Seismic exploration and monitoring for geothermal resources

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Description and state of the art

In many areas of Europe, geothermics has the potential to contribute to the transition towards decarbonized energy production. Important programmes are being developed e.g. in France, Germany, Switzerland, Croatia and the UK. In Italy, the potential is particularly high and can give a very important contribution to the energy transition. Together with other renewable energy sources, geothermics can:

- Contribute to decarbonisation of energy sources for electricity, heating, cooling and transportation;
- Help balance the energy networks through the availability of variable sources;
- Create new jobs and contribute to the European technological and industrial leadership in the sector of the Green Economy.

All this is in perfect agreement with the Italian national plan for recovery and resilience (PNRR) and the Italian national programme for research (PNR 2021-27).

In spite of the lucky situation in terms of resource availability, the use of geothermal resources in Italy has not shown any significant increase over the past decade and no clear perspective is for the time ahead. This is the consequence of a mix between a biased perception by the public opinion and the un-necessarily complex bureaucratic system of permissions. Two risks are to be tackled in order to boost the geothermal energy sector:

(1) The mining exploration risk: even though temperature increases steadily with depth to an average gradient of about 25°C/km, important regional and local differences exist. In addition, temperature is not the only governing factor for the exploitation of the geothermal resource, and maybe not even the principal one: permeability to water and natural recharge of geothermal reservoirs is a key factor for the exploitation and the sustainability of the resource. Therefore, inaccurate characterization of the subsoil may lead to loss of important financial investments.

(2) The environmental risk: the transition to renewable energies must be sustainable also in terms of their acceptability by the public opinion with positive fallouts on legislation and administrative constraints, and thus attract the necessary large investments. For geothermics,

the sustainability requirements above are generally linked to the concept of induced seismicity. While destructive earthquakes have never been caused by geothermal projects, a few examples for high enthalpy (high temperature, deep projects, for electrical power production) show that a risk exists: the Basel earthquake (magnitude 3.4) in 2006, the St. allen earthquake in 2013 (magnitude 3.5), both in Switzerland, and the Vendenheim (Strasbourg) 2019 and 2020 earthquakes (3.1 and 3.5).

Note that in order to make geothermal energy useful, particularly at medium-low enthalpy, the resource is to be sought close to the end users (heat is used directly) and this implies that exploration and exploitation must be conducted in or close to urban environments. This exacerbates the need to reduce both mining and induced seismicity risks.

Scientific goals and added value

The project’s scientific goals are in line with the need to tackle the main risks above. Research will be conducted with three intertwined goals:

(1) Improve the efficiency of exploration seismics in complex (often urbanized) environments, in order to reduce costs, improve precision and ultimately reduce the mining risk;
(2) Tailor seismological monitoring to the specific needs of geothermal projects monitoring, in terms of spatial resolution and alert capabilities, also using non-conventional seismic networks;
(3) Use the geometric information from exploration seismics and the micro-seismic information from local seismological networks to build and refine 3D geothermal models based on coupled flow in porous media and heat transfer, in order to manage the geothermal reservoir and, at the same time, interpret correctly the possible induced seismicity.

Exploration seismics

As exploration is often required in, or close to, urban settings, a number of intricacies must be tackled in order to produce high quality data. First, urban environments require that highly irregular geometries are used, possibly reducing spatial coverage in some areas. Second, urbanized areas are characterized by high noise levels. The targets of geothermal exploration are often fractures in deep rocks that ensure sufficient permeability for hot water circulation. This requires that high resolution, accurate imaging of complex geological structures be ensured in order for the targets to be reached by deep, expensive exploitation wells. This goal requires that 3D seismic illumination be free from artefacts caused by out-of-planes and distortions due to crooked acquisition lines. This goal requires that a number of strategies be conceived, tested and adopted: (a) optimize geometries, aiming at identifying the minimal sparse 3D geometry; (b) define metrics to qualify the chance of design success; (c) identify, test and select optimal recording systems, assess their performance and use in high noise areas: nodal systems are to be preferred for their flexibility; (d) identify, test and select optimal sources: consider flexibility, power, cycle time, and disturbance, as well as induced vibrations; (e) design, test and optimize processing sequence for sparse 3D and 2D data in urban environment. For accurate geometry imaging, in addition, also refined velocity estimates are necessary, using pre-stack depth migration approaches. Velocity estimates are also necessary for accurate location of induced seismicity events (see below).

Monitoring geophysics:

Seismological or micro-seismic monitoring systems are state-of-the-art for applications that range from regional earthquake surveying to local fracking or other engineered applications. Yet, monitoring of geothermal systems have both specific requirements and possible specific uses. First, resilience to relatively high ambient noise levels is to be ensured, given the urbanized area of application. Second, a need exists for high-resolution event localization capacity at large depths, as events are likely to be localized along main faults/fractures that are stimulated by fluid injection. And proper knowledge of these locations and the likely slip mechanism are necessary for adequate modelling and understanding of the phenomena to be kept under control. Finally, monitoring systems must be linked to real time alarms, that shall be calibrated not to give too many false positives. These challenges prompt for advancement in the use of dense networks of individual 3-component nodes, and in the development of inversion/localization algorithms that make full use of all available information, including the accurate velocity estimates from 3D active seismics (see above).

The PhD work plan

The PhD student will be involved in all phases of the project, but with a particular emphasis on the geophysical aspects and specifically on the seismic acquisition and monitoring. Exposure to the other aspects of the overall project is expected and will contribute to the all-around formation of the young researcher. Stays and field activities in France and Switzerland are expected to be available to the PhD student.

Funding and collaborations

The research will be carried out with in collaboration of:

- Seismoring Sàrl, Switzerland
- Isamgeo Italia Srl, Italy
- Realtimeseismic SA, France
- OGS, Italy

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