



A General Overview of the UNFC for Geothermal Energy Resources and Examples of Algeria's Geothermal Resources

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ABSTRACT

This work is divided into two parts. The first part provides an overview of the UNFC for geothermal energy resources. The second part highlights the Algerian GER, considering a new vulnerability concept model to improve GER management in the Sahara. The UNFC on geothermal energy resources provides an understanding of the needed mechanisms for effective management of national resources, which are crucial for the SDGs. Additionally, it supports the optimization of sustainable management and resource development, positively affecting the socio-economy and the environment. The G-axis serves as a foundation, allowing a transition to the F-axis and E-axis. For the G-axis, exploration methods for geothermal energy typically mirror those used in oil prospecting or hydrogeology, especially geological, geochemical, and geophysical techniques. In Algeria, understanding geothermal potential requires a multidisciplinary investigation framework, particularly in the Sahara. It is useful to discuss applying the UNFC guideline for geothermal energy (GER) exploitation to better recognize geothermal energy's role in the energy mix and transition. Accordingly, some key areas with geothermal sources are highlighted.

1. INTRODUCTION

The United Nations has done a framework classification to manage a Resource Project called the UNFC for resources. It includes a principles-based classification system that explains the environmental and socio-economic viability, as well as the technical feasibility, of the project to develop resources (UNECE, 2020). The application of UNFC for mineral resources in Algeria was discussed (Khaldi et Mokhtar, 2018). It seems useful to ask a question about the use of this classification in the geothermal

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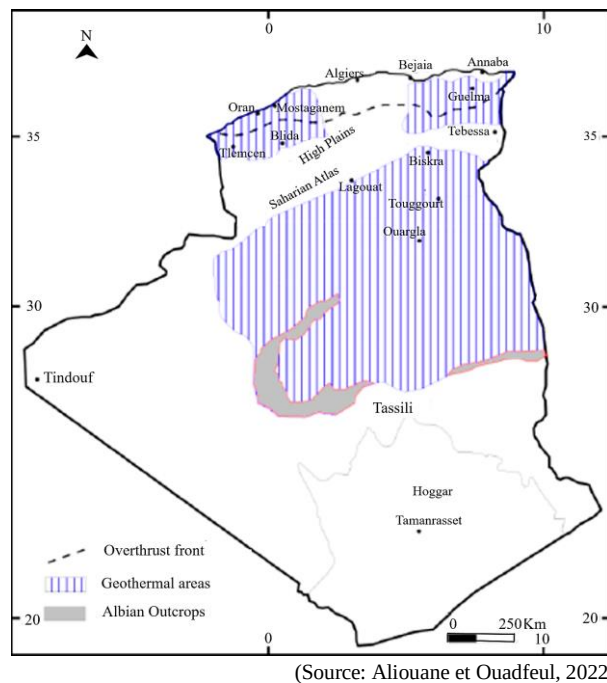


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resources, especially in the Sahara, considering that the mastery of the geothermal potential for various uses requires a multidisciplinary investigation framework. The exploration methods of geothermal energy are generally those used in oil prospecting or hydrogeology. Knowledge of the structural, hydrogeological, thermal, and geochemical conditions of the reservoirs becomes essential to establish different models. In the North, the geological investigations allow the determination of volcanic and hydrothermal sources. Geochemical methods, sampling from water, gas, and hydrothermal deposits, aim to determine the physical and chemical characteristics of the water, in particular the pH, flow rates, and water-rock equilibrium temperature. Additionally, the geophysical methods commonly employed in hydrogeological research and oil exploration are used. However, some other methods have been developed to meet the needs of geothermal prospecting. Sonatrach has investigated geothermal resources since the 1960s (Amrouche et al., 2023) for a safe future approach that allows for enriching the energy mix and consequently the energy transition. The evolution of geothermal power worldwide in 2023 indicates a capacity factor of 67,54% for the generation of 96,552 (GWh) (Luis and Gutiérrez-Negrín, 2024).

The Algerian GER

Algeria is considered a privileged country for investing in GER compared to other African countries (Elbarbary et al., 2022) (Fig 1). An update of the national thermal springs inventory reveals more than 240 hot sources, with the highest temperatures recorded as follows: 68°C for the western zone, 80°C for the central zone, 98°C for the eastern zone, and a mean temperature of 50°C for the southern zone. The north-east, which covers an area of 15,000 km², remains the most interesting geothermal area, with the Barda spring giving 100 L/s, and Hammam Meskoutine, which has the highest temperature in the country (98°C) (Saibi, 2015). The geothermal energy is ranked first among renewable energies and offers low-temperature 700 MW (Dib et al, 2012).



(Source: Aliouane et Ouadfeul, 2022)

Fig 1. Heat flow map of Algeria

The Algerian GERs are determined on the basis of the G-axis, notably the geological knowledge that ensures a guaranteed transition to the technical feasibility. The geophysical and structural modelling (Amrouche et al., 2023; Bayou et al, 2023), chemical geothermometers, gas chemistry, and stable isotopes (Belhai et al., 2015; Belhai et al., 2020) are the tools used for determining GER potential.

The eastern part of Algeria, notably Guelma, has the hottest hydrothermal systems, where the temperatures are up to 98°C (Bayou et al. 2023). On the basis of gravimetric data, a subsurface density distribution 3D model that illustrates the locations of the dominant subsurface thermal systems is established (Bayou et al. 2023). The presence of fractures in the Hammam Debagh and Hammam Ouled Ali hydrothermal systems controls the hot springs, while the chemical analysis of Guelma's thermal spring waters reveals three groups of water with low, moderate, and high salinity (Bouaicha et al., 2017).

For the north-central part, an HRG model was established where thermal waters are classified into two main types. The first is Ca–Na–SO₄ (Cl) and Ca–Na– SO₄ (HCO₃) (Belhai et al., 2015). The second indicates a Ca–Na–HCO₃ water type. This mineralization heterogeneity of waters is related to the complex geological features of the Tellian sector, where the chemistry of hot water is controlled by the dissolution of gypsum/anhydrite.

For the western part, a conceptual geothermal model for HSNA based on the geochemical characteristics of discharged fluids is established. This model facilitates the investigation of the origin of thermal waters, where a potential reservoir has been defined (Belhai et al., 2020). According to the hydrochemical analysis, HSNA has been classified into five groups: Group 1 Na-(Ca)-Cl-(HCO₃); Group 2 Na-(Ca)-HCO₃-(Cl); Group 3 Na-HCO₃; Group 4 Ca-HCO₃; and Group 5 Na-Ca-SO₄. The most reliable temperatures reach at least 140°C, making them useful for electricity generation through the binary cycle and for various direct uses (Belhai et al., 2020). The most prominent geothermal region is located in the western province of Aïn Témouchent, particularly at Hammam Bouhdjar (HBH) hot spring. In the South, notably the Remchi in Tlemcen, temperature oscillates between 26 and 48°C and water shows notable artesianism, while in the Saïda Mountains, thermal springs have temperatures ranging from 29 to 44.5°C. Geophysical modelling has improved the presence of the fault network that controls the groundwater flow (Yousfi et al., 2024). In addition, the hydrogeochemical analysis shows that the waters are sodium chloride and sodium sulfate (Khiati et al., 2021). The geothermal reservoirs in southern Algeria provinces include the Albian geothermal system (Ait-Ouali et al, 2019). This reservoir is primarily exploited by wells for domestic and agricultural purposes, and its importance for local economic development, particularly energy, is currently being discussed. The water is highly mineralized, classified as Na-Cl type, representing the deep thermal waters, as well as Ca-SO₄ type (Ait-Ouali et al, 2019).

In the Sahara, notably Adrar and In Salah, water temperatures are low (19°C), while in Biskra, Ouargla, and Touggourt, they exceed 60°C. Of the 111 boreholes tapping the Albian reservoir, 36 are classified as mesothermal (22°C<T<37°C), 17 as orthothermal (37°C<T<45°C), and 68 as hyperthermal (T >45°C) (Ouali, 2018). In the Sahara, reservoir engineering is essential for a comprehensive geological knowledge, aiming to determine the volume of geothermal resources. Exploitation of geothermal energy from deep reservoirs should be grounded in several conditions, including sustainable use of available resources and safety and efficiency of operations throughout the project's lifetime (IPCC, 2018), given that geothermal resources are underground and require deep drilling. For the Albian geothermal project in the Sahara, a new scientific contribution for a safe exploitation is discussed in this work, notably the lithological and structural vulnerability concept of the subsurface (Khebizi et al., 2023) for a safe and sustainable use.

2. MATERIAL AND METHODS

This work comprises two distinct parts; the first discusses the UNFC for geothermal energy resources, while the second part discusses the Saharan geothermal resources. For the first part, we gave a definition of the GES, GEP, GER.

The second part focuses on G-Axis, particularly on the geological knowledge of the subsurface in the El Oued region, to better understand the impact of anarchic drilling from the TC on lithological stability and the nearby deep geothermal Albian wells. To do this, we established three models that synthesize the geological modelling work done by Khebizi et al. (2022, 2023, and 2024), introducing a new interpretation concept for determining the structural and lithological vulnerability of the subsurface (Khebizi et al., 2023). This concept was developed through lithological correlation using various geological sheets and Petrel software (Khebizi et al., 2022; Khebizi et al., 2023; Khebizi et al., 2024). Vulnerability mapping of the zones designated for drilling and the required pumping depths from the TC can be performed based on the lithological vulnerability both in depth and laterally. Besides reducing water salinity and being ideal for drilling dedicated to irrigation and drinking water supply from the TC, the vulnerability map will be an essential tool to ensure the stability and sustainability of nearby deeper wells, especially the geothermal Albian wells.

3. RESULTS AND DISCUSSION

3.1 UNFC for geothermal energy resources

The UNFC is a comprehensive resource management system that integrates social and environmental aspects, in line with the 2030 Agenda, at its core, together with the criteria of economics, technical feasibility, and resource uncertainty (UNECE, 2019). The definitions of GES, GEP and GER given in this work are based on the report of Supplementary Specifications for the application of the United Nations Framework Classification for Resources (Update 2019) to Geothermal Energy Resources (UNECE, 2022).

3.1.1 The GES

The underground contains a thermal energy source, notably rocks, sediments, and soils, as well as naturally occurring fluids, which are accessible for extraction and/or conversion into energy product. A GES is considered to be a **known** GES when wells or springs indicate, through test, sampling, and/or logging, a significant quantity of recoverable thermal energy. However, a geothermal energy source is considered **potential** in the absence of direct evidence, while geophysical, geochemical, and other indirect methods are employed.

3.1.2 The GEP

The GEP is an energy product that includes sold, used, or delivered product by a project associated with at the minimum one GES.

3.1.3 The GER

The GER are GEP cumulative quantities that will be extracted from the GES since the effective date of the evaluation, and that are measured and/or evaluated at a declared reference point.

3.2 Sahara GRE exploitation

3.2.1 Subsurface vulnerability

A recent study on the structural geology of the Terminal Complex in the Algerian Lower Sahara, notably in the El Oued region, has made it possible to define for the first time an interpretation concept of lithological and structural vulnerability (Khebizi et al, 2022) that allows for stopping uncontrolled pumping (Khebizi et al, 2023, Khebizi et al, 2024). The concept is introduced thanks a geological and

geophysical modelling using Petrel geological software. The results allowed a classification of dedicated areas to water pumping from the TC according to their lithological and structural vulnerability. Three distinct areas are defined (Fig 2):

- An area of zero degree vulnerability;
- An area of first-degree vulnerability;
- An area of second-degree vulnerability.

The first vulnerability degree area concerns pumping from the sandy Mio-Pliocene, whose host rock is dolomitic Eocene (Fig 2). In this case, there is no dissolution of evaporitic minerals risk; consequently no vulnerability zone (Fig 2). The second vulnerability is related to pumping from the sandy Mio-Pliocene and the carbonate Eocene, whose host rock is the carbonate Senonian, where drilling should be reduced for depths between 250 and 400 m.

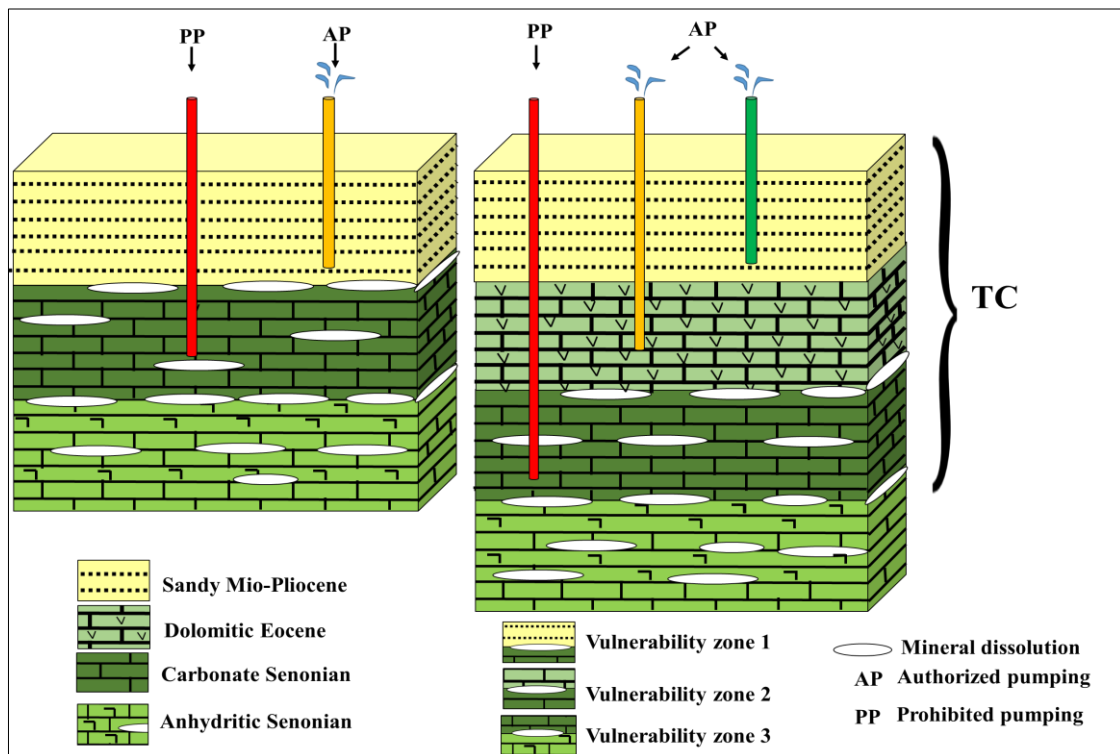
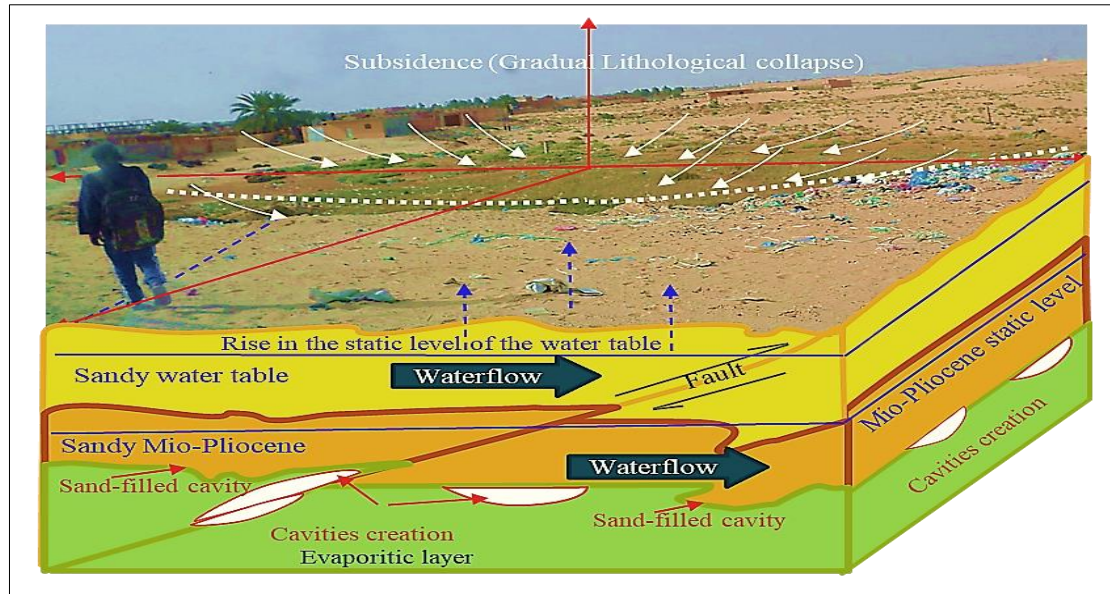


Fig 2. 3D model of TC lithological and structural vulnerability

The third vulnerability degree is indicated by two cases where the first is related to pumping from the sandy Mio-Pliocene and/or carbonate Eocene in contact with the anhydritic Senonian by faults (Fig 3). The second is pumping from the carbonate Senonian, whose host rock is anhydritic Senonian, where pumping is strictly prohibited (Fig 2). Abnormal contact of the sandy groundwater with the anhydritic Senonian forms an underground leaching front, which induces combined problems of rising water and/or gradual lithological subsidence, which are accelerated by pumping. A vulnerability map of the subsurface becomes a proactive measure for better managing deep groundwater.



(Source: Khebizi et al., 2023)

Fig 3. 3D model of TC lithological and structural vulnerability

3.2.2 Albian geothermal exploitation

The introduction of the lithological and structural vulnerability of the subsurface in geothermal deep wells project, notably the Albian, will help to have a good idea when identifying the project viability, confidence, and the feasibility degrees. It offers the best indication about the exploitation safety of GER, in particular for the choice of areas presenting a degree of zero or minimum structural and lithological vulnerability (Fig 4).

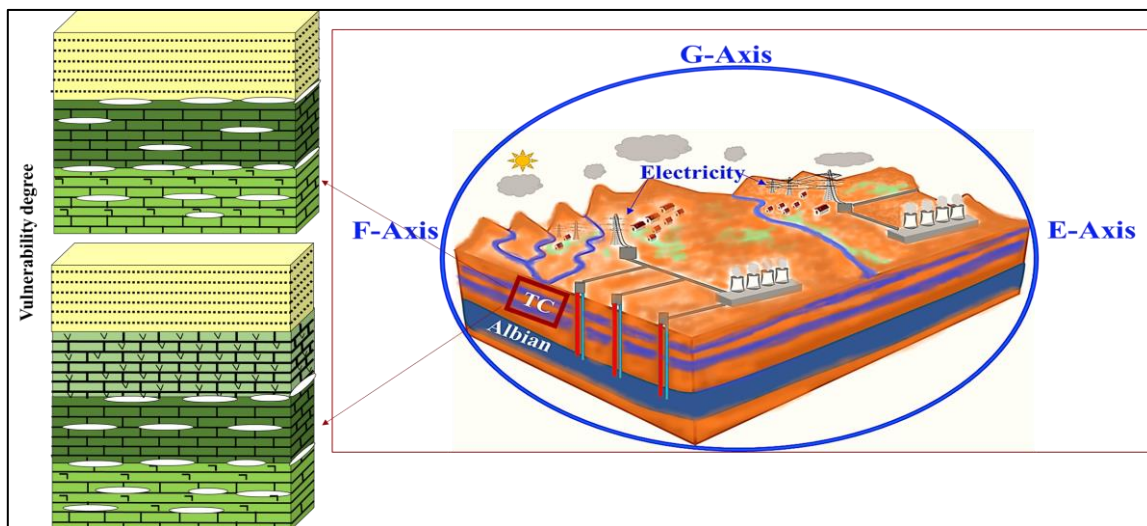


Fig 4. 3D model of GRE for electricity generation from Albian

CONCLUSION

Geothermal energy is classified as a renewable resource and is the cleanest source. Nowadays, this energy is discussed, and the technical potentials tend to increase as technology progresses. It constitutes a real potential to ensure the energy mix and the energy transition. The Algerian geothermal potential

encourages investment to offer different electricity sources and/or other uses. The UNFC for geothermal provides at least inspiration to investigate the GER and diversify the energy sources.

The exploitation of deep groundwater geothermal resources requires, first, a subsoil vulnerability map, which becomes a basic tool as a proactive measure to better manage deep geothermal sources in a safe, secure manner and for a sustainable exploitation of this resource for electricity production.

AUTHORS CONTRIBUTION

Conceptualization and methodology: (HK, BB, and HM); Data analysis and discussion: (HK); Manuscript preparation (HK); Manuscript review and editing (HK, BB, and HM).

CONFLICT OF INTEREST

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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NOMENCLATURE

E-axis	Socio-Economic Viability
F-axis	Technical Feasibility
G-axis	Geological Knowledge
GES	Geothermal Energy Source
GEP	Geothermal Energy Product
GER	Geothermal Energy Resource
HBH	Hammam Bouhdjar
HSNA	Hydrothermal System of North-western Algeria
HRG	Hammam Righa Geothermal
SDGs	Sustainable Development Goals
TC	Terminal Complex
UNFC	United Nations Framework Classification

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