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The global sustainability of high-temperature aquifer thermal energy storage as indicated by LCA and CED analysis

Jasper Griffioen (1,2), Jacques Werner (3,4), and Joris Koornneef (3)

(1) TNO Geological Survey of the Netherlands, Utrecht, Netherlands (jasper.griffioen@tno.nl), (2) Copernicus Inst. of Sustainable Development, Utrecht University, Utrecht, the Netherlands, (3) TNO Applied Geosciences, Utrecht, the Netherlands, (4) Stevin Technology Consultants, Baarn, the Netherlands

High-temperature aquifer thermal energy storage (HT-ATES) is a form of energy storage that receives increasing attention under the current energy transition. It can in particular be used to seasonally buffer heat production and demand from a variety of heat sources. In this way HT-ATES systems may improve the efficiency of large scale heat sources by facilitating heat production to function at maximum capacity throughout the year, irrespective of fluctuations in demand. This research aims to investigate the global sustainability of this form of heat storage by quantifying the environmental and energy footprints for the total lifetime. The concepts of life cycle assessment (LCA) and life cycle cumulative energy demand (CED) analysis are used for this.

Two HT-ATES systems were investigated: one combined with a geothermal plant delivering heat for use in greenhouses and the other with a waste-to-energy incinerator as coupled to a district heating system. The analysis is carried out based on the final delivery of 1 GJ of heat as the comparison basis. The systems are compared to a conventional natural gas incinerator for heat delivery as frequently found in the Netherlands (being a major gas producing country).

The life cycle assessment indicates that the major impacts happen for climate change, ozone depletion, terrestrial acidification, freshwater- and marine eutrophication, photochemical oxidant formation, particulate matter formation and metal depletion. The installation phase of a HT-ATES system is negligible when compared to the operational phase due to considerable use of electricity to operate their pumps. The latter also implies that the source of the electricity determines the global sustainability of the HT-ATES systems to a large extent. When compared with conventional heat delivery by natural gas incinerator in the Netherlands, HT-ATES systems directly exhibit fossil fuel savings and climate change reduction. They may thus positively contribute in the energy transition by lowering CO_2 emissions.

Primary energy demand is higher for HT-ATES systems than for conventional means of heat delivery largely due to loss of heat in the subsurface. Here, the storage efficiency is estimated to be 46 or 84%, which causes a substantial loss of energy especially for the first situation. The storage efficiency depends on factors as temperature difference between injected and redrawn groundwater, local hydrogeology and the Coefficient of Performance of the heat pump.

The general results indicate that the environmental effects of HT-ATES systems on heat sources are unsubstantial compared to the heat storage benefits they provide. The storage efficiency and electricity used for pumps are major aspects in overall energy efficiency and primary energy demand. Hence, more efficient operation means better overall performance, which is also a general truth.