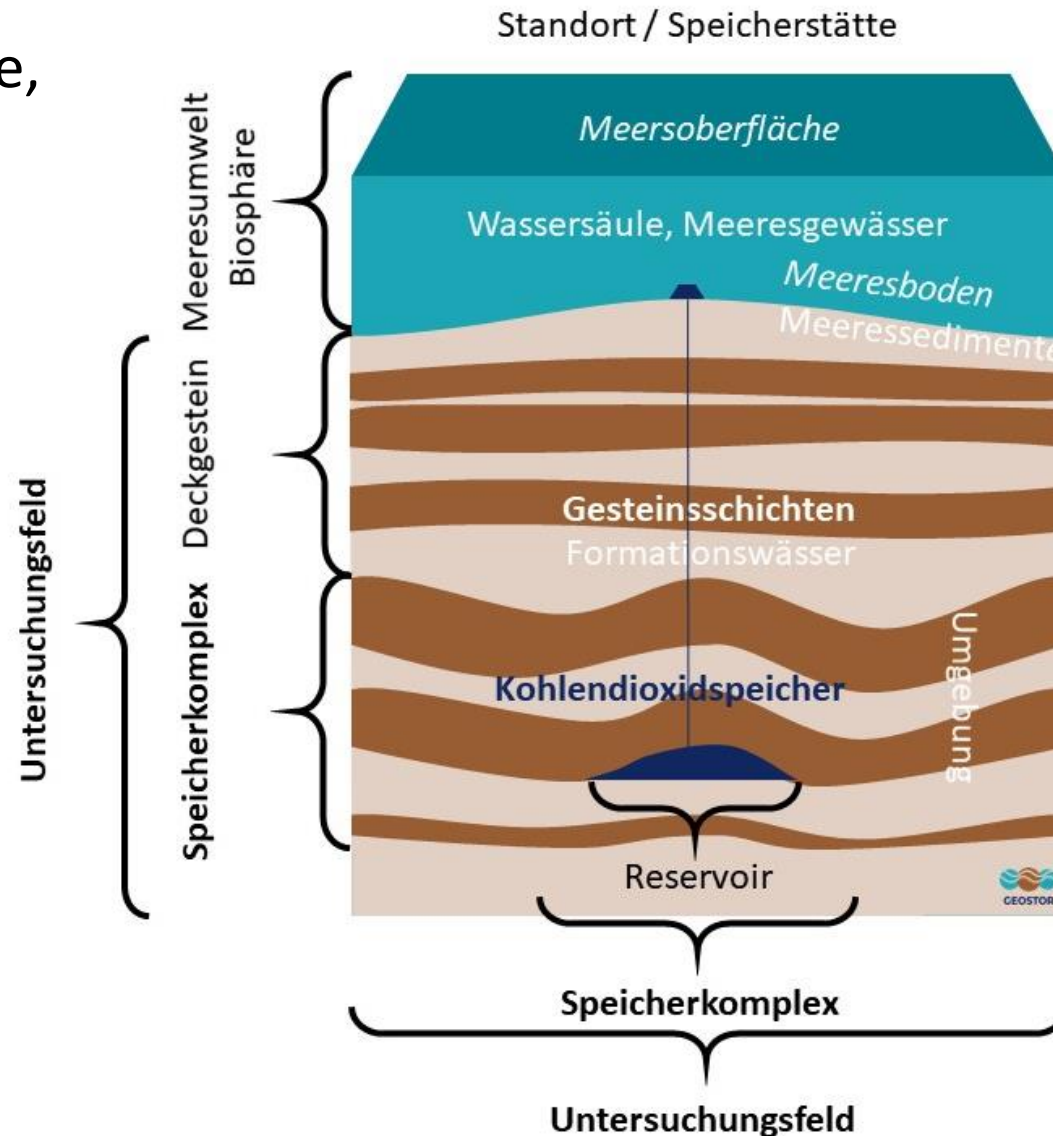


Relevance: Regulation EU 2024/1735 (Net Zero Industry Act) mandates the EU Commission to publish guidelines for appropriate compositions of CO₂ streams

- EU Guidance document to 2009/31/EC No. 2:2024 on characterization and monitoring

Monitoring objects

- > Objects to be monitored are, free and dissolved CO₂, impurities, formation fluids & other properties, effects and impacts of CO₂ storage
- > reservoir
- > storage complex
- > injection facilities
- > surrounding environment
- > usable groundwater



Legal terms in German CO₂ storage law (KSpG):
defined terms
used terms
not mentioned

zweite Ausbreitungsbarriere
Reservespeicher
primäre Deckschicht
Reservoir
Hydraulische Einheit

Legal requirements

- > Operator's monitoring (& monitoring after transfer of liability)
- > Monitoring concepts are required in the applications for storage permits.
- > Monitoring concepts have to be up-dated every five years considering
- > HSE, and long-term risks, & technical developments.
- > Geotechnical requirements on monitoring are specified in **Annex 2** KSpG:
- > 6 aspects are mandatory, and more technologies are “eventually” to be used.
- > Quantification of emissions and leakage from capture, transport, injection and storage of CO₂ is required according to EU Regulation 601/2012 & Implementing Regulation 2018/2066 .

Some Challenges

- > Selection of monitoring methods
- > Offshore Wind-Farms
- > Site-specific monitoring plans
- > Quantification of Leakage
- > Appropriate baselines
- > Durability of equipment, technical developments, updated plans

Selection of Methods

- > Legal requirements result in a multitude of monitoring tasks.
- > A conucopia full of monitoring methods and devices potentially could be used.

Compilations of (marine) exploration and monitoring methods evaluated in a meta-study
26 publications (2002 – 2022) listing methods considered
45 methods with many variations and applications, (many useful for exploration; baseline)



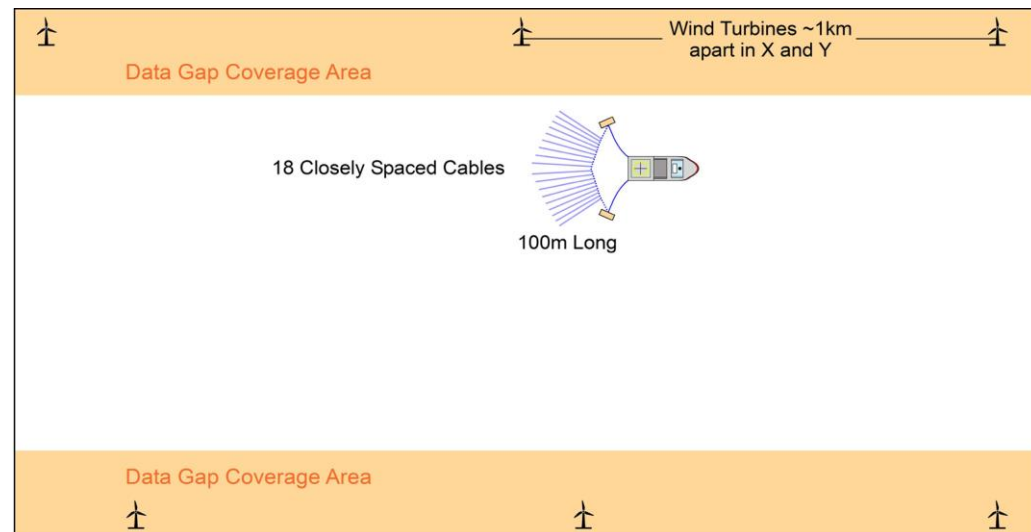
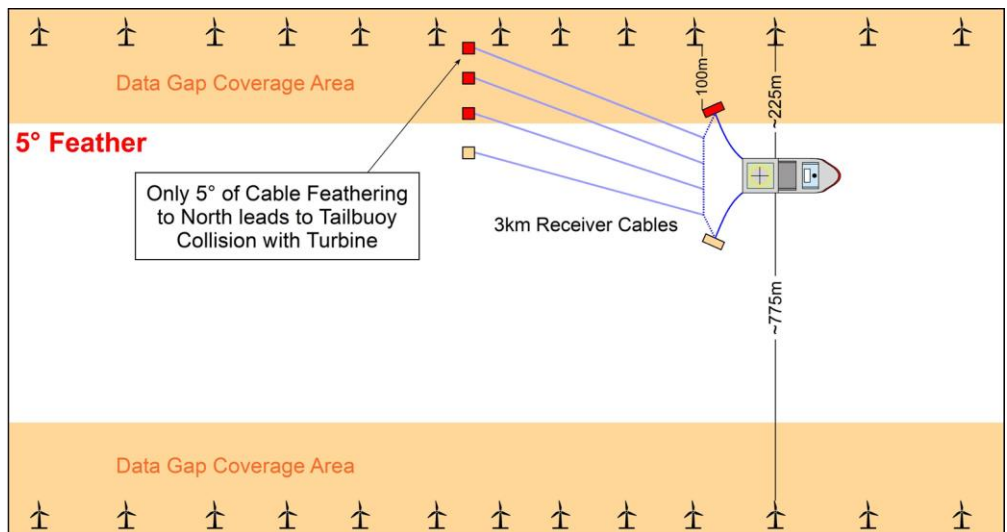
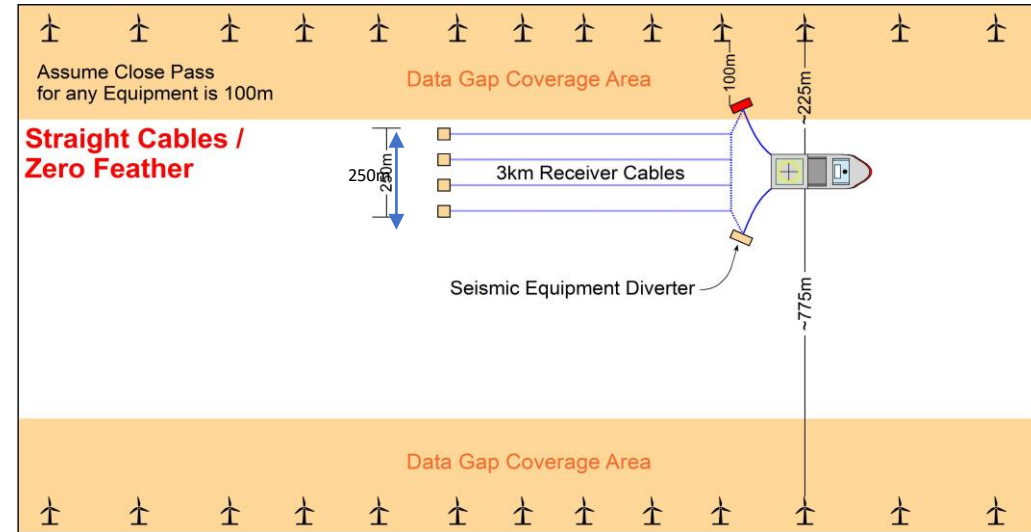
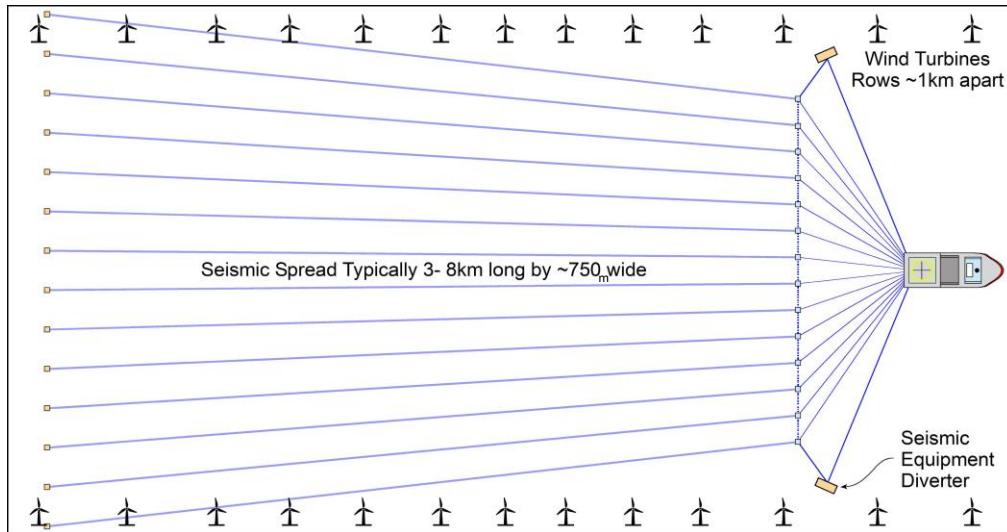
- > Various approaches were proposed, for the selection of site specific methods.
- > Criteria for selection: in Annex 2 KSpG (a.o. risk-based) or in the EU-Guidance Document
- > selection tools, such as that of the IEA-GHG

Selection of Methods

<u>Reservoir location</u>	<u>Reservoir depth</u>	<u>Reservoir type</u>	<u>Landuse at site</u>	<u>Monitoring phase</u>	<u>Monitoring aims</u>		<u>Tool package</u>
<input type="radio"/> Onshore	<input type="radio"/> 0.5-1.5 km	<input checked="" type="radio"/> Aquifer	<input type="radio"/> Settled	<input type="radio"/> Pre-injection	<input checked="" type="checkbox"/> Plume	<input type="checkbox"/> Calibrate	<input type="radio"/> Core
<input checked="" type="radio"/> Offshore	<input checked="" type="radio"/> 1.5-2.5 km	<input type="radio"/> Oil	<input type="radio"/> Agricultural	<input checked="" type="radio"/> Injection	<input checked="" type="checkbox"/> Top-seal	<input checked="" type="checkbox"/> Detect	<input type="radio"/> Extra
<input type="radio"/> Both	<input type="radio"/> 2.5-4 km	<input type="radio"/> Gas	<input type="radio"/> Wooded	<input type="radio"/> Post-injection	<input checked="" type="checkbox"/> Overburden	<input type="checkbox"/> Quantify	<input checked="" type="radio"/> All
	<input type="radio"/> >4 km	<input type="radio"/> Coal	<input type="radio"/> Arid	<input type="radio"/> Closure	<input type="checkbox"/> Processes	<input type="checkbox"/> Seismicity	
			<input checked="" type="radio"/> Protected			<input checked="" type="checkbox"/> Wellbores	
Tool	Rating %	Plume	Top-Seal	Overburden	Detect	Wellbores	
<u>3D surface seismic</u>	75	4.0	3.0	4.0	1.0	3.0	
<u>Multicomponent surface seismic</u>	55	3.0	3.0	3.0	0.0	2.0	
<u>Tracers</u>	50	1.0	2.0	1.0	3.0	3.0	
<u>Downhole pressure/temperature</u>	45	1.0	4.0	1.0	0.0	3.0	
<u>Geophysical logs</u>	45	1.0	2.0	2.0	0.0	4.0	
<u>Shallow seismic profiling (P-cable)</u>	43	0.3	0.3	4.0	2.0	2.0	
<u>Microseismic monitoring</u>	40	2.0	3.0	1.0	0.0	2.0	
<u>Above-zone pulse testing</u>	40	0.0	2.0	3.0	0.0	3.0	

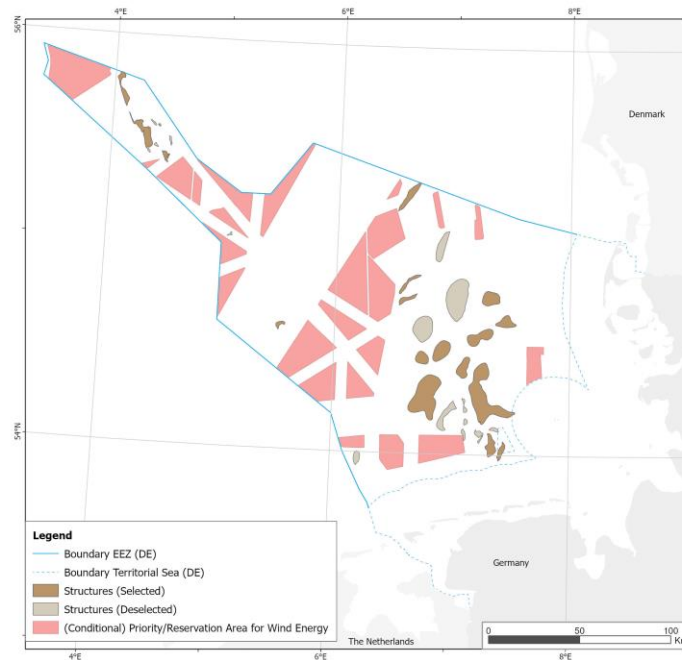
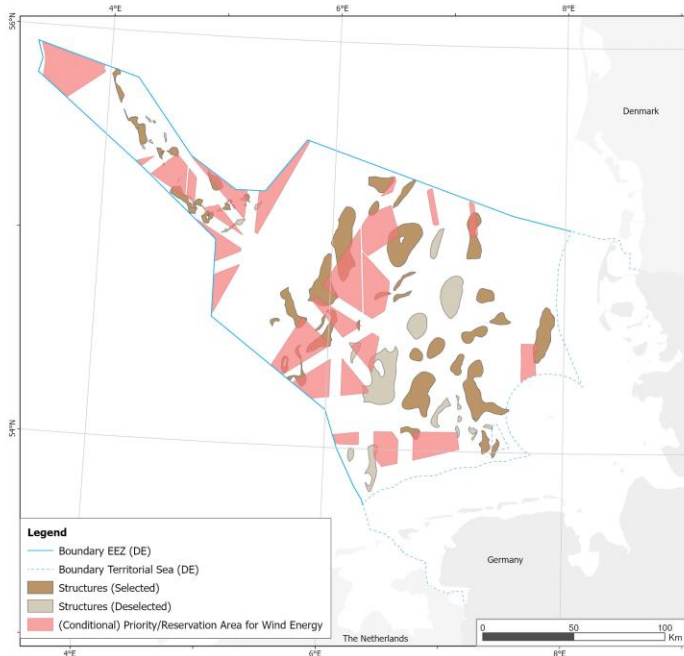
> no single method fits well for all purposes

3D Surface Seismics and Offshore Wind Farms

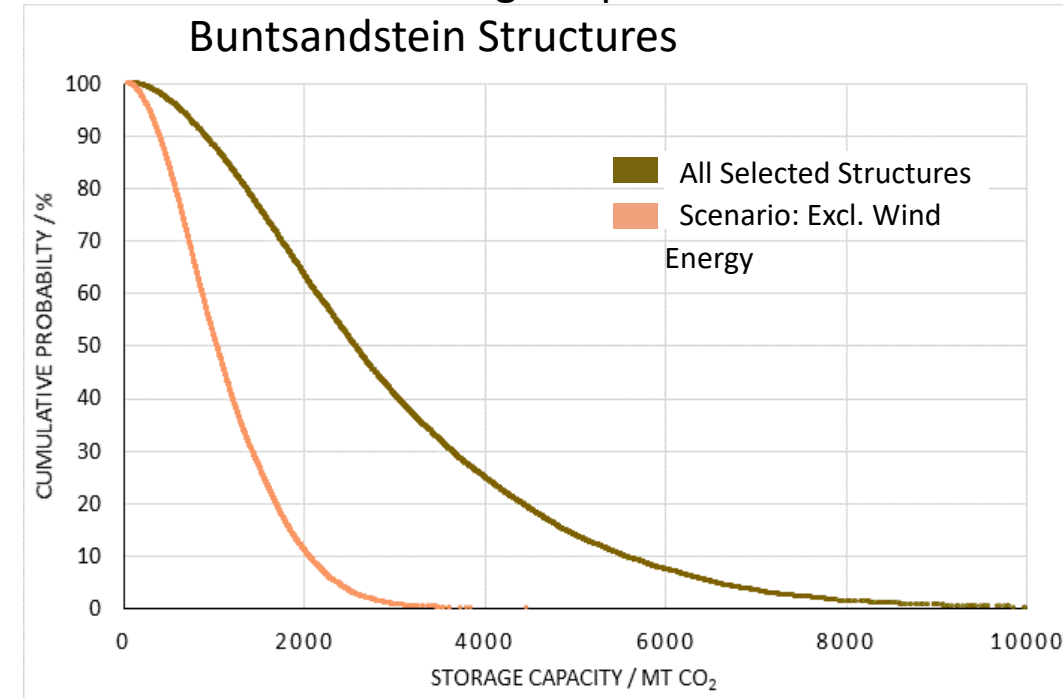


3D Surface Seismics and Offshore Wind Farms

- > general traffic restrictions in wind-farms for ships > 24 m (e.g. seismic survey vessels)
- > draft KSpTG gives priority to offshore-wind development over CO₂ storage



Estimated Storage Capacities for Buntsandstein Structures



3D Surface Seismics and Offshore Wind Farms

> Promising developments:

- spot seismics (Greensand)
- passive seismics
- (permanent) ocean bottom networks of seismic receivers
- deployment of receivers by autonomous underwater vehicles
- fibre optical methods

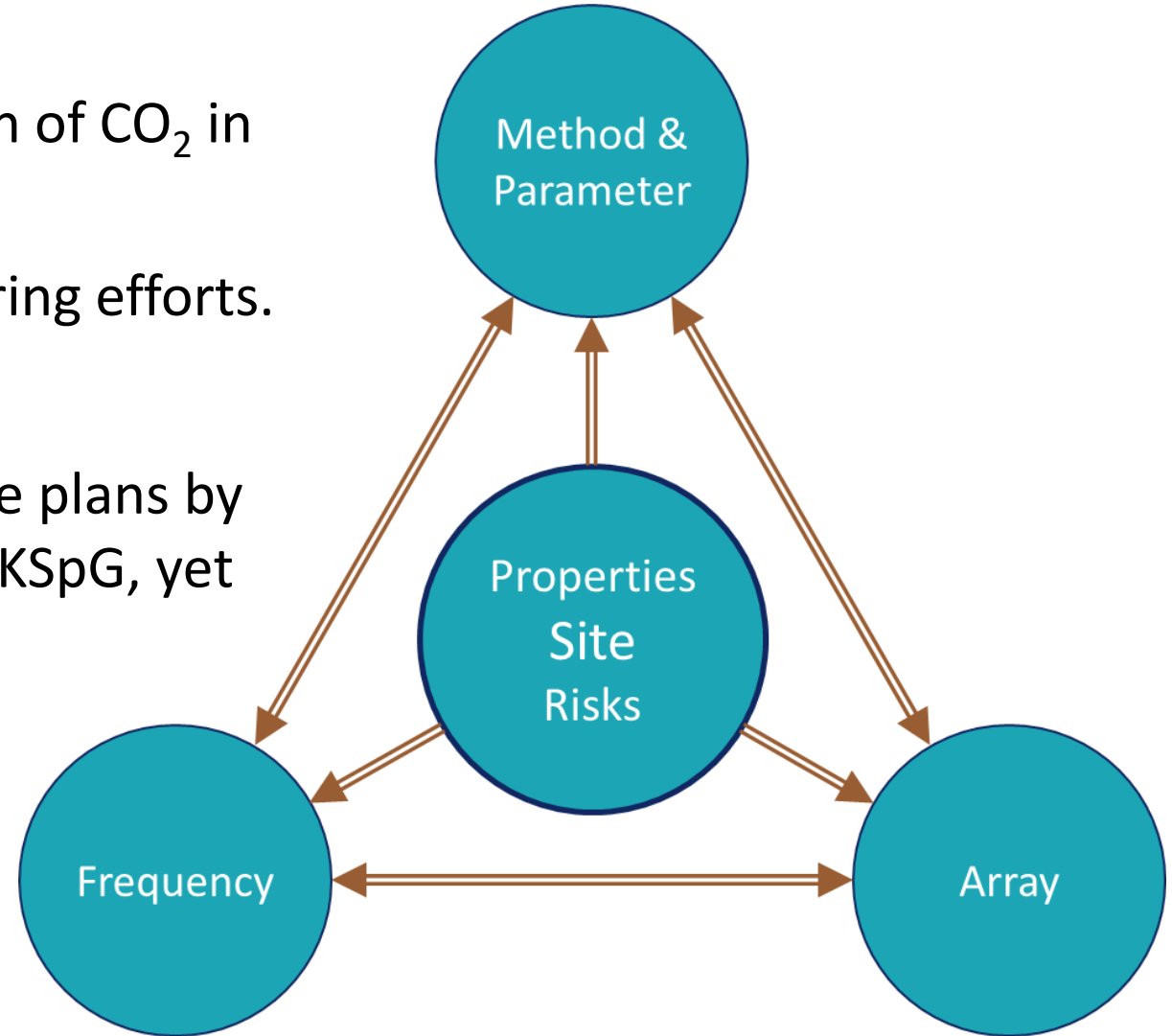
More on marine spatial planning and CO₂ storage:

Geostor WP 5.1, Rütters et al. (2024)

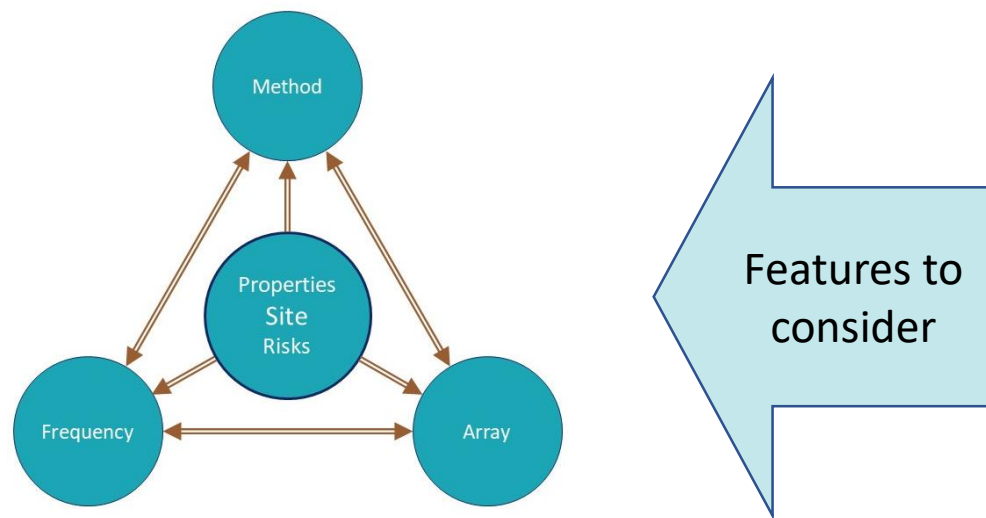
UK Offshore Wind and CCUS Co-Location Forum

Site-Specific Monitoring Plans

- > I.a. should facilitate precise localization of CO₂ in the subsurface (KSpG)
- > How precise ? Will depend on monitoring efforts.
- > No provisions or guidance on adequate plans by implementation regulations according KSpG, yet



Site-Specific Monitoring Features



- > ~8 million possible combinations of features for 14 selected criteria
- > uniqueness of sites suggest to abstain from universal provisions in regulations

storage option	saline aquifer	oil reservoir	gas reservoir	
storage structure	closed		open	
sovereign territory	coastal water		EEZ	
storage size	pilot or demonstration		full scale commercial	
well infrastructure	fixed platform	floating platform	seafloor installation	
water depth	tidal waters	open shelf	continental slope	
potential pathwas	faults	wells	cap rocks	spill points
project phase	construction and baseline	normal operation	irregular incident	post-injection, post-abandonment
monitoring aim	storage operation	HSE		accounting of emission certificates
fluid substance	CO ₂ stream	formation and sea water	residual gas	oil
processes	fluid migration	geo-mechanical	geo-chemical	biological
compartment	storage complex	overburden	waer column	seafloor
CO ₂ leakage rate	low	intermediate	high	blowout
leakage type	diffuse	distributed dicrete vents		single vent

Quantification of Leakage



> Seep and blow out of natural CO₂

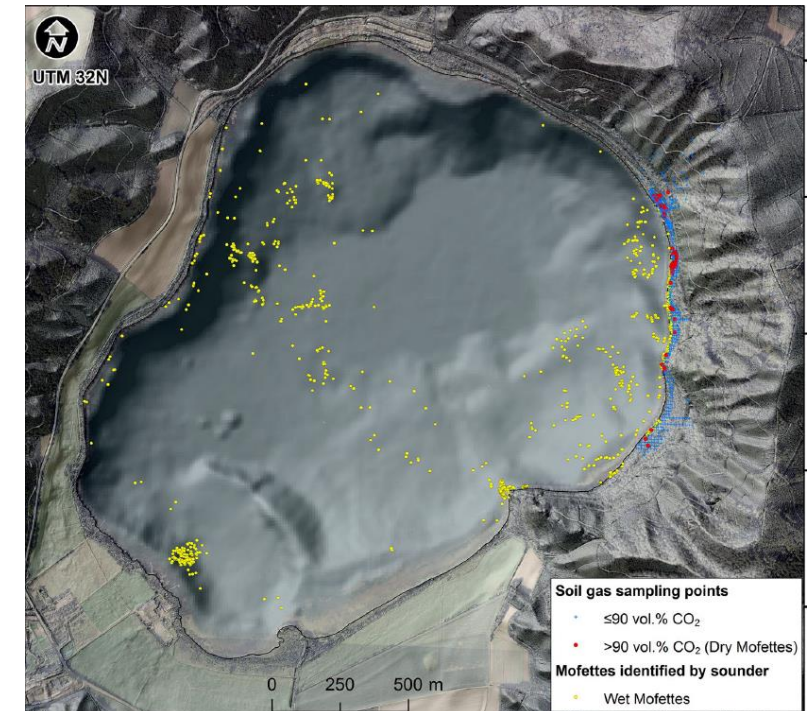


Quantification of Leakage

- > leakage out of storage complex (KSpG) →
operator reports kind and magnitude
- > into atmosphere or water columns (Monitoring Directive) →
hourly determination of the mass of CO₂, according to monitoring plan
- > Tolerance for measurement uncertainties of 7.5 %
- > Excess uncertainty would have to be reported as emission
- > 19 published rates for blow-outs; reported uncertainties ranging from 6 – 906 %

Detection & Quantification of Fugitive Emissions

- > Fugitive emissions (Monitoring Directive): irregular, not localized, too diverse, or too small and too many to be measured individually
- > Detection threshold, from North Sea experiments 10 – 50 t/a (Dean et al. 2022)



Quantification of Fugitive Emissions

- > Monitoring of potential sources of diffuse emissions required.
- > Quantification by calculation or measurement,
- > based on documented “industry best practice guidelines”.
- > Uncertainty levels 7.5%; (10 %, if proven to be technically or economically impossible)
- > terrestrial Laacher See, e.g. 24 % uncertainty of CO₂ flux (dissolved fraction only)

- > Whether monitoring plans are sufficient to fulfil all monitoring tasks, will depend on site-specific conditions and possibly on requirements specified in regulations or in permits.
- > Experience lacs for practical monitoring of full-scale operational storage sites, permitted under the EU CO₂ Storage Directive 2009/31/EG.
- > In principle, adequate monitoring of marine storage sites in the German EEZ appears feasible with currently available technologies.
- > Novel monitoring tools and concepts are required to exploit storage potential in marine areas serving multiple purposes.

Report:

May, F. (2024): *Geotechnische Implikationen rechtlicher Rahmenbedingungen für die Erkundung und Überwachung von CO₂-Speichern unter dem Meeresboden.*

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<https://geostor.cdrmare.de/>

