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I Congress of the GEOthermal Research and Innovation Network for Portugal and Spain (Geo-RIN)

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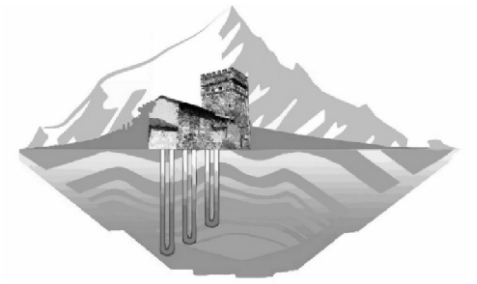

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ÍNDICE

Carta de Bienvenida del Alcalde de Benasque

Es un honor para la Villa de Benasque acoger la celebración del primer Congreso de la Red de Investigación e Innovación en Geotermia de Portugal y España (Geo-RIN). Como alcalde de este municipio pirenaico, me complace dar la bienvenida a todos los participantes que nos visitan desde distintos puntos de la península ibérica y de otros países europeos.

El valle de Benasque es un enclave natural único, rodeado de montañas, aguas termales y un valioso patrimonio geológico que lo convierten en el lugar ideal para reflexionar sobre el papel que la geotermia puede desempeñar en un futuro energético más sostenible y descentralizado. Nos sentimos especialmente orgullosos de que nuestra localidad sea escenario de este encuentro científico y técnico que promueve la colaboración transfronteriza y el avance del conocimiento.

Quiero agradecer a los organizadores su elección de Benasque como sede, y desear a todos los asistentes unos días provechosos de trabajo, intercambio y disfrute del entorno. Espero que esta experiencia sea tan enriquecedora profesionalmente como grata a nivel personal.

¡Bienvenidos a Benasque!

Manuel Mora, Excmo. Alcalde de la Villa de Benasque.

Welcome Letter from the Mayor of Benasque

It is an honor for the town of Benasque to host the first Congress of the Portuguese-Spanish Geothermal Research and Innovation Network (Geo-RIN). As mayor of this Pyrenean municipality, I am pleased to welcome all the participants visiting us from across the Iberian Peninsula and other European countries.

The Benasque Valley is a unique natural enclave, surrounded by mountains, thermal waters, and a valuable geological heritage, making it the ideal place to reflect on the role that geothermal energy can play in a more sustainable and decentralized energy future. We are especially proud that our town is hosting this scientific and technical meeting, which promotes cross-border collaboration and the advancement of knowledge.

I would like to thank the organizers for choosing Benasque as the venue and wish all attendees a productive few days of work, exchange, and enjoyment of the surroundings. I hope this experience will be as enriching professionally as it is personally rewarding.

Welcome to Benasque!

Manuel Mora, Mayor of the town of Benasque.

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Prólogo científico

Javier F. Urchueguía Schölzel

Profesor de la Universidad Politécnica de Valencia y Chair del European Geothermal Panel

En el contexto de la transición energética europea, la atención no se centra únicamente en el carácter renovable y sostenible de las fuentes de energía. En los últimos tiempos, impulsados por los acontecimientos internacionales, se ha puesto cada vez más énfasis en garantizar que la energía no solo sea limpia, sino también segura y de origen local, reduciendo así la dependencia de las fluctuaciones geopolíticas y los conflictos armados.

En este contexto, la energía geotérmica está cobrando relevancia como una fuente que cumple precisamente estos criterios de seguridad de suministro. Su versatilidad permite su uso tanto para la generación de electricidad como para la producción de calor a altas y bajas temperaturas. Cabe destacar la combinación de energía geotérmica con bombas de calor alimentadas con electricidad 100% renovable, una solución que ofrece altos coeficientes de rendimiento y resulta especialmente atractiva para aplicaciones de refrigeración, un área de creciente interés debido al aumento de las temperaturas en las ciudades europeas.

En respuesta a estos desafíos, numerosas ciudades europeas están desarrollando estrategias y planes específicos para incorporar la energía geotérmica a gran escala como una solución urbana sostenible y descarbonizada. En mi presentación, revisaré algunas de estas estrategias y exploraré perspectivas futuras, destacando ejemplos y mejores prácticas implementadas en diferentes ciudades europeas que pueden ayudar a acelerar una transición energética más rápida, más sostenible y más segura en Europa.

Scientific foreword

In the context of the European energy transition, the focus is not solely on the renewable and sustainable nature of energy sources. In recent times, driven by international events, there has been growing emphasis on ensuring that energy is not only clean, but also secure and locally sourced, thereby reducing dependence on geopolitical fluctuations and armed conflicts.

Within this framework, geothermal energy is gaining prominence as a source that meets precisely these supply security criteria. Its versatility allows it to be used both for electricity generation and for the production of heat at high and low temperatures. Particularly noteworthy is the combination of geothermal energy with heat pumps powered by 100% renewable electricity—a solution that offers high coefficients of performance and is especially attractive for cooling applications, an area of increasing interest due to rising temperatures in European cities.

In response to these challenges, numerous European cities are developing specific strategies and plans to incorporate large-scale geothermal energy as a sustainable and decarbonized urban solution. In my presentation, I will review some of these strategies and explore future perspectives, highlighting examples and best practices implemented in different European cities that can help accelerate a faster, more sustainable, and more secure energy transition in Europe.

Low-enthalpy geothermal resources for improving the resilience of road infrastructure within the framework of GEO-ROAD project

Recursos geotérmicos de baja entalpía para mejorar la resiliencia de las infraestructuras viarias en el marco del proyecto GEO-ROAD

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Abstract: Geothermal systems are an excellent solution for improving the resilience of road infrastructure to extreme weather events. The properties of this renewable energy (such as its independence from external weather conditions and the possibility of continuous use) make its implementation in these infrastructures a significant advance compared to the usual practices of de-icing and protecting the road surface from high temperatures. In this context, this research presents GEO-ROAD project, whose objective is to develop a predictive platform to identify the most potential locations for the implementation of geothermal energy in road infrastructure. As a key aspect of this project, this work delves into the methodology used to characterize the subsurface energy resource in the study area (Spain) and the development of geothermal potential models. After a preliminary geological and thermal approach, the development of a refined model based on geophysical information from satellite sources, airborne systems, and field measurements is presented. Finally, the importance of these precision geothermal potential models is highlighted, as they contribute to optimizing the use of geothermal energy, specifically in the road sector evaluated.

Key words: Geothermal energy; road infrastructure; energy potential; satellite sources; geophysics.

Resumen: *Los sistemas geotérmicos constituyen una excelente solución para la mejora de la resiliencia de infraestructuras viarias ante la exposición a fenómenos meteorológicos extremos. Las propiedades de esta energía renovable (como su independencia de las condiciones climáticas externas o la posibilidad de utilizarla de forma continua) hacen que su implantación en estas infraestructuras suponga un avance significativo respecto a las prácticas habituales de deshielo y protección del firme ante elevadas temperaturas. En este contexto, se presenta en esta investigación el proyecto GEO-ROAD, cuyo objetivo es el desarrollo de una plataforma predictiva que identifique los emplazamientos más potenciales para la implementación de geotermia en infraestructuras viarias. Como punto esencial de este proyecto, se profundiza aquí en la metodología empleada para la caracterización del recurso energético del subsuelo en la zona de estudio (España) y el desarrollo de modelos de potencial geotérmico. Tras una aproximación geológica y térmica preliminar, se presenta el desarrollo de un modelo refinado basado en información geofísica proveniente de fuentes satelitales, sistemas aerotransportados y mediciones sobre el terreno. Finalmente, se destaca la importancia de estos modelos de potencial geotérmico de precisión que contribuyan a la optimización del aprovechamiento de la energía geotérmica, específicamente en el sector viario evaluado.*

Palabras clave: *geotermia; infraestructuras viarias; potencial energético; fuentes satelitales; geofísica.*

INTRODUCTION

Transportation networks have become critical pillars for the continuous development of modern society. As the backbone of economic activity, social interaction, and mobility, these systems must be resilient enough to operate effectively under adverse and extreme weather conditions. Ensuring that transportation networks can maintain functionality during extreme weather events is vital for minimizing disruptions and response times, which in turn supports public safety and well-being (de Abreu et al., 2022).

To address the problem of icy and high-temperature roads, public and private institutions invest millions of euros or dollars annually. In the case of road icing, the most widely used method is to spread salt or chemical agents such as calcium chloride, sodium chloride, and potassium acetate to minimize ice formation on road surfaces. However, this approach has significant drawbacks, such as structural damage to pavements and serious environmental consequences, such as water, soil, and vegetation contamination (Xu et al., 2021)

In this context, shallow geothermal resources constitute a viable alternative for warming pavement through buried heat exchangers (Mauro and Grossman, 2017). This renewable approach also enables road cooling by storing heat in the ground for reuse in winter, contributing to prevent structural damage during high temperature exposure. Despite these benefits, the application of geothermal energy remains limited, particularly in heating and cooling systems, due to high maintenance and pumping costs (Blázquez et al., 2017).

To advance in the implementation of geothermal energy and enhance road system resilience against extreme weather conditions, interdisciplinary and integrated technologies are essential. This includes combining geospatial and satellite data with efficient underground resource management (Blázquez et al., 2022). The integration of Artificial Intelligence (AI) can optimize decision-making, enabling the development of technically and economically viable solutions tailored to the characteristics of the geothermal resource and capable of responding effectively to specific weather events.

Taking into account the above, GEO-ROAD project *("Proyectos de Generación de Conocimiento", 2022 call*) led by the authors of this research, aims to develop a global simulation engine that integrates geospatial data and AI techniques, providing predictive and prescriptive capabilities to address extreme weather events on roads through the implementation of innovative and adaptive geothermal solutions.

This work presents the developments made to date regarding the evaluation of the geothermal potential of the considered area its integration into the predictive model of the mentioned project.

METHODOLOGY AND MAIN RESULTS

The intelligent analysis of the road infrastructure has been designed for the specific case of Spain, with a diverse and multifunctional road network. The methodology followed in GEO-ROAD project (currently underway) is shown in Figure 1. This research focuses on Phase 3 concerning the geothermal module development.

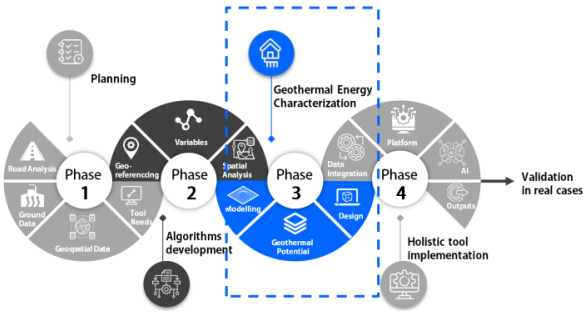

FIGURE 1. *GEO-ROAD project global workflow.*

Road Risk Map

Although this work is focused on the geothermal energy component, it is important to contextualize the project and its current state of progress. In this regard, a systematic methodology for gathering multi-source information has been implemented to identify the road infrastructure sections most affected by exposure to extreme temperatures. After homogenizing and processing the information, a geospatial module was generated. Once applying the corresponding machine learning and AI techniques, the winter and summer risk maps presented in Figure 2 were obtained.

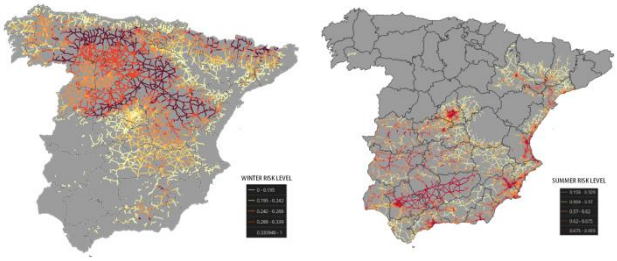

FIGURE 2. *Winter (left) and summer (right) risk maps obtained in GEO-ROAD project.*

Geothermal Approach

The development of the geothermal module is crucial for identifying areas with the highest potential for exploitation and assessing their suitability for road infrastructure exposed to extreme weather conditions. Given the conditions of the study area and the objective of the geothermal energy in this work (heating/cooling of the road infrastructure), the use of this energy is initially focused on low enthalpy systems that allow stabilizing the road surface temperature during the most critical periods.

As starting point, during this phase, an exhaustive characterization of the geological formations that make up the country under study has been carried out. Thus, a lithological analysis of the formations has begun based on different properties such as thermal conductivity, permeability, and porosity, as well as an evaluation of surface thermal power. Firstly, based on the available information and specific measurements on boreholes and ground samples, different maps of the country have been developed considering the mentioned variables (Figure 3).

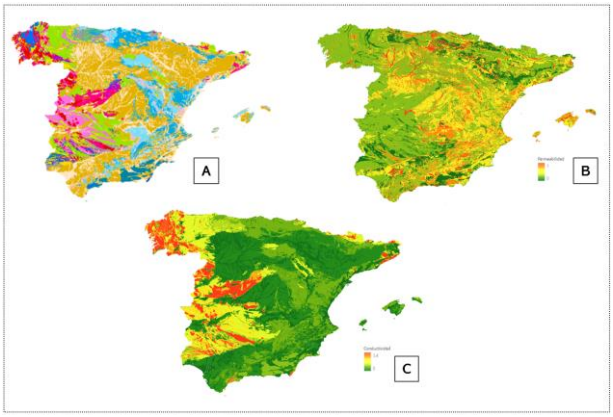

FIGURE 3. *Maps of lithological distribution (A), permeability (B) and thermal conductivity (C).*

An initial assessment of the geothermal potential was conducted using surface thermal capacity and temperature in different depths along with key parameters (such as the previously included in Figure 3) and applying different processing algorithms and map algebra techniques. This approach evaluates the thermal characteristics of the materials within the study area, enabling an analysis of heat distribution and its potential for geothermal energy utilization. As a result, the preliminary map of the shallow geothermal potential of Spain has been obtained and is shown in Figure 4.

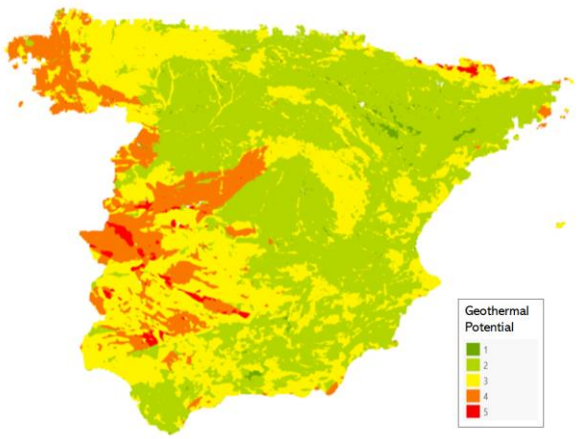

FIGURE 4. *First approximation to the geothermal potential of the area under study.*

The map presented in the previous Figure 4 has been developed using Model Builder in ArcGIS Pro. As can be observed, it provides a preliminary assessment of the shallow geothermal potential in Spain, categorizing regions into five levels of favourability. Green areas indicate lower potential, while red highlights the most favourable zones for geothermal energy development. As already mentioned, this analysis provides a first approximation that needs to be complemented with additional information.

In this sense, and in order to achieve more precise and detailed results, ongoing efforts focus on collecting and analysing data from direct temperature measurements and additional geophysical studies. These data are essential to generate a comprehensive assessment of the geothermal potential for the purposes of the study.

Within this second approach, and as part of the project described in this paper, geophysical information derived from satellite sources has been considered. Satellite missions provide high-precision magnetic and gravity data that are essential for studying the thermal and geodynamic structure of the subsurface, significantly contributing to the estimation of the geothermal potential (Kim, 2021; Utama et al., 2024). It is thus considered essential to include this source of information as a tool for refining the preliminary obtained model. Specifically, the satellites sources described in the following Table I have been evaluated.

Data obtained from the previous satellite, airborne and ground sources were homogenized using a routine programmed in Python and ArcGIS, in order to sample exclusively data with similar spatial equivalents. This method involves selecting a reference satellite point and overlaying a sampling window to incorporate data from other missions or airborne sources. A weighted average of these secondary data points is then computed using the Inverse Distance Weighting (IDW), assigning the final value to the reference satellite point (Garzón-Machado et al., 2014). The mentioned methodology has allowed obtaining a total of 1,621 satellite data with at least one point related to second base or airborne-ground values. After adjusting all data to a uniform resolution and height, statistical comparisons were performed to assess accuracy and validity.

Source	Type	Aplication
Ørsted	High resolution Earth's magnetic field	Models of the Earth's crust, variations in material composition and internal geodynamic processes. Detection of magnetic anomalies associated with deep, high-temperature structures.
CHAMP		
GRACE	High precision Earth's gravitational field	Identification of changes in subsurface mass distribution, for detecting active tectonic processes. Detection of areas of high heat flow linked to magmatic activity or steep thermal gradients.
GRACE-FO		
GOCE	Very high resolution Earth's gravity model	Detection of gravitational anomalies, linked with unusual thermal characteristics.
EMAG2	Earth Magnetic Anomaly Grid 2-arc-minute (compiled from satellites, airborne and marine acquisitions)	Identification of subsurface geological structures and basement depth. Regional geothermal prospecting.

TABLA I. *Description of satellite sources considered in the evaluation of geothermal potential.*

Once levelled the data, Oasis Montaj software is used for the processing and filtering of geophysical data. Within this workflow, the analytical signal is calculated and the inversion process is applied for the generation of geophysical distribution models from the measurements obtained, facilitating a clearer and more detailed results interpretation. Figure 5 shows an example of geophysical processing of data from Ørsted and EMAG2. Finally, after integrating this geophysical information and additional ground measurements, the geothermal potential map presented in Figure 6 has been generated.

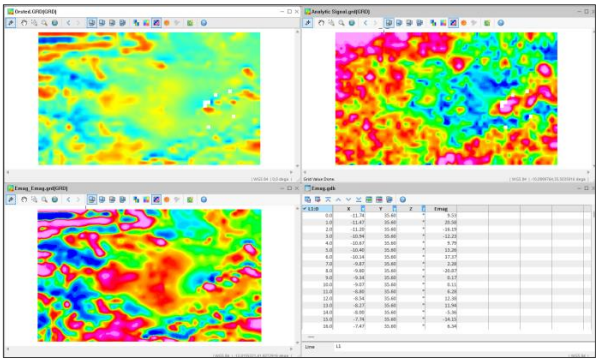

FIGURE 5. *Geophysical processing of data obtained from Ørsted and EMAG2.*

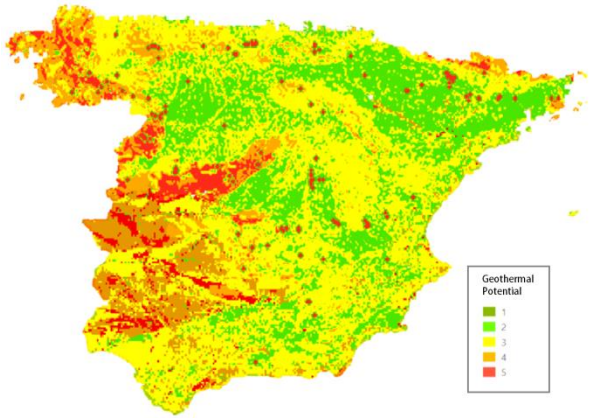

FIGURE 6. *Geophysical processing of data obtained from Ørsted and EMAG2.*

CONCLUSIONS AND FURTHER STEPS

The present research outlines the methodology followed in the national GEO-ROAD project, with a focus on the development of geothermal potential models for the area under evaluation (country of Spain). Given the project's objective of selecting optimal locations for improving the resilience of road infrastructure through the use of geothermal resources, it is essential to have an accurate geothermal potential model as a basis for future decision-making.

A preliminary map has been developed estimating the geothermal potential of the country, considering different geological and thermal variables, through the application of several processing algorithms and map algebra techniques. Based on this initial approach, data from multiple sources, including satellite, airborne, and field geophysical data, has been incorporated to refine the mentioned geothermal model.

Once the final mapping of the geothermal potential has been achieved, future developments will aim to combine, in the geospatial module, the winter and summer risk maps of the road sections most affected by extreme weather exposure with the results of geothermal modelling, in order to identify the most optimal locations for the implementation of these energy systems (also including external factors such as the existence of thermal industries or potential users that could also make use of the geothermal energy). Once made the identification of potential sites, different pilot cases will be selected to advance in the development of specific geothermal exploitation solutions already adapted to the conditions of the proposed scenario. This will include thermal modelling of the subsurface and its precise characterization, proposing novel heat exchange configurations that do not necessarily involve the lifting of the road surface (which would make their technical and economic implementation difficult).

ACKNOWLEDGMENTS

This work has received funding from GEO-ROAD project (PID2022-142097OA-I00). Miguel Ángel Maté-González and Cristina Sáez Blázquez acknowledge the grants RYC2021-034813-I and RYC2021-034720-I, respectively, funded by the Ministerio de Ciencia e Innovación and by the European Union 'NextGenerationEU'/PRTR.

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