DELIVERABLE 4.8

NEW INNOVATIVE PRODUCT, GUIDELINE AND SERVICE FOR 'DYNAMIC SYSTEM APPROACH FOR GEOFLUIDS AND THEIR RESOURCES' (DSA-GR)

ENeRAG
Excellency Network Building for Comprehensive Research and Assessment of Geofluids

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About the ENeRAG project

The 'Excellency Network Building for Comprehensive Research and Assessment of Geofluids'-ENeRAG project significantly strengthen research and innovation capacities in geofluids' research and aligned geological resource assessment of groundwater, geothermal energy and hydrothermal mineral resources at Eötvös Loránd University (ELTE, Hungary) by capacity enhancement through cooperation with Geological Survey of Finland (GTK) and University of Milan (UMIL, Italy), with 7 supporting stakeholders. The ENeRAG raises the research profile and excellence of ELTE in comprehensive understanding, tracing and modelling of geofluid systems focusing on their interrelationships through 4 staff exchanges, organisation of 5 sessions and attendance on 9 high-level international conferences; through joint open access publications (15 +1 special issue). It will ensure to fill networking gaps and deficiencies of ELTE, and enhance the S&T and innovation capacity in the field of sustainable development and eco-friendly exploitation of geofluids and their resources by 6 training workshops, 2 innovative video trainings, 1 summer and 1 winter school, expert visits, 3 laboratory and field trainings. Due to ENeRAG ELTE improves its innovative capability to gain national and international EU funding, and to furtherly widen cooperation through agreements with institutes and stakeholders. The ENeRAG contributes to improved knowledge transfer and to aligned interpretation and sustainable utilisation of geofluids in Hungary. The project and its resulted guideline strengthen the hands-on hands experience in geofluid research, legislation and exploitation. The ENeRAG guideline provides a missing novelty service, gives base for prioritization of geofluid-related resources in Hungary and in the EU. Consequently, ENeRAG

improves stakeholder experience, legislation and contribute to the dissemination of knowledge toward the scientific community and the society on national and EU level.

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1. INTRODUCTION

Deliverable D4.8 contains a new innovative product, such as a Guideline and Service for 'Dynamic System Approach for Geofluids and their Resources' (DSA-GR).

2. ACTIONS RELATED TO DELIVERABLE 4.8

Within the ENeRAG project basically **all activities and actions** served the purpose of compiling a Guideline and Service for 'Dynamic System Approach for Geofluids and their Resources', but the next 2 Actions played a prominent role in this:

1. Action 4.7.1: Aligned business cooperation *(see details in Deliverable 3.2)*
2. Action 4.7.2: Technology and results deployment to industry *(see details in Deliverable 4.3)*

3. PREPARATION OF THE GUIDELINE AND SERVICES

We prepared the Guideline and Service based on the specific Workflow set up during the project (*the workflow was published as a Concept Paper with the title "Groundwater Flow System-Based Dynamic System Approach for Geofluids and Their Resources" by Czauner et al. 2022 in the Special Issue in Water MDPI*).

The first version of the Guideline was prepared by Judit Mádl-Szőnyi (ELTE) and Brigitta Zentai-Czauner (ELTE). Then it was sent to the partners' institutions for a review. In the closing conference of the ENeRAG, the suggestion of the consortium for the **Guideline and Services** for the stakeholders were presented in an interactive form. We involved the stakeholders and the audience to receive feedback about the presented result (i.e. the Guideline and Services). Then, before finalising the Guideline and Services, we sent them to the stakeholders again by email, asking for their recommendations.

4. GUIDELINE AND SERVICES FOR THE DYNAMIC SYSTEM APPROACH FOR GEOFLUIDS AND THEIR RESOURCES

- Objectives:
  - knowledge transfer to public and governmental institutions, companies, NGOs, universities
  - demonstration of the potential practical applications

1. Significance

Fundamental Problem: the current European and national legislative approaches do not provide a common framework for managing and using geofluids together.

Consequences: neglecting interrelationships, misinterpreting processes, false prognoses and suboptimal use of natural resources, negative environmental consequences.

Why was the 'Dynamic System Approach for Geofluids and their Resources' (DSA-GR) developed?

To harmonize research and sustainable exploration of different forms of geofluids (e.g., groundwater, geothermal and hydrothermal fluids) and the related geo-resources (groundwater, geothermal energy and hydrothermal minerals). (Hydrocarbons can also be mentioned, though these were not involved directly in the project.)

What is its significance?

It aids to achieve the Sustainable Development Goals (SDGs) of the United Nations by 2030 (e.g., zero-hunger, good health, clean water and energy, sustainable cities, climate action, life below water and on land) and the related aims of the European Green Deal by 2050 (e.g., zero carbon emissions, circular economy).

2. Key concepts of the DSA-GR

- *Characterization of basin-scale groundwater flow systems*

  Groundwater often interacts with many other geofluids during its movement. Therefore, it is not enough to focus on understanding the hydraulic and thermal properties of the rock matrix. We have to understand groundwater flow pattern on different scales. The basis of the application of the DSA-GR is the characterization of flow systems at the basin scale, which could be followed by local-scale investigations.

- *Application of system approaches in geofluid research*

  It is based on applying analogous source-migration-accumulation models in geothermal, mineral and petroleum exploration.

- *Incorporating groundwater flow systems in geofluid research through the DSA-GR*

  The incomparable strength of groundwater flow system approach lies in the handling of migration, namely that migration pathways of fluids or groundwater flow paths, which transport matter and heat can be evaluated quantitatively and in a distributed manner. Consequently, DSA allows site-specific search for geofluid-related resources (e.g., groundwater, geothermal energy, hydrothermal minerals), which can be viewed simply as products of groundwater's moving geologic agent.

3. The main steps of the application (based on the workflow)

1. *Basin-scale groundwater flow system evaluation*
   Methods: i) retrospective research to understand the quasi-natural conditions of flow systems; ii) survey of groundwater-flow related phenomena and processes; iii) characterization of the hydrostratigraphic build-up; iv) hydraulic, water chemical and isotope data analysis for wells and springs.

2. *Numerical flow modelling of steady-state and transient groundwater flow pathways and intensities*
   provides the base for transport modelling of mass (conservative or reactive) and heat, and paleo flow system modelling.

3. *Mass or contaminant transport simulations (local scale)*
   can be used for instance in groundwater vulnerability assessment and Managed Aquifer Recharge (MAR) evaluation, whilst heat transport simulations can be applied for instance in shallow (and deep) geothermal (groundwater and bedrock) energy utilization.

4. *Paleo flow system modelling*
   requires preliminary geodynamic and structural modelling, then complemented with mineralogical and lithogeochemical studies it can be used for target generation in mineral exploration.

5. *Use of stable, radioactive and radiogenic isotopes as environmental tracers, and stochastic and spatial statistical modelling*
   can significantly improve the modelling results such as groundwater vulnerability and mineral potential evaluation.

4. Integrated methodologies for practical challenges

Groundwater

Problems connected to the vadose zone
Numerical modelling of the vadose zone combined with environmental tracers.

- The physical behavior of MAR site
- The fate of dissolved and gaseous contaminants in the soils
- Water budget in the topsoil layer
- Water budget in the topsoil layer for irrigation scheduling
- Quantification and distribution of natural aquifer recharge

Problems connected to the saturated zone
Numerical modelling of the saturated zone combined with environmental tracers.

- The fate of dissolved contaminants in groundwater
- Uncertainty analysis for the risk-based decision-making process
- Assessment of the maximum extension of a solute plume contamination for aquifers
- Evaluation of contaminant spreading undergoing geochemical and biochemical reactions for aquifers
- Assessment of (future) spring discharges or spring dries out
- Assessment of drinking water vulnerability in terms of safeguard zones
- Water budget of the aquifers and groundwater dependent ecosystems

Statistical groundwater vulnerability assessment

- GW vulnerability assessment of porous aquifers to non-point sources of contamination
- GW vulnerability assessment in karst environments

Shallow geothermal energy

- Thermal effect on groundwater in operating ATES (Aquifer Thermal Energy Storage) systems
- The effect on groundwater flow to BTES (Borehole Thermal Energy Storage) system
- Optimizing shallow geothermal energy utilization

Mineral systems

- Sources of fluids and their components
- Transportation pathways of fluids
- Primary footprints of mineral deposits (fluid-rock interaction)
- Traps for mineral deposition
- Preservation, remobilization

5. Potential application areas of the DSA-GR related to future Services

Sustainable groundwater management including adaptation to climate change

DSA-based evaluation reveals the basin-scale groundwater flow systems and hydraulic connections between aquifers and aquitards, thus allows of the tracing of groundwater from infiltration (recharge) to discharge. In water management it could effectively contribute to

- the identification and (chemical and quantitative) status assessment of groundwater bodies (e. g. compilation of conceptual models, assessment of pollution plumes and contaminant pathways according to the EU Groundwater Directive (2006/118/EC);
- the water budget of the groundwater bodies, determination of water demand thresholds for different parts of groundwater bodies;
- the determination of the amount of recharging water and the water demand of groundwater dependent ecosystems, thus the possible amount of sustainable groundwater abstraction;
- the protection of operating drinking water sources and exploration of potential drinking water resources;
- the protection of groundwater and connected aquatic and ecosystems from contaminations;
- MAR (Managed Aquifer Recharge) research and implementation for groundwater replenishment and ecosystem restoration;
- planning agricultural land-use and amelioration of saline soils;
- designation irrigation zones and determination of irrigation water needs;
- protection and restoration of groundwater dependent ecosystems;
- using radionuclides as natural tracers, etc.

Determination of open and closed geofluid systems

DSA-based evaluation reveals the basin-scale pressure regimes, which determine the open (usually normally pressured) or closed (usually abnormally pressured) hydraulic character – on a human time-scale – of the geofluid resources, irrespectively of the depth. This resource characteristic determines the potential of fluid production and injection (fluid sequestration), which has particular significance in geothermal systems and hydrocarbon exploration.

Planning and optimization of open and closed loop shallow geothermal energy utilization

Questions raised by groundwater production of open loop systems were partly covered in the previous points. However, operation of closed loop systems (with a circulated carrier fluid) is also influenced by groundwater flow. For instance, intensive advective heat transfer can cause a significant loss in geothermal energy storage. Consequently, DSA-based evaluation can help to find proper sites for geothermal energy use and to optimize the operation of the systems for direct utilization and energy storage.

- *Utilization of heat and raw materials from thermal waters*

DSA-based evaluation also reveals the temperature and geochemical conditions of geofluids, as well as their controlling factors and processes such as mass and heat transport, fluid-rock interactions, porosity development, etc. Scaling can cause significant problems, which requires the use of different inhibitors. The combined utilization of heat-minerals and application of the fitted inhibitors optimize the exploration of thermal waters with high total dissolved solid content, the critical raw material (e.g., Magnesium, Lithium) or other specified content. Besides, the multifaceted and cascade system use of thermal waters is highly recommended to exploit as much energy and raw material as possible. In addition, utilization of the heat and raw material content of mine drainage is also worth considering.

- *Mineral potential evaluation*

DSA-based modelling of paleo-flow systems and fluid-rock interactions can efficiently contribute to mineral potential evaluation and increase the knowledge base of mineral deposits to optimize mining. On the other hand, evaluation of the present groundwater flow systems enables to assess the potential environmental consequences of mining activities regarding surface and groundwaters and the connected ecosystems.

- *Utilization of abandoned/dry hydrocarbon wells*

Knowledge of the groundwater flow systems and the related systematic heat and mass distribution can significantly contribute to the optimized (re)utilization of abandoned and dry hydrocarbon wells for instance for geothermal energy or groundwater production, or fluid and gas sequestration. Producing hydrocarbon wells of mature fields with high water percentage could also be considered regarding the wastewater's heat and raw material content (e.g., petrolithium). Among the previously described issues several are concerned also here (e.g., determination of open and closed geofluid systems, planning and optimization of open and closed loop heat pump systems, utilization of heat and raw materials from thermal waters), which clearly demonstrates the necessity of harmonized geofluid research and utilization.

- *Utilization of the knowledge of petroleum exploration and exploitation in deep geothermal energy production*

Knowledge (experiences, technologies, risk assessment system) of petroleum exploration and exploitation can be efficiently applied or adapted in geothermal exploration, particularly based on the similar production necessities and environmental problems of unconventional hydrocarbon resources and Enhanced (efficiency) Geothermal Systems (EGS) regarding for instance hydraulic fracturing and induced seismicity. The holistic approach of DSA-GR can help to handle and optimize these issues as well.

6. Recommendations

Further recommendations to facilitate the harmonization of geofluid research for sustainable and cost-effective utilization:

- Create open access digital databases, webservices (atlas, maps), models
- Enhance the cooperation of experts and application of interdisciplinary approaches
- Enhance the cooperation with NGOs for societal engagement
- Create country specific guidelines for authorities and the business sector for the application of DSA-GR
- Advertising the project results in social media, create expert groups for further knowledge exchange