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The DELPHI Expert Process of the German Umbrella Project AUGE - Status of CO_2 Storage in Germany and Recommendations to the Review Process of the German CO_2 Storage Legislation

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Abstract

To scientifically underpin the German national "Carbon Dioxide Storage Law" (KSpG) and derive recommendations for its review and implementation, a Delphi expert process was initiated within the national German umbrella project AUGE. In two Delphi rounds experts from science, industry and regulatory bodies were asked for their assessment of CO_2 storage in general and the KSpG in particular. Overall, CO_2 storage is seen essential for reaching a 2°C target and experts agree that knowledge and technology allow implementing a demo-scale project. However, experts also agree that the current KSpG version prevents implementation of CCS in Germany and requires revision.

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Keywords: CO_2 storage; CO_2 storage regulation; transfer of liability

1. Introduction

In 2012, the German parliament passed the transposition of the EU CCS Directive 2009/31/EG [1] into the national "Carbon Dioxide Storage Law" (KSpG) [2]. Beside minor differences between both regulations, Annexes 1 and 2 of the EU CCS Directive and the KSpG, which in both regulations define the criteria how to set up and

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monitor CO_2 storage, are comparable. Annex 1 of the KSpG lists “Criteria for the characterization and assessment of a potential CO_2 storage site and potential storage complex as well as its surroundings” whereas Annex 2 lists “Criteria for design and update of a monitoring concept and for post-injection, pre-transfer surveillance”. The criteria given in these Annexes are of general nature reflecting (i) that CO_2 storage technology is still being developed and (ii) that site specific aspects need to be considered. To scientifically underpin the two Annexes of the KSpG, an umbrella project called AUGE has been launched in 2012 by the German Federal Ministry of Education and Research (BMBF) to compile and summarize the results of the different GEOTECHNOLOGIEN projects. Within the GEOTECHNOLOGIEN funding scheme for geological CO_2 storage by the BMBF in Germany 33 projects (135 subprojects) have been funded with a total budget of 58 Mio € (excluding industry funds) from 2005 to 2015. By integration of the individual project results AUGE aims at derive recommendations for the review and implementation of the KSpG. The recommendations shall be drafted based on a common ground of science, public authorities and industry. Therefore, the AUGE project includes a Delphi expert process as an essential part.

2. Description of the Delphi process

The Delphi method is a systematic, multi-stage review process with participation of interdisciplinary experts and stakeholders and iterative feedback of the results between the different process stages [3]. Due to its iterative nature the distribution of opinions and judgements is typically much more explicit than in single-stage review processes. By this, a Delphi process is able to clearly identify aspects, for which i) consensual agreement can be reached, ii) consensus on dissent is agreed, or iii) no consensus can be reached at all. It is typically used for the evaluation of technologies and for technological impact assessments. The here presented Delphi process was performed in a two stage manner (Fig. 1).

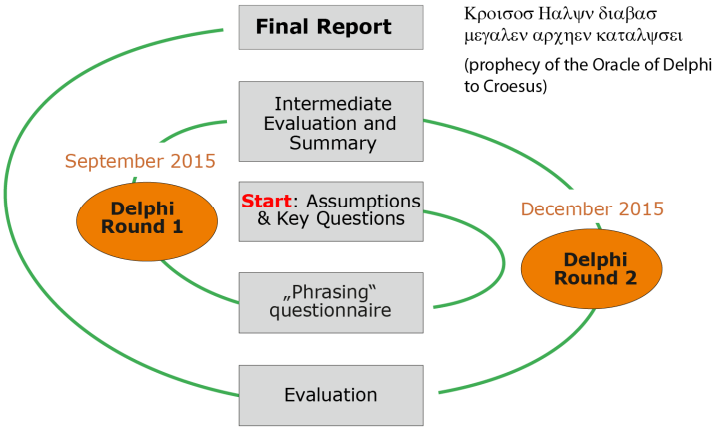


Fig. 1: General procedure of the Delphi process. The questionnaire was phrased based on expert interviews. For the second round, evaluation of the first round answers and an updated questionnaire were distributed to active participants of the first round. The questionnaire for the second round was restricted to controversial questions and/or highly scattering answers of the first round. [But as painfully learned the hard way by Croesus, it are not the answers but their evaluation that may lead to wrong conclusions.]

For the first round a standardized questionnaire was produced and sent to relevant stakeholders and experts on CO_2 storage in Germany. Basis for the questionnaire were initial interviews with different experts form science and industry, results of the AUGE project on status of German CO_2 storage research as derived from the review of the different GEOTECHNOLOGIEN projects, and the KSpG itself with its Annexes. The questions were organized into six chapters: 1) General aspects of carbon dioxide storage, 2) General issues of the law to geological CO_2 storage

(KSpG), 3) Characterization and assessment: establish criteria for characterization and assessment of potential CO_2 storage sites as well as potential storage formations and their environment (referring to Annex 1 of the KSpG), 4) Monitoring: criteria for development and updating of the monitoring concept and for the follow-up care (referring to Annex 2 of the KSpG), 5) Personal information by the experts, and 6) Open remarks. Questions either asked for i) rating individual statements on a scale from 1 (e.g., fully disagree) to 8 (e.g., fully agree; see example in Fig. 2), ii) ranking of statements within a group of statements, or iii) refusal or approval in case of dichotomous questions. Except for chapters 5) and 6), questions also asked for experts´ self-assessment regarding confidence in own judgement (Fig. 2).

Below you can find some general statements concerning the „KSpG". How far do you agree to these declarations? Please quote 8 if you agree totally, and 1 if you disapprove completely.									How confident do you feel during responsing the questions?			
	1 dis-agree	2	3	4	5	6	7	8 agree	very confident	fairly confident	fairly not confident	not confident

Fig. 2: Example of a rating question (from group 2 "General issues of the law to geological CO_2 storage (KSpG)") and the expert´s self-assessment.

The questionnaire of Round 1 was sent to 128 German experts from science (64 experts), industry (47 experts) and regulatory bodies (17 experts) (Fig. 3). Of these, 40 experts (= 31%) replied and sent their judgements to the different questions. The results of the first round were evaluated and a second questionnaire was prepared based on the evaluation outcome. Depending on the statistical variability and standard deviations of the answers, questions were either re-asked (high variability, large standard deviation) in the second round or skipped from the questionnaire (low variability, small standard deviation). Questions for which most of the experts voted "fairly not confident" or even "not confident" in their self-assessments were also re-asked in the second round. The second round questionnaire was sent to those 40 experts that replied to first round questionnaire. Together with the second questionnaire also the results and evaluation of the first round were sent to the experts allowing them to reassess and potentially revise their earlier answers in light of the replies of other members of the panel. Of the 40 invited experts for the second round, 21 (= 53%) replied and sent their final and potentially revised judgements to the different questions.

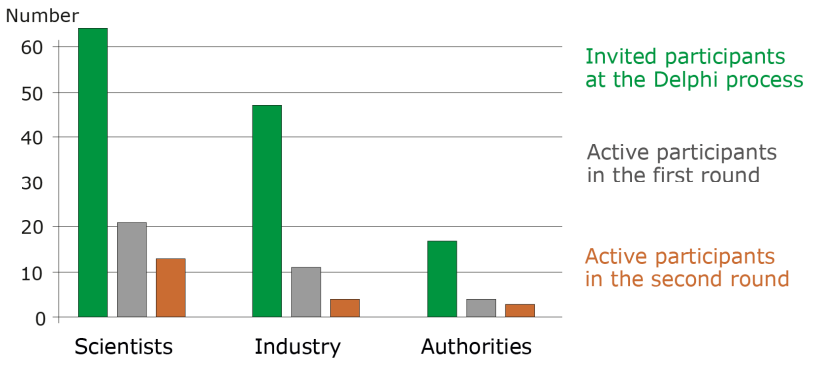


Fig. 3: Overview of invited and active participants for first and second round of the Delphi process. In total 128 experts have been invited for the first round, 40 (= 31%) of these replied and were invited for the second round. 21 participants (= 53%) answered the second questionnaire.

3. Results

According to the general organization of the Delphi process, the main results are presented in the following according to the six chapters of the first and second round questionnaires. The return and answers of the first and second round have been in a range to be realistically expected for a Delphi process. However, one should bear in mind that i) in the second round only 21 experts participated, which may not be seen as statistically representative for the German CO2 storage community and ii) only experts have been invited and the results therefore do not represent the opinion of the general public on CCS in general and CO_2 storage in particular.

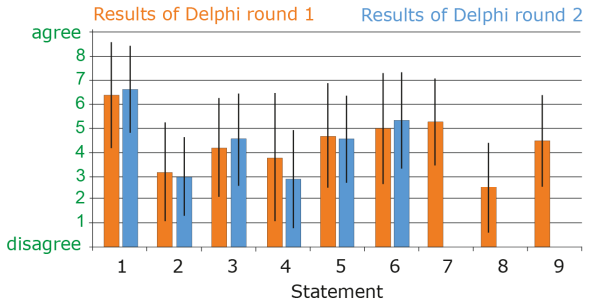
3.1. Chapter 1: General aspects of carbon dioxide storage

On average, the experts see CO_2 storage as essential for reaching a 2°C target. The variance of the answers decreased from the first to second round so that overall consensus can be assumed. The need for additional site independent basic research and R&D projects up to a maximum of 100 kt CO_2 injected is seen ambivalently albeit relatively consensually. On the other hand, the statement that a demo-scale project up to a maximum of 1 Mt CO_2 injected can be implemented in Germany is consensually agreed by the experts. The question for the recommended lead of such a demo-scale project is seen controversially. Answers are equally distributed between "by the government", "by industry", "by science", "by industry and science" and "by industry, government and science". There is a consensual tendency towards support of CCS implementation in Germany and an even slightly higher support for global CCS implementation. With regard to usage of the available storage capacities, experts agree on priority for storage of CO_2 from industrial processes and fossil fuel use; usage of storage capacities for CO_2 from air capture or in context of Bio-CCS is seen less important. Experts were also asked which irregularities they see most probable and which most problematic. Upward brine displacement and migration into drinking water horizons is seen as most probable and most problematic. Induced seismicity and reactivation of faults on the other hand are seen as less probable and less problematic. Wellbore leakage is seen as probable but less problematic whereas leakage of CO_2 out of the storage complex is seen less probable but problematic if occurring. Overall, experts consensually rate risk of irregularities in general and leakage in particular as rather low.

3.2. Chapter 2: General issues of the law to geological CO_2 storage (KSpG)

With regard to general aspects of the KSpG (Fig. 4) the experts agree that the actual legislation prevents implementation of CCS in Germany and that revision of the KSpG is recommended. By this, the KSpG shall make a clear distinction between requirements for research, demo-scale and industrial scale CO_2 storage projects. However, ambivalently judged are the statements i) that recent, new scientific results require review of the KSpG and ii) that a revision of the KSpG will increase the possibility of CCS implementation in Germany.

For the time after 2016, experts were asked whether the KSpG should define explicit maximum amounts of permitted injected CO_2 for pilot, demo-scale and industrial scale sites. It is consensual opinion that such maximum permissible values are senseless for industrial scale projects; a view that is opined by one third of the experts also for demo-scale and pilot projects. One third argues for maximum permissible amounts between 1 and 3 Mt CO_2 for demo-scale projects while half of the experts vote for a comparable low maximum permissible amount of below 100 kt CO_2 for pilot projects. Experts were also asked to judge on maximum permissible concentrations of various impurities in the CO_2 stream defined by the KSpG (Table 1). For Ar and N_2 the majority vote against any definition of maximum permissible concentration. For all other listed impurities, the majority of the experts see maximum permissible concentrations as clearly site dependent and explicit maximum permissible values should therefore not be given in the KSpG.



Statements:

1. The actual „KSpG" prohibits the application of CCS in Germany
2. The „KSpG" shall remain as it is
3. Current scientific insights require a revision of the „KSpG"
4. A revision of the „KSpG" is useless, because geological storage of CO_2 is simply not accepted by the society
5. A revision of the „KSpG" increases the chance, that geological storage of CO_2 will be implemented in Germany
6. The „KSpG" has to make a clear differentiation between pilot, demonstration and industrial projects
7. In the „KSpG" clear specifications are missing, which make the decision process for the approval of different CO_2 storage reservoirs comparable
8. In the „KSpG" precise numbers, e.g. of maximum injection rates, should be mentioned
9. Many processing steps are overregulated in the „KSpG"

Fig. 4: Example of typical outcome and process steps of Delphi rounds 1 and 2. Participants were asked to judge the listed statements on a scale from 1 (= fully disagree) to 8 (= fully agree). Statements 1 to 6 were re-addressed during round 2 while statements 7 to 9 were only addressed in round 1 as evaluation indicated lack of any dissent.

Table 1: Expert judgement on maximum permissible concentrations of individual impurities in the injected CO_2 stream. Bold numbers refer to number of experts.

impurity	not acceptable	acceptable below	without limits	depending on storage site
N_2	**0**	*< 0.01%* **1** *< 1%* **1**	**8**	**6**
H_2S	**6**	*< 0.01%* **2**	**1**	**8**
O_2	**3**	*< 0.01%* **1** *< 0.1%* **1** *< 1%* **2** *< 5%* **1**	**1**	**8**
SO_x	**5**	*< 0.01%* **2** *< 0.1%* **1**	**1**	**7**
NO_x	**2**	*< 0.01%* **3** *< 0.1%* **2** *< 5%* **1**	**1**	**7**
Ar	**0**	*< 0.1%* **2** *< 1%* **1**	**7**	**6**
Σ impurities	**1**	*< 1%* **3** *< 5%* **4**	**0**	**8**

3.3. Chapter 3: Characterization and assessment: establish criteria for characterization and assessment of potential CO_2 storage sites as well as potential storage formations and their environment (referring to Annex 1 of the KSpG)

The KSpG in its present form lists and defines criteria and data that have to be included to characterize the storage complex in a more general way. The experts were asked whether these criteria should be more explicit and precise (Fig. 5). The majority objects to such more explicit and precise formulations, especially with regard to topics "hydrogeology", "geomechanical properties", "seismics", "natural and anthropogenic fluid pathways", and "geochemistry". Only with regard to topic "geology and geophysics" a majority of the experts votes for more detailed definition in the KSpG. Overall, the experts agree that the current technologies at hand are sufficient to reliably characterize the storage complex. The requirement that 3D geological models shall characterize the storage complex is very generically defined in the KSpG. The experts generally agree with such a generic definition, only two aspects are mentioned that should be added to the definition: i) Characterization of cap rock and hydraulically influenced areas outside the storage complex and ii) other geological features that may impact on the integrity of the storage complex. As for the geological model, definitions and requirements for dynamic modelling are rather generic in the KSpG. Also for the dynamic modelling aspects the experts clearly object to more explicit formulations, especially with regard to aspects "storage capacity and pressure gradients", "risks of facture formation within the storage complex" and "risks of leakage". Objection against more explicit formulations is less clear for the aspect "lateral and vertical distribution of CO_2 with time". Distinct consensual agreement is reached regarding wellbore data; here the experts unequivocally demand that industry has to make their wellbore data publicly available.

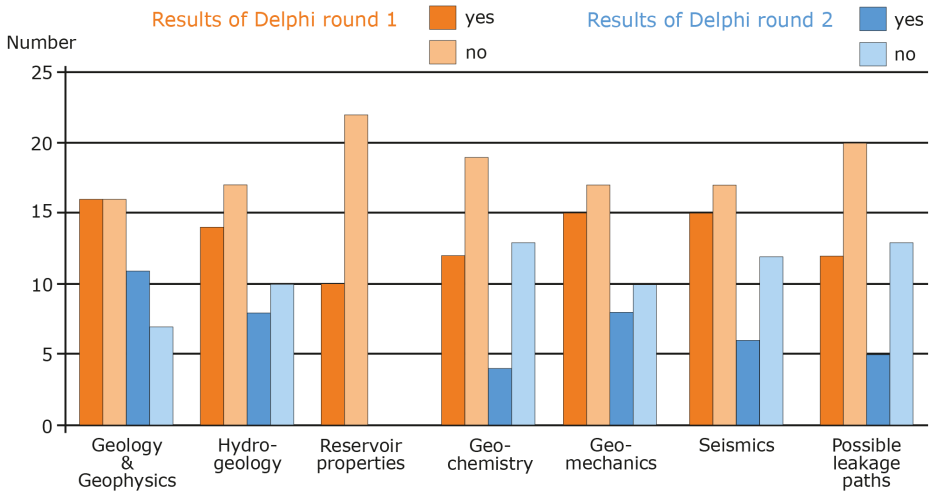


Fig. 5: Example for survey on criteria for the characterization and assessment of the potential CO_2 storage sites according to Annex 1 of the KSpG. Participants were asked on what aspects listed they support a specification or rather more detailed phrasing to deduce essential activities. Except for aspect "geology & geophysics" participants in both rounds negate need for specification or more detailed phrasing. Overall, negation is more pronounced in the second than in the first round.

3.4. Chapter 4: Monitoring: criteria for development and updating of the monitoring concept and for the follow-up care (referring to Annex 2 of the KSpG)

The experts were asked to rank and prioritize different monitoring areas the operator shall target to detect leakages and irregularities. Monitoring the wells, the reservoir and specific critical zones like faults gained slightly higher priority while monitoring the surface and the overburden are seen as slightly less important. However, the differences are only very minor and indicate rather equal weighting of importance of the different areas for monitoring.

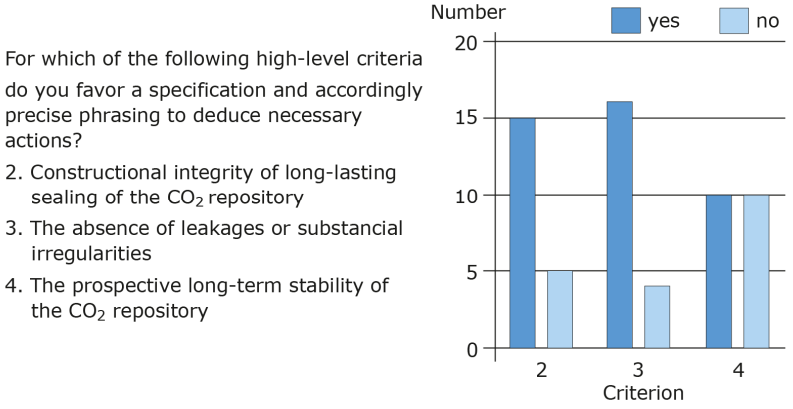


Fig. 6: Example for survey on criteria for the monitoring concept and the follow-up care according to Annex 2 of the KSpG. According to the experts´ judgement, criteria 2 and 3 need specification while criterion 4 is seen ambivalent.

For transfer of liability from the operator to the competent authority, the KSpG defines a 40 years' minimum time span between end of injection and transfer of liability. The majority of the experts see a fixed time span generally critically as transfer of liability should not depend on some pre-defined time span but on the behavior and evolution of the storage system. One third of the experts agree with the minimum time span set in the KSpG. Besides a minimum time span, the KSpG also defines four high-level criteria that have to be fulfilled and evidenced by the operator prior to transfer of liability: 1) conformance between observed and modelled behavior of the stored CO_2, 2) constructional integrity of long-lasting sealing of the reservoir, 3) absence of leakages and/or significant irregularities, and 4) prospective long-term stability of the reservoir. The experts agree with formulation of criterion 1) but support revision and specification of criteria 2) and 3); criterion 4) is seen ambivalent (Fig. 6).

4. Conclusions

The return rates for round 1 and 2 of 31% and 53%, respectively, are in a range to be expected for the topic and the length of the questionnaires. In absolute numbers, however, these return rates transfer into only 40 active participants in round 1 and 21 active participants in round 2. For several topics addressed consensus can be assumed already after round 1 providing a better statistical basis and higher confidence in the conclusions drawn for these topics. Main outcomes of this Delphi process for which consensual agreement of the experts can be assumed include: i) CCS is inevitable to reach the two-degree warming objective, ii) the use of CCS in Germany and on a global scale is generally supported, iii) preference for usage of the pore space should be given to industrial and fossil fuel based emissions, iv) a German demonstration project (with a total amount of 1 Mt of CO_2) is technically

feasible, v) CO_2 leakages are considered to be of low risk after a thorough site selection process, vi) the current German legislation (KSpG) hinders the use of CCS in Germany and should be partially revised, and vii) despite the need for revision, experts in general do not ask for more precise and explicit formulations in the KSpG but rather ask for performance based formulations.

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