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A comparison of the geological potential for methane, hydrogen and compressed air energy storage

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Energy transition from conventional to renewable energy sources requires large energy storage capacities to balance energy demand and production, due to the fluctuating weather-dependent nature of renewable energy sources like wind or solar power. Subsurface energy storage in porous media may provide the required large storage capacities. Available storage technologies include gas storage of hydrogen, synthetic methane or compressed air. Determination of the spatial dimensions of potential geological storage structures is required, in order to estimate the achievable local storage potential. This study, therefore, investigates the energy storage potential for the three storage technologies using a part of the North German Basin as study region.

For this study, a geological model of the geological subsurface, including the main storage and cap rock horizons present, was constructed and consistently parameterized using available data from the field site. Using spill point analysis potential trap closures were identified, also considering existing fault systems and salt structures for volumetric assessment. Volumetric assessment was performed for each storage site for methane, hydrogen and compressed air, as storage gases and their gas in place volumes were calculated. The effects of uncertainty of the geological parameters were quantified accounting for porosity, permeability and the maximum gas saturation using regional petrophysical models. The total regional energy storage capacity potential was estimated for methane and hydrogen, based on their lower heating values, while an exergy analysis of methane, hydrogen and compressed air was used to compare all available storage technologies. In addition to the storage capacity, also deliverability performance under pseudo-steady state flow condition was estimated for all sites and storage gases.

The results show significant gas in place volumes of about 2350 bcm for methane, 2080 bcm for hydrogen and 2100 bcm for compressed air as a regional gas storage capacity. This capacity is distributed within three storage formations and a total of 74 potential trap structures. Storage sites are distributed rather evenly over depth, with shallow sites at about 400 - 500 m and deep sites reaching depths of about 4000 m. The exergy analysis shows that hydrogen and methane storage technologies have high exergy values of about 15.9 kWh and 8.5 kWh per m^3, due to the high chemical part of the exergy, while for compressed air energy storage only the physical part is used during storage and the corresponding value is thus reduced to 6.1 kWh. The total energy storage capacity thus identified of about 32000 TWh of methane and 8400 TWh of hydrogen, with a low estimate of 23000 TWh and 6100 TWh accounting for uncertainty of geological parameters.

Thus, the potential is much larger than predicted required capacities, showing that the subsurface storage technologies have a significant potential to mitigate offsets between energy demand and renewable production in a sustainable and renewable future energy system.