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Characterization and Modeling of the Subsurface in the Context of Ecological Transition
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Editorial **Open Access**

Characterization and modeling of the subsurface for sustainable use in the context of the energy transition

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One of the biggest challenges of the energy transition is to transform radically the energy mix from a fossil-based one to one composed of low-carbon energy sources. Indeed, today, still 80% of the world's primary resources are constituted of fossil resources: coal, oil & gas leading to CO_2 emissions through conversion into energy and heating.

In geoscience's history, exploration of oil and gas reservoirs has led to a large improvement in the knowledge related to the earth's subsurface. Structure, properties, composition, physical and chemical processes have been extensively studied. However, evolving toward an energy mix without fossil resources is not evolving toward a smaller importance of the subsurface. On the contrary, the subsurface appears to be of strategic importance in the context of the energy transition.

Firstly, the subsurface is still an energy provider. One important source of energy without carbon is heat. Geothermal energy has a huge potential but the industrial sector is still at the beginning of its development worldwide. Low enthalpy geothermal energy can be deployed largely in a lot of areas. It uses heat pumps and is convenient for houses or offices' heating and cooling purposes. Deep geothermal energy at intermediate enthalpy has also the potential to produce decarbonized heat for urban networks at a large scale as is the case in the Paris basin in France with more than 50 doublets drilled for urban heat in the last 50 years. High enthalpy deep geothermal energy can provide electricity as is the case in Alsace, France, Italy, and Turkey. However, it requires specific geological locations with high thermal gradients.

A potential new energy resource that opens a novel scientific and operational area is the extraction of natural hydrogen directly produced by deep processes in the subsurface. In recent years, different processes, like water reduction by iron-rich rocks, late maturation of organic matter, and radiolysis have been shown to produce hydrogen within the subsurface. Natural hydrogen exploration is only at its beginning and is an active area in places like Australia, the USA, and also France. The work already done is showing that the potential resources could be large but many questions are still to be solved.

The subsurface is also useful for large-scale storage of fluids and this property is strategic for decarbonation. Indeed, only the subsurface has the volume capacity and the sealing properties to store the order of magnitude of giga tons of CO_2 per year in large aquifers or depleted oil or gas reservoirs. Developing the geological sequestration of CO_2 is an essential element of the energy transition to quickly limit CO_2 emissions and enable the construction of the new energy system based on non-fossil primary energies (renewable, nuclear, geothermal, natural hydrogen, biomass, etc.).

Storage of energy vectors in deep aquifers or salt cavities is also of interest. Historically, salt cavities were created by water injection to generate the volume of the order of millions of m^3 to store methane. Those cavities can be retrofitted or new ones can be created for biogas but also hydrogen storage. Indeed, if the industrial chain of hydrogen would deploy, the need to adjust the different sources of production with the variation of the demand would require storage capacities.

All those needs for the energy transition created new scientific, technical, and operational questions and concerns and they also require an adaptation of methods, tools, and skills in earth sciences.

This thematic issue of STET is bringing together a set of 8 articles presenting research works and original results devoted to the characterization and modeling of the subsurface in this context of the energy transition.

The first topic of this thematic issue is thermodynamics. Introducing new gases, like hydrogen, or a mixture of gas needs to have a good description of the properties of the mixtures. It is the case for hydrogen or air injection in cavities for energy storage. In both cases, and it is the objective of the article of **A.F. Kiemde** *et al.*, it is needed to characterize, the properties of the mixture. Compression anddecompression of those gases can cause heat changes that can be important. Temperature distribution along wellbores needs to have also an estimation of Joule Thompson coefficient, this is the subject of article **A. Oumarou** *et al.*

Developing new characterization of the subsurface also needs to have also adapted monitoring system. This is the case of the article by **J.L. Mari** *et al.* on acoustic logging and the article by **V.H. Le** *et al.* showing an original method of calibration for gas-detecting tools.

Reactive transport in porous media is also a key issue. CO_2 injection in aquifers modifies the pH of the water and can trigger geochemical reactions like dissolution or precipitation. It is then crucial to be able to calibrate, model, and evaluate the risks of permeability reduction or increase. Salting out is also an important issue that couple thermodynamics and flow. Those subjects are developed in two articles on this issue, **D. Bauer** *et al.* and **M. Mascle** *et al.*

Complex fluids in porous media are still a subject of interest with applications on depolluting and this is the work exposed in the article of **F. Douarche** *et al.*

At last, basin-scale modeling, a tool that is very useful for O&G exploration is also of high interest in the context of the energy transition. The article of **F.S. Patacchini** *et al.* deals with a new method to improve mechanical behavior in basin modeling.

This special volume shows how the subject of the use of the subsurface for the energy transition is in question in order to implement safe and effective solutions, which are respectful of the environment. We hope that the reader, an actor at his or her level in this industrial revolution, will benefit from the experiences and concepts recounted in this special issue.

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