N° 47

May 2019

European Geologist

Journal of the European Federation of Geologists

Geology and the energy transition

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We would like to express a particular thanks to all those who participated in the peer reviewing of this issue and thus contribute to the improvement of the standards of the European Geologist Journal. The content of this issue has been reviewed by János Földessy, Steve Henley, Gareth Jones, Győző Jordán, Nenad Maric, Máté Osvald, Manuel Regueiro and János Szanyi.

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Cover photo:
© Tamás Miklovicz (LPRC). Strokkur, Iceland. Strokkur geyser erupts in about every 5 minutes, and it can reach up to 20 meters. It is part of the famous Icelandic Golden Circle. The spectacular geyser shows only a fraction of the vast geothermal potential that lies below, mostly untapped, waiting for the energy transition.

ISSN: 1028 - 267X

Foreword

EurGeol. Vítor Correia, EFG President

"We need an energy miracle."[1]
Bill Gates

Humankind has already experienced three energy transitions[2]. First, humans mastered fire, which allowed us to liberate energy from the sun by burning wood. Second came farming, which converted and concentrated solar energy and muscle power (from animals and humans) into food. Third came industrialisation and, with it, the rise of fossil fuels. Coal, oil, and natural gas in turn rose to prominence, and energy production became the domain of power plants.

We are now on the verge of the fourth energy transition[3]: a move to energy sources that do not emit carbon dioxide and a return to relying on the sun's and earth's current energy flows. This will curb CO_2 emissions and may have a positive impact on climate change. But the transition will take several decades[4]: existing technologies have high inertia; the world energy consumption is growing fast; and despite considerable investments to promote renewables, coal, oil, and natural gas still supply 90% of the world's primary energy[5].

There are, however, two factors that can hasten the fourth energy transition. One is a breakthrough in energy storage. Research labs, universities and manufacturers are exploring innumerable options to produce cheaper batteries with a larger lifetime and more energy density, using a diverse array of materials[6] that include ionic ceramics, carbon, aluminium, sodium, sulphur and (of course) lithium, in all sizes, from the smallest applications such as button cells to large stationary systems such as redox-flow batteries (water-based).

The other factor that can speed the energy transition is a change in consumer behaviour. I'm generally sceptical of people's capacity to change, but I must recognise that the new generation can make a difference. Greta Thunberg, a frail Swedish girl aged 16, kicked off last March the most prominent environmental protests the world has ever seen[7]. Since then she has been lauded at the UN, met Emmanuel Macron, shared a podium with Jean-Claude Juncker and has been endorsed by Angela Merkel.

We now have two beacons of hope for a faster energy transition and a better world future: researchers and the new generation.

1 Interview given by Bill Gates to *The Atlantic* magazine, published in the November 2015 issue, retrieved from ***https://www.theatlantic.com/magazine/archive/2015/11/we-need-an-energy-miracle/407881/***.

2 Smil, V. (2010). *Energy Transitions: History, Requirements, Prospects*. Praeger: Santa Barbara, CA.

3 In between we had the failure of nuclear power, the energy source densest in power, hindered because of its risks and public opposition.

4 A crude example presented by Vaclav Smil in an interview with *Science* in 2018 shows that our perception on the adoption of renewables is often biased. He points out about wind turbines that the foundations of wind turbines are dug with heavy equipment powered by oil, the concrete is made in kilns fired with natural gas, and the steel towers are forged with coal. Full interview retrieved from ***https://www.sciencemag.org/news/2018/03/meet-vaclav-smil-man-who-has-quietly-shaped-how-world-thinks-about-energy.***

5 The dependence has grown in recent years compared to 2000, when nuclear and hydropower had a bigger contribution to the energy mix. Source: ***https://ourworldindata.org/energy-production-and-changing-energy-sources***

6 Lithium, graphite, cobalt and nickel are the main raw materials used today in lithium-ion batteries, and the investments made in mineral exploration projects targeting these minerals are huge. But this will probably change in the short term, because cheaper batteries with a longer lifetime and more energy density will possibly use other raw materials.

7 Greta Thunberg started to sit down in front of the Swedish parliament back in September 2018. The movement then quickly spread across Sweden, Belgium, Germany, and then Australia and other parts of the world. In March 2019 students from 700 cities in 71 countries engaged in the Global Climate Strike. More information in Watts, J. (2019, March). How a 16-Year-Old Girl Started a Global Climate Protest. Wired. Retrieved from ***https://www.wired.com/story/a-teen-started-a-global-climate-protest-what-are-you-doing/***

P.S.: This is my last foreword in the *European Geologist* Journal. I will step down at the next Council meeting, after six years as President of EFG. I have been afforded the privilege of serving with a team of enthusiastic and talented colleagues in the EFG Board and Office, and I want to thank all of them for the immeasurable professionalism, energy, enthusiasm, commitment and joy they put into the running of EFG and the discharge of their duties. The EFG Board, with Marko Komac as President, is strong, experienced and capable of taking EFG to a superior level, and EFG is in good shape, having a clear mission, resources to advance initiatives and growing membership. I wish the EFG Board and Office, and you, all the best.

Exploration of flooded mines as support to the battery industry and the energy transition in Europe

Giorgia Stasi, Isabel Fernandez and Yves Vanbrabant*

The transition to renewable energy needs minerals to build wind, solar, and battery technology for energy production and storage. In order to help the development of this sector and to maintain and enhance the possibility of the EU to become more independent from the import of raw materials we need to improve the research activity for both known and undiscovered mineralization. For this purpose, the UNXEMIN project is developing autonomous submersible robots to explore, map and characterize abandoned flooded mines in Europe. Along with robot development, the first inventory of flooded mines in Europe has been created, that now contains more than 8,000 entries from 24 countries. This database can be used in the European industrial framework as a resource for research in specific critical raw materials.

La transition vers une énergie renouvelable nécessite des minéraux spécifiques pour la mise en œuvre de technologie basée sur l'éolien, le solaire et les batteries, capable de produire et stocker cette énergie renouvelable. Pour aider au développement de ce secteur et maintenir et accroître la possibilité, de la part de l'Europe, de s'affranchir au mieux de l'importation de matières premières, nous avons besoin d'optimiser nos activités de recherche concernant à la fois les minéralisations connues et celles à découvrir. Pour cela, le projet UNEXMIN a construit des robots submersibles autonomes pour explorer, cartographier et caractériser les mines européennes abandonnées et inondées. Tout en développant ce robot, un premier inventaire des mines inondées en Europe a été établi et contient aujourd'hui plus de 8 000 noms, fournis par 24 pays. Cette base de données peut être utilisée dans le cadre industriel européen en tant que ressource pour la recherche de matières premières spécifiques et critiques.

La transición energética hacia energías renovables, necesita minerales para desarrollar instalaciones eólicas, solares y baterías con el fin de producir y almacenar energía. Para potenciar el desarrollo de este sector, mantener y mejorar las probabilidades de independencia energética de la UE en lo que respecta a importaciones de materias primas; hay que mejorar la investigación tanto en minería conocida como no descubierta. Por este motivo, el proyecto UNEXMIN está desarrollando robots autónomos y sumergibles para explorar, mapear y caracterizar minas abandonadas e inundadas en Europa. Además del desarrollo del robot, ha sido creado el primer inventario de minas inundadas en Europa, el cual contiene más de 8000 emplazamientos en 24 países europeos. Esta base de datos puede ser usada en el marco industrial europeo como recurso para la investigación en materias primas críticas.

UNEXMIN as support to the battery industry in Europe

The UNEXMIN project is developing autonomous submersible robots to explore, map and characterize abandoned, underground flooded mines in Europe. These robots will be able to map and sample underground flooded mines at up to 500 m depth. But how can the UNEXMIN project help Europe in the energy transition?

The transition to renewable energy needs wind, solar and battery technology, which require a lot of minerals. Renewable ener-

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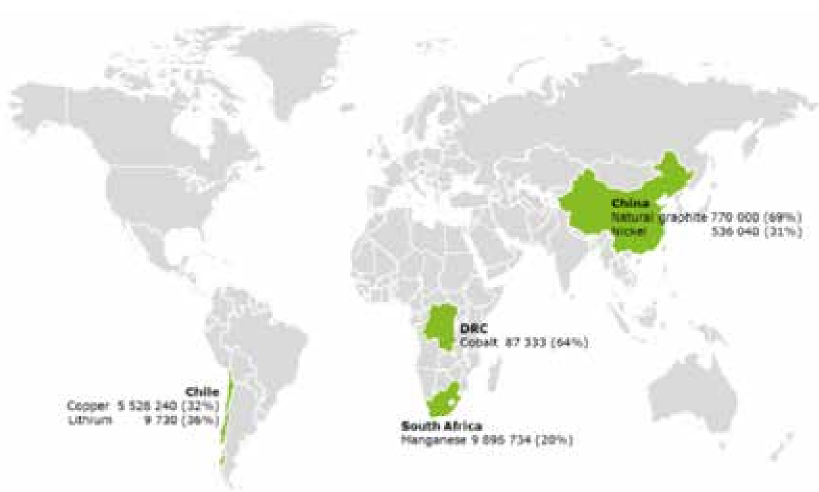

Figure 1: Countries supplying critical raw materials for batteries, amount (tonnes) and percentage of global supply (from EC SDW (2018)).

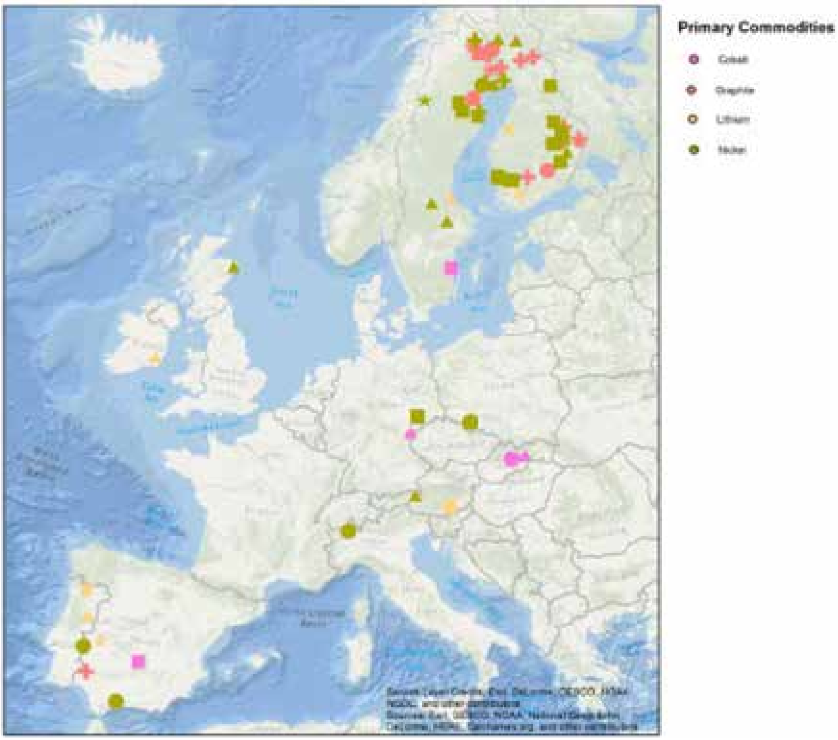

Figure 2: Status of mineral exploration activities for cobalt, graphite, lithium and nickel in 2017 (from EC SDW (2018)).

gies like water, solar and wind power are often not continuously available, so efficient interim storage is necessary to ensure a steady supply of power. Battery storage systems are an advantageous option in this regard. The EU is highly dependent on imports of metallic minerals, as its domestic production is limited to about 3% of world production (COM (2008) 699). One of the main goals of Europe is to reduce the dependency on the import of raw materials and solve issues along the entire value chain. This project could steer the EU to the forefront in sustainable minerals surveying and exploration technologies; it can increase Europe's capacity to re-evaluate its abandoned mines for their mineral potential, with reduced exploration cost and increased investment security for any future mining operations (Lopes *et al.*, 2017).

Battery development and production is a strategic imperative for Europe in the context of the clean energy transition. There is a strong need to create competitive and sustainable battery manufacturing in Europe. Working towards this goal, the European Commission is promoting a cross-border and integrated European approach covering the whole value chain of the battery ecosystem and focusing on sustainability, starting with the extraction and processing of raw materials, the design and manufacturing phase of battery cells and battery packs and their use, second use, recycling and disposal in a circular economy context. The Strategic Action Plan on batteries (COM (2018)293 Annex 2) combines targeted measures at EU level including the areas of raw materials (primary and secondary), research and innovation, financing/investment, standardisation/ regulation and trade and skills development. The aim is to make Europe a global leader in sustainable battery production and use, in the context of the circular economy. More specifically it aims to facilitate access to European sources of raw materials and to secure access to raw materials from resource-rich countries outside the EU (COM (2008) 699). The policy is also based on sustainable domestic raw materials production and resource efficiency and supply of secondary raw materials.

Critical raw materials for batteries

At present, optimised LIB (Lithium Ion Batteries) cells represent the core technology for energy storage. The supply of critical raw materials for LIB is ensured by working along three routes: sourcing from third countries developing domestic sourcing; and promoting recycling of battery materials as well as reuse of batteries. The sourcing of the four essential raw materials (cobalt, lithium, nickel and graphite) is concentrated in only a few countries (***Figure 1***). The Democratic Republic of Congo is the source of 64% of the global supply of cobalt and Chile is the main supplier of lithium with 36%.

In the EU countries Finland is a major supplier of refined cobalt (it meets 66% of EU demands for ores and concentrates); however, the extent of domestic sourcing of EU demand is very limited for the other materials (nickel and lithium) (COM (2018)293 Annex 2).

In order to help the development of this sector and to maintain and enhance the possibility of EU to become more independent from the import of raw materials, an improvement in research activity for known and undiscovered mineralisation of the targeted materials (cobalt, lithium, nickel and graphite) is needed and expected.

The current status of mineral exploration activities for battery applications is shown in ***Figure 2*** (EC SWD(2018)); activities remain concentrated in Portugal, Finland, Sweden and Central Europe.

UNEXMIN inventory of flooded mines as a research tool

In the UNEXMIN project, along with the robot construction, project participants are carrying out a comprehensive inventory of underground flooded mines in Europe. The total number of flooded mines in Europe is still unknown. Depending on the definition (e.g. fully developed mine on an industrial scale versus artisanal medieval mining site or individual mine versus mining district), estimations range from ≈5,000 to >30,000 mines in Europe (ISRM 2008) but no comprehensive dataset has been available up to now.

In order to gather relevant data for the open-access database of UNEXMIN, information about flooded mines has been systematically collected by 15 national associations of the European Federation of Geologists (EFG) and by the Geological Survey of Belgium (RBINS-GSB). The data were retrieved through the review of existing datasets (ProMine, Minerals4EU), desk research and automated approaches (manual data extraction and automated data web-crawling). As the information related to the abandoned mines in Europe is mostly spread among different authorities, associations or publications, the quantity and the quality of the recovered information varies from country to country and from mine to mine.

UNEXMIN's inventory currently covers ~8,100 mines from 24 countries (D5.4, 2018) (***Figure 3***) and contains information about the mine name(s), its location, its

Figure 3: Web interface of the UNEXMIN database.

accessibility, the extracted commodities, the geological information related to the available maps and sections, the classification of the deposit, the ownership, the activity level, the potential legal restrictions and other useful information. This new open-access database could be used as a research tool to identify abandoned mines that could potentially be re-opened in the future.

Through the web interface of the UNEXMIN database it is possible to select all of the flooded mines with the targeted minerals as commodities (***Figure 4a***). At this current stage we count a total of 72 mines of Li, Co, and Ni as principal or secondary commodities in 10 countries (***Figure 4b***).

For each mine we have information about the deposit type, the geology of the area, the water level, the distance from the nearest road, the mine size and the year of the closure. The majority of the mines were closed at the end of the 19th century or in the middle of the 20th century, mostly due either to economic reasons or exhaustion of the principal commodity.

Czech Republic

One deposit of nickel as a secondary commodity has been found. This is a syn-deformational hydrothermal and replacement deposit. The mineral resource was considered exhausted in 1978 but now new exploration can be planned with the brand-new exploration technology.

Finland

As the primary commodity 5 nickel mines, 11 nickel and cobalt mines have been identified, plus 2 cobalt mines as secondary commodity. Except for one nickel-cobalt deposit of hydrothermal origin, all the other deposits are of magmatic origin. The two cobalt deposits are volcanogenic massive sulfide (VMS) deposits, one nickel deposit is associated with komatiite, and the others are VMS or synorogenic Ni-Cu deposits in (ultra)basic intrusions.

Germany

In Germany 24 underground flooded mines have been found, of which 8 contain lithium, 8 cobalt, 4 nickel and 4 nickel-cobalt. The lithium deposits are of magmatic, hydrothermal and metasomatic origin: these are porphyry-associated deposits, pegmatitic deposits and skarn deposits. The cobalt deposits are of hydrothermal origin, and the nickel deposits are VMS, a layered mafic-ultramafic intrusion deposit and a deposit with marine-sedimentary origin. The deposits with both nickel and cobalt as principal commodity are classified as porphyry-associated deposits and fractioned granitoid-associated deposits.

Italy

In Italy 7 nickel mines and 1 nickel-cobalt mine have been found. These deposits have magmatic origin.

Poland

One nickel mine has been identified in a lateritic-nickel-cobalt deposit.

Portugal

In Portugal there are 3 lithium mines: 2 of magmatic origin, a syn-deformational hydrothermal and replacement deposit and a pegmatitic deposit; and 1 fractionated granitoid-associated deposit.

Serbia

In Serbia a skarn deposit with cobalt as a secondary commodity has been found.

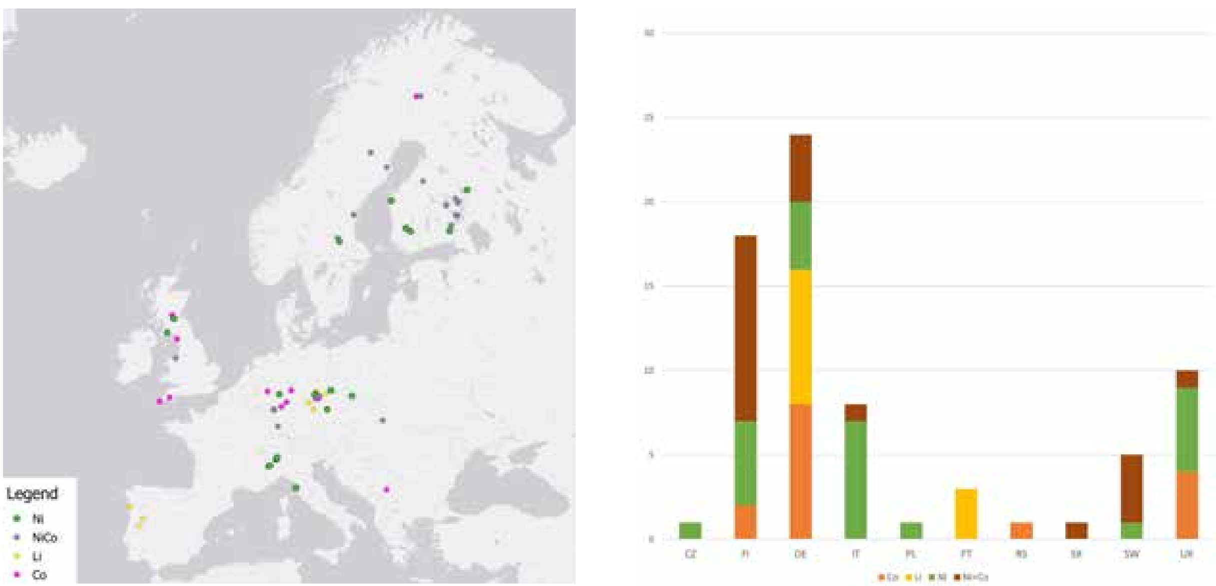

Figure 4: Selection of UNEXMIN mines for the EU battery industry: a) map distribution of the mines, b) graph distribution of the mines by mineral and country.

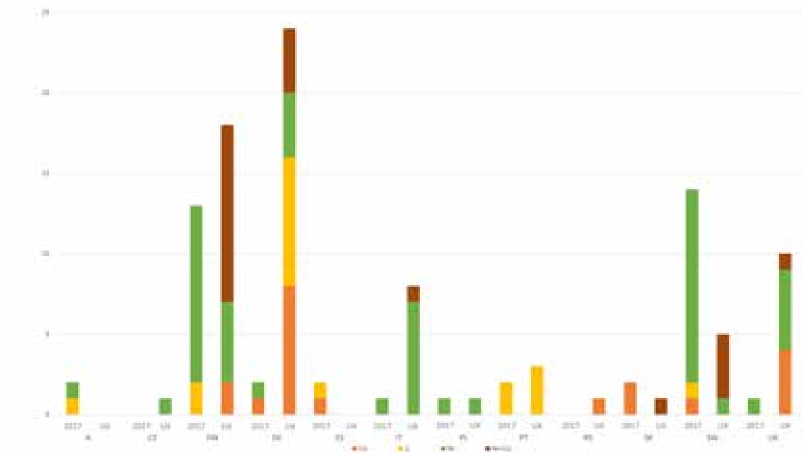

Figure 5: Distribution of mines among European countries, comparison of selected UNEXMIN database (UX) results and the status of mineral exploration activities in 2017 (EC SDW (2018)). The selected UNEXMIN mines are closed or abandoned but can be reconsidered for future exploitation after further study.

Slovakia

In Slovakia there is a layered mafic-ultramafic intrusion deposit with nickel and cobalt as primary commodities.

Sweden

In Sweden there are 4 nickel-cobalt mines and 1 mine of nickel. One nickel-cobalt mine is located in a VMS deposit while the others are associated with komatiite, as is the nickel mine.

UK

A total of 4 cobalt mines, 5 nickel mines and 1 nickel-cobalt mine have been found in the UK. All these mines are in vein type deposits of hydrothermal origin.

Conclusion

Figure 5 graphically represents the UNEXMIN data and the exploration activities in 2017 (EC SWD(2018) 245/2)[1]. Comparing this graph and the maps (***Figures 2 and 4***) it is possible to notice that, while in most of the countries the number of exploration activities in 2017 reflect approximately the closed or abandoned mines listed in the UNEXMIN inventory, in Germany there could be the possibility to expand the exploitation of cobalt, lithium and nickel. As the UNEXIM database is currently being updated it is not possible to compare figures for France or Spain, but preliminary results suggest that a similar situation will emerge for France.

Many of these mines may still contain profitable quantities of raw materials. The main reason for the closure or the abandonment of the mines was economic: the technology and the methods used for mineral extraction were too expensive and it was more convenient to import the necessary raw material from other countries (e.g. Chile, Congo, China, etc.). With the geological information, the deposit classification and the last owner's data, the UNEXMIN database is a potentially important research tool for the initial estimation and identification of potential sites for future exploitation for the battery industry.

Nowadays, with the development of new mining and refining technologies, mines that were considered no longer exploitable for economic and technical reasons at the time of closure can be re-contemplated and re-evaluated in order to reduce the dependency of Europe on the import of raw materials.

The UNEXMIN submersible robot can be used in the study of potential sites. It is able to explore and map underground flooded mines and to provide useful data for the mining industry with its scientific instrumentation. The scientific equipment includes a water sampler, a conductivity and pH measuring unit, a sub-bottom profiler, a magnetic field measuring unit, UV fluorescence imaging and multispectral imaging units (Lopes *et al.*, 2017). It is hoped that the UNEXMIN database and robot will both contribute to expansion of the battery industry in Europe.

1 Austria did not participate in the UNEXMIN project. Spanish data are under update and at the time of writing there is no mine that fit the research criteria for the battery industry.

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Co-production of clean energy and metals – the CHPM concept

*Éva Hartai[1], Tamás Madarász[1] and the CHPM2030 Project Team**

CHPM2030 is an EU-funded H2020 project with the strategic objective to develop a novel technological solution that can help satisfy the needs for energy and strategic metals in a single interlinked process. In the CHPM technology vision, an enhanced geothermal system (EGS) will be established in a deep-seated (4 km or more) metal-bearing geological formation. By leaching metals from the mineralised rock body and recovering them at surface, the co-production of energy and metals will be possible and may even be optimised according to market demands.

Le projet CHPM2030 dérive du projet européen H2020 avec, comme objectif stratégique, le développement d'une solution technologique nouvelle qui puisse satisfaire les besoins en énergie et en métaux stratégiques à partir d'un procédé associé unique. Dans l'approche technologique CHPM, un système géothermal optimisé sera mis en place au sein d'une formation minéralisée située à grande profondeur (4 kilomètres ou plus profond encore). Par lessivage des métaux à partir du corps rocheux minéralisé et leur récupération en surface, la production combinée d'énergie et de métaux sera possible et pourra même être optimisée selon la demande du marché.

CHPM2030 es un proyecto financiado por el programa europeo H2020 con el objetivo estratégico de desarrollar una solución tecnológica y novedosa que pueda ayudar a satisfacer las necesidades energéticas y de metales estratégicos mediante un proceso interconectado. En la visión tecnológica de CHPM, será establecido un sistema de mejora geotérmica en un dispositivo metálico profundo (4 km o más), emplazado en una formación geológica. Por filtración desde el cuerpo rocoso mineralizado y posteriormente recuperado en superficie; la co-producción de energía y metales será posible y podría incluso ser optimizada de acuerdo con las exigencias del mercado.

Introduction

The European Commission actively promotes research and development on enhanced geothermal systems (EGS). The main problems related to these systems are improving the efficiency of the underground heat exchanger, increasing the economic lifetime of EGS plants and lowering capital and operative costs. With the recovery of metals from the geothermal fluid, the CHPM technology can contribute to the solving of these problems. The technology is worked out in the frame of the European Union's Horizon 2020 project 'CHPM2030 – Combined Heat, Power and Metal extraction from ultra-deep ore bodies'. The project started in January 2016 and runs for 42 months, but aims to initiate pilot plants by 2030.

In the envisioned technology, an engineered geothermal system is established within a metal-bearing geological formation at depths of 4 km or more, which will be manipulated in such a way that the co-production of energy and metals will be possible (***Figure 1***). Critical to this is the understanding of the natural networks of hydraulically conductive mineral veins that could function as heat-exchange surfaces and sources of metals. If metals can be leached from the orebodies in high concentrations, and over a prolonged period of time, then their recovery may substantially influence the economics of the engineered geothermal systems. Furthermore, leaching of metals from subsurface pathways in a controlled way has the potential to improve fluid flow, and so increase system performance over time.

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Identification of the geological setting

When planning the establishment of a CHPM system, first the applicability of the technology in the given area has to be examined. Working with the tools of geophysics, geology, geochemistry, hydrogeology, rock mechanics and geoenergetics, the boundary conditions for both energy and potential for metal recovery have to be defined.

In the early phase of the project, the four major European metallogenic provinces were reviewed, which correlate with the larger tectonic zones. The focus was on the EGS potential of the main ore deposit types within the provinces. The prospective zones or formations for the CHPM technology were assessed in each metallogenic province (Hartai *et al.*, 2016). The most appropriate settings are:

1. Magmatic-hydrothermal mineralisations associated with intrusive bodies, as the mechanical properties of the mostly granitic host rocks are appro-

priate for drilling and maintaining open fracture systems allowing fluid transport.

2. Basins in rift or subduction zones, where mineralised horizons form as a consequence of submarine volcanism and exhalation. Such mineralised formations may be relatively thin, but with large lateral extension.
3. Deep-rooted fault zones, with larger extension and elevated heat flow. Shallow level hydrothermal ore deposits in this environment often originate from remobilisation of metals of an earlier mineralisation. These deposits may indicate a deep-seated fertile rock body, which can have a potential for further leaching (Németh *et al.*, 2017).

Metal mobilisation

Leaching tests were carried out at the British Geological Survey and at the University of Szeged. The rock and ore samples for the tests were collected by the project partners and represent the four study sites: the Cornubian Ore Field (SW England), the Banatitic Magmatic and Metallogenic Belt (Romania), Norrbotten and Skellefte mining districts (Sweden) and the Iberian Pyrite Belt (Portugal). The collection was completed by different ore types from Hungary.

A key aspect of the CHPM2030 concept is that metals can be transported in solution in rock bodies and extracted at the surface. The extraction process is more efficient with higher dissolved metal concentrations, but too large a dissolved load may lead to problems of precipitation within production boreholes or surface infrastructure. Thus, the potential for recovering more metals should be balanced against increased maintenance operations. Environmental aspects also have to be considered when additives to the geothermal fluids are used as 'mild' leaching agents. The leaching experiments conducted within the project were aimed at testing a range of possible additives in terms of their leaching behaviour in several different types of mineralised rocks.

The rock types contained different ore minerals, though all were dominated by sulphide mineralisations. These were exposed to and reacted with a range of leaching solutions that included deionised water, tap water, dilute brine (0.6 M sodium chloride), de-ionised water with 20 bar P_{CO_2}, 0.1 M ethylenediaminetetraacetic acid (EDTA),

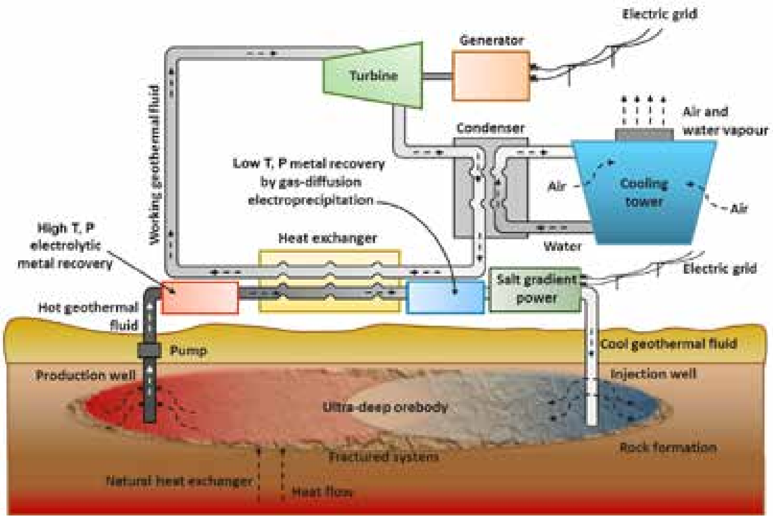

Figure 1: Schematic overview of the envisioned CHPM facility. © CHPM2030 Team.

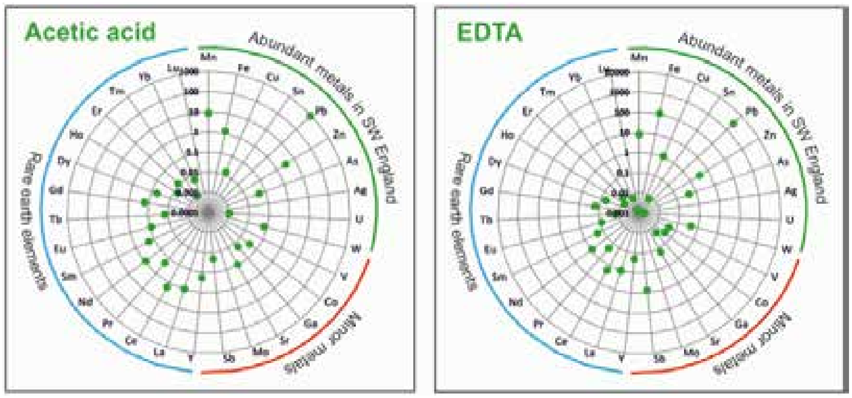

Figure 2: Amounts of metals released after 4 weeks of reaction at 70 °C. The centre of each plot represents 0 ppm, and the outer part of the plot 1,000 ppm (left) and 10,000 ppm (right) for dilute acetic acid or dilute EDTA solution (Kilpatrick et al.*, 2017).*

0.1 M acetic acid, 0.1 M sodium dodecyl sulfate (SDS), 0.1 M ammonia (NH_3), 0.1 M hydrogen peroxide (H_2O_2), 0.1 M hydrochloric acid (HCL) with 0.03 M nitric acid (HNO_3), and 0.01 M hydrochloric acid with 0.003 M nitric acid.

Three types of experimental equipment were used for the leaching tests at the premises of the British Geological Survey. A rotating mixing assembly holding up to twenty 250 ml HDPE bottles filled with approximately 200 ml of leaching solution and 5 g of granulated ore. This equipment was maintained at 70 °C inside an oven and used to test the reactions of the ore samples with a wide variety of different leaching solutions.

1. Titanium or PTFE-lined stainless-steel autoclaves, which held approximately 330 ml of leaching solution and 8.8 g of granulated ore. These were stirred periodically, rather than continuously, and ran at 100 °C, 150 °C and 200 °C and at 20 MPa pressure.
2. Titanium-lined Dickson-type rocking autoclaves, which held 200 ml of leaching solution and 5 g of granulated ore. These were run at 200 °C and 20 MPa pressure.

The elevated temperatures and pressures of the latter two types of experiments make them more representative of in-situ conditions within an ultra-deep metal enrichment. Most experiments ran successfully for approximately 4 weeks. Analytical data were obtained from samples of solution and solids extracted at the end of the experiments, though certain experiments were subsampled more regularly to provide time-series data.

The mixture of mineral acids was the most effective solution used for liberating a range of metals; however, solutions containing organic compounds (EDTA, acetic acid, SDS) also proved effective (***Figure 2***).

EDTA and SDS (like mineral acids) led to higher concentrations of dissolved aluminium and silica, whereas acetic acid did not. This could be an advantage, as lower concentrations of aluminium and silica would tend to disfavour clay formation - clays could potentially occlude fluid flow if they formed within flow zones. Oxidation reactions were critical in breaking down sulphide minerals, and experiments with more oxygen appeared to result in more dissolution. Where $Fe3+$ ions stay in solution, their formation (e.g. from chalcopyrite or pyrite dissolution) appears to be key in enhancing the rates of dissolution of other sulphide minerals – largely because $Fe3+$ can act as a very effective oxidising agent and catalyse sulphide oxidation reactions.

Sulphide oxidation produced acidity, and whilst this might benefit metal mobility, it may lead to corrosion issues for well linings and surface infrastructure. Reaction of this acidity with carbonate or aluminosilicate minerals was observed, as evidenced by dissolution features such as etch pits. Such reaction of gangue minerals in fractures or minerals in the wallrock has the potential to buffer fluid pH to more neutral values, though reaction types will be site-specific (Kilpatrick *et al.*, 2017).

Experiments on the use of carbon nanomaterials for metal mobilisation were performed at VITO. This included the modification of selected materials for improved metal sorption selectivity/capacity under different temperature and pressure conditions (i.e. towards targeted recovery of individual metals). One of the findings was that functionalisation of the carbon nanoparticles changed the nature of the sorption performance. In some cases this resulted in lower overall sorption, but metal sorption occurred over a broader pH range, which might facilitate metal capture over a wider range of natural environments (Mullens *et al.*, 2018).

Recovery of metals from the geothermal fluid

Metal recovery experiments were carried out at two sets of conditions: by high pressure, high temperature electrolysis and at lower pressure and temperature, with gas-diffusion electroprecipitation and electrocrystallisation.

High pressure, high temperature electrolysis

Experiments on high pressure, high temperature electrolysis were conducted at KU Leuven. During the metal recovery process, the first step is the exploration of the technical feasibility of extraction of the leached metals from the solution phase using electrodeposition at high pressure and high temperature conditions of the brines emerging from the geothermal wellhead. Metal ions present in the leachate can be reduced onto a substrate by passing current to drive the electrode to a potential lower than the reduction potential of the metal. Additionally, the high pressure also prevents silica from precipitating further in the reactor, which can potentially interfere with the metal electrodeposition. Based on potential-pH diagrams developed at elevated temperatures and pressures for several metals of interest (Cu, Ag, Ni, Sn, Pb and Zn), Cu was chosen as the primary metal of interest.

In the reactor, mesoporous platinum deposits on a Pt disk were achieved with pore size ranging between 5 nm and 10 nm. The electrodes showed a rapid and stable potential response. Additionally, the stability of the electrode with temperature was confirmed. Cyclic voltammograms indicated that the electroreduction of Cu^{2+} ions and subsequent electrooxidation of Cu in aqueous medium at pressures of 5 MPa behaved similarly as that at atmospheric pressure. However, SEM images indicate that the electrodeposits at elevated pressures are denser and closely packed. As expected, at temperatures greater than 100 °C and elevated pressures, the cyclic voltammograms exhibited currents that were at least 10 times higher than those obtained at room temperatures. Additionally, the deposit morphology at 100 °C does not exhibit the crystalline-type deposit observed at room temperature, instead displaying a layered deposit which was rather scattered and porous (Fransaer *et al.*, 2018).

Gas-diffusion electroprecipitation and electrocrystallisation

Experiments on gas-diffusion electroprecipitation and electrocrystallisation (GDEx) were carried out by VITO in a flow-by three-chamber electrochemical cell. Platinum was used as a counter anode, and a gas-diffusion electrode was used as the working cathode (***Figure 3***).

It was observed that temperature affects the performance of the system, and since the brine treated by the GDEx technology can be within 20-60°C, this parameter was evaluated in the system, first using simulated brines. The most important effects of temperature within this range concerned the formation of different products, variations on the system resistance, processing time, level of current, and process efficiency. The long-term performance under these conditions was also assessed. Based on the relevant brine compositions obtained from the literature study, experiments with simulated Li Al brines were conducted, as well as with real brines containing these metals (i.e., Romanian geothermal brines). The formation of mixed metal hydroxides was obtained, which have ample commercial relevance. Recovery of Li and Al was demonstrated using the GDEx process. However, a more in-depth analysis is needed to evaluate the process and how the varied parameters can affect it. The feasibility of employing microbial-electrochemical systems (i.e., bioanodes coupled to GDEx cathodes) was also tested, proving that

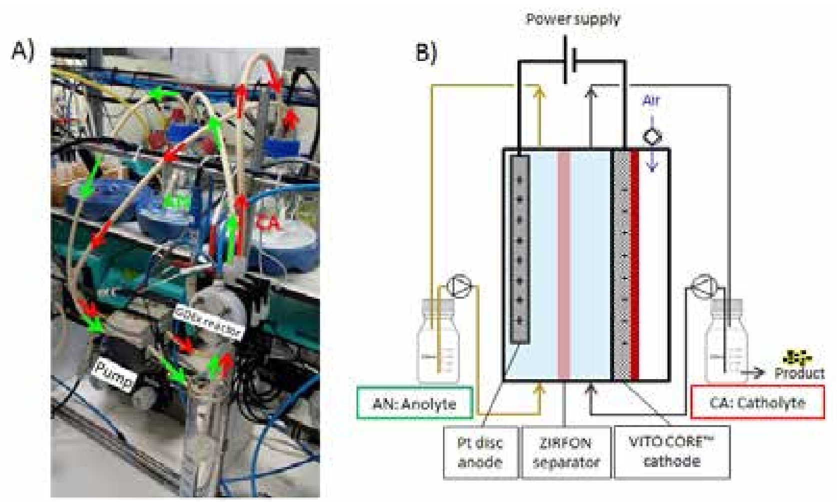

Figure 3: Schematic diagram of the gas-diffusion electroprecipitation and electrocrystallisation (GDEx) technology for metal recovery from geothermal brine:. (A) setup used for experiments and (B) schematic diagram of the experimental setup (Dominquez-Benetton et al.*, 2018).*

Figure 4: Semi-pilot setup for salt gradient power generation by reverse electrodialysis (SGP-RE) experiments (Photo: Joost Helsen)

the GDEx system could be operated with lower or negligible power consumption, or could even be used for the co-generation of electricity. Overall, the GDEx process is two- to three-fold more economical than classical mineral processing at the metal concentrations of geothermal brines and its upscalability is feasible (Dominquez-Benetton *et al.*, 2018).

Salt gradient power generation

The CHPM project concept involves the feasibility assessment of extracting surplus electrical energy from the geothermal brine. Chemical energy is stored in the brine in the form of dissolved salts. This energy can be tapped using a process called 'reverse electrodialysis'. Reverse electrodialysis (RE) has been tested at a pilot scale for river water, sea water and concentrated brine applications. Extracting salt gradient power (SGP) from geothermal brines is a new concept, launched in this project. A specific lab-scale setup to test a single cell pair SGP-RE system was designed and built for investigating the applicability of the process (***Figure 4***). Four steps were taken to elucidate the most important factors influencing the performance: (1) examination of the performance of three commercially available membrane pairs, (2) effect of increased temperature, (3) effect of multivalent ions and (4) combined effect of multivalent ions and increased temperature.

The experiments at increased temperature showed a very clear benefit of using geothermal brines at 60 °C or even higher. The power density at high temperatures increased 10 times compared to the tests at room temperature, even though the cell potential was less than expected due to deteriorating permselectivity at high temperatures (Helsen *et al.*, 2018).

System dynamics

The consortium identified the main technological elements of the CHPM system at a rather early stage of the project and then began to conceptualise the system's behaviour and identify a set of design parameters for plant operation. The seven distinct technological elements of the proposed CHPM plant are as follows (***Figure 5***):

1. Underground heat exchange, metal mobilisation
2. Production wells
3. Electrolytic metal recovery
4. Heat exchanger
5. Gas diffusion electrocrystallisation
6. Salt gradient power generation
7. Injection wells

The critical technical conditions that must be met for the technology to be operational are the design parameters. The availability of these parameters is problematic, especially for those technology components that are in the early laboratory testing phase. Even if lab-scale systems run under well-constrained conditions, it does not necessarily mean that these exact conditions will exist during the full-scale operation, or that the full range of these parameters will be known.

Design parameters provide useful information on the operability of the single CHPM technology building blocks; by comparing them one can retrieve the first hints on a crucial question of the CHPM innovation undertaking, namely the compatibility of these elements. The CHPM2030 project promises a technology to be framed together from engineered concepts that have never before been connected into a system. The identification of the parameters and the integration of the technological components into one operable CHPM system will be worked out by the end of the project.

Ongoing and further activities

Recent activities by the consortium are focused on establishing the mathematical models of the single technology elements. These technology components are at different TRLs (Technology Readiness Levels): some of them are at lab scale, while others

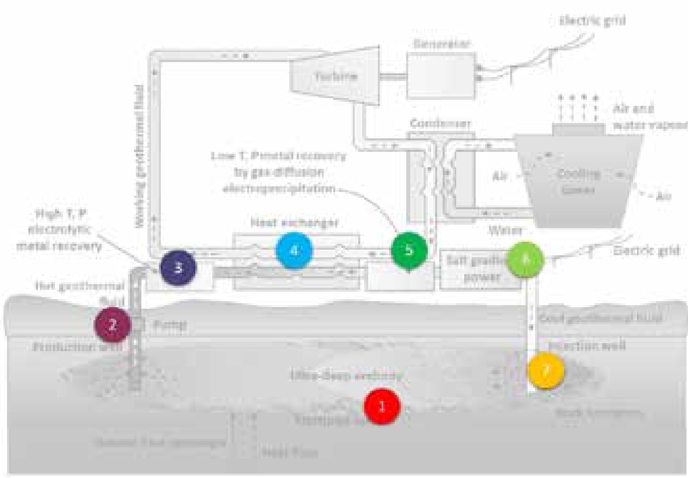

Figure 5: Components of the CHPM technology loop (Madarász et al.*, 2017).*

are capable of being upscaled. After the harmonisation of the components data, they will be connected to create the dynamic system model for various operational scenarios and potential pilot site operations.

The integrated assessment of the sustainability of the technology is also ongoing and will provide results by the end of the project. The framework for the complex assessment and the methodology for the economic feasibility assessment have been worked out. Several factors of the environmental impact have been studied (see Szanyi *et al.*, 2019). The ethical and the policy aspects of the application of the technology are under investigation.

The CHPM technology, as a whole, is still at low TRL and needs forward-looking efforts. Due to the disruptive nature of some of the innovative elements of the project and the parallel development of lab-scale technologies, it is inevitable that some knowledge gaps can be filled only after the closure of the project. Two time horizons have been identified: 2030 for pilot-scale operation and 2050 for full-scale operation. The forward-looking efforts are being undertaken in three interlinked areas: 1) mapping convergent technology areas, 2) studying pilot areas and 3) developing research roadmaps. The two roadmaps (2030 for early application, 2050 for breakthrough research) will be provided by the end of the project, June 2019, and describe how to get to the desired future destination through emerging issues from the technology baseline of today.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654100.

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Use of depleted hydrocarbon reservoirs for geothermal energy and its significance in energy transfer toward a low-carbon economy: a paper factory project in Slatina, Croatia

*Ratko Vasiljević**

The city of Slatina is placed in the Croatian part of the Pannonian Basin, an oil and gas bearing region with a long tradition of exploitation and exploitation. Due to depletion of hydrocarbon reserves, since the 1980s the possibilities of using geothermal energy from the existing wells have been considered. This paper presents the project of a new paper factory in Slatina. In the first phase, it will use geothermal water directly in the paper factory for heating and in manufacturing processes. A geothermal power plant will be constructed in the second phase. In case of success, this project can serve as a good example of energy transfer toward a low-carbon economy.

La ville de Slatina est située dans la partie croate du Bassin de Pannonie, une région de pétrole et de gaz et une longue tradition d'exploitation. Dû à l'épuisement des réserves d'hydrocarbures, depuis les années 1980, l'on a considéré les possibilités d'utiliser l'énergie géothermique à partir des puits existants. Cet article expose le projet de création d'une nouvelle usine à papier à Slatina. Dans une première phase, l'eau géothermale est utilisée directement comme source de chaleur et pour les procédés de fabrication du papier. Une centrale électrique géothermique sera construite lors d'une deuxième phase. En cas de succès, ce projet peut servir de bon exemple de transfert d'énergie en faveur d'une économie peu carbonée.

La ciudad de Slatina se encuentra en la parte croata de la cuenca Pannoiana, una región productora de Oil&Gas con una tradición de explotaciones. Desde los años 80, y debido al depletado de las reservas de hidrocarburos, se ha tenido en cuenta la posibilidad de utilizar los pozos existentes con fines geotérmicos. Este articulo expone el proyecto de una nueva fábrica de papel en Slatina. En los primeros estadios, se utilizará agua geotérmica directamente para calefacción y para procesos de manufactura en la fábrica. Una planta de energía geotérmica será construida en estadios posteriores. En caso de éxito este proyecto podría servir como buen ejemplo de transición energética hacia una economía de descarbonización.

Introduction

The city of Slatina is situated in north-eastern Croatia (***Figure 1***) in the Croatian part of Pannonian Basin, within an oil and gas (O&G) bearing region with a long tradition of fossil fuel exploitation which resulted from a high degree of exploration. After the peak in 1981, the oil production in Croatia slowly declined. Although depletion of hydrocarbon reserves was still decades away, in the 1980s, the possibilities of using geothermal energy from the existing wells were already being considered. Oil and gas fields and geothermic aquifers are placed in Neogene sandstone and breccia reservoirs screened by marl at depth intervals between 1 to 5

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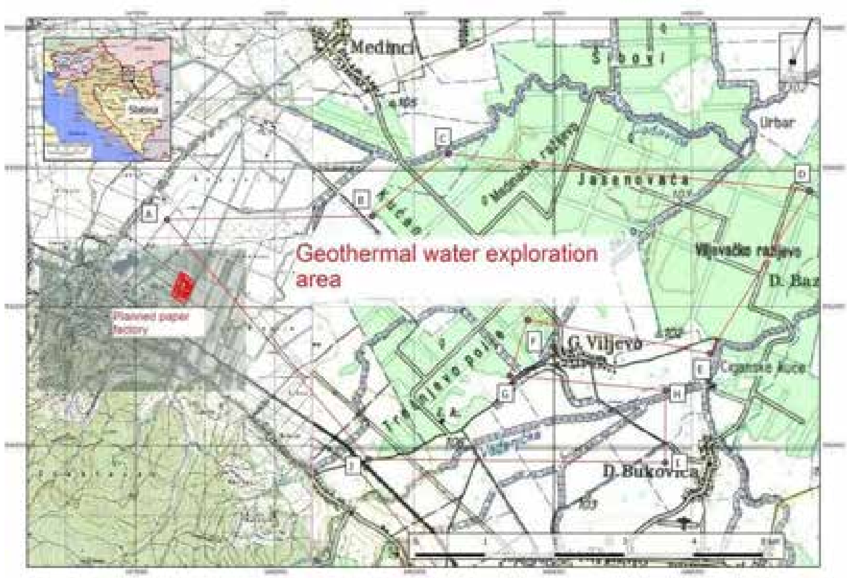

Figure 1: Location of the project (ECOINA, 2013).

km. Successful conversion of O&G exploration wells in geothermal fields has taken place and significant reserves of geothermal energy have been discovered in the Lunjkovec and Ferdinandovac aquifers or in the surroundings of the Molve and Kalinovac O&G fields (***Figure 2***). Considering these developments, it was decided to use geothermal energy from the old oil wells in the new paper factory to be built in Slatina (***Figure 3***).

In the first phase of the project geothermal water will be used as the heating source for water used in manufacturing processes and for the heating of halls and offices. In further phases we plan to install a geothermal power plant in order to supply the factory with electricity and possibly the Slatina City electric grid, as well.

In the area of Slatina, geothermal potential was determined based on investigations carried out in the second half of the last century. The National Croatian Oil Company INA conducted exploratory drilling for the purpose of determining oil and gas reserves from the 1960s through the 1980s. Significant reserves of geothermal water with a temperature range of 130–191°C at depths of 3,000–5,000 metres were found in more than a dozen exploration wells.

The geothermal potential of the area will be used in a new paper factory. In the first phase the paper factory will use thermal energy directly, and in the second phase it is planned to install a geothermal power plant. The idea is not to use geothermal energy for the paper factory only, but to spread it to satisfy part of the energetic needs of Slatina City in the future. During the planned two-phase development of the paper factory, the knowledge obtained is expected to ensure input for the future development of the geothermal infrastructure.

In the first phase, geothermal water will be used directly in the paper factory for heating halls and offices and in manufacturing facilities. The first phase requires a flow rate of 73 litres per second with a temperature between 150 and 200 °C (ECOINA, 2013). Capacities of similar reservoirs are between 100 to 347 litres per second (Dukić, 2012). In the second phase, the planned geothermal power plant will use geothermal water at a temperature of 190 °C and a pressure of about 80 bar. The power of the power plant is 10 MW. The second phase requires a capacity of 83 litres per second (ECOINA, 2013).

Urban planning documentation for the city of Slatina in Virovitičko–Podravska County takes into account the use of geothermal energy in the future and the synergy potential of the new paper factory (***Figure 1***), with the plant being recognised as the starting point in this process. The required Environmental Impact Assessment (ECOINA, 2013) was approved by a government commission and passed public review with discussion, and finally was accepted by the Ministry of Environment and Energy, Republic of Croatia (MEP 2014).

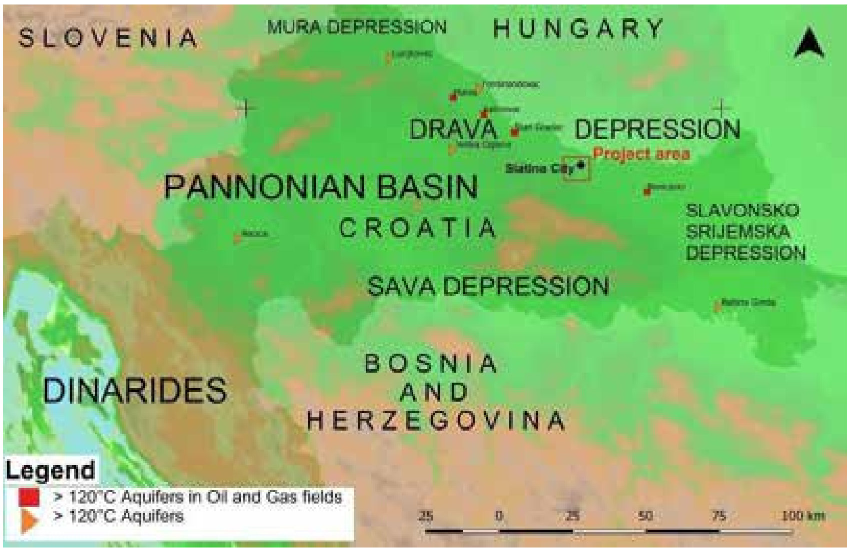

Figure 2: Project area and significant geothermic aquifers in Croatia suitable for use in geothermic binary process power plants (modified after Geoslatina, 2010).

Table 1: Lithostratigraphic division of the Croatian part of the Pannonian Basin (after INA – Naftaplin, 1988, simplified).

Sava Depression	*Drava Depression*	*Mura Depression*	*Slavonsko – Srijemska Depression*	*Stratigraphy unit*
Lonja Formation	*Lonja Formation*		*Vuka Formation*	*Upper and Middle Pliocene and Quaternary*
Široko Polje Formation	*Bilogora Formation*		*Vera Formation*	*Upper Pontian*
Kloštar–Ivanić Formation	*Kloštar–Ivanić Formation*	*Lendava Formation*	*Vinkovci Formation*	*Lower Pontian*
Ivanić–Grad Formation	*Ivanić–Grad Formation*			*Upper Pannonian*
Prkos Formation	*Križevci Formation*	*Murska Sobota Formation*	*Valpovo Formation*	*Lower Pannonian*
Prečec Formation	*Mosti Formation*		*Vukovar Formation*	*Pre-Badenian, Badenian, Sarmatian*
Pre-tertiary rocks, Mesozoic carbonates, Paleozoic magmatite and metamorphic complex				

Geology

The Republic of Croatia can be roughly divided in two different areas: the Pannonian basin and the Dinarides. In the Dinarides the average geothermal gradient is 0.018 °C/m. In the Pannonian basin, the average geothermal gradient is much higher: 0.049 °C/m (EIHP, 2017). Since the geothermal gradient in the Pannonian area is considerably higher than the European average (0.043 °C/m), in addition to already discovered geothermal fields, it is probable that new ones will be discovered.

The Croatian part of the Pannonian Basin is divided into four depressions: the Drava Depression, Mura Depression, Sava Depression and Slavonija-Srijem Depression. Oil and gas reservoirs along with source rocks are placed in a neogene complex, which is divided into formations. Since the geothermal water is connected with oil and gas reservoirs, this division is applicable in the exploration of geothermal energy. Each depression has its own division (***Table 1***). Dominated lithology members are sandstones and marls, with oil and gas fields, formed in sandstone reservoirs from Lower Pannonian to Upper Pontian, while some reservoirs are also placed in eroded rocks of a pre-Tertiary complex. Reservoirs are screened lithologically, with marls, or tectonically, by faulting. Slatina is placed in the Croatian part of the Pannonian Basin in the Drava Depression (***Figure 2***).

Methodology

In the thirty years between 1959 and 1989 thirteen oil wells were drilled around Slatina City (***Figure 3***). The depth of boreholes ranged from 800 m to more than 5,000 m with an average geothermal gradient of 0.04 °C/m (***Table 2***).

According to available temperature logs from the wells (ISOR/EFLA, 2011), at depths of 4–5 km the temperature reached 190 °C, i.e. the resulting measured geothermal gradient is approximately 45 °C/km (***Figure 4***). The temperature at a depth of 800 meters is constant and is about 30 °C, after which it grows approximately linear up to a depth of 2,800 m where it reaches a value of 90–100 °C, so the geothermal gradient in that interval is between 30 and 35 °C/km. At depths of 2,800–2,900 meters there is a temperature leap of 20 °C to 110 °C and from this depth to 4,500 m there is a mostly linear increase in temperature to 190 °C (gradient of 50 °C/km). In some wells, the jump rates in intervals between 3,300 to 3,400 m were from 150 to 185 °C and in intervals between 3,600 to 3,700 m leaps in measured temperatures from 140 to 180 °C were found.

The temperature generally increases in depth, however at some intervals, the growth is unexpectedly sudden, and in some locations a decrease in temperature was recorded. Unfortunately, there are no detailed data on the measuring conditions so interpretation is limited by this factor. Most oil wells in the observed area were drilled between the 1960s and 1980s. At that time geothermal energy, with some exceptions, was generally not considered as a significant energetic source. Temperature loggings were made immediately after drilling, when infiltrated drilling mud was present in surrounding rocks of a well channel, which could affect the results of measurement. This could be an explanation for the drop in temperature in Well PS-5 in the interval between 3,900 to 4,500 m.

Considering the measured values in petroleum wells, a geothermic reservoir is classified as medium-temperature

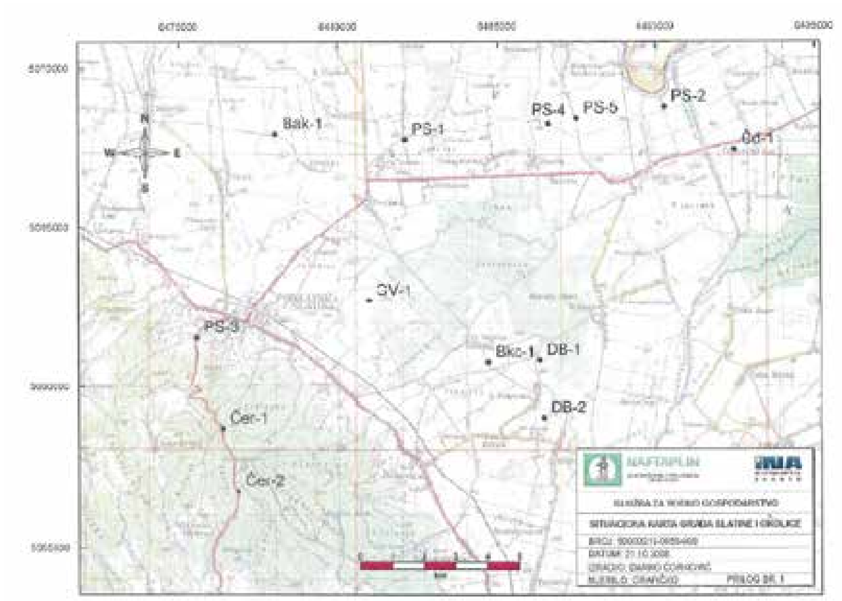

Figure 3: Oil boreholes drilled around Slatina City (INA, from Geoslatina, 2010).

Table 2: Oil boreholes drilled around Slatina City (INA, modified according to Geoslatina, 2010 and Brajko, 2014).

No.	Borehole	Drilling period	Final depth (m)	Measured temperature	Calculated geothermal gradient (°C/m)
1	Podravska Slatina 1 (PS-1)	May to Aug. 1959	2,925	110 °C	0.038
2	Podravska Slatina 1 (PS-5)	Jul.1984 to Apr. 1985	5,051	183 °C	0.036
3	Ćeralije (ćer 1)	Dec. 1962 to Feb. 1963	1,878	69 °C	0.037
4	Podravska Slatina 2 (PS-2)	Aug. to Nov. 1959	3,306	138 °C	0.042
5	Podravska Slatina 3 (PS-3)	Dec. 1961 to Feb. 1962	2,707	99 °C	0.037
6	Podravska Slatina 4 (PS-4)	Jun. to Nov. 1962	3,510	No data	-
7	Ćeralije 2 (ćer-2)	Mar. 1963	813.9	No data	-
8	Gornje Viljevo (GV-1)	Jul. 1988 to Jan.1989	4,092.5	172 °C at 3,943 m	0.044
9	Gornje Viljevo 1alfa (GV-1a)	Feb. to May 1989	5,080	191 °C at 4,500 m	0.042
10	Bakić 1 (BAK-1)	Jun. to Oct. 1984	4,999	178 °C at 4,872 m	0.037
11	Donja Bukovica 1 (DB-1)	Jun. to Nov. 1978	4,496	178 °C	0.040
12	Bukovica 1 (BKC-1)	Nov. 1988 to Mar. 1989	4,102	170 °C	0.041
13	Donja Bukovica 2 (DB-2)	Jun. to Sept. 1984	3,874	174 °C	0.045
Min.					0.036
Max.					0.045
Average					0.040

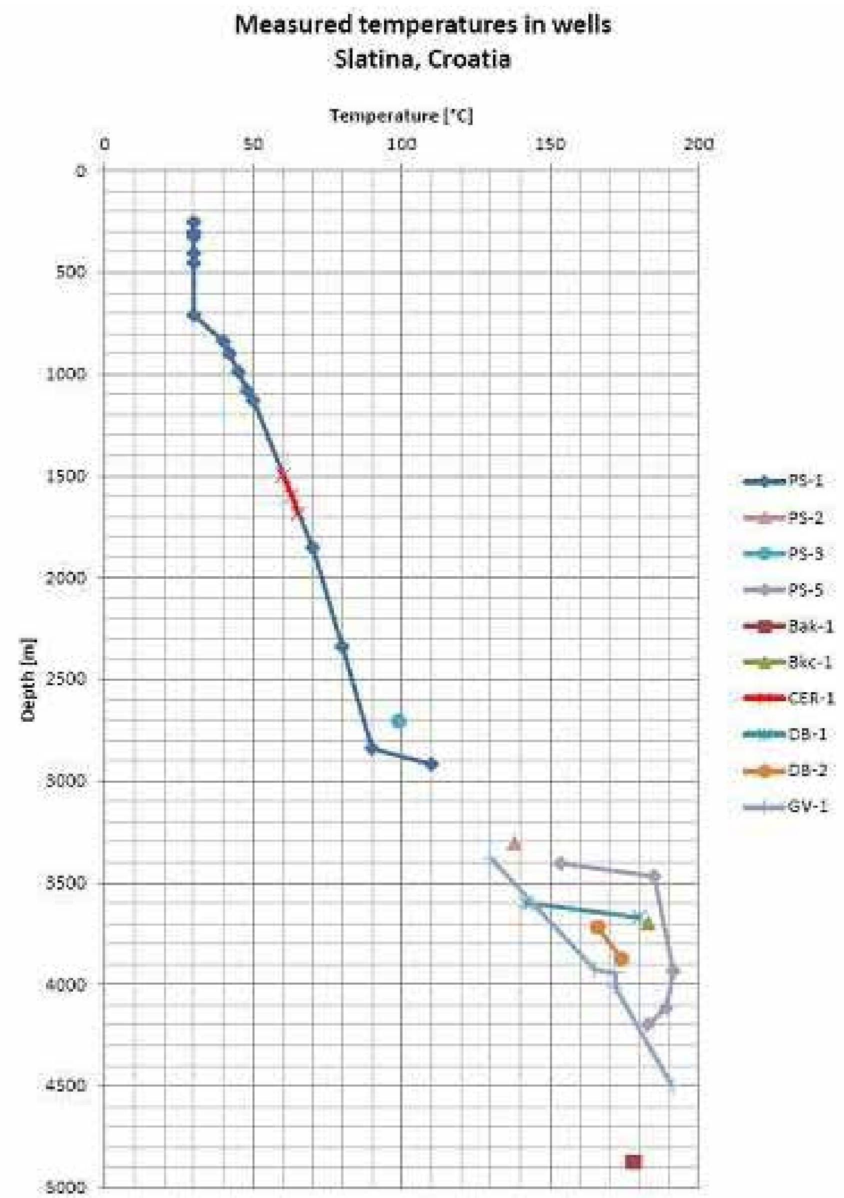

Figure 4: Measured temperatures in oil wells in the Slatina area (ISOR/EFLA, 2011).

(100–200 °C), and geothermal energy from these reservoirs can be exploited for space heating, in various technological processes and for the production of electricity by the binary process.

In order to determine the possibility of using geothermal water in the production process, the Icelandic company ISOR/EFLA reviewed the potential of the surrounding area for the exploitation of geothermal water.

Based on preliminary results, additional exploration activities on geothermal energy reservoirs were carried out in 2011. The studies included magnetic telemetry (MT) measurements on 61 probes. The principle of MT measurement is based on the detection of natural changes in the Earth's magnetic field flux due to changes in the lithology in the underground, where the depth zones of different resistance are located, which in this case indicated the existence of geothermal fluids (ISOR/EFLA, 2011). MT measurements have established the location of fault zones, which would be the most appropriate goal for possible additional drilling to obtain greater yield.

The drilling target is at depths of about 3,000–4,000 m. At a depth of 3,000 m the geothermal water temperature is lower, but still significantly above 100 °C, whereas at depths of 4,000 m it would be realistic to expect temperatures between 150 and 200 °C.

UNFC-2009 classification

The reserves were classified in compliance with the UNFC- 2009 classification (***Tables 3 and 4***) regarding the criteria of economic and social viability (E), the maturity of studies (F) and geological knowledge (G). Concerning the criteria of economic and social viability (E), present research results show sustained discharge for use of heat in a production process. The required capacity of 73 l/s is proven by previous well testing, and the minimum required temperature of 150°C was proven by well logging, so in part for direct use it can be considered as a commercial project.

The future power plant was classified as E2 (a future thermal power plant); according to data from similar projects in Croatia, its expected capacity is at least 2 to 5 times greater than required (Dukić, 2012), but to prove this, additional measurements of capacity are necessary.

Considering the maturity of studies (F), feasibility of extraction for direct use has been confirmed, but for the further phase, the development of the thermal power plant, additional research should confirm whether the required geothermal resources are present.

A rating of G2 was given for geological knowledge (G) – quantities associated with a known deposit that can be estimated with a moderate level of confidence. G categories may be used discretely, particularly when classifying solid minerals and quantities in place, or in cumulative form (e.g. G1+G2), as is commonly applied for recoverable fluids (UNFC, 2009). Although the quantity is sufficient for the first phase, it is necessary to perform further investigations in order to define reserves of thermal water and to define the impact on the thermal water reservoir.

Contribution to transfer to a low-carbon economy

In order to prevent dangerous climate change, in October 2014 the leaders of Member States adopted the Climate and Energy Policy Framework of the EU for the period from 2020 to 2030, which includes a binding EU target of at least 40% lower greenhouse gas emissions by 2030 compared to 1990 (UNFC, 2009).

For example, the expected electrical efficiency for a natural gas electric generator is approximately 50% (GE, 2015), that means for each MWh of produced electric energy it is necessary to combust 2 MWh of natural gas. The power of the planned geothermal power plant is 10 MW, which

Table 3: Classification of the project regarding economic and social viability (E).

Category	UNFC-2009 definition	Reasoning for classification
E1	Extraction and sale has been confirmed to be economically viable	Present research results show sustained discharge for use of heat in a production process. Required flow of 73 l/s is proven by previous well testing, minimum required temperature of 150 °C was proven by well logging.
Sub-category	**UNFC-2009 definition**	Synthesis of conclusions and economic feasibility was confirmed in the Environmental Impact Assessment (ECOINA, 2013).
E1.1	Extraction and sale is economical on the basis of current market conditions and realistic assumptions of future market conditions	The classification of E1.1 only applies to the heat for direct use in production.
Category	**UNFC-2009 definition**	**Reasoning for classification**
E2	Extraction and sale are expected to become economically viable in the foreseeable future	The classification of E2 refers to future thermal power plant. According to data from similar projects in Croatia, expected capacity is at least 2 to 5 times greater than required (Dukić, 2012). The factory will use electricity for its own purpose, and according to urban planning documentation there is an interest to use electricity from geothermal power plant in the city of Slatina. Additional measurements of capacity and temperature will be done in the first phase.

Table 4: Classification of the project regarding the maturity of studies (F) and geological knowledge (G).

Category	UNFC-2009 definition	Reasoning for classification
F1	Feasibility of extraction by a defined development project or mining operation has been confirmed	For the first phase of the project (direct use of heat), exploration, well testing and simulation are complete.
Sub-category	**UNFC-2009 definition**	
F1.3	Sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development project or mining operation.	
F2.1	Project activities are ongoing to justify development in the foreseeable future.	Preliminary studies and experience from similar projects indicate the feasibility of development of a geothermal power plant, which is boosted by interest of a local community. Additional research should confirm whether the required geothermal resources are present.
G2	Quantities associated with a known deposit that can be estimated with a moderate level of confidence.	

theoretically means 240 MWh of produced electrical energy per day or 87,600 MWh of produced electrical energy per year. In gas consumption that means a savings of 480 MWh (1.73 TJ) of natural gas per day, or 175,200 MWh (630.72 TJ) of natural gas per year.

Rising energy prices and supply instability have led to a serious increase in interest in developing geothermal resources for electric power generation, and turned to a completely new way of understanding country's geothermal potential (Kolbah *et al.*, 2015). The average energy capacity of geothermal direct heat consumption in Croatia is 3–4 MWt and it is expected that there is another 1,500 to 2,000 MWt , which could generate as much heat as 600 million m^3 of natural gas per year (Kolbah *et al.*, 2015).

Each terajoule obtained by combustion of methane emits 54.9 tons of CO_2, that means the emission factor of Methane is 54.9 tCO_2/TJ (Commission Regulation 601/2012), which means a decrease in greenhouse gas emissions by 95 tCO_2 / day, or 34,627 tCO_2 / year. These annual emissions of CO_2 are relatively low, and an installation with these emissions would be classified as category A, but obtained experience is expected to enable development of further capacities in the future. Another stimulus can be found in the EUETS Directive 2003/87/EC, where it was prescribed that a significant part of the revenues generated from the auctioning of allowances should be used, among others, to develop renewable energies to meet the commitment of the EU to renewable energies (Article 10(3)). No free allocation shall be made in respect of any electricity production (from combustion) by new entrants (Article 10a(7)) and some allowances will be available to stimulate the construction and operation of projects that aim at the environmentally safe capture and geological storage ('CCS') of CO_2, as well as innovative renewable energy and energy storage technologies (Article 10a(8)). That actually means destimulation of the production of electricity from fossil fuels and encouraging production from renewable sources.

Conclusion

A new paper factory planned in the Slatina area of Croatia will use geothermal energy. The Environmental Impact Assessment (ECOINA, 2013) proposed two phases of project development. In the first phase detailed monitoring of geothermal reservoir will be performed, and if it is feasible, a geothermal power plant will be installed in the second phase.

The first phase in the paper factory requires a capacity of 73 l/s with a temperature between 150 and 200 °C. According to data from the Croatian national oil company INA (ISOR/EFLA, 2011), all existing wells are capable of ensuring the required capacity. Two wells of up to 4,000 meters deep are planned, one for exploitation and one for injection, at the factory location.

Since the original measurements were performed primarily for oil exploitation, it will be necessary to perform additional measurements along with the re-evaluation of previously performed measurements in the older boreholes to precisely define temperatures and capacities during the first phase of geothermal energy exploitation in order to determine the feasibility of the electric power plant that is planned in the second phase.

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The role of geothermal in the energy transition in the Azores, Portugal

António Franco and Carlos Ponte*

The Azores Archipelago is characterised by a challenging power market, where each island corresponds to an independent power generation system and where demand is low and very asymmetric, limiting the size of the renewable projects that can be built and economically feasible locations.
Traditionally, the power generation in the Azores Islands has been based on the consumption of fuel oil in thermal Diesel power plants, and in the early 1990s more than 90% of the electricity supply relied on fossil fuels. However, over the past two decades the share of renewables for power generation has progressively increased; they currently provide 37% of the electricity needs in the Archipelago. Amongst the renewables, geothermal plays the predominant role on the most populated islands, providing up to 42% of the electricity needs of São Miguel Island and 11% of Terceira Island.
This paper summarises the key contributions from geothermal for the ongoing energy transition in the Azores, including plans for and challenges to future expansion of geothermal production in such small and isolated power generation systems.

L'Archipel des Açores est caractérisé par un marché énergétique à valeur de défi car chaque ile correspond à un système indépendant de production d'énergie avec une demande énergétique peu élevée et très asymétrique ce qui limite la taille des projets à énergie renouvelable qui pourraient être réalisés et en des lieux économiquement viables.
Traditionnellement, le système énergétique insulaire des Açores est représenté fondamentalement par la consommation de pétrole dans des centrales électriques thermiques, et, au début des années 1990, plus de 90% de la fourniture d'électricité dépendait d'hydrocarbures fossiles. Cependant, durant la dernière vingtaine d'années, la part du renouvelable en production d'énergie a augmenté de manière constante; elle fournit actuellement 37% des besoins en électricité de l'Archipel. Parmi les sources d'énergie renouvelables, la géothermie a un rôle prédominant dans les iles les plus peuplées, fournissant 42% des besoins électriques à São Miguel et 11% à Terceira.
Cet article résume les contributions fondamentales apportées par la géothermie dans la transition énergétique en cours aux Açores, y compris le planning et les défis liés à la future expansion de la production géothermique dans des contextes de production énergétique, faible et isolé.

El archipiélago de las Azores está caracterizado por un desafiante mercado energético, donde cada isla está asociada con un sistema de generación eléctrica independiente y donde la demanda es baja e irregular, limitando el tamaño de los proyectos de energías renovables que pueden ser desarrollados y tengan ubicaciones económicamente viables.
Tradicionalmente, la generación eléctrica en las Azores ha estado basada en el consumo de combustibles pesados en plantas térmicas; y a comienzos de los 90, más del 90% del suministro de energía recaía en energías fósiles. Sin embargo, en las dos últimas décadas la generación eléctrica por medio de energías renovables ha ido progresivamente incrementándose; actualmente producen el 37% de las necesidades eléctricas en todo el archipiélago. De entre las renovables, la energía geotérmica juega un papel predominante en las islas con mayor población, suministrando hasta el 42% de las necesidades eléctricas de la isla de São Miguel y el 11% en la isla de Terceira.
Este articulo resume las principales contribuciones de la energía geotérmica para la transición energética en las Azores, incluyendo planes para ello y retos para una futura expansión de la producción geotérmica en cada uno de los pequeños e aislados sistemas de generación existentes.

Introduction

The Azores Archipelago, in the North Atlantic Ocean, is composed of 9 islands spread along 600 km (***Figure 1***), with the nearest continental area being Portugal mainland, 1600 km away to the East. There is no electrical interconnection between the Islands or to any continent, so each island corresponds to an independent power generation system. In this context, the climate and the volcanic nature of the Azores Islands offer specific opportunities to use renewable energy sources for power generation, namely geothermal, wind and - hydro. In the Azores, EDA RENOVÁVEIS S.A., is the main renewable power operator, and its only client is EDA, S.A., the power utility of the region.

There are no large-scale industries in the Azores and almost 80% of the power consumption derives from households, commerce and services. On top of that, most of the consumption is concentrated in the more populated islands (***Figure 2***), so the demand is not only low but also very asymmetric, limiting the size of the renewable projects that can be built and where they are economically feasible to build.

Formed at the triple junction between the North American, African and Eurasian plates, the Azores are in an active geological zone, with a history of intense seismic and volcanic activity, which is still ongoing. In fact, all the islands are volcanic in origin and most still have active volcanoes (currently dormant). There are abundant surface geothermal manifestations, including fumaroles, hot springs and soil degassing areas, and at certain sites there is great potential for utilising high-temperature geothermal resources for power generation.

The low demand however, limits the geothermal development. This is caused by the high up-front costs and resource risk in the

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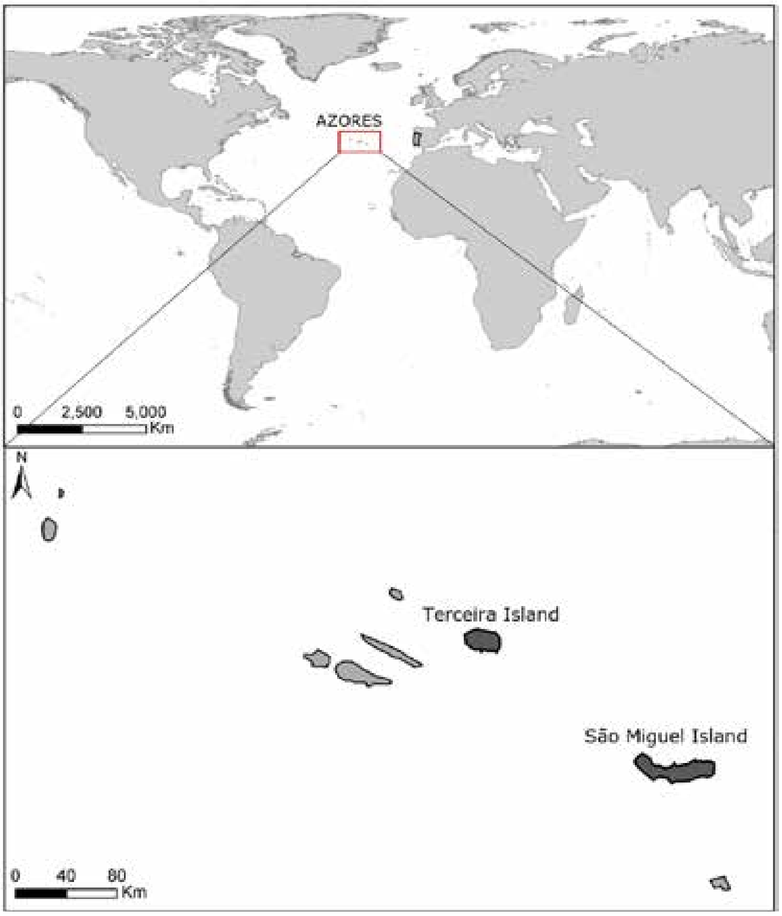

Figure 1: The Azores Archipelago.

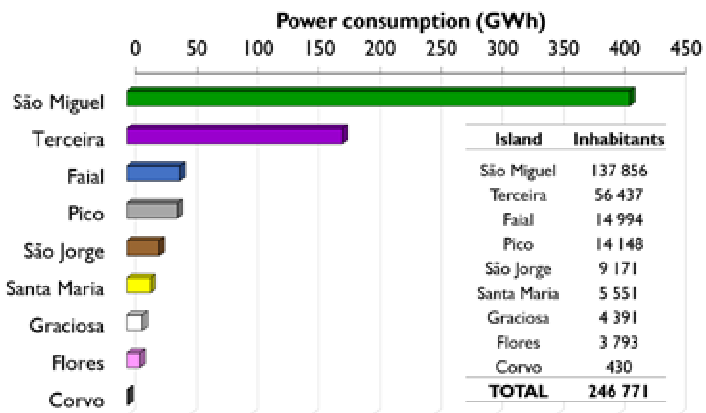

Figure 2: Power generation in the Azores, 2018 (sources: EDA S. A. 2018; Statistics Portugal, 2011).

early stages of development, compared to other renewable energy sources, mostly related to the cost of drilling exploratory deep wells. As a result, the development has been only focused in São Miguel and Terceira Islands, where the demand is a bit higher and, consequently, where the projects are economically feasible.

This paper summarises the main milestones of geothermal development and describes the history of power generation in the Archipelago, quantifying the main contributions from geothermal to the on-going energy transition away from fossil fuels. In addition, the challenges in expanding the geothermal capacity are briefly discussed.

Geothermal development

In the Azores, the initial geothermal exploration dates from the 1970s and was carried out roughly in parallel on São Miguel and Terceira Islands. However, following the more promising results in São Miguel Island, development was initially focused there, following a stepwise strategy. The Terceira Island project was resumed in 2000, but the first power plant was only installed in 2017. The main milestones of the development and the power generation history are described below.

São Miguel project

The geothermal project is in the Ribeira Grande geothermal field (***Figure 3***), on the north flank of Fogo Volcano, one of the three active (dormant) central volcanoes of the Island. This is a brown field, with 4 decades of exploitation experience and with a total of 23 deep drillings (1-2 km depth). The geothermal system is characterised by a 240 °C liquid-dominated reservoir, which can be tapped by relatively shallow wells (1–1.5 km depth). The resource has a fluid enthalpy of 900–1100 kJ/kg and most wells discharge up to 25-40 l/s at wellhead pressures ranging from 6 to 16 bar-g.

The first milestone of geothermal power generation was in 1980, with the operation of a small 3 MW pilot plant in the Pico Vermelho area (Meidav, 1981), consisting of one back-pressure steam turbine designed by Mitsubishi. The pilot plant only generated an average net power of 0.8 MW (1980–2005), but the lessons learnt from its operation supported the next stages of project development.

1994 marked the beginning of the commercial exploitation of geothermal resources in the Azores, when Phase A of the Ribeira Grande ORC (organic Rankine cycle) binary power plant came online (***Figures 3 and 4***). The plant was designed by ORMAT and in 1998 it was later expanded to 13 MW (Ponte, 2002). More recently, the pilot plant was dismantled and was replaced by the 10 MW Pico Vermelho ORC binary plant (Kaplan *et al.*, 2007), also designed by ORMAT, installed at the same location (***Figures 3 and 4***). The Pico Vermelho plant has been online since December 2016.

The power demand on São Miguel Island showed progressive growth from 1990 to 2010. In the early 1990s, the power generation was based on the consumption of fossil fuels in thermal diesel power plants, producing 90% of the electricity needs. However, over the past 30 years, the growth in the demand was accompanied by an increase in renewables production, from 10% to 51%, and this has been directly linked to the expansions of the geothermal installed capacity (***Figure 4***). On São Miguel Island, the current share of renewables reaches up to 51%, with geothermal assuming the predominant role, providing 42% of the island's electricity needs. The remainder is provided in roughly equal parts by hydro and wind.

Terceira project and power generation history

On Terceira Island, the project is in the Pico Alto geothermal field (***Figure** 5*) located on Pico Alto Volcano, one of the three active (dormant) volcanic complexes of the island. This is a greenfield site, with only five deep drillings and an exploitation experience of less than 18 months. The geothermal system is characterised by a 270–300 °C liquid-dominated reservoir, which can be tapped by 1–2 km depth wells. The resource has a fluid enthalpy ranging from 1200 to 1900 kJ/kg, and, as in many other greenfield sites, the output from the first set of wells is relatively low, discharging 6-13 l/s at variable wellhead pressures (4 to 12 bar-g).

The geothermal exploration in Terceira Island started in the late 1970s, but there were no significant developments for 20 years. In 2000, GEOTERCEIRA (which merged into EDA RENOVÁVEIS in 2014) deployed a new exploration program, concentrated on the central part of the island near the fumaroles of Furnas do Enxofre. The initial program included a detailed audiomagnetotelluric (AMT) survey and the drilling of 4 temperature gradient holes to 400–600 m depth (Henneberger *et al.*, 2004). The results from these supported the drilling of five exploratory wells to 1100–1900 m depth and the subsequent flow tests indicated an estimated available output of 3.5 MW (Franco *et al.*, 2017).

Like in Ribeira Grande (São Miguel), the Pico Alto project is following a stepwise strategy, with Phase A being the installation of a small pilot plant and Phase B being the expansion of the plant capacity (up to 10 MW), supported by additional drillings. As part of Phase A, a 3.5 MW ORC binary power plant was installed in Pico Alto, designed by the consortium EXERGY S.p.A. & CME, and it has been online since August 2017.

Before 2008, more than 98% of the power generation relied on fossil fuels, with a small contribution of hydropower (1–2%). During this period, demand was growing rapidly, and this created interest in utilising the endogenous resources of the Island, including geothermal resources. Despite the stagnation of the demand after 2008, the energy mix became more diverse as new projects were installed, utilising wind, waste-to-energy and geothermal resources (***Figure** 6*). As a result, the proportion of renewables has increased significantly, initially based on the operation of wind turbines, and more recently also on the Pico Alto geothermal plant.

In 2018, the island is still reliant on fossil fuels to meet its electricity needs (66%), but with the operation of the Pico Alto

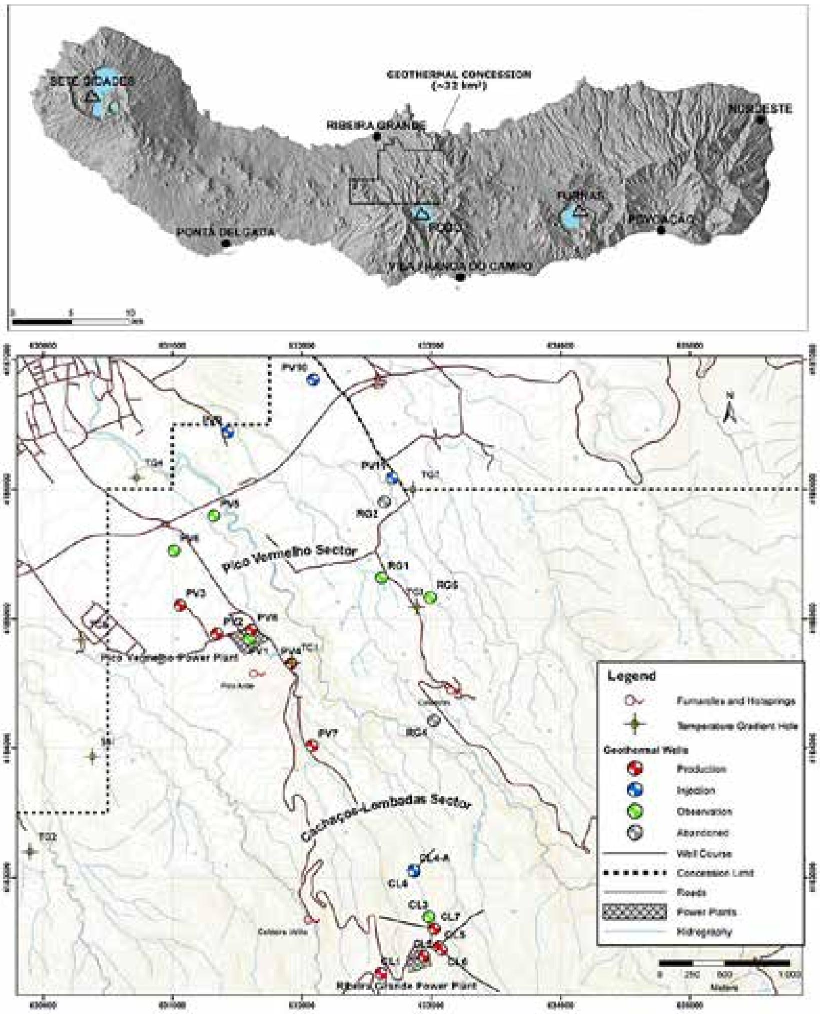

Figure 3: The Ribeira Grande geothermal field.

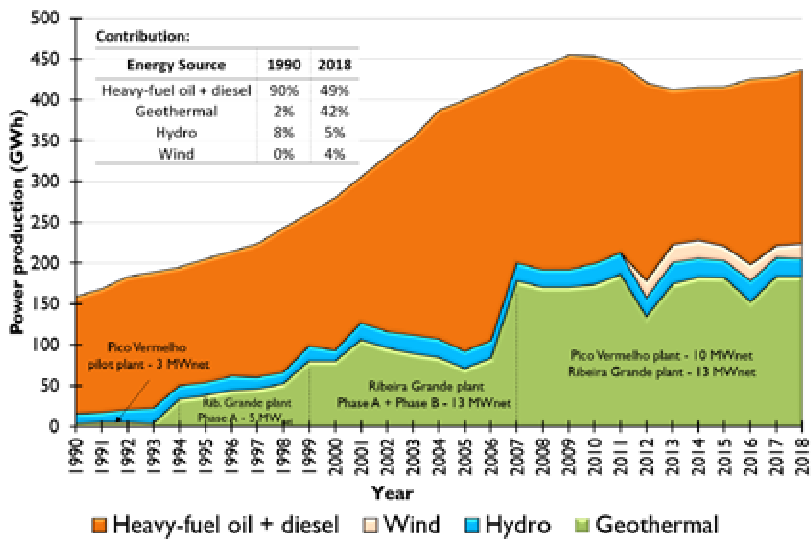

Figure 4: History of power generation on São Miguel Island (sources: EDA, S. A., 2007 to 2018; EDA RENOVÁVEIS, S. A., 2007 to 2018).

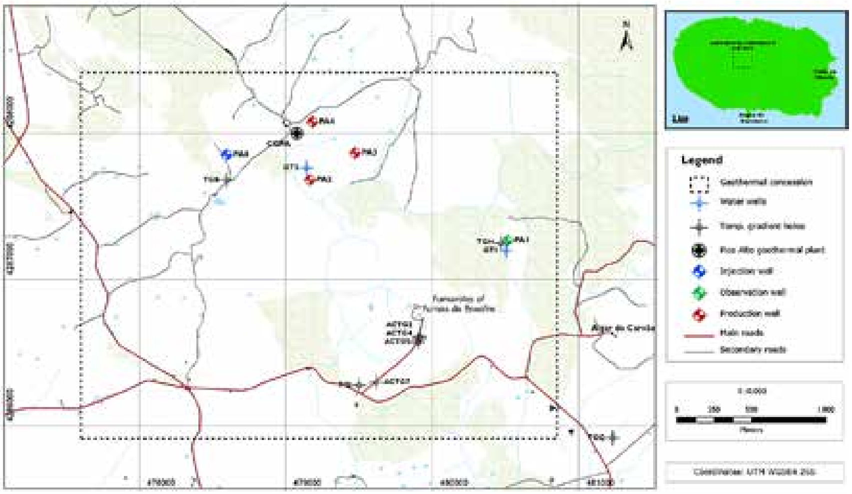

Figure 5: The Pico Alto geothermal field.

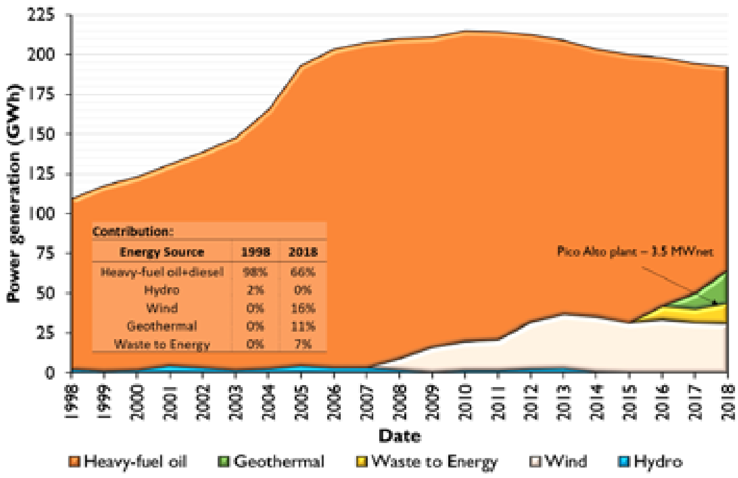

Figure 6: History of power generation on Terceira Island (sources: EDA, S. A., 2007 to 2018; EDA RENOVÁVEIS, S. A., 2007 to 2018).

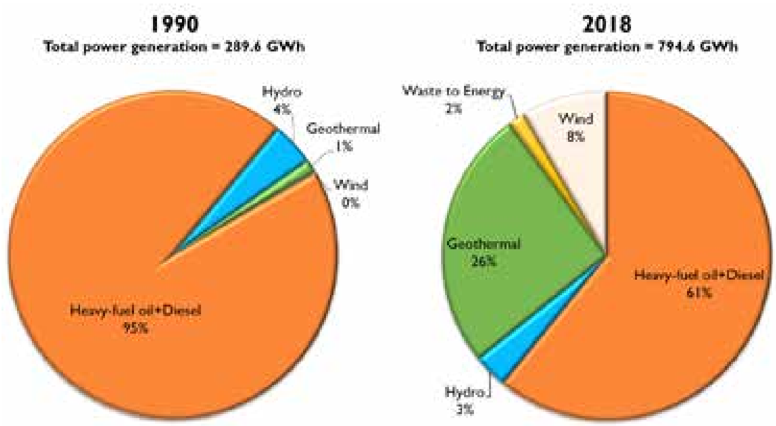

Figure 7: Distribution of power generation in the Azores, 1990 and 2018 (sources: SOGEO, 1990; EDA, S. A., 2018).

geothermal plant, the share of renewables reached a historical maximum of 27%, with geothermal providing 11% and wind 16%. The remainder was provided by a waste-to-energy facility (7%).

Power generation history in the Azores

In the early 1990s, the share of renewables was minimal, with 95% of the power generation deriving from fossil fuels. However, over the past 30 years and accompanying the growth in demand, EDA RENOVÁVEIS S. A. has made several investments to increase the installed capacity of renewables. The contribution from renewable power generation increased from 5% to 37% (***Figure 7***), progressively reducing the dependency on fossil fuels. This energy transition was essentially fostered by the growth of geothermal, from 1% to 26%, and, on a smaller scale, by wind power production (currently 8%). On the other hand, the proportion of hydropower has remained constant, as the main resources have been already in use for several decades. Currently, there are 12 hydropower plants in the Azores with a total installed capacity of 8.7 MW, distributed on four of the nine islands of the Azores. Categorised by capacity, 2 are small plants (1.6 MW) and 10 are mini plants (0.1 to 0.8 MW). All are run-off river plants with a limited amount of storage, where a fraction of the water's stream is diverted downhill through a penstock to a small size turbine that sits downstream alongside the river. In summer, the runoff may be rather low, reducing the output of the plants. There are also small solar photovoltaic installations on six of the nine islands of the Archipelago, but they are mostly microgeneration for domestic dwellings. Despite having a so-far restricted share in the power generation in the Azores (<0.1%), photovoltaic microgeneration is growing at a rather promising pace, from 0.01 GWh in 2010 to 0.28 GWh in 2017.

In addition, on the tiny Graciosa Island a hybrid plant came online at the end of 2018, combining a Battery Energy Storage System (6.0 MW/3.2 MWh) with renewable power generation (4.5 MW of wind and 1.0 MW of photovoltaic). The project is promoted by Graciólica Unipessoal Lda and is expected to generate up to 65% of the electricity needs on the island (Wartsila, 2019).

Utilisation of low-temperature geothermal resources

In site-specific locations of the Azores, there are abundant low-temperature resources (<100 °C; <250 m depth) suitable for direct uses of the geothermal heat. However, only a small part of these shallow resources has been utilised, and most are yet to be assessed. Historically, the direct uses of geothermal heat have been essentially for thermal baths, either using the natural discharge of hot springs or by tapping hot water in pumped wells (<100 m depth).

On São Miguel Island, the steam discharge from the natural fumaroles at Furnas Volcano, and since 2014 also at Caldeiras da Ribeira Grande, has been utilised to

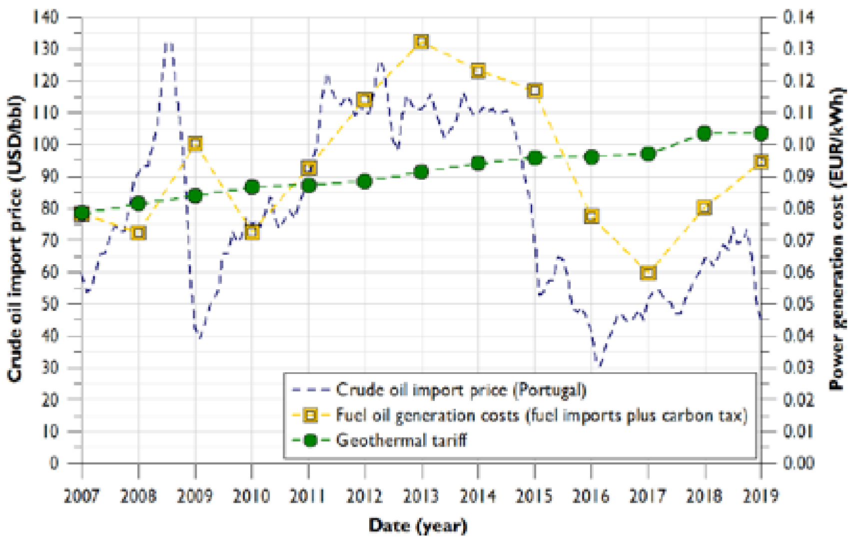

Figure 8: History of power generation costs by energy source (sources: EC, 2019; EDA, S. A., 2007 to 2018; EDA RENOVÁVEIS, S. A., 2007 to 2018).

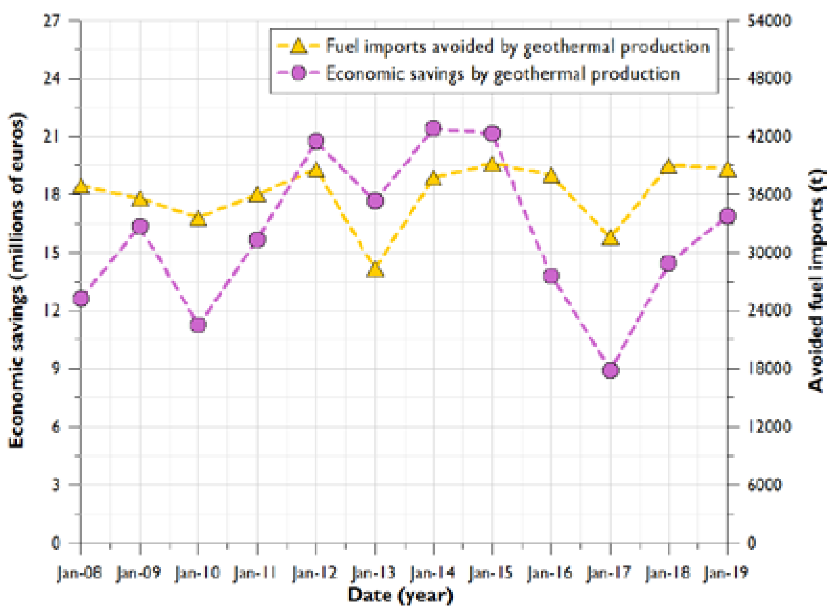

Figure 9: History of savings on fuel imports by geothermal production on São Miguel Island (sources: EDA, S. A., 2007 to 2018; EDA RENOVÁVEIS, S. A., 2007 to 2018).

cook a traditional Portuguese meat stew with vegetables, which is highly appreciated by locals and tourists. In the 1990s a small greenhouse demonstration project promoted by the INOVA Institute used heat from the geothermal water discharged from the Pico Vermelho pilot power plant for horticulture, but the project was abandoned upon the dismantling of the pilot plant in 2005. There are no ground source heat pumps in the Azores.

The Azores Archipelago has mild ambient temperatures, limiting the need for space heating. Thus, apart from those described above, there are no other direct uses of geothermal heat in the archipelago. Over the past decade, some projects were envisaged for São Miguel Island. The more prominent are the use of geothermal heat for industrial uses in dairy processing plants or to heat the swimming pool of the Ribeira Grande municipality, but the greatest challenge to development has been the demonstration of economic feasibility, because of the low demand and the lack of investors.

Contributions of geothermal energy

Traditionally, power generation in the Azores has been based on the consumption of fuel oil in thermal power plants. However, over the past 30 years, the contribution of renewables to power generation has increased significantly, predominantly driven by the geothermal developments on São Miguel and Terceira Islands, and this has produced important environmental and economic benefits.

In the Azores, the geothermal tariff is relatively stable (~0.10 €/kWh), whilst the production cost from the thermal plants fluctuates highly over time (***Figure 8***), as it is greatly dependent on the crude oil price on the international market. Moreover, geothermal production allows the investment to stay in the local economy, whilst the money spent on purchasing fuel is lost by the region.

Since 2007, geothermal production in São Miguel Island has replaced about 390,000 tonnes of fuel, with an estimated total worth of 178 million euros (***Figure 9***). Likewise, in 2018, the geothermal production in Terceira Island replaced about 4,700 tonnes of fuel, corresponding to savings on the import of fuel of 2.2 million euros.

Geothermal energy is also environmentally friendly, helping to reduce the carbon footprint of power generation. The geothermal fluid is composed of hot water and steam, and a small fraction of the steam corresponds to non-condensable gases. These are the same gases that are released in the natural fumaroles, corresponding mostly to CO_2, minor amounts of H_2S and vestigial fractions of CH_4 and H_2 (Ferreira *et al.*, 2005). After the heat exchange process in the binary plants, these gases are released to the atmosphere, along with some water vapour.

Compared to the fossil fuel alternative, for the same given power generation, the geothermal emissions are one-third to one-quarter of those released by the thermal power plants (***Figure 10***). However, a more appropriate comparison between geothermal and the fossil fuel alternative should include the CO_2 emissions resulting from the direct combustion of fuel and also the emissions generated by its extraction, processing, and transportation to the Azores. Thus, to make more realistic comparisons, the complete fuel-cycle emissions are required. For 2018, geothermal production in the Ribeira Grande field has avoided the emission of about 87,000 tonnes of CO_2, which is equivalent to the electricity use of about 15,000 homes in one year (EPA, 2019). Moreover, recent studies have estimated that natural CO_2 emissions occurring in Furnas volcano (Pedone *et al.*, 2015), released by fumaroles, hot springs and degassing soils, make up 1,030 t/day.

This is 10 times greater than the combined emissions from the Pico Vermelho and Ribeira Grande plants (~90 t/day).

Challenges for the geothermal expansion

Due to the relevance of the current geothermal contribution on São Miguel and Terceira Islands, there are on-going plans to expand the geothermal installed capacity in the Ribeira Grande (+5 MW) and Pico Alto (+7 MW) fields. In addition, there are several prospects with potential for development on other smaller islands (Faial, Graciosa, Pico and São Jorge) waiting to be evaluated.

Worldwide, geothermal projects for power generation are generally designed to fill the base of the load diagram. This is because geothermal output is always on, with the power plants operating continuously and at higher capacity factor than other renewables with intermittent output. This favours geothermal development, securing it the status of guaranteed power. However, in the small power systems of the Azores, geothermal expansion faces some challenges imposed by the low demand.

In fact, following the load diagram of São Miguel and Terceira power systems, the demand during off-peak hours constrains the additional geothermal capacity that can be installed. This is because geothermal production shares the base-load needs with the thermal plants, with the diesel generator units operating at the minimum required technical limits to ensure the stability of the power systems, namely by providing the grid forming capabilities (spinning reserve and the controls of frequency and voltage). Moreover, during the off-peak hours, production from intermittent renewables (wind) is already being partly or completely curtailed.

Bearing this in mind, and with the stagnation in demand throughout the last decade, the integration of additional geothermal production may depend on the ability of geothermal to provide the same grid forming capabilities that are currently assured by the thermal plants. This may require the geothermal projects of the Azores to follow the example of Puna Ventura in Hawaii (Nordquist *et al.*, 2013) and possibly adjust the operation of the ORC binary plants into flexible and dispatchable units that can swiftly ramp up and down, following the load needs.

An alternative (or complementary) solution is to implement energy storage projects. For São Miguel and Terceira Islands, there are projects under development to install Battery Energy Storage Systems

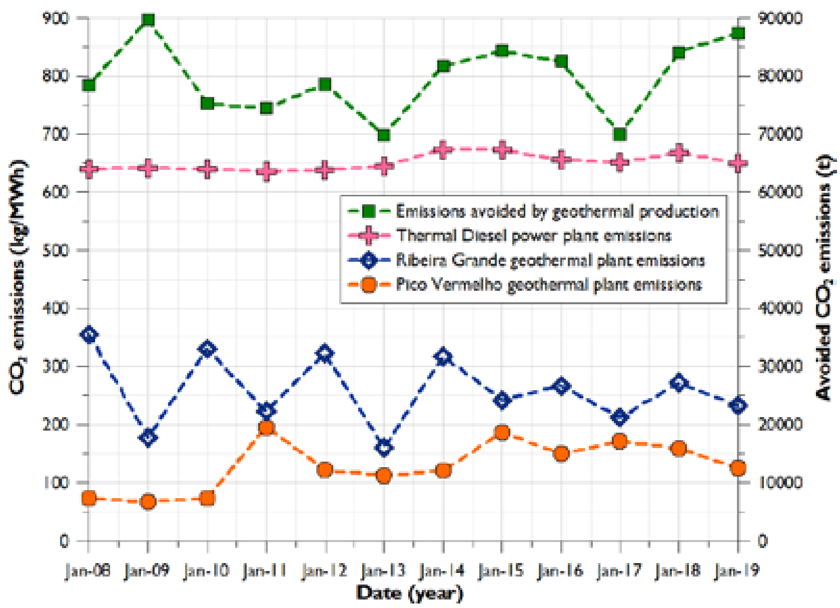

Figure 10: History of CO_2 emissions by energy source (sources: EDA, S. A., 2007 to 2018; EDA RENOVÁVEIS, S. A., 2007 to 2018).

(BESS). These will allow the integration of additional renewable production by storing the excess power produced during off-peak hours and discharging it to the grid during peak-load or medium-load hours, and securing the grid forming capabilities. The success of the BESS projects will surely benefit geothermal expansion.

In addition, geothermal development in the smaller Islands, where the base-load demand is less than 4 MW, is currently not economically feasible. However, exploration works in the more promising prospects should be encouraged by the Azores Regional Government to assess the resource potential, as investment opportunities may follow.

Conclusions

Over the last 30 years there has been a significant increase in renewable power generation in the Azores, where its contribution has grown from 5% to 37%. Geothermal is at the forefront of this energy transition away from fossil fuels, currently providing 42% of the electricity needs on São Miguel and 11% on Terceira Island.

Geothermal production is environmentally friendly, reducing the carbon footprint from power generation. For the same given power generation, the geothermal emissions are one-third to one-quarter of that from the thermal plants consuming fossil fuels, not counting the emissions from the extraction, refining, and transport of the fuel oil to the Azores. As a result, in 2018 the geothermal production on São Miguel Island avoided the emission of 87,000 tonnes of CO_2, which is equivalent to the electricity use of 15,000 homes in one year.

In the Azores, geothermal is also a cost-effective option, capable of competing with the fossil fuel alternative. The geothermal tariff is very stable over time, as it is not dependent on the fluctuations of the crude oil price in the international market. Therefore, geothermal has great economic value, acting as a price stabiliser for power generation, reducing the dependency on the import of fuel and fostering the energy self-sufficiency of the Azores.

There are on-going plans to expand the geothermal capacity on São Miguel and Terceira Islands, but there are challenges imposed by the low demand during off-peak hours. This may require geothermal to adjust its binary plants into a more flexible operation that can quickly ramp up and down, following the load to meet the electricity needs throughout the day or it may require solutions for energy storage to be implemented (or both). The Battery Energy Storage System projects that are under development for these islands will be crucial to integrating additional geothermal power generation.

Acknowledgements

The authors would like to thank EDA RENOVÁVEIS S.A. and EDA S. A. for authorising this paper and providing valuable data from the geothermal projects in São Miguel and Terceira Islands.

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Shallow geothermal energy: Geological energy for the ecological transition and its inclusion in European and national energy policies

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Of all possible forms of energy substitution of oil and gas, geothermal energy is the one most closely related to geology. Shallow geothermal energy is a source of clean, renewable and virtually inexhaustible energy that is directly related to geographical areas, where heat fluxes and temperature gradients can vary due to several factors. This document summarises the current situation of the policies on the use of shallow (low temperature) geothermal energy in Europe to generate hot water and air conditioning. The current status of legislation in some European countries and the promotion of shallow geothermal energy in the EU28 are also discussed.

Parmi toutes les formes d'énergie de remplacement du pétrole et du gaz, l'énergie géothermique représente celle qui est la plus proche de la géologie. L'énergie géothermique à faible profondeur constitue une source d'énergie propre, renouvelable et virtuellement éternelle, en relation directe avec les zones géologiques pour lesquelles les gradients de flux et de température peuvent varier en fonction de plusieurs facteurs. Le document présenté résume la situation actuelle concernant les politiques européennes d'utilisation de la géothermie peu profonde (basse température ou basse enthalpie) pour la production d'eau chaude et d'air conditionné. Sont abordés ici l'état actuel de la législation relative à quelques pays européens ainsi que la promotion de l'énergie basse enthalpie à destination des 28 pays de l'Union Européenne.

De todas las fuentes de energía posibles para sustituir al Oil&Gas, la energía geotérmica es la que más estrechamente se relaciona con la geología. La energía geotérmica superficial es una fuente de energía limpia, renovable y virtualmente inextinguible que está directamente relacionada con determinadas áreas geográficas, donde el flujo de calor y el gradiente de temperatura puede variar debido a determinados factores. Este documento resume la actual situación de las políticas de uso de la energía geotérmica de baja entalpia en Europa para generar agua caliente y aire acondicionado. De la misma manera, se ponen en discusión el estado actual de la legislación y la promoción de esta energía en algunos de los países europeos.

Introduction

In Europe, the air conditioning (heating and cooling) of buildings makes up a large part of the energetic demand in the present society, since heat/cold is a vital part of the energetic needs of the human beings. This type of energy demand accounts for approximately 86% of final energy consumption in homes, 76% in commerce, services and agriculture and 55% in the manufacturing industry (Burkhard, 2011).

At present, 81% of this energy required for air conditioning in the EU28 countries is generated from coal and oil. This is why the current heating and cooling systems not only increase the high cost of imports of fossil fuels from third countries (some of them unfriendly to international environmental regulations), but also represent an important contribution to greenhouse gas emissions and, by extension, to climate change. In this context, shallow geothermal energy for space heating/cooling and hot water represents a source of renewable energy with a large potential for energy savings and also reduction of pollution, since it is used in the same place where it is produced.

A definition of what shallow geothermal energy is found in Article 2(c) of Directive 2009/28/EC: 'Shallow geothermal energy means energy stored in the form of heat under the surface of solid earth'. Similarly, UNECE (the United Nations Economic Commission for Europe), defines geothermal energy as the thermal energy contained in a body of rock, sediment and/or soil, including any fluid contained in them that is available for extraction and conversion into energy products.

Among the different types of geothermal energy is the shallow type, also known as low or very low enthalpy (since the temperatures in the shallow soil located up to 500 m of depth are low), which can achieve

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up to 70% energy savings compared to traditional systems of air conditioning and hot water generation (Stylianou *et al.*, 2017) and is therefore one of the technologies that can decarbonise this sector. In addition, these systems can supply not only heat but can also meet the demand for cooling.

However, the sector faces important challenges, some of which are related to regulatory barriers at different levels that affect the implementation of these systems in the cities at the level of self-promotion, for housing groups or at the area level with a district heating system.

In this regard and taking into account the basic European Union regulations on the implementation of renewable energies within the regulatory framework for EU28 countries, the European Commission is committed to achieving the following objectives by the end of the year 2020:

- Reducing at least 20% of greenhouse gas emissions compared to 1990 levels;
- Achieving 20% of the final energy consumption from renewable sources;
- And finally, achieving an improvement in energy efficiency in the construction sector of 20%.

With these objectives for the entire EU28 territory, shallow geothermal energy represents a renewable energy source with wide potential and therefore it should be a key technology in achieving the objectives of the EU's energy policy in the years to come.

Some additional benefits of the use of shallow geothermal technologies are:

- Reducing dependence on fossil fuel imports – which in many cases are subject to the swings of financial markets – and increasing the security of the energy supply;
- Increasing local added value, generating wealth, creating jobs, establishing population and businesses;
- Attracting innovation by creating industrial R&D and technology parks;
- Contributing to the provision of affordable energy without the price volatility that is typical of fossil fuels in international commodity markets.

How shallow geothermal energy works

Shallow geothermal energy is used to describe systems installed at no more than a depth of 500 m to take advantage of the temperature, which is below 100 °C in the case of low enthalpy and below 25 °C in the case of very low enthalpy (Rivas, 2019).

Shallow geothermal energy is usually produced using heat pump technology which is an electrical device that extracts heat from one place and transfers it to another. These devices transfer heat by circulating a substance through evaporation-condensation cycles. A compressor pumps this refrigerant between two coils that exchange heat. In one of them the refrigerant evaporates at low pressure and absorbs the heat from its immediate surroundings. Then, the refrigerant is compressed at high pressure in the other coil where it condenses. At this point, it releases the heat that it absorbed previously. The heat pump cycle is fully reversible, and heat pumps can provide year-round climate control – heating in winter and cooling and dehumidifying in summer. Since the ground and air outside always contain some heat, a heat pump can supply heat even on cold winter days (NRC, 2018).

In a favourable context to the use of shallow geothermal energy, the heat can be extracted directly from the ground or, where appropriate, from the groundwater contained by the aquifers. The depth required to use a heat pump will depend on the heating demand. The need for heating in a single-family home is not the same as what a neighbourhood, a residential area or an industrial estate. This is why the geothermal surface energy can be divided according to the depth and constant temperature of the subsoil in several types that are directly related to the indicated heat output (Krarti *et al.*, 1995):

- Up to 0.5 m depth: The surface of the soil exchanges heat with the atmosphere and is undergoes daily temperature variations.
- Up to around 10 m depth: Seasonal temperature variations are noticeable in the ground. Some authors consider that in the south of Europe from 5 m depth, the temperature is around 15°C with small variations (e.g. Burroughs, 2003). From 10 m deep and depending on the characteristics of the subsoil the temperature of the ground can remain constant throughout the year.
- At a depth of 15 m: The soil is considered to be at constant temperature all year round with a value that, depending on the external climatic conditions, may be slightly higher than the average annual surface temperature. From this depth, the temperature of the subsoil does not depend on seasonal variations in temperature, only on geological and geothermal conditions.
- Below 20 m depth: The temperature increases at a rate of 3 °C per 100 m (average geothermal gradient), being 25–30 °C at 500 m depth in most of the planet.

With all the exposed so far, it can be said that from 15 m depth the temperature of the subsoil will be constant throughout the year, being higher than the atmospheric temperature in winter and much colder in summer (obviously this will depend on the climatic zone where the geothermal installation is located).

Also, taking into account that a heat pump has a better performance the lower the temperature difference between the indoor environment (home) and the environment where heat is sought (subsoil or groundwater), it seems clear that it will be more efficient to get the heat from a medium where the temperature is around 15 °C throughout the year than from an environment where the temperature in winter can be below zero degrees and in summer reach 40 °C (Llopis y Rodrigo, 2014).

To know the exact characteristics and temperature of the subsoil it is necessary to carry out tests, which are often expensive, so for the design of low-power (e.g. single-family residences) installations standardised values of the thermal properties of the land are usually used. These values serve as a guide for a first estimate of the number of geothermal drillings or metres of surface pipe required, although afterwards it will be necessary to check these data.

When/why/where to choose a heat pump

The outside air is the fundamental parameter to determine whether it is possible to use a heat pump as an air conditioning system. The reason is that the interior conditions are fixed by the regulations (in Spain, Regulation of Thermal Installations in Buildings, RITE), while the outside temperature depends on each location. With the heating mode of the heat pump you can know if it is possible to use this type of air conditioning.

The decrease in the outside temperature decreases the heating capacity of the system making it very complicated to install a heat pump in places with temperatures below 0 °C during many winter days. For coastal areas where temperatures are moderate and stable are frequent, good results are obtained. In practice, it is considered that -5 °C is the operating limit temperature for an air-air pump (Somogyi *et al.*, 2017).

Types of heat pumps (Omer, 2008; Sarbu and Sevarchievici, 2013)

Depending on the fluid (air or water) found in the hot or cold spots of the air conditioning, there are different kinds of heat pumps:

Air-Air

This is very typical in domestic air conditioning since its installation is very simple. Split type units are the most used in homes of 60–120 m^2. They consist of an indoor unit and an external unit with two different operations that take advantage of the phase change of the refrigerant: in summer, they take the heat from the interior and transport it to the outside, while in winter they take heat from the outside air and pump it inside.

Air-Water

The air-water heat pump also uses outside air and still has the outside temperature limitations of air-to-air pumps. It is used in systems with the support of another heating system or domestic hot water. Water with this system is heated to between 30 °C and 60 °C. This system is suitable in those places where, due to its temperature range, heating is required in winter and cooling in summer. When used to generate hot water its annual yield is optimal.

Water-water

The system is similar to the previous one but the heat transfer is in a water circuit. The disadvantages regarding the proximity of surface water sources are similar to those of the previous system. Its combined use with renewable energies, such as solar thermal energy, may be adequate for this system, although it is quite complex.

Earth-Water

The heat and cold of the air conditioning system is achieved with the transfer of heat from and to the ground. A large area is needed to place the buried installation, about four times the surface of the building to be heated. The study of the shallow soil in this type of systems is fundamental to correctly dimension this type of heat pump. If land area is limited, vertical geothermal energy is another option. To calculate the type and depth of boreholes it is necessary to know the geology of the subsoil and a series of parameters related to the geothermal gradient.

Shallow geothermal energy in the EU28

If we take into account the territory occupied by the current members of the European Union, in terms of the number of facilities, installed capacity and energy produced, shallow geothermal is the largest and most widespread geothermal energy sector in Europe; the power generation facilities (medium and high enthalpy) are restricted to a few countries with certain geological conditions, such as Italy, France or Iceland (outside of the EU28 but in the EEA), for example.

In this context, the European countries with the most quantity in number of installations of shallow geothermal heat capture systems are Sweden, Germany, France and Switzerland (not included in the EU28). These four countries account for 64% of all installed capacity in Europe (ReGeoCities, 2017).

EU legislation on shallow geothermal energy

The basic legislation of the European Union on energy was based for many years exclusively on the European Commission Authority for the internal market and the environment. However, with the inclusion of a modification in the Lisbon Treaty of 2009, energy has become an area of shared competence between the institutions of the Union and the Member States.

In fact, Article 194 of the Treaty of the Union states that in the context of the establishment and functioning of the internal market and regarding the need to preserve and improve the environment, the European Union's energy policy, in the spirit of solidarity between Member States, should try to:

a. ensure the functioning of the energy market;
b. strengthen the security of energy supply in the European Union;
c. promote efficiency, energy saving and the development of new and renewable forms of energy.

This provision, therefore, legitimises the European Union to legislate on various issues that directly or indirectly affect the geothermal sector of low and very low temperature.

Therefore, we can summarise the fundamental legislation for geothermal energy in the EU28 in the following:

- Directive 2009/28/EC on the promotion of the use of energy from renewable sources;
- Consolidated Directive 2010/31/EU on the energy performance of buildings;
- Directive 2012/27/EU on energy efficiency;
- Consolidated Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products;
- Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU on the indication through labelling and standardised product information on energy consumption and other resources in energy-related products.

Based on this legislative background, the European Commission set a timetable for the implementation of EU28 legislation relevant to shallow geothermal energy with the following milestones:

- By July 2012: Member States had to transpose the 2010 version of the Directive that replaced the previous version of 2002;
- 2013: The European Commission published guides on the calculation of renewable energy of heat pumps;
- 2014: Member States had to renew an average of 3% of public buildings each year in relation to energy efficiency and substitution of fossil fuels for clean energies;
- 2015: Member States should establish minimum levels of renewable energy in the energy consumption of buildings;
- 2017: Member States had to incorporate to the own legislation the 2017 Regulation that replaced the previous Directive 2010/30;
- December 31, 2018: All new public buildings must be constructions where renewable energy prevails against fossil fuels of any kind
- December 31, 2020: All new private buildings must be constructions where renewable energy prevails against fossil fuels of any kind.

Table 1: Energy objectives of renewable energies in some of the EU Member States, 2010 and 2020 (modified from ReGeoCities).

Country	Final energy consumption in 2010 (ktoe)	Part of renewables in air conditioning in 2010 (ktoe)	Part in percentage (%)	Predicted final energy consumption in 2020 (ktoe)	Predicted share of renewables in air conditioning in 2020 (ktoe)	Predicted share in percentage (%)
Austria	12,007	3657	30.5	12,802	4179	32.6
Belgium	21,804	766	3.5	21,804	2588	11.9
Czech Republic	17,805	1810	10.2	18,680	2672	14.3
Denmark	8,042	2480	30.8	7,653	3042	39.7
Finland	14,010	5210	37.2	15,300	7270	47.5
France	67,159	11124	16.6	60,000	19732	32.9
Germany	111,597	10031	9.0	93,139	14431	15.5
Greece	8,644	1269	14.7	9,674	1908	19.7
Hungary	10,347	949	9.2	9,719	1863	19.2
Ireland	5,160	220	4.3	4,931	591	12.0
Italy	58,976	3851	6.5	61,185	10456	17.1
Netherlands	24,612	906	3.7	24,989	2179	8.7
Poland	32,400	3980	12.3	34,700	5921	17.1
Portugal	7,286	2240	30.7	8,371	2507	29.9
Romania	15,788	2819	17.9	18,316	4038	22.0
Spain	33,340	3764	11.3	29,849	5645	18.9
Sweden	14,488	8237	56.9	16,964	10543	62.1
United Kingdom	60,000	518	0.9	51,500	6199	12.0

Management of shallow geothermal resources and protection of the environment

The development of shallow geothermal systems of low or very low temperature can be affected by administrative measures at different levels for the promotion of renewable energy and energy efficiency, as well as by the European and State regulation aimed at protecting and improving the environment.

For example, Directive 2000/60/EC, which establishes a framework for community action in water policy and specifically for groundwater located in aquifers, requires Member States to implement measures to prevent water deterioration and prevent or limit its contamination.

Groundwater is considered quantitatively (in volume) much more significant than surface water. Therefore, the prevention of possible contamination due to any cause, its monitoring and, where appropriate, its restoration are much more complicated due to its direct inaccessibility. That is why this Directive gives priority to any other condition and establishes the prohibition of direct water discharge to groundwater.

Due to this, the application of water legislation to shallow geothermal energy will depend on the system for capturing heat from soil. It is important to highlight that – following the tendency to share responsibility between the European Union and national governments – Article 11 of Directive 2000/60/EC gives the Member States the possibility of authorising the re-injection of the water used for shallow geothermal purposes into the same aquifer in the case that it does not compromise the environmental objectives.

This Directive is complemented by Directive 2006/118/EC on the protection of groundwater against its pollution and deterioration. This Directive establishes specific measures to prevent pollution and to limit the introduction of pollutants. It also introduces criteria for the good chemical status of groundwater and criteria for the identification of points of change.

However, in other fields that also affect shallow geothermal energy, the EU only defines a general framework or one that has a minor impact. This means that the largest source of regulation is national and that, finally, it can vary and in fact does vary from one country to another. This is the case with, for example, soil protection.

Likewise, it remains a national competence to determine whether a shallow geothermal drilling project should be subject to a study in accordance with Directive 2011/92/EC on the effects of certain public and private projects on the environment. In the case of Spain, for example, it is the mining law that regulates the implementation of drilling, establishing responsibilities and competent technicians.

Finally, it is important to emphasise that, while the evolution of legislation in the European Union may increase the opportunities to implement shallow geothermal systems in Europe, the development of these technologies will depend on national and, in some cases, regional or local legislation.

National objectives regarding the use of shallow geothermal energy

Renewable Energy Directive (2009/28/EC) required the Member States to send renewable energy action plans before June 30, 2010. These plans were intended to provide detailed roadmaps of how each EU28 State hoped to achieve the goals committed for 2020 in renewable energies and the energy mix that they hoped to use to supply the population, agriculture and industry. ***Table 1*** shows the objectives of selected Member States for 2010 and 2020.

We can see how the European Union has set objectives to ensure that from 2020 all new buildings are energy efficient, while recognizing the differences in the types of buildings built and the climate of different countries and regions of Europe.

This is why Directive 2010/31/EU requires that Member States must ensure that all new buildings occupied and in possession of local authorities after 31 December 2018 will be almost zero energy , by 31 December 2020 all new buildings are also in this category Member States should also develop national plans to increase the number of buildings with low energy consumption characteristics and develop policies that take measures for the establishment of stimulus objectives for the transformation of buildings to low-consumption energy buildings. Such buildings are defined in Article 2 of the recast Directive as buildings with high energy efficiency: 'The demand for energy, close to zero or very small, should be covered mainly by renewable sources, including renewable energy produced on or near the site.'

Unfortunately, the main building codes and incentives for the construction or renovation of buildings towards those with low energy consumption rarely mention shallow geothermal systems. However, the option of including them under the umbrella of other renewable systems is generally accepted, since these shallow geothermal systems fit into national legislation on renewable energies at all levels. The methods of calculating energy savings must be carried out with methods approved by the European Union.

In some countries, such as France, Spain, Italy and the Netherlands, the regulations of air conditioning and building codes do not clearly indicate that shallow geothermal systems should be considered as a possible solution for reducing energy consumption in buildings (Haehnlein *et al.*, 2010):

- In France, the 2012 regulation for new constructions (RT2012) gives maximum energy consumption values for heating, domestic hot water, refrigeration, lighting and auxiliaries.
- In Spain, in the Technical Building Code (CTE) there are requirements related to renewable energies exclusively for the production of water (60% of hot water must come from renewable sources), which in most cases is achieved by means of thermal solar panels regulated by regulations of regional or local scope.
- In Italy, the Legislative Decree of 3 March 2011 (n.28) introduces quantitative objectives for the integration of heating, ventilation and air conditioning systems with renewable energy in regard to new buildings and structural rehabilitation of buildings. Shallow geothermal systems are not specifically considered.
- In the Netherlands, shallow geothermal energy is not directly integrated into the legislation for air conditioning of buildings but is indirectly affected by the Construction Regulations.

Conclusions

We can conclude that although European legislation includes and encourages the use of shallow geothermal energy as an important means of reducing greenhouse gases in the generation of hot water and air conditioning of housing, agriculture and industry, the legal frameworks of the different EU28 members are very diverse in what concerns the obligation of the inclusion of surface geothermal energy among the different renewable energy systems that can be used for these tasks. Likewise, different countries, depending on the transposition mode of the European Directives on energy, water and environment, enact legislation that regulates to a greater or lesser extent the use of different shallow geothermal capture systems and how to interact with the masses of groundwater.

This overview also indicates that the regulatory framework can be a barrier to the development of shallow geothermal systems. The lack of regulation, complex procedures, delays in administrative approvals, costly procedures, distribution of competences in a complex manner between different authorities (national and local) and heterogeneous procedures depending on the region could be usually the most common obstacles to national development and regional shallow geothermal systems in the air conditioning of buildings.

Shallow geothermal energy of low and very low temperature is a type of energy directly related to geology, relatively easy to extract, not requiring transport, with a cost perhaps somewhat more expensive in its installation than a diesel installation but with a higher efficiency and return on investment to families and also to industry (the average cost of a geothermal installation in a single-family home is between 20,000–40,000 euros depending on the number of wells to be made and the type of terrain, as well as the power of the heat pump to be used (Clickrenovables.com, 2018). It can be supplied according to needs and without uncertainty in the prices, since it is not subject to speculative ups and downs produced by financial markets. It is a clean and inexhaustible energy that constitutes a real energy transition from fossil fuels and that unfortunately has not been sufficiently promoted and encouraged by the national and regional authorities in their legislative capacity.

This is why the shallow geothermal energy should have a regulatory framework that goes hand in hand with the advancement of science and technology in shallow geothermal heat capture systems to encourage their use in newly built and refurbished homes and buildings, in agriculture and in industry.

Finally, broader geological survey of the entire territory of the EU28 would lead to better knowledge of the shallow soil for the most efficient systems of extraction of underground heat for hot water and air conditioning, thus reducing the effects of climate change and helping to ensure the future of our planet.

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Consolidated Directive 2010/30/EC on the indication through labeling and standardized product information on energy consumption and other resources in energy-related products.

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Compiled by Isabel Fernández Fuentes and Anita Stein, EFG Office

EFG Council approves revised CPD scheme

During the EFG Council meeting in November 2018, a revised version of EFG's regulation regarding Continuing Professional Development (CPD) was approved.

The revised CPD scheme includes the following changes for European Geologist title holders:

- To simplify the CPD classification scheme, the two Formal Learning categories (FLT and FLU) have been merged to one new FL category and the two categories of "Participating in the Geoscience Community" (PGC) to one.
- Following up on discussions with overseas sister organisations, the need for training courses in Social Competence and Ethics has been recognised and is honoured in the new CPD scheme with two subcategories:
    - Social Responsibility (SR): first aid, fire protection, mine rescue, etc.
    - Ethics (ETH): courses on ethics and compliance in professional life.
- To promote the excellence and the quality of the EuroWorkshops and EFG's Endorsed Training Programme, a new category has been included: EWS (EuroWorkshop & Endorsed Training).
- In addition, an extra category for activities relating to EFG's International Mentoring Programme has been added.
- Within the category "Professional practice", a subcategory on "Non-job learning" (NJL) has been included which encourages European Geologists to extend their CPD programme to other non-geological fields like learning languages and improving their management skills.

These changes within the CPD scheme have been implemented in the EurGeol App (***www.eurgeoltitle.eu***), a completely revamped version of the former EurGeol tool, launched in February 2019.

In addition to these changes, which impact the requirements for European Geologists in terms of reporting their CPD activities, a change for new title applications has been implemented in the Federation's regulations. For most certified geologists and Competent Persons worldwide, the major requirement is a minimum of five years' professional experience in the relevant field of geology. During the Çesme Council Meeting in May 2018, it was therefore decided to lift the requirements for applicants to the EurGeol title from four to five years of experience in all fields of geology. This change to the EFG regulations was officially implemented during the November Council meeting and is now applicable to all new title applications.

More information about the EurGeol title: ***https://eurogeologists.eu/eurgeol-title/***

EFG signs Memorandum of Understanding with Indonesian Society of Economic Geologists

On 5 December 2018, EFG and the Indonesian Society of Economic Geologists (MGEI) signed a Memorandum of Understanding (MoU) at the 10th Annual MGEI Meeting in Makassar, Indonesia, which will foster the cooperation between both organisations. On behalf of EFG, the agreement was signed by President-Elect Marko Komac.

MGEI is a professional organisation that includes specialists in the field of economic geology, and especially geologists engaged in the mineral and coal mining business in Indonesia. MGEI is a commission of the Indonesian Association of Geologists (IAGI), founded in 2008 with the purpose of encouraging experts and enthusiasts in economic geology in Indonesia to play an active role in the development potential, management and use of economic minerals in Indonesia to benefit the prosperity of people as much as possible.

According to the MoU, EFG and MGEI will promote the following activities:

- Exchange of information on key programmes and initiatives;
- Expansion of membership of both organisations through possible joint programmes;
- Exchange of information and possible joint activities concerning international cooperation, educational opportunities, student programmes and professional services;
- Exchange of information and possible co-organisation of scientific conferences.

EAGE/EFG photo contest 2018

From January till March 2019, all members of EAGE and EFG's National Associations were invited to submit their photos to the annual photo contest. This year the contest runs under a new theme, "Legends of Geoscience", and the participants were invited to cover one of the following questions: How would you depict the link between geoscience and society? Do you know women who are role models in geology? Is there any beautiful geological landscape you would like to reveal in a different light? More than 60 photos have been submitted to this edition and public voting is currently ongoing to determine the winners, who will be announced in October.

More information: ***https://eage.eventsair.com/photocontest***

Annual report 2018

EFG is glad to release its annual report of activities for the year 2018. The report is structured according to the six strategic action plans of the EFG Strategic Plan "Towards a sustainable future" for the period 2018-2022:

- EFG Members,
- EFG Network,
- Professional Expertise,
- EFG Projects,
- EFG Communication, and
- Panels of Experts

The report is available at ***https://eurogeologists.eu/annual-reports/***

Horizon 2020 projects

Horizon 2020 is the biggest EU research and innovation programme ever, with nearly €80 billion of funding available to secure Europe's global competitiveness in the period 2014–2020. EFG is currently involved in five active Horizon 2020 projects: UNEXMIN, CHPM2030, INFACT, INTERMIN and MINLAND. The projects FORAM and VAMOS recently closed, but new projects have already been granted and will start soon. Below you will find descriptions of the topics and aims of these projects.

¡VAMOS!

642477 - VAMOS
¡Viable and Alternative Mine Operating System!
START DATE: 1 February 2015
DURATION: 42 MONTHS
http://vamos-project.eu

Stated objectives:

The aim of the EU-funded ¡VAMOS! (Viable Alternative Mine Operating System) project is to design and build a robotic, underwater mining prototype with associated launch and recovery equipment, which will be used to perform field tests at four EU mine sites. Deriving from successful deep-sea mining techniques, the ¡VAMOS! mining solution aspires to lead to: 1) reopening abandoned mines; 2) extensions of open cut mines which are limited by stripping ratio, hydrological or geotechnical problems; and 3) opening new mines in the EU.

EFG role and current status:

EFG supports the project through stakeholder engagement and dissemination activities.

The project has delivered an Innovative Mining System Prototype. In this context, EFG supported the selection of mining sites for field tests and the planning of field activities. For the future, the project has produced a feasibility, viability and market up-take. EFG contributed to the evaluation of the economic feasibility studies and to the Exploitation Plan for the VAMOS technology.

FORAM

730127 – FORAM
Towards a World Forum on Raw Materials
START DATE: 1 November 2016
DURATION: 24 MONTHS
http://foramproject.net/

Stated objectives:

The project Towards a World Forum on Raw Materials (FORAM) will develop and set up an EU-based platform of international experts and stakeholders that will advance the idea of a World Forum on Raw Materials (WFRM) and enhance the international cooperation on raw material policies and investments. This platform will work together on making the current complex maze of existing raw material related initiatives more effective. As such, the FORAM project will be the largest collaborative effort for raw materials strategy cooperation on a global level so far. The FORAM Consortium is composed by twelve international organisations and government bodies, industries, SMEs, and universities with mixed and exclusive expertise in international dialogues in the field of non-energy abiotic raw materials. The Project Coordinator is the Swiss based World Resources Forum Association (WRFA).

EFG role and current status:

EFG led Work Package 3 on "Strategic Planning", which will set the stage for the World Forum on Raw Materials (WFRM) using a highly participative process. WP3 was intended to define and present a long-term vision and its strategic positioning, as well as an appropriate framework to measure performance and to respond to geo-political, technological and economic changes.

EFG contributed to the global mapping of existing initiatives, actions and stakeholders on mineral raw materials, and contributed to setting up and organising the Stakeholders Panel and leading several meetings and consultations with relevant stakeholders on international cooperation.

In WP3 Strategic Planning, EFG led the WP, defined the strategic vision of the Forum (D3.2), its strategic plan (D3.3) and the corresponding analytical dashboard, taking into consideration a scenario contingency plan (D3.4).

Regarding WP4 Roadmap, Pilot & Recommendations, EFG contributed to the organisation of the pilot event of the World Forum (D4.2) and to the synthesis report with the final recommendations to the EU (D4.3). A news article on the pilot event was produced and shared both on the EFG and on the FORAM website (***http://www.foramproject.net/index.php/2018/07/13/foram-18-pilot-event/***).

The project closed on 31 October 2018.

CHPM2030

654100 - CHPM
Combined Heat, Power and Metal extraction from ultra-deep ore bodies
START DATE: 1 January 2016
DURATION: 42 MONTHS
http://chpm2030.eu

Stated objectives:

The CHPM2030 project aims to develop a novel, pilot level technology which combines geothermal resource development, minerals extraction and electro-metallurgy in a single interlinked process. In order to improve the economics of geothermal energy production the project will investigate possible technologies of manipulating metal-bearing geological formations with high geothermal potential at a depth of 3-4 km in a way that the co-production of energy and metals will be possible and may be optimised according to the market demands in the future. Led by the University of Miskolc, the project will be implemented in the cooperation of 12 partners from 10 European countries.

EFG role and current status:

EFG supports the activities relating to the CHPM2030 methodology framework definition (WP1), particularly European data integration and evaluation: during the first months of the project, EFG's Linked Third Parties (LTP) collected publicly available data at a national level on deep drilling programmes, geophysical and geochemical explorations and any kind of geo-scientific data related to the potential deep metal enrichments. They also collected data on the national geothermal potential. Guidelines and templates for data collection were provided by EFG.

EFG also supported activities relating to road mapping and preparation for Pilots (WP6). EFG's Linked Third Parties assessed the geological data on suitable ore-bearing formations and geothermal projects collected in WP1, in relation with the potential application of the CHPM technology. This work combines these data with the outcomes of the most recent predictive metallogenic models. Only existing datasets will be utilised; no new surveys will be carried out.

EFG also leads the Work Package on dissemination.

The 42-month project is now entering its final stage. Many important tasks have already been completed and the project team is now working on the last elements to conclude the project successfully:

- System integration: The contemporary power plant design will be adapted to the expected temperature, between 120 and 190 degrees Celsius, and the conditions of extreme salinity that will occur under the CHPM2030 scheme.
- Integrated sustainability assessments: To ensure that the CHPM technology is safe for the environment and for society, the project is setting up a framework to assess environmental and socio-economic impacts, and is carrying out baseline economics for energy and mineral raw materials.
- Roadmapping and preparation of pilots: To pave the way for the long-term future of the CHPM technology, the project team is analysing study areas in the UK, Romania, Sweden and Portugal where the technology could be applied, and is using different foresight tools for the horizon 2030–2050.

Preliminary outcomes and results will be presented to the public at the CHPM2030 final conference to be held on 23 May 2019 in Delft, the Netherlands, in the framework of the EuroWorkshop "Geology and the Energy Transition".

UNEXMIN

690008 - UNEXMIN
Autonomous Underwater Explorer for Flooded Mines
START DATE: 1 February 2016
DURATION: 45 MONTHS
www.unexmin.eu

Stated objectives:

UNEXMIN is an EU-funded project that develops a novel robotic system for the autonomous exploration and mapping of Europe's flooded mines. The Robotic Explorer (UX-1) will use non-invasive methods for autonomous 3D mine mapping for gathering valuable geological and mineralogical information. This will open new exploration scenarios so that strategic decisions on the re-opening of Europe's abandoned mines could be supported by actualised data that cannot be obtained by any other ways.

The Multi-robot Platform will represent a new technology line that is made possible by recent developments in autonomy research that allows the development of a completely new class of mine explorer service robots capable of operating without remote control. Such robots do not yetexist; UX-1 will be the first of its kind. Research challenges are related to miniaturisation and adaptation of deep-sea robotic technology to this new application environment and to the interpretation of geoscientific data.

Work is ongoing with component validation and simulations to understand the behaviour of technology components and instruments to the application environment. This will then be followed by the construction of the first prototype. Post processing and data analysis tools will be developed in parallel, and pre-operational trials will be launched in real-life conditions. The final, most ambitious demonstration will take place in the UK with the resurveying of the entire flooded section of the Ecton underground mine (UK), which nobody has seen for over 150 years.

EFG role and current status:

Some of EFG's national associations participate in this project as Linked Third Parties and support the consortium through data collection for the inventory of flooded mines. EFG also supports the Work Package on dissemination and EFG's Third Parties disseminate the project results at national level in web portals, newsletters, conferences, workshops, educational activities, exhibitions or by any other relevant means.

As Work Package leader of WP5 (Stakeholder identification and engagement), EFG has recently focused on working on and coordinating the Task 5.1 Stakeholder identification and engagement and Task 5.4 Inventory of flooded mines.

Task 5.1 started at the beginning of the project and lasts until its end. Stakeholder identification and communication is essential to ensure the proper execution and success of the UNEXMIN project. The process will enable us to maximise support as the project progresses. Therefore EFG has decided to review the stakeholder dataset that has been continuously created in collaboration with the Partners since the beginning of the project, in order to reorganise and complete it. EFG has also prepared a stakeholders' engagement campaign.

Part of the UNEXMIN project was to create an inventory of flooded mines in Europe that will facilitate an online open-access user interface for browsing the database.

The pressure hull of the second UX-1 robot – UX-1b – has been produced, mechanical parts put together and pressure tested in Finland as part of TUT's work. It is now on its way to Porto, Portugal, where the technical teams (INESC TEC, UPM, UNIM) will assembly all the components and test the new robot in a pool where both hardware and software will be proved. The aim is to have two operational robots – UX-1a and UX-1b – ready for the field missions at the Urgeiriça uranium mine in Portugal. UX-1b, the second robot from the multi-robotic platform created within the UNEXMIN project, will be similar to its first counterpart, but with some other specificities. Mainly, differences in the scientific payload will be seen between the two robots. This will guarantee that different sensors are carried while reducing the size, weight and power demands for individual robots to do the exploration and mapping of the flooded mine environment.

The Urgeiriça trials took place during March and April 2019, 9–10 days in each month. Between the two sets of missions, the robots undergo fine-tuning and testing in INESC-TEC's testing pool in Porto. Here, the autonomy, control, movement and data collection and analysis of the robots will be extensively studied in order to get the most out of the robotic system.

INFACT

776487 – INFACT
Innovative, Non-invasive and Fully Acceptable Exploration Technologies (INFACT)
START DATE: 1 November 2017
DURATION: 36 MONTHS
www.infactproject.eu

Stated objectives:

Exploration discovery of raw material resources requires innovations that either change the geological targets of exploration, the physical places that are reached, or the manner in which they are explored. Despite its rich history of mining and residual mineral wealth, current conditions within the EU present a number of social, political, legislative, cost, technical and physical obstacles to raw material exploration: obstacles to be overcome by innovation, dialogue and reform.

The Innovative, Non-invasive and Fully Acceptable Exploration Technologies (INFACT) project unites stakeholders of Europe's future raw materials security in its consortium and activities. Via effective engagement of civil society, state, research and industry, the project will focus on each of these obstacles. It will co-develop improved systems and innovative technologies that are more acceptable to society and invigorate and equip the exploration industry, unlocking unrealised potential in new and mature areas.

The project will develop innovative geophysical and remote sensing technologies (less invasive than classical exploration methods) that promise to penetrate new depths, reach new sensitivities and resolve new parameters.

The project will also set the EU as a leader on the world stage by establishing permanent infrastructure to drive innovation in the next generation of exploration tools: tools that are cost-effective, designed for EU conditions and its raw materials strategy, and high-performing in terms of environmental impact, social acceptability, and technical performance.

INFACT is comprised of the following main components:

- Development and testing of innovative, non-invasive exploration technologies.
- Foundation of 3 test sites for exploration technology in the south, centre and north of Europe.
- Stakeholder engagement, education and policy reform.

These actions combine to reach each of the main areas in which the EU has the power to influence change in its raw materials security.

EFG role and current status:

EFG leads the work package on dissemination and impact creation and several of the Federation's National Associations are actively involved in the project as Linked Third Parties.

In spring 2019, 3 main geophysical measurements are planned at INFACT's Spanish reference site at the Rio Tinto and Las Cruces Mines:

- A passive seismic survey in Las Cruces (in collaboration with the EU project PACIFIC)
- Drone-based magnetometer and hyperspectral surveys in Las Cruces and Rio Tinto (performed by HIF HZDR)
- A helicopter-based airborne electromagnetic survey in Las Cruces and Rio Tinto (performed by Geotech and the subcontracting helicopter company Koopmann)

All measurements are planned to take place between mid-March and late April. The INFACT partners involved in stakeholder engagement activities are currently consulting with surrounding municipalities on their festivities in that period, particularly around Easter ("Semana Santa" in Spanish)) which is celebrated all over Andalusia between 15 and 21 April. Partners are also in contact with environmental authorities to ensure the lowest possible impact of the project activities on the local wildlife.

INTERMIN

776642 – INTERMIN
INTERNATIONAL NETWORK OF RAW MATERIALS TRAINING CENTRES
START DATE: 1 February 2018
DURATION: 36 months
http://interminproject.org/

Stated objectives:

INTERMIN will create a feasible, long-lasting international network of technical and vocational training centres for mineral raw materials professionals. Specific objectives:

- Develop common metrics and reference points for quality assurance and recognition of training;
- Develop a comprehensive competency model for employment across the primary and secondary raw materials sectors;
- Introduce an international qualification framework for technical and vocational training programmes;
- Create a conceptual framework for the development of joint educational training programmes based on present and future requirements by employers;
- Create and launch a joint international training programme by a merger of competences and scope of existing training programmes.

EFG role and current status:

EFG is cooperating with the project partners in six work packages and acting as the leader in WP3 (Towards enhanced training programmes (Response)). The INTERMIN project aims at mapping, connecting and enhancing the existing European training and education initiatives in the raw material sector. Therefore, the INTERMIN consortium aims at creating a self-sustainable international network of specialised training centres for professionals from the raw materials sector, and BDG (Berufsverband Deutscher Geowissenschaftler e.V.) is participating in the INTERMIN project as a third party of EFG. The Polish Association of Minerals Asset Valuators (PAMAV) is also involved in the project as an EFG Linked Third Party.

EFG is supporting the communication activities, sharing relevant information about the project through its website, newsletters and social media accounts.

In WP1 (International mapping of training programmes on raw materials and resources) EFG has contributed to the definition of a skills catalogue used by the raw materials sector (D1.1). The INTERMIN survey on mineral raw materials training programmes (D1.2) (http://intermin.limequery.com/324595?lang=en) has been shared broadly within the EFG network.

Regarding WP2 (Raw materials sector skills, gaps and emerging knowledge needs), EFG is contributing to the assessment of employers' needs and to the definition of skills gaps (D2.1).

MINLAND

776679 – MINLAND
Mineral resources in sustainable land-use planning
START DATE: 1 December 2017
DURATION: 24 MONTHS
http://minland.eu/

Stated objectives:

Access to mineral resources in Europe is one of the pillars of the Raw Materials Initiative (RMI). Yet competing societal interests, such as expanding cities, infrastructure development, agriculture and nature conservation, have had negative effects on the available area for exploration and mining of mineral resources. Consequently, the supply of mineral raw materials within the EU is at risk. Therefore, the integration of mineral resources policies into land-use planning at different scales and levels is a key factor for achieving the goals of the RMI.

The MinLand project is designed for addressing this challenge: to facilitate minerals and land-use policy making and to strengthen transparent land use practice. MinLand is composed around the acknowledgement that the call requires a broad and competent consortium with strong links to related projects and activities, a comprehensive and structured data repository, an efficient work flow and strong and broad stakeholder involvement.

EFG role and current status:

EFG supports the activities for valorisation and valuation of geological and societal data and civil society impacts. It is also involved in the network and clustering activities and in the communication, dissemination and exploitation of the project.

EFG is supporting communication activities by sharing relevant information about the project through its website, newsletters and social media accounts. Information about the MINLAND Delphi survey on "Future stakeholder needs and interests in mineral safeguarding and land use" (***bit.ly/2yJPbJQ***) has been shared broadly within the EFG network.

EFG is also producing a series of factsheets on the case studies analysed and studied within WP3. These factsheets will present a selection of relevant case studies in a visually attractive way.

In WP4 Land use practices, valorisation and valuation of geological and societal data and civil society impacts, EFG is contributing to the investigation of mineral policies and its requirements regarding land use in the EU Member states.

Submission of articles to European Geologist Journal

Notes for contributors

The Editorial Board of the European Geologist journal welcomes article proposals in line with the specific topic agreed on by the EFG Council. The call for articles is published twice a year in December and June along with the publication of the previous issue.
The European Geologist journal publishes feature articles covering all branches of geosciences. EGJ furthermore publishes book reviews, interviews carried out with geoscientists for the section 'Professional profiles' and news relevant to the geological profession. The articles are peer reviewed and also reviewed by a native English speaker.
All articles for publication in the journal should be submitted electronically to the EFG Office at ***info.efg@eurogeologists*** according to the following deadlines:

- Deadlines for submitting article proposals (title and content in a few sentences) to the EFG Office (***info.efg@eurogeologists.eu***) are respectively 15 July and 15 January. The proposals are then evaluated by the Editorial Board and notification is given shortly to successful contributors.
- Deadlines for receipt of full articles are 15 March and 15 September.

Formal requirements

Layout
- Title followed by the author(s) name(s), place of work and email address,
- Abstract in English, French and Spanish,
- Main text without figures,
- Acknowledgements (optional),
- References.

Abstract
- Translation of the abstracts to French and Spanish can be provided by EFG.
- The abstract should summarise the essential information provided by the article in not more than 120 words.
- It should be intelligible without reference to the article and should include information on scope and objectives of the work described, methodology, results obtained and conclusions.

Main text
- The main text should be no longer than 2500 words, provided in doc or docx format.
- Figures should be referred in the text in italic.
- Citation of references in the main text should be as follows: 'Vidas and Cooper (2009) calculated…' or 'Possible reservoirs include depleted oil and gas fields… (Holloway *et al.*, 2005)'. When reference is made to a work by three or more authors, the first name followed by '*et al.*' should be used.
- Please limit the use of footnotes and number them in the text via superscripts. Instead of using footnotes, it is preferable to suggest further reading.

Figure captions
- Figure captions should be sent in a separate doc or docx file.

References
- References should be listed alphabetically at the end of the manuscript and must be laid out in the following manner:
- Journal articles: Author surname, initial(s). Date of publication. Title of article. Journal name, Volume number. First page - last page.
- Books: Author surname, initial(s). Date of publication. Title. Place of publication.
- Measurements and units
- Measurements and units: Geoscientists use Système International (SI) units. If the measurement (for example, if it was taken in 1850) was not in SI, please convert it (in parentheses). If the industry standard is not SI, exceptions are permitted.

Illustrations
- Figures should be submitted as separate files in JPEG or TIFF format with at least 300dpi.
- Authors are invited to suggest optimum positions for figures and tables even though lay-out considerations may require some changes.

Correspondence

All correspondence regarding publication should be addressed to:
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Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: ***info.efg@eurogeologists.eu***

Note

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Advertisements

EFG broadly disseminates geology-related information among geologists, geoscientific organisations and the private sector which is an important employer for our professional members, but also to the general public.

Our different communication tools are the:
- EFG website, ***www.eurogeologists.eu***
- GeoNews, a monthly newsletter with information relevant to the geosciences community.
- European Geologist, EFG's biannual journal. Since 2010, the European Geologist journal is published online and distributed electronically. Some copies are printed for our members associations and the EFG Office which distributes them to the EU Institutions and companies.

By means of these tools, EFG reaches approximately 50,000 European geologists as well as the international geology community.

With a view to improving the collaboration with companies, EFG proposes different advertisement options. For the individual prices of these different advertisement options please refer to the table.

Prices for advertisements

EGJ	**One Insertion**	**Two Insertions**
Full page (colour)	820 Euro	1320 Euro
Half page (colour)	420 Euro	670 Euro
Quarter page (colour)	220 Euro	350 Euro
Full page (black and white)	420 Euro	670 Euro
Half page (black and white)	220 Euro	350 Euro
Quarter page (black and white)	120 Euro	200 Euro
Business card size	90 Euro	150 Euro
Preferential location	25% plus	
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Ad for training opportunities in the job area of the homepage	500 Euro	
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