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Environmental impacts from constructing seasonal underground thermal energy storage systems

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The utilization of underground thermal energy storage (UTES) systems is essential for balancing fluctuations between high demand and surplus of heating/cooling in modern energy systems. By integrating intermittent renewable energy sources and reducing reliance on conventional energy sources, UTES contributes significantly to a more sustainable heat and cold supply. Long-term seasonal storage, in particular, provides a potential solution for reducing greenhouse gas emissions. In recent years, several UTES systems have been constructed, contributing to the ongoing development and eventual market maturity of various ground-based technologies. Nevertheless, there is no comprehensive environmental evaluation available yet that compares these technologies across their life cycle phases. Thereby, the construction phase is of particular importance, as environmental impacts can vary significantly depending on the type of installation, specific components, and storage size.

This study evaluates the environmental impacts related to the construction phase of three different types of UTES using the life cycle assessment (LCA) framework according to ISO 14040 and 14044. The following three thermal energy storages are comparatively analyzed: a tank thermal energy storage in Munich (Germany), a water-gravel thermal energy storage in Eggenstein-Leopoldshafen (Germany), and a pit thermal energy storage in Marstal (Denmark). Results are further compared with those from an aquifer thermal energy storage (ATES) system in Bonn (Germany). The LCA identifies and quantifies the key factors influencing environmental impacts during construction, highlights significant differences among the technologies, and identifies opportunities for improvement. For instance, the utilization of water as a filling material in closed systems, an underground construction method, and the realization of large storage volumes with a reduced surface-to-volume ratio enhance environmental performance. Conversely, materials such as concrete, steel, foam glass gravel, and polyethylene contribute significantly to the environmental impact and should be replaced or minimized wherever possible, using sustainable alternatives without compromising storage capacity and efficiency.