D3.2 Report on the outcomes of the Societal Embeddedness Level Assessment for CCS in four countries: Norway, the Netherlands, Greece and Germany

DigiMon

Digital monitoring of CO_2 storage projects

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Executive summary

This document (DigiMon deliverable D3.2) describes the assessment of societal embeddedness level (SEL) of CCS in Norway, the Netherlands, Greece and Germany. It also provides recommendations for improving the societal embeddedness of CCS technology per country.

Research approach

Based on a contextualization of CCS for each country the SEL was evaluated using the methodology as described in the DigiMon deliverable D3.1 "Guideline Societal Embeddedness Assessment"[1]. An overview of the SEL methodology is presented schematically in Figure 1. The SEL was assessed for each one of its dimensions, which are (1) the impact on the natural and social environment, (2) stakeholders' involvement, (3) legal and regulatory framework and (4) market and financial resources, starting from the average TRL level for CCS development at national level. For each dimension the so-called societal embeddedness *level* was identified, varying from SEL 1 to SEL 4 (see Figure 2). Based on the SEL values per dimension an overall SEL value was identified, as described in DigiMon deliverable D3.1[1]. The assessment was performed by combining the results of desk research based on literature review and insights from interviews with CCS experts.

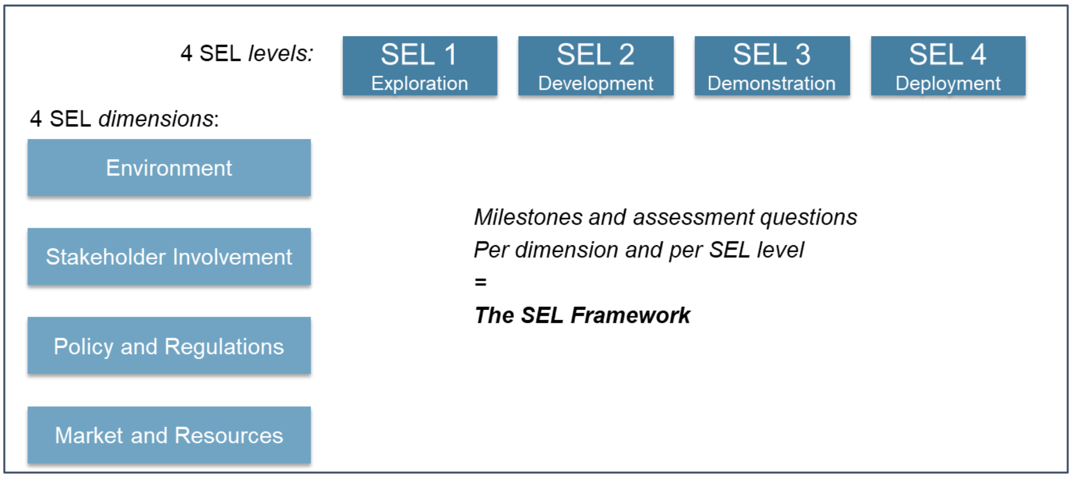

Figure 1 Overview of the SEL methodology consisting of 4 SEL dimensions and 4 SEL levels. For each SEL level and each SEL dimension, milestones and research questions have been drawn in order to evaluate the societal embeddedness level of an innovation. [1]

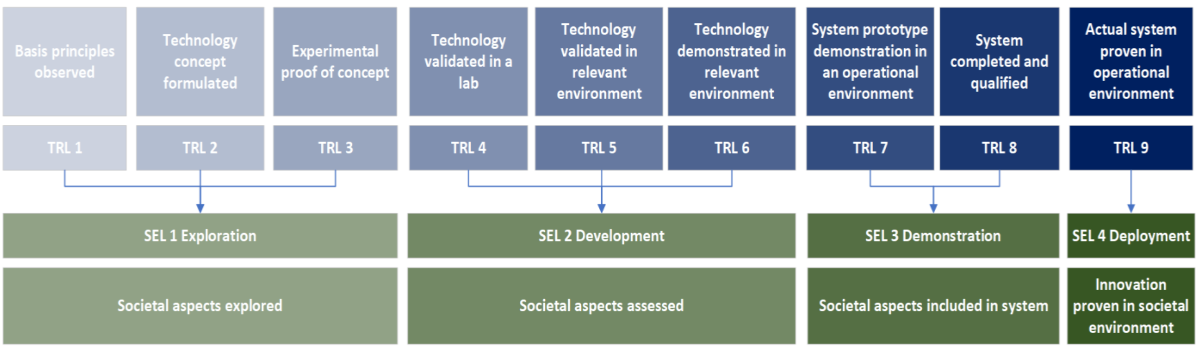

Figure 2 Connection between TRL and SEL. [1]

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

In Norway the evaluation of the SEL was based on one particular project demonstrating the full value chain form capture to storage, while in the other three countries the assessment concerned generic CCS developments at national level, based on previously tested CCS technology chains or current CCS developments.

4 national case studies

The SEL assessment carried out in the four national case studies is summarized in Table 1.

Table 1 Overview of SEL assessment per country

		SEL 1 Exploration	SEL 2 Development	SEL 3 Demonstration	SEL 4 Ready for deployment
Norway	Enviroment				
	Stakeholders				
	Policy and Regulations				
	Market and Resources				
The Netherlands	Enviroment				
	Stakeholders				
	Policy and Regulations				
	Market and Resources				
Greece	Enviroment				
	Stakeholders				
	Policy and Regulations				
	Market and Resources				
Germany	Enviroment				
	Stakeholders				
	Policy and Regulations				
	Market and Resources				

Legend	All milestones reached	Some milestones reached	No milestones reached

In Norway, CCS is associated with the offshore hydrocarbon resources in the North Sea. The first CO_2 capture and geological storage project commenced in the 1990s, while new integrated CCS projects are under development at present. National SEL was evaluated as 3 in dimensions (1), (2) and (4), in alignment with TRL and as 4 in dimension (3), which is the upper SEL value corresponding to complete societal embeddedness. Further improvement should focus in improving SEL to reach its maximum value of 4 in the dimensions (1), (2) and (4).

In the Netherlands, as onshore projects faced public opposition in the past, and as a consequence the political decision to only support CCS developments offshore, new CCS developments have been moving offshore with new projects underway, supported by the hydrocarbons industry. National SEL was evaluated at 2 for dimensions (1), (2) and (4), in alignment with present TRL and at SEL 3 in dimension (3), as legal framework is already suitable for the forthcoming CCS demonstration. Further SEL improvement therefore should focus on also advancing dimensions (1), (2) and (4) to SEL 3, in order to prepare local society for the offshore demonstration projects underway.

In Greece, CCS development has been driven by the power industry during the 2000s. In the 2010s the strategic decision to abolish the lignite fired power plants was taken and the interest to CCS declined, leaving technology development to low TRL with no CCS pilot or demonstration facilities in the country. Renewed interest in CCS has become evident in the 2020s, this time by the hydrocarbons industry, but no further development has taken place until now. The SEL assessment indicated that in dimensions (2), (3) and (4), the milestones towards SEL 1 have been only partially fulfilled. Only the environmental dimension (1) has all milestones reached towards SEL 1. Further development should aim at reaching SEL 2 in all dimensions.

In Germany, CCS research commenced during the 2000s. One scientific pilot project operated for several years. However, follow-up projects of the power industry that aimed to apply CCS technology to lignite power plants faced strong public opposition. In consequence of these protests and the looming coal phase-out interest in CCS diminished. In 2012 a law was introduced that limited and later on banned new CCS projects. More recently political discussions on CCS have revitalised around residual emissions from industry sites but so far a regulatory barrier remains and political support is uncertain. The SEL assessment indicated level 2 for dimension (1) and level 1 for dimension (2). Not all milestones for a SEL 1 in the dimensions (3) and (4) could be reached. This result is in disagreement with the CCS technological progress in the country. Further SEL improvement efforts should focus primarily on removing legal barriers as securing financial support for demonstration, as well as social acceptance and stakeholder support are linked to the uncertain regulatory status of CCS.

Overarching insights

Each country has a different societal embeddedness level of CCS, with Norway being at SEL 3 with considerable progress towards level 4, followed by the Netherlands with SEL 2 with several initiatives towards offshore demonstration projects and then by Greece and Germany with SEL 1.

In Norway there have been several CCS offshore pilot projects in operation and further under development, in Germany one onshore project operated for several years in the past, in the Netherlands previous initiatives for onshore CO2 storage failed, while there are no CCS projects in operation in Greece. The Netherlands shifted CCS scope from onshore to offshore, while Greece and Germany have considered only onshore CCS projects. In Norway and the Netherlands the main CCS driver has been the hydrocarbons industry, while in Greece and Germany the coal power generation industry has been behind CCS developments. As policies in Greece and Germany have shifted towards abolishing coal based power generation, it is not yet clear, what a business case for CCS would look like and which other technologies (e.g. blue hydrogen, hydrocarbons industry, residual emissions from industry) could be main drivers.

The national SEL assessments for CCS show that monitoring currently is a regulatory requirement as part of permitting procedures. Furthermore, the national assessments give an indication that monitoring alleviates community concerns on safety, although no in-depth scientific studies have been carried out in this direction. In order to effectively contribute to trust-building among stakeholders concerned (governmental representatives, concerned public but also industry actors and NGOs) and outreach activities, a CCS monitoring system should be low cost, efficient and easy to maintain over a long time, measure and predict leakages and plume movement, transparent allowing real-time access to monitoring data, provide reliable access to experts for questions on the data continuously, externally supervised by impartial institutions and connected to a safety concept that states what happens when the data divert from normality.

Applicability SEL assessment framework

During the SEL assessment carried out in the four countries, each team evaluated the applicability of the SEL methodology in their own country and kept track of methodological difficulties that came across during the assessment. Recommendations towards further improving the assessment were proposed.

Value of the outcomes

The insights from the four national case studies and the overarching analysis will be further used in the DigiMon project to develop the innovative societally embedded DigiMon monitoring system. Firstly, we will discuss the outcomes of the national case studies, in which we studied the SEL for CCS, with all DigiMon partners, and jointly identify how the outcomes could serve to further improve the design and development of the DigiMon system. This will be done via an interdisciplinary (online) event in which researchers, industries and governments with different backgrounds will participate. Secondly, the outcomes of the national assessments will be used for preparing and executing the planned local case studies (task 3.2 in the DigiMon project): in these case studies we will assess how the DigiMon system could contribute to better embed CCS development in their local societal environments. Thirdly, we plan an evaluation among the research team to capture their experiences with applying the SEL Guideline in order to learn from their feedback, to identify improvements for the SEL methodology and to jointly explore important adaptations for applying the SEL framework at the local level. These activities will all be part of the further research process of the DigiMon project, about which we will publish in the next coming year. Besides the research activities within DigiMon, the SEL methodology is also being applied in other policy domains in different research projects. Both the learnings in DigiMon regarding the SEL methodology, as well as in other collaborations will contribute to further improve the instrument aiming at better embedding technological innovations in their societal context.

1. Introduction

In this chapter we introduce the objectives and applied research methodology for the national assessments of the societal embeddedness of CCS in four countries. Furthermore we share some reflections on the limitations of the research we carried out and finally we provide the structure of this report.

Objectives

The main objective of this study is to analyse the societal embeddedness level (SEL) for CCS at the national level in four countries: Norway, the Netherlands, Germany and Greece. The identification of the societal embeddedness level of CCS in these countries will consist of an assessment of the SEL in each dimension of (1) impact on the natural and social environment, (2) stakeholders' involvement, (3) legal and regulatory framework and (4) market and financial resources, by:

- Literature review
- Interviews with CCS experts

Other objectives of the national assessments are:

- identify the main challenges towards further improvement of the SEL for CCS in each country,
- identify main focus areas for a societal embedded CCS monitoring system, the DigiMon system,
- provide feedback on the SEL methodology implemented,
- review CCS context and its future perspectives in each one of the 4 countries studied.

Methodology for SEL assessment in each country

The SEL assessment was conducted in 11 steps, as follows:

1. A SEL reference point is determined, which corresponds to the expected SEL, based on the current TRL, see Figure 3.

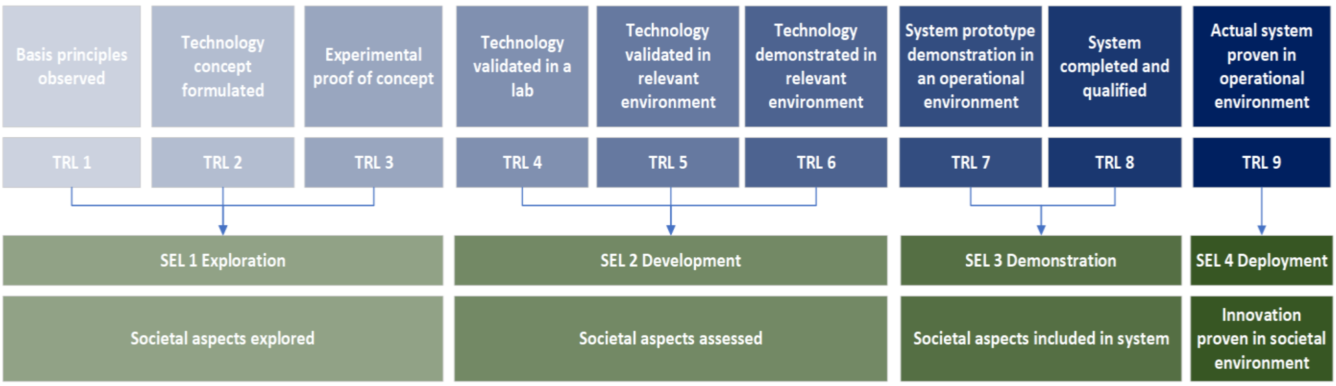

Figure 3 Connection between TRL and SEL[1].

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

2. Desk research is carried out gathering information about the topics as mentioned in the objectives section above. The following approach was adopted for the desk research:

- Google scholar was used as search engine
- Web sites of Ministries were searched
- Partner internal documents were used
- Reference lists of publications and snowball searching were used

Search words considered were "CO_2 Storage", "carbon (capture) storage + country", "CCS + country", also adding dimensions "policy and regulations", "Market and Resources", "Environmental" and/or "Stakeholder involvement". The search terms where adapted to the specific circumstances of each country.

A maximum of 20 articles were selected per country based on the following criteria listed in priority: reports, published/reviewed articles, white papers, recent publications. Conference abstracts were excluded from the study.

3. The national CCS context was drafted. It includes historical experiences with CC(U)S, latest developments at political level including discussion on onshore and/or offshore projects, financial and political support, regulations and legislative framework, general public opinion, what provisions have been considered for CCS monitoring, type and number of actual CC(U)S projects (capture, transport and/or storage) and description of CC(U)S applications. Local cases are mentioned as examples.

4. The SEL assessment was conducted based on literature reviews. Questions and milestones outlined in the SEL assessment framework, as described in DigiMon deliverable D3.1[1], were used to guide the desk research. If required, questions and milestones were adapted country-specific.

5. Additional questions concerning monitoring were asked for all SEL dimensions, in order to facilitate the next step of local SEL assessments. They included:

- Environment: In what way (how) is the impact on the environment monitored? And what are the requirements for environmental monitoring?
- Stakeholder involvement: How does (or: could) monitoring affect the stakeholder attitude towards CCS? How can monitoring contribute to reducing societal concerns? Is there any experience with participatory monitoring?
- Policy and regulations: What is the position of monitoring in the current regulatory framework?
- Market and financial resources: how does monitoring of CCS affect the financial circumstances and market position? (i.e., more expensive; more funding opportunities?)

6. Knowledge gaps were identified if it was not possible to answer questions based on the desk research. The additional information needed was specified.

7. An interview protocol was setup to gain the information needed to finish the SEL assessment. For this purpose milestones were turned into questions or questions behind milestones were used when additional information beyond the milestones was needed. Additional questions were asked concerning prospective developments of CCS in the country.

8. CCS experts were invited for interviews on specific topics regarding CCS, in order to collect additional information regarding the identified knowledge gaps. The combination of desk study and the interviews led to identification of the SEL for each dimension. Based on this the overall SEL was

derived as well as related societal challenges. The interdisciplinarity needed for the assessment was organised by selecting experts with different backgrounds and expertise on each of the four dimensions with different scientific or professional backgrounds.

9. Main challenges for further improving societal embeddedness of CCS in each country were analysed based on the SEL assessment results.

10.Based on the findings in the SEL framework and the context, a forecast of future developments (social and technology) was attempted, using the supporting policies/subsidies that are available in each country. This scenario was drafted on national level and then the most likely developments and implications at local level were added.

11. Finally, methodological challenges that came across during the SEL assessment were highlighted, together with dimensions or subjects that could not be addressed, including justification. The application of the SEL assessment at national level was evaluated. Improvements were suggested when needed.

Limitations

During the national SEL assessments we faced some limitations in setting up the research.

In Greece, the accuracy of the SEL assessment is bound by the limited availability of literature for the desk research, as only 15 relevant papers and reports were identified in total, all of which were used in the assessment. Furthermore, there was limited availability of CCS experts due to the little experience with CCS developments in the country. In Greece no projects have been implemented yet and there we no CCS activities during the last 10 years

Furthermore, during the assessment it appeared that some of the research questions for assessing the milestones in each of the SEL dimensions were open to multiple interpretations. This could have consequences for the comparability of the results in the four country studies. In chapter 6 we give an overview of the outcomes of the overarching analysis of the four country studies.

The starting point for a SEL assessment is an estimation of the current Technology Readiness Level (TRL) for CCS at national level. However, such an estimate is ambiguous, due to the broad CCS concept consisting of different technologies in each phase of the CCS chain (capture, transport and storage), the dependence of TRL on individual technologies considered and the international nature of technology research and development. A complex technological system such as CCS can include multiple components with different TRL and it is hard to assess an overall TRL.

Document structure

After this introduction, SEL summaries of the assessments performed in each one of Norway, the Netherlands, Greece and Germany are presented in chapters 2, 3, 4 and 5 respectively are written, followed by an overarching analysis comparing all 4 assessments in chapter 6, and findings on monitoring aspects in chapter 7, presenting national teams experiences during the assessment, methodological difficulties encountered and recommendations to overcome them in chapter 8, drafting main societal challenges to overcome during CCS implementation towards demonstration and development, conclusions in chapter 10, proposals for continuing research in chapter 11, while all four national assessments are listed in detail in the Annex.

2. National SEL assessment in Norway

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This is a summary of the SEL assessment for Norway, presenting the most important findings regarding the current situation of CCS in Norway. The complete report can be found in appendix.

Norway has built an encompassing competence for CCS over the last 25 years. One reason for the leading competence is the experience from planning of CO_2 handling projects in Norway. Closely connected to this is the big continental shelf with rich opportunities for CO_2 storage in geological formations in the sub seabed. Third, different governments have over time supported technology development, testing and piloting projects and stressed CCS as an important technological instrument in international climate negotiations. This has made Norway, together with the Netherlands and Great Britain, guiding in the development of CCS in Europe.

In 1991, Norwegian authorities introduced a charge on offshore CO_2 emissions which together with the specifications for dry gas on the continent contributed to the development of the first CO_2 handling project on a platform in the North Sea named Sleipner. Since 1996, gas has been captured and stored at the Sleipner platform and stored in the nearby Utsira formation. In 2008, and based on the experiences from Sleipner, Equinor introduced a new full-scale project at the Snøhvit (Snowhite) platform in the Barents Sea. The Sleipner and Snøhvit projects together reduce Norwegian CO_2 emissions by 3-4 percentage points per year and thus represent important scale experiences with capture and storage as well as developing important knowledge production for the CCS innovation system. Moreover, Yara, an ammonia plant, has for a long time captured CO_2 and transported it on ship and on trucks to the foodstuff industry for further processing. Today, Sleipner and Snøhvit are the only two storage sites for CO_2 operating in Europe.

Knowledge and experience from the oil and gas industry has been essential for the development of CCS in Norway. Connected to this, we have a big and well explored continental shelf with good opportunities to store CO_2. The Norwegian Petroleum Directorate has documented that the potential for storing CO_2 under the seabed on the Norwegian continental shelf is great, allowing for storage of big volumes of CO_2 from European countries. Moreover, EUs storage directive is implemented in the relevant Norwegian legal system so that the necessary legal framework is in place.

A key to understanding the development of CCS in Norway is the active role taken by the Norwegian authorities. Norwegian authorities has over decades been goal-oriented in going after all aspects of the CCS technology and has over time built solid specialist environments for the research and development chain at the same time as they have financed crucial research infrastructure into the innovation system for CCS. Due to the overtime political support, the research environment for CO_2 treatment in Norway is solid and covers all parts of the enterprise. The strong research environments have been developed across time through the R&D programme CLIMIT, financed by the Norwegian Research Council. The programme has funded several Centres for Environment-friendly Energy Research directed at CCS specifically, both at SINTEF and at the Christian Michelsen Research (now NORCE). Currently running is the Norwegian CCS Research Centre, hosted by SINTEF. The building and running of the Technology Centre Mongstad (TCM), a test centre for capture technologies, has also allowed for crucial knowledge building, together with the planning of full-scale capture projects at two locations (Kårstø and Mongstad) which have given valuable knowledge both for the industry as well as for government administration.

Given the great hydropower resources in Norway, the amount of CO_2 emissions in Norway suitable for CCS is limited. Thus, for Norway's commitment to CCS to result in large-scale emission reduction, it is necessary with international cooperation on CCS. The Longship demonstration project, announced by the government in October 2020, is one of the key projects that can create an infrastructure for CO_2 storage in Europe, and since January 2020 it has held the status as one of the European energy projects called 'Project of Common Interest'. These projects are identified as key cross border infrastructure projects that link the energy systems of EU countries and the storage part of the Longship value chain includes 16 partners from 7 countries. CO_2 sources from all over Europe can connect to the infrastructure for storage created in the project.

In the SEL assessment for Norway we focus on the Longship project. The overarching goal of the Longship project is to contribute to knowledge and efficiency improvement so that subsequent projects will have reduced costs. The innovation in the Longship project is (1) demonstration of a whole, yet flexible, chain with CO_2 capture from cement production, transport by ship and storage of CO_2 underneath the seabed off the Western coast of Norway. (2) European and Norwegian regulations are used in an entire chain with different actors. The project demonstrates use of the European emission allowance system as well as the EU storage directive. (3) A flexible transport and storage solution with the capacity to receive CO_2 from several sources. (4) a commercial framework with incentives for further development of CO_2 handling in Europe.

SEL assessment

Although we consider an entire technology system of Longship where all components of the value chain have reached high TRL levels separately, there is insecurity related to the interfaces from capture to transport and from transport to storage. Thus, we have identified the Longship project to have a TRL level equal to 7 – "system prototype demonstration in an operational environment". This places the Longship project at a reference point for SEL to equal 3 – Demonstration.

Dimension 1: Environment

This dimension deals with the impact of the realization of the Longship project on the natural, built and social environment, the end goal being that it is kept as low as reasonably achievable. According to the Regulations related to pollution control from 1971, all industrial projects must do an impact assessment of the impacts of the natural environment before they are considered for a license and can realize their projects. This is also the case for the Longship project, and the impacts of the system on the natural environment has been assessed through several impact assessments and documentation reports. Impact assessments on the built environment, which in the case of Longship includes the capture site and the onshore facility for discharging CO_2, have also been conducted. The social environment is not much affected as the system is mainly placed at sea or at industrial sites. Moreover, a number of mitigation efforts have been effectuated to meet the identified effects on the natural, built and social environment. For example, to minimize emissions, LNG fuel for the CO_2 transport ships is used and a quay to quay solution is chosen. Moreover, the pipeline trace is placed to minimize exposure to third party in case of leakage and monitoring systems are in place to allow for control with the injected CO_2. The current regulations and the assessments and mitigations for the Longship project on the environment identifies SEL 3 for this dimension to be completed.

Dimension 2: Stakeholder involvement

This dimension focuses on the inclusion and support of stakeholders in technology development. Their perceptions and participation in the process are explored to assess the extent to which stakeholders' beliefs and concerns are integrated in an adequate way through the development process. For this dimension, the Longship case is placed as SEL level 3. Impact assessments both for the site for CO_2 capture and CO_2 storage and white papers all identify stakeholders who would be impacted by the technology and its system. Stakeholders who are relevant for the demonstration are identified both through feasibility studies and through numerous assessments both of the transport and storage part of the project as well as of the entire Longship project. Identified stakeholders are included through popular meetings, consultations and open hearings and are able to give their feedback in time to actually inflict on the final project. As such, it seems necessary trust building actions are taken in the process of developing the Longship project. In terms of translation of stakeholder concerns and perspectives we see that the consultation process have resulted in changes, for example related to the planning of the pipeline which has changed route both onshore and offshore to take local authorities and other stakeholders' concerns into account. The general public is supportive of CCS and the environmental organizations are either positive or passive. Thus, stakeholders in Norway are pro-CCS in terms of its role and impact.

Dimension 3: Policy and regulations

This dimension asks for the policies and regulations that limit or support a technology. Policies, regulations and accompanying barriers need to be addressed and overcome. In the Norwegian case the Longship project reaches SEL 4 – ready for deployment. Necessary permit and certification requirements are assessed and awarded, including for the monitoring system. Furthermore, supporting policies, laws and regulations are in place for the demonstration project of an entire CCS value chain. National policies related to CO_2 tax and ambitious goals for climate change mitigation are clearly supportive of the further deployment of CCS. The support scheme for the Longship project shows the authorities' commitment to the further development of CCS technology. Regulatory barriers are assessed and overcome. The London Protocol has been the main regulatory barrier inhibiting storage of foreign CO_2 in Norway, but this was overcome in 2019.

Dimension 4: Market and financial resources

This dimension covers the financial resources for the technology and whether there is a market for the technology. In the case of Longship, this dimension has SEL level 3. The assessment of the project finds that the financial resources for demonstration of the whole system is sufficient. A big majority of the funds going into the full-scale demonstration is public (approx. 80%), although costs for monitoring is not included in this agreement this far. When it comes to market strategy the white paper on the Longship project writes that the overarching goal of the is to contribute to knowledge and efficiency improvement so that subsequent projects will have reduced costs. This relates to the market failure of CCS technology to explain the motivation by the state to fund CO_2 handling. Thus, the market strategy is to move the international CCS development further towards a future market where commercial actors want to invest through overcoming the current situation of high investments and operational costs combined with low potential for income and technical risks. The long-term plan for the authorities is that the costs are sufficiently reduced to ensure CO_2 handling projects become commercial and receive sufficient incentives through general schemes such as CO_2 price and higher prices for climate friendly products. When it comes to business case, private financers are identified and are also involved on the financial side in the Longship project (with approx. 20% of the funding) but the market failure mentioned above limit their involvement at the demonstration stage. Although there are no great market needs at this point in time, the Longship project aims to lead to so much technological development and learning that the next capture and storage sites will have considerably lower costs connected to it. Overall, a key motivation for the Longship project is that it should develop a cost-efficient solution to handle CO_2 and a technology that multiple actors can make use of.

Overall SEL level

The evaluation overview is presented in Table 2. Table 2 identifies the overall SEL level found for the Norwegian case based on an assessment of the full-scale demonstration project called the Longship project to be 3 – Demonstration.

Table 2 Overall SEL Evaluation for the Norwegian CCS development

	SEL 1 Exploration	SEL 2 Development	SEL 3 Demonstration	SEL 4 Ready for deployment
Dimension 1: Environment	All milestones reached	All milestones reached	All milestones reached	Some milestones reached
Dimension 2: Stakeholder Involvement	All milestones reached	All milestones reached	All milestones reached	Some milestones reached
Dimension 3: Policy and Regulations	All milestones reached	All milestones reached	All milestones reached	All milestones reached
Dimension 4: Market and Financial Resources	All milestones reached	All milestones reached	All milestones reached	Some milestones reached

Main challenges for improving SEL in Norway

Overall, the SEL evaluation for the Longship project assesses that the project has arrived at an advanced level in terms of social embeddedness. Common for the three dimensions that fail to complete the maximum SEL level 4, is that some of the milestones inn these dimensions cannot be answered until the demonstration is operational. Thus, the incorporated procedural aspect of the SEL framework thus hinders the identification of a more advanced level here although much work is done in all these dimensions to reach SEL 4. With this background, I discuss what I conceive of as the main challenges for the future improvement of SEL in Norway.

Technology interfaces and the risk of environmental harm. In terms of the impact of CCS on the environment, most aspects have been assessed through impact assessments and mitigation measures have been introduced where this has been considered necessary. Although the maturity has been demonstrated and confirmed for all three components of the value chain, capture, transport and storage, before, the risk of damaging the environment in the interface between the three components has not been examined as an entire chain has not been put together this way before. Thus, it is first after the Longship demonstration is realized in 2023 that mitigation efforts can be discussed and assessed for the entire value chain. It is first at this stage one will know the actual costs of the project on the environment and know what is needed to reach SEL level 4.

A possible change to political and public acceptance. The Longship project, as all CCS projects in Norway, is likely to be less controversial due to the fact that the CO_2 is stored under the seabed off the Norwegian coast. The overwhelming support for CCS mentioned earlier seems to support this hypothesis. Also, the political landscape has the last two decades been marked by a more or less unanimous support for CCS technology as a vital part of the solution to reach the Paris agreement, the only exception being the Progress Party which recently withdrew their support for the Longship project due to the expenses on the tax payers. The industry actors are also highly positive of CCS.

Still, there is insecurity among the Norwegian population regarding the risk of CO_2 leakage, and although the full-scale Longship demonstration has passed without much protest, the realization of the full-scale project and the planned expansion of the number of storage sites in the North Sea and the import of CO_2 from other countries to store outside of Norway may cause popular opposition. At the same time, the increased public awareness of climate change and the emission reductions ratified in the Paris agreement have created more legitimacy to support the development of CCS with public money. Yet, a question that seems to be raised in the public debate now, partly initiated by the Progress Party withdrawing their support, is how much money it is reasonable that the Norwegian state uses on CCS. This aspect was also raised by the Director of CLIMIT and introduced as a potential challenge for further deployment of CCS.

Limited market and the need for more capture sites. The SEL assessment for Norway identifies that the lack of an existing market is a main challenge for further CCS development. Yet, one of the main motivations for the full-scale Longship project is to move CCS technology closer to being a technology that is mature for the market. In relation to this, Equinor has stated that they are working on the establishment of a Northern European market for CCS storage in the North Sea. Moreover, a main goal of the transport and storage part of Longship is to move closer to realizing a European network for CO_2 transport and storage (Northern lights, 2020).

Another historical challenge identified is that the diversity of demonstration and commercial projects has been rather small and connected to the oil and gas industry for very long, despite a growing number of entrepreneurs. The literature review identifies the lack of large-scale CCS projects in relation to the power-intensive industry and EOR as something that may hinder CCS value chains from moving further forward and for a market of different CCS technologies to develop. The fact that no new full-scale CCS projects was initiated between Statoil's Snøhvit project started in 2007 and the Longship project was launched in 2020 is telling in this respect. That said, the Longship project is a step away from the oil and gas sector, focusing on the cement industry and thus offering an important step forward. Yet, more capture sites are needed to develop a fully flexible system that can help a mature market for capturing and storing CO_2 to develop.

Scenarios

A likely future development is that Norway is successful in the realization of the Longship project and that this, together with developments in f.ex. the UK will accelerate the maturing of CCS technology at quite a high speed. I think it is reasonable to assume that by 2030 foreign CO_2 is being stored on the Norwegian continental shelf. This is a clear policy goal for the Norwegian government and the EU alike and there is the development of capture projects in countries bordering on the North Sea planning to use the Norwegian storage infrastructure. The publication of the government climate strategy coming out in January 2021, indicating radical increases in the CO_2 tax of EUR 200/t CO_2 will, if it is realized, take the current CCS technology a big step further towards being ready for a market.

Despite these developments, I think it is likely that as the Longship project is realized and a discussion of a market for storing CO_2 from other European countries under the North Sea develops, increased public opposition may occur. We are seeing signs of this in recent surveys and the fact that the Progress party withdraw its support for the Longship project may indicate that we are entering a period with more salient political debate surrounding CCS. In this debate it will be interesting to see how the Environmental organization will place themselves, in particular those who have been silent or passive up until this stage.

3. National SEL assessment in the Netherlands

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Context of CCS in the Netherlands

Although global rollout of CCS was envisioned in 2025, most demonstration projects that were planned in the Netherlands were delayed or cancelled, like Barendrecht, Northern Netherlands and the ROAD initiative in the Port of Rotterdam. Many reasons for delayed or cancelled developments exist, such as technological failures, rising costs, regulatory uncertainty and a lack of public acceptance.

The Barendrecht case received the most attention and became an example for lessons on stakeholder involvement in CCS and community engagement. As one of the demonstration projects of the Dutch Government, Barendrecht was a CCS project in a depleted gas field. After the rejection of the plans for CO2 storage by the local community in Barendrecht, one of the conclusions was that local politicians and local initiatives were able to organize local resistance well-timed and to influence decision making at higher governmental levels. Hereby, their movement to scale-up their procedural critique to the national level was successful. Furthermore, 'justice as recognition' played an important role in the resistance towards the project. According to local community, the increased focus on the technical approach diminished their say the project. They were looking for a an independent way to make a decision on the issues around the establishment and implementation of the project.

To them, it was much more important that they had a real say in the establishment and implementation of the project, in the sense that they wanted be able to independently decide upon the issues that were important in the context of the project in 'their' local environment and every-day life.

A lack of public support may therefore reduce deployment speed and affordability and exclude some technological configurations, such as onshore storage in the Netherlands, from the realm of possibilities for CCS. In the process of reducing CO_2 emissions, the climate agreement for the industry agreed to store CO_2 off-shore in empty gas fields in the North Sea. The initial disillusionment for CCS has been replaced with rising expectations and ambitions. In the Netherlands, for example, the government has expressed the ambition to reduce substantial amounts of CO_2 from industry in 2030 using CCS. This ambition will be supported with policy instruments that are currently in development, such as a CO_2 tax and a subsidy scheme (SDE++).

Since the national Dutch climate agreement implies that CO_2 can only be stored off-shore, the projects that are being prepared are situated close to the coast line in the Port of Rotterdam area and the IJmond area (Province of North Holland). Porthos is an initiative of the Ports of Rotterdam and Antwerp in combination with Dutch natural gas infrastructure and transportation company (GasUnie) and a natural gas exploration, production, transportation and sale company owned by the Dutch Government (EBN). Athos is initiated by GasUnie, EBN, the large steel factory Tata Steel IJmuiden and The Amsterdam Harbour. This project is in an earlier phase, where the feasibility analysis has been successfully completed, but several follow up studies are necessary to set up the infrastructure plan.

Forecast of future developments of CCS in the Netherlands

In the Netherlands, the conditions for CCS to play a more prominent role in reaching the CO_2 reduction targets for 2030 and 2050, seem to be on the rise. Institutions like the Dutch environmental assessment agency (Dutch: Planbureau voor de leefomgeving – PBL) predict an essential role for CCS in reaching a reduction of 95% in the 2050. The most likely application of CCS is CO_2 capture at industrial installations, transport via pipeline and offshore storage. In addition, the Dutch Climate agreement foresees a more prominent role for Carbon Capture and Usage in the near future. This climate agreement describes the infrastructure of CCS as one an uncertainty and one of the conditions that have to meet for CCS to play a role. The meet the right conditions for CCS to contribute to the reduction targets, two polices are likely to support CCS technologies, namely the SDE++ subsidy and the European Trading System. The link between the SDE++ subsidy and ETS will be further explained in the SEL Market and financial resources section.

A reason to believe that CCS is likely to play an increasing role in the energy transition in the Netherlands is that while most CCS applications in the past were developed for power generation, such as coal- and gas-fired power plants, recent developments are more strongly focused on CCS at industry. Another application is connection between CCS developments in combination with the hydrogen industry in the Ijmond area. Many industries have few alternatives to CCS for deep CO_2 emission reductions. For these industries, CCS can be a cost-effective solution for short term emission reductions. In the future, additional applications for CCS are foreseen. Primarily the use of biomass in combinations with CCS (BECCS) to remove CO_2 from the atmosphere - creating negative emissions. Such applications of CCS are needed because some sources of CO_2 will remain, especially in agriculture.

SEL assessment

Although the DigiMon project focusses on CO_2 geological storage, it became clear that CCS projects cannot be developed without taking the full CCS chain into account. As a consequence, for applying the SEL assessment framework on CCS developments in the Netherlands at a national level, we thus looked at the whole CCS chain of CO_2 capture, transport and storage. The SEL reference point for CCS in the Netherlands is set on SEL 2 as there is no demonstration site in the Netherlands yet.

Table 3 Outcome of the national SEL assessment for the Netherlands.

	SEL 1 Exploration	**SEL 2 Development**	**SEL 3 Demonstration**	**SEL 4 Ready for deployment**
Dimension 1: Environment	All milestones reached	Almost all milestones reached	Not all milestones reached	No milestones reached
Dimension 2: Stakeholder involvement	All milestones reached	All milestones reached	Some milestones reached	No milestones reached
Dimension 3: Policy and Regulations	All milestones reached	All milestones reached	All milestones reached	No milestones reached
Dimension 4: Market and Financial Resources	All milestones reached	All milestones reached	Not all milestones reached	No milestones reached

For the assessment of SEL in the Netherlands we used the agreed upon desk research protocol with additional search terms, snow ball sampling and expert interviews to answer the questions of the SEL framework. Most of the SEL assessment is done through desk research. Additionally, we consulted several CCS experts with different backgrounds to account for interdisciplinarity and fill the knowledge gaps. The experts were asked to give input on specific milestones and research questions[1] for a detailed description of the approach for the SEL assessment). Three experts provided written input and four have been interviewed. In the interviews we brought up one or more milestones.

Environment

The knowledge about the impact on the natural and built environment is advanced and would be in SEL 3 at this moment. However, we are not sure about the extent to which the impact of the technology on the social environment is taken into account. Most experiences reflect the perspective how local community dynamics could possibly impact the progress of the project development at local level, instead of the other way around. For this reason the SEL of dimension 1: environment in the Netherlands is set at two but made orange.

Regulatory frameworks for CCS initiatives require technological, geological and environmental feasibility studies as part of the exploration phase of a CCS project in the Netherlands. These feasibility studies explore whether the project is technologically feasible, identifies the natural and built environment and explores whether the project is feasible in that specific environment. Multiple follow-up studies, like a so called ‘Memo on the scope and level of detail of the Environmental impact assessment’ and the environmental impact assessment itself are necessary as part of the permit procedures before the project can actually be demonstrated or deployed at its specific location. In the decision-making process of the project, the results of the environmental impact assessment have to be taken into account. In this way the dimension environment plays a full role in the decision making process.

Stakeholder involvement

The dimension stakeholder involvement is currently in SEL 2, but could be in SEL 3 as well, as the assessment did not give a clear few on how stakeholder involvement is arranged in current CCS projects in the Netherlands.

With exploring the social environment of the technology in an early stage of development (as referred to in dimension ‘environment’), an effort is taken to realize (early) stakeholder involvement. Although guidelines for stakeholder involvement are taken into account in Dutch regulations for spatial projects, current CCS projects appear to make more effort for early stakeholder involvement.

At this moment the Dutch public is neutral to slightly positive about CCS after they are informed. This improved since the situation during the former CCS projects in the Netherlands, like the Barendrecht CCS project, which got cancelled due to opposition from local communities. However, there are still concerns.

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

Policy and regulations

The political support, regulatory framework and current subsidies are sufficient to further develop CCS in the Netherlands and start a demonstration, and therefore this dimension in in SEL 3. Former CCS projects were – on a regulatory level – ready for demonstration as well. There are, however, still some issues that need to be dealt with before CCS can be successfully deployed in the Netherlands. Some issues of the implementation of the CCS directive need further clarification. These issues consist of lack of clear standards and criteria about safety (site selection and monitoring) and liability, regulation with regard to third party access to infrastructure of CO_2 transport and storage and trans-boundary cooperation with regard to the infrastructure of transport and storage. In addition, an important barrier is the comprehensive financial security which is needed to comply with the permit requirements and to take the responsibility of the storage of CO_2.

Market and financial resources

For the dimension 'Market and Financial Resources', SEL 2 has been reached. Financial resources could be sufficient for development of the technology and it's system towards the first demonstration of CCS in the Netherlands. However, due to a lack of incentives (for example a higher ETS) and substantial financial risks, up to now the industry has been reluctant to come forward to start a first demonstration site. The financial risks are mainly caused by the risk of leaking CO_2 in the atmosphere. If the future ETS price is high, a high price should be paid back per leaked ton of CO_2, this is a risk the government does not guarantee yet, and the industry is not willing to wear yet. In december 2020 the costprice of CO_2 per Mton CO_2 was €100, the ETS was €25. The gap of €75 per Mton CO_2 will be bridged through the SDE++ subsidy from mid 2021, for a period of 15 years.

Overall SEL

The overall SEL of CCS in the Netherlands is equal to the lowest level reached in one of the four dimensions. The overall SEL of CCS in the Netherlands is 2. This is equal to the SEL reference point. This means that there are no societal challenges to overcome. However, as there are CCS projects heading towards the demonstration phase in the Netherlands, we decided to identify the societal challenges that lay ahead to reach SEL 3. These societal challenges are described in chapter 6.

CCS and monitoring in the Netherlands

There are several methods to monitor the storage of CO_2, ranging from relatively affordable to very expensive. European legislation on the monitoring of CCS is based on CO_2 storage in aquifers, and is therefore not tailored for the Dutch situation, in which CO_2 will be stored in depleted gas fields (offshore). In the Dutch Mining Law, articles about monitoring are included. These state that a monitoring plan should be included in the permit application and the permit itself, and that results of the monitoring program and the used technology should be shared yearly. No limits have been set for both the monitoring period and the leakage risk (to be calculated as the leaked volume times the price at that time of CO_2 emission rights). The way the monitoring should be organized is assessed per project, the law does not provide in exact specifications of what the monitoring plan should consist of. Currently, in the Netherlands there are no extra funding opportunities associated with more extensive monitoring. Therefore, monitoring always adds on to the costs of CCS. However, the extensiveness of the monitoring will depend on the risk profile of the CCS site.

Societal challenges for CCS developments in the Netherlands

The societal challenges are identified by comparing the overall SEL to the SEL reference point. Based on the SEL assessment we conclude that the current SEL of CCS in the Netherlands is equal to the SEL reference point (SEL 2). However, for the dimension 'environment' the SEL assessment did not result in a clear view on how CCS developers/initiators are mapping the impact of a CCS project on the social environment.

As some current CCS projects in the Netherlands are working towards a demonstration, we identified the societal challenges towards reaching SEL 3 on all dimensions. For the dimension 'policy and regulations' SEL 3 is already reached. For this dimension we described the societal challenges that should be overcome towards the fourth stage; deployment of CCS in the Netherlands. The different dimensions influence each other's' challenges. Therefore, the descriptions of the separate dimensions below overlap in some occasions.

Environment

In the dimension 'environment', the social environment has been underexposed. Although the societal context has been explored and is given attention to in the light of stakeholder involvement, the impact of the technology on the social environment is unknown.

Stakeholder involvement

Although there has been a significant progress in the dimension stakeholder involvement since the failure of former CCS projects, there is room for progress in development of actions for information providing, trust building and securing the cooperation of stakeholders and the public. Also attention has to be payed to the momentum of participation and the best fitting participation levels in the demonstration phase. Although it would be unrealistic to strive for a positive attitude towards CCS from all stakeholders, there is room for improvement in raising awareness about the role of CCS in the climate agreement and how CCS compares to renewable energy sources.

At this moment, stakeholder participation mostly consists of informing. By shifting the focus of participation towards having a conversation about the application of CCS in a broad regional development an added value is sought for all parties.

Policy and regulations

Although the dimension policy and regulation is the most advanced, there are still some hurdles to overcome until it is ready for deployment. First, the current regulatory framework does not provide enough (financial) incentives yet. There are also some issues relating to the implementation of the CCS directive. These issues consist of a lack of clear standards and criteria about safety (site selection and monitoring) and liability, regulation with regard to third party access to infrastructure of CO_2 transport and storage and trans-boundary cooperation with regard to the infrastructure of transport and storage. Finally, unclear regulations about transfer of liability is a barrier for market parties to become storage operator.

Market and financial resources

Financial incentives for market parties have been insufficient until recent developments. Due to the lacking regulations about transfer of liability, the (long term) financial risks regarding to CO_2 leakage and long term monitoring are high. Finally, the coordination barrier is a financial challenge for pioneering CCS initiatives. Initiators now have to pre-invest in the CO_2 transport and storage infrastructure.

Reflection on applicability of the SEL methodology

We came across several methodological challenges, which concern: The level of scale between a national and local level; the formulation of the questions of the SEL framework, which causes that some questions are open to interpretation; the scope of the desk study protocol; the applicability of the SEL reference point for the assessment of the whole CCS chain; the transition between SEL levels and the fit of milestones and questions for the assessment of the SEL of CCS in the Netherlands.

Finally, we found some of the questions hard to answer for a 'national' situation. We solved this through consider it an assessment for CCS in the 'Enterprise Netherlands', and applying subtleties is the explanations.

Conclusion

The overall SEL of CCS in the Netherlands is 2. This is equal to the SEL reference point which was used for the scope of this assessment, which means that there are no societal challenges left to 'catch-up' with the SEL reference point. However, as currently two CCS projects in the Netherlands are heading to demonstration, the societal challenges towards SEL 3 are described in this report. The main societal challenges consist of gaining insight in the impact of CCS on the societal environment, shifting the focus of participation towards having a conversation about the application of CCS and making CCS financially more attractive for initiators. We found that the dimension 'Policy and Regulations' is already in an advanced stage, comparing to the other dimensions. Also, we found that the dimension 'Stakeholder Participation' made a significant process in comparison with the former Dutch CCS projects. We think that this advancements can be assigned to the fact that, although there have been no full chain CCS demonstrations before, there have been some former projects in which experience has been gained.

4. National SEL assessment in Greece

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CCS context

One of the largest sources of CO_2 in Greece are lignite fired power plants which generate 56% of the electricity of the country and emit approximately 20 Mt/yr CO_2, accounting for approximately 30% of total CO_2 emissions in Greece. CO_2 emissions in Greece peaked in 2007, and since then there has been a steady reduction, down to ~60 Mt/yr in2018. This can be attributed to the on-going economic crisis in the country, and to the implementation of the national policy towards the reduction of CO_2 emissions of the electricity sector.

CCS has been initially investigated by the Public Power Corporation of Greece (PPC) during the decade 2000-2009 spurred by the forthcoming (at that time) CO_2 taxation policy. As the bulk of lignite power plants are located in the Northwest part of the country, CO_2 storage sites initially proposed were the sedimentary basins of Mesohellenic Trough, Ptolemais, Alexandria, West Thessaloniki and Prinos.

During the next decade 2010-2019, the National policy changed from keeping the lignite fired power plants to phasing them out by 2030, and the main driver of CCS changed from the power generation industry to the hydrocarbons industry, also spurred by the offshore hydrocarbons exploitation plans. Recently, as the TAP gas transmission pipeline to European market through Greece was completed, the hydrogen use came in the foreground again, and aquifer thermal energy storage gained acceptance, new sites and storage uses of the underground emerged, in addition to CO_2 storage. They include geological hydrogen storage, geological natural gas storage, aquifer thermal energy storage (ATES) and geological CO_2 storage.

The public in Greece has been in general unaware of the CCS opportunity, as there have been no systematic dissemination activities by the stakeholders concerned. CCS was made legally possible, when relevant legislation was introduced on 7 November 2011, comprising the Joint Ministerial Decision 48416/2037/E.103/2011 (GG B 2516) corresponding to the implementation in National level of the EU Directive 2009/31/EC on the geological storage of CO_2.

No pilot CCS projects have taken place in Greece until now.

Methodology

The SEL assessment in Greece was carried out according to the methodology described in DigiMon Deliverable D3.1.

Firstly, a desk review was performed in order to define the achievement level of the milestones, by providing justified answers to as many questions next to milestones as possible. For this purpose, 15 publications were identified related to CCS SEL aspects, all of which were considered in the assessment. It was quickly realized that there were very few publications and articles available on CCS in Greece and that the SEL starting point was SEL=1, as neither CCS projects nor CCS related activities, other than an incomplete inclusion of EC directive on CCS in Greek legislation, could be identified. The corresponding **CCS TRL is at level 2** (technology concept formulated), as no laboratory experiments or pilot projects have taken place until now. Knowledge gaps were filled by distributing dedicated questionnaires to CCS experts depending on their background and collecting their replies.

As no projects of any kind (pilot, demo or permanent CO_2 storage facilities) have been or are planned in the near future in Greece, all replies in questions at SEL levels 3 and 4 are negative in all dimensions. A collective NO reply with a collective justification was provided, also for level 2 of the market & resources dimension.

CCS monitoring is compulsory according to present legislation and a monitoring strategy has been proposed for a particular possible future demonstration facility. There is a general belief that monitoring alleviates concerns on safety.

Assessment

CCS activities are limited to identification of CO_2 storage sites, evaluation of environmental impact, rough estimates of costs involved, an incomplete legal framework, no financing available, limited involvement of positive stakeholders only, and the absence of any lab experiments, pilot plants or permanent CO_2 storage facility. Public awareness is very low, while monitoring is foreseen by the legal framework and is perceived positively to alleviate safety concerns. As **TRL of CCS** in Greece is at **level 2**, the SEL entry point for the assessment is 1 in all four SEL dimensions. In each SEL dimension the achievement of relevant milestones was evaluated based on the results of the desk research and the experts' interviews/replies. The results are summarised in Table 4.

Table 4 CCS assessment briefing in Greece

	SEL 1 exploration	**SEL 2 development**	**SEL 3 demonstration**	**SEL 4 deployment**
Dimension 1: Physical & Social Environment	All Milestones reached	Some Milestones reached	No Milestones reached	No Milestones reached
Dimension 2: Stake-holders Involvement	Some Milestones reached	Some Milestones reached	No Milestones reached	No Milestones reached
Dimension 3: Policy & Regulations	Some Milestones reached	No Milestones reached	No Milestones reached	No Milestones reached
Dimension 4: Market & Financial Resources	Some Milestones reached	No Milestones reached	No Milestones reached	No Milestones reached

As shown in Table 4, all SEL milestones of level 1 have been fulfilled only in the environmental dimension. Regarding SEL 2, only some milestones have been reached in dimensions 1-Environment and 2-Stakeholders' Involvement, while no milestones have been achieved in the other two dimensions. SEL 3 and 4 milestones are completely out of reach. **Overall SEL is at level 1.**

SEL dimension 1 – Environment (physical and social)

In Greece, potential CO_2 storage basins have been identified and the state of the art of geological settings and geographical areas above them is known. This also applies to atmospheric conditions, surface lakes, rivers and streams, subsurface aquifers, sea environment for offshore areas, flora and fauna including nearby Natura protected zones. State of the art of cities, towns and villages, spaces and overlaying infrastructure is also known, as well as of population social aspects, cultural milieus and institutions. In general, public awareness is low, as only ~25% of population are aware of CCS, but only ~5% informed, while although CCS perception is slightly positive (>50%) among the Greek population, the not-in-my-backyard attitude prevails (>50%), with safety being the main concern of people (~85%).

Simulation of impacts of potential CO_2 storage leaks have been made for Prinos Basin, while the impact to local geological environment has been studied for the Mesohellenic Trough. Studies carried out indicated that concentration of other pollutants (NOx, NH3) is expected to rise in CO_2 capture plants, while CO_2 rise in the air to suffocating levels may occur in case of explosive leaks. In addition, simulation of potential impacts of CO_2 storage leaks to above laying seawater, to groundwater and nearby Natura protected areas have been made for the Prinos Basin, CO_2 storage site. The impacts of CCS technology to be applied on land, air and water were assessed, but its impact on life remains uncertain. Social impact studies of CCS concept, as well as induced seismicity evaluation concerning CCS concept, system and technology to be applied have been carried out by the power industry.

Concerning monitoring, there is a general belief that it alleviates concerns on safety.

No milestones corresponding to SEL levels 3 and 4 are fulfilled, as neither assessments nor mitigation actions other than definition of monitoring strategy have been considered for a particular demonstration facility. Moreover, no mitigation measures have been taken for a particular permanent CO_2 geological storage site.

SEL dimension 2 – Stakeholder involvement

Key Stakeholders that could be impacted by the CCS concept, technology and/or system and its implementation in Greece are Local Authorities, Local Population, the Public Power Corporation (PPC) and the Ministry of Energy (YPEN), while the ones that could have impact on CCS concept and technology are the Ministry of Energy (YPEN), as well as the Hellenic Survey of Geology and Mineral Exploration (HSGME), Hellenic Hydrocarbon Resources Management S.A. (HHRM), the Institute of energy of Southeast Europe (IENE), the Centre for Research and Technology Hellas (CERTH) and the Centre for Renewable Energy Sources and Saving (CRES). Although the main knowledge, opinions, questions, concerns and perspectives that the above stakeholders have had so far concerning novel innovations in CCS or similar sectors are known, the potential influence of social media has not been evaluated.

Stakeholders relevant to the CCS development are Local Authorities, Local Population, Civil Society, Grassroot Organisations, PPC, YPEN, CRES, CERTH, HSGME and HHRM, but their participation level and contribution has not been defined. Only stakeholders that may have positive impact on CCS have been involved, while ones who can have negative impact such as NGOs and Green Peace have not been invited. Dissemination efforts have been limited to a communication brochure produced by EAGME, forums organized to instigate a dialogue, a few interviews and articles published in newspapers, magazines and electronic media. Technology providers, private energy companies and other industrial players have expressed interest in CCS, but no widespread communication action has taken place.

Concerning trust, there are concerns among public population on CCS technology and system safety, its impact to health and possible leaks to surface.

Neither the stakeholders concerned, their participation, concerns and perceptions have been identified, nor any trust building actions other than definition of monitoring strategy have been considered for a particular demonstration facility. In addition, no stakeholder participation scheme has been designed or materialized and no stakeholder support has been secured for a particular permanent CO_2 geological storage site.

SEL dimension 3 – Policy and Regulations

The current political climate and context is described in the National Blueprint for Energy and Climate (ΕΣΕΚ). One of the policy priorities in the field of Research, Innovation and Competitiveness concerns the development of innovative technologies regarding capture, storage and use of CO_2.

Regulatory support for innovation is secured through the Patent or Copyright certification process. There are general provisions about Patents, but there is not a specific regulatory regime concerning relative innovations.

Presidential Degree 51/2007 (GG. A 54), transposition of EU Directive 2009/31/EC and Joint Ministerial Decision 48416/2037/E.103/2011 (GG B 2516) "Measures and conditions s for CO_2 storage in geological formations" have been published but not put to practice. However, the existing framework requires updating and further elaboration, as specific but important details have not been regulated yet. Following EU Dir. 2009/31/EC and the above legislation no projects were undertaken in order to explore relevant European, national, regional and local policies and regulations and the way they interact.

The relevant authorities for CCS are the General Secretariat of Energy and Mineral Resources for licensing and the Directorate General for the Environment for environmental licensing of the Ministry of Environment and Energy. However, it is not clear which Department or Directorate issues the licensing for exploration and storage. The Department of Geothermal Energy of the Ministry of Environment and Energy is responsible for expressing opinions on relevant matters, but not issuing licenses. Lastly, the environmental inspection activities are carried out by the Directorate General of Inspectors of the Ministry of Environment and Energy. As no CCS projects exist in Greece, there has been no need to activate any contacts between the Authorities concerned until now.

Apart from a few reports regarding the possible locations for storage, including a recent one by The Greek Hydrocarbon Management Company (HHRM), we have no knowledge of specific reports about the possible relevant existing policies and regulations concerning CCS technology.

There is a policy priority on CCS, as described in the National Blueprint for Energy and Climate, but the specific measures are not set yet. However, policy and regulatory barriers have not been assessed due to lack of specification and relevant experience. Important risk factors are the lack of baseline research and the slow judicial processes. As current policies are not sufficiently effective for further development of the technology, there is a need for further elaboration of regulatory framework.

Permit requirements for CCS technology have not been assessed due to lack of specification and relevant experience. General provisions of EU Certification rules apply only for CCS technology certificate requirements. Despite collaboration between licensing agencies and environmental licensing authorities is required by law, it has not been established yet. Furthermore, there is no professional lobbying among CCS interest groups or technology platforms. There are no certificates, nor permits, while policy & regulatory drivers are not assessed and no support has been secured for a particular demonstration facility. Furthermore, neither permits or certificates, nor supportive regulatory framework are in place for a particular permanent CO_2 geological storage site.

SEL dimension 4 – Market and Financial Resources

Although the budget needed for funding CCS concept development has been estimated for several CO_2 storage sites, the necessary funding has not been made available. Potential customers are power plants, refineries and heavy industries. CO_2 prices are determined in the CO_2 stock exchange. Substitutes include CO_2 trade, fuel switch, use of biomass and biogas, renewable electricity and heat. Potential suppliers and competitors are not available yet. Market needs and trends have not been assessed and no business case has been evaluated other than estimation of capital and operation costs. The necessary financial resources are not available, while market strategy, business case and system technology have not been adapted for demonstration. In addition, there is no solid business case, nor financial support for a CO_2 permanent geological storage facility.

Main challenges for further improving SEL

At a first stage, a CCS development strategy should aim for the completion of technology innovation and development activities, with the first stage objective to create and operate a pilot CCS facility, in order to acquire experience at country level and build the necessary trust for the technology. This can be done quite fast, by importing technology in the country from foreign players who already operate CCS demonstration facilities and reaching TRL=6 at national level, rather than developing own technology. This action should be accompanied by advancing in parallel the societal embeddedness level to 2, by reaching all corresponding SEL milestones of levels 1 and 2.

Concerning SEL dimension 1 on environment this implies that activities should focus on assessing the impact of CCS technology on the natural, built and social environment. Concerning SEL dimension 2 on stakeholders'-involvement activities should include involvement of social media, engaging and informing all stakeholders especially the ones who can have negative influence which may hamper CCS development, and assessing their interests, attitude, perceptions and concerns. Concerning SEL dimension 3 on policy-and-regulations, the focus should be to update, complete and streamline existing regulatory framework. It is imperative to establish collaboration between the different local, regional and national Authorities concerned. Policy drivers and barriers, as well as certification and permitting requirements should be assessed in terms of effectiveness and being supportive to CCS. Concerning SEL dimension 4 on market-and-resources, the focus should be on market analysis, needs and trends, on securing the necessary financial resources for technology development and on developing the first business case.

Scenario

In the near future, CCS is expected to be spurred by the abundant availability of natural gas in the country, either transported by the TAP pipeline, or produced offshore. The main challenge will be to achieve the necessary societal embeddedness level, which will facilitate CCS development and secure the CCS acceptance by the local communities concerned.

In parallel to developing and operating the first pilot CCS facility, SEL advancing activities should focus on achieving SEL=2 at first stage. If the pilot CCS project is successful, next step should be to build and operate a CCS demonstration plant, while further advancing SEL to level 3. SEL advancement to level 3 implies mitigation of the physical and social environmental impacts, engaging and trust building among all stakeholders' concerned and social media, incorporating society aspects in policy and regulatory framework, while securing sufficient financial resources and orienting technology, market strategy and business plan towards customer and other market actors' needs.

Reflection on SEL methodology

Despite the limited availability of local literature and expertise in the country, SEL dimensions and milestones seem appropriate for application at national level in Greece. They provide a good starting framework to provide guidance, in order to facilitate CCS implementation and address social issues which could hamper CCS development. Further evaluation will be possible, when CCS becomes a reality in the country and sufficient experience will be gained during its development.

5. National SEL assessment in Germany

Author: Danny Otto, UFZ

The following summary of the National SEL assessment presents the most important findings on the current situation of carbon capture and storage in Germany (please see appendix for the complete report). It aims to briefly describe the socio-historical context of carbon storage in Germany and to give an overview of the situation per SEL dimension and a summary of the main societal challenges.

Carbon capture and storage (CCS) entered the broader political and scientific discussion in Germany in the early 2000s. Studies assessed the geological storage capacities and Europe's first large scale onshore CO_2 storage project at Ketzin (70 km west of Berlin) was initialized. The project served exclusively for research purposes and was conducted by the German Research Centre for Geosciences (GFZ) in Potsdam. Between June 2008 and August 2013 a total amount of 67 kt of CO_2 was injected without any safety issues or public opposition. In the following years, larger industrial projects by major energy producers followed. These focused on the onshore storage of CO_2 captured at fossil fuel power plants and faced strong public opposition and funding problems. Eventually, this led to the discontinuation of the projects. Since then, initiatives for CCS in the fossil fuel power sector have not been renewed.

Following the first pilot projects and the public opposition towards CCS, various studies on public opinion on CCS have been conducted and mixed results on technology awareness and acceptance have been reported. The level of CCS awareness in Germany reaches from very low to moderate. Studies show a span of attitudes that include high rates of rejection of the technology or negative perceptions of it but also positive views of CCS.

From 2000 to 2012 the political focus for CCS implementation was on the continuation of fossil fuel usage for energy production. After the vehement public opposition to industrial CCS projects the situation changed. CCS lost prominence in the political discourse and was reframed in policy papers. The discussion of potential applications of CCS has moved to residual emissions from industrial processes and to negative emissions (bio-energy and CCS or direct-air-capture and CCS).

This political shift highly effects business cases and market potentials of CCS in Germany. Economic analyses for CCS have focused on the storage of CO_2 from fossil fuel power plants and based their assessments on this CCS chain. An increase in energy production costs and the problems and uncertainties regarding refinancing investments in CCS technology through the energy market are highlighted. Together with the political developments, public opposition and legal challenges (see below) these insecurities have been disincentives for investments. Overall the business case for CCS in Germany remains questionable and is connected to high uncertainties.

In 2012, a new law for the demonstration and utilization of technologies for the capture, transport and storage of CO_2 became effective. This new law not only included stricter rules for the processes of capturing and storing CO_2 as well as the subsequent monitoring of it, it also delegated the final permission decision of any kind of CO_2 storage to the federal states and limited the annual amount of sequestered CO_2 in individual projects to 1.3 million tons. Some federal states have since then issued moratoria for the geological storage of CO_2. Adding to this regional regulatory barrier for CCS, the new law set December 31, 2016 as a deadline for CO_2 storage project applications (no matter the CO_2 sources or technologies involved). **Since this deadline is expired the geological storage of CO_2 in Germany is faced with a severe regulatory lock-in.**

SEL assessment

Dimension 1: Environment

This SEL dimension addresses the question if the harm to the environment is kept as low as reasonably achievable by exploring, assessing and mitigating the impact of an innovation (in our case CCS) on the environment. The natural, built and social environment of the technological innovation are considered. Potential risks and negative environmental impacts have been assessed for the demonstration site at Ketzin (involving all steps from Oxyfuel capture, to truck transport and storage). These include increased emissions of nitrogen dioxide or other gases, risks of leakage during transport or underground CO_2 plume movement. The potential risks for the social, built or natural environment have been studied for the short-term. They, however, have not been mitigated and tested in other projects. Hence it is doubtful whether negative impacts are actually mitigated. This limits the SEL for this dimension to a completed level 2 “development” with major work already done for SEL level 3 “demonstration”. It is furthermore uncertain which long-term effects (especially regarding plume movement, saltwater intrusion or induced seismic activity) might emerge and how upscaling to the industrial operation would factor into assessments. An additional challenge is that the configuration of CCS at Ketzin does not represent the technological options that are politically discussed at the moment. As this discourse has moved from fossil fuel power plants as CO_2 sources to capturing emissions from industrial sources (e.g. steel, cement) or bio-energy plants (BECCS) it is unclear how the environmental assessments could be transferred to these applications of CCS.

Dimension 2: Stakeholder involvement

In this dimension, the focus is on the support of stakeholders. Stakeholder participation as well as stakeholder needs and opinions are explored so that they can be integrated in the further technological development. Germany can be placed in the development stage (SEL level 2) for this dimension. An inventory of relevant stakeholders in the field and the system has been established for previous projects and methods for public and stakeholder outreach have been tested. It became clear, however, that a successful communication and engagement strategy is site specific and cannot be transferred to another socio-technical setting without adjustments. The same is true for the organization of participation. So far decisions on the level of participation have not been taken and it appears that they can only be taken site specifically. In expert interviews it was made explicit that stakeholder support is uncertain after the initial failure of CCS projects in Germany. The existing research on the perception of CCS by stakeholders and publics shows strong variations depending on sample, CCS technology chain, onshore or offshore storage and many other aspects. Experts frequently stated that “societal acceptance” is one of the most important challenges for CCS in Germany. They name two reasons for this. 1) Trust in the technology has eroded because of the failed deployment attempts, strong industry involvement and 2) a linkage that is established between the underground storage of radioactive waste and CO_2. In consequence, possible trust issues have been identified but it is unclear how the shift away from fossil fuel power generation and towards the application of CCS for industry emissions or BECCS has effected this.

Dimension 3: Policy and Regulations

This dimension asks for the policies and regulations that limit or support a technology. Policies, regulations and accompanying barriers need to be addressed. In the German case CCS technologies remain on SEL 1. As previously stated, CCS faces a hard regulatory lock-in in Germany. Although we find studies that have explored the policies and regulatory frameworks for CCS, the current political climate of CCS is not explored. There are no studies that could give an up-to-date assessment on political views on this technology. During the expert interviews it became clear that it is a highly contested field and that many actors view CCS as a “political minefield”. Although politicians of different parties and spokespersons of environmental NGOs see a need, to some degree, for carbon capture in order to reach the Paris climate goals, it is unclear how CCS in Germany would be politically feasible. The application deadline noted in the German CCS law, which expired in December 2016, **makes it impossible to apply for new sites (onshore or offshore) for carbon storage in Germany**. The experts stated that it would have been possible to reform the CCS law in this year (2020) to extend the application deadline, but it was decided that the law will not be reformed at this point.

Dimension 4: Market and financial resources

The core question of this dimension is if the market is ready to adopt the technology and if sufficient financial resources are available from development until deployment. This includes research funding as well as funding for industrial projects and thereby addresses market dynamics and possible business cases. CCS in Germany is not well embedded from a market and financial resources viewpoint (SEL 1). The market potential of CCS in Germany has been studied. For emissions from the fossil fuel energy sector and heavy industries, a high increase of costs connected to CCS application has been found and it is uncertain if these investments will be refinanced. This uncertainty about potential gains, risks and business cases is reflected in the expert interviews. Energy company representatives distanced themselves from CCS and highlighted the strong public opposition, previous failure, the regulatory lock-in and the consequential impossibility to have CCS in Germany as reasons for this decision. Additionally, it is questionable if CO_2 capture at lignite or hard coal power plants will be profitable in light of the coal phase-out in Germany (by 2038). Representatives from the steel industry followed a similar line of argument to explain their decision to follow other paths (mostly hydrogen usage or carbon capture and utilization/CCU) to make their production process more sustainable and potentially carbon neutral. Since this option to decarbonize production does not (yet) exist for the cement industry they have to rely on CCS to reach carbon neutrality. So far, however, there is little incentive for investments in CCS technology since capturing is expensive, storage is not legal and public opposition is feared to damage the company.

Overall SEL level

Based on the presented assessments for each dimension Table 5 displays the overall SEL for CCS in Germany. As the overall SEL is equal to the lowest level reached in one of the four dimensions, CCS in Germany is in the stage of exploration (SEL 1).

Table 5 Overview SEL level CCS in Germany

	SEL 1 Exploration	**SEL 2 Development**	**SEL 3 Demonstration**	**SEL 4 Ready for deployment**
Dimension 1: Environment	All milestones reached	All milestones reached	Some milestones reached	No milestones reached
Dimension 2: Stakeholder involvement	All milestones reached	Some milestones reached	No milestones reached	No milestones reached
Dimension 3: Policy and Regulations	Not all milestones reached	No milestones reached	No milestones reached	No milestones reached
Dimension 4: Market and Financial Resources	Not all milestones reached	No milestones reached	No milestones reached	No milestones reached

Main challenges for improving SEL in Germany

Based on the SEL assessment three main challenges can be identified.

1. Lack of social acceptance and stakeholder support

Public opposition to earlier CCS projects in Germany has shown that geological storage of CO_2 is a highly contested issue. Experts and studies indicate that this opposition is partly caused by the link between CCS and lignite power plants that was established in the first wave of CCS projects in Germany. It remains open how publics would respond to CCS that captures and stores CO_2 from other sources. Much of the opposition was connected to the prolonging of fossil fuel power generation and social acceptance might change if CO_2 came from bio-energy plants or industry processes that are hard to decarbonize. Research on public engagement and community consultations at the research pilot site at Ketzin has stressed the difficulties and the efforts it takes to gain public and stakeholder trust for CCS in Germany. After the failures of larger industrial projects, experts where critical of the future social perception of carbon capture and storage technologies. Especially political and industrial experts marked the lack of societal acceptance and local stakeholder support as highly relevant barrier for CCS.

2. Regulatory lock-in

The expired deadline (December 31, 2016) for applications for any kind of carbon storage project in Germany is the central regulatory barrier for this technology. It is hard to imagine how carbon capture and storage technologies could be moved ahead in Germany without a reform of the law. It is not clear which actors would push for legislative change since the earlier failure to establish CCS for lignite power plants or enhanced gas recovery has led to strong political opposition and made CCS a “toxic issue” for stakeholders and policy makers alike.

3. Limited market gap for CCS in Germany and lack of investments

This barrier is strongly linked to the regulatory lock-in. Since there is no legal basis for carbon storage sites, no public or private funding for the deployment of this technology is available. There are funding opportunities for the exploration of capacities, the improvement of capture processes and the transport of CO_2. Industrial actors shy away from investments because of the high political, social and legal uncertainty connected to the technology. Furthermore, the market gap for CCS in Germany is unclear because CO_2 intensive industries and energy producers have followed alternate routes to decarbonize after the discouraging development of carbon storage. Industrial emitters that are not (yet) able to fully decarbonize production without CCS (like the cement industry) are reluctant to count on the availability of CCS in the future.

Monitoring is not seen as a key instrument to overcome the named barriers in Germany. It is not seen as a potential measure, which could increase social acceptance and trust, but as a simple regulatory requirement. Experts even argued that too much emphasis on monitoring can increase doubts and engender distrust towards the safety of projects. If monitoring should play a role in trust-building and outreach activities it should have the following characteristics:

- Be cheap, efficient and easy to maintain over a long time
- Measure and predict leakages and plume movement
- Be transparent and allow real-time access to monitoring data
- Provide reliable access to experts for questions on the data (continuously, not just at outreach events)
- Be externally supervised by impartial institutions

- Be connected to a security concept that states what happens when the data shows anomalies.

Scenarios

Based on the literature review and the expert interviews that were conducted for this assessment, the future of CCS in Germany has to be considered as highly uncertain. Big incentives and pushes to establish a new foothold for this technology (especially for the storage part) would be necessary. Due to the regulatory lock-in there are not many routes to renewed CCS deployment in Germany.

Scenario 1: The German CCS law is reformed and the deadline for storage permit applications is extended.

This would enable new options for CCS but the experts felt that this is highly unlikely in the current political climate. The evaluative report of the Federal Government (Deutscher Bundestag 2018) does not state a need to update the law and experts see no parties or institutions pushing for such a change.

Scenario 2: CO_2 is captured from industrial processes in Germany and transported to storage sites in other EU countries

This option is discussed by policy makers and the industries (mainly the cement industry, other CO_2 intensive industry sectors are looking at other decarbonisation options). Transport via pipelines is seen critically because of public opposition, risks of leakages, and regulatory issues. Ship transport faces economic issues because of high costs (Benrath et al. 2020). Taking this into consideration, experts deemed this scenario to be rather unlikely.

Scenario 3: CO_2 is captured from bio-energy power plants and stored to reach negative emissions

Since the IPCC report on limiting global warming to 1.5°C there have been discussions about negative emission technologies in Germany. It is yet uncertain how BECCS, as one technological option alongside other possibilities like enhanced weathering, rewetted peatlands or afforestation, will be pursued in the future.

Scenario 4: CCS applied in hydrogen production

The German hydrogen strategy has incited a discussion on hydrogen production that includes the option of “blue hydrogen” (meaning hydrogen production with natural gas and the application of CCS technology capturing the resulting CO_2). Experts were generally sceptical about the hydrogen strategy. Some emphasized the priority of “green hydrogen” (hydrogen production with renewable energy) others noted that it might be necessary to use “blue hydrogen” to follow the outlined strategy but questioned where the captured CO_2 could be feasibly stored.

None of the above mentioned scenarios was perceived by the experts as likely under the current regulatory circumstances and in the present political climate.

6. Comparison between countries

A summary of the outcomes of the SEL assessments for the four national case studies in Greece, the Netherlands, Germany and Norway, is shown in Figure 4. This Figure shows the outcomes per SEL dimension per country.

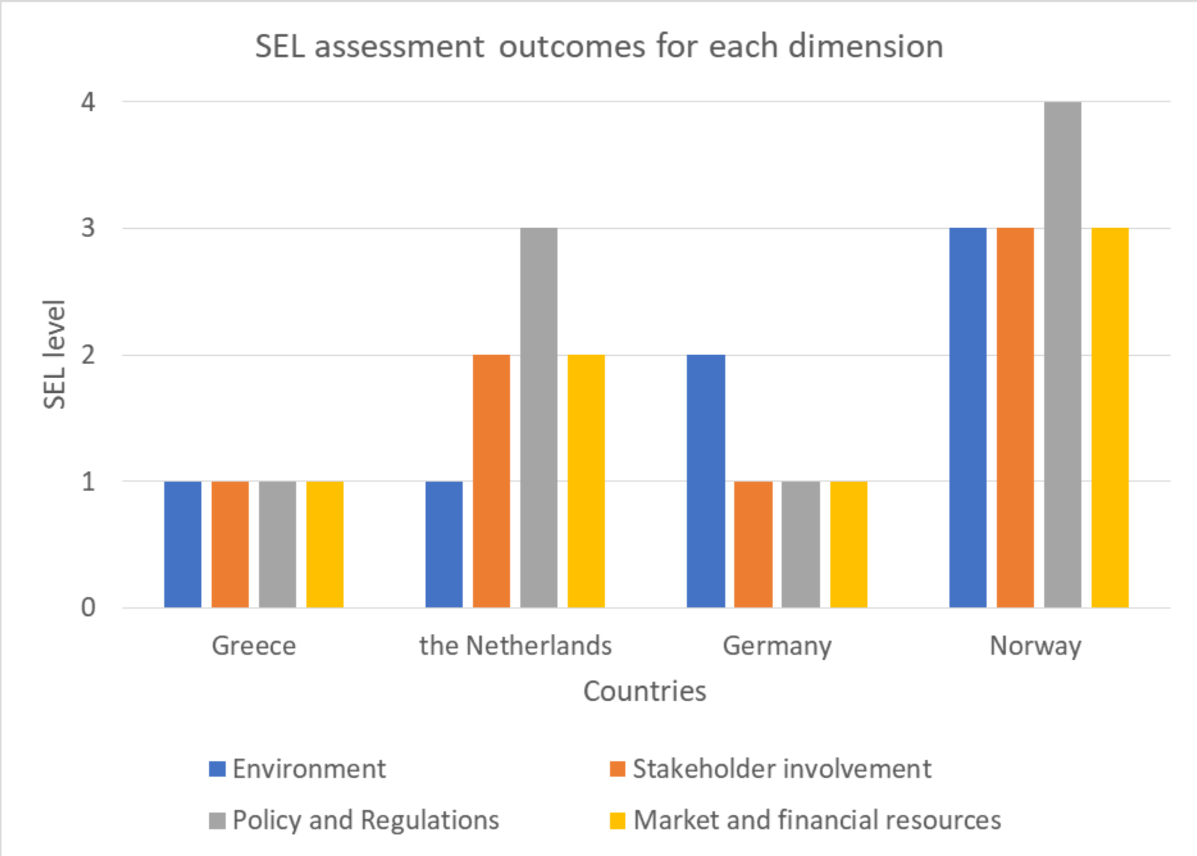

Figure 4 Outcomes of the Social Embeddedness Level (SEL) Assessment in Greece, the Netherlands, Germany and Norway per SEL dimension.

Based on the outcomes as shown in Tables 2, 3, 4 and 5, Figure 4 shows for each one of the 4 countries assessed, the Societal Embeddedness Level of each dimension. The SEL level per dimension is set by the extent to which the milestones corresponding to each level have been reached, or not. Only if all milestones of the SEL level have been reached, the SEL level is achieved. Furthermore, no overall SEL is visualized in Figure 4. For example, in the Dutch case study, for the 1st dimension 'impact on environment' nearly all milestones within the 2nd SEL level have been met (see: Table 3 in chapter 3), nevertheless the SEL level for this dimension has been set on SEL 1 in the above Figure 4.

As introduced in the SEL Guideline[1], the SEL assessment starts with identifying the current TRL level for CCS per country. In order to do so, we made use of the TRL system commonly used by the EU Commission. Subject to the limitations analysed in chapters 1 and 8, the estimated TRL for CCS in each country is as follows:

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

- In Greece, where no demonstration or lab experiments concerning CCS have been made, TRL was set to 2- technology concept formulated.
- In the Netherlands, over the last decades, several research and/or industry projects have been developed in every phase of the CCS chain (capture, transport and storage) and contributed to technical-oriented improvements for CCS deployment. Furthermore, in two industrial areas in the Netherlands new CCS initiatives are in development. Nevertheless, there are currently no full demonstration projects in which capture, transport and storage are integrated into one CCS initiative. Therefore, the TRL for CCS in the Netherlands was set to 5-technology validated in relevant environment.
- The TRL for Germany was set to 6 (technology demonstrated in relevant environment) because a CCS demonstration project, that combined oxyfuel capture at a lignite power plant, truck transport and storage in saline aquifers, was in operation from 2004-2013.
- In Norway, which is the leading country in CCS technology, with more than one demonstration projects already in operation, the TRL was set to 7.

The reasoning behind this first step in the SEL assessment is that each TRL level corresponds to a certain SEL level. Figure 3 of chapter 1 presents the connection between the TRL system and the SEL levels, as introduced in the SEL Guideline. Based on the current TRL, the corresponding SEL reference point could be determined, as a starting point for getting insight in the societal aspects that should be developed in close connection to the techno-economic developments towards CCS deployment. In essence Figure 3 provides a guidance for which societal aspects should be integrated in the ongoing CCS development, in order to have a smooth acceptance (initially) and adoption (finally) of CCS by local and national community.

Starting from the relation between TRL and SEL, and comparing the estimated TRL levels with the outcomes of the SEL assessments per country, Table 6 shows to which extend each country meets the SEL level corresponding to the estimated TRL.

Table 6 Comparison between the estimated TRL level for CCS and the outcomes of the SEL assessment per country.

	Greece	the Netherlands	Germany	Norway
TRL (estimated)	2	5	6	7
SEL (outcome assessment)	1	2	1	3
Comparison SEL-TRL link	in line	in line	not in line	in line

Comparing the national assessments as presented in Figure 4 we draw the following remarks:

In Norway, where CCS has been on the agenda for more than 30 years now, SEL is at level 3 at the environmental dimension (for both natural and social environment) in complete alignment with SEL reference point, while dimensions of stakeholders' involvement and market and resources are more advanced and dimension on policy and regulations has reached the maximum level of complete support towards CCS, which corresponds to the SEL reference point for full CCS deployment.

In the Netherlands, the market and resources dimension is at SEL 2, in alignment with its reference point, while the environmental (both natural and social environment) dimension is almost there (at SEL 2). The stakeholders' involvement dimension is advanced midway towards the next level (SEL 3), while the policy and regulations one is also at SEL 3, ready for the forthcoming offshore demonstration projects. In case of CCS proceeding towards demonstration, attention should be paid towards improving the environmental, market and resources, and the stakeholders' involvement dimensions to next level 3, which is the corresponding SEL reference point for demonstration.

In both the Netherlands and Norway the CCS driver has been the hydrocarbons industry, with continuing interest in the technology. New CCS demonstration projects are underway, all of them are offshore, as onshore CO_2 transport and geological storage facilities face strong public opposition.

In Greece, where CCS has been on the agenda for around 20 years now, the CCS driver has been the coaled fired power generation industry. But, as national policy has shifted towards abolishing coal fired power plants in the near future, CCS interest stopped. SEL has never advanced above current levels, which are a bit less than 2 for the environmental dimension, but much less than 1, below SEL reference level in all other dimensions. The advancement of the environmental dimension is probably attributed to the experience the power company gained from the renewables power generation sector. Further CCS development in the country towards pilot demonstration, which has a SEL reference point of 2, should therefore be accompanied by efforts to improve SEL in these dimensions (stakeholders' participation, legal and regulatory frameworks and market and financial resources).

Similar to Greece, the capture and storage of emissions from coal fired power plants was a main driver for the development of CCS in Germany. A scientific pilot project operated successfully for several years. However, follow-up projects of the power industry faced strong public opposition. In consequence of these protests and the looming coal phase-out the political and industrial interest in CCS diminished. New regulations that limited and from 2017 on banned new CCS projects in Germany led to further complications driving back SEL in the corresponding dimension, also dragging the market and financial resources behind. As a result, despite the CCS technological development in the country the reference SEL 2 has only be exceeded in the environmental dimension, almost reached in the stakeholders' participation dimension, but in the policy and regulations and the market and resources dimensions SEL has dropped much below the reference point, even below level 1. This implies that if in the future CCS will proceed to demonstration in the country, a lot attention should be paid to these two SEL dimensions.

7. Monitoring aspects

Monitoring can help to estimate storage efficiency, provide information on the CO_2 plume location, movement and pressure in the subsurface and evolution over time. Methods include: (i) 4D (time lapse 3D) seismic monitoring of the reservoir to image subsurface CO_2 movements, as well as (ii) monitoring wellhead pressure and flowrate plus temperature and stress to depth within the injection well. Experience from Sleipner and Snøhvit CO_2 storage sites in saline aquifers with time lapse 3D seismic monitoring provided confidence on the technology to detect any major CO_2 leakages into the overlying cap rock. New technologies used are DAS. Monitoring is perceived as an important safety measure helping to control the CO_2.

There are several methods to monitor the storage of CO_2, ranging from relatively affordable to very expensive monitoring technologies. In addition, monitoring costs can be reduced by reusing existing infrastructure of offshore oil and gas production facilities. Currently, there are no extra funding opportunities associated with more extensive monitoring.

In the Northern Lights project in Norway, public funding of monitoring has not been provided, other than a provision after project stopping due to lack of CO_2 supply. Therefore, monitoring always adds on to the costs of CCS. However, the extensiveness of the monitoring will depend on the risk profile of the CCS site. The higher the risk profile, the higher the monitoring costs will be. Based on current legislation, the expenses of monitoring can have significant impact on the additional costs of a CCS project. When a market party has to cover the additional expenses for monitoring, as well as the provisions for covering unknown risks, the actual costs for CO_2 storage can be higher. Furthermore, due to the lacking regulations about transfer of liability, the financial risks regarding long term monitoring are high.

Regulations are in place at National, EU and international levels. The project owner must control the CO_2 distribution in the reservoir, detect possible leakages below the surface (seabed or ground surface) and take the necessary corrective measures. Legislation mainly focuses on aquifer CO_2 storage and has no provisions for storage in depleted gas fields. Although monitoring is compulsory and its results should be shared with the Authorities, there are no specifications, clear standards, duration and safety criteria in place.

Previous research shows that the general public is concerned about CO_2 leakages. Therefore CCS monitoring should increase public support for CCS developments, although there is no study available yet about the influence of monitoring on social acceptance of CCS. Regarding the DigiMon project, an important research question therefore is how a low-cost innovative monitoring system – the DigiMon system – could contribute to better embedding CCS projects in the societal context. In addition, there is a lack of experience with participation of external stakeholders in CCS monitoring[1]. Public opinion surveys however, identified a general belief that monitoring alleviates concerns on safety and that it is perceived positively among the general public.

In Germany, monitoring is not seen as a key instrument to overcome the CCS barriers. It is not seen as a potential measure, which could increase social acceptance and trust, but as a simple regulatory requirement. Experts even argued that too much emphasis on monitoring can increase doubts and endanger distrust towards the safety of projects.

[1] In the EU project SECURe (Subsurface Evaluation of CCS and Unconventional Risks) research is being done on participatory monitoring in four countries. The outcomes of this study are being expected in April 2021). See also the SECURe website www.securegeoenergy.eu.

If monitoring should play a role in trust-building and outreach activities it should have the following characteristics:

- Be cheap, efficient and easy to maintain over a long time
- Measure and predict leakages and plume movement
- Be transparent and allow real-time access to monitoring data
- Provide reliable access to experts for questions on the data continuously, not just at outreach events
- Be externally supervised by impartial institutions
- Be connected to a safety concept that states what happens when the data divert from normality

In the Netherlands, the topic of (participatory) monitoring becomes more and more important related to the safety of geo-energy projects. The gas production in the Groningen gas field and the corresponding seismic events as a consequence of the gas extraction decreased the trust of local communities in the operating company as well as the supervising authorities; local entrepreneurs started developing low-cost monitoring sensors to increase the local involvement in monitoring activities and safety management strategies. Currently, with the seismic events in the Groningen area in mind, geothermal developments are also facing many questions from local communities regarding the safety of the foreseen geothermal project related to seismicity. As part of the European research project ENOS (enabling onshore CO_2 storage) the topic of monitoring CO_2 storage activities has also been discussed with a focus group of citizens in the Rotterdam area (the Netherlands). These citizens were given a general introduction to CCS monitoring and how CCS monitoring is part of Dutch legislation for CO_2 storage (Mining Act). The citizens concluded that CCS monitoring experts seem to have sufficient knowledge to recognize and manage the technical, geological risks as well as to design an appropriate monitoring program to reduce the identified risks. Their concern was mostly with the operational risks of a project. How is the monitoring program executed and how are monitoring data used to improve the operations of a project? In a second meeting about monitoring with this group, the value of participatory monitoring was explored. The main research question in this meeting was if the citizens thought that an approach for participatory monitoring could be a way of including citizens' questions, concerns and perspectives into the strategy for developing a new CO_2 storage project. The citizens emphasized that their interest to be involved in the design and implementation of a monitoring program would increase when trust in the operators and/or authorities is low. When trust in the operators and/or authorities is not an issue, they had less interest to become involved. They would, however, like to have more insight in what happens with the collected monitoring data. Who takes the decision whether more or less CO_2 is injected? Or that a project is being cancelled? These questions connected to the use of data during the operation of a CO_2 storage project. [2]

In the next phase of the DigiMon project we will focus more on the question what role monitoring could play in trust building, as well as in better embedding CO_2 *storage projects in their societal context.*

[2] Brus & Puts, 2020 "CO2 Storage Best Practice indications from Rotterdam area community. Lessons learned from a long term collaborative research process with a group of Dutch citizens: towards societally embedded CO2 geological storage projects". Final report D5.4 of the EU project ENOS.

8. Reflections on applicability of the SEL assessment framework

The SEL methodology is developed for assessing the extent to which technological innovations meet societal requirements towards deployment[1]. In the DigiMon project, we applied the SEL methodology to assess the societal embeddedness level of CCS in four different countries: Norway, the Netherlands, Greece and Germany. Here the SEL has been assessed for the technological innovation CCS at national level. The four national SEL assessments provided insights in the main societal challenges at national level for further development of CCS.

Although the SEL methodology has not been designed for assessing a chain of technologies like with CCS, our study shows that using the SEL assessment framework does provide insight in the main societal challenges for further development of CCS at national level.

The main reflections on the applicability of the SEL methodology are described in this chapter here.

The four teams who have conducted the SEL assessment in four national case studies reflected on the applicability of the SEL methodology at national level for CCS. As a result of this evaluation, we kept track of methodological difficulties that came across during the assessment. In this chapter we elaborate whether any dimensions/subjects could not be addressed for CCS and what methodological difficulties we came across.

Norwegian assessment team

The SEL framework worked quite well as a tool to do the national assessment, although in the Norwegian case the time spent to do the assessment and write the report was longer than what was anticipated. It is a detailed framework with many research questions to answer and many milestones to analyse, and a lot of reading was required to be able to answer all the research questions. The research questions also vary quite a bit in how detailed they are.

A main take-away from doing the assessment is that the connection between TRL and SEL is challenging as TRLs are developed for each technological solution within the CCS value chain. In Norwegian case, the Longship project, which is the one assessed, consists of different technologies put together into one value chain. The technologies are all mature, but they have not been merged into one coherent system before and thus there is insecurity related to, in particular, the interfaces between capture and transport and transport and storage this that TRL does not pick up. Thus, the assessment was carried out without basing the reference SEL level on the TRL, but rather focusing on the fact that this is a demonstration project putting together an entire CCS value chain with a flexible transport and storage solution. To conclude, basing a reference level on TRL is not necessarily the best way to go forward when starting a SEL assessment. In addition, the close connection between TRL and SEL does not seem to connect well with the actual world when you start using the framework.

Also, although not a big problem for the Norwegian case, the recipe to identify an overall SEL level makes clear that this is a very conservative approach as all milestones need to be reached within all four dimensions. One can easily imagine that there may be quite big differences across dimensions, e.g. SEL 4 on “market and financial resources” dimension and 1 on “stakeholder involvement”

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

dimension. Deciding then that the overall SEL level is 1 leaves out a lot of nuance of the case. This is something we should think about when discussing SEL further.

One uncertainty that followed in working with the SEL assessment was as follows: When there is something you do not find any information about through the suggested methodologies, what do you then answer in the SEL and how does this affect the overall SEL evaluation? Is “don’t know” to be understood as the same as NO in the framework? This was unclear and there is no information in the Guideline on how to deal with this. If one was to treat don’t know as NO, that could be quite dramatic when setting the overall SEL level. Maybe one should collect all the “don’t knows” as part of the assessment the same way as NO answers are identified?

On a more conceptual level, it should be defined more clearly on what the word “societal embeddedness” implies in the SEL framework. What are we preoccupied with identifying here? There are (at least) two ways of considering societal embeddedness: one can be preoccupied with how well society is embedded in the CCS process, or one can be preoccupied with how well the technology is embedded in society. These are two quite different approached to embeddedness, and the first would maybe be where most social scientists would put their effort. Question: is the SEL framework meant to be a tool to identify and work to ensure societal participation in a technological development or is society more a necessary evil that needs to be on the supportive side for a technology to be realized? Although not a very hands-on feedback, this is something that was considered about quite a bit during the assessment and it is important to make clear what we mean by societal embeddedness.

Also, another instruction in the SEL guidelines is connected with the above point of the expected link between SEL and TRL. On p.7 it says: “These societal barriers need to be addressed in order to embed CCS into society.” Yet it is in no case given that addressing the societal barriers will embed CCS into society. It is too simple to expect such a one to one causal relationship. It may even move in the opposite direction! In democracies where the realization of all (major) projects rely on the public will, there may not always exist acceptance (public and/or political) for deployment although one does everything in one’s power to address their concerns and worries. Thus, such an assumption needs to be changed to reflect the cases we study: liberal democracies.

Dutch assessment team

Subjects that could not be addressed

In general, we faced difficulties to answer many questions for a ‘national’ situation concerning CCS developments. The research questions as part of the SEL assessment framework[1] are developed to be answered for a site or project specific SEL assessment. We managed this by taking the ‘Enterprise Netherlands’ as a starting point for the SEL assessment looking at different project initiatives and a more generic level of CCS development; while answering the research questions we added many subtleties in the explanations per milestone and per dimension.

Environment: We were not able to adequately answer the questions about the impact of CCS on the social environment. There are no procedures that prescribe the identification, exploration and assessment of the social environment, and project specific we were not able to gain such detailed information. However, we found that there is some information about how the possible impact of

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

the social environment to the SEL can be taken into account. For this reason, the box of SEL 2 for this dimension is made orange (some milestones reached; see Table 3 in chapter 3). Also, in the framework the 'assessment of the impact on the environment' was meant to be reached after the technology was demonstrated, however, the EIA (environmental impact assessment) is done before the start of the demonstration. For this reason it is possible for the SEL to easily catch up or go further than the TRL. This might be a methodological issue we need to look in to. The level of detail in this dimension is open to interpretation as well. While developing the research questions as part of the SEL assessment framework we presumed that the impact on the environment can only be thoroughly assessed when the technology is in the demonstration phase, because only then the exact impact on the environment around a specific site location can be measured. However, the environmental impact assessment is a pretty specific assessment, which is done before the actual demonstration starts. For this reason the milestones in level 3 of the dimension 'environment' can (theoretically) be reached before there is an actual demonstration site.

Stakeholder involvement: The research questions on this dimension where the hardest to answer on a national level. There is a legal procedure for stakeholder informing and involvement, but actual CCS projects make more effort than the required 'minimum'. This is a subject that can be studied more extensive in the local assessment. For this reason the SEL 3 box for this dimension is made orange.

Policy and regulations: All milestones and questions are sufficiently addressed.

Market and financial resources: Questions about the market, customers, competitors and substitutes are hard to answer for this technology, because there is no 'typical market' situation for CCS.

Methodological challenges that came across during the SEL assessment

We came across several methodological challenges during the performance of the national assessment of the SEL of CCS in the Netherlands. These challenges concern the level of scale between a national and local level; the formulation of the research questions within the SEL assessment framework, which causes that some research questions are open to interpretation; the scope of the desk study protocol; the applicability of the SEL reference point for the assessment of the whole CCS chain; the transition between SEL levels and the fit of milestones and questions for the assessment of the SEL of CCS in the Netherlands.

National-vs-local: The questions in the SEL assessment are focused on assessing a particular project/initiative; this makes it challenging to apply the assessment on a national level. For example the business case, the impact on natural environment of a demonstration site and the involvement of stakeholders are particular

Some-questions-are-open-to-interpretation: This occurs in all dimensions. For example, the answer on questions like: 'Are stakeholders involved on the moments that benefits them most?', 'Is budget for R&D sufficient?' will depend on who is interviewed.

Desk study protocol: We found that the predetermined search words do not cover all information and that scientific papers do not provide up-to-date information. Also there is the question to what extend can desk study research be neutral, as extremely 'good' or 'bad' cases are more often studied and described then 'regular' cases. This might cause biased data.

SEL-reference-point: We found that, especially on a national level, the SEL reference point is hard to determine. The SEL reference point is based on the current TRL of the technology that is assessed in the SEL assessment. However, CCS consists of a chain of technologies, which all have a different TRL. Besides, when assessing the SEL on a national level, no specific technology is assessed, but more of a concept of a chain of technologies. For all sub-systems (CO_2 capture, transport and storage), multiple technologies can and will be used.

Transitions-between-SEL-levels: We found that in the Netherlands there is currently no CCS demonstration site. However, as there were some former projects very close to demonstration before, several milestones and even the dimension policy and regulations already reached level 3. We think we should determine whether or not it is possible to go to SEL three and beyond, without having a demonstration site. It might help to add control questions per dimension, which are closely related to the TRL. Additionally we think – for CCS – it might be hard to define the transition between SEL 3 and SEL 4. It might vary per technology/system when a demonstration site transfers to deployment. It might be helpful to add control questions for this transition, which can vary between technologies (for example; financial independency).

Fit-of-milestones-and=questions: Some questions might not fit all kinds of technological innovations. We found it hard to answer questions about the impact of CCS on the social environment, and could not scope all questions in the dimension market and financial resources for the CCS situation.

Interlinkages between the dimensions: During the assessment, we found that the four dimensions have many interlinkages. These interlinkages cause overlap and interferences between the dimensions.

Greek assessment team

No important CCS developments have taken place in Greece with complete absence of CCS projects and no innovation or development activities, other than formulating CCS concept and its possible environmental impact, identifying potential CO_2 geological storage sites and importing the EU directive on CCS in national legislation. For this reason, the main challenge during this assessment has been to identify enough articles published and enough experts who will be willing to provide their views.

SEL dimensions and milestones seem appropriate for application at national level in Greece. They provide a good starting framework to provide guidance, in order to facilitate CCS implementation and address social issues which could hamper CCS development. Further evaluation will be possible, when CCS becomes a reality in the country and sufficient experience will be gained during its development.

German assessment team

Overall, it was found that the SEL is a useful tool for the assessment of the situation of CCS on a national level. It particularly helped to systematically keep track of different aspects that might affect societal embeddedness and to make the interconnections between different dimensions visible. It was, however, not always easy to assess CCS since the technology can include different components. This is especially problematic when there is no local case to focus on. A local case would have a specific CCS technology chain and this could be assessed using the SEL. On a national level there are a lot of contingencies to consider and to describe in the report. Taking this into consideration, it would be helpful to decouple the SEL starting point from the TRL, as a complex technological system can include multiple components with different TRLs and it is hard to assess an overall TRL.

The “storylines” of development within the different dimensions worked well. One improvement concerning the milestone 4 in SEL 3 of the policy and regulations dimension (“Regulatory and policy framework supports demonstration of the technology and its system”) will be to add a corresponding milestone in SEL 2 for the development stage.

In-depth evaluation applicability SEL assessment framework

In parallel with writing this report we are executing a more in-depth evaluation among the researchers who applied the SEL assessment framework for conducting the national SEL assessments in Germany, Greece, the Netherlands and Norway. In-depth interviews with all national research teams will be held, followed by an analysis of all experiences with and feedback on the applicability of the SEL assessment framework. The outcomes will provide insight in possible improvements in the SEL methodology as well as in design challenges for the planned local SEL assessments as part of the DigiMon project.

9. Societal challenges for CCS developments per country

The outcomes of the national societal embeddedness assessments give insight in the main societal challenges for continuing CCS developments in the four countries: Germany, Greece, the Netherlands and Norway. In this chapter, we will give an overview of the main challenges, based on the national SEL assessments, for improving the societal embeddedness of CCS developments.

In Norway, complete societal embeddedness of CCS, thus for SEL to reach 4 in all its dimensions, needs development of a CO_2 market, securing unanimous support or consent for CCS by all stakeholders, and mitigating all environmental impacts in the entire CCS value chain. The later awaits the commencement of operations at the Longship project, which will provide complete experience from full scale integrated CCS demonstration. Concerning policy and regulations, a framework providing full support towards CCS commercial operation, has already been put in place, see Figure 4.

In the Netherlands, as TRL is progressing towards demonstration, reaching SEL 3 is the objective in the short run. SEL 3 has already been achieved by current policy and regulations framework, as shown in Figure 4. Societal embeddedness efforts should therefore focus on the other three SEL dimensions. Concerning SEL dimension on the environment, where most attention should be given, as is the one behind all others (see Figure 4), the focus should be on assessing the requirements for the social environment. At the market and financial resources dimension, societal aspects need to be introduced. Regarding the stakeholders' involvement dimension, efforts should focus on achieving stakeholder participation in discussions of CCS merits towards mitigating climate change and regional development.

In Germany, immediate action is needed in reforming current regulatory framework, in order to lift the ban imposed on new carbon storage projects. This is also expected to drift the market and financial resources dimension upwards. The short term objective should be to assess market needs and trends, as well as to establish a business case for demonstration and to update the research on societal perception of CCS. Concerning stakeholders' involvement, stakeholders' participation should be sought in order to obtain their support and achieve public acceptance. De-coupling CCS from coal power generation and stressing the application of CCS for residual industrial emissions or negative emission technologies (like BECCS) promises to aide this process.

In Greece, further CCS development towards a pilot facility, should be accompanied by SEL improvement towards level 2. Short to medium term objectives should be to assess the concrete impact to physical and social environment, identify interests, attitude, perceptions and concerns of stakeholders, assess present policy and regulatory framework in terms of posing barriers and drivers to CCS development, evaluate possible market impact and financial needs, as well as assess market needs and trends and establish a business case for pilot demonstration.

10. Conclusions

The SEL assessment for CCS in Norway, the Netherlands, Germany and Greece established different SEL scores for each country. Based on desk research and expert interviews we found the highest in Norway (SEL=3), followed by the Netherlands (SEL=2), Germany (SEL=1) and Greece (SEL=1). In each country the SEL also varied among its four dimensions: physical and social environment, stakeholders' involvement, policy and regulations and market and financial resources.

Although the Norwegian and Dutch team faced some challenges to set an overall TRL level and identify the corresponding SEL reference point, it is interesting that there seems to be alignment between TRL and SEL in both countries, where the main driver for CCS development has been the hydrocarbons industry. In Norway a full demonstration project is in development (high in TRL), corresponding to high scores for the different SEL dimensions; and in the Netherlands preparations for CO_2 capture and storage projects are being done in 2 geographical areas (mid-range in TRL), corresponding to the outcomes of the SEL assessment. Further SEL advancement is needed towards the next level (3 for the Netherlands and 4 for Norway), in order to align with an expected TRL increment towards demonstration in the Netherlands and full scale implementation in Norway. Both countries focus their efforts on the offshore deployment of CCS.

In Germany and Greece, where CCS has been on the agenda for the last 20 years and was mainly driven by the local power industry, which operates lignite fired power plants, the SEL has remained low. For the Greek case, this is attributed to the strategic political decisions taken towards phasing out lignite power generation, which resulted in not developing CCS legal framework. After successful scientific pilot projects in Germany CCS connected to coal power plants faced public opposition and political as well as regulatory scrutiny. The latter resulted in a legal barrier for CCS implementation from 2017 onwards. If CCS returns as a national objective in Greece or Germany, this time potentially driven by other actors and goals (e.g. hydrocarbons industry, residual emissions from industrial processes), SEL advancement is needed to correspond with expected TRL development towards pilot (Greece) or demonstration plants (Germany). New insights on the societal challenges and barriers provided by the SEL could guide the setup of new CCS projects and, in the German case, help to avoid problems previous projects faced.

11. Further research

Within DigiMon

The insights from the four national case studies and the overarching analysis will be further used in the DigiMon project to develop the innovative societally embedded DigiMon monitoring system.

Firstly, by discussing the outcomes of the four national case studies as described in this report with all DigiMon partners during an interdisciplinary event, in which we will jointly identify how the outcomes of the four national case studies could serve the further improvement of the design and development of the DigiMon monitoring system. This interdisciplinary (online) event will be open for all DigiMon researchers, industries and governments aiming at making optimal use of the different backgrounds of all participants. Secondly, the outcomes of the national assessments will be used for preparing and executing the planned local case studies (task 3.2 in the DigiMon project): in these case studies we will assess how the DigiMon system could contribute to better embed CCS development in their local societal environments. Thirdly, we are currently finalizing an in-depth evaluation among the research team who applied the SEL methodology in four national case studies, to capture their experiences with applying the SEL Guideline in order to learn from their feedback, to identify improvements for the SEL methodology and to jointly explore important adaptations for applying the SEL framework at the local level.

The above activities will all be part of the further research process of the DigiMon project, about which we will publish in the next coming year (see Figure 5).

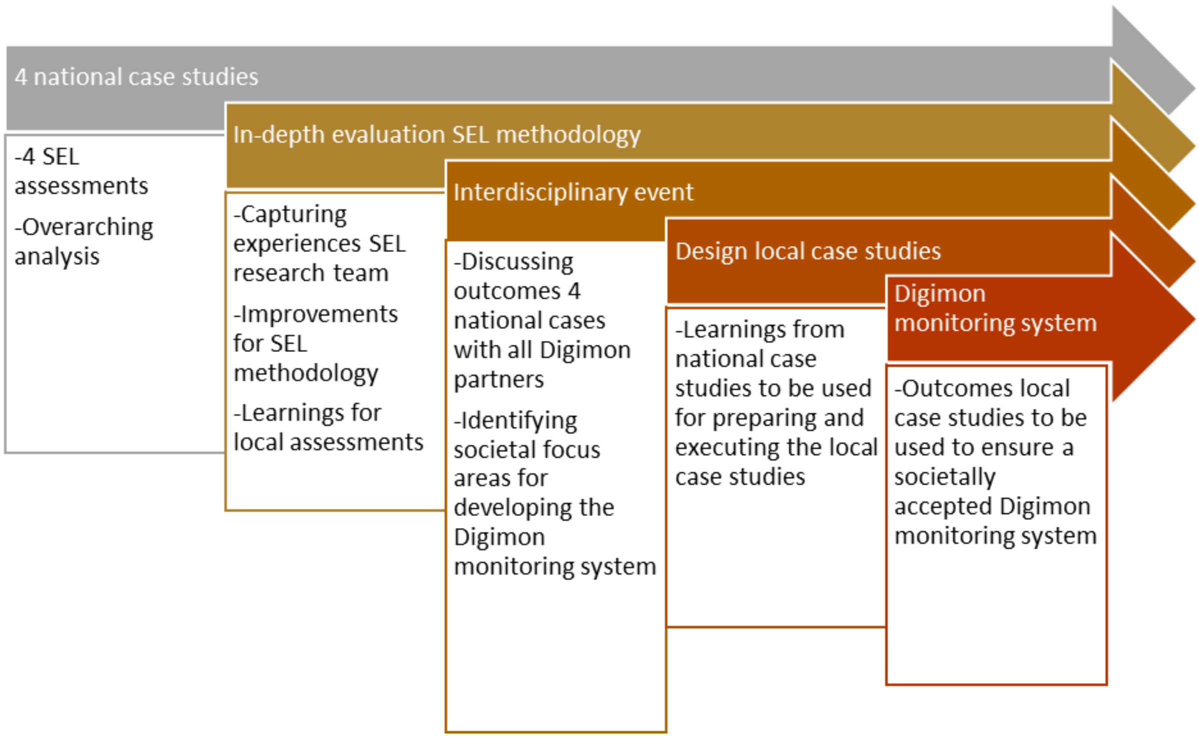

Figure 5 Continuing research on social embeddedness aspects of CCS monitoring

Beyond DigiMon

The experiences with applying the SEL methodology for assessing the societal embeddedness level of CCS developments at national level (this report) as well as the local level (next phase of DigiMon research) will provide valuable insights and reflections for further improving the SEL methodology. On the one hand, the insights so far raise new research questions regarding the upscaling of CCS and which role the SEL methodology could play in this upscaling process; these questions are not on the current research agenda of the DigiMon project and should be taken into account while developing a follow up research program (DigiMon 2.0). On the other hand, the continious exchange of experiences and perspectives among DigiMon partners also give insight in new methodological research questions regarding further improving the SEL methodology and accelarting its applicability in new policy domains. It seems valuable to continue this reflection and research to improve the applicability of the SEL methodology, both for CCS developments, but also in other policy domains.

Some of these reflective questions are listed below:

- **Consider connecting the outcomes of the national SEL assessments to the broader European/global context**: each of the teams are briefly touching on some major change process happening now in Europe or the world: the EU's sustainable finance initiative is encouraging both investors and civil society to demand more transparency and disclosure in a language they understand; CCS is discussed as a key enabler for a European hydrogen industry; environmental justice is particularly pressing in the US right now but Europe continues to struggle balancing climate protection and citizen/workers' rights. The direction of travel is clear: in Europe, there will be an increasing need for monitoring, reporting and verification of environmental performance as a matter of business success.

- **How we talk about CCS: is it a technology or a supply chain?** While a few years back CCS was designed and construed as a set of three technologies to be demonstrated locally/nationally, new CCS projects are more and more designed as cross-border supply chains e.g. capture happening in the UK, transport across the North Sea and storage in Norway. How does this influence the design and applicability of the SEL framework?

- **Europe's emerging model of strategic industrial leadership is in the process of a big change:** from unempathetic technology development to user-driven development driven by sustainability. What does this imply for Europe's industrial leadership? US and Asia are not there yet. Can the SEL methodology be a key enabler of Europe's strategic industrial leadership in the emerging industries of hydrogen, batteries, recycling, CO_2 and methane monitoring, biotech etc.?

- **Do you need to research the correlation between SEL 1.0 and governance systems or technological maturity?** Norway, the Netherlands and Germany all have very decentralised governance systems, in some cases regions might be stronger than national/federal government and all three teams struggled to align the SEL framework with their governance systems while the Greek team had less of an issue. Is there merit in testing the SEL framework in a few more "Napoleonic", centralised structures e.g. France, UK etc.? The other reflection was that both Germany and Greece struggled less with the SEL methodology and have the lowest technology maturity. Do lower technological maturity levels offer a better sweet spot for TRL-SEL alignment from the project initiation phase?

- **The role of civil society**: In NL and DE Millieudefensie and Deutsche Umwelthilfe can sue you into extinction, this is not the case in Greece or Norway. Is it worth exploring if there is a correlation between the role of civil society and the SEL methodology take-up by industry?

- **The share of public vs. private finance in project financing and the role of private investors**: most CCS projects in Europe are publically funded with private investors playing a minor role for now. Is it worth exploring the relationship between the structure of financing and the SEL take-up by industry? Another reflection is whether it is worth exploring the role of investors in SEL take-up by industry. The Netherlands is home to most of the world's ESF funds and they tend to be very active in setting ESG performance expectations on their portfolio companies. Norway's oil fund is an important institutional investor whose voice cannot be ignored. Is it worth exploring them in a future project?

- **Amplification of results and roll-out across sectors**: the way the DigiMon project is designed, and the application of the SEL methodology is a first –of-kind project attempting to understand the major shift currently underway which is that of taking society in the technology development from the start, ensuring society co-creates instead of being on the receiving end with no agency to influence anything. This novel methodology might be of very high relevance to European innovators. The SEL methodology has the potential to be a game changer, it is super important that both Horizon Europe and national/regional budgets keep this line of research funded and used.

ANNEX: National SEL Assessments

1. National SEL assessment in Norway

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1.1 Introduction

CCS plays an important role in the Norwegian climate and energy policy. It is seen as an important technology to meet Norway's twin challenge of reducing CO_2 emissions while at the same time meeting its growing energy demand with domestic resources. Due to continued government support of CCS from the late 1980s and until today, Norway has an international leadership position in the development of CCS (van Alphen et al. 2008).

Norway has a comparatively long history of carbon capture and storage, connected to the big oil and gas fields in the North Sea. In the 1990s the Sleipner oil and gas field started capturing and injecting CO_2 into the seabed to avoid big economic costs as a result of the CO_2 tax that was implemented in 1991. However, the infrastructure necessary to make CCS available for other industries has not been equally developed as the CCS technology was something the authorities focused on for the oil and gas industry in the beginning. In 2016, the Norwegian government initiated plans to develop a new and flexible full-scale CO_2 capture, transport and storage project, linking onshore industrial CO_2 sources to offshore storage. In October 2020, the government announced their decision to realize and invest in this full-scale demonstration project which they named the Longship project. It is this Longship project that the SEL assessment for Norway will focus on.

1.2 National context

a. Historical context

Norway has built an encompassing competence for CCS over the last 25 years. One reason for the leading competence is the experience from planning of CO_2 handling projects in Norway. Another reason is the big continental shelf with rich opportunities for CO_2 storage in geological formations in the sub seabed. Third, different governments have over time supported technology development, testing and piloting projects and stressed CCS as an important technological instrument in international climate negotiations.

In 1991, Norwegian authorities introduced a charge on offshore CO_2 emissions which together with the specifications for dry gas on the continent contributed to the development of the first CO_2 handling project on a platform in the North Sea named Sleipner. Since 1996, gas has been captured and stored at the Sleipner platform and stored in the nearby Utsira formation. From the Gudrun field was opened in 2014 this gas also goes through the Sleipner plant allowing all CO_2 from this gas field to be captured and stored. In 2008, and based on the experiences from Sleipner, Equinor introduced a new full-scale project at the Snøhvit (Snowhite) platform in the Barents Sea. The Sleipner project, together with the Snøhvit project, reduce Norwegian CO_2 emissions by 3-4 percentage points per year and thus represent important big scale experiences with capture and storage as well as developing important knowledge production for the CCS innovation system (Ministry of Petroleum and Energy, 2014-2015: 117). Moreover, Yara, and ammonia plant, has for a long time captured CO_2 and transported it on ship and on trucks to the foodstuff industry for further processing. Today, Sleipner and Snøhvit are the only two storage sites for CO_2 operating in Europe. Norway, together with the Netherlands and Great Britain, are guiding in the development of CCS in Europe.

The building and running of CCS projects at the Sleipner and Snøhvit platforms have for several decades demonstrated secure storage of CO_2 in geological formations under the seabed on the

Norwegian Continental Shelf (Ringrose, 2018). To secure storage, monitoring programs and reservoir simulations have been developed which new projects may derive advantage from. Knowledge and experience from the oil and gas industry has been essential for the development of CCS in Norway. Connected to this, we have a big and well explored continental shelf with good opportunities to store CO_2. The Norwegian Petroleum Directorate has documented that the potential for storing CO_2 under the seabed on the Norwegian continental shelf is great, allowing for storage of big volumes of CO_2 from European countries. Moreover, EUs storage directive is implemented in the relevant Norwegian legal system so that the necessary legal framework is in place. With authorization in this framework the first license is awarded Equinor for the Northern Lights project, making up the transport and storage part of the Longship project that was announced in the fall 2020.

In Norway emissions from industry belonging to the sector subject to the duty to surrender allowances make up 23 percent of the country's total CO_2 emissions, which is similar to the size of the sector in the EU. Still, due to hydropower Norway has very little CO_2 emission connected to the power industry. In 2016 the Federation of Norwegian Industries published a roadmap for the emission cuts in the processing industry where they made clear that they see that two thirds of their cuts to become carbon neutral in 2050 will come from CCS technology. Furthermore, based on the roadmap the Federation of Norwegian Industries has also established a CCS expert group working on how the processing industry can best adapt to and stay competitive within a low carbon future. This shows how central CCS is considered to be amongst Norwegian industries to meet the Paris agreement.

Given the great hydropower resources in Norway, the amount of CO_2 emissions in Norway suitable for CCS is limited. Thus, for Norway's commitment to CCS to result in large-scale emission reduction, it is necessary with international cooperation on CCS. The model in the Longship project is well placed to increase the number of projects that can be connected to a Norwegian storage site.

Gassnova (2019) write in their report on the status of CCS in general that from a technological perspective all parts of the CCS chain - capture, transport and storage – are sufficiently mature and ready for full scale realization. As such, the biggest insecurity seems to be related to the interfaces in the value chain, from capture to transport and from transport to storage. We will come back to this later.

A key to understanding the development of CCS in Norway is the active role taken by the Norwegian authorities. Norwegian authorities have over decades been goal-oriented in going after all aspects of the CCS technology and have over time built solid specialist environments for the research and development chain at the same time as they have financed crucial research infrastructure into the innovation system for CCS. Due to the overtime political support, the research environment for CO_2 treatment in Norway is solid and covers all parts of the enterprise. The strong research environments are connected, amongst others, to a Norwegian CCS Research Centre which solely dedicates itself to the handling of CCS. Moreover, the research programme CLIMIT, a program under the Research Council Norway, is an important source of funding for research and demonstration. The building and running of the Technology Centre Mongstad (TCM)), a test centre for capture technologies, has also allowed for crucial knowledge building, together with the planning of full-scale capture projects at two locations (Kårstø and Mongstad) which have given valuable knowledge both for the industry as well as for government administration. The current Longship project has benefitted from these other efforts.

Longship is one of the key projects that can create an infrastructure for CO_2 storage in Europe, and since January 2020 it has held the status as one of the energy projects of common European interest called ‘Project of Common Interest’. These projects are identified as key cross border infrastructure projects that link the energy systems of EU countries and the storage part of the Longship value chain includes 16 partners from 7 countries. CO_2 sources from all over Europe can connect to the infrastructure for storage created in the project. Many of the projects currently under planning in Europe are sole CO_2 capture projects that consider the Northern lights storage site as a possible storage solution for their CO_2 (OED, 2020).

I. Experiences with CO_2 capture

Both full-scale CCS projects in Norway so far have been situated at oil and gas platforms off the Norwegian coast. The Sleipner CCS project starting up in 1996 was the first Norwegian full-scale CCS project and the world’s first offshore platform-based CO_2 capture facility. Sleipner is a gas and condensate field located 250 km offshore southern Norway. Using amine technology, the CO_2 was captured before being injected and stored in the Utsira formation at a depth of 1000m below the sea surface in saline aquifers (Ringrose, 2018).

The other full-scale CCS project currently running is the Snøhvit (Snowhite) CCS project in the Barents Sea. It started in 2008 and here the CO_2 is removed from the gas at an onshore processing plant at Melkøya before it is transported via a 150 km long pipeline to a geological formation under the Barents Sea (ibid.).

A main development within the history of CCS in Norway was the initiative taken by the social democratic Stoltenberg government in 2006 to establish Technology Centre Mongstad (TCM) in collaboration with Equinor (former Statoil). The plant is located at one of Norway’s most complex industrial facilities, Mongstad, and initially, the plan was to test CCS technology that could capture CO_2 emissions from the planned thermal power plant and the oil refinery at Mongstad. However, these plans were never realized, and today TCM is the world’s largest and most flexible test centre for developing CO_2 capture technologies, and it has proven important for developing technology that can be used on all kinds of industrial plants. It is also a leading competence centre for carbon capture. TCM is currently owned by the Norwegian state through Gassnova (73,9 %), together with the industrial partners Equinor, Shell and Total, all owing a share of 8,7 % (TCM, 2020).

Norwegian land-based electricity production is almost entirely based on renewable hydropower. Thus, Norway has few sites of large-scale point emission related to the combustion of fossil fuel. Still, there are some industrial sites with big CO_2 emissions related to processing. As regards the Longship project, three companies have studied the feasibility of CO_2 capture at their industrial facilities. Norcem assessed the feasibility of capturing CO_2 from the flue gas at its cement factory in Brevik. Yara Norge AS assessed CO_2 capture from three different emission points at its ammonia plant at Herøya in Porsgrunn, and the Waste-to-energy agency in Oslo municipality (EGE) assessed CO_2 capture from the energy recovery plant at Klemetsrud. The study concluded that NORCEM and EGE (later FORTUM) were the two sites best suitable for the Longship project, but in the end the Norwegian government decided to fully fund only the NORCEM plant (although FORTUM is also offered 50% funding if they are able to also receive EU funding) (Ministry of Oil and Energy, 2016).

II. Experiences with Transportation of CO_2

Norway has experience with transport of CO_2 using two different methods: transport by ship and pipeline systems. From the Snøhvit project, Equinor has experience with full-scale transport of CO_2 through a 110 km long pipeline from their Liquefied natural gas (LNG) plant on Melkøya before it is injected into a geological formation in the Barents Sea. As regards transport by ship this solution is part of the everyday operation in the foodstuff industry, although here the volumes transported are smaller (Gassnova 2019, OED 2002: 13).

In the Longship project, the distance between the capture site and the storage site is 400 nautical miles. The distance, together with allowing for a more flexible system with capture from numerous sites, argues for a solution with transport of CO_2 by ship. Here, a ship with a freight capacity of 7500 tonnes would be able to transport approximately 600 000 tons CO_2 per year. Although there is an already existing, mature commercial market for transport of CO_2, several issues still drive R&D within transport of CCS: (1) the volumes of CO_2 are big and there is a need for more cost-efficient solutions, (2) Prospective transport networks and junctions where CO_2 from different sources are mixed and (3) subsea pipeline transport in general holds higher costs and operational risks than corresponding onshore installations (Gassnova, 2019).

There are also several technologies used to inject the transported CO_2 into the storage site. The Longship project decided on offloading the transported CO_2 to an onshore intermediate storage site. This type of offloading system is available today and is technically the simplest solution with regard to ship transport as the ship does not need to be dimensioned for offshore offloading. Two competing solutions based on offshore offloading and injection, either via an offshore installation or directly from the transport ship, was not chosen for Longship due to its lower levels of technical maturity (Gassnova 2019). Ship transport of CO_2 between locations for capture and storage has been assessed for three different pressure and temperature conditions and conclude that all three solutions are technically feasible.

III. Experiences with Storage of CO_2

Norway's two industrial-scale CO_2 storage projects at the Sleipner and Snøhvit platforms are the only two projects currently running in Europe. Here, the captured CO_2 has been stored in saline aquifers. Since 1996, the Norwegian industry has gained valuable experience from its CO_2 storage operations at the Sleipner West gas field where 1 Mt CO_2 is injected into a sub-surface reservoir, consisting of saline aquifers, each year. Due to the activities on the Norwegian continental shelf, Norway has considerable competence on storing CO_2 in geological formations. The Norwegian Petroleum Directorate has developed a storage atlas for the Norwegian continental shelf which has identified a number of possible storage locations which made them conclude that it is possible to store more than 80 billion tonnes CO_2 on the continental shelf (Norwegian Petroleum Directorate, 2020).

For the Longship demonstration project, a feasibility study of three possible storage locations concluded that an injection well in the Smeaheia area had the biggest potential for future capacity extensions. By contrast, a concept study of CO_2 storage was done as part of the Northern lights cooperation between Equinor, Shell Total E&P, and this concluded that there were great insecurities regarding the storage capacity in the chosen storage location of Smeaheia. Thus, they recommended an alternative storage in the Aurora complex in the nearby Johansen formation as they argue that this area showed greater potential for CO_2 storage from other sources as well as decreased risks in the Longship project (OED, 2020, Gassnova 2019). In late November 2019 a verification well was drilled in the Johansen formation to verify the potential for CO_2 storage here. The well confirmed the suitability of the Aurora complex outside Western Norway, approximately 3000 meters below sea level for the Longship project.

As of today, there are few CO_2 handling projects being established in Europe. As there are rather small amounts of CO_2 in need of storage in Norway, the Norwegian government stresses the importance of many countries joining in on the CO_2 capture technology outside of Norway to scale up CO_2 storage activity internationally.

IV. <u>The innovation system</u>

One of the reasons why Norway has developed an international leadership position within the deployment of CCS technology is the fact that Norway has been successful in building an innovation system around the CCS technology (van Alphen et al., 2009). Norwegian authorities early on considered CCS to be part of the solution for the industry towards the low carbon society, and thus they have introduced several initiatives to facilitate a further maturity of CCS technology adapted to Norwegian needs.

Crucial in creating this innovation has been directing resources towards research and development. The research program CLIMIT was launched by the government in 2005 to support the development of CCS technology for gas power plants. The program should contribute to develop technology and solutions for capture, transport and storage of CO_2. In 2008, the program was expanded to include power generation based on all fossil fuels and in 2010 industrial emissions were included. The Research program is divided in two where the Norwegian Research Council covers the research phase and Gassnova covers the pilot/demonstration phase. Their primary goal is, through the funding of projects, to: (1) "Develop knowledge, expertise, technology and solutions that can contribute towards cost reductions and international deployment of CCS" and (2) "Leverage national advantages and develop new technology and service concepts with commercial and international potential". In total, CLIMIT Demo has co-financed approximately 370 development projects in CO_2 capture, transport and storage, with a total support of approximately NOK 1.2 billion. The two largest projects in CLIMIT Demo's portfolio have been the development of Aker Solutions' capture technology in the SOLVit program (2008 – 2015) with NOK 132 million in support and Norcem's test centre project (2013 – 2017) with NOK 66 million in support (CLIMIT, 2020).

In the program plan 2017-2022, "early full-scale CO_2 value chain in Europe" is defined as a separate goal. "Large-scale storage of CO_2 on the North Sea continental shelf" is another priority area. CLIMIT can contribute to develop solutions for enhanced oil recovery (EOR) and hydrogen production with CO_2 storage as well as support technology suppliers and industry actors in the development of new solutions for CO_2 capture (ibid.).

The Technology Centre Mongstad (TCM) is also part of the CCS innovation system, being the world's biggest technology centre for CO_2 capture. Several providers have tested their capture technology since the opening in 2012. Taking advantage of synergies with the Norwegian full-scale project is an outspoken part of TCMs strategy going forward (TCM, 2020; OED, 2020)

Norway also has had three research centres for environmental energy (FME) dedicated to the handling of CO_2 funded by the Norwegian Research Council (two lead by SINTEF Energy and one lead by CMR, currently NORCE). On FME is ongoing, the CCS Norwegian CCS Research Centre (NCCS) which was launched in 2016, is led by SINTEF and is financed for eight years. NCCS has approximately 20 research and industry partners and a budget exceeding 4000 million NOK. NCCS has clearly stated goals which support the Longship project. Amongst other, it is stated that: «NCCS should see to it that Norway realizes CO_2 storage in the North Sea», and that "NCCS should contribute to the government's ambition to realize a full-scale CCS value chain by 2020" (Ministry of Petroleum and Energy, 2014-2015).

A great number of development projects in Norway within CCS have been supported the last 20 years. It includes a large number of actors involved from the universities, research institutions, technology companies, service providers and companies that are potential end-users of CCS technology. To illustrate a specific technology development that has profited from state subsidies we can mention Aker Solution's development of amine-based CO_2 capture technology which has been developed from basic research to being ready for full-scale deployment, amongst other through testing at the TCM test centre. This is the technology that will be used for the Longship project.

There also exists a long list of international networks, programs and for a where CO_2 capture and storage is discussed and developed. The Ministry of Petroleum and Energy, Gassnova and the research Council Norway are represented in many such institutions. These institutions play an important role in contributing to an international focus and coordinating research, development and demonstration of CCS. Norway is a member of the following networks:

- EraNET-ACT
- Zero Emission Platform (ZEP)
- Strategic Energy Technologies Implementation Plans (SET-planeri EU)
- Carbon Sequestration Leadership Forum (CSLF)
- CEM
- Mission innovation
- Global CCS Institute (GCCSI)
- IEA Greenhouse Gas R&D Programme (IEAGHG)
- Memorandum of Understanding (MoU) of CO_2 handling with the US
- North Sea Basin Task Force
- The Carbon Capture & Storage Association (CCSA)
- CO_2 Geological Storage Europe (CO_2 GeoNet)

b. Political context

In an international context, Norway stands out with unusually strong political support for CCS. By broad political support is meant (1) a central place for CCS on the national climate policy agenda, (2) strong statements of commitment to a CCS strategy by political leaders, and (3) policy measures to foster technology development and commercial applications (Tjernshaugen 2011). One example of the strong commitment to a CCS strategy was the statement by the social democratic Prime Minister Jens Stoltenberg (made in the 2006 New Years' speech) that the successful development of full-scale CCS technology would be Norway's 'moon landing project' (Tjernshaugen 2007).

An important change in the CCS development in Norway across time that has also inflicted on the political support is a move away from solely seeing CCS as a way to make oil and gas extraction more cost-efficient to seeing CCS as a vital part of Norway's commitment to reduce CO_2 emissions and reach international climate agreements. Consequently, Norway's CCS development long centred around the oil and gas industry, gas extraction and gasworks with low CO_2 footprint. Yet, the last decade it has centred more around capture from industrial sources and flexible storage technologies that can store CO_2 from several sources.

A cross-national study using government 2005 RD&D budgets as an indicator of political commitments to a CCS strategy found that among high-income countries in Europe and North America, political commitment is closely related to oil and gas reserves per capita as well as the share of a country's GDP that comes from oil and gas extraction (Tjernshaugen 2008). This link between the large oil and gas sector and the political support for CCS is important, but not the entire answer, according to Tjernshaugen (2011). Tjernshaugen argues that a fundamental driver for Norwegian CCS policy has been the conflict between energy and climate policy goals, as well as the fact that early CCS activity bred more CCS activity later. In Tjernshaugens (2011: 240) own words: "Early CCS activities and debate helped build relevant expertise, familiarity with and stakeholder support for CCS, all of which helped pave the way for later policy initiatives".

In the debate over a CO_2 tax on the offshore oil and gas industry, environmental bureaucrats as well as ENGO activists experienced how CCS and other technological proposals helped convince politicians to introduce regulations.

Norwegian authorities have pushed CCS for several decades. In the political platform of the current government, the Sundvolden platform, the Government states that it will "invest on a broad front to develop cost-effective technology for carbon capture and storage (CCS) and seek to build at least one full-scale carbon capture demonstration plant by 2020" (Ministry of Petroleum and Energy 2014-2015: 115). The Government's CCS strategy was presented in Proposition 1S to the Storting (Ministry of Petroleum and Energy, 2014-2015). The strategy covers a wide range of activities, like R&D and demonstration projects, a realization of full-scale demonstrations CCS value chain, international activity and work with creating a solid foundation for a future market for CO_2 handling (Ministry of Petroleum and Energy 2014-2015).

During their work with the strategy for Norway's CO_2 handling, the Ministry of Oil and Energy (2014-2015) reports to have been in dialogue with the following stakeholders: the Federation of Norwegian industries, the ENGOs Bellona and Zero, research organizations and different companies that are involved with CO_2 handling in Norway and abroad. Moreover, the government has received feedback from the Norwegian Environment Agency, the Norwegian Petroleum Directorate, the research organization SINTEF and Research Council Norway. This shows that a wide range of stakeholder groups have been included in the process by the authorities, although it is interesting to read that they do not seem to have been in contact with the ENGOs that are less positive towards CCS technology.

I. <u>Onshore-offshore discussion</u>

In the Norwegian context, the discussion surrounding the development of CO_2 storage has exclusively focused on offshore storage. Mappings done by Norway's geological study has shown that Norway does not have suitable geological formations underground on land. Thus, in Norway it is only possible to store CO_2 in the sub-seabed on the Norwegian continental shelf (OED, 2020: 13). According to the Norwegian Petroleum Directorate's CO_2-storage atlas (2020), it is theoretically possible to store more than 80 billion tons CO_2 on the continental shelf. This makes up the current Norwegian CO_2 emissions for more than a thousand years. Thus, the Norwegian continental has been pointed to by the EU as a main site for Europe's CO_2 storage. Moreover, due to the history of offshore oil and gas production in the North Sea, the technology and the infrastructure is already partly in place. Moreover, and for the same reasons, the industry is well placed to develop technologies and infrastructure for transport and storage under the offshore seabed.

In Norway, CO_2 will be stored under the seabed far away from residential areas, which reduces concerns about local effects in case of unexpected leakage from storage sites. The fact that the CO_2 storage site is off the coast and under the seabed also contributes to keep CCS somewhat an abstract technology, as only a small number of Norwegian citizens physically see the infrastructure necessary to facilitate large-scale CCS systems. It is mainly in connection with the CO_2 capture sites. This is also expected to lead to less controversy, and the fact that a great majority of Norwegians support CCS may serve as an indicator of this (Andersen 2020, Tvinnereim and Steinshamn 2016).

II. Subsidies (financial support)

The Norwegian government has been and is key to the development of CCS in Norway. The Norwegian Pollution Control Authority (SFT) began funding CCS RD&D already in 1988 (Tjernshaugen 2011: 241). The early dedication of the national government to reduce Norway's CO_2 emissions has led to a consistent build-up of a national CCS innovation system across several decades (van Alpern et al., 2008).

In the Longship white paper, the authorities recognize that there is market failure connected to CCS technology preventing industry actors to develop and make use of necessary climate technology. They point at two market failures: (1) the CO_2 emission prize is lower than the social costs connected to such emissions. Thus, there are negative externalities as the actors producing CO_2 do not carry the social costs of their emissions. By pricing emissions, through taxes or through a quota marked, Norwegian authorities forces the social costs of emissions on the companies; (2) development of new technology is a common good in the sense that more than the actor developing the technology may make use of it. Thus, those who develop the technology will carry the costs, while the gains will be shared by the many. Thus, suppliers of technology, develop experience and knowledge causing later actors to meet lower costs. Thus, there is an incentive in the market to wait until someone else takes the costs of developing the technology. These two market failures work cumulative, and that is problematic in a situation where the Paris Agreement tells us we need to develop new technologies and use them in industrial scale to reach the 2 degrees target. In this way, taxing emissions and funding development of CCS technology seems the most efficient to Norwegian authorities (Ministry of Petroleum and Energy, 2020: 27-28). A last point is that there are investment barriers connected to establish the storage facilities, and before the entire CCS system has developed functioning markets for the entire chain of activities, there are risks connected to whether others will develop solutions for the other parts of the CCS chain. This is a risk that actors producing CO_2 are not willing to take and should not take, according to Norwegian authorities. To sum up, then, high investment and operational costs combined with low income potential and technical risk makes it challenging for commercial actors to invest in capture and storage of CO_2 (OED, 2020). Thus, it is an outspoken motivation for the Norwegian government to help move CCS technology towards cost-efficient solutions preparing it for a future market.

III. Political support

An international study including attitudes towards CCS among stakeholders from the energy sector, found that stakeholders in Norway are the most pro-CCS in Europe in terms of its role and impact. Moreover, they argue that stakeholder opinions tend to reflect the state of play on CCS in the respective countries. Hence, for Norway, there is more optimism among stakeholders "that CCS will be deployed without major impediments, that it is a 'good thing' with manageable risks and that the public will not object" (Shackley et al. 2007: 5107).

Illustrating of the findings above is the distinct characteristic of the Norwegian CCS issue, namely the presence from the mid-1990s of a high-profile environmental non-governmental organization, Bellona, actively promoting CCS solutions (Tjernshaugen 2011). Key environmental organizations were recruited as CCS promoters at a very early stage.

Tjernshaugen (2011) analyses the growth of political support for CCS in Norway and puts forward what he denotes the 'clean fossil fuels activists' as a distinct branch of the environmental movement which has been influential in the Norwegian CCS debate. In particular, the ENGO Bellona experienced a great deal of success with its early CCS initiatives in the mid-1990s in terms of policy outcomes, media attention and establishing dialogue with influential actors in politics and business. This strengthened Bellona's standing in the Norwegian climate policy debate and was used to promote CCS further. Bellona's success also inspired the establishment of the organization Zero Emission Research Organization (ZERO), another environmental organization that sought to promote CCS as a key element of Norwegian climate and energy policy. In short, the CCS debate helped establish these clean fossil fuel activists as a distinct voice in the Norwegian climate policy debate and helped provide these organizations with the resources they needed to promote CCS further. Moreover, Tjernshaugen argues that the relatively weak position of the international ENGO Greenpeace, which has represented a distinctly sceptical voice in the international CCS debate, may have also contributed to the relatively positive attitude towards CCS among Norway's environmental organizations.

As opposed to environmental organizations in most other countries, the Norwegian environmental organization have been either positive (Zero and Bellona) or passive towards the development of CCS technology. As part of his dissertation on Norwegian environmental organization and CCS development, Swensen (2015) finds that key personnel in some organizations found it challenging to be publicly negative towards CCS technology as CCS has become so intertwined with mitigating climate change that being against was side-lined with questioning whether climate change was at all real. Thus, some actors reported to stay silent in the debates on CCS, although they were sceptical of the technology.

The Norwegian government mentions explicitly that CO_2 storage is meeting a lot of opposition in other countries and argue that due to this, Norway should be active in the international arena and talk about the good experiences in Norway regarding storing on the Norwegian continental shelf. They hope that this will improve the reputation and regulation of CO_2 storage in Europe (OED, 2020).

The political elite are also clear in their support of CCS. Since the beginning of the 2000s there has been close to unanimous support among the parties in parliament of CCS technology as a key solution to reduce Norwegian CO_2 emissions. Yet, a new development was seen in the wake of the launch of the Longship project in October 2020. Then, the rightist Progress Party announced that they would not support the project due to the high costs placed on the shoulders of Norwegian taxpayers (Teknisk ukeblad, 2020). Interestingly, they have had the last three Ministers of Petroleum and Energy in the current government, until they left government in January 2020, so the Progress Party has been important in the development of the project. This change in policy view also indicates more disagreement at an important stakeholder group that we do not yet know the consequences of in terms of continued public support for the Longship project.

c. Regulations and legislative framework

Emissions due to industry is regulated by the Regulations related to Pollution control which has been part of the Norwegian legal system since 1971. This regulation says that all activities involving pollution must be applied for and given a license prior to startup. As part of the application the polluter must conduct an impact assessment covering impacts on all environmental aspects (the natural, the built and the social environment) and give feedback on how they will mitigate issues uncovered. In the final stage it is the Norwegian Environment Agency that decided whether a license should be given.

As regards legal framework for CO_2 storage, Norway had no specific regulations when Statoil initiated its Sleipner and Snøhvit projects. Therefore, existing mining regulations applied to them. According to these regulations, Statoil is responsible for the stored CO_2 as long as the field is in operation, but after the operation has ended, the company needs to prepare the field to hand it over to the Norwegian government, which is then liable for the sequestered CO_2.This transfer of liability of the stored CO_2 was further refined as the issue was taken up in European directives (van Alphen et al. 2009: 48) that Norway, as an EEA member, has ratified.

The two most important international regulatory frameworks for Norway's CCS development are the London protocol and the Oslo-Paris Convention (OSPAR). The London Protocol is an international regulation based on the "Convention on the prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972". Norway is one of the 21 countries which have ratified the London Protocol, and the protocol was ratified in 1975. The London Protocol has been an obstacle to efficient international regulation of transport and storage of CO_2 because it has not allowed for foreign waste to be stored permanently in a different country. In 2009, Norway got a Resolution for Provisional Application through, allowing for export of CO_2 to geological storage. Still, for the amendment to come into force, 2/3 of the 51 parties to the protocol had to ratify the amendment, and this progress was extremely slow with only six countries having ratified it over 10 years. Thus, Norwegian authorities, together with Dutch authorities, took the initiative to include an amendment that removed the last international barrier to CCS, allowing for CO_2 to be transported across international borders to offshore storage. This amendment to the London Protocol was accepted in 2019 and has been developed, but as of now few countries have ratified it, so the Norwegian Ministry of Petroleum and Energy actively works to influence more countries to ratify these changes. If the North Sea is going to be able to store CO_2 from a range of countries, this amendment to the London Protocol needs to be ratified in the source countries (OED, 2020: 52-53).

The OSPAR convention was made to protect marine life. Relevant to the Norwegian CCS projects is that in 2007 the OSPAR commission ratified changes to the convention to allow for storage of CO_2 in geological formations under the seabed. At the same time OSPAR agreed on general requirements for risk assessment in relation to CO_2 storage under the seabed (OED, 2020: 53).

One of the main goals of the Longship project is to use European and Norwegian regulations in an entire chain with different actors. The project demonstrates use of the European emission allowance system as well as the EU storage directive. The EU storage directive was implemented in the Norwegian legal system in 2015 as regulations. Moreover, Norway also has political joint declarations and agreements which comprise cooperation on CO_2 capture and storage with the UK.

Last, there is an informal forum of cooperation called the North Sea Basin Task Force (NSBTF) consisting of the authorities and representatives from the industry from Norway, Great Britain, the Netherlands and Germany. The objective for the task force is to develop common principles for secure transportation and storage of CO_2 in the North Sea basin (Ministry of Petroleum and Energy 2014-2015: 124).

d. General public support

A distinctive feature relevant to public support is that the legitimacy of CCS as an environmental policy measure has mostly been taken for granted in the Norwegian debate. This has not been the case in most other countries (Tjernshaugen 2011).

In general, there seems to be broad popular support for CCS today. Recent studies conducted in 2019 and 2020 and not yet published, report that approximately 75 percent of Norwegian citizens are positive towards CCS (Andersen, 2020). Moreover, in a study where respondents are introduced to the Longship project and asked about their opinion, 68 percent of the respondents placed themselves on the positive side of the scale (ibid.). Still, when it comes to the being introduced to a specific realization of the Longship project, a clear minority voice their concerns, arguing that it is a pipe dream, that it is too expensive, and that taxpayers' money should be prioritized on other projects. It is an open question whether opposition will increase as more full-scale projects are realized and a market for CO_2 storage in the North Sea develops. Yet, so far concerns related to climatic consequences related to leakage from storage sites as well as the discussion of whether CCS might help 'lock in' fossil fuels and compete with renewable energy for public subsidies have been relatively marginal issues in the Norwegian public debate (Tjernshaugen 2011: 228). Instead, the debate has focused more on the costs, practical feasibility and realistic time frames for the introduction of full-scale CCS solutions (Tjernshaugen 2011). That said, Andersen (2020) may point to CO_2 storage being more contested in the future when he reports that the nationality of the CO_2 seems to matter to Norwegians. They are significantly less supportive of storing foreign CO_2 permanently in the North Sea when compared to storing Norwegian CO_2.

e. Status monitoring of CCS

The 25 years of monitoring of CO_2 connected to the storage of CO_2 from the Sleipner platform has been based on seismic 3D monitoring. CO_2 plume monitoring observations at Sleipner indicate an overall storage efficiency of around 5% after 14 years of injection, with approximately one tenth of this volume dissolved in the brine phase. Future storage projects could expect storage efficiencies of a similar order of magnitude, although very dependent of the specifics of the geology (Ringrose 2018).

The necessary regulations are in place for monitoring, both nationally and internationally. Regulations related to pollution control oblige the project owner to keep control with the CO_2 distribution in the reservoir, to detect possible leakage to the sub-seabed as well as corrective measures. In terms of public support, Andersen (2020) presents an unpublished study by him and colleagues finding that a considerable number of citizens are worried about leakage from the plume. This may serve as an indicator that informing them about the R&D within monitoring systems may help increase public support for CCS in Norway further.

For the Longship project the main monitoring strategy is twofold: First, direct monitoring will be done at the injection well supervising both temperature and pressure of the CO_2 to identify changes in the reservoir. Second, seismic monitoring of the sub-seabed will be done to gain insights into the flow behaviour of CO_2 in the reservoir.

f. Environmental implications

The environmental implications of the current CCS project in Norway are hard to quantify. In terms of reduced CO_2 emissions, we know that the Sleipner and Snøhvit CCS projects reduce Norwegian CO_2 emissions by 3-4 percentage points per year. The white paper for the Longship project state that the direct national reductions in CO_2 emissions will be approximately 400 000 tons CO_2 per year. According to the impact assessment this would reduce Norway's total CO_2 emissions by 1 percentage point, based on 2018 emission levels (Equinor, 2019: 140). Indirectly, the Longship project is also argued to pay off by successfully demonstrating an entire, flexible value chain with CCS and by establishing an infrastructure for CO_2 transport and storage which will lead to reduced costs for later projects (OED, 2020: 64-65).

In terms of the natural, built and social environment the environmental implications of the current projects are considered small, and this is also the overall conclusion for the Longship project, as treated in the impact assessments (Equinor, 2019; OED 2020, Multiconsult 2019). As most of the infrastructure is under the sea off the Norwegian coast it does not have big implications for fisheries, and few citizens are affected directly by the ongoing CCS projects.

g. Type and number of CC(U)S projects

Underneath follows a short description of the most important CCS projects (except Longship, as this is treated in detail during the SEL assessment) in the Norwegian case:

Sleipner – the first industrial scale CCS project in Norway started in 1996. Since then, Sleipner has captured and stored 22 Mt of CO_2 in saline aquifers offshore Norway (Ringrose 2018).

Snøhvit – the Snøhvit CCS project started in 2008 as part of the Snøhvit gas field development in the Barents Sea. The CO_2 is removed from the gas at the onshore liquefied natural gas (LNG) processing plan at Melkøya and then transported via a 150 km long pipeline to a subsea injection template in the Barents Sea. By the end of 2017 almost 5 Mt CO_2 had been injected into the subsurface.

Yara – From the Ammonia plant N2 at Herøya in Porsgrunn, Yara capture 200 000 tons of CO_2 per year and sell for use within food production.

Northern lights – this is the first full-scale transport and storage project, where the government gave its final investment decision in 2020. Northern Lights is the transport and storage part of the Norwegian full-scale demonstration project assessed in this report, the Longship project. Thus, Northern Lights comprises transport, reception and permanent storage of CO_2 in a geological reservoir in the northern parts of the North Sea. The first phase is planned to be operational in 2023 and will include an onshore offloading, intermediate storage and export site in Øygarden commune, west of Bergen, a pipeline and control wire from the onshore site and to an injection well and a geological reservoir for injection and permanent storage of CO_2 (Gassco, 2017).

TCM, Technology Centre Mongstad, is the biggest test site for CO_2 capture technology in the world and has been a core element in the strategy work of CO_2 treatment. The main objective of TCM is "to test, verify and demonstrate different technologies related to cost-efficient and industrial scale CO_2 capture" (TCM, 2020). The centre covers a hole in the chain of technology development by offering a site to test different capture technologies in industrial scale. The capture technology used at NORCEM for the capture part of the Longship project was tested and developed at TCM by Aker Solutions (Gassnova, 2019).

1.3 SEL assessment for CCS in Norway

a. Determining reference point for SEL

Depending on which CCS project, or which part of the CCS value chain you choose to focus on, the TRL-level will vary. In this report, we base our SEL assessment on the Longship project introducing a complete, full-scale CCS value chain from capture to storage. Although we consider an entire technology system where all components of the value chain have reached high TRL levels separately, there is insecurity related to the interfaces from capture to transport and from transport to storage. Thus, we have identified the Longship project to have a TRL level equal to 7 – "system prototype demonstration in an operational environment". This places the Longship project at a reference point for SEL to equal 3 – Demonstration. Although evaluating an entire CCS value chain does create some challenges related to answering some of the research question, it is in this full-scale project that the greatest potential for further up-scaling and successful storing of great amounts of CO_2 is the biggest and thus it seems most valuable to evaluate this project, which is illustrated in Figure 6 below.

The overarching goal of the Longship project is to contribute to knowledge and efficiency improvement so that subsequent projects will have reduced costs. The innovation in the Longship project is (1) demonstration of a whole, yet flexible, chain with CO_2 capture from cement production, transport by ship and storage of CO_2 underneath the seabed; (2) based on European and Norwegian regulations in an entire chain with different actors. The project demonstrates use of the European emission allowance system as well as the EU storage directive; (3) a flexible transport and storage solution with the capacity to receive CO_2 from several sources; (4) a commercial framework with incentives for further development of CO_2 handling in Europe. (OED 2020: 20)

This SEL assessment is based on three main analytical approaches. The first approach is a document study based on 20 chosen documents that were identified through searching dedicated search words and through a snowballing method where we went through reference lists for central publications and found documents that seems to be at the core to describe the state of CCS in Norway. Second, two expert interviews were conducted to cover some aspects in the SEL framework that were not so easy to get hold of through the document study. Third, I have also e-mailed two different experts specific questions from the SEL framework asking for their feedback when it has been difficult to find an answer based on the other two methods used.

Thus, when we continue to systematically go through the research questions per milestone, it is within SEL level 3 we start out. The evaluation is structured so that each milestone and the corresponding research questions are covered in some paragraphs. Moreover, a table for each dimension is presented identifying the relevant milestones and whether the milestones have been reached or not. Green highlighting indicates that the milestone is met, whereas red indicates that the milestone is not met. It is important to mention again that when the SEL assessment asks about impacts of a specific system, the system that I evaluate is the Longship project demonstration of an entire innovation chain from CO_2 capture via transport and to storage.

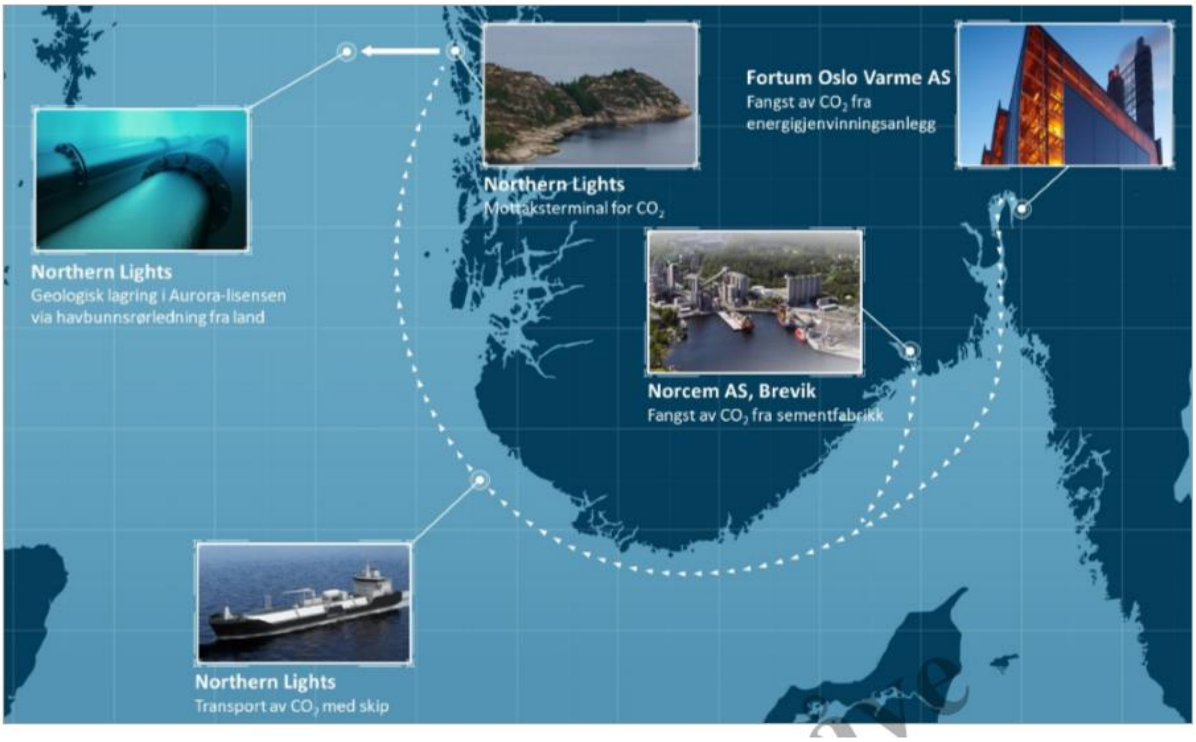

Figure 6 Illustration of the Longship project. Note that the Norwegian government only decided to fully fund CO_2 capture at the NORCEM site, whereas FORTUM is encouraged to apply for co-funding from the EU [1]

Table 7 Dimension 1: Environment

	SEL 3 Demonstration
Milestone 1	The impacts of the system on the natural environment are assessed
Milestone 2	The impacts of the system on the built environment are assessed
Milestone 3	The impacts of the system on the social environment are assessed
Milestone 4	Negative impacts of the technology and its system on the natural environment are mitigated
Milestone 5	Negative impacts of the technology and its system on the built environment are mitigated
Milestone 6	Negative impacts of the technology and its system on social environment are mitigated
Milestone 7	Impacts of the technology and its system that emerge from the demonstration phase are assessed

[1] Source: Gassnova.

Milestone 1: The impacts of the system on the natural environment are assessed

According to the Regulations related to pollution control from, 1971 all industrial projects must do an impact assessment of the impacts of the natural environment before they are considered for a license can realize their projects. This is also the case for the Longship project, and thus all the RQ asking within Milestone 1 has been assessed. Impacts of the system, on land, on air, on water and on life are all assessed. For the capture plant, NORCEM, assessments of Health, safety and the environment (HSE) have been conducted related to the operating phase, identifying no HSE aspects that prevent construction and operation of their CO_2 capture plant. There are issues related to emissions, waste and use of chemicals, yet for the full-scale capture which is planned to use amine-based CO_2 capture technology this is concluded to take place in a manner that is safe for both people and the environment. The spread of emissions to air and water is also assessed by NORCEM, and they have studied accidental CO_2 spills, which is identified as one of the greatest HSE risks. The most dramatic scenario of a full pipe rupture in a CO_2 storage tank is far below the acceptance criteria used by the Norwegian Directorate for Civil Protection for such incidents (Equinor 2019; Multiconsult, 2019).

There are several impact assessments carried out in relation to the Longship projects where environmental implications are discussed. An impact assessment based on the transport and storage part of the project (named Northern Lights) have gone through systematic danger indications as well as qualitative risk assessments for onshore facility, export pipeline and underwater systems. They find no dangers indicating high risks (Equinor, 2019). Moreover, evaluations on the natural environment were explicitly addressed through a number of documentation reports. They describe the impact of the system on land, on the fjord system and on air. More detailed, they evaluate marine nature types and the effect of the system on plankton, marine mammals, fish stocks, birds and seafloor fauna and shell grit (ibid.). Thus, the impact of the Longship project on the natural environment seems well assessed.

Milestone 2: The impacts of the system on the built environment are assessed

As most of the technological system is based at sea, this point is mostly relevant for the capture site and for the onshore facility of discharging CO_2. The possible threat of the building and operation of CO_2 capture in relation to the NORCEM plant and its immediate surroundings have been evaluated and found to be negligible (Multiconsult, 2019).

The impact of the project for cultural heritage, the local environment and landscape is assessed. Impacts on traffic, road safety and childhood environment are discussed. The issue of noise and consequences for the housing areas surrounding the plant for transferring CO_2 from ship to pipelines are also discussed. Effects on drinking water supply and power supply is also taken into consideration.

Milestone 3: The impacts of the system on the social environment is assessed.

Through impact assessments of the different parts of the CCS chain for the Longship project and a final assessment of the entire chain, the system is not found to have particular negative impacts on social relationships, cultural milieus or institutions of immediate physical surrounding. As the system is mainly placed at sea it does not come into physical conflict with built society to the same extent as an onshore CCS system would.

Consequences for different industries at sea are also evaluated. Especially, the look at consequences for fisheries, fish farming, shipping, offshore wind parks and sea grass withdrawal is considered.

Also, consequences for land-based industry, mainly agriculture, are considered. Overall, the conclusion is that the Longship project has limited impact on the social environment (Equinor, 2019).

Milestone 4: Negative impacts of the technology and its system on the natural environment are mitigated

By using ships in the transport phase, emissions to air follow. To minimize emissions, it is decided to use LNG as fuel for the CO_2 transport ships. For the same reasons, a quay to quay solution is chosen, with CO_2 emissions estimated at about 1.3 to 2.9 per cent of the transported volume of CO_2 (Equinor, 2019). Moreover, the ships will have shore supply when they lie alongside the quay. Also, the pipeline trace is placed to minimize exposure to third party if leakage should occur.

The most dramatic consequence of CCS would be leakage of CO_2, either through transport and into the air, or into the sea through the pipelines or through leakage out of the plume and into the seabed. As part of the impact assessment for Northern lights, the risk for leakage is considered to be low. Yet, monitoring is an important instrument to keep control of the injected CO_2 and to enable the operators to detect movement and pressure in the plume across time. Here, they draw on knowledge from the Sleipner and Snøhvit storage projects. A public-private research effort, co-funded by the EU but coordinated by Statoil, included many international oil, gas and energy companies and research institutes. The aim of the project, running from 1998 to 1999, was to monitor the CO_2 behaviour at Statoil's storage site in the Utsira formation (the Sleipner project). This led to the world's first 3D seismic survey of CO_2 in an aquifer (Torp and Gale, 2004). They concluded that conventional time-lapse seismic data was a successful monitoring tool for CO_2 injected into a saline aquifer, building their confidence that any major leakage into the overlying cap rock succession would have been detected (Torp and Gale, 2004).

Thus, the main strategy of monitoring in the Longship project is divided into primary and secondary monitoring. The primary monitoring will be connected to the injection well and consists of monitoring injected CO_2 and CO_2 rate on the wellhead to control the amount on injected CO_2. Moreover, they will monitor temperature and tension in the well to detect changes in the reservoir conditions as well as any possible leakage in or nearby the well. Secondary monitoring is connected to the underground and includes collection of 4D seismic (3D seismic repeated across time) to update the understanding of the reservoir and indicate if CO_2 should move out of the storage complex. They also consider passive monitoring through Digital Acoustic Sensing or through a system of seismic point sensors at the storage site. Although not mitigation per se, the monitoring strategies allow for control with the injected $CO_{2,}$ which is an important safety issue.

Milestone 5: Negative impacts of the technology and its system on the built environment are mitigated

With the Longship project, not much built environment is affected as most of the infrastructure is either already in place or will be built into the sea. The NORCEM facility will be expanded to fit a temporary storage area for the CO_2 awaiting transport and the land-based plant receiving and sending the transported CO_2 into a pipeline is established in an already developed industrial area in a rural part of Norway. As such, negative impacts for the built environment are kept at a minimum (Multiconsult, 2019).

Milestone 6: Negative impacts of the technology and its system on social environment are mitigated.

The social environment is to a very small degree impacted by the Longship project, and as such mitigation measures are not considered to be necessary (Equinor, 2019; Multiconsult, 2019).

Milestone 7: Impacts of the technology and its system that emerge from the demonstration phase are assessed.

Although the full-scale demonstration is not yet realized, all parts of the chain has been through full-scale demonstration. Thus, the impacts of the system that may still be insecure is related to the interphases between the three main components of the value chain: between capture and transport, and between transport and storage.

To sum up, all research questions and milestones within SEL 3 has been answered with yes, allowing us to identify the environment dimension to have reached SEL 3. When I have not identified the environment dimension to reach SEL level 4 Deployment, this is mainly due to the lack of fulfilment of Milestone 1 at that level; "Negative impacts of the technology and its system that emerged from the demonstration phase are mitigated". It is impossible at the current stage to mitigate negative impacts of the demonstration phase before the full-scale demonstration is realized (which is what will be done in the Longship project).

Table 8 Dimension 2: Stakeholder Involvement

	SEL 3 demonstration
Milestone 1	Inventory of all relevant stakeholders in the field for the technology and it's system
Milestone 2	Decision on level of participation of the stakeholders in demonstration process of the technology and it's system
Milestone 3	Design for Stakeholder participation tailored to stage of demonstration of the technology and it's system
Milestone 4	Knowledge, opinions, questions, concerns and perspectives of all relevant stakeholders of demonstration site translated into the project design/strategy for further development.
Milestone 5	Trust building actions are taken for demonstration of the technology and it's system

Milestone 1: Inventory of all relevant stakeholders in the field for the technology and its system

Impact assessments both for the site for CO_2 capture and CO_2 storage and white papers all identify stakeholders who would be impacted by the technology and its system. In particular, there is focus on the consequences for fisheries and surrounding industry, but stakeholders like the broader public is also mentioned. In terms of stakeholders who can impact on the technology and its system, this can be interpreted in a broad and narrow sense. In a narrow sense, the feasibility study identifies numerous technological actors that have been important in fine tuning the technology, in particular through their participation at TCM Mongstad, and that may play a role as partners in future projects. It is repeatedly argued that the technological environment working on CCS is very advanced in Norway (Equinor, 2019; Multiconsult, 2019).

Other stakeholders are industry partners. Here, CCS has been favoured by a powerful coalition of the Norwegian Confederation of Trade Unions and the Federation of Norwegian Industries. Together with the national oil companies, these interest groups occupy a privileged role in Norwegian politics and thus make up a powerful lobby for deployment of CCS in the political arena (OED, 2020).

Milestone 2: Decision on level of participation of stakeholders in demonstration process of the technology and its system.

Stakeholders who are relevant for the demonstration are identified both through feasibility studies and through numerous assessments both of the transport and storage part of the project as well as of the entire Longship project.

Who are relevant stakeholders for the demonstration is a complex question. This, however, is to a certain extent regulated through the process of impact assessments where the plans for the Longship project has been sent to affected parties, affected authorities as well as interest organizations. Moreover, local politicians and citizens are also considered to be stakeholders and they have been included through popular meetings and the possibility for people to give feedback in the consultation process.

Milestone 3: Design for Stakeholder participation tailored to stage of demonstration of the technology and its system

As mentioned, stakeholder participation is arranged through popular meetings, consultations and open hearings in the process. Stakeholders are able to give their feedback in time to actually inflict on the final project. The process is inclusive independent on whether the stakeholders are positive or negative towards the project. It is hard to identify what is the most beneficial point in time to be involved, but crucial to the process of impact assessment is that all possible stakeholders are given the opportunity to give relevant feedback. In the end it is the Norwegian Environmental Agency that approved the impact assessments and awarded the necessary licenses to realize the project.

Milestone 4: Knowledge, opinions, questions, concerns and perspectives of all relevant stakeholders of demonstration site translated into the project design/strategy for further development.

We see, that the consultation process and popular meetings have resulted in changes to the project, in particular related to the planning of the planned pipeline from the onshore site on the coast and the injection well on the Norwegian continental shelf. The pipeline was supposed to go on land through the gas terminal Kollsnes, but due to neighbours, an impact area for drinking water and the nesting area for the eagle owl, the pipeline will go offshore immediately. Similarly, the projected line for the pipeline is offshore to avoid an area with local fishing areas and an area of high recreational value. Also, due to massive local resistance both publicly and among local government, a planned control station on land on the island municipality of Fedje was replaced by an offshore host installation connected to the Oseberg oil and gas field (Equinor, 2019).

Monitoring is an important tool to meet a concern that is present among Norwegians regarding the possibility of leakage from the injected CO_2 (Andersen 2020). Thus, the development of best practice monitoring may contribute to reduce societal concerns. Still, as of now no study has looked into the potential for increased support based on this. Participatory monitoring has not been used.

Milestone 5: Trust building actions are taken for demonstration of the technology and its system

Popular meetings and consultations have been held as part of the preparation of both the storage site and the capture sites (Equinor, 2019; Multiconsult, 2019).

To sum up the result of the SEL assessment for Dimension 2 – stakeholder involvement, all research questions and milestones for SEL 3 is reached. When I have not identified stakeholder involvement as reaching SEL level 4, deployment, this is due to the lack of fulfilment of Milestone 4 “The relevant stakeholders are included in the deployment process”. As the Longship value chain is not up and running yet, the role of the stakeholders in the deployment process in terms of information, coordinated knowledge flows and the optimal involvement of stakeholders in time is not possible to assess.

Table 9 Dimension 3: Policy and Regulations; milestones towards SEL 3

	SEL 3 demonstration
Milestone 1	Certification and permit requirements for the system are assessed
Milestone 2	Interactions between developers and governments to create support for demonstration of the technology and its system
Milestone 3	Policy and regulatory drivers and barriers are assessed for the system
Milestone 4	Regulatory and policy framework supports demonstration of the technology and its system

Milestone 1: Certification and permit requirements for the system are assessed

Yes, necessary certification and permit requirements are assessed for the system. This also applies to the monitoring system planned for the injected CO_2.

Milestone 2: Interactions between developers and governments are in an advanced stage and have secured support for demonstration of the technology and its system.

The Longship project is a big investment for the Norwegian government as they invest 17 billion NOK in this full-scale demonstration. Thus, several departments and authorities cooperate and collaborate in this project. The Ministry of Petroleum and Energy owns the project, but both the ministry of climate and environment and the ministry of trade, industry and fisheries have been part of the process, as well as several national agencies. At the regional and local levels, typically in relation to the sites for CO_2 capture storage, local governments have been involved in the process and have been asked to give feedback on the planned project. Also, the county governors have been active in the impact assessments both for CO_2 capture and CO_2 storage (Equinor, 2019; OED, 2020).

The question of lobbying is a complex one, due to the way CCS has developed in Norway. In a way one may speak of invert lobbying from bureaucrats in the ministry of oil and energy towards Equinor to secure development and demonstration sites for CCS technology (Nøttvedt, 2020). The government established GASSNOVA in 2007 as a business enterprise with the government being the majority stockholder, to work for government interests related to CO_2 as a stage towards full-scale CCS projects. This impression that the development has been pushed by the government more than by the industry also was visible after the economic crisis in 2008. It was vital for the current realization of the Longship project that the government kept their obligations to CCS development by keeping the Climit programme and working for TCM Mongstad both through the economic crisis of 2008 and of the oil crisis in 2014 (Nøttvedt, 2020). That said, the oil and gas industry has in general been positive, but more reluctant to bear the costs. When it comes to interest groups, parts of the environmental movement have been very pro CCS and have argued for the establishment of CCS in relation to fossil fuel power plants since the late 1990s.

I am insecure whether it is the advanced interactions between developers and governments that secure support for CCS. The government has been pushing the full-scale demonstration and take the economic risk, so the developers are in a very good position already at the outset. Also, the cooperation is mainly between the Norwegian government and companies with partial or full state ownership and this may lead to more increased support than what could be the case if the private actors had been more important on the financial side.

Milestone 3: Policy and regulatory drivers and barriers are assessed for the system

A special regulatory framework and CO_2 taxation in combination with extensive expertise in the oil and gas industry was what fostered CCS initiatives already in the 1990s. That said, the lack of CCS regulations has been considered one of the main obstacles to business initiatives, so also in Norway. To start with national regulations, Statoil did go ahead with investments in the 1990s despite regulatory uncertainties. Still, in the 2000s the Norwegian government worked on a supportive legal framework for CCS technology, including the development of qualification guidelines for CCS technologies (moving closer to similar EU directives). The EU storage directive was implemented in the Norwegian legal system in 2015 as regulations (van Alphen et al. 2008; OED 2020).

As regards international regulations, the London Protocol has been an obstacle to efficient international regulation of transport and storage of CO_2 because it has not allowed foreign waste to be stored permanently in a different country. This has been a severe obstacle to the plan of an international storage site in the North Sea. In 2009, Norway got a Resolution for Provisional Application through, allowing for export of CO_2 to geological storage. Still, for the resolution to come into force, 2/3 of the 51 parties to the protocol had to ratify the amendment, and this progress was extremely slow with only six countries having ratified it over 10 years. Thus, Norwegian authorities, together with Dutch authorities, took the initiative to include a similar amendment that did not depend on ratifications by 2/3 of member countries and that allowed for CO_2 to be transported across international borders to offshore storage. This amendment to the London Protocol has been developed, but as of now few countries have ratified it, so the Norwegian Ministry of Petroleum and Energy actively works to influence more countries to ratify these changes. If the North Sea is going to be able to store CO_2 from a range of countries, this amendment to the London Protocol needs to be ratified in the source countries.

Thus, today, both the national and international legal framework supports the development of CCS technology.

In addition to the legal framework, there are other drives in the system. Norway has political joint declarations and agreements which comprise cooperation on CO_2 capture and storage with the UK. Moreover, there is an informal forum of cooperation called the North Sea Basin Task Force (NSBTF) consisting of the authorities and representatives from the industry from Norway, Great Britain, the Netherlands and Germany. The objective for the task force is to develop common principles for secure transportation and storage of CO_2 in the North Sea basin.

One of the main goals of the Longship project is to use European and Norwegian regulations in an entire and flexible value chain with different actors. The project plans to demonstrate use of the European emission allowance system as well as the EU storage directive.

Milestone 4: Regulatory and policy framework supports demonstration of the technology and its system

Given the launch of the Longship project, which is a demonstration project financed by the state, we can conclude that regulatory and policy framework is supportive of the demonstration of the innovation system. The innovation is highly embedded in policy strategies, at the national level but also at the regional level, in particular the regions where CCS sites have been developed this far. We also know that locally, in relation to TCM Mongstad, there were also a lot of local strategies related both to the industry and education in the surrounding municipalities. The local sites for capture and storage plant both have positive ramifications for their local environments in terms of job creation and corporation tax.

To sum up, all research questions and milestones for Dimension 3 – policy and regulations could be answered with a ‘yes’, allowing us to conclude that SEL level 3 is reached also here. Nevertheless, for this dimension, we can go even further and also fulfil SEL 4 – deployment. The assessment underneath takes on this task.

Table 10 Dimension 3: Policy and Regulations; milestones towards SEL 4

	SEL 4 Ready for deployment
Milestone 1	Regulatory barriers are overcome for the technology and its system
Milestone 2	Supporting policies, laws and regulations are in place for the technology and its system
Milestone 3	Required permits and/or certificates for deployment of the technology and its system are awarded
Milestone 4	(Inter)national policy and regulatory framework supports deployment of the technology and its system

Milestone 1: Regulatory barriers are overcome for the technology and its system

Due to the unified political support for CCS development as part of the solution to reduce CO_2 emissions to meet the Paris agreement, the ability to pass legislation is clearly in place. For the Longship project, no new national legislation seems to have been necessary (Equinor, 2019, Multiconsult, 2019). The main regulatory barrier has been the London Protocol inhibiting storage of foreign CO_2 on Norwegian continental shelf. Yet, as already mentioned this legal hinder has been overcome due to recent initiatives from Norwegian and Dutch authorities. Still, parties need to ratify the amendment if they are to be able to store CO_2 on the Norwegian continental shelf. But as this is only relevant for phase 2 of the Northern Lights project this is not a challenge at this stage.

Milestone 2: Supporting policies, laws and regulations are in place for the technology and its system

The Longship project is initiated and financially supported by the authorities and can be realized within current laws and regulations. National policies, especially related to CO_2 tax and the ambitious goals for climate change mitigation, are clearly supportive for the further deployment of CCS (OED, 2020).

Milestone 3: Required permits and/or certificates for deployment of the technology and its system are awarded

The Regulations related to pollution control set out conditions for granting licenses, and a central condition is an impact assessment. In the case of Longship, the required permits and certificates are reported to be in place (Nøttvedt, 2020).

Milestone 4: (Inter)national policy and regulatory framework supports deployment of the technology and its system

Both national and international policy and regulatory framework is in place to support the deployment of the full-scale demonstration project. For a long time, the London Protocol was preventing the possibility of the storage site to receive and store CO_2 not only from Norwegian emission sites but also from abroad. With the successful amendment to the London Protocol done in 2019, this regulatory barrier is gone. As mentioned earlier, support schemes are definitely in place for the project. The Norwegian state covers 80 percent of the total cost of 25.1 billion Norwegian kroner for the Longship project. A vital reason for the government's funding is the recognition that CCS technology development has been marked by market failure and thus the development has not moved as quickly forward as expected. Thus, to encourage further maturity of the technology and develop cost-efficient solutions the Norwegian authorities have taken on a role as a driver of CCS development. Last, the innovation is closely embedded in national strategies, in particular connected to climate change policies, where CCS is identified to be one of the main ways to be able to reach the goals set in the Paris agreement (OED, 2020).

To sum up, in terms of Dimension 3 - policy and regulations, the Longship project operates at the highest SEL level 4 – deployment. Crucial to this advanced SEL level is the Norwegian authorities' early and continuous support for the development of CCS technology across three decades.

Table 11 Dimension 4: Market and Financial Resources

	SEL 3 demonstration
Milestone 1	Financial resources sufficient for demonstration of technology and its system
Milestone 2	Market strategy adapted to market dynamics
Milestone 3	Business case developed for demonstration
Milestone 4	Technology and it's system adapted to market/customer demands

<u>Milestone 1: Financial resources is sufficient for demonstration of technology and its system</u>

The evaluation from the project is that the financial resources for demonstration of the whole system are sufficient. A big majority of the funds going into the full-scale demonstration are public, made available by the government. The state will set aside 18.7 billion NOK for the Longship project, whereas the industry sets aside 4.5 billion NOK. This includes investment costs and ten years of operational costs. In the agreement with Equinor, on behalf of Northern Lights, the Norwegian authorities are obliged to cover 80 % of the expenses until after ten years of establishment. Costs for monitoring are not included in this agreement. If supply of CO_2 is low and the transport and storage operator is not able to recruit sufficient third-party customers, the state is obliged to cover 80 % of the costs connected to finishing, monitoring and removal of the storage system (OED, 2020).

<u>Milestone 2: Market strategy adapted to market dynamics.</u>

The government's white paper on the Longship project spends a considerable number of pages describing the market failure of CCS technology to explain the motivation by the state to fund CO_2 handling. They highlight two main points: 1) negative externalities – the CO_2 emission costs are lower than the societal costs connected to emissions of this kind. Thus, there is a mismatch between private profitability and societal/public profitability hindering emission producers to change their way. And 2) Positive externalities – developing new technology is a public good, and it is expensive. This means that the actors that develop the technology will bear the costs, whereas the gain will be shared by many and at much lower costs. Because of this, it is profitable for private companies to wait for someone else to take the costs of developing and demonstrating the new technology (OED, 2020).

To sum up, high investments and operational costs combined with low potential for income and technical risks makes it unlikely for commercial actors to invest in CCS at an early stage.

Norwegian authorities will also fund the next couple of projects quite extensively, but they expect that the projects will compete for support from more general schemes, for example through Enova or the EU Innovation fund. In the mature phase it is the government's plan that the costs are sufficiently reduced to ensure CO_2 handling projects to become commercial and receive sufficient incentives through general schemes like for example CO_2 price/charge and higher prices for climate friendly products. On January 8, 2021, the government announced its climate strategy to reach the Paris accord, and an important political tool identified is to increase the CO_2 tax fourfold by 2030, from 500 NOK per ton CO_2 today to 2000 NOK per ton CO_2 in 2030. This political tool is likely to push the demand after CO_2 storage, and further maturing CCS for commercial profit for operators of CO_2 storage. Over time, this can lead to effects on business and industry independent of government subsidies. It is expected that the Longship project will create 1500-3000 person-years during the construction period and 170 person-years in the operation phase. This estimate should increase depending on how many CO_2 handling projects are implemented in Europe (OED, 2020).

<u>Milestone 3: Business case adapted to findings for demonstration</u>

Private financers are identified, but given the market failure mentioned above their involvement in the Longship project is limited. As already mentioned, Norwegian authorities takes 80 % of the bill for the establishment of the infrastructure and organization necessary for the Longship project. NORCEM and Aker Carbon Capture are private financers at the CO_2 capture site; whereas Equinor, AS Norske Shell and Total E&P Norge AS are private financers in the Northern Lights project (OED, 2020, Equinor, 2019).

<u>Milestone 4: Technology and its system adapted to market/customer needs</u>

The main challenge for CCS is to develop a value chain that is cost-efficient enough for a market to become established. A key motivation for the Longship project is that it should help develop a cost-efficient solution to handle CO_2, and a technology that several actors can make use of. The Longship project is a joint effort between the state and commercial actors, but where the Norwegian authorities take the financial burden of the full-scale realization. There is also insecurity related to the price of CO_2 emissions in the near and far future, and there is insecurity as to how the market for CO_2 storage will develop in Europe. Yet, Longship is seen by the Norwegian government to be an important contribution to creating value chains for CO_2 handling in Europe (OED, 2020).

An overarching goal of the project is that the project will lead to so much technological development and learning that the next storage site (fangstanlegget) will have considerably lower costs connected to it.

It is verified that the Aurora-area is a well-suited place for storing CO_2. This has been secured by drilling a combined verification and injection well and a well-developed plan to monitor the storage. Gassnova (2019) concludes in their evaluation of the transport and storage part of the project that these activities have reduced the technical risk of CO_2 transport and storage project to an acceptable level. This is expected to be of importance to market and customer needs.

Gassnova also concludes that Northern Lights have developed a ship design for CO_2 transportation making it possible to transport CO_2 in a safe and efficient way. A big job has been done with choosing location for the facility where CO_2 is transferred from ship to pipelines, and through the Northern lights project they have decided on a model with onshore CO_2 transmission. Also, they reuse the oil and gas infrastructure from the Oseberg A platform to manage and monitor the well. As such, monitoring is not mentioned as a component that makes the project considerably more expensive.

To sum up, all research questions and milestones for Dimension 4 – market and financial resources have been answered with 'yes', identifying SEL 3 for this dimension to have been reached. When I have not identified the market and financial resources dimension to reach SEL level 4: Deployment, this is mainly due to a lack of fulfilment of Milestone 4: "Whole system meets market/customer needs". The integration of market and customer needs based emerging from the demonstration phase and based on the entire CCS value chain cannot be met until the Longship project is up and running. Yet it is clearly stated in the Longship White Paper that building a system that meets customer and market needs is a major ambition behind the political support for this full-scale demonstration project (OED, 2020).

1.4 Overall SEL level for the Norwegian case

The evaluation leaves us with the overview table found in Table 12. This table identifies the overall SEL level found for the Norwegian case based on an assessment of the full-scale demonstration project called the Longship project to be 3 – Demonstration.

Table 12 Overall SEL Evaluation for the Norwegian CCS development

	SEL 1 Exploration	**SEL 2 Development**	**SEL 3 Demonstration**	**SEL 4 Ready for deployment**
Dimension 1: Environment	All milestones reached	All milestones reached	All milestones reached	Not all milestones reached
Dimension 2: Stakeholder Involvement	All milestones reached	All milestones reached	All milestones reached	Not all milestones reached
Dimension 3: Policy and Regulations	All milestones reached	All milestones reached	All milestones reached	All milestones reached
Dimension 4: Market and Financial Resources	All milestones reached	All milestones reached	All milestones reached	Not all milestones reached

1.5 Main challenges for improving SEL in Norway

As the SEL assessment has shown, there is a high degree of social embeddedness in place for CCS in Norway. In this section I will discuss what can be considered main challenges for improving SEL further. I will discuss the main challenges identified within each of the four dimensions used for the SEL evaluation: Environment, Stakeholder involvement, Policy and Regulations and Market and Financial Resources.

a. The environment

In terms of the impact of CCS on the environment, most aspects have been assessed through impact assessments and mitigation measures have been introduced where this has been considered necessary. Although the maturity has been demonstrated and confirmed for all three components of the value chain, capture, transport and storage, before, the risk of damaging the environment in the interface between the three components has not been examined as an entire chain has not been put together this way before. Thus, it is first after the full-scale demonstration is realized in 2023 that mitigation efforts can be discussed and assessed for the entire value chain. It is first at this stage one will know the actual costs of the project on the environment and know what is needed to reach SEL level 4.

b. Stakeholder involvement

The Longship project, as all CCS projects in Norway, is likely to be less controversial due to the fact that the CO_2 is stored under the seabed off the Norwegian coast. The overwhelming support for CCS mentioned earlier seems to support this hypothesis. Also, the political landscape has the last two decades been marked by a more or less unanimous support for CCS technology as a vital part of the solution to reach the Paris agreement, the only exception being the Progress Party which recently withdrew their support for the Longship project due to the expenses on the tax payers. The industry actors are also highly positive of CCS. Still, there is insecurity among the Norwegian population regarding the risk of CO_2 leakage, and although the full-scale Longship demonstration has passed without much protest, the realization of the full-scale project and the planned expansion of the number of storage sites in the North Sea and the import of CO_2 from other countries to store outside of Norway may cause popular opposition. At the same time, the increased public awareness of climate change and the emission reductions ratified in the Paris agreement have created more legitimacy to support the development of CCS with public money. Yet, a question that seems to be raised in the public debate now, partly initiated by the Progress Party withdrawing their support, is how much money it is reasonable that the Norwegian state uses on CCS. This aspect was also raised by the Director of CLIMIT introduced as a possible challenge for further deployment of CCS (Melaaen, 2020).

c. Policy and regulations

For policy and regulations, this assessment has found that all milestones are reached for the highest SEL-level. Thus, SEL cannot be improved for this dimension.

d. Market and financial resources

The SEL assessment for Norway identifies that the lack of an existing market is a main challenge for further CCS development. Yet, one of the main motivations for the full-scale Longship project is to move CCS technology closer to being a technology that is mature for the market. In relation to this, Equinor has stated that they are working on the establishment of a Northern European market for CCS storage in the North Sea. Moreover, a main goal of the transport and storage part of Longship is to move closer to realizing a European network for CO_2 transport and storage (Northern lights, 2020).

Another historical challenge identified is that the diversity of demonstration and commercial projects has been rather small and connected to the oil and gas industry for very long, despite a growing number of entrepreneurs. The literature review identifies the lack of large-scale CCS projects in relation to the power-intensive industry and EOR as something that may hinder CCS value chains from moving further forward and for a market of different CCS technologies to develop. The fact that no new full-scale CCS projects have been initiated between Statoil's Snøhvit project started in 2007 and the Longship project launched in 2020 is telling in this respect. That said, the Longship project is a step away from the oil and gas sector, focusing on the cement industry and thus offering an important step forward. Yet, more capture sites are needed to develop a fully flexible system that can help a mature market for capturing and storing CO_2 to develop.

1.6 Scenario

I think a likely future development is that Norway is successful in the realization of the Longship project and that this, together with developments in f.ex. the UK will accelerate the maturing of CCs technology at quite a high speed. I think it is reasonable to assume that by 2030 foreign CO_2 is being stored on the Norwegian continental shelf. This is a stated policy goal for the Norwegian government and the EU alike and there is the development of capture projects in countries around the North Sea planning to use the Norwegian storage infrastructure. The publication of the government climate strategy just coming out in January 2021, indicating radical increases in the CO_2 tax to EUR 200/t CO_2 will, if it is realized, take the current CCS technology a big step further towards being ready for a market. Gassnova has talked about a Northern European market for CO_2 capture and storage and with this current policy this is likely to happen by 2030. Still, for an international market to develop equal changes in other countries are necessary.

Despite these developments, I think it is likely that as the Longship project is realized and a discussion of a market for storing CO_2 from other European countries under the North Sea develops, increased public opposition may occur. We are already seeing signs of this in recent surveys and the fact that the Progress party withdraw its support for the Longship project may indicate that we are entering a period with more salient political debate surrounding CCS. In this debate it will be interesting to see how the Environmental organization will place themselves, in particular those who have been silent or passive up until this stage. I think the political debates we will have in Norway in the following years will be important for the continued development of CCS in Norway.

Last, another development that is likely to come if the Longship project is successful is related to the scaling up of blue hydrogen production, which also depends on transport and storage of CO_2. The economic potential of this industry will however depend on whether blue hydrogen is included in the EU taxonomy over environmentally friendly activities or not. The taxonomy is under development and will be presented in summer 2021.

1.7 Reflections on the SEL methodology

The SEL framework worked quite well as a tool to do the national assessment, although in the Norwegian case the time spent to do the assessment and write the report was longer than what was anticipated. It is a detailed framework with many research questions to answer and many milestones to analyse, and my experience was that I had to read a lot to be able to answer all the research questions. The research questions also vary quite a bit in how detailed they are.

A main take-away from doing the assessment is that the connection between TRL and SEL is challenging as TRLs are developed for each technological solution within the CCS value chain. In Norwegian case, the Longship project, which is the one assessed, consists of different technologies put together into one value chain. The technologies are all mature, but they have not been merged into one coherent system before and thus there is insecurity related to, in particular, the interfaces between capture and transport and transport and storage this that TRL does not pick up. Thus, I ended up not basing the reference SEL level on the TRL, but rather focusing on the fact that this is a demonstration project putting together an entire CCS value chain with a flexible transport and storage solution. Thus, basing a reference level on TRL is not necessarily the best way to go forward when starting a SEL assessment.

Moreover, I find that the expectation that SEL will follow TRL does not really hold. There are countless examples of technologies that are mature and ready for the commercial market yet are not realized due to no societal or political support, or due to a lack of funding and a functioning market. An example could be nuclear power plants in Norway, where the technology was ready many decades ago, yet the political and popular will was never there and thus Norway to this day has no nuclear power plants. This shows that TRL may be 9, yet SEL level may be as low as 1. So this view of society as following a linear trend towards more acceptance as technology develops do not hold in meeting with the empirical world.

A related point also taking up the problematic assumption that TRL and SEL will develop in tandem: when a technology is new, no one in society knows anything about this technology. This is the period where stakeholders and market actors are probably most open towards the technology simply because they don't know much about it and it has probably not become politicized or taken up by important stakeholder groups. So, following this logic, stakeholders, in particular, should have a high SEL when TRL is low. Again, the point here is that the close connection between TRL and SEL does not seem to connect well with the actual world when you start using the framework.

Also, although not a big problem for my case, the recipe to identify an overall SEL level makes clear that this is a very conservative approach as all milestones need to be reached within all four dimensions. I understand the logic behind it, being able to set a common level and work from there, but one can easily imagine that there may be quite big differences across dimensions, f.ex SEL 4 on "market and financial resources" dimension and 1 on "stakeholder involvement" dimension. Deciding then that the overall SEL level is 1 leaves out a lot of nuance of the case. This is something we should think about when discussing SEL further.

One insecurity that followed me in working with the SEL assessment was as follows: When there is something you do not find any information about through the suggested methodologies, what do you then answer in the SEL and how does this affect the overall SEL evaluation? Is "don't know" to be understood as the same as NO in the framework? This was unclear to me and I also could not find information in the Guideline on how to deal with this. If one was to treat don't know as NO, that could be quite dramatic when setting the overall SEL level. Maybe one should collect all the don't knows as part of the assessment the same way as NO answers are identified?

On a more conceptual level, I wish more clarity on what the word "societal embeddedness" implies in the SEL framework. What are we preoccupied with identifying here? There are (at least) two ways of considering societal embeddedness: one can be preoccupied with how well society is embedded in the CCS process, or one can be preoccupied with how well the technology is embedded in society. These are two quite different approached to embeddedness, and the first would maybe be where most social scientists would put their effort. Question: is the SEL framework meant to be a tool to identify and work to ensure societal participation in a technological development or is society more a necessary evil that needs to be on the supportive side for a technology to be realized? Although not a very hands-on feedback, this is something I have thought about quite a bit during the assessment and I think being clear on what we mean by societal embeddedness is important.

Also, another instruction in the SEL guidelines is connected with the above point of the expected link between SEL and TRL. On p.7 it says: "These societal barriers need to be addressed in order to embed CCS into society." Yet it is in no case given that addressing the societal barriers will embed CCS into society. It is too simple to expect such a one to one causal relationship. It may even move in the opposite direction! In democracies where the realization of all (major) projects rely on the public will, there may not always exist acceptance (public and/or political) for deployment although one does everything in one's power to address their concerns and worries. Thus, I think such an assumption needs to be changed to reflect the cases we study: liberal democracies.

1.8 Literature

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2. National SEL assessment in the Netherlands

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2.1 Introduction

This report presents the national assessment of the Societal Embeddedness Level (SEL) of Carbon Capture and Storage (CCS) in the Netherlands and is written as a part of deliverable 3.2 of the ACT DigiMon project, which contains a total of 4 SEL assessments for 4 different European countries (Germany, Greece, Norway and the Netherlands). The assessment is carried out according to the 'Guideline Societal Embeddedness Assessment'[1] between September 2020 and December 2020. Additionally, this report contains methodological reflections on applying the SEL assessment on a national level for CCS.

First, in chapter two, the context of CCS in the Netherlands is elaborated. Chapter three provides a forecast of future developments of CCS in the Netherlands. Chapter four contains the SEL assessment, which consists of a description of the followed procedure and the results of the assessment alongside the four SEL dimensions, followed by chapter five, which goes into the monitoring of CCS in the Netherlands. Then, in chapter six, the societal challenges of CCS in the Netherlands according to the SEL assessment results are elaborated. Chapter seven reflects on the applicability of the SEL methodology for a SEL assessment on a national level focused on CCS and methodological difficulties that were encountered during the assessment. Finally, a short conclusion is drawn on the SEL of CCS in the Netherlands.

2.2 Context of CCS in the Netherlands

Carbon capture and storage (CCS) is a family of technologies used to capture CO_2 at an emission source, transport it to a storage location in the subsurface and store the CO_2 there for a long period with the aim of mitigating climate change[2]. In each project, the particular technological configuration used may differ in capture technologies (e.g. post-combustion capture), point sources (e.g. coal-fired power plants or steel production), transport methods (e.g. pipeline or ship) and subsurface storage locations[3] (e.g. offshore empty gas fields). Each technological configuration has a specific development trajectory with accompanying challenges, but many developments and challenges are similar across these configurations.

At first, expectations for CCS to contribute substantially to climate change mitigation were high at a global level of scale. A diverse set of actors expressed support for CCS after the publishing of a special IPCC report on CCS, the preparation of a storage framework for CO_2 (the EU CCS directive) and the establishment of a global CCS institute. Although global rollout of CCS was envisioned in 2025[4], most demonstration projects that were planned in the Netherlands were delayed or cancelled[5], like Barendrecht[6], Northern Netherlands[7] and the ROAD initiative in the Port of

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[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

[2] Reiner, D. (2016). Learning through a portfolio of carbon capture and storage demonstration projects. Nat Energy 1, 15011 https://doi.org/10.1038/nenergy.2015.11

[3] van Egmond, S. & Hekkert, M.P. (2012) Argument map for carbon capture and storage. International Journal of Greenhouse Gas Control. 11.148-159. ISSN 1750-5836. https://doi.org/10.1016/j.ijggc.2012.08.010.

[4] Gibbins, J. & Chalmers, H. (2008) Carbon capture and storage. Energy Policy. 36 (12). 4317-4322. ISSN 0301-4215. https://doi.org/10.1016/j.enpol.2008.09.058.

[5] Reiner, D. (2016). Learning through a portfolio of carbon capture and storage demonstration projects. Nat Energy 1, 15011 https://doi.org/10.1038/nenergy.2015.11

Rotterdam[8]. Many reasons for delayed or cancelled developments exist, such as technological failures, rising costs[9], regulatory uncertainty and a lack of public acceptance[10].

The Barendrecht case received the most attention and became an example for lessons on stakeholder involvement in CCS and community engagement. As one of the demonstration projects of the Dutch Government, Barendrecht was a CCS project in a depleted gas field[11]. Shell, as the initiating company, organized an Environmental Impact Assessment and two information evenings. The municipality responded with a review framework and political parties where able to organize substantial resistance with a protest march and an opposing report against the conclusions of the EIA[12]. One of the conclusions after the rejection of the plans is that in the Barendrecht case, is the scaling up procedural critique to a national level was successful.

Although political support is currently on the rise, for many years CCS has received little support by governments in Europe. The lack of political support may have been driven by a lack of public support in some countries. A lack of public support may therefore reduce deployment speed and affordability and exclude some technological configurations, such as onshore storage in the Netherlands, from the realm of possibilities for CCS[13]. In the process of reducing CO_2 emissions, the climate agreement for the industry agreed to store CO_2 off-shore in empty gas fields in the North Sea.[14]

The initial disillusionment for CCS has been replaced with rising expectations and ambitions. In the Netherlands, for example, the government has expressed the ambition to reduce substantial amounts of CO_2 from industry in 2030 using CCS. This ambition will be supported with policy instruments that are currently in development, such as a CO_2 tax and a subsidy scheme[15] (SDE++). Even though CCS is seen as one of the most cost effective ways to reduce CO_2 emissions, since this subsidy supports the most cost-effective sustainable technology, CCS is competing with other technologies in this scheme. The climate agreement shows that the Dutch government and industry see CCS as an important technical measure to reach the climate goals in a cost effective way. The policy instruments stimulating CCS like SDE++ cannot, however, go at the expense of other sustainable techniques. At the same time, the subsidy for CCS should give the industry enough

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[6] Feenstra, C. F. J., Mikunda, T., & Brunsting, S. (2010). What happened in Barendrecht. Case study on the planned onshore carbon dioxide storage in Barendrecht, the Netherlands. Prepared by the Energy research Centre of the Netherlands (ECN) Project, 6.

[7] https://www.provinciegroningen.nl/actueel/nieuwsartikel/grootschalige-afvang-en-opslag-van-co2-in-noord-nederland/

[8] https://www.portofrotterdam.com/en/news-and-press-releases/road-project-to-be-cancelled-ccs-to-continue

[9] Reiner, D. (2016). Learning through a portfolio of carbon capture and storage demonstration projects. Nat Energy 1. 15011. https://doi.org/10.1038/nenergy.2015.11

[10] Cuppen E, Brunsting S, Pesch U, Feenstra Y (2015) How stakeholder interactions can reduce space for moral considerations in decision making: A contested CCS project in the Netherlands. Environment and Planning A: Economy and Space. 47(9). 1963-1978. doi:10.1177/0308518X15597408

[11] Verhoeven, I. (2020) Contentious governance around climate change measures in the Netherlands. Environmental Politics. 1-23 DOI: 10.1080/09644016.2020.1787056

[12] Cuppen E, Brunsting S, Pesch U, Feenstra Y (2015) How stakeholder interactions can reduce space for moral considerations in decision making: A contested CCS project in the Netherlands. Environment and Planning A: Economy and Space. 47(9). 1963-1978. doi:10.1177/0308518X15597408

[13] Watson, J., Kern, F. and Markusson, N. (2014). Resolving or managing uncertainties for carbon capture and storage: Lessons from historical analogues. Technological Forecasting and Social Change. 81. 192-204, ISSN 0040-1625. https://doi.org/10.1016/j.techfore.2013.04.016.

[14] https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/kliimaatakkoord-hoofdstuk-industrie/klimaatakkoord-c3+Industrie.pdf

[15] https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/kliimaatakkoord-hoofdstuk-industrie/klimaatakkoord-c3+Industrie.pdf

perspective to reduce CO_2 in a cost effective way. This combination puts a cap on the time and size of CCS policy instruments[16].

Since the national Dutch climate agreement implies that CO_2 can only be stored off-shore, the projects that are being prepared are situated close to the coast line in the Port of Rotterdam area and the IJmond area (Province of North Holland). Porthos is an initiative of the Ports of Rotterdam and Antwerp in combination with Dutch natural gas infrastructure and transportation company (GasUnie) and a natural gas exploration, production, transportation and sale company owned by the Dutch Government (EBN). It has completed its EIA this year (2020) and has planned the construction start of the system for 2022.[17] Various companies capture and transport the CO_2 to an empty gas field 20 km off the coast. This project aims to be operational by 2024. Athos is initiated by GasUnie, EBN, the large steel factory Tata Steel IJmuiden and The Amsterdam Harbour. This project is in an earlier phase, where the feasibility analysis has been successfully completed, but several follow up studies are necessary to set up the infrastructure plan. Currently the Athos consortium is preparing the Environmental Impact Assessment as part of the formal steps of the permit procedures. The planning is to have this project up and running by 2027[18]. Both projects have been nominated for European subsidies for cross border projects.

In previous years, many studies have been done into citizens' opinions about CCS. These studies show that citizens tend to have low awareness and knowledge about CCS[19]. Citizens tend to have neutral opinions about CCS, but commonly prefer other means for reducing CO_2 emissions, such energy efficiency or renewable energy technologies[20]. Citizens may be concerned about the safety of CO_2 transport and storage, its end-of-pipe nature[21] or its competition with renewables for resources[22]. Yet, many of these studies have been carried in a different societal and political context than is present today and with a focus on different technological configurations (i.e. a stronger focus on CCS for power generation with onshore CO_2 storage). Studies have shown that citizens may be more conducive to CCS when it is applied to industry[23].

The notion of energy justice adds to the recent developments in the social embeddedness of CCS. In the well-known CCS project in Barendrecht, the Netherlands, justice as recognition played an important role[24]. According to citizens, the increased focus on the technical approach diminished

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[16] https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/kliimaatakkoord-hoofdstuk-industrie/klimaatakkoord-c3+Industrie.pdf
[17] https://www.porthosco2.nl/en/project/
[18] https://athosccus.nl/project/
[19] Ashworth, P., Wade, S., Reiner, D. and Liang, X. (2015).
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[21] L'Orange Seigo, S., Dohle, S. and Siegrist, M. (2014) Public perception of carbon capture and storage (CCS): A review. Renewable and Sustainable Energy Reviews. 38. 848-863. ISSN 1364-0321. https://doi.org/10.1016/j.rser.2014.07.017.
[22] Wallquist, L., Visschers, V.H.M. and Siegrist, M (2009). Lay concepts on CCS deployment in Switzerland based on qualitative interviews. International Journal of Greenhouse Gas Control. 3 (5). 652-657. ISSN 1750-5836. https://doi.org/10.1016/j.ijggc.2009.03.005.
[23] Broecks, K.P.F., van Egmond, S., van Rijnsoever, F.J., Verlinde-van den Berg, M. and Hekkert, M.P.(2016). Persuasiveness, importance and novelty of arguments about Carbon Capture and Storage. Environmental Science & Policy. 59. 58-66. ISSN 1462-9011. https://doi.org/10.1016/j.envsci.2016.02.004.
[24] Pesch, U., Correljé, A., Cuppen, E. and Taebi, B. (2017)
Energy justice and controversies: Formal and informal assessment in energy projects. Energy Policy. 109. 825-834. ISSN 0301-4215. https://doi.org/10.1016/j.enpol.2017.06.040.

their say the project. They were looking for a way to independently control the issues that the project inflicted on 'their' environment. Recognition helps to ensure different conceptions of technologies are considered, which might contribute in a positive perception of a new technology in society[25]. This has been lacking in the context for CCS, where local and remote stockholders were undervalued, often treated as unknowledgeable in participatory processes. Especially in the development and implementation phase of CCS projects, there is a need for further emphasis on social embeddedness with an integrated approach towards the moral causes of perceived discomfort.

A recent study in the Netherlands showed that Dutch citizens' opinions about industrial CCS with offshore CO_2 storage are neutral to slightly positive after they have been informed about CCS, its likely implementation scenario and its outcomes[26]. Citizens tend to be positive about its climate and economic outcomes (e.g. employment effects), but are slightly concerned about safety. Furthermore their opinions depend strongly on their attitude toward industry. Hence, future public engagement strategies should take those aspects into account. Engagement for upcoming projects is currently ongoing, such as for the Porthos project in the Netherlands and the Net Zero Teeside project in the UK.

Since these first demonstration plans, research into CCS technologies is ongoing because many uncertainties remain regarding system integration, upscaling capacity or the viability of new technological configurations[27].Furthermore, new technological developments, such as the DigiMon system, may reduce risk and drive down costs of implementation. Many previous developments have been hampered by high costs and the uncertain commercial and financial viability of CCS[28].

The current societal context, the current state-of-the-art in research into CO_2 storage and the current presence of the four types of barriers discussed above will discussed further in deliverable D3.2 (national assessment of the SEL for CO_2 storage).

2.3 Forecast of future developments of CCS in the Netherlands

In the Netherlands, the conditions for CCS to play a more prominent role in reaching the CO_2 reduction targets for 2030 and 2050, seem to be on the rise. Institutions like the Dutch environmental assessment agency (Dutch: Planbureau voor de leefomgeving – PBL) predict an essential role for CCS in reaching a reduction of 95% in the 2050. Especially in the industry, where the Dutch government aims to achieve a 14.3 Mton CO_2 emissions reduction. This is likely primarily by large scale implementation of CCS[29]. The most likely application of CCS is CO_2 capture at industrial installations, transport via pipeline and offshore storage.

[25] McLaren, D., Krieger, K., and Bickerstaff, K. (2013). Justice in energy system transitions: the case of carbon capture and storage. Energy justice in a changing climate. Just Sustainabilities: Policy, Planning and Practice. 158-181
[26] https://www.alignccus.eu/sites/default/files/ALIGN-CCUS%20D6.1.2%20Journal%20article_Executive%20summary.pdf
[27] Markusson, N., Kern, F., Watson, J. Arapostathis, S., Chalmers, H., Ghaleigh, N., Heptonstall, P., Pearson, P., Rossati, D. and Russell, S (2012) A socio-technical framework for assessing the viability of carbon capture and storage technology. Technological Forecasting and Social Change. 79(5), 903-918. ISSN 0040-1625. https://doi.org/10.1016/j.techfore.2011.12.001.
[28] Markusson, N., Kern, F., Watson, J. Arapostathis, S., Chalmers, H., Ghaleigh, N., Heptonstall, P., Pearson, P., Rossati, D. and Russell, S (2012) A socio-technical framework for assessing the viability of carbon capture and storage technology. Technological Forecasting and Social Change. 79(5), 903-918. ISSN 0040-1625. https://doi.org/10.1016/j.techfore.2011.12.001.
[29] https://www.pbl.nl/sites/default/files/downloads/pbl-2019-effect-kabinetsvoorstel-CO2-heffing-industrie-3737.pdf

Based on earlier studies, the lack of public support can be a barrier for the implementation of CCS and even contributed to the cancellation of CCS projects. These studies were largely based on onshore CCS, whereas offshore storage is more likely in the future CCS scenarios. Even so, they give a clear indication that future policies and projects should not only focus on knowledge and perceptions when it comes to societal support. This is also determined by socio-political factors like a fair distribution of costs and benefits on a local level, perceived fairness in decision-making procedures and trust in authorities.

In existing example scenario's made by EBN in a research commissioned by the Ministry of Economic Affairs and Climate change, the amount of CO_2 that can be captured by the industry and power plants and the volumes that can be stored in offshore gas fields and platforms are the most influential[30]. The three scenario's (low, mid, high) for 2060 differed in their capture and storage capacity. The CO_2 capture by power plants plays an important role in reaching the mid (20 megaton CO_2 capture annually) and high (30 megaton) scenario. The replacement of coal by gas and more sustainable production of electricity are two factors that influence this role.

The Dutch Climate agreement foresees a more prominent role for Carbon Capture and Usage in the near future[31]. For example, the horticulture sector can use CO_2 to grow plants in greenhouses. Furthermore, CO_2 can be used to raw material to produce plastics and synthetic fuel for the aviation sector. This climate agreement describes the infrastructure of CCS as one an uncertainty and one of the conditions that have to meet for CCS to play a role. The meet the right conditions for CCS to contribute to the reduction targets, two polices are likely to support CCS technologies, namely the SDE++ subsidy and the European Trading System.

The SDE++ (Stimulating Sustainable Energy transition) subsidy opened on the 24th of November 2020 as a successor of the SDE subsidy[32]. This subsidy used to stimulate sustainable energy production, but in its new form also stimulates CO_2 reduction. This implies that companies can get financial support for the transport storage of CO_2. This subsidy has an assignment term of 2,5 years with a realization term of 5 years. In reaching the climate agreement concerns have been raised on the financial benefits for CCS at the expense of sustainable energy technologies like wind and solar. To prevent this, the subsidy for CCS will be limited by amongst others a cap of max 7.2 Mton CO_2 reduction subsidies by 2030. The future developments will tell whether the right balance will be found between preventing clean energy technologies from reaching their potential and utilizing CCS to its reduction potential. This brings along some insecurities for CCS future developments.

The efficiency of the Dutch industry is dependent on the ETS[33]. At the moment, the emission rights are not high enough to stimulate a substantial change, but this might change in the future. PBL expects the a price rice of 46 euro's per ton CO_2 emission. This would mean positive development towards CO_2 reduction developments and thus CCS. On the other hand, the Netherlands with its relative heavy industry in comparison to the rest of Europe, does not want the ETS-system to account for reaching the emission reduction targets on its own. It wants to use its technological

[30] https://www.ebn.nl/wp-content/uploads/2018/07/Studie-Transport-en-opslag-van-CO2-in-Nederland-EBN-en-Gasunie.pdf
[31] https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/kliimaatakkoord-hoofdstuk-industrie/klimaatakkoord-c3+Industrie.pdf
[32] https://www.rvo.nl/subsidie-en-financieringswijzer/stimulering-duurzame-energieproductie-en-klimaattransitie-sde/aanvragen-sde/kenmerken
[33] https://www.rvo.nl/subsidie-en-financieringswijzer/stimulering-duurzame-energieproductie-en-klimaattransitie-sde/aanvragen-sde/kenmerken

possibilities to become a frontrunner in the transition. With its regional clusters, CCS should help achieving this[34]. A higher ETS price would stimulate the usage of CCS in the future[35].

A reason to believe that CCS is likely to play an increasing role in the energy transition in the Netherlands is that while most CCS applications in the past were developed for power generation, such as coal- and gas-fired power plants, recent developments are more strongly focused on CCS at industry. Many industries have few alternatives to CCS for deep CO_2 emission reductions[36]. For these industries, CCS can be a cost-effective solution for short term emission reductions.

In the future, additional applications for CCS are foreseen. Primarily the use of biomass in combination with CCS (BECCS) to remove CO_2 from the atmosphere - creating negative emissions. Such applications of CCS are needed because some sources of CO_2 will remain, especially in agriculture[37]. Furthermore, BECCS will be even more relevant in case of an overshoot of the 2 degree limit in temperature rise[38]. Although these future applications differ, many of the same types of barriers to the implementation of CCS may be present.

2.4 SEL assessment

This chapter first describes the scope of the SEL assessment for CCS in the Netherlands. Then the followed procedure of the assessment is explained. Finally the results of the assessment of the SEL for CCS in the Netherlands are elaborated alongside the four SEL dimensions.

Scope

Starting from the definition of the four SEL levels, the lower SEL levels, SEL 1 and SEL2, look at individual system components; the higher SEL levels, SEL 3 and SEL 4, look at the complete system of a technology and the linkages and interdependencies of all system components. Applying the SEL assessment framework therefore implies that while assessing the Societal Embeddedness Level of a technology or technological development, the whole system will be included.[39] Although the DIGIMON project focusses on the aspect of CO_2 geological storage, it became clear that CCS projects cannot be developed without taking the full CCS chain into account. As a consequence, for applying the SEL assessment framework on CCS developments in the Netherlands at a national level, we thus looked at the whole CCS chain of CO_2 capture, CO_2 transport and CO_2 storage. However, when executing the SEL assessment on the Dutch situation, it appeared that the focus, especially when it comes to stakeholders' engagement, lies on CO_2 storage. For this reasons, the storage of CCS prevails.

Identification of SEL reference point for SEL assessment

[34] https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/kliimaatakkoord-hoofdstuk-industrie/klimaatakkoord-c3+Industrie.pdf
[35] https://www.ce.nl/publicaties/download/2615
[36] Leeson, D., Mac Dowell, N., Shah, N., Petit, C. and Fennell P.S (2017). A Techno-economic analysis and systematic review of carbon capture and storage (CCS) applied to the iron and steel, cement, oil refining and pulp and paper industries, as well as other high purity sources. International Journal of Greenhouse Gas Control. 61. 71-84. ISSN 1750-5836. https://doi.org/10.1016/j.ijggc.2017.03.020.
[37] https://www.pbl.nl/sites/default/files/downloads/pbl-2017-negatieve-emissies-technisch-potentieel-realistisch-potentieel-en-kosten-voor-nederland_2606.pdf
[38] Detz, J.R. & van der Zwaan. B. (2019) Transitioning towards negative CO2 emissions. Energy Policy. 133 110938. ISSN 0301-4215. https://doi.org/10.1016/j.enpol.2019.110938.
[39] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

The SEL assessment starts with determining the SEL reference point. The reference point of the SEL provides insight in the societal embeddedness needed for the particular technology development stage. It is determined by linking the TRL to the SEL.[40]

In the Netherlands there are various demonstration projects for the different parts of the CCS chain (capture, transport and injection in a gas field), however, there is no demonstration in which the whole CCS chain is operational. As SEL 3 requires a full chain operational demonstration site, the SEL reference point for CCS in the Netherlands is set on SEL 2. There are two initiatives in the phase of development and permitting; the Porthos initiative (Port of Rotterdam) and the Athos initiative (IJmond area).

Approach Data collection to determine the SEL dimensions

In collaboration with the DIGIMON WP3 team a case study protocol for assessing the SEL on a national level has been made.

According to the case study protocol 20 documents are selected from google scholar, ministry websites and internal documents, using the following search words:

- CO_2 Storage and/or carbon (capture) storage + country
- CCS + country
- CCS + country + environment
- CCS + country + stakeholder involvement
- CCS + country + policy and regulations
- CCS + country + market and financial resources

For the assessment of SEL in the Netherlands we used this protocol with additional search terms, snow ball sampling and expert interviews to answer the questions of the SEL framework. During the process we found that scientific literature we found on google scholar is not the most up-to-date information about CCS in the Netherlands. For this reason we decided to use regular google searches as well. This resulted in more ministry websites and CCS project related websites, providing us with recent information and reports.

Case study approach used in the Netherlands

For the national assessment of the SEL of CCS in the Netherlands we applied the before mentioned protocol with minor modifications. We used the following search words, supplemented with snowball sampling technique to gather more articles and articles/sources which were recommended by experts.

- CO_2 Storage and/or carbon (capture) storage + country
- CCS + country
- CCS + policy and regulations (and policy and regulations separate)
- CCS + environment (separately added social, built, natural)
- CCS + market and financial resources (and market separate)
- Project + stakeholders
- CCS + permits
- CCS + subsidies

[40] Ibid

Interdisciplinarity

Most of the SEL assessment is done through desk research. However, based on literature and online sources not all research questions could be answered. Therefore, we consulted several CCS experts with different backgrounds to account for interdisciplinarity and fill the knowledge gaps. The experts were asked to give input on specific milestones and research questions[41] for a detailed description of the approach for the SEL assessment). Two experts provided written input and four have been interviewed. In the interviews we brought up one or more milestones. Find the list of involved CCS experts below.

<u>CCS experts with an interdisciplinary background</u>

Table 13 List of consulted experts

Dimension	Role	Subjects
Environment	CCS scientist (TNO)	In what way (how) is the impact on the environment monitored? And what are the requirements for environmental monitoring? What is the position of monitoring in the current regulatory framework?
	Senior communication advisor (RVO)	Are actions for information providing, trust building and securing the cooperation of stakeholders and the public developed for CC(U)S as a technology? Are stakeholders that may have a positive/negative impact on CC(U)S involved? CCS media analysis
	Strategic advisor energy and environment (TNO)	What is known about the impact of CCS on the social environment?
Stakeholder involvement	Policy officer (ministry of economics and climate)	Are actions for information providing, trust building and securing the cooperation of stakeholders and the public developed for CC(U)S as a technology? Are stakeholders that may have a positive/negative impact on CC(U)S involved?
	Strategic advisor energy and environment (TNO)	How do current CCS projects design the stakeholder participation?
Policy and regulations	Senior policy advisor (ministry of economics and	Are actions for information providing, trust building and securing the cooperation of stakeholders and the public developed for CC(U)S as a technology?

[41] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

	climate)	Are stakeholders that may have a positive/negative impact on CC(U)S involved? CCS media analysis
Market and financial resources	Geologist (TNO)	Are financial resources sufficient for development of the technology How does monitoring of ccs affect the financial circumstances and market position? (i.e., more expensive; more funding opportunities?)

SEL per dimension

<u>SEL assessment of dimension "Environment"</u>

The SEL methodology defines 'the environment' as the natural, built and societal environment, and is meant to keep any negative impact the technology might have on the environment as low as possible.[42] Regulatory frameworks for CCS initiatives require technological, geological and environmental feasibility studies as part of the exploration phase of a CCS project in the Netherlands.[43] These feasibility studies explore whether the project is technologically feasible, identifies the natural and built environment and explores whether the project is feasible in that specific environment. Multiple follow-up studies are necessary as part of the permit procedures before the project can actually be demonstrated at its specific location. A so-called 'Memo on the scope and level of detail of the Environmental Impact Assessment' (in Dutch: Notitie Reikwijdte en Detailniveau, NRD) defines the research topics for assessing the impact of the planned project on the natural and built environment. The NRD is a preparation for the Environmental Impact Assessment (EIA). It elaborates what subjects the EIA should focus on. The NRD process starts with a public notice of the project intentions as well as a draft version of the NRD, on which stakeholders then can react with their opinions, questions and concerns. As part of this process, external advisors and local and regional governing bodies have to be consulted about the scope and level of detail of the environmental impact assessment. All inputs have to be taken into account and should be used to finalize the NRD document. Based on the final NRD, the EIA will be executed. Finally, with the environmental impact assessment, the impact of the technology on the natural and built environment is assessed. In the decision-making process of the project, the results of the environmental impact assessment have to be taken into account. In this way the dimension environment plays a full role in the decision making process.

In the Netherlands there are currently two full-chain CCS projects in development. Porthos[44], in the Rotterdam area, is currently the most advanced project. For Porthos the environmental impact assessment is finished in 2020. For Athos[45], in the IJmond area, the NRD will be published in 2021.

The SEL assessment did not result in a clear view on how CCS developers/initiators are mapping the impact of a CCS project on the social environment. Most experiences reflect the perspective how

[42] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project
[43] https://www.infomil.nl/onderwerpen/integrale/mer/procedurehandleiding/procedurele/procedurestappen-0/reikwijdte/
[44] https://www.porthosco2.nl/
[45] https://athosccus.nl/

local community dynamics could possibly impact the progress of the project development at local level, instead of the other way around. We found that the social environment is often identified with the aim to provide insight in who should be informed about the new CCS initiative, rather than exploring how the project could impact the social environment or could create local benefits. The impacts of a CCS project on the social environment is hardly explored nor assessed in the Netherlands. However, current collaborations with the developers/initiators of the Athos project indicate that efforts are being made to better include interests from the local community as much as possible in the technology development. The companies involved try to do their best to set up an open dialogue with local stakeholders to explore how to optimal embed the Athos project in the IJmond region).[46] This gives reasons to assume that – at local level - an exploration of the impact of CCS on the social environment in the Netherlands is currently underway.

The knowledge about the impact on the natural and built environment is advanced and would be in SEL 3 at this moment. However, we are not sure about the extent to which the impact of the technology on the social environment is taken into account. For this reason the SEL of dimension 1: environment in the Netherlands is set at two but made orange.

Table 14 SEL of CCS in the Netherlands on Dimension 1: Environment

	SEL 1 Exploration	**SEL 2 Development**	**SEL 3 Demonstration**	**SEL 4 Ready for deployment**
Dimension 1: Environment	All milestones reached	Almost all milestones reached	Not all milestones reached	Not all milestones reached

<u>SEL assessment of dimension “stakeholder involvement”</u>

With exploring the social environment of the technology in an early stage of development (as referred to in dimension ‘environment’), an effort is taken to realize (early) stakeholder involvement. Although guidelines for stakeholder involvement are taken into account in Dutch regulations for spatial projects, current CCS projects make more effort for early stakeholder involvement. [47] They do this by gaining information about the area and (future) autonomous developments, collaborating with knowledge institutions, discussions with interest groups, being ahead of the NRD process by asking opinions about the projects, building trust relationships with stakeholders, appointing dedicated community engagement managers to projects and providing sufficient and transparent information and presentations about the progress of the project.

At this moment the Dutch public is neutral to slightly positive about CCS after they are informed. This improved since the situation during the former CCS projects in the Netherlands, like the Barendrecht CCS project, which got cancelled due to opposition from local communities. However, there are still concerns about safety. And the same political concern whether investments should go to the development of renewal energy sources, instead an ‘end of pipe’ solution like CCS is apparent in the public opinion.

[46] Expert interview: Strategic advisor energy and environment (TNO)
[47] *31 januari 2019 CONCEPT-NRD - PORTHOS I&BBF8260-101-100R001D0.9 38*

Also, environmental organizations still speak out against CCS. However, the environmental organizations were involved in negotiations about the climate agreement and some of them delivered input for current policies.

Citizens' concerns are (i.e.) collected in stakeholder processes Enos[48] and the CCS roadmap[49]. The concerns involve the role of CO_2 storage in the Dutch energy policy, as some people have the opinion that CCS is an 'end of pipe' solution, which means that 'garbage' is stored, which does not fit the ambitions towards a circular economy.[50] They think the investments are better off with renewable energy sources, like solar and wind energy.[51] Also, citizens ask questions about the safety and impact on the environment[52] and how this is monitored.[53] People think of CCS as an underdeveloped technology.[54] Lastly, some people think the costs of CCS are too high in comparison with other (renewable) energy sources.[55] They feel like investments in CCS might hamper the development of other (renewable) energy sources[56] and they are concerned about the distribution of costs of the CO_2 storage, and think that it is unfair that citizens end up paying for the pollution of the industry.[57]

The Enos study found that citizens have concerns about the usefulness and necessity of CCS. However, they stated that the conversation contributes to a better understanding of the role of CCS in the Dutch energy policy.[58]

In the CCS roadmap process, several measures to increase societal support are discussed, like emphasizing the urgency to use and fund CCS to reach the climate goals, and presenting CCS as a part of a total transition package, in which CCS is deployed in particular where there are no alternatives and in such a way that it does not hinder renewable energy sources in any way. Also, clear and accessible communication about the technology, usefulness and necessity of CCS might help to increase support.*59*

Table 15 SEL of CCS in the Netherlands on dimension 2: Stakeholder Involvement

	SEL 1 Exploration	**SEL 2 Development**	**SEL 3 Demonstration**	**SEL 4 Ready for deployment**
Dimension 2: Stakeholder involvement	All milestones reached	All milestones reached	Some milestones reached	Not all milestones reached

[48] Brus & Puts, 2020 "CO2 Storage Best Practice indications from Rotterdam area community. Lessons learned from a long term collaborative research process with a group of Dutch citizens: towards societally embedded CO2 geological storage projects". Final report D5.4 of the EU project ENOS.
[49] https://www.rijksoverheid.nl/documenten/publicaties/2018/03/05/routekaart-ccs
[50] Ibid
[51] Ibid
[52] Ibid
[53] Brus & Puts, 2020 "CO2 Storage Best Practice indications from Rotterdam area community. Lessons learned from a long term collaborative research process with a group of Dutch citizens: towards societally embedded CO2 geological storage projects". Final report D5.4 of the EU project ENOS.
[54] https://www.rijksoverheid.nl/documenten/publicaties/2018/03/05/routekaart-ccs
[55] Ibid
[56] Ibid
[57] Ibid
[58] Expert interview: Strategic advisor energy and environment (TNO)
[59] https://www.rijksoverheid.nl/documenten/publicaties/2018/03/05/routekaart-ccs

The assessment did not give a clear few of how the stakeholder involvement is arranged in current CCS projects in the Netherlands, therefore we are not sure whether SEL 3 is reached.

SEL assessment of dimension "Policy and regulations"

The directive on the geological storage of CO_2 (CCS directive) establishes a European legal framework for safe geological storage of carbon dioxide, to contribute to the fight against climate change. The CCS directive covers all CO_2 storage in geological formations in the EU during the entire lifetime of the storage sites as well as provisions on the capture and transport components of CCS.[60] However, the latter are covered by other EU environmental legislation, such as the Environmental Impact Assessment (EIA) and the Directive or the industrial Emissions Directive, combined with changes introduced by the CCS Directive.

The CCS Directive is mainly transposed into Dutch legislation by means of adaptation of the Dutch Mining legislation. The Dutch national government – the Ministry of Economic Affairs and climate - coordinates all formal procedures for all required permits as well as the multiple decision making process for CCS projects, according to the so-called National Coordination Regulation (in Dutch: Rijks Coordinatie Regeling, RCR). Through the RCR, decisions about permits and exemptions are taken simultaneously and in consultation with competent authorities. The coordination of the EIA is also covered in this regulation. The competent authorities, consisting of various levels of government, are in charge of license applications and exemptions regarding the natural and built environment. The Ministry for Economic Affairs and Climate is the competent authority for the permits for storage, permanent storage of CO_2 and the permit for exploring CO_2 storage facilities. The State Supervision on Mines (Dutch: Staatstoezicht op de Mijnen) monitors the compliance with the Mining Act.

For the realization of a CO_2 storage project, the following laws are in place in addition to the mining act: Act of Environmental Conservation (Dutch: Wet milieubeheer), the Law for Environmental Planning (Dutch: Wet ruimtelijke ordening), the Crisis and Recovery Law (Dutch: Crisis en Herstelwet) The Water Law (Dutch: Waterwet), the Nature Conservation law (Dutch: Wet Natuurbescherming), The Soil Protectipon Law (Dutch: Wet bodembes-cherming).[61]

The Dutch Enterprise Agency RVO supports the Ministry of Economic Affairs and Climate and represents the Netherlands in several international CC(u)S related groups, like ERANET Cofund ACT. In addition, the Dutch Enterprise Agency RVO ensures payment of subsidies to national CC(U)S projects through various subsidy schemes.

From November 2020 the new SDE++ is in pace. This is the first structural national policy that applies to CC(U)S. The former Road project in the Netherlands got subsidies from the EU and the Dutch government, but these were based on funds instead of structural policies.[62] The SDE++ subsidy is applicable to all energy technologies, but is granted to the most CO_2 reduction effective technologies. To prevent CC(U)S from getting to much of the subsidy where other, in some cases conceived more sustainable technologies, also apply for, there is a maximum of 7.2 megaton per year for CCS subsidies, the subsidy is granted until 2030 and the necessity of CCS is revised yearly.

[60] https://ec.europa.eu/clima/policies/innovation-fund/ccs/directive_en
[61] https://europadecentraal.nl/onderwerp/klimaat/co2-en-luchtkwaliteit/co2-opslag/
[62] Interview Senior Policy Officer Ministry of Economic Affairs and Climate Policy

From 2030 onwards the combination Gas/CCUS and renewable energy systems might be in competition with each other.[63]

All in all, the political support, regulatory framework and current subsidies are sufficient to further develop CCS in the Netherlands and start a demonstration. Former CCS projects were – on a regulatory level – ready for demonstration as well. There are, however, still some issues that need to be dealt with before CCS can be successfully deployed in the Netherlands. Some issues of the implementation of the CCS directive need further clarification. These issues consist of lack of clear standards and criteria about safety (site selection and monitoring) and liability, regulation with regard to third party access to infrastructure of CO_2 transport and storage and trans-boundary cooperation with regard to the infrastructure of transport and storage.[64] In addition, an important barrier is the comprehensive financial security which is needed to comply with the permit requirements and to take the responsibility of the storage of CO_2. [65] Therefore, for the dimension Policy and Regulation, SEL 3 is reached.

Table 16 SEL of CCS in the Netherlands on dimension 3: Policy and Regulations

	SEL 1 Exploration	**SEL 2 Development**	**SEL 3 Demonstration**	**SEL 4 Ready for deployment**
Dimension 3: Policy and Regulations	All milestones reached	All milestones reached	All milestones reached	Not all milestones reached

SEL assessment of dimension "Market and financial resources"

There is a reasonably good estimate of the budget needed for a CCS demonstration site. At the same time, the costs per MT stored CCS can vary per moment in time, as the ETS fluctuates. The first demonstration site will be the most expensive, as it has to build up an infrastructure and knowledge base from scratch. CCS sites that follow the first demonstration can built upon previously gained knowledge and experience and an existing infrastructure, and will therefore be easier to realize.

Although the budget is always tight - especially for fundamental research - , there seems to be a sufficient amount of funds available for fundamental research as well as R&D activities. The EU as well as the Dutch enterprise agency provide in various kinds of subsidies to support the development of CCS applications.*66* The SDE++ subsidy can be considered the financial carrot of the policy measures. The national CO_2 tax will be the stick.[67] The industry as well preserves a budget for the R&D of CCS. The Porthos project in the Netherlands is currently preparing a demonstration expecting to use the SDE ++ subsidy scheme and collaborating with state-owned enterprises, who are allowed to take financial risks.

At this moment, the market for CCS is artificial. The ETS is a European 'cap and trade' system. This 'emission trading market' has been set up as one of the tools to achieve a climate-neutral EU by 2050, and the intermediate target of an at least 55% net reduction in greenhouse gas emissions by

[63] Ibid
[64] Lako, Paul & van der Welle, Adriaan & Harmelink, M. & Kuip, M. & Haan-Kamminga, Avelien & Blank, F. & Wolff, J. & Nepveu, Manuel. (2011). Issues concerning the implementation of the CCS Directive in the Netherlands. Energy Procedia. 4. 5479-5486. 10.1016/j.egypro.2011.02.533.
[65] https://www.rijksoverheid.nl/documenten/publicaties/2018/03/05/routekaart-ccs
[66] Interview Geologist (TNO)
[67] Interview Senior Policy Officer Ministry of Economic Affairs and Climate Policy

2030.[68] There is a maximum amount of CO_2 that is allowed to be emitted per year (the cap). These allowances emission allowances can be received or bought by emitting companies. Companies can also buy limited amounts of international credits from emission saving projects around the world. There is a limit on the total number of allowances. Companies must surrender a sufficient amount of allowances to cover all its' emissions. Fines are imposed when the emissions are higher than the amount of allowances the company owns. It is possible to keep 'spare' allowances to cover future needs, or sell them to other companies who are short of allowances. In recent years, the CO_2 prices in the ETS were around € 5.00 per ton CO_2. Depending on the specific application, the costs are in the order of € 50.00 per ton CO_2. For this reason the application of CCS in the energy sector and industry asks for comprehensive investments, and the EU ETS provides inadequate economic incentives to the industry to make this investments.

As there is not yet a market for CO_2 transport and storage services, investments should anticipate the market.[69] This creates a coordination barrier, because for the decision to capture CO_2, requires certainty about the transport and storage services. However, the storage infrastructure needs certainty about the amount of CO_2 to be stored. Practice has shown that this is difficult to coordinate, the question who should pay the high pre-FID-costs for transport and storage, even when the project fails, in particular.[70] However, based on the urgency of the climate problem, CCS is argued to be an essential technology to rapidly decrease current CO_2 emissions, and therefore it must be deployed to reach the (2030) climate goals.[71] This is why CCS is seen as an important technology to reach climate goals in a (cost effective) way, by the Dutch government as well as industry,[72] especially for industry parties, who do not have another way of bringing back there CO_2 emissions with such high percentages.[73] However, critics state that switching to renewable energy sources should be possible/feasible for these parties as well, and is inhibited by CCS.

All in all, for the dimension 'Market and Financial Resources', SEL 2 has been reached. Financial resources could be sufficient for development of the technology and its system towards the first demonstration of CCS in the Netherlands. However, due to a lack of incentives (for example a higher ETS) and substantial financial risks, up to now the industry has been reluctant to come forward to start a first demonstration site. The financial risks are mainly caused by the risk of leaking CO_2 in the atmosphere. If the future ETS price is high, a high price should be paid back per leaked ton of CO_2, this is a risk the government does not guarantee yet, and the industry is not willing to wear yet.[74]

Table 17 SEL of CCS in the Netherlands on dimension 4: Market and Financial resources

	SEL 1 Exploration	**SEL 2 Development**	**SEL 3 Demonstration**	**SEL 4 Ready for deployment**
Dimension 4: Market and Financial Resources	All milestones reached	All milestones reached	Not all milestones reached	Not all milestones reached

[68] https://ec.europa.eu/clima/policies/ets_en
[69] CCS roadmap
[70] Ibid
[71] CCS roadmap
[72] Climate agreement
[73] Interview Senior Policy Officer Ministry of Economic Affairs and Climate Policy

[74] Interview Geologist (TNO)

Overall SEL of CCS in the Netherlands

Table 18 displays the outcome of the national SEL assessment for the Netherlands.

Table 18 Overall SEL of CCS in the Netherlands

	SEL 1 Exploration	SEL 2 Development	SEL 3 Demonstration	SEL 4 Ready for deployment
Dimension 1: Environment	All milestones reached	All milestones reached	Not all milestones reached	Not all milestones reached
Dimension 2: Stakeholder involvement	All milestones reached	All milestones reached	Not all milestones reached	Not all milestones reached
Dimension 3: Policy and Regulations	All milestones reached	All milestones reached	All milestones reached	Not all milestones reached
Dimension 4: Market and Financial Resources	All milestones reached	All milestones reached	Not all milestones reached	Not all milestones reached

Overall SEL: The overall SEL of CCS in the Netherlands is equal to the lowest level that has been reached in one of the four dimensions.[75] The overall SEL of CCS in the Netherlands is 2. This is equal to the SEL reference point. This means that there are no societal challenges to overcome. However, as there are CCS projects heading towards the demonstration phase in the Netherlands, we decided to identify the societal challenges that lay ahead to reach SEL 3. These societal challenges are described in chapter 6.

2.5 CCS and Monitoring in the Netherlands

Although monitoring is not included in the SEL framework, a chapter is spent on this subject to gather valuable input for the local assessment in the next stage of the DigiMon project. For each dimension a specific monitoring question is asked, namely:

Environment: In what way (how) is the impact on the environment monitored? And what are the requirements for environmental monitoring?

Stakeholder involvement: How does (or: Could) monitoring affect the stakeholder attitude towards CCS? How can monitoring contribute to reducing societal concerns? Is there any experience with participatory monitoring?

Policy and regulations: What is the position of monitoring in the current regulatory framework?

Market and financial resources: how does monitoring of ccs affect the financial circumstances and market position? (i.e., more expensive; more funding opportunities?)

The dimensions 'environment' and 'policy and regulations' are merged because the answers overlap.

Environment and policy and regulations

[75] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

European legislation on the monitoring of CCS is based on CO_2 storage in aquifers, and is therefore not tailored for the Dutch situation, in which CO_2 will be stored in depleted gas fields (offshore). In the Dutch Mining Law, some articles about monitoring are included.[76] These roughly state that a monitoring plan should be included in the permit application and the permit itself, and that results of the monitoring program and the used technology should be shared yearly. No limits have been set for both the monitoring period and the leakage risk (to be calculated as the leaked volume times the price at that time of CO_2 emission rights). The way the monitoring should be organized is assessed per project, the law does not provide in exact specifications of what the monitoring plan should consist of. The intensity of the monitoring depends on the risk profile of the storage site.[1]

Stakeholder involvement

There is no literature about the influence of monitoring on social acceptance of CCS in the Netherlands. Citizen science would be interesting to apply, but this is not relevant for offshore storage.

Market and financial resources

There are several methods to monitor the storage of CO_2, ranging from relatively affordable to very expensive. Currently, there are no extra funding opportunities associated with more extensive monitoring. Therefore, monitoring always adds on to the costs of CCS. However, the extensiveness of the monitoring will depend on the risk profile of the CCS site. The higher the risk profile, the higher the monitoring costs will be. Based on current legislation, the expenses of monitoring can have significant impact on the additional costs of a CCS project. When a market party has to cover the additional expenses for monitoring, as well as the provisions for covering unknown risks, the actual costs for CO_2 storage can be higher.

2.6 Societal challenges for CCS development in the Netherlands

The societal challenges are identified by comparing the overall SEL to the SEL reference point.[77] Based on the SEL assessment we conclude that the current SEL of CCS in the Netherlands is equal to the SEL reference point (SEL 2). However, for the dimension 'environment' the SEL assessment did not result in a clear view on how CCS developers/initiators are mapping the impact of a CCS project on the social environment.

As some current CCS projects in the Netherlands are working towards a demonstration, we identified the societal challenges towards reaching SEL 3 on all dimensions. For the dimension 'policy and regulations' SEL 3 is already reached. For this dimension we described the societal challenges that should be overcome towards the fourth stage; deployment of CCS in the Netherlands. The different dimensions influence each other's' challenges. Therefore, the descriptions of the separate dimensions below overlap in some occasions.

Environment

In the dimension 'environment', the social environment has been underexposed. Although the societal context has been explored and is given attention to in the light of stakeholder involvement, the impact of the technology on the social environment is unknown.

[76] https://wetten.overheid.nl/BWBR0014168/2020-07-01
[1] Interview CCS scientist (TNO)
[77] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

Stakeholder involvement

Although there has been a significant progress in the dimension stakeholder involvement since the failure of former CCS projects, there is room for progress in development of actions for information providing, trust building and securing the cooperation of stakeholders and the public. Also attention has to be payed to the momentum of participation and the best fitting participation levels in the demonstration phase. Although it would be unrealistic to strive for a positive attitude towards CCS from all stakeholders, there is room for improvement in raising awareness about the role of CCS in the climate agreement and how CCS compares to renewable energy sources.

At this moment, stakeholder participation mostly consists of informing. By shifting the focus of participation towards having a conversation about the application of CCS in a broad regional development an added value is sought for all parties.

Policy and regulations

Although the dimension policy and regulation is the most advanced, there are still some hurdles to overcome until it is ready for deployment. First, the current regulatory framework does not provide enough (financial) incentives yet. There are also some issues relating to the implementation of the CCS directive. These issues consist of a lack of clear standards and criteria about safety (site selection and monitoring) and liability, regulation with regard to third party access to infrastructure of CO_2 transport and storage and trans-boundary cooperation with regard to the infrastructure of transport and storage. Finally, unclear regulations about transfer of liability is a barrier for market parties to become storage operator.

Market and financial resources

Societal challenges in the dimension market and financial resources are closely related to challenges in policy and regulations. Financial incentives for market parties have been insufficient until recent developments (the SDE++ might meet this need). Due to the lacking regulations about transfer of liability, the (long term) financial risks regarding to CO_2 leakage and long term monitoring are high. Finally, the coordination barrier is a financial challenge for pioneering CCS initiatives. Initiators now have to pre-invest in the CO_2 transport and storage infrastructure.

2.7 Reflection on applicability of the SEL methodology to CCS developments in the Netherlands

During the study of the SEL in the Netherlands, we evaluated the applicability of the SEL methodology and we kept track of methodological difficulties that came across during the assessment. In this chapter we elaborate whether any dimensions/subjects could not be addressed for CCS in the Netherlands and what methodological difficulties we came across.

Subjects that could not be addressed

In general, we found lots of questions hard to answer for a ‘national’ situation. The questions are developed to be answered for a site/project specific assessment. We solved this through consider it an assessment for CCS in the ‘Enterprise Netherlands’, and applying subtleties is the explanations.

Environment

We were not able to adequately answer the questions about the impact of CCS on the social environment. There are no procedures that prescribe the identification, exploration and assessment of the social environment, and project specific we were not able to gain such detailed information. However, we found that there is some information about how the possible impact of the social environment to the SEL can be taken into account. For this reason, the box of SEL 2 for this dimension is made orange.

Also, in the framework the ‘assessment of the impact on the environment’ was meant to be reached after the technology was demonstrated, however, the EIA is done before the start of the demonstration. For this reason it is possible for the SEL to easily catch up or go further than the TRL. This might be a methodological issue we need to look in to.

The level of detail in this dimension is open to interpretation as well. While developing the questions we presumed that the impact on the environment can only be thoroughly assessed when the technology is in the demonstration phase, because only then the exact impact on that specific environment can be measured. However, the environmental impact assessment is a pretty specific assessment which is done before the actual demonstration. For this reason the milestones in level 3 of the dimension ‘environment’ can (theoretically) be reached before there is an actual demonstration site.

Stakeholder involvement
The questions on this dimension were the hardest to answer on a national level. There is a legal procedure for stakeholder informing and involvement, but actual CCS projects make more effort than the required ‘minimum’. This is a subject that can be studied more extensive in the local assessment. For this reason the SEL 3 box for this dimension is made orange.

Policy and regulations
All milestones and questions are sufficiently addressed.

Market and financial resources
Questions about the market, customers, competitors and substitutes are hard to answer for this technology, because there is no ‘typical market’ situation for CCS.

Methodological challenges that came across during the SEL assessment

We came across several methodological challenges during the performance of the national assessment of the SEL of CCS in the Netherlands. This challenges concern the level of scale between a national and local level; the formulation of the questions of the SEL framework, which causes that some questions are open to interpretation; the scope of the desk study protocol; the applicability of the SEL reference point for the assessment of the whole CCS chain; the transition between SEL levels and the fit of milestones and questions for the assessment of the SEL of CCS in the Netherlands.

National vs local
The questions in the SEL assessment are focused on assessing a particular project/initiative, this makes it challenging to apply the assessment on a national level. For example the business case, the impact on natural environment of a demonstration site and the involvement of stakeholders are particular

Some questions are open to interpretation
This occurs in all dimensions. For example, the answer on questions like: ‘Are stakeholders involved on the moments that benefits them most?’, ‘Is budget for R&D sufficient?’ will depend on who is interviewed.

Desk study protocol
We found that the predetermined search words do not cover all information.

- Search words do not cover all information;

- Scientific papers do not provide up-to-date information;
- To what extend can desk study research be neutral? Extremely ‘good’ or ‘bad’ cases are more often studied and described then ‘regular’ cases. This might cause biased data.

SEL reference point
We found that, especially on a national level, the SEL reference point is hard to determine. The SEL reference point is based on the current TRL of the technology that is assessed in the SEL assessment. However, CCS consists of a chain of technologies, which all have a different TRL. Besides, when assessing the SEL on a national level, no specific technology is assessed, but more of a concept of a chain of technologies. For all sub-systems (CO_2 capture, transport and storage), multiple technologies can and will be used.

Transitions between SEL levels
We found that in the Netherlands there is currently no CCS demonstration site. However, as there were some former projects very close to demonstration before, several milestones and even the dimension policy and regulations already reached level 3. We think we should determine whether or not it is possible to go to SEL three and beyond, without having a demonstration site. It might help to add control questions per dimension, which are closely related to the TRL.

Additionally we think – for CCS – it might be hard to define the transition between SEL 3 and SEL 4. It might vary per technology/system when a demonstration site transfers to deployment. It might be helpful to add control questions for this transition, which can vary between technologies (for example; financial independency).

Fit of milestones and questions
Some questions might not fit all kinds of technological innovations. We found it hard to answer questions about the impact of CCS on the social environment, and could not scope all questions in the dimension market and financial resources for the CCS situation.

Interlinkages between the dimensions
During the assessment, we found that the four dimensions have many interlinkages. These interlinkages cause overlap and interferences between the dimensions.

2.8 Conclusion

The overall SEL of CCS in the Netherlands is 2. This is equal to the SEL reference point which was used for the scope of this assessment, which means that there are no societal challenges left to ‘catch-up’ with the SEL reference point. However, as currently two CCS projects in the Netherlands are heading to demonstration, the societal challenges towards SEL 3 are described in this report. The main societal challenges consist of gaining insight in the impact of CCS on the societal environment, shifting the focus of participation towards having a conversation about the application of CCS and making CCS financially more attractive for initiators. We found that the dimension ‘Policy and Regulations’ is already in an advanced stage, comparing to the other dimensions. Also, we found that the dimension ‘Stakeholder Participation’ made a significant process in comparison with the former Dutch CCS projects. We think that this advancements can be assigned to the fact that, although there have been no full chain CCS demonstrations before, there have been some former projects in which experience has been gained.

3. National SEL assessment in Greece

Authors: Dimitrios Mendrinos and Olympia Polyzou (CRES)

3.1 Introduction

This report describes the national assessment carried out for Greece concerning the Societal Embeddedness Level (SEL) of CCS concept, technology and system, according to the methodology described in DigiMon deliverable D3.1 “Guideline Societal Embeddedness Assessment”. It was implemented as a part of DigiMon deliverable D3.2 “Report on the SEL of four countries: Norway, the Netherlands, Greece and Germany”. It is based on the common national assessments outline agreed between TNO, NORCE, UGZ and CRES.

Firstly, a historical review on the CCS context in Greece is implemented. Following a description of the methodology adopted, the national SEL assessment for Greece is presented, which includes the main findings and the achievement level of milestones in each one of the four SEL dimensions on environment, stakeholders’-involvement, policy-and-regulations and market-and-financial-resources. Based on this assessment, the main challenges for further advancing societal embeddedness levels in Greece are analysed. Then a possible socio-technological scenario for further CCS development in Greece is drafted and the report closes with a discussion on SEL application methodology findings for Greece.

3.2 Historical context of CCS in Greece

One of the largest sources of CO_2 in Greece are power plants with coal burning (lignite) in Western Macedonia ranking Greece second European and sixth in the world in lignite production. According to today data, PPC's eight lignite power plants are located in Ptolemais (NW Greece) and generate 56% of the electricity of the country (PPC SA, 2020) and emit approximately 20 Mt/yr CO_2, accounting for approximately 30% of total CO_2 emissions in Greece, as shown in Figure 7 (IEA, 2018).

CO_2 emissions in Greece peaked in 2007, and since then there has been a steady reduction, reaching a total amount just exceeding 60 Mt/yr in2018, as shown in Figure 7. This can be attributed to the consequences of the on-going economic crisis in the country, as well as in the overall effort of the governments towards the reduction of CO_2 emissions of the electricity sector. According to the National Energy and Climate Plan lignite and diesel fired power plants are in the process of being phased out and under replacement by natural gas fired ones, as well by central and distributed renewable energy sources, mainly wind and photovoltaic. This trend is expected to continue during the current decade 2020-2030.

CCS has been initially investigated by the Public Power Corporation of Greece (PPC) during the decade 2000-2009 spurred by the forthcoming (at that time) CO_2 taxation policy, as PPC lignite fired power plants accounted for a large share of countrywide CO_2 emissions, see Figure 7. As the bulk of lignite fired plants are located in Ptolemais (see Figure 8), as initial CO_2 storage sites the nearby sedimentary basins of Mesohellenic Trough, Ptolemais, Alexandria, West Thessaloniki and Prinos were considered. Detailed evaluation studies of these basins are presented in Koukouzas et al. (2009) and Tasianas and Koukouzas (2016).

During the next decade 2010-2019, the National policy changed from keeping the lignite fired power plants to completely phasing them out by 2030, and the focus of CCS changed from the power generation industry to the hydrocarbons industry, also spurred by the offshore hydrocarbons exploitation plans. Recently, as the TAP gas transmission pipeline to European market through

Greece was completed, as the hydrogen use came in the foreground again, and as the idea of aquifer thermal energy storage gained acceptance, new storage uses of the underground emerged, in addition to CO_2 storage. They include geological hydrogen storage, geological natural gas storage, aquifer thermal energy storage (ATES) and geological CO_2 storage. Potential sites and their storage capacity are analysed in Arvanitis et al. (2020) and their location in the map is shown in Figure 9.

Concerning public awareness, the public in Greece has been in general unaware of the CCS opportunity, as there have been no systematic dissemination activities by the stakeholders concerned. CCS was made legally possible, when relevant legislation was introduced on 7 November 2011, comprising the Joint Ministerial Decision 48416/2037/E.103/2011 (GG B 2516) corresponding to the implementation in National level of the EU Directive 2009/31/EC on the geological storage of CO_2.

No pilot CCS projects have taken place in Greece until now.

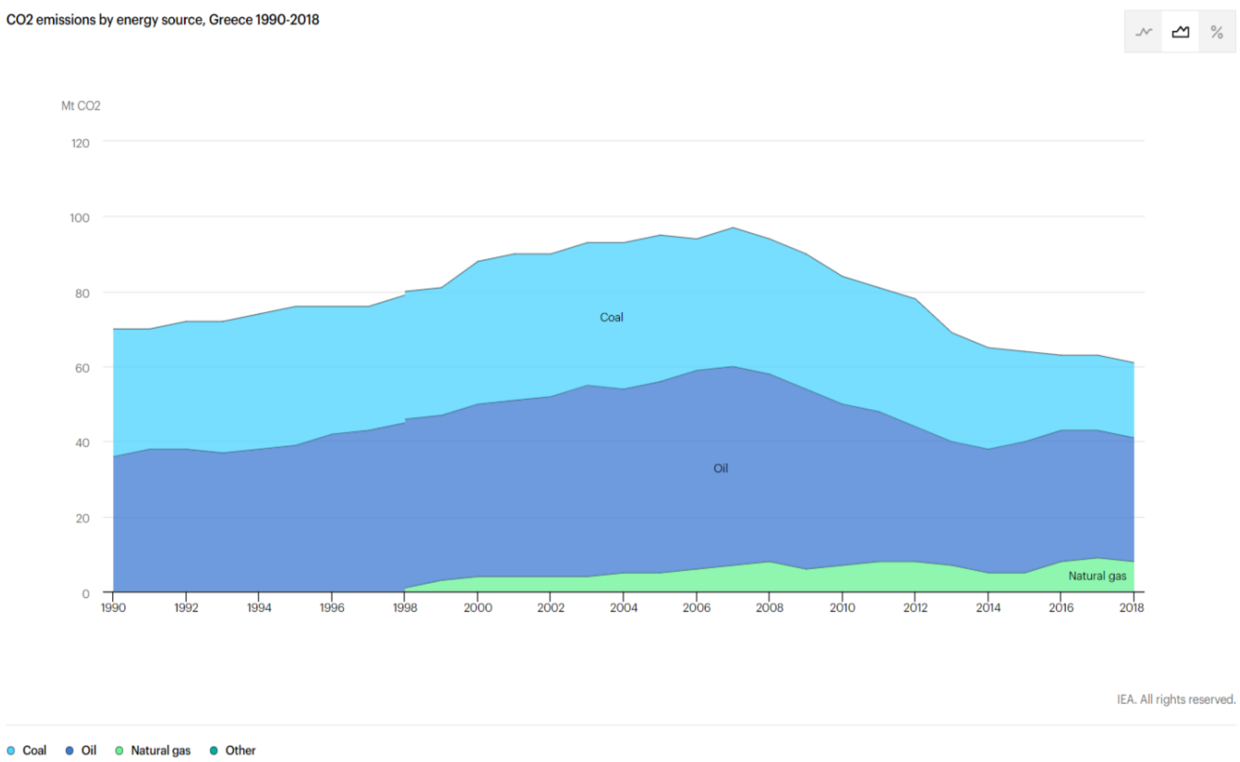

Figure 7 Evolution of CO_2 emissions in Greece since 1990 according to fuel type [1]

[1] IEA (2018), https://www.iea.org/

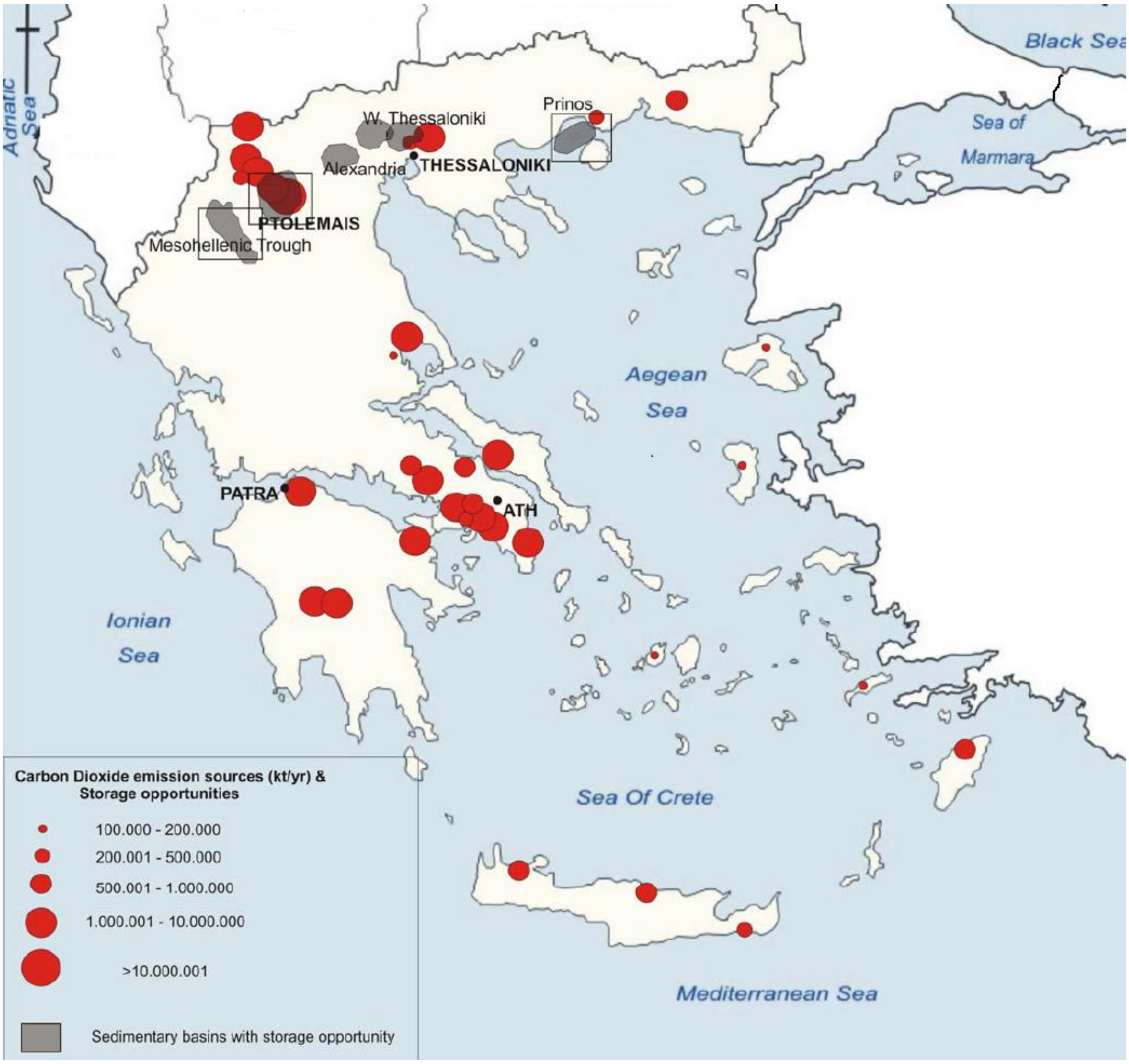

Figure 8 Main CO_2 emission sites in Greece and CO_2 geological storage basins considered by PPC during 2000-2009 [2]

[2] Modified from Koukouzas N., Ziogou F., Gemeni V., (2009), "Preliminary assessment of CO2 geological storage opportunities in Greece", International Journal of Greenhouse Gas Control 3 (2009), pp 502–513

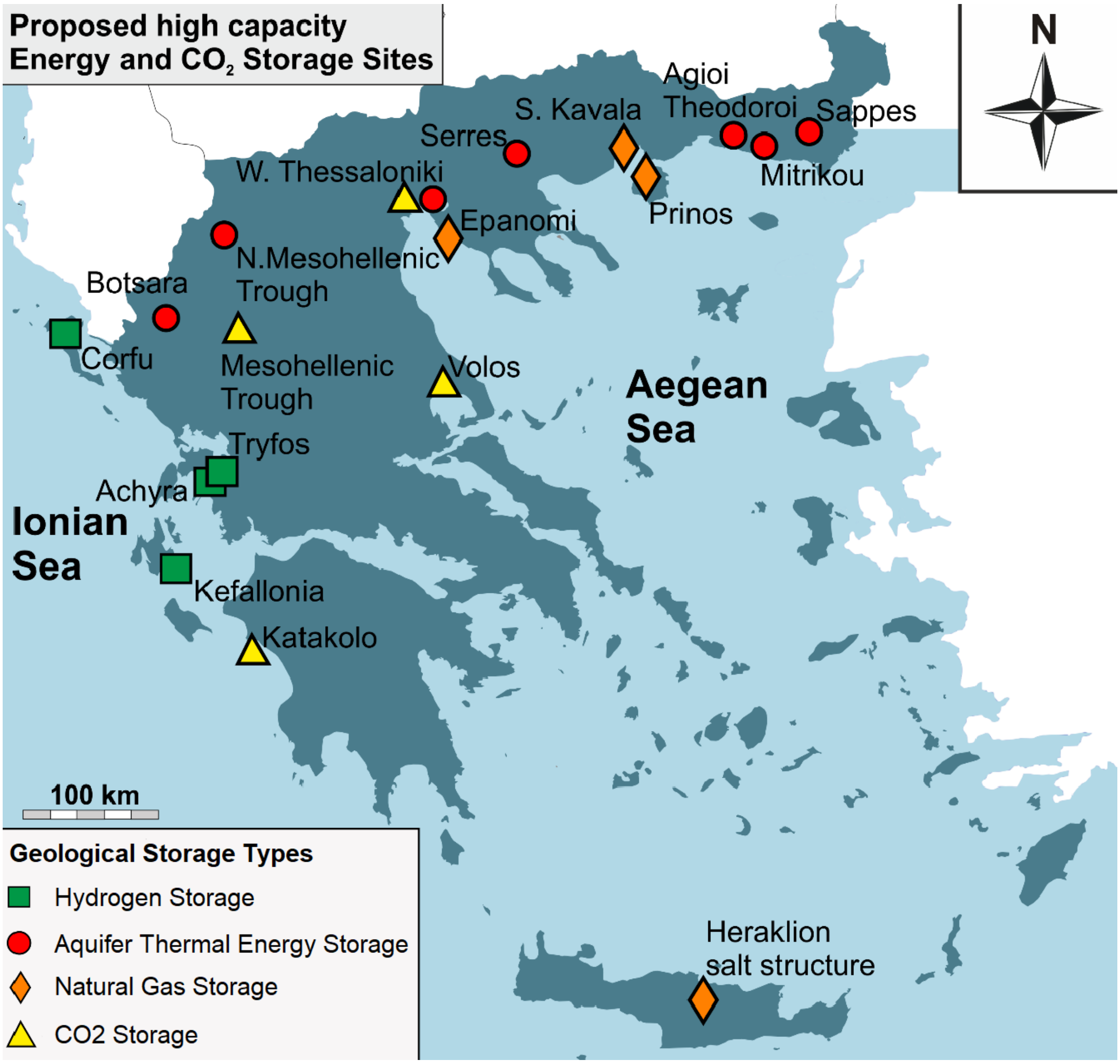

Figure 9 Location of potential geological storage systems in Greece: hydrogen, heat, natural gas and CO_2 [3]

3.3 Approach for performing the assessment

The SEL assessment in Greece was carried out according to the approach described in DigiMon Deliverable D3.1. The SEL dimensions, the milestones and the questions behind each dimension described in D3.1 were used.

Firstly a desk review was performed in order to define SEL starting point and milestones level of fulfilment, by answering as many questions next to milestones as possible. It was quickly realized that there were very few publications and articles available on CCS in Greece and that the SEL

[3] modified from: Arvanitis A., Koutsovitis P., Koukouzas N., Tyrologou P., Karapanos D., Karkalis C. and Pomonis P. (2020), "Potential Sites for Underground Energy and CO2 Storage in Greece: A Geological and Petrological Approach", Energies 2020, 13, 2707; doi:10.3390/en13112707

starting point was SEL=1, as neither CCS projects nor CCS related activities, other than an incomplete inclusion of EC directive on CCS in Greek legislation, could be identified in Greece. The corresponding **CCS TRL is at level 2** (technology concept formulated), as no laboratory experiments or pilot projects have taken place until now.

In order to gain a complete picture of CCS SEL in Greece a very broad search was carried out at the google online search engine. 20 relevant publications were identified, of which 15 concerned SEL aspects. Due to the small number of articles, all of them were considered in the assessment. The articles studied are listed in Table 19.

The initial SEL assessment was carried out by answering and commenting all questions next to milestones in all 4 dimensions and all 4 society embeddedness levels, using the information that was made available during the desk research.

An interview protocol was prepared for the experts interviews. However, due to the lockdown imposed as a counter COVID-19 measure, it was not possible to conduct face-to-face interviews and the questionnaires were distributed to the experts by email and replies were received by email. Telephone communication was also performed when necessary.

Based on the initial assessment we prepared a questionnaire dedicated to legal and selected financing aspects, which was sent to the Ministry of Energy experts and we collected their replies, which gave us a complete picture of SEL legal dimension. Another questionnaire was distributed to PPC experts, who were leading CCS research in Greece during the 2000's.

As no projects of any kind (pilot, demo or permanent CO_2 storage facilities) are planned in the near future in Greece, all replies in questions at levels 3 and 4 are negative. We therefore provided a collective NO reply and a collective justification for levels 3 and 4 – this was also the case in level 2 of the market & resources dimension.

Concerning CCS monitoring aspects in Greece we identified the following:

- There is general belief that monitoring alleviates concerns on safety
- A monitoring strategy has been proposed for a particular possible future demonstration facility
- Monitoring is compulsory according to present legislation

Table 19 List of publications on CCS context in Greece and associated SEL dimensions

Article, presentation or publication	**SEL dimensions**
European Commission, DG-Energy (2011), "Public Awareness and Acceptance of CO_2 capture and storage", Report, Special Eurobarometer 364	1-Social 1-Monitoring 2-Stakeholders
IGME (2006), "A Geologic Solution in Climate Changes", CO_2net, Brochure (in Greek), http://www.geology.cz/geocapacity/downloads/GEOLOGICAL_STORAGE_ CO_2.pdf	4-Economic
Kelektsoglou K. (2018), "Carbon Capture and Storage: A Review of Mineral Storage of CO_2 in Greece", Sustainability 2018, 10, 4400; doi:10.3390/su10124400	4-Economic
Koukouzas N., (2009), "Perspectives for CCS application in the Greek Thermal Power Plants", presentation, presented during ENERTECH 09, Athens, , October, https://www.dei.gr/Images/KOUKOUZAS.pdf	3-Legal 4-Economic
Koukouzas N., Klimantos P., Stogiannis P., kakaras E., (2006), "CO_2 Capture and Storage in Greece: a Case Study from Komotini NGCC Power Plant", *Thermal Science*, Vol. 10, No 3, 71-80	4-Economic
Koukouzas N., Kypritidou Z., Purser G., Rochelle C., Vasilatos C., Tsoukalas N., (2018), "Assessment of the impact of CO_2 storage in sandstone formations by experimental studies and geochemical modeling: The case of the Mesohellenic Trough, NW Greece", *International Journal of Greenhouse Gas Control*, Volume 71, April 2018, Pages 116-132, https://doi.org/10.1016/j.ijggc.2018.01.016	1-Environment
Koukouzas N., Lymperopoulos P. and Tasianas A, (2016), "Safety Issues when monitoring CO_2 Storage in the Prinos Area, Greece", *Bulletin of the Geological Society of Greece*, 50(4), 2304-2313. doi:https://doi.org/10.12681/bgsg.14296	1-Environment
Koukouzas N., Lymperopoulos P., Tasianas A, Shariatipour S., (2016), "Feasibility Study for The Setting Up of a Safety System for Monitoring CO_2 Storage at Prinos Field, Greece", IOP Conf. Ser.: Earth Environ. Sci. 44 052043, doi:10.1088/1755-1315/44/5/052043	1-Environment 1-Monitoring 4-Economic
Ktenas D., Kosmidou B., Spinos S., (2020), "Underground Geological Storage of CO_2 and Natural Gas in Greece", Hellenic Hydrocarbon Resources Management S.A. (HHRM S.A.) Report, 78 pp.	1-Environment 3-Legal 4-Economic
Ministerial Decree 48416/2037/E.103, (2011), "Measures and conditions for the storage of carbon dioxide in geological formations", Government Gazette of The Hellenic Republic 2516B, 7 November 2011	3-Legal
Pietzner K. et al (2011), "Public Awareness and Perceptions of Carbon Dioxide Capture and Storage (CCS): Insights from Surveys Administered to Representative Samples in Six European Countries", Energy Procedia 4, 6300–6306, doi:10.1016/j.egypro.2011.02.645	1-Social
Rütters, H. and the CGS Europe partners, (2013), State of play on CO_2 geological storage in 28 European countries. CGS Europe, report No. D2.10, June 2013, 89 pp.	2-Stakeholders 3-Legal 4-Economic
Tcvetkov P., Cherepovitsyn A., Fedoseev S., (2019), "Public perception of carbon capture and storage: A state-of-the-art overview", Heliyon 5 (12) e02845, https://doi.org/10.1016/j.heliyon.2019.e02845	1-Social
Terzi A. (2014), "Study of CO_2 effect in groundwater quality under flowing conditions", Master's Thesis, Chemical Engineers Department, Polytechnic School, University of Patras, 173 pp, (in Greek)	1-Environment
Vazaios I. (2009), "How can CO_2 emissions from energy production be eliminated in Greece by 2050?", Bellona.org, https://bellona.org/news/ccs/2009-09-how-can-co2-emissions-from-energy-production-be-eliminated-in-greece-by-2050	2-Stakeholders

3.4 SEL assessment

CO_2 storage concept in Greece at TRL = 2, as no technology validation experiment in lab, relevant environment, or site has taken place in Greece, while no CO_2 storage demonstration sites nor permanent CO_2 storage sites exist in Greece, and are not planned for the near future. As **TRL of CCS** in Greece is at **level 2**, the SEL entry point for the assessment is 1 in all four SEL dimensions. Following the methodology described in previous chapter, in each SEL dimension the achievement of relevant milestones is evaluated based on the results of the desk research and the experts' interviews/replies. The SEL assessment results follow.

SEL dimension 1 – Environment (physical and social)

CO_2 storage basins have been identified in Greece. Considering that Greece is a well explored country, the state of the art of geological settings and geographical areas above them is known. This also applies to atmospheric conditions, surface lakes, rivers and streams, subsurface aquifers, sea environment for offshore areas, flora and fauna including nearby Natura protected zones. State of the art of cities, towns and villages, spaces and overlaying infrastructure is also known, as well as of population social aspects, cultural milieus and institutions. In general, public awareness is low, as only ~25% of population are aware of CCS, but only ~5% informed, while although CCS perception is slightly positive (>50%) among the Greek population, the not-in-my-backyard attitude prevails (>50%), see Pietzner K. et al (2011). The main concern of people (~85%) towards CCS is safety.

Table 20 Milestones achievement for SEL Dimension 1 on physical and social Environment

SEL 1 Exploration		SEL 2 Development		SEL 3 & 4
Identification of natural environment of CCS concept	☑	Identification of natural environment of CCS system	☑	
Identification of built environment of CCS concept	☑	Identification of built environment of CCS system	☑	
Identification of social environment of CCS concept	☑	Identification of social environment of CCS system	☑	
Exploration of potential impact of CCS concept on the Natural environment	☑	Potential impacts of CCS system on the natural environment are explored	☑	
Exploration of potential impact of CCS concept on the built environment	☑	Potential impacts of CCS system on the built environment are explored	☑	☒
Exploration of potential impact of CCS concept on the social environment	☑	Potential impacts of CCS system on the social environment are explored	☒	
		The impact(s) of CCS technology on the natural environment are assessed	??	
		The impact(s) of CCS technology on the built environment are assessed	☑	
		The impact(s) of CCS technology on the social environment are assessed	☒	

Simulation of impacts of potential CO_2 storage leaks have been made for Prinos Basin, while the impact to local geological environment has been studied for the Mesohellenic Trough. Studies carried out indicated that concentration of other pollutants (NOx, NH3) is expected to rise in CO_2 capture plants, while CO_2 rise in the air to suffocating levels may occur in case of explosive leaks. In addition, simulation of potential impacts of CO_2 storage leaks to above laying seawater, to groundwater and nearby Natura protected areas have been made for the Prinos Basin, CO_2 storage site.

The impacts of CCS technology to be applied on land, air and water were assessed, but its impact on life remains uncertain.

Social impact studies of CCS concept have been carried out by PPC, but have been kept confidential until now. Induced seismicity evaluation has been also done by PPC, concerning CCS concept, system and technology to be applied, which were also kept confidential.

Concerning monitoring, there is a general belief that it alleviates concerns on safety.

No milestones corresponding to SEL levels 3 and 4 are fulfilled, as neither assessments nor mitigation actions other than definition of monitoring strategy have been considered for a particular demonstration facility. Moreover, no mitigation measures have been taken for a particular permanent CO_2 geological storage site.

Based on the above, the milestones achievement of SEL dimension 1 on physical and social environment are summarized in Table 20.

SEL dimension 2 – Stakeholder involvement

Key Stakeholders that could be impacted by the CCS concept, technology and/or system and its implementation in Greece are Local Authorities, Local Population, the Public Power Corporation (PPC) and the Ministry of Energy (YPEN), while the ones that could have impact on CCS concept and technology are the Ministry of Energy (YPEN), as well as the Hellenic Survey of Geology and Mineral Exploration (HSGME), Hellenic Hydrocarbon Resources Management S.A. (HHRM), the Institute of energy of Southeast Europe (IENE), the Centre for Research and Technology Hellas (CERTH) and the Centre for Renewable Energy Sources and Saving (CRES).

Although the main knowledge, opinions, questions, concerns and perspectives that the above stakeholders have had so far concerning novel innovations in CCS or similar sectors are known, the potential influence of social media has not been evaluated. This is a very important knowledge area to further develop. One segment which is very influential comprises the Energy Twitter and the Climate Modelling Twitter, as these two communities can have significant influence on how governments think about CCS.

Stakeholders relevant to the CCS development are Local Authorities, Local Population, Civil Society, Grassroot Organisations, PPC, YPEN, CRES, CERTH, HSGME and HHRM, but their participation level and contribution has not been defined. Only stakeholders that may have positive impact on CCS have been involved, while ones who can have negative impact such as NGOs and Green Peace have not been invited. Dissemination efforts have been limited to a communication brochure produced by EAGME, forums organized to instigate a dialogue, a few interviews and articles published in newspapers, magazines and electronic media. Technology providers, private energy companies and other industrial players have expressed interest in CCS, but no widespread communication action has taken place.

Concerning trust, there are concerns among public population on CCS technology and system safety, its impact to health and possible leaks to surface.

Neither the stakeholders concerned, their participation, concerns and perceptions have been identified, nor any trust building actions other than definition of monitoring strategy have been considered for a particular demonstration facility. In addition, no stakeholder participation scheme has been designed or materialized and no stakeholder support has been secured for a particular permanent CO_2 geological storage site.

Based on the above, the fulfilment of milestones related to SEL dimension 2 on Stakeholders' involvement is summarized in Table 21.

Table 21 Milestones achievement for SEL Dimension 2 on Stakeholders' involvement

SEL 1 Exploration		**SEL 2 Development**		**SEL 3 & 4**
Basic inventory of all stakeholders in CCS field	☑	Inventory of all relevant stakeholders in the field for CCS technology	☑	
Insight into the societal attitude towards novel technologies in CCS sector	☒	Decision on level of participation of the stakeholders in development process of CCS	☒	
		Design for stakeholder participation tailored to stage of development	☒	☒
		Knowledge, opinions, questions, concerns and perspectives of all relevant stakeholders regarding CCS innovation are assessed and integrated into innovation development strategy	☒	
		Inventory of all relevant stakeholders in the field for CCS system	☑	
		Identification of possible trust issues for CCS technology and system	☑	

SEL dimension 3 – Policy and Regulations

The current political climate and context is described in the National Blueprint for Energy and Climate (ΕΣΕΚ). One of the policy priorities in the field of Research, Innovation and Competitiveness (as described in the National Blueprint for Energy and Climate) concerns the development of innovative technologies regarding capture, storage and use of CO_2. Regulatory support for innovation is secured through the Patent or Copyright certification process. There are general provisions about Patents, but there is not a specific regulatory regime concerning relative innovations.

Presidential Degree 51/2007 (GG. A 54), transposition of EU Directive 2009/31/EC and Joint Ministerial Decision 48416/2037/E.103/2011 (GG B 2516) "Measures and conditions s for CO_2 storage in geological formations" have been published but not put to practice. However, the existing framework requires updating and further elaboration, as specific but important details have not been regulated yet. Following EU Dir. 2009/31/EC and the above legislation no projects were undertaken in order to explore relevant European, national, regional and local policies and regulations and the way they interact.

According to the aforementioned Ministerial Decision, the relevant authorities for CCS are the General Secretariat of Energy and Mineral Resources for licensing and the Directorate General for the Environment for environmental licensing of the Ministry of Environment and Energy. Due to the fact that the details of the Decision have not been set yet, it is not clear which Department or Directorate issues the licensing for exploration and storage. The Department of Geothermal Energy of the Ministry of Environment and Energy is responsible for expressing opinions on relevant matters, but not issuing licenses. Lastly, the environmental inspection activities are carried out by the Directorate General of Inspectors of the Ministry of Environment and Energy. As no CCS projects exist in Greece, there has been no need to activate any contacts between the Authorities concerned until now.

Apart from a few reports regarding the possible locations for storage, including a recent one by The Greek Hydrocarbon Management Company (HHRM), we have no knowledge of specific reports about the possible relevant existing policies and regulations concerning CCS technology.

There is a policy priority on CCS, as described in the National Blueprint for Energy and Climate, but the specific measures are not set yet. However, policy and regulatory barriers have not been assessed due to lack of specification and relevant experience. Important risk factors are the lack of baseline research and the slow judicial processes. As current policies are not sufficiently effective for further development of the technology, there is a need for further elaboration of regulatory framework.

Permit requirements have not been assessed for CCS technology due to lack of specification and relevant experience. General provisions of EU Certification rules apply only for CCS technology certificate requirements.

Despite collaboration between licensing agencies and environmental licensing authorities is required by law, it has not been established yet. Furthermore, there is no professional lobbying among CCS interest groups or technology platforms.

There are no certificates, nor permits, while policy & regulatory drivers are not assessed and no support has been secured for a particular demonstration facility. Furthermore, neither permits or certificates, nor supportive regulatory framework are in place for a particular permanent CO_2 geological storage site.

Table 22 Milestones achievement for SEL Dimension 3 on Policy and Regulations

SEL 1 Exploration		**SEL 2 Development**		**SEL 3 & 4**
The current political climate and context on CCS is explored	☑	Existing policies and regulatory framework for CCS technology are assessed	☒	☒
Existing policies and regulatory framework for CCS innovation explored	☒	Policy and regulatory drivers and barriers are assessed for CCS technology	☒	
Access to CCS regulatory process is possible	☒	Certification and permit requirements for CCS technology are assessed	☒	
First interactions between developers and governments to create support for CCS technology have been made	☒	Interactions between developers and governments to secure support for CCS technology development are underway	☒	

Based on the above, the fulfilment of milestones related to SEL dimension 3 on Policy and Regulations is summarized in Table 22.

SEL dimension 4 – Market and Financial Resources

Although the budget needed for funding CCS concept development has been estimated for several CO_2 storage sites, the necessary funding has not been made available.

Potential customers are power plants, refineries and heavy industries. CO_2 prices are determined in the CO_2 stock exchange. Substitutes include CO_2 trade, fuel switch, use of biomass and biogas, renewable electricity and heat. Potential suppliers and competitors are not available yet.

Market needs and trends have not been assessed and no business case has been evaluated other than estimation of capital and operation costs.

The necessary financial resources are not available, while market strategy, business case and system technology have not been adapted for demonstration. In addition, there is no solid business case, nor financial support for a CO_2 permanent geological storage facility.

Table 23 Milestones achievement for SEL Dimension 4 on Market and Financial Resources

SEL 1 Exploration		SEL 2 Development		SEL 3 & 4
Financial resources are sufficient for exploration of CCS idea	☒	Financial resources are sufficient for development of CCS technology	☒	
Current market dynamics, size and potential growth are identified	☒	Market segments, niches, size, growth and its future potential are assessed	☒	☒
A market need/gap is identified	☑	The market need/gap is analysed and evaluated	☒	
		A first business case is made	☒	

The corresponding milestone achievements regarding SEL level Dimension 4 on Market and Financial Resources, as derived from the above analysis, are summarized in Table 23.

Overall SEL assessment in Greece

The assessment of CCS societal embeddedness level (SEL) in Greece analysed in detail above, is summarized in Table 24.

Table 24 CCS assessment briefing in Greece

	SEL 1 exploration	SEL 2 development	SEL 3 demonstration	SEL 4 deployment
Dimension 1: Physical & Social Environment	All Milestones reached	Some Milestones reached	No Milestones reached	No Milestones reached
Dimension 2: Stakeholders Involvement	Some Milestones reached	Some Milestones reached	No Milestones reached	No Milestones reached
Dimension 3: Policy & Regulations	Some Milestones reached	No Milestones reached	No Milestones reached	No Milestones reached
Dimension 4: Market & Resources	Some Milestones reached	No Milestones reached	No Milestones reached	No Milestones reached

In Greece, CCS activities are limited to identification of CO_2 storage sites, evaluation of environmental impact, rough estimates of costs involved, an incomplete legal framework, no financing available, limited involvement of positive stakeholders only, and the absence of any lab experiments, pilot plants or permanent CO_2 storage facility. Public awareness is very low, while monitoring is foreseen by the legal framework and is perceived positively to alleviate safety concerns.

Overall SEL is at level 1, with all milestones reached level 1 in the environmental dimension only. SEL 1 milestones are partially reached in the other three dimensions. Regarding SEL 2, only some milestones have been reached in dimensions 1-Environment and 2-Stakeholders' Involvement, while no milestones have been achieved in the other two dimensions. SEL 3 and 4 milestones are completely out of reach.

3.5 Main challenges for improving SEL in Greece

In Greece CCS is in its infancy, both on technological, as TRL=2 and on societal embeddedness terms, as overall SEL equals to 1. Concerning SEL dimensions, only the environmental one has all its milestones fulfilled at the 1^{st} societal embeddedness level.

At a first stage, a CCS development strategy should aim for the completion of technology innovation and development activities, with the first stage objective to create and operate a pilot CCS facility, in order to acquire experience at country level and build the necessary trust for the technology. This can be done quite fast, by importing technology in the country from foreign players who already operate CCS demonstration facilities and reaching TRL=6 at national level, rather than developing own technology. This action should be accompanied by advancing in parallel the societal embeddedness level to 2, by reaching all corresponding SEL milestones of levels 1 and 2.

Concerning SEL dimension 1 on environment this implies that activities should focus on assessing the impact of CCS technology on the natural, built and social environment.

Concerning SEL dimension 2 on stakeholders'-involvement activities should include involvement of social media, engaging and informing all stakeholders especially the ones who can have negative influence which may hamper CCS development, and assessing their interests, attitude, perceptions and concerns.

Concerning SEL dimension 3 on policy-and-regulations, the focus should be to update, complete and streamline existing regulatory framework. It is imperative to establish collaboration between the different local, regional and national Authorities concerned. Policy drivers and barriers, as well as certification and permitting requirements should be assessed in terms of effectiveness and being supportive to CCS.

Concerning SEL dimension 4 on market-and-resources, the focus should be on market analysis, needs and trends, on securing the necessary financial resources for technology development and on developing the first business case.

3.6 Scenario

Following the political decisions to phase out lignite and diesel fired power plants during the next decade and to develop the onshore and offshore hydrocarbons resources, the CCS driving force shifted from the power industry to the hydrocarbons producing industry. The latter is under development and is expected to grow in the following years.

Considering also that the use of hydrogen as a fuel has regained interest among policy makers, also supported by the passing through the country of the TAP natural gas transporting pipeline to Italy, a likely scenario seems to be the production of blue hydrogen coupled to CO_2 capture and geological storage. CCS is expected to be spurred by the abundant availability of natural gas in the country, either transported by the TAP pipeline, or produced offshore.

Possible CO_2 geological storage locations have been defined (see Figures 8 and 9), the necessary technology will be imported, so if the decision to proceed with CCS is taken at high political level, the main challenge will be to achieve the necessary societal embeddedness level, which will facilitate CCS development and secure the CCS acceptance by the local communities concerned.

In parallel to developing and operating the first pilot CCS facility, SEL advancing activities should focus on achieving SEL=2 at first stage, as described in previous chapter. Considering that SEL=2 should be reached when TRL=6 is achieved at national level, and based on general technology development timeframes, this process may be implemented within an eight to ten year period.

If the pilot CCS project is successful, next step should be to build and operate a CCS demonstration plant, while further advancing SEL to level 3. SEL advancement to level 3 implies mitigation of the physical and social environmental impacts, engaging and trust building among all stakeholders' concerned and social media, incorporating society aspects in policy and regulatory framework, while securing sufficient financial resources and orienting technology, market strategy and business plan towards customer and other market actors' needs. This part may last approximately another four to five years, again based on general technology development timeframes for advancing TRL from 6 to 8.

3.7 Reflection on SEL methodology

No important CCS developments have taken place in Greece with complete absence of CCS projects and no innovation or development activities, other than formulating CCS concept and its possible environmental impact, identifying potential CO_2 geological storage sites and importing the EU directive on CCS in national legislation. For this reason, the main challenge during this assessment has been to identify enough articles published and enough experts who will be willing to provide their views.

SEL dimensions and milestones seem appropriate for application at national level in Greece. They provide a good starting framework to provide guidance, in order to facilitate CCS implementation and address social issues which could hamper CCS development. Further evaluation will be possible, when CCS becomes a reality in the country and sufficient experience will be gained during its development.

3.8 References

Arvanitis A., Koutsovitis P., Koukouzas N., Tyrologou P., Karapanos D., Karkalis C. and Pomonis P. (2020), "Potential Sites for Underground Energy and CO_2 Storage in Greece: A Geological and Petrological Approach", *Energies* 2020, 13, 2707; doi:10.3390/en13112707.

IEA (2018), https://www.iea.org/

Koukouzas N., Ziogou F., Gemeni V., (2009), "Preliminary assessment of CO_2 geological storage opportunities in Greece", *International Journal of Greenhouse Gas Control* 3 (2009), pp 502–513.

Pietzner K. et al (2011), “Public Awareness and Perceptions of Carbon Dioxide Capture and Storage (CCS): Insights from Surveys Administered to Representative Samples in Six European Countries”, *Energy Procedia* 4, 6300–6306, doi:10.1016/j.egypro.2011.02.645.

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Tasianas A. and Koukouzas N. (2016), “CO_2 storage capacity estimate in the lithology of the Mesohellenic Trough, Greece”, *Energy Procedia* 86 (2016) pp. 334 – 341.

4. National SEL assessment in Germany

Author: Danny Otto, UFZ

4.1 Introduction

This assessment provides an overview of the current socio-political, socio-technical and socio-historical setting of carbon capture and storage (CCS) technologies in Germany. It uses the "Societal Embeddedness Level Framework" (SEL) as an instrument to evaluate the environmental, political, societal and economic contexts and challenges that carbon sequestration methods face. The following section provides a socio-historical contextualization of CCS in Germany. An overview of the methods applied is presented in chapter 3. The SEL assessment and the major challenges to the implementation of CCS technologies are provided in chapters 4 and 5. The report closes with potential future scenarios and a methodological discussion on the application of the SEL.

4.2 Socio-historical context of CCS in Germany

Carbon capture and storage (CCS) technologies have been studied in Germany for about 20 years. CCS had been applied in different contexts (e.g. enhanced oil recovery) in North America (e.g. Donaldson et al. 1989, 1985) and Europe (e.g. Sleipner see Korbol/Kaddour 1995) for many years before it entered a broader political and scientific discussion in Germany in the early 2000s. The main reasons for this were:

- The start of projects to assess the geological storage capacities in Germany (e.g GESTCO – Geological Storage of CO_2 from fossil fuel combustion 2000-2003, May et al. 2003) (see Figure 10).
- Start of the CO_2SINK (CO_2 Storage by Injection into a Natural saline aquifer at Ketzin) project located near the town of Ketzin, Germany (close to Berlin). This was the first demonstration project for large-scale on-shore CO_2 storage in Europe (Juhlin et al. 2007).
- The seminal special report of the IPCC on carbon capture and storage (2005) as well as the following intensification of discussions on a European level, which resulted, for instance, in the European CCS Demonstration Project Network (start 2009, see Kapetaki et al. 2017).

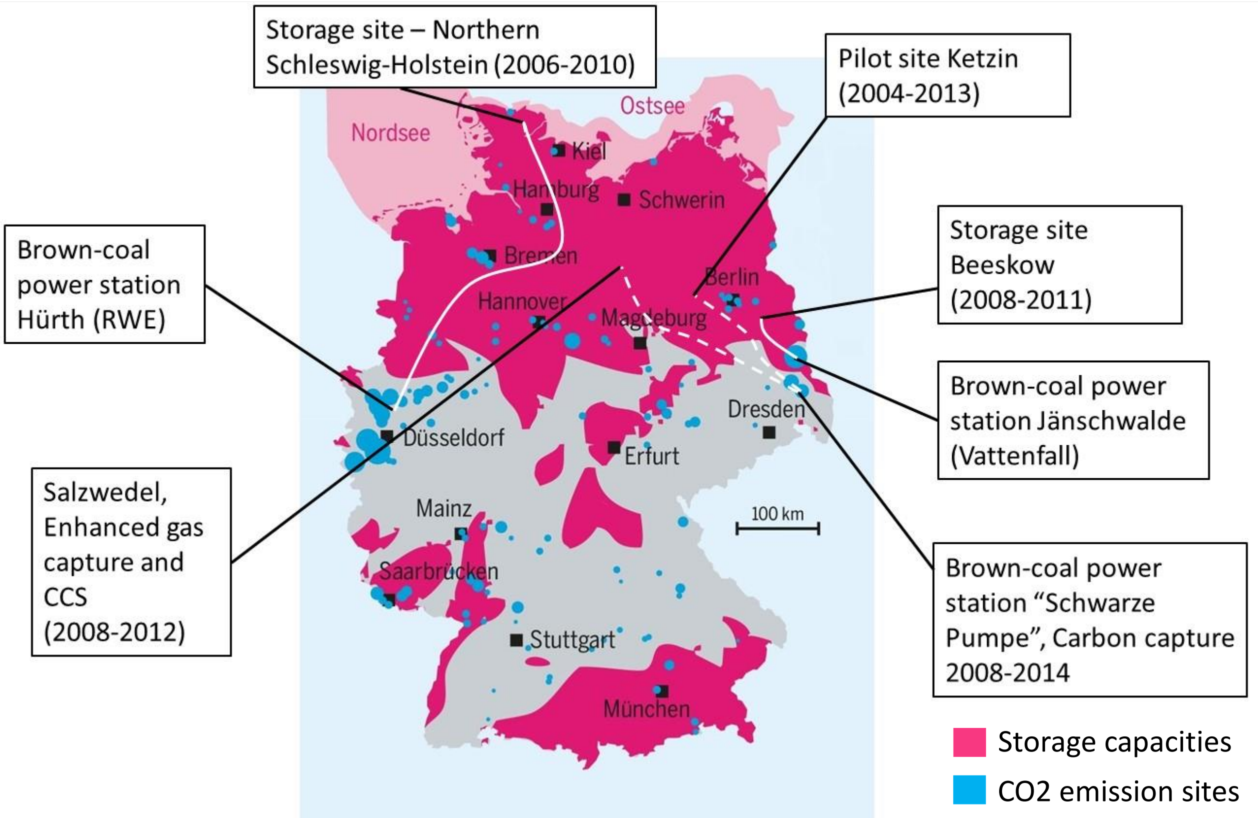

Figure 10 Geological storage capacities in Germany, sites of CO_2 production and previous CCS projects[1]

To contextualize the following description of CCS projects in Germany Figure 10 shows the geological storage capacities in Germany and the sites of CO_2 production. It also indicates the location of CCS project sites (including the location of CO_2 sources and storage facilities).

The pilot study at Ketzin[2] was successful. Between June 2008 and August 2013a total amount of 67 kt of CO_2 was injected without any safety issues (Martens et al. 2014). The 67 kt of CO_2 include 1510 t of carbon emissions captured at the brown-coal power station "Schwarze Pumpe". With the use of Oxyfuel-procedures it was possible to capture CO_2 very pure (99,7%) at the power station. It was then transported to Ketzin by truck and successfully stored underground. The minor quantities injected, local site characteristics[3], a comprehensive public engagement strategy and the fact that all projects at the Ketzin site were scientific and not industrial reinsured local stakeholders and resulted in no notable public opposition (Dütschke 2011; Szizybalski et al. 2014). Soon larger industrial projects of major energy producers followed. These focused on the onshore storage of CO_2 captured at fossil fuel power plants. RWE aimed to capture CO_2 from a brown-coal power station in North Rhine-Westphalia (Hürth) and to transport it via pipeline to a storage site in Schleswig-Holstein. Likewise Vattenfall planned to store CO_2 captured at a brown-coal power facility in Jänschwalde in saline aquifers under the small city of Beeskow. Furthermore GDF Suez (another energy provider) and Vattenfall wanted to combine CO_2 storage with enhance gas recovery in Saxony-Anhalt

[1] Groll, Stefanie/Fuhr, Lili/Löffelsend, Tina (2017): Kohleatlas. Daten und Fakten über einen globalen Brennstoff. 2. Auflage. Berlin: Heinrich-Böll Stiftung.
[2] Ketzin is located about 70 km west of Berlin and counts about 6500 inhabitants.
[3] Ketzin had previous experiences with gas storage (town and natural gas was seasonally stored in a shallower sandstone reservoir from 1964 until 2000) and the interest in the CO_2 storage site, that benefits the local tourism industry, contributed to the positive public response (Dütschke 2011).

(Salzwedel). All of these projects were discontinued either because of strong public opposition and/or funding problems (e.g. Fischer et al. 2010; Dütschke 2011; Rost 2015; Radgen et al. 2014; Kühn/Münch 2013) (see also Table 25). Since then initiatives for CCS in the fossil fuel power sector have not been renewed.

Table 25 Overview of previous carbon capture and storage projects

Location (operator)	Runtime	CO_2 Source	CO_2 stored	Project status
Ketzin (research site)	2004-2013	Hydrogen production and oxy fuel pilot plant (“Schwarze Pumpe”, brown-coal power station)	67.000 tons	*Completed*
Northern Schleswig-Holstein (RWE)	2006-2010	RWE IGCC-CCS power station Hürth, NRW (brown-coal power station)	0 tons	*Cancelled in planning stage*
Beeskow (Vattenfall)	2008-2011	Oxyfuel and Post-Combustion power plant Jänschwalde (brown-coal power station)	0 tons	*Cancelled in planning stage*
Salzwedel (GDF Suez, Vattenfall)	2008-2012	Oxy fuel pilot plant (“Schwarze Pumpe”, brown-coal power station)	0 tons	*Discontinued and removed*

Following the first pilot projects and the public opposition towards CCS various studies of public opinion on CCS have been conducted and mixed results on technology awareness and acceptance are reported. The level of CCS awareness in Germany reaches from very low (Arning et al. 2019; Dütschke 2011: 6235) to moderate (this is often connected to an existing or planned CCS site nearby, see Schumann 2015; Schumann et al. 2014). The assessment of public acceptance of CCS has also yielded disparate results based on the application of different empirical research methods, timing and specific configurations of CCS technology chains. Furthermore, it is called into question if opinions can be measures reliably when awareness of the technology is so low (Arning et al. 2019; Schumann 2015). Studies show a span of attitudes that include high rates of rejection of the technology or negative perceptions of it (Upham/Roberts 2011; even for sub-seabed storage, see Braun et al. 2018) but also positive views of CCS (Arning et al. 2019).

This development is mirrored by changes in political support for carbon capture technologies in Germany. From 2000 to 2012 the political focus for CCS implementation was the continuation of fossil fuel usage for energy production. As put in the government program of the CDU/CSU (Christian Democratic Union of Germany/Christian Social Union, majority partner in ruling coalition with the SPD, Social Democratic Party of Germany or FDP, Free Democratic Party, since 2005) in 2009, CCS is envisioned to provide crucial contributions to the “climate friendly usage of fossil energy sources” (CDU/CSU (Christian Democratic Union of Germany/Christian Social Union) 2009). Left and green parties showed scepticism towards CCS or rejected the technology altogether since they were in strong favour of the expansion of renewable energy technologies and saw CCS as hampering this process. Governmental agencies were (and still are) also undecided on the issue. While the Federal Ministry for Economic Affairs and Energy (e.g. 2020) or the Federal Institute for Geoscience and Natural Resources (e.g. Gerling 2010) underlined the potential of CCS the Federal Environment Ministry (2019) highlights other options and the Federal Environment Agency (2013, 2020) is critical of the technology. After the vehement public opposition to industrial CCS projects between 2007 and 2012 the situation changed. CCS lost prominence in the political discourse (for instance it completely disappeared from government or election programs) and was reframed in policy papers (UBA (Umweltbundesamt/Federal Environmental Agency) 2019). In this new conceptualisation CCS is no longer mainly thought to be an emission reduction technology for fossil fuel power plants (mostly lignite) and the discussion of potential applications of CCS has moved to residual emissions from industrial processes and to negative emissions (bio-energy and CCS or direct-air-capture and CCS)[1]. This becomes apparent in the climate protection program of the Federal Government (BMU 2019) or the latest evaluative report to the Federal Government on CCS (Deutscher Bundestag 2018). The energy transition pathways for Germany reflect this state of developments by including only a limited amount of carbon storage. The main focus is on energy efficiency and renewable energy technologies (BMU 2019).

This shift highly affects the business cases and market potentials of CCS in Germany. Economic analyses for CCS (e.g. Kuckshinrichs/Vögele 2015) have focused on the storage of CO_2 from fossil fuel power plants and based their assessments on this CCS chain. The literature discussed the increase in energy production costs and the problems and uncertainties regarding refinancing investments in CCS technology through the energy market (for instance the development of renewable energy costs or CO_2 allowance pricing). Fewer publications (e.g. Kuckshinrichs/Vögele 2012; Fleer/Kuckshinrichs 2015) discussed emissions from carbon-intensive industries. The high investment and operation costs are marked dependent on the capturing technologies applied (e.g. 32% production cost increase for cement with oxyfuel technology and a 102% increase if carbon is captured with post-combustion technology). Since neither demonstration nor commercial CCS plants operated on an industrial scale the economic estimates are subject to great uncertainty. Together with the political developments, public opposition and legal challenges (see below) these insecurities have been disincentives for investments. Overall the business case for CCS in Germany remains questionable and is connected to high uncertainties.

The legal situation changed as well at the end of the first decade of 2000. While the storage at the Ketzin pilot site and early exploration permits (for instance at Beeskow) were regulated under German law according to the legislation of mining from the state of Brandenburg the legal situation was challenged for industrial projects. The “EU council directive 2009/31/EC on the geological storage of carbon dioxide” (2009) only provides a frame for the national development of laws on the capture, transport, storage and monitoring of CCS. In 2012 a new law for the demonstration and utilization of technologies for the capture, transport and storage of CO_2 (Federal Law Gazette 2012) became effective. This new law did not only include stricter rules for the process and its monitoring. It delegated the final permission decision of any kind of CO_2 storage (including pilot sites for research) to the federal states and limited the annual amount of sequestered CO_2 in individual projects to 1.3 million tons. A couple of federal states (mainly those with geological storage capacities like Lower Saxony) have since then issued moratoria for the geological storage of CO_2.

[1] This development is connected to discussions on reaching Net-Zero emissions and has been intensified by the IPCCS report on limiting global warming to 1.5 °C (IPCC 2018).

Adding to this regional regulatory barrier for CCS, the new law set December 31, 2016 as a deadline for CO_2 storage project applications (no matter the CO_2 sources or technologies involved). **Since this deadline is expired the geological storage of CO_2 in Germany is faced with a severe regulatory lock-in** (see Fischer 2015; Krämer 2018)**.**

In accordance with the regulations, monitoring for CO_2 storage sites had to be in place. Different methods for the monitoring of the CO_2 plume in the underground have been developed and field tested since 2001 (e.g. Barth et al. 2015; Bergmann et al. 2016; Brune et al. 2002; Lüth et al. 2020; Polak et al. 2006)[1]. It has also been studied how the climate and the environment are impacted by geological carbon storage. It is pointed out that it is hard to come to an overall assessment of CCS because of the "wide range of possible capture and storage technologies" (Marx et al. 2011: 2455). Studies that focus on the specific configuration that has been tested in Germany (e.g. Schreiber et al. 2009; Markewitz et al. 2009; Schreiber et al. 2015) come to the conclusion that carbon capture and storage has positive (less CO_2 emitted) and negative effects (increase of other emissions like nitrogen oxides or carbon monoxides, reduced energy efficiency) on the environment. Risks of technical malfunctions and leakages have been assessed for the Ketzin test site and mitigation measures have been discussed (e.g. Guen et al. 2011; Lüth et al. 2020; Pfennig et al. 2011).

4.3 Approach for performing the assessment

The Assessment of the Societal Embeddedness Level (SEL) of CCS in Germany is conducted based on the illustrated socio-historical context. Since CCS does include a number of different components that can be linked in different technology chains (e.g. different capture, transportation or storage processes, and different CO_2 sources) it is difficult to assess a precise TRL or SEL for this bundle of technologies. Therefore, the specific combination of CCS technologies in previous German sites will be discussed in the assessment.

A combination of methods was used for to assess the current SEL of CCS technologies in Germany. **A literature review** was conducted to approach the current political and scientific debates on CCS in Germany. The corpus material was established by a google scholar search (keywords illustrated in Table 26), exploration of ministerial websites and snowball searches based on the references in the texts. A corpus of 20 key publications for the status of CCS technology in Germany was identified and analysed (see Table 27).

Table 26 List of keywords and keyword combinations

<table>
<tr><td rowspan="8">CCS/
Carbon capture and storage/
CO₂ storage</td><td rowspan="8">+</td><td>Policy</td><td rowspan="8">+</td><td rowspan="8">Germany</td></tr>
<tr><td>Regulation</td></tr>
<tr><td>Market</td></tr>
<tr><td>Economy</td></tr>
<tr><td>Stakeholder</td></tr>
<tr><td>Perception</td></tr>
<tr><td>Acceptance</td></tr>
<tr><td>Environment</td></tr>
</table>

[1] These monitoring methods include among others: Seismic and geoelectric monitoring, Pulse Neutron Gamma borehole logging and permanent pressure and temperature monitoring,

Table 27 List of key publications

Arning, K./Offermann-van Heek, J./Linzenich, A./Kaetelhoen, A./Sternberg, A./Bardow, A./Ziefle, M. (2019): Same or different? Insights on public perception and acceptance of carbon capture and storage or utilization in Germany. In: *Energy Policy*, 125, 235–249.
Barth, J. A. C./Nowak, M. E./Zimmer, M./Norden, B./van Geldern, R. (2015): Monitoring of Cap-Rock Integrity during CCS from Field Data at the Ketzin Pilot Site (Germany): Evidence from Gas Composition and Stable Carbon Isotopes. In: *International Journal of Greenhouse Gas Control*, 43, 133–140.
Bellotti, D./Sorce, A./Rivarolo, M./Magistri, L. (2019): Techno-Economic Analysis for the Integration of a Power to Fuel System with a CCS Coal Power Plant. In: *Journal of* CO_2 *Utilization*, 33, 262–272.
BMU (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit/Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) (2019): Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050. Berlin: Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit.
Braun, Carola/Merk, Christine/Pönitzsch, Gert/Rehdanz, Katrin/Schmidt, Ulrich (2018): Public Perception of Climate Engineering and Carbon Capture and Storage in Germany: Survey Evidence. In: *Climate Policy*, 18 (4), 471–484.
Deutscher Bundestag (2018): Evaluierungsbericht der Bundesregierung über die Anwendung des Kohlendioxid-Speicherungsgesetzes sowie die Erfahrungen zur CCS-Technologie. Drucksache 19/6891. Berlin: Deutscher Bundestag.
Dütschke, Elisabeth/Wohlfarth, Katharina/Höller, Samuel/Viebahn, Peter/Schumann, Diana/Pietzner, Katja (2016): Differences in the Public Perception of CCS in Germany Depending on CO 2 Source, Transport Option and Storage Location. In: *International Journal of Greenhouse Gas Control*, 53, 149–159.
Fischer, Wolfgang (2015): No CCS in Germany Despite the CCS Act? In: Kuckshinrichs, Wilhelm/Hake, Jürgen-Friedrich (Hrsg.), Carbon Capture, Storage and Use: Technical, Economic, Environmental and Societal Perspectives. Cham: Springer International Publishing, 255–286.
Flamme, Stefan/Benrath, Daniel/Glanz, Sabrina/Hoffart, Franziska/Pielow, Christian/Roos, Michael/Span, Roland/Wagner, Hermann Josef/Schönauer, Anna Lena (2019): The interdisciplinary approach of the German case study to enable a low carbon economy by hydrogen and CCS. Präsentiert auf: 2019, *Energy Procedia*, Elsevier Ltd, 3709–3714.
Fleer, Johannes/Kuckshinrichs, Wilhelm (2015): Cost Analysis for CCS in Selected Carbon-Intensive Industries. In: Kuckshinrichs, Wilhelm/Hake, Jürgen-Friedrich (Hrsg.), Carbon Capture, Storage and Use. Cham: Springer International Publishing, 173–182.
Glanz, Sabrina/Schönauer, Anna-Lena (2021): Towards a Low-Carbon Society via Hydrogen and Carbon Capture and Storage: Social Acceptance from a Stakeholder Perspective. In: *Journal of Sustainable Development of Energy, Water and Environment Systems*, Međunarodni centar za održivi razvoj, energetike, voda i okoliša, 9 (1), 9–0.
Jones, Christopher R./Olfe-Kräutlein, Barbara/Kaklamanou, Daphne (2017): Lay Perceptions of Carbon Dioxide Utilisation Technologies in the United Kingdom and Germany: An Exploratory Qualitative Interview Study. In: *Energy Research & Social Science*, 34, 283–293.
Karimi, Farid (2017): Timescapes of CCS Projects: Is Deferring Projects and Policies Just Kicking the Can Down the Road? In: *Energy Procedia*, 114, 7317–7325.
Krämer, Ludwig (2018): Germany: A country without CCS. In: Havercroft, Ian/Macrory, Richard/Stewart, Richard (Hrsg.), Carbon capture and storage. Emerging legal and regulatory issues. Oxford/Portland, Oregon: Hart Publishing, 59–74.
Kuckshinrichs, Wilhelm/Vögele, Stefan (2015): Economic Analysis of Carbon Capture in the Energy Sector. In: Kuckshinrichs, Wilhelm/Hake, Jürgen-Friedrich (Hrsg.), Carbon Capture, Storage and Use. Cham: Springer International Publishing, 147–171.
Lüth, Stefan/Henninges, Jan/Ivandic, Monika/Juhlin, Christopher/Kempka, Thomas/Norden, Ben/Rippe, Dennis/Schmidt-Hattenberger, Cornelia (2020): Geophysical Monitoring of the Injection and Postclosure Phases at the Ketzin Pilot Site. In: Kasahara, Junzo/Zhdanov, Michael S./Mikada, Hitoshi (Hrsg.), Active Geophysical Monitoring (Second Edition). Elsevier, 523–561.
Noothout, Paul/Schäfer, Moritz/Spöttle, Matthias/Bons, Marian/Whiriskey, Keith (2019): Assessment of bio-CCS in 2°C compatible scenarios. Dessau-Roßlau: UBA (Umweltbundesamt/Federal Environment Agency).
Schreiber, Andrea/Zapp, Petra/Marx, Josefine (2015): Environmental Aspects of CCS. In: Kuckshinrichs, Wilhelm/Hake, Jürgen-Friedrich (Hrsg.), Carbon Capture, Storage and Use. Cham: Springer International

Publishing, 101–126.
UBA (Umweltbundesamt/Federal Environmental Agency) (2020): Resource-Efficient Pathways towards Greenhouse Gas- Neutrality (RESCUE). Dessau: UBA (Umweltbundesamt).
Vögele, Stefan/Rübbelke, Dirk/Mayer, Philip/Kuckshinrichs, Wilhelm (2018): Germany's "No" to Carbon Capture and Storage: Just a Question of Lacking Acceptance? In: *Applied Energy*, 214, 205–218.

This desk research was followed up with **expert interviews** to close knowledge gaps and to get an up-to-date perspective on CCS. 24 interviews were conducted with:

- Political representatives for environmental policy (various levels, all parties within current federal government) – 11 interviews
- Industry experts (cement, steel, energy production) – 6 interviews
- Scientists (Geology, political science, Environmental science) – 3 interviews
- Environmental NGOs - 4

The interview protocol was developed corresponding to the dimensions of the SEL[1] and included questions concerning the following thematic areas in relation to CCS (see Table 28).

Table 28 Overview of interview protocol

SEL Dimensions	Thematic areas
TRL	Technological and research related factors
Dimension 1: Environment	Ecological/environmental factors
	Built and social environmental factors
Dimension 2: Stakeholder involvement	Societal factors
	Stakeholder involvement
Dimension 3: Policy and regulations	Political factors
	Regulations and legal framework
Dimension 4: Market and Resources	Economic factors

The results of desk research and expert interviews are combined to provide an encompassing view of the current situation of CCS technology in Germany.

4.4 SEL assessment

As stated above it is difficult to determine a TRL as a reference point for the initial SEL since CCS includes different components that can be (and have been) applied in various local settings. I therefore start from SEL level 1 in each dimension and see which milestones have been reached. I will establish the SEL level for each of the 4 dimensions:

- Dimension 1: Environment
- Dimension 2: Stakeholder Involvement
- Dimension 3: Policy and Regulations
- Dimension 4: Market and Financial Resources

In conclusion I will argue for an overall SEL level for CCS in Germany.

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

Dimension 1: Environment

This SEL dimension addresses the question if the harm to the environment is kept as low as reasonably achievable by exploring, assessing and mitigating the impact of an innovation (in our case CCS) on the environment. The natural, built and social environment of the technological innovation are considered[1]. It is not easy to assess the study of environmental impacts of CCS in general because of the different specifications of the technology chain.

Table 29 Overview of milestones for SEL Dimension 1: Environment

SEL1 Exploration	**SEL 2 Development**	**SEL 3 Demonstration**			**SEL 4 Deployment**
Milestones reached	Milestones reached	M1	The impacts of the system on the natural environment are assessed	✓	Milestones not reached
		M2	The impacts of the system on the built environment are assessed	✓	
		M3	The impacts of the system on the social environment are assessed	✓	
		M4	Negative impacts of the technology and its system on the natural environment are mitigated	?	
		M5	Negative impacts of the technology and its system on the built environment are mitigated	?	
		M6	Negative impacts of the technology and its system on the social environment are mitigated	?	
		M7	Impacts of the technology and its system that emerge from the demonstration phase are assessed	✓	

For the assessment of the German situation I therefore focus on configurations of CCS that have been field tested before. Potential risks and negative environmental impacts have been assessed for the demonstration site at Ketzin (involving all steps from Oxyfuel capture, to truck transport and storage) (e.g. Barth et al. 2015; Lüth et al. 2020; Schreiber et al. 2015). These include increased emissions of nitrogen dioxide or other gases, risks of leakage during transport or underground CO_2 plume movement. The potential risks for the social, built or natural environment have been studied for the short-term (mostly related to the runtime of the Ketzin pilot site). These risks, however, have not been mitigated and tested in other projects. Hence it is doubtful if negative impacts are actually mitigated and milestones M4-M6 remain unclear and limit the SEL for this dimension to a completed level 2 “development” with major work already done for SEL level 3 “demonstration”. It is furthermore uncertain which long-term effects (especially regarding plume movement, saltwater intrusion or induced seismic activity) might emerge and how upscaling to the industrial operation would factor into assessments.

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

An additional challenge is that the configuration of CCS at Ketzin does not represent the technological options that are politically discussed at the moment. As this discourse has moved from fossil fuel power plants as CO_2 sources to capturing emissions from industrial sources (e.g. steel, cement) or bio-energy plants (BECCS) it is unclear how the environmental assessments could be transferred to these applications of CCS.

<u>Dimension 2: Stakeholder involvement</u>

In this dimension the support of stakeholders for an innovation is in focus. Stakeholder participation as well as stakeholder needs and opinions are explored so that they can be integrated in the further technological development[1]. Table 30 gives an overview of the stakeholder situation in Germany.

Table 30 Overview of milestones for SEL Dimension 2: Stakeholder involvement

SEL1 Exploration	SEL 2 Development			SEL 3 Demonstration	SEL 4 Deployment
Milestones reached	M1	Inventory of all relevant stakeholders in the field for the technology	✓	Milestones not reached	Milestones not reached
	M2	Decision on level of participation of the stakeholders in development process of the innovation	☒		
	M3	Design for stakeholder participation tailored to stage of development	✓		
	M4	Knowledge, opinions, questions, concerns and perspectives of all relevant stakeholders regarding the innovation are assessed and integrated into innovation development strategy	?		
	M5	Inventory of all relevant stakeholders in the field for the system	✓		
	M6	Identification of possible trust issues for the technology and it's system	?		

It shows that not all of the milestones in the development stage (SEL level 2) could be reached. An inventory of relevant stakeholders in the field and the system has been established for previous projects (especially for Ketzin as it had to include in inventory of relevant stakeholders for both, the same is true for the storage project in Beeskow, which was discontinued in the planning stage) and also methods for public and stakeholder outreach have been tested (e.g. Szizybalski et al. 2014). It became clear, however, that a successful communication and engagement strategy is site specific and cannot be transferred to another socio-technical setting without adjustments (e.g. Dütschke 2011). The same is true for the organization of participation. So far decisions on the level of participation (milestone 2) have not been taken and it appears that they can only be taken site specifically.

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

In the expert interviews it was made explicit that stakeholder support is uncertain after the initial failure of CCS projects in Germany. The existing research on the perception of CCS by stakeholders and publics shows strong variations depending on sample, CCS technology chain, onshore or offshore storage and many other aspects (Arning et al. 2019; Braun et al. 2018; Linzenich et al. 2019). Dütschke et al. (2016) highlight that CCS sources strongly effect public opinions (with CO_2 from coal-fired power plants being perceived less positively than from biomass or industry) and that the geological characteristics of the local site are important (saline aquifers viewed less favourable than depleted natural gas fields) as are the methods of transport. Combined with an overall low awareness for CCS technology (Arning et al. 2019), which is reported to be heightened if planned storage sites are nearby (Schumann et al. 2014), this calls milestone 4 into question. It is highly uncertain if opinions and knowledge on CCS can be reliably captured on a national level and how local level perception would relate to that.

Experts frequently stated that "societal acceptance" is one of the most important challenges for CCS in Germany and name two reasons for this. 1) Trust in the technology (for the few that know of it) has eroded because of the failed deployment attempts, strong industry involvement (and the feeling of "green washing") and a linkage that is established between the underground storage of radioactive waste and CO_2. It is especially this last frame that causes a lot of concern and mistrust in the German CCS debate. In consequence, possible trust issues (milestone 6) are identified but it is unclear how the shift away from fossil fuel power generation and towards the application of CCS for industry emissions or BECCS has effected this.

<u>Dimension 3: Policy and Regulations</u>

This dimension asks for the policies and regulations that limit or support a technology. Policies, regulations and accompanying barriers need to be addressed[1]. In the German case CCS technologies remain on SEL 1 (see Table 31).

Table 31 Overview of milestones for SEL Dimension 3: Policy and regulations

SEL1 Exploration			SEL 2 Demonstration	SEL 3 Development	SEL 4 Deployment
M1	The current political climate and context is explored	☒	Milestones not reached	Milestones not reached	Milestones not reached
M2	Existing policies and regulatory framework for innovation explored	✓			
M3	Access to regulatory process	?			
M4	First interactions between developers and governments to create support for technology	?			

As previously stated in the socio-historical context description CCS faces a hard regulatory lock-in in Germany. Although we find studies that have explored the policies and regulatory frameworks for CCS (Fischer 2015; Krämer 2018), the current political climate of CCS is not explored (milestone 1). There are no studies that could give an up-to-date assessment on political views of CCS. During the

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

expert interviews it became clear that it is a highly contested field and that many actors view CCS as a “political minefield”. The political parties in the Bundestag are reluctant to approach CCS – maybe with the liberal party as a supportive exception. Environmental NGOs are split on CCS and their positions pend between:

1. no need for CCS, we rely on natural solutions for CDR and 100% renewables;
2. CCS is unwanted but unavoidable;
3. We need CCS urgently.

Although politicians of different parties and spokespersons of environmental NGOs see a need for some degree of carbon capture to reach the Paris climate goals, it is unclear how CCS in Germany would be politically feasible. Despite the slide shift towards support for CCS for residual industry emissions and negative emission technologies it is yet unclear how to get out of the regulatory lock-in because no political parties are picking the topic up.

First and foremost this is explained by the lack of a legislative basis for new CCS projects since the application deadline noted in the German CCS law has expired in December 2016. **This makes it impossible to apply for new sites (onshore or offshore) for carbon storage in Germany**. The experts stated that it would have been possible to reform the CCS law in this year (2020) to extend the application deadline, but it was decided that the law will not be reformed at this point. It is an open legal question if some kinds of CCS (like enhanced gas recovery with the storage of CO_2) would be covered by mining law. The experts are uncertain about this and emphasize the lock-in, which makes access to regulatory processes (milestone 3) and interactions between developers and government (milestone 4) practically impossible despite lobbying for a reform of the CCS law.

Dimension 4: Market and financial resources

The core question of this dimension is if the market is ready to adopt the technology and if sufficient financial resources are available from development till deployment. This includes research funding as well as funding for industrial projects and thereby addresses market dynamics and possible business cases[1]. For CCS in Germany Table 32 shows that this technology is not well embedded from a market and financial resources viewpoint.

Table 32 Overview of milestones for SEL Dimension 4: Market and financial resources

SEL1 Exploration			SEL 2 Demonstration	SEL 3 Development	SEL 4 Deployment
M1	Financial resources are sufficient for exploration of the idea	☒	Milestones not reached	Milestones not reached	Milestones not reached
M2	Current market dynamics, size and potential growth are identified	✓			
M3	A market need/gap is identified	?			

Previous research has studied the market potential of CCS in Germany (milestone 2) and potentials have been discussed (e.g. Bellotti et al. 2019; Fleer/Kuckshinrichs 2015; Kuckshinrichs/Vögele 2015).

[1] Geerdink et al., 2020. 'Guideline Societal Embeddedness Assessment'. Final report of D3.1 of the ACT DIGIMON project

For emissions from the fossil fuel energy sector and heavy industries, a high increase of costs has been found and it is uncertain if these investments will be refinanced. This uncertainty about potential gains, risks and business cases is reflected in the expert interviews. Energy company representatives distanced themselves from CCS and highlighted the strong public opposition, previous failure, the regulatory lock-in and the consequential impossibility to have CCS in Germany as reasons for this decision. Additionally, it is questionable if CO_2 capture at lignite or hard coal power plants will be profitable in light of the coal phase-out in Germany (till 2038). Representatives from the steel industry followed a similar line of argument to explain their decision to follow other paths (mostly hydrogen usage or carbon capture and utilization/CCU) to make their production process more sustainable and potentially carbon neutral (Deutscher Bundestag 2018). Since this option to decarbonize production does not (yet) exist for the cement industry they have to rely on CCS to reach carbon neutrality. So far, however, there is little incentive for investments in CCS technology since capturing is expensive, storage is not legal and public opposition is feared to damage the company. Taking this into consideration milestone 1 is not reached. Some public funding for research on CCS is available (for instance to explore storage capacities or study the capture process) but due to the CCS law it would not be possible to practically study carbon storage in Germany.

It is also unclear whether a business case or at least a market gap exists in the Germany. As mentioned there are some carbon intensive industries for which it is not technically feasible to avoid CO_2 emissions. These would be in need for CCS options but the high costs and the small number of applications limits the market potential drastically.

Overall SEL level

Based on the presented assessments for each dimension, Table 33 displays the overall SEL for CCS in Germany. As the overall SEL is equal to the lowest level reached in one of the four dimensions, CCS in Germany is in the stage of exploration (SEL 1).

Table 33 Overview SEL level CCS in Germany

	SEL 1 Exploration	**SEL 2 Development**	**SEL 3 Demonstration**	**SEL 4 Ready for deployment**
Dimension 1: Environment	All milestones reached	All milestones reached	Some milestones reached	No milestones reached
Dimension 2: Stakeholder involvement	All milestones reached	Some milestones reached	No reached	No milestones reached
Dimension 3: Policy and Regulations	All milestones reached	No milestones reached	No reached	No milestones reached
Dimension 4: Market and Financial Resources	All milestones reached	No reached	No reached	No milestones reached

4.5 Main challenges for improving SEL in Germany

Based on the SEL assessment three main challenges can be identified.

1. Lack of social acceptance and stakeholder support

Public opposition to earlier CCS projects in Germany has shown that geological storage of CO_2 is a highly contested issue. Experts and studies indicate that this opposition is partly caused by the link between CCS and lignite power plants that was established in the first wave of CCS projects in Germany. It remains open how publics would respond to CCS that captures and stores CO_2 from other sources. Much of the opposition was connected to the prolonging of fossil fuel power generation and social acceptance might change if CO_2 came from bio-energy plants or industry processes that are hard to decarbonize. Some studies (Arning et al. 2019; Dütschke et al. 2016) point in this direction. Research on public engagement and community consultations at the research pilot site at Ketzin has stressed the difficulties and the efforts it takes to gain public and stakeholder trust for CCS in Germany (Szizybalski et al. 2014). After the failures of larger industrial projects, experts were critical of the future social perception of carbon capture and storage technologies because of this negative point of reference. Especially political and industrial experts marked the lack of societal acceptance and local stakeholder support as highly relevant barrier for CCS.

2. Regulatory lock-in

The expired deadline (December 31, 2016) for applications for any kind of carbon storage project in Germany is the central regulatory barrier for this technology. It is hard to imagine how carbon capture and storage technologies could be moved ahead in Germany without a reform of the law. It is not clear which actors would push for legislative change since the earlier failure to establish CCS for lignite power plants or enhanced gas recovery has led to strong political opposition and made CCS a “toxic issue” for stakeholders and policy makers alike.

3. Limited market gap for CCS in Germany and lack of investments

This barrier is strongly linked to the regulatory lock-in. Since there is no legal basis for carbon storage sites no public or private funding for the deployment of this technology is available. There are funding opportunities for the exploration of capacities, the improvement of capture processes and the transport of CO_2. Industrial actors shy away from investments because of the high political, social and legal uncertainty connected to the technology. Furthermore, the market gap for CCS in Germany is unclear because CO_2 intensive industries and energy producers have followed alternate routes to decarbonize after the discouraging development of carbon storage. Industrial emitters that are not (yet) able to fully decarbonize production without CCS (like the cement industry) are reluctant to count on the availability of CCS in the future.

Although the environmental dimension has been pushed successfully ahead in previous projects, the listed barriers limit the potential for CCS to a large degree. Since all the challenges are strongly interlinked they are hard to overcome.

Monitoring is not seen as a key instrument to overcome the named barriers in Germany. It is not seen as a potential measure, which could increase social acceptance and trust among stakeholders concerned (governmental representatives, concerned public but also industry actors and eNGOs), but as a simple regulatory requirement. Experts even argued (in line with literature - see for instance L’Orange Seigo et al. 2011) that too much emphasis on monitoring can increase doubts and engender distrust towards the safety of projects. If monitoring should play a role in trust-building and outreach activities it should have the following characteristics:

- Be cheap, efficient and easy to maintain over a long time
- Measure and predict leakages and plume movement
- Be transparent and allow real-time access to monitoring data
- Provide reliable access to experts for questions on the data (continuously, not just at outreach events)
- Be externally supervised by impartial institutions
- Be connected to a security concept that states what happens when the data shows anomalies.

4.6 Scenario

Based on the literature review and the expert interviews the future of CCS in Germany has to be considered as highly uncertain (on the national and the local level). While some political actors, environmental NGOs and scientists I interviewed pointed out that carbon storage will probably be necessary to reach the Paris climate goals, they also stated that it is unclear how the storage of carbon emissions in Germany would be possible. Big incentives and pushes to establish a new foothold for this technology (especially for the storage part) would be necessary. Due to the regulatory lock-in there are not many routes to renewed CCS deployment in Germany.

Scenario 1: The German CCS law is reformed and the deadline for storage permit applications is extended.

This would enable new options for CCS but the experts felt that this is highly unlikely in the current political climate. The evaluative report of the Federal Government (Deutscher Bundestag 2018) does not state a need to update the law and the experts see no parties or institutions pushing for such a change.

Scenario 2: CO_2 is captured from industrial processes in Germany and transported to storage sites in other EU countries

This option is discussed by policy makers and the industries (mainly the cement industry, other CO_2 intensive industry sectors are looking at other decarbonisation options). Transport via pipelines is seen critically because of public opposition, risks of leakages, and regulatory issues. Ship transport faces economic issues because of high costs (Benrath et al. 2020). Taking this into consideration experts deemed this scenario to be rather unlikely.

Scenario 3: CO_2 is captured from bio-energy power plants and stored to reach negative emissions

Since the IPCC report on limiting global warming to 1.5°C (IPCC 2018) there have been discussions about negative emission technologies in Germany. It is yet uncertain how BECCS, as one technological option alongside other possibilities like enhanced weathering, rewetted peatlands or afforestation, will be pursued in the future. A report of the Federal Environmental Agency on carbon dioxide removal (CDR) by BECCS (Noothout et al. 2019: 5) highlights:

“that CDR appears to be one important measure in maintaining global warming below 2°C, but its potential is expected to be limited. Too heavy reliance on CDR technologies reduces the likelihood of limiting warming to less than 2°C, as carbon dioxide removal may not be practically availably at the scales required. This means rapid decarbonisation of the energy sector and rapid reductions in overall emissions are of utmost priority, to ensure that the limited amount of carbon dioxide removal potential that will likely be available can still provide net zero emissions.”

Scenario 4: CCS applied in hydrogen production

The German hydrogen strategy (e.g. Flamme et al. 2019) has incited a discussion on hydrogen production that includes the option of "blue hydrogen" (meaning hydrogen production with natural gas and the application of CCS technology capturing the resulting CO_2. Experts were generally sceptical about the hydrogen strategy. Some emphasized the priority of "green hydrogen" (hydrogen production with renewable energy) others noted that it might be necessary to use "blue hydrogen" to follow the outlined strategy but questioned where the captured CO_2 could be feasibly stored.

None of the above mentioned scenarios was perceived by the experts as likely under the current regulatory circumstances and in the present political climate.

4.7 Reflection on SEL methodology

Overall, I found the SEL to be a useful tool for the assessment of the situation of CCS on a national level. It particularly helped me to systematically keep track of different aspects that might affect societal embeddedness and to make the interconnections between different dimensions visible. It was, however, not always easy to assess CCS since the technology can include different components. This is especially problematic when there is no local case to focus on. A local case would have a specific CCS technology chain and this could be assessed using the SEL. On a national level there are a lot of contingencies to consider and to describe in the report. Taking this into consideration, I think it would be helpful to decouple the SEL starting point from the TRL, as a complex technological system can include multiple components with different TRLs and it is hard to assess an overall TRL.

The "storylines" of development within the different dimensions worked well. I only found that milestone 4 in SEL 3 of the policy and regulations dimension ("Regulatory and policy framework supports demonstration of the technology and its system") should have a corresponding milestone in SEL 2 for the development stage.

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