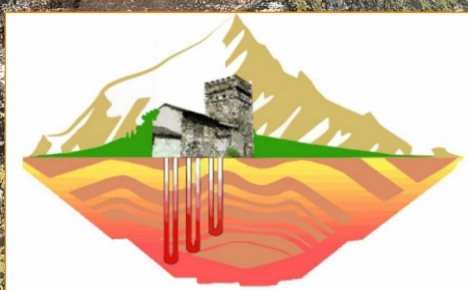


## Volumen 21

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# Application of the Play-Based Exploration Pyramid Approach Adapted to Deep Geothermal Resource Mapping at the European Scale in the EU GSEU Project

## *Aplicación del enfoque 'Play-Based Exploration Pyramid' adaptado al mapeo de recursos geotérmicos profundos a escala europea en el proyecto Europeo GSEU*

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**Abstract:** This work introduces version 1.0 of the Pan-European Atlas of Sustainable GeoEnergy Capacities (SGC), developed within the GSEU (Geological Service for Europe) project. The Atlas applies the Play-Based Exploration Pyramid (PBEP) approach to harmonize and standardize the assessment of deep geothermal resources across Europe. The methodology follows a multiscale structure—Levels 0 to 3—that refines geothermal understanding from regional geosystems to detailed local targets. Version 1.0 has been published in spring 2025 via the European Geological Data Infrastructure (EGDI) and includes Levels 0 and 1. Level 0 provides public data from boreholes and thermal springs, serving as the base for Level 1, which maps favorable areas for geothermal exploration using Geothermal Play Typing (GPT). The release includes a catalogue of near 400 factsheets describing each GPT unit, along with a metadata report. Future versions (2.0 in 2025 and 3.0 in 2026) will introduce deeper layers of detail. Level 2 will identify potential geothermal reservoirs using 1D stochastic estimations of geothermal and heat storage potential. Level 3 will compile existing 2D/3D maps and models for detailed local-scale reservoir assessments. Altogether, the Atlas supports Europe's energy transition by enhancing knowledge and visibility of its deep geothermal potential.

**Key words:** GSEU, EGDI, Pan-EU Atlas of Sustainable GeoEnergy Capacities, Geothermal Play type, EuroGeoSurveys.

**Resumen:** Este trabajo presenta la versión 1.0 del Atlas Paneuropeo de Capacidades Geoenergéticas Sostenibles (SGC), desarrollado en el marco del proyecto GSEU (Geological Service for Europe). El Atlas aplica el enfoque del 'Play-Based Exploration Pyramid' (PBEP) para armonizar y estandarizar la evaluación del potencial de recursos geotérmicos profundos en Europa. La metodología sigue una estructura multi-escala —niveles 0 a 3— que permite refinar progresivamente el conocimiento geotérmico desde grandes sistemas geológicos hasta objetivos locales detallados. La versión 1.0, que se ha publicado en primavera de 2025 a través de la Infraestructura Europea de Datos Geológicos (EGDI), incluye los niveles 0 y 1. El Nivel 0 recopila datos públicos de sondeos y manantiales termales, base para el Nivel 1, que ofrece mapas armonizados de áreas favorables mediante la tipificación de plays geotérmicos (GPT). La publicación se complementa con un catálogo de alrededor de 400 fichas descriptivas y un informe de metadatos. Las futuras versiones 2.0 (2025) y 3.0 (2026) incorporarán más detalle: el Nivel 2 identificará reservorios potenciales mediante estimaciones estocásticas 1D, y el Nivel 3 integrará modelos existentes en 2D/3D para una evaluación local detallada. El Atlas contribuye así a la transición energética europea, mejorando el conocimiento sobre el potencial geotérmico profundo.

**Palabras clave:** GSEU, EGDI, Pan-EU Atlas of Sustainable GeoEnergy Capacities, Geothermal Play type, EuroGeoSurveys.

## INTRODUCTION

The Geological Service for Europe (GSEU) is a Horizon Europe co-funded project (2022–2027), coordinated by EuroGeoSurveys (EGS), which represents Europe's Geological Survey Organisations. With over 10,000 experts, EGS leads collaborative research and data harmonization efforts across the

continent (Fig. 1). Aligned with the European Green Deal, GSEU brings together 49 partners from 36 countries, aiming to establish a permanent pan-European geological data infrastructure to support the sustainable and safe use of subsurface resources. The project covers key themes such as raw materials, geenergy, groundwater, coastal and marine geology, geological mapping, and the European Geological Data

Infrastructure (EGDI) <https://www.europe-geology.eu/>, a platform that will play a central role in delivering knowledge to policymakers and stakeholders.



FIGURE 1. GSEU project. The Geological for Service for EU (<https://www.geologicalservice.eu/>)

### THE PAN-EU ATLAS OF SGC AND THE PLAY BASED EXPLORATION APPROACH FOR THE DEEP GEOTHERMAL PART

The GSEU project's GeoEnergy activities are developed under Work Package 3 (WP3), which focuses on creating pan-European inventories, characterizations, and knowledge related to Sustainable Geo-Energy Capacities (SGCs), including geothermal energy resources, underground CO<sub>2</sub> storage, and temporary subsurface storage of hydrogen, heat, and cold. WP3 is structured around three main deliverables: a database inventory, the named online GIS 'Pan-EU Atlas of Sustainable GeoEnergy Capacities - Pan-EU Atlas SGC' - (Herms et al., 2023), and a Knowledge and Competence Hub to support national Geological Survey Organisations and stakeholders. The main output, the Atlas, will provide harmonized maps and databases on geothermal resources and storage capacities, based on both existing data and new national assessments. Building on the previous Horizon 2020 co-funded GeoERA programme, WP3 will enhance data integration using shared standards and frameworks through the EGDI platform, supporting improved subsurface management and decision-making. Version 1.0 of the Atlas, released in May 2025, includes the first three datasets.

The GSEU project adopts a structured, knowledge-based approach to assess deep geothermal resources and Medium to High Temperature Aquifer Thermal Energy Storage (M/HT-ATES) across the EU, inspired by the *Play-Based Exploration Pyramid* (Moeck et al., 2019, 2020; Weydt et al., 2025) with the *Geosystems, Plays and Prospects*. The GSEU products are organized into four levels (from Levels 00 to 03), with different coverage and geological detail:

**Level 00:** This foundational level, included in version 1.0 published in Spring 2025, provides basic datasets

such as inventory of boreholes (41,899 points) and thermal springs (6,621 points), containing attributes like depth, drill year, Bottom Hole Temperature, flow rate, and temperature, among others. **Level 01:** Geosystems: also in version 1.0 (Spring 2025), provides a harmonized map of near 400 geosystems, classified based on Moeck's (2014) GPTs. It highlights favourable regions for geothermal exploration, with each geosystem having a downloadable fact sheet (Fig. 7) that includes a map referenced using the IGME 5000 database (Asch & Tschopp, 2005), geological descriptions, citation of the potential geothermal reservoirs specifying depth and temperature ranges, and references. Additional areas, such as those in Greece, Romania, and offshore zones suitable for power generation, are still under development. **Level 02:** Plays (Reservoirs): This level will offer a continental-scale assessment of the identified potential deep geothermal reservoirs and for M/HT-ATES. It will include 1D lumped stochastic simulations of Heat-in-Place (HIP) and Heat Storage Potential (HSP) methods (Muffler & Cataldi, 1978; Frick et al., 2022) to estimate base resources and capacities. A Python-based open-access tool for these simulations has been coded, and later it will be available through the GSEU knowledge hub. **Level 03:** Prospects, corresponding to a project scale, will provide the most detailed evaluation of geothermal systems through spatially resolved 2D/3D data, describing both qualitative and quantitative attributes. It will compile existing datasets from previous national or cross-border projects, ongoing co-funded research EU projects, which will be preserved in the EGDI geological repository. This level will be progressively expanded with new contributions from ongoing and future projects.

This pyramid-based methodology allows for a consistent, scalable assessment of geothermal potential, enabling informed decision-making and ongoing updates as new data becomes available (Fig. 2).

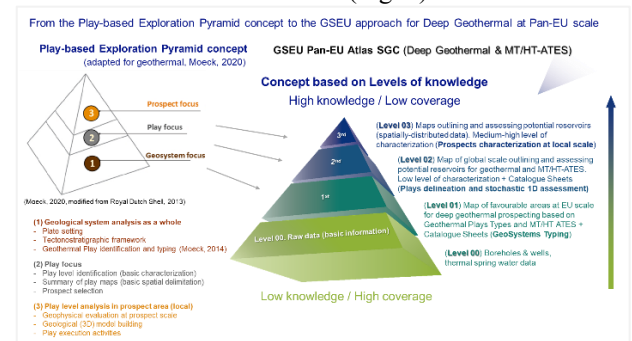


FIGURE 2. From the Play-based Exploration Pyramid concept (Moeck, et al. 2019, 2020) to the GSEU approach at Pan-EU scale.

### THE CONTENT OF VERSION 1.0 (SPRING 2025) OF THE PAN-EU ATLAS OF SGC

The first version (1.0) of the Pan-EU Atlas was published in Spring 2025 (Fig. 3). This initial release focuses on the first datasets related to deep geothermal energy topics with the Level 00 (Figs. 4 and 5) and Level 01 (Figs. 6 and 7).

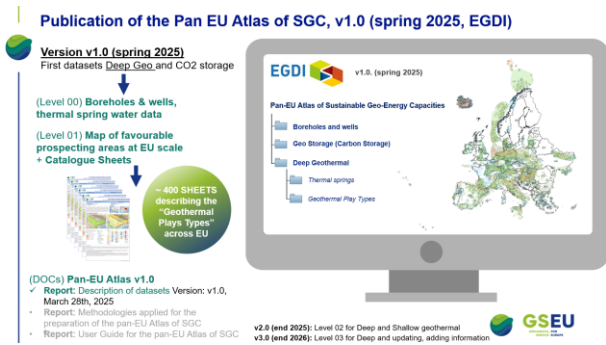


FIGURE 3. Publication version 1.0 of the Pan-EU Atlas of SGC,

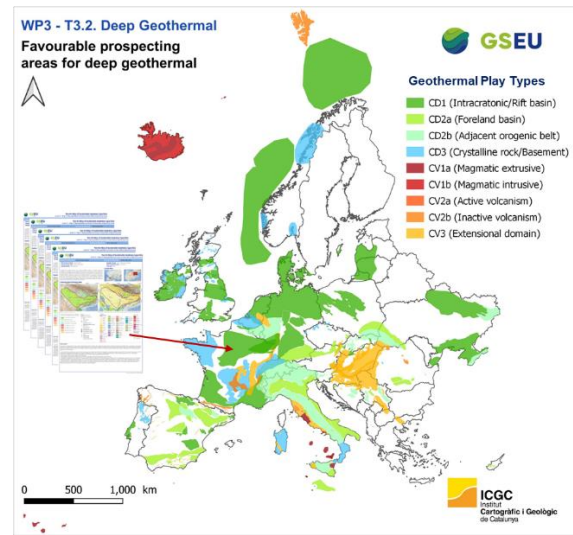


FIGURE 6. GSEU Project (2025). Map of favourable prospecting areas for deep geothermal across the EU classified according to the geothermal play catalogue (Moeck, 2014).

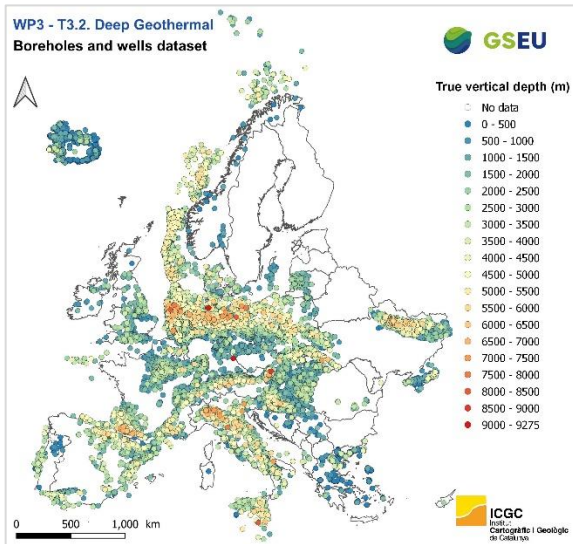


FIGURE 4. GSEU Project (2025). Map of Geo-Energy Boreholes and Wells. Version 1.0. (41,899 points) classified according to the vertical length (m).

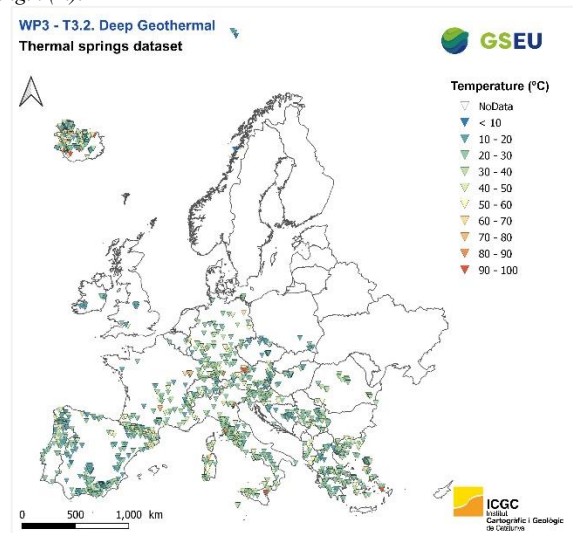


FIGURE 5. GSEU Project (2025). Map of natural Thermal Water Springs. Version 1.0.

A preliminary statistical analysis was performed on the Level 01 dataset to characterize potential geothermal reservoirs by temperature and depth ranges across different play types. Results are presented as percentiles (P10 for minimum and P90 for maximum values), providing insights into typical and extreme conditions across Europe.

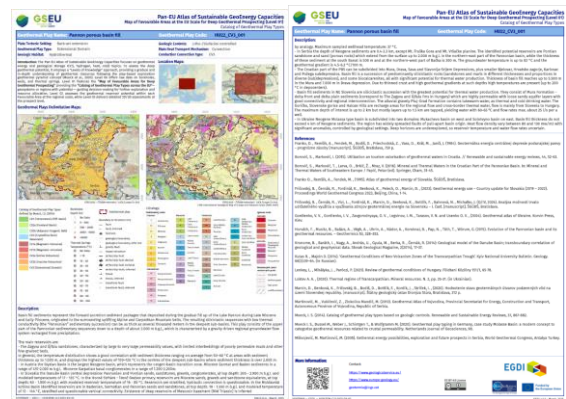


FIGURE 7. Example of the two pages-based fact sheets for one geosystem (geothermal play type). The image corresponds to the Pannonian basin geothermal play (code HU22\_CV3\_001).

For conduction-dominated geosystems (CD1, CD2a, CDb), temperatures range from 50 °C (P10) to 180 °C (P90) with depths from 1,500 m (P10) to 5,300 m (P90). Fractured crystalline rocks (CD3) show temperatures from 100 °C (P10) to 150 °C (P90), and depths from 2,500 m (P10) to 5,100 m (P90). Convection-dominated settings (CV1a, CV1b) linked to volcanic reservoirs show temperatures between 200 °C (P10) and 340 °C (P90), with depths from 990 m (P10) to 2,000 m (P90). For plutonic-associated systems (CV2a, CV2b), temperatures range from 130 °C (P10) to 260 °C (P90), and depths from 700 m (P10) to 3,300 m (P90). Finally, CV3-type geosystems show temperatures from 50 °C (P10) to 176 °C (P90), and depths from 2,000 m (P10) to 5,000 m (P90). This analysis supports further exploration and resource assessment. Moving forward, Level 02 will estimate Heat in Place (HIP) and Heat Storage Potential (HSP) densities for these reservoirs using stochastic methods, expressed in PJ/km<sup>2</sup>

It's expected that version 2.0 of the Pan EU will be compiled and completed by December 2025, with publication in Q1 of 2026. It will include Level 02—a

map assessing potential deep geothermal reservoirs and medium- to high-temperature ATES for deep geothermal, as well as storage capacity calculations for CO<sub>2</sub> storage.

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