Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

The GEO-URBAN Project - Identification and Assessment of Deep GEOthermal Heat Resources in Challenging URBAN Environments

James McAteer, Duygu Kiyan, Giuseppe Maggio, Pilar Queralt, Beatriz Benjumea, Paul Stafford, Sarah Blake, Julie Clarke and the GEO-URBAN Consortium

Unit A2, Nutgrove Office Park, Rathfarnham, Dublin 14, D14 X627, Ireland.

jmcateer@gdgeo.com

Keywords: Geothermal Exploration, Pre-feasibility, Passive Seismic, Electromagnetics, Geophysics.

ABSTRACT

Deep geothermal resources in challenging, low-enthalpy settings are generally poorly understood and remain largely untapped. The GEO-URBAN project is funded by the EU GEOTHERMICA ERA-NET Co-fund, and aims to investigate the deep geothermal resources of two urban locations using a novel combination of geophysical techniques. This three-year study is conducting an initial assessment of the potential for low enthalpy geothermal energy in two study areas, Dublin City, Ireland and Vallés, Catalonia, Spain. A multi-disciplinary geophysical exploration strategy has been developed for both targets to overcome exploration challenges in the built urban environment. A combination of electromagnetic methods, including magnetotellurics and controlled source electromagnetics, will be utilised in conjunction with passive seismic methods, including H/V and ambient noise cross-correlation. This multi-disciplinary method can be easily deployed in urban regions to increase the understanding of subsurface structures where legacy datasets are inadequate for geothermal exploration, and also for regions where funding for the collection of new data is limited.

The GEO-URBAN project includes significant local stakeholder involvement to ensure that exploration activities align with local sustainable energy plans and district heating strategies. Furthermore, a review of the current policy and legislation governing the development of geothermal energy systems is being undertaken in conjunction with the geophysics survey programme; this review will conclude with recommendations and examples of policy measures proven to stimulate market growth in other European countries. This will assist the sustainable exploitation of deep geothermal energy resources in each region by increasing awareness amongst stakeholders and policy makers but also by highlighting the barriers towards geothermal development in an effort to de-risk future developments.

The overall objective of GEO-URBAN is to identify the geothermal resources available in two challenging urban locations and to demonstrate a commercialisation strategy that has the potential to be adapted in other similar locations, thus advancing the uptake of geothermal energy in the study locations and emerging markets internationally.

1. INTRODUCTION

This paper will give an overview of the GEO-URBAN project, which began in 2018 with a consortium comprised of ten partner members from three European countries, Ireland, Spain and Denmark (Fig. 1). The study areas of Dublin City, Ireland and Valles, Catalonia, Spain (Fig. 2) were chosen due to similarities in the level of geothermal development, the lack of deep subsurface data and the hard rock characteristics of the target reservoirs. These commonalities are seen regularly in immature geothermal markets across Europe and the rest of the world. Where these study areas differ is climate, reservoir lithologies and national policy. These differences are again common variables among immature geothermal markets and therefore the two study sites are representative of immature geothermal markets with a lack of deep subsurface data globally.

Research into the potential for geothermal exploitation in the study areas has been carried out in the past. With the acceleration of geothermal technologies resulting in the increased applicability of geothermal technologies worldwide, it is becoming feasible to exploit geothermal energy but due to a lack of data, market maturity, governing policy and awareness among stakeholders, a significant uptake in geothermal technologies has not been achievable. The GEO-URBAN project aims to address these issues.

In order to address these barriers to development, the GEO-URBAN project is implementing a multi-disciplinary geophysical survey to help bolster the understanding of the geothermal targets. The project will also be addressing the policy and legislation issues governing the development of geothermal energy systems by undertaking a review of the current situation alongside a review of the policy and legislation in more mature markets in order to understand how the implementation of governing strategies can influence the growth of geothermal industries in these immature markets. Stakeholder engagement is another necessary task in order to increase the awareness amongst policy makers and potential end users of geothermal energy to add increased pressure for the implementation of new policies and legislation as well as incentives and financial frameworks to accelerate the uptake of geothermal energy systems.

The two test regions are comprised of "hard rock" reservoirs, meaning those characterised as having low primary porosity. Dublin City is underlain by Viséan limestone and the Vallés region is underlain by Infra-Silurian and Variscan igneous rocks. The procurement of accurate geological data, and in particular data regarding geological structures, is paramount to the exploitation of these reservoirs. New geological models of each study area are being developed as part of the GEO-URBAN project and the multi-disciplinary survey data is a key dataset in assessing the potential resource at both locations. The identification of potential water-bearing structures at depth will in turn help to de-risk the drilling phase of any future commercial geothermal operations.

Figure 1 GEO-URBAN Project Consortium

Figure 2: GEO-URBAN study locations, Dublin City, Ireland (Left), Vallés Catalonia, Spain (Right)

2. GEOTHERMAL INDUSTRIES IN IRELAND AND SPAIN

The geothermal markets in Ireland and Spain can be characterised as immature. Shallow geothermal heat pump systems dominate the industry with no deep geothermal installations in either country. Deep geothermal research in both regions has built a greater understanding of the potential resources, with deep geothermal potential of both regions having been highlighted in several publications to date (Iñigo et al., 2019; Pasquali et al., 2019).

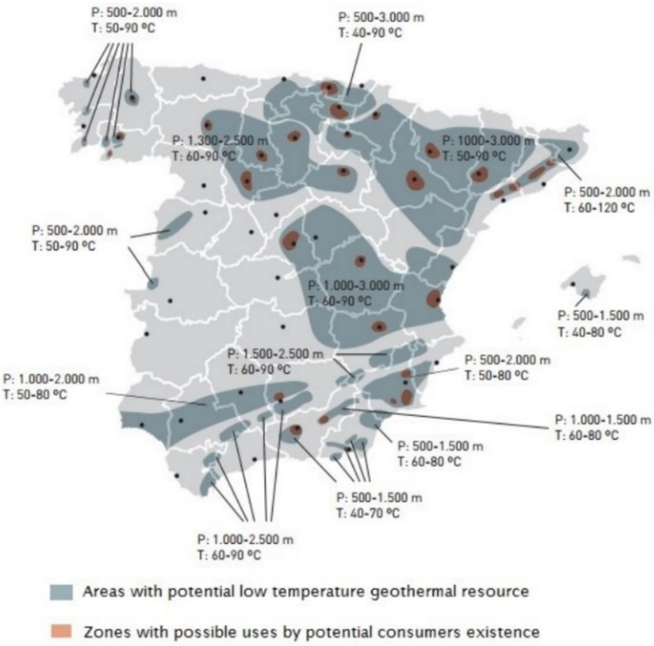

Figure 1 Geothermal Potential of Spain (Iñigo et al., 2019)

In Spain shallow geothermal continues experiencing a steady growth as it becomes more popular and increasingly applicable in building refurbishments. Geothermal for power generation continues to be hampered due to the ongoing regulatory framework discussions and therefore at present, there is no geothermal power generation in Spain. Low-temperature geothermal energy, shallow or very low temperature geothermal energy used for cooling and heating is however already feasible in Spain and it is estimated that from 2019 onwards, several heating and cooling network projects may be launched. The geothermal potential of Spain has been highlighted in the past with low, medium and high temperature resources having been identified (Fig. 3), but given the lack of clear policy and lack of comprehensive subsurface data, no deep geothermal projects have been developed. The GEO-URBAN project will de-risk the barriers to development by addressing these issues (Iñigo et al., 2019).

The exploitation of low enthalpy geothermal resources in Ireland using ground source heat pumps for heating and cooling applications dominates geothermal application at present. Extensive research aimed at furthering the understanding of deep geothermal resources in different geological settings in Ireland has been undertaken. Targets of interest included radiogenic granites, fractured Carboniferous limestones and associated thermal springs, uranium-bearing shales, and Permo-Triassic sandstone reservoirs. Research projects to assess the potential of deep, fractured carbonates and palaeokarst targets have been undertaken as part of the "Irish Carboniferous Palaeokarst" and "HotLime" projects, which focus mainly on the Dublin, Clare and Lough Allen Carboniferous Sedimentary Basins, as well as the Kilmurry prospect in the Adare play, Co. Limerick (Pasquali et al., 2019).

The geothermal sectors in both Spain and Ireland to date have revolved primarily around the shallow geothermal sector, specifically ground source heat pump technology used predominantly in Ireland for domestic and commercial heating and both heating and cooling in Spain. Despite the hurdles to deep geothermal development in both Ireland and Spain, research is ongoing and the potential of regions such as Vallés and Dublin have been highlighted in several studies to date.

The characteristics of hard rock geothermal targets coupled with the energy demand in areas lacking sufficient subsurface data and clear legislative directives is commonplace in emerging geothermal markets. Overcoming these hurdles to development and focusing efforts on de-risking potential future projects is imperative to the growth of geothermal sectors in these emerging markets which to date have been overlooked as economic markets for development.

3. MULTI-DISCIPLINARY METHODOLOGY FOR GEOPHYSICAL SURVEYING

The geophysical surveying program undertaken as part of the GEO-URBAN project involves a multi-disciplinary methodology for geophysical surveying using electromagnetic techniques, including magnetotellurics (MT) and controlled source electromagnetics (CSEM), as well as passive seismic methods, including the H/V technique, array methods, ambient noise cross-correlation and auto-correlation.

Both methods are scientifically innovative in their joint application to geothermal targets, and the project partner teams at the University of Barcelona (UB), Dublin Institute for Advanced Studies (DIAS) and Institut Cartogràfic i Geològic de Catalunya (ICGC) are pioneers in the use of these techniques. These survey techniques are easily deployed and offer a much better cost value over more traditional exploration techniques such as vibroseis.

The CSEM method has become commonplace in offshore hydrocarbon exploration and it has been demonstrated as suitable to be used in other offshore applications such as gas hydrate exploration or geophysical monitoring offshore. Although the underlying physical principles are the same in both onshore and offshore environments, relevant differences exist in terms of surveying methodology and data interpretation. Experimental conditions on land are less advantageous compared with those in marine environments for CSEM exploration; airwave prevalence, inconvenient noise conditions and low penetration of the EM signals in the subsurface all present sub-optimal conditions for CSEM surveying. Nevertheless, novel experimental configurations are being investigated to enhance the sensitivity of the method to deep structures or to improve the signal-to-noise ratio although there are few experiments reported. Researchers at UB have developed and tested an experimental onshore CSEM methodology as well as a data processing flowchart, in the context of the characterisation and monitoring of the reservoir for CO_2 storage. The innovation for GEO-URBAN is the implementation of these previously developed CSEM tools for geothermal reservoir studies in Dublin and Vallès, and to explore their potential as a complementary technique to MT.

Passive seismic techniques will also be applied to the study targets. The H/V techniques proposed by Nakamura (1989) allow us to calculate the depth of the sediment/bedrock interface. It consists of assessing the dominant frequency of the local stratigraphy by calculating the ratio between the amplitude spectra of the horizontal (H) to vertical (V) components of the microtremor recorded at a single station. The use of natural noise sources has now become a standard approach in passive seismology; the urban setting in which this experiment will take place will furthermore imply the presence of additional, anthropogenic noise that will be taken advantage of for imaging the subsurface.

Ambient noise cross-correlation is also an innovative technique that is being applied. Active seismic methods require signals generated by identifiable sources with high precision knowledge of location and "time zero". However, passive seismic methods allow for the extraction of unrecorded signals or wave-propagation properties to analyse seismic ambient noise. This technique consists of recording ambient noise through an array of seismic stations. The noise that we record is generated by multiple sources, ranging from the low-frequency oceanic microseism to the high-frequency anthropogenic signals. These methods have been recently imported from earthquake studies to exploration seismology with an increased number of applications, especially in urban geophysics. In particular, ambient noise cross-correlation relies on the retrieval of Green's Function using cross-correlation between pairs of ambient noise records in different receivers. The capability of this technique to obtain a velocity model of the geothermal reservoir is being tested. Green's Function retrieval using ambient noise correlation theoretically requires noise sources to be homogeneously distributed, while they tend in fact to be geographically localised. Although this can be partly mitigated by long-term observations in the case of natural sources, it may not be the case for those sources of anthropogenic origin. The spatial distribution and frequency characteristics of the noise sources will therefore need to be analysed to ensure theoretical requirements are met.

3.1 Vallés Geophysical Program

3.1.1 Seismic Survey Summary

The targets of seismic surveys in the Valles site are bedrock depth and fault imaging. A combination of H/V and array methods are used to delineate the sediment/bedrock contact. H/V method provides soil resonance frequencies associated with that contact that can be converted into depth using shear-wave velocity profile of the sediments. Up to date 135 H/V stations have been measured in the survey area and three array surveys will be performed in the autumn of 2019. Regarding the second target, high resolution seismic active and passive methods are integrated to obtain both Vp and Vs models of fault structures. Active seismic refraction tomography as well as surface wave analysis are suitable to delineate lateral changes in the first 30-40 m depth. Seismic interferometry is added to increase investigation depth using lower frequency surface waves included in ambient noise. The combination of seismic techniques will allow characterising and imaging fault zones in urban areas.

3.1.2 Electromagnetic Survey Summary

Electromagnetic surveys in the Vallés region began in 2019. This region benefits from having been subject to several previous EM studies carried out by UB in the past. In 2019 for the GEO-URBAN project in particular, two CSEM profiles have been acquired to date (Fig. 4); these latest acquisitions will serve as a good complementary dataset to existing data in the Vallès region.

The magnetotelluric technique images the Vallès fault very well given the high contrast of the electrical resistivity between the rocks and sediments that make up this fault system. Works are in progress to obtain CSEM-MT joint inversions using the MARE2DEM code (Key, 2016) as well as CSEM forward modeling using PETGEM, a novel numerical code (Castillo-Reyes et al. 2019). With the aim of completing the 3D resistivity model based on the MT database, new MT sites will be acquired in the autumn of 2019. Moreover, further CSEM tests will be carried out, allowing us to study the contribution of CSEM data to the MT resistivity models.

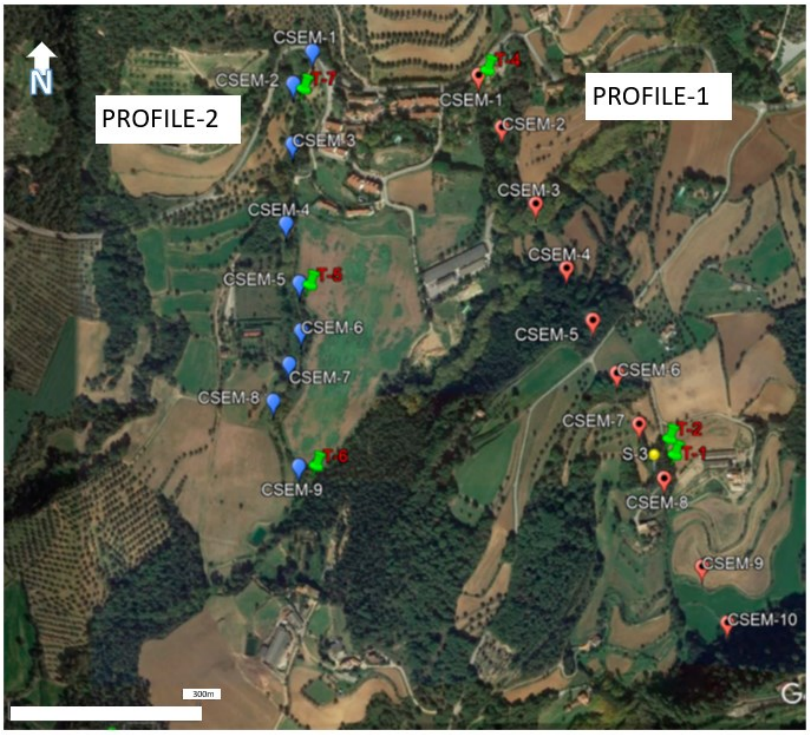

Figure 2 Location of the CSEM profiles in the Vallès region

3.2 Dublin Geophysical Program

3.2.1 Seismic Survey Summary

In early 2019 the initial seismic surveying began in Dublin. This involved the installation of 19 passive seismic monitoring points across the urban center of Dublin City. This task was made significantly easier with the addition of the local council, Dublin City Council (DCC) as project partners. This allowed access to a multitude of different buildings across the city. A review of all available locations was undertaken and an approximate 5x5 kilometer grid was outlined across the city (Fig. 5). The basements of municipal buildings including libraries, fire stations, offices, and community centers across the city were utilised.

The passive seismic stations will be left to record over a period of at least six months. This lengthy acquisition time is best for achieving a homogenous source ideal for the use of the cross-correlation technique.

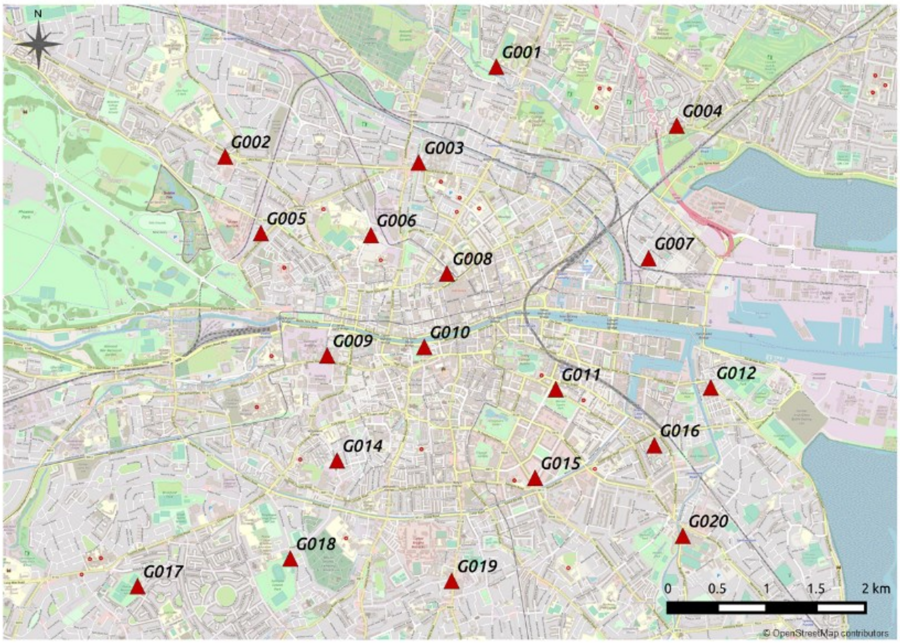

Figure 3 Location Map of Passive Seismic Monitoring Stations in Dublin City

3.2.2 Electromagnetic Survey Summary

EM surveying started in Dublin in early 2019. The first MT data acquisition was undertaken in the Merrion Square Park in Dublin City centre using Phoenix Geophysics equipment, namely MTU-5A recording boxes and MTC-50 induction coils. Magnetic time-series data were simultaneously recorded at a remote reference site about 45 km away. At the site, the two horizontal, perpendicular magnetic field components were recorded, as well as the vertical magnetic field component. The two horizontal, perpendicular electric field components were measured using non-polarising Pb–PbCl (lead–lead chloride) electrodes laid out in a cross with a dipole length of 60 m. This first data acquisition has highlighted some issues with anthropogenic noise in the urban area. The MT time-series, particularly the electric fields, were heavily contaminated and distorted due to electromagnetic noise from Dublin City tram /railway systems and other infrastructure. Since Dublin City is underlain by resistive Viséan limestone, one can anticipate that noise signals have large-scale influence. The next step will involve new MT and CSEM data acquisition within the Dublin Basin during the autumn/winter of 2019. In order to accurately image the subsurface in Dublin City, variable CSEM survey configurations are now being tested.

4. GEOLOGICAL ASSESSMENT

Geological assessment of geothermal targets requires careful integration of existing geological, geophysical, and hydrological information. Pre-drilling studies commonly include the definition of three-dimensional (3-D) subsurface models, incorporating predictions of reservoir and lithological parameters (thicknesses, porosity, permeability, structure, and temperature), and their associated uncertainties.

Stress, structure, and fluid flow are intrinsically linked in fracture-hosted geothermal systems and can be best understood through 3-D geo-mechanical models, which incorporate stress data derived from geological (e.g., borehole and laboratory based), hydrogeological and geophysical constraints. The geo-mechanical models are used to investigate fluid flow heterogeneity in the subsurface, and represent an essential prelude to future drilling development plans and the associated de-risking of well planning and placement.

Data collected during the geophysical survey program will feed directly into the development of new 3-D geological models. These models will build upon existing databases and geological understanding combined with newly collected geophysical survey data. It is anticipated that an increased understanding of the geological structures will give new insight into the potential geothermal targets at both regions. These newly developed geological models will focus on characterizing the nature of subsurface structures that may be controlling the hydrothermal fluids at depth.

An accurate geological conceptual model of a geothermal resource is essential to assess the commercial feasibility of utilising the geothermal energy for heat or power. The development of a roadmap to commercial deep geothermal heating is used to investigate and assess the best commercial path for utilising the geothermal aquifer resources. These resources are proven to offer cheap, secure, low carbon energy solutions for space heating and hot water.

5. POLICY REVIEW AND COMMERCIALISATION STRATEGY

Given the current level of geothermal development in both Spain and Ireland, the GEO-URBAN project will also be undertaking a review of the current legislation and policy governing the development of geothermal energy systems in both regions. It is anticipated that this review will highlight the shortcomings in the current process of geothermal developments. Policy implementation case studies from more mature markets where an acceleration of market growth can be attributed to the implementation of policies and legislation will be reviewed and these will form the basis of recommendations for policy adoption in the study regions and immature geothermal markets globally.

GEO-URBAN project partner GEOOP will be leading this section of the project. GEOOP have extensive experience at all phases of geothermal energy system development and they will oversee the production of a "Roadmap" to geothermal whereby a step by step guide to the commercialisation of the geothermal targets will be developed. In conjunction with the national geothermal associations, The Geothermal Association of Ireland (GAI) and GEOPLAT, the geothermal Roadmap will address all the barriers to geothermal development in each region and provide recommendations for accelerating the development of deep geothermal energy systems.

6. OUTREACH ACTIVITIES

The motivation for the GEO-URBAN project as a whole is to promote the use of geothermal energy systems in immature markets by highlighting and developing a methodology to overcome common barriers to development. Part of this promotional effort involves several outreach activities. To date the GEO-URBAN project has been represented at four national and international conferences to showcase the project's methodologies. Several presentations have been given to local councils and academic institutes to help promote the GEO-URBAN project and geothermal as a whole to key stakeholders within each region.

The outreach activities of the project are a key aspect of driving significant change and increased uptake of geothermal in these immature markets. The inclusion of national geothermal association, GAI and GEOPLAT, as co-operation partners in the GEO-URBAN project helps widen the project's reach to key stakeholders. The national geothermal associations will also be organising stakeholder engagement workshops in both study regions to help disseminate the project findings.

CONCLUSIONS

The GEO-URBAN project is a collaborative innovation project in geothermal energy that brings together an international consortium from Ireland, Spain and Denmark. The project consortium combines industry, universities, research institutes, local planning authorities and non-profit organisations that are actively involved in the development of geothermal energy markets and technologies, and in promoting the potential exploitation of this resource as an alternative energy source to fossil fuels.

The GEO-URBAN project supports the GEOTHERMICA objective to accelerate the demonstration and validation of novel concepts of geothermal energy supply, and to identify paths to commercially viable deployment. Specifically, the project will accelerate the deployment of deep geothermal energy technology in previously undeveloped regions in Europe (i.e., Spain and Ireland) through the demonstration of improved geophysical exploration techniques and modelling methods for assessing the available geothermal energy resources in challenging urban locations situated on "hard rock" reservoirs (granite, metamorphic rock, limestone, etc.). These techniques are demonstrated for two test locations in Dublin City, Ireland and Vallès, Catalonia, Spain, and, as such will showcase an exploration and technology advancement method to help support the growth of geothermal industries in immature markets across Europe and globally.

ACKNOWLEDGEMENTS

This project has been subsidised through the GEOTHERMICA ERA-NET co-fund (Project no. 731117), and has received funds from the European Commission, the Irish Department of Communications, Climate Action and the Environment / Geological Survey Ireland, and the Spanish Ministry of Economy, Industry and Competitiveness / State Research Agency (MINEC-AEI).

This large project consortium is a combination of private businesses, academic institutes, local councils and national bodies. The authorship represents the individuals who contributed to the text of this paper. This paper outlines the work of the consortium as a whole, representatives of which are acknowledged below;

Gavin and Doherty Geosolutions; J. McAteer, J. Clarke, P. Stafford, P. Doherty and S. Blake.

Barcelona Supercomputing; J. de la Puente.

Dublin City Council; S. Cull and V, Coe.

Dublin institute for Advanced Studies; D. Kiyan, G. Maggio, C. Bean, H. Mohamed, Colin Hogg, and Robert Delhaye

GEOOP; J. Baubsgaard, D. Simmons and A. Oliveira.

GEOPLAT; A. Casillas, M. Gregorio and P. Pérez.

The Geothermal Association of Ireland; R. Pasquali.

Institut Cartogràfic i Geològic de Catalunya; B. Benjumea, A. Macau, A. Gabàs, F. Bellmunt and S. Figueras

Irish Centre for Research in Applied Geosciences; J. Walsh, P. Rodriguez Salgado and D. McNamara.

Universitat de Barcelona; P. Queralt, J. Ledo, A. Marcuello, G. Mitjanas, G. Alias, A. Marti and P. Varas-Piña.

REFERENCES

Castillo-Reyes, O., de la Puente, J., García-Castillo, L. E. and Cela, J.: Parallel 3-D marine controlled-source electromagnetic modelling using high-order tetrahedral Nedéléc elements *Geophysical Journal International*. (2019). doi: 10.1093/gji/ggz285

Iñigo, A. et al. Geothermal Energy Use, Country Update for Spain, *Proceedings*, European Geothermal Congress, The Hague, Netherlands (2019).

Key, K.: MARE2DEM: a 2-D inversion code for controlled-source electromagnetic and magnetotelluric data. *Geophysical Journal International,* **207**, (2016), 571-588.

Nakamura, Y. A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface, QR of RTRI, February, (1989), 30, 1, 25-33.

Pasquali, R. et al. Geothermal Energy Use, Country Update for Ireland, *Proceedings*, European Geothermal Congress, The Hague, Netherlands (2019).