Application of the Societal Embeddedness Level methodology to underground hydrogen storage in the Netherlands.

Introduction

National and European studies emphasize that large-scale hydrogen buffer capacities will be required between 2030 and 2050 to support the energy transition and establishment of a hydrogen economy (e.g. Peterse et al., 2024). These capacities enable the balancing of supply and demand of energy while the share of variable renewable energy sources grows. The subsurface plays an essential role in providing such capacities and an extensive theoretical potential for underground storage of hydrogen has been identified across Europe in both rock salt formations (Caglayan et al., 2020) and deep porous formations (Cavanagh et al., 2022; Réveillère, A. and Le Gallo, Y., 2023). Internationally, the technical aspects of UHS are being investigated and tested through scientific research and pilot projects with the aim to raise the Technical Readiness Level (TRL) of underground hydrogen storage (UHS) towards demonstration and commercial development (Hydrogen TCP-Task 42, 2023).

Particularly in the underground domain, there are many examples where emerging technologies failed at the licensing stage despite the fact that the level of technical maturity was ready for demonstration in a real environment. Projects such as underground CO_2 storage in Barendrecht (Feenstra et al., 2010; Brunsting et al., 2011) were among others canceled because of lacking societal support resulting from failed communication and public engagement. The exploration of shale gas in Southern Netherlands (Cuppen et al., 2019) partly failed because the potential impacts and risks of development were insufficiently known and only investigated when there was already an application for exploration and a permitting procedure for test wells. The offshore development of CO_2 storage in the Netherlands has been set-off for many years among others because of unfavorable financial conditions and incomplete permitting procedures (Roggenkamp, 2020; Akerboom et al., 2021).

The above examples illustrate that the development of demonstratable technologies is subject to failure or substantial delay when the societal aspects are considered very late in the technical development timeline (i.e. when site-selection, licensing and permitting have already commenced). The Societal Embeddedness Level (SEL) methodology (Sprenkeling et al., 2022) recommends that social aspects are already investigated during the early phases of technology development (e.g. conceptualization) and that these aspects are gradually elaborated and implemented as the technology moves towards commercialization and scale-up. The SEL framework helps to identify gaps in the environmental, social, regulatory and market context which could jeopardize, delay or lead to high unforeseen costs of deployment and provides guidance on required actions to bridge these gaps.

Adapting the SEL methodology for underground hydrogen storage

In this paper we present the application of the SEL methodology to UHS, based on an example case for demonstration in the Netherlands. To this end, the four key social dimensions of the SEL framework have been adapted to specific requirements for the exploration, demonstration and upscaling of UHS. These dimensions entail (1) impact on the environment; (2) stakeholders and public involvement, (3) policy and regulations and 4) market and financial resources. Each societal dimension has been assessed based on a set of milestones (criteria) that align with ascending levels of technical maturation: according the Technology Readiness Levels" (TRL). Together these requirements define a 2D matrix with four social dimensions on the vertical axis, and four ascending levels of maturation on the horizontal axis. Ideally, technology development and societal embedding proceed in parallel and societal aspects are included from the technical conceptualization stage onward (see Figure 1).

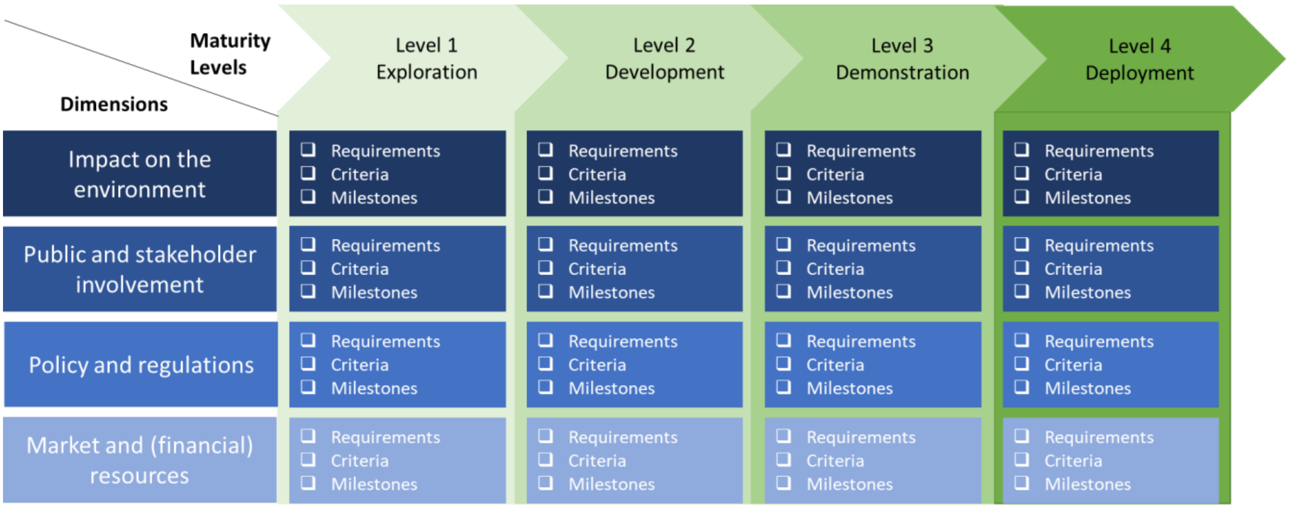

Figure 1 *SEL assessment framework (after: Sprenkeling et al., 2022)*

The SEL methodology requires a transdisciplinary research strategy. To assess the development of the four societal dimensions and draw their implications towards demonstration and upscaling of UHS, asks for not only crossing disciplinary boundaries, but extends to engaging with stakeholders other than those from academic research in framing and solving problems (Gross and Stauffacher, 2014; Otto et al., 2022).

Applying the SEL methodology to UHS development in the Netherlands; a case study

Based on the SEL definitions and requirements for UHS, the status of societal embeddedness has been assessed for the Netherlands context. In this case, the government heavily invests in R&D and deployment of the hydrogen value chain and infrastructure. UHS has evolved in the direction of demonstration, and first commercial operation is expected in commence in 2028 in salt caverns at the Zuidwending UGS site (https://www.hystock.nl/), which will be connected to a national hydrogen transport grid.

Each of the four dimensions and four maturity levels were defined in a transdisciplinary setting with different stakeholders from authority parties, operators and research institutes. First results provide an insight in the progression of societal aspects in the Netherlands in relation to the status of technical development. The assessment illustrates that, although societal aspects are already being implemented for demonstration of the technology, the societal embeddedness is not yet fully matured accordingly for all societal dimensions. The SEL evaluation furthermore demonstrates that the societal aspects do not evolve in parallel with the technical development. Consequently, several aspects require specific attention in order to resolve potential societal hurdles for demonstration and commercial deployment. This includes among others 1) the implementation of a widely accepted and verified strategy for management and monitoring of specific UHS risks and environmental impacts, 2) public engagement based on a balanced and factual narrative that addresses the societal costs and benefits of UHS and expected implications of upscaling, 3) the anchoring of specific definitions, standards and decision guidelines for safe and accepted deployment of UHS within the existing regulatory and legal frameworks, and an evaluation of potential policy measures and conditions to help establishing a viable market for UHS (Nationaal Waterstof Programma, 2022). The evaluation of societal embeddedness of UHS in the Netherlands will be further extended and improved in the coming years with insights from additional stakeholder groups and comparable cases in other countries.

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