Glossary

Terms related to urban seismic exploration of geothermal resources and the URGENT project

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1. Geothermal energy

Geothermal energy is energy which is generated and stored within the Earth in the form of heat. The sources of this thermal energy in the deep earth are the heat from when the planet formed and accreted, which has not yet been lost. Heat produced by the decay of radioactive elements, as well as frictional heating caused by the denser core material sinking to the centre of the planet. Geothermal energy can be exploited as a reliable and constant source of low-carbon, renewable heat that is not dependent on weather conditions[i].

2. Geothermal resources

Geothermal resources are reservoirs of hot water/brine or water steam that exist or are human-made at varying temperatures and depths below the earth's surface. Wells ranging from a few feet to several miles deep can be drilled into underground reservoirs to tap steam and hot water/brine that can be brought to the surface for use in a variety of applications[ii].

For example, in the urban context, we can make direct use of this geothermal energy for district heating.

3. Deep subsurface

Sedimentary basins and hard rock basement are crucial geological settings for geothermal energy in Europe. Sedimentary basins, often containing productive aquifers, can reach temperatures of up to 100°C and are characterised by high porosity and permeability, making them ideal for geothermal extraction. Meanwhile, hard rock basement formations, typically composed of igneous or metamorphic rocks, present opportunities for enhanced geothermal systems, where heat can be accessed at greater depths[iii,iv,v].

The URGENT project will focus on improving exploration methods specifically for these geological formations, widely represented across Europe, to enhance urban geothermal energy development.

4. Reservoir characterisation

Reservoir characterisation in geothermal projects involves creating a detailed description of subsurface properties crucial for assessing resource potential. It combines various data types, including seismic surveys, well logs, and petrophysical analyses, to understand reservoir geometry, fluid content, and heat flow[vi,vii].

The URGENT project aims to improve these characterisation methods for urban geothermal development across Europe's sedimentary basins and hard rock basement formations.

5. Faults/fractures

Faults and fractures are critical geological features for geothermal energy exploration and production, acting as conduits for thermal fluids to circulate and heat up in the subsurface. These structures provide secondary permeability, with large-scale fractures within fault zones often representing more promising targets than smaller, distributed fractures. Detection and characterisation of these features are crucial for geothermal exploration, employing methods such as seismic surveys, and three-component (3C) beamforming technique to detect and characterise faults and fractures in geothermal fields[viii,ix].

The URGENT project aims to leverage machine learning models to improve exploration methods for identifying and characterising faults and fractures in sedimentary basins and hard rock basement formations.

6. Strike

Strike is the direction of the line formed by the intersection of a fault, bed, or other planar feature with a horizontal plane. It is typically expressed as a compass direction and is crucial for mapping and understanding the orientation of geological structures. In geothermal exploration, strike measurements help create detailed 3D models of subsurface features, enabling more precise targeting of geothermal resources[x].

7. Dip

Dip refers to the angle of inclination of a planar feature, such as a fault or rock layer, measured from the horizontal plane. In geothermal contexts, understanding the dip of faults and fractures is essential for predicting fluid flow directions and reservoir characteristics[x].

8. Modern seismic data acquisition techniques

Methods used to gather information about underground rock structures. Vibroseis trucks create vibrations on the surface, while seismic nodes (receivers) record the echoes of these vibrations as they bounce off underground layers. This data enables the creation of detailed subsurface images vital for locating geothermal reservoirs and planning well placements[xi,xii].

9. 2D/3D land seismic surveys

2D/3D land seismic surveys are methods used to create images of subsurface structures, essential for mapping geothermal reservoirs and identifying drilling targets. In 2D surveys, seismic waves are generated and recorded along a single line, producing a vertical cross-section of the subsurface. 3D surveys, on the other hand, use a grid of source points and receivers to create a three-dimensional volume of data, offering more detailed and accurate subsurface imaging. While 2D surveys are quicker and more cost-effective, 3D surveys provide higher resolution and better characterisation of complex geological structures while requiring more sensors to be utilised[xiii,xiv].

For geothermal projects like URGENT, these surveys are crucial for identifying and mapping potential reservoirs in sedimentary basins and hard rock basement formations across Europe, helping to optimise well placement and enhance the success rate of geothermal energy development in urban areas.

10. Seismic data processing

Seismic data processing is a crucial step in geothermal exploration that transforms raw seismic data into interpretable subsurface images. It involves applying various algorithms and techniques to enhance the quality and resolution of seismic data, removing noise, and correcting for distortions[xv].

In URGENT, advanced processing methodologies such as inverse scattering will be employed to extract maximum information from the data, enhancing the accuracy of subsurface characterisation.

11. Seismic interpretation

Seismic interpretation in geothermal exploration involves analysing seismic data to understand the subsurface geology, particularly focusing on structures and formations that may indicate geothermal resources. This process examines the timing and characteristics of seismic reflections to infer the structure, stratigraphy, and lithology of underground formations. The interpretation is categorised into structural, stratigraphic, and lithologic analyses. Structural interpretation maps the subsurface to identify potential geothermal reservoirs, while stratigraphic interpretation helps understand the depositional history and identify suitable layers for geothermal energy. Lithologic interpretation assesses rock properties and fluid content, crucial for locating geothermal resources. The goal is to create accurate subsurface maps and models by integrating seismic data with other geological information, aiding in the identification and development of geothermal energy sites. This process requires a strong understanding of regional geology and careful planning to achieve reliable results[xvi].

12. Induced seismicity risk & risk management

Induced seismicity risk is the potential for geothermal activities to cause small earthquakes. Induced seismicity risk and risk management are crucial aspects of geothermal projects, particularly in urban areas. This involves assessing the potential for human-induced earthquakes and implementing strategies to minimise and manage this risk[xvii].

The URGENT project incorporates advanced monitoring techniques and decision-making protocols to ensure safe and sustainable geothermal energy production in European cities.

13. Electric low-impact seismic source (eVibe)

Electric low-impact seismic sources, such as eVibes, represent a new generation of environmentally friendly seismic technology. Their purpose is to create seismic waves for subsurface imaging in geothermal exploration. These compact, electric-powered sources reduce the environmental impact of geothermal exploration while achieving the required depth of penetration, making them ideal for urban settings[xviii,xix].

In URGENT, the ambition is to surpass most of the technologies worldwide relying on the use of the common sources for land seismic survey, that are not well suited for urban contexts. The innovative technology will provide solutions for low-impact, high resolution geothermal reservoir mapping and monitoring. URGENT aims at doubling the force of the *Storm* eVibe to reach deeper geothermal targets (around 4000 meters), while maintaining a high duty cycle (60-100%), therefore, being able to reduce exploration costs.

14. Microelectromechanical systems (MEMS)-based seismic sensors

Microelectromechanical systems (MEMS)-based seismic sensors are highly sensitive devices used in geothermal exploration. These advanced sensors improve the quality and resolution of seismic data, enabling more accurate subsurface imaging and reservoir characterisation in complex urban environments[xx,xxi].

The National Institute for Subatomic Physics Nikhef in the Netherlands, has successfully miniaturised anti-spring technology into a micro-scale accelerometer[xxii]. This innovation in seismic sensors allows the combination of high-precision motion sensing, in a small form factor. In URGENT, this development will integrate the high-precision MEMS accelerometer and lowpower internet-of-things (IoT) communication technology, both developed at INNO, into a small, QC-enabled, and sensitive seismic recording node ideal for deep geothermal exploration in urban environments.

15. High-density and high-quality seismic data

High-density and high-quality seismic data are essential for detailed subsurface imaging in geothermal projects. By using a large number of closely spaced sensors and advanced processing techniques, this approach provides more accurate and detailed images of geothermal reservoirs[xxiii].

The URGENT project will leverage these technologies to enhance urban geothermal exploration and reduce geological uncertainties across Europe.

16. Social engagement

Social engagement in the development of any process refers to the active participation and collaboration of individuals, communities, and stakeholders in shaping and influencing its outcome. This can involve a wide range of activities, such as public consultations, community meetings, online forums, and collaborative decision-making, all aimed at ensuring that diverse perspectives are considered and that the process benefits from the collective input and expertise of those involved. In essence, social engagement helps to create more inclusive, transparent, and effective processes by fostering a sense of ownership and accountability among all participants. This can lead to better decision-making, increased trust, and improved outcomes that reflect the community's needs and aspirations.

The URGENT project includes the social engagement in order to improve the acceptance of the work done in the project.

17. The Cross-Impact Method

The Cross-Impact Method analyses how different events or factors might influence one another and shape future outcomes. Developed by Theodore Gordon and Olaf Helmer in 1966, it helps reduce uncertainty by examining the relationships between events and predicting their combined effects.

The method is used as a part of URGENT work to assess how different factors influence the project's outcome and its practical applications. This will help understand the impact of various elements on achieving the project's goals and how these insights can be applied in real-world scenarios.

REFERENCES

[i] HTTPS://WWW.THINKGEOENERGY.COM/GEOTHERMAL/WHAT-IS-GEOTHERMAL-ENERGY/
[ii] HTTPS://WWW.ENERGY.GOV/EERE/GEOTHERMAL/GEOTHERMAL-BASICS
[iii] HTTPS://WWW.BRGM.FR/EN/REFERENCE-COMPLETED-PROJECT/NEW-PROSPECTING-METHODS-DEEP-GEOTHERMAL-RESOURCES
[iv] HTTPS://GEOEXPRO.COM/GEOTHERMAL-ENERGY-FROM-BURIED-BASEMENT-ROCKS/
[v] HTTPS://NORA.NERC.AC.UK/ID/EPRINT/504718/1/ACCEPTED HYDRO PAPER AUG 2013.PDF
[vi] HTTPS://GLOBALRENEWABLENEWS.COM/ARTICLE/ENERGY/CATEGORY/GENERATION/52/1093201/EU-URGENT-PROJECT-LAUNCHED-TO-REDUCE-COSTS-FOR-URBAN-SEISMIC-GEOTHERMAL-EXPLORATION.HTML
[vii] HTTPS://PANGEA.STANFORD.EDU/ERE/DB/GEOCONF/PAPERS/SGW/2022/AYDIN3.PDF
[viii] HTTPS://EN.WIKIPEDIA.ORG/WIKI/FAULT_(GEOLOGY)
[ix] HTTPS://SE.COPERNICUS.ORG/ARTICLES/13/1843/2022/
[x] HTTPS://EN.WIKIPEDIA.ORG/WIKI/STRIKE_AND_DIP
[xi] HTTPS://WIKI.AAPG.ORG/SEISMIC_DATA_ACQUISITION_ON_LAND
[xii] HTTPS://EN.WIKIPEDIA.ORG/WIKI/SEISMIC_DATA_