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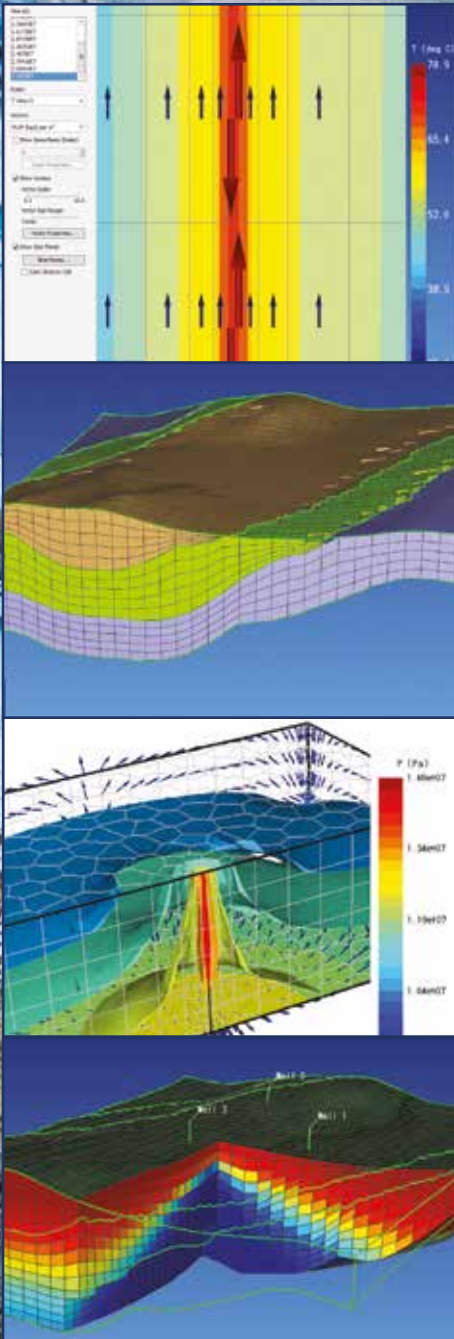
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Foreword

EurGeol. Vítor Correia, EFG President
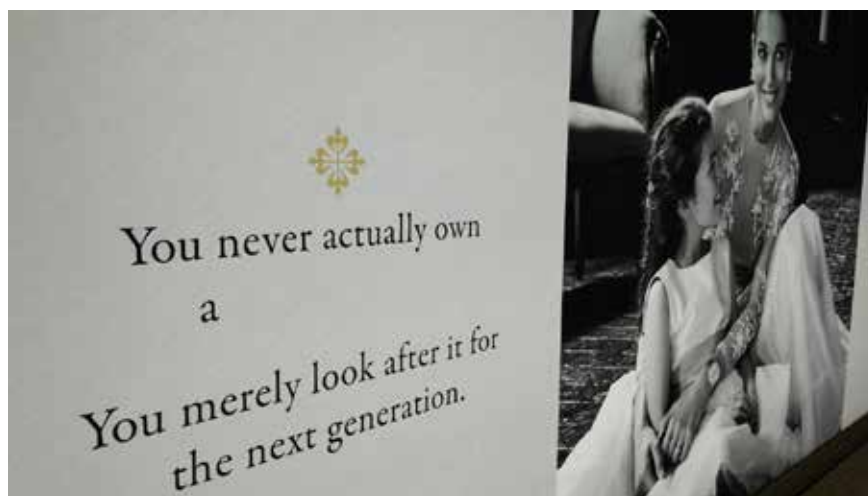
Photo of a billboard taken at the Geneva airport. The brand name of the watch was blurred on purpose.

I am writing this foreword after attending the World Resources Forum, held in Geneva at the end of October. It was interesting to hear the perceptions of people coming from different research areas and having different science backgrounds on sustainability and sustainable management of resources. And I'd like to share three aspects that become clear to me.

First, we to tend discuss and talk about resource topics in closed circles. It just happens that in science (like in life) people tend to hear only the opinions of people they engage with, and they (we) have chosen to engage because they (we) share common beliefs and values. This creates closed self-feeding circles, and it often creates misunderstandings in basic assumptions, such as the meaning of words[1]. Worse, this also produces organisations that work in closed silos, and a lot of duplication is happening in many governments and institutions because they don't establish communication channels[2], thus affecting their performance and consuming (wasting) time and money.

Second, there is no "one solution fits all" when we are talking about sustainability and pushing circular economy models forward. For example, enhancing resource efficiency and recycling makes sense in the developed world, especially in economies that are import-dependent on raw materials. But this speech does not have resonance in economies that depend on the export of raw materials or that don't have basic infrastructures. There, recycling often isn't economically feasible. But we (in the developed world) tend to push our models onto other social and economical contexts, and this is many times a source of more problems. Using a plain example, it is not acceptable to throw away an empty plastic bottle in the middle of a

1 The word "resource" is a good example: in mine reporting it has a very strict meaning, different from the meaning it has in life cycle assessment (LCA) accounting systems. Journalists and politicians use the meaning (and shape the headlines) they prefer.
2 In the 21st century this is a paradox. We've never had such sophisticated communication tools. But the excess of data and information is limiting our capacity to see and seek behind the obvious. Many departments and organisations behave like taxi drivers that are not interested in knowing the street names and routes of the city where they work (and don't talk with fellow drivers about this) because they use a GPS device.

street in a European city, but crushing it and putting it in a trash bin in many poor countries is also unacceptable, because it takes out of circulation a "resource" that might have been reused again and again for many purposes.

Third, and this is perhaps the most important aspect, we often name resources "commodities", especially geological resources such as minerals, water or even soil. By definition a commodity is a product that has all its properties clearly defined, and that only differs in price, meaning a copper concentrate produced in Spain differs from a copper concentrate from Chile only in its price, and the same applies to the water we receive in our houses from the water supply company or to the oil and gas exploited in oilfields around the world. By using the tag "commodity" we obliterate the fact that the complexity of natural systems allows us to get different products from the same mine (e.g. an apatite mine can provide phosphorus for fertilisers, uranium and thorium for medical applications and rare earth elements for the electronics industry[3]). This happens with many other ores, and also with oil, gas, water, geothermal reservoirs and soil. But by branding geological resources commodities, we oversimplify the complex exploitation and beneficiation processes associated to their extraction and treatment, and buyers push those mature industries (oil & gas, mining, geothermal, water supply and even agriculture) to provide their products at the lowest possible price. The profits of these industries are low if compared with the massive efforts and work required to extract and transform the corresponding natural resources. And the bottom line is that geological resources, the real providers of the infrastructure we need to live (water, food, energy and raw materials) don't receive fair revenue or the recognition of society[4] because they are unevaluated.

We need to change this, by helping society to realise that geological resources are paramount. But here comes the hard part: it's difficult to pass this message to policy makers or to the general public. Using scientific facts, reports and numbers on the importance of geological resources is not enough, as we all know (because we have been doing it for years). Going back to Geneva (this time for the photo above, taken at the airport) perhaps we can learn from the example of a Swiss watchmaker who uses emotions to deliver a powerful message that augments the value of the watch.

All things considered, a balanced combination of scientific facts and emotions might be the key to break down silos and reach people's minds (and hearts) when we talk about the importance of geological resources.

Vitor Co

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3 Sometimes being controlled or managed by different departments in governments and policy-making organisations (such as the European Commission and many intergovernmental organisations), hence driving us back to the first aspect.

4 Let me draw your attention to an example using the copper value chain. It starts in a copper mine somewhere, exploring a mineral deposit. It includes the smelters and refiners who produce copper cathodes, and it goes up to the builders of computers and mobile phones who use copper wires and strips. But it normally ends there and it does not include the service providers that are using the communication infrastructure made possible by copper mining. This explains why the revenue per employee of Goggle, Facebook or Apple is among the highest in the world. These service providers just build their offer on an infrastructure that is not being valued, that is underrated. Meaning miners, at the beginning of this value chain, are receiving less than they should for the copper concentrate, and this makes difficult for them to distribute (to local populations) a bigger share of the wealth generated by the mine. And this contributes to the rising social opposition to mining.

Developing, testing and demonstrating onshore storage of CO$_2$: First results from the ENOS field sites

Kris Piessens*, Roman Berenblyum, Carlos de Dios, Vit Hladik, Mariëlle Koenen and Kris Welkenhuysen

In the H2020 project ENabling Onshore CO$_2$ Storage in Europe (ENOS), research and development at five field sites takes a prominent role. Each of these gives attention to particular challenges or different applications of injected CO$_2$. Research initiated on three of the five pilot sites gives an overview of which different challenges will be tackled and how they are approached. These include the direct geological and technical challenges of CO$_2$ injection (Hontomin), oil production compatible with the climate-energy nexus (CO$_2$-EOR, LBr-1), and the integration of geological storage in CO$_2$ capture and utilisation schemes (Q16-Maas).

Dans le cadre du projet H2020 validant le stockage de CO$_2$ en Europe continentale, (ENOS), la recherche et le développement concernant cinq sites à terre jouent un rôle prééminent. Chacun d'eux fait l'objet d'une grande attention vis-à-vis des défis spécifiques ou des diverses applications relatives à l'injection de CO$_2$. La recherche, initiée sur trois des cinq sites pilote, fournit une vue d'ensemble avec définition des divers défis auxquels s'atteler et comment leur faire face. Ceux-ci incluent les problèmes d'injection de CO$_2$ au niveau géologie locale et techniques d'injection (Hontomin), production d'hydrocarbures compatible avec les interactions climat et énergie (CO$_2$-EOR, LBr-1), et l'intégration du stockage géologique aussi bien pour la capture du CO$_2$ que pour les plans de son utilisation (Q16-Maas).

Los trabajos de investigación y desarrollo en cinco áreas de estudio in situ han jugado un papel relevante en el proyecto H2020 ENabling Onshore CO$_2$ Storage in Europe (ENOS). Cada uno de estos emplazamientos se centra en desafíos particulares o diferentes en la aplicación de inyección de CO$_2$. La investigación desarrollada en tres de los cinco areas piloto ofrece una visión general de los diferentes desafíos y cómo se abordarán. Estos incluyen los desafíos geológicos y tecnologicos directos de la inyección del CO$_2$ (Hontomin), la producción de petróleo compatible con el nexo clima-energía (CO$_2$-EOR, LBr-1) y la integración del almacenamiento geológico en los esquemas de captura y utilización del CO$_2$ (Q16-Maas).

The ambition of the ENOS project (Gastine *et al.*, 2017) is to study several aspects of CO$_2$ Geological Storage (CGS) in order to streamline the implementation of this technology as a climate mitigation measure. An additional challenge is to demonstrate feasibility and especially acceptability of CGS in on-shore settings. To make this concrete, ENOS has identified five actual pilots and near-future projects. The three field sites discussed in this paper each focus each on a totally different approach for bringing full-scale CGS to Europe.

The ENOS project is funded by the EC under H2020. ENOS is the acronym for ENabling Onshore CO$_2$ Storage in Europe. The project is an initiative of CO$_2$GeoNet, the European network of excellence on the geological storage of CO$_2$ (Czernichowski-Lauriol & Stead, 2014). The consortium is composed of 29 partners from 17 European countries.

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The EC remains adamant that CGS, as the final element of CO$_2$ capture and storage, has an essential role to play in reducing the climate impact of industry and the power sector (IEA, 2017), even when renewable energy technologies such as photovoltaic solar are reducing costs faster than anticipated. An element of increasing importance in the search for using CO$_2$ as a feedstock is so-called CO$_2$ capture and utilisation schemes, and two of the discussed field sites look into the geological aspects of such realisations.

At Hontomin (Spain) the first injection tests with CO$_2$ have been carried out in order to test reservoir, equipment and monitoring systems. Injection will be scaled up from this point onward. Research on the currently abandoned gas and oil field LBr-1 in the Czech Republic it is aimed at bringing it back online, with a specific focus to develop it for CO$_2$-enhanced oil recovery. A particular challenge will be to integrate reservoir and techno-economic modelling to determine the best development strategies from economic and environmental points of view. In the Netherlands, the currently producing but small Q16-Maas natural gas and condensate field will soon be depleted. It will then be suitable for development as geological CO$_2$ buffer storage, allowing the reuse of industrial CO$_2$ in horticulture to be scaled up.

Hontomín

The Hontomín Technology Development Plant (TDP) is currently the only operational on-shore injection site in Europe, located close to the city of Burgos (Spain). The main reservoir/seal pair is formed by Jurassic limestones and seal rocks belonging to the Lias and overlying Dogger formations, whilst the primary hemipelagic seals are marls and black shales of Pliensbachian and Toarcian age. The site represents a structural dome, with the reservoir and seal rocks being located at a depth from 900 (top of the dome) to 1832 m (flanks). The main seal is the Marly Lias and Pozazal formations (highly carbonated marls, 160 m thick) and the reservoir is the Sopeña Formation (limestones and dolomites, 120 m thick; Rubio *et al.*, 2014). Both have a
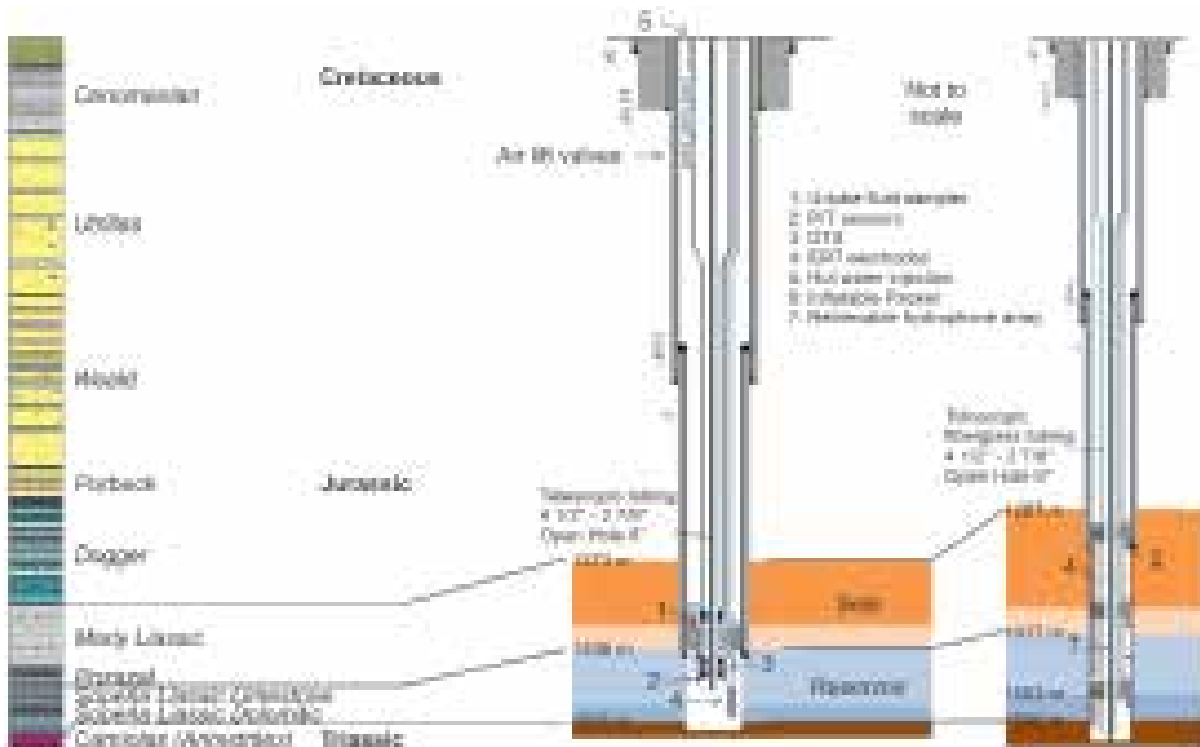
Figure 1: Lithological column on left side describes geological formations of the seal and reservoir. Injection well (middle) and observation well (right) with their deep monitoring devices form part of the Hontomín TDP.

high level of fracturing in different geological blocks, but this does not affect the seal integrity.

One injection well (HI) and one observation well (HA) form part of the pilot (*Figure 1*), with the facilities for CO_2 injection and water conditioning (to adjust brine pressure, temperature and salinity). Both vertical wells have been drilled to the depths of up to 1,600 m on the flank of the domed reservoir, with a distance of 50 m between them at surface (de Dios *et al.*, 2017).

The HI well is equipped with super duplex tubing anchored to the liner by a hydraulic packer (at 1433 m Measured Depth), two P/T sensors located below the packer, one Distributed Temperature Sensing System (DTS) and one Distributed Acoustic Sensing System (DAS) joined along the tubing, six ERT electrodes and one U-tube device to sample fluids, installed in the bottom hole.

The HA well is equipped with a fibreglass tubing anchored to the liner with 3 inflatable packers (at 1275 m, 1379 m and 1497 m MD) that section the open hole into intervals with different permeability, four pressure/temperature (P/T) sensors and 28 ERT electrodes installed in the seal and reservoir formations.

CO_2 injection and water conditioning facilities, a seismicity monitoring network and hydrogeological monitoring wells also form part of the TDP. The CO_2 injection facility consists of three cryogenic tanks with a total capacity of 150 t, and three pumps with the following operating parameters: flow 0-2 kg/s, pressure up to 120 bar, and two heat exchangers for conditioning the CO_2 temperature in the range of 10–40 °C. The water conditioning facility is used to support CO_2 injection (i.e., according to the operational procedure it is necessary to inject brine before and after the injection of CO_2).

Thirty-one passive seismic stations form part of the monitoring network, covering an area of 18 km² around the TDP. The hydrogeological monitoring network comprises eight wells, three of which have been specifically drilled for the project (150–400 m depth) into the Utrillas Formation overlying the top seal where the freshwater aquifers are located, equipped with instrumentation for remote control of groundwater composition and level monitoring.

Three different types of injection strategies will be performed at the Hontomín TDP in the ENOS project:

- **Discontinuous strategies.** Focusing on gathering knowledge to improve the hydrodynamic stability at the fractured reservoir.

- **Continuous strategies.** Handling the operational parameters to control storage integrity in long-term injection.
- **Alternative strategies.** Cold injection will be designed and tested, with the aim of finding the most efficient operational parameters.

The results from injection campaigns are expected to provide solutions to the following technical gaps, in order to define a safe and efficient industrial procedure:

- Monitoring the CO_2 phase at the well head, its evolution along the tubing and the fluid density at the bottom hole;
- Energy consumption for each injection scheme, determining the associated performance;
- BHP evolution and its influence on the pair seal-reservoir integrity;
- BHT evolution and the analysis of thermal effects during injection;
- Alteration of the operating process (e.g. hydrates formation).

At this preliminary stage of ENOS project, first discontinuous injections of CO_2 and brine have been conducted on site in
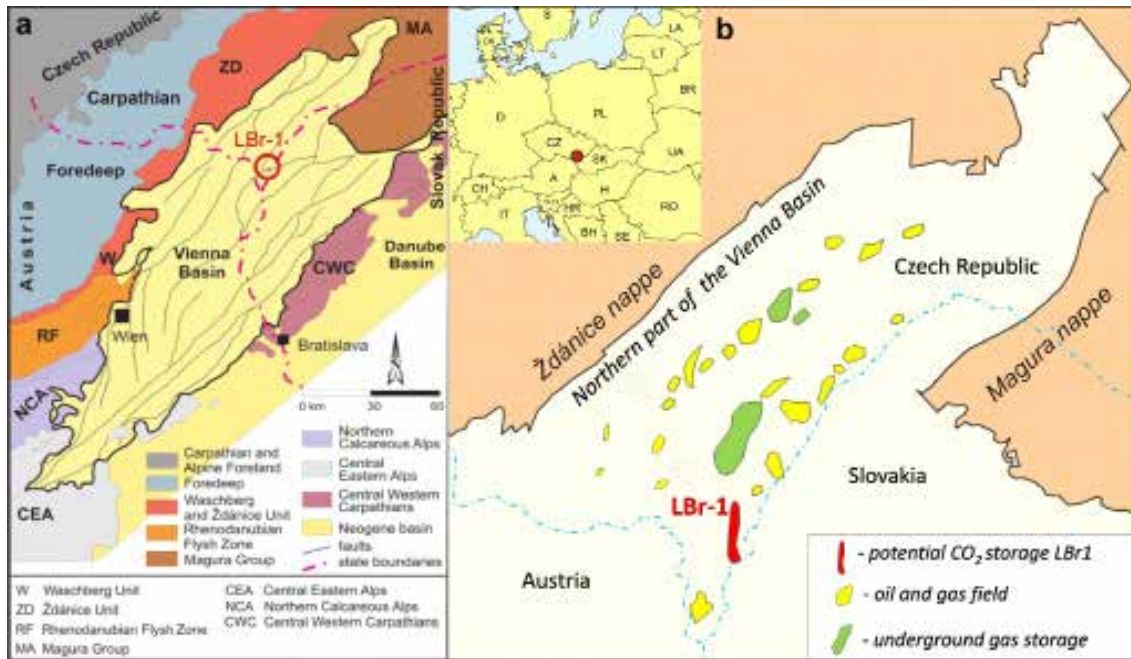
Figure 2: Sketch maps of the whole Vienna Basin (a) and its Northern part (b) with the location of the LBr-1 field (Francu et al., 2017, adapted from Kováč et al., 2008).

order to determine the reservoir behaviour during the injection and shut-in periods. Deep sampling of reservoir water to analyse its chemistry evolution and tests to perform first 3D VSP campaign for plume tracking are other activities that have been performed at the Hontomín TDP in ENOS.

CO$_2$-EOR as a business case for Europe

While the North Sea Basin has been long identified as a possible large-scale storage site for the whole of Europe, it is important to engage local stakeholders (policy makers, population and industry) to enable CCS in Europe. LBr-1 is a relatively small abandoned hydrocarbon field in the Czech Republic that is located close to the Slovakian and Austrian borders. Based on earlier work carried out in the REPP-CO$_2$ project (Hladik *et al.*, 2017), the field has indeed been confirmed as a very good pilot site for this exercise. As a small field it is representative of the mature Vienna Basin oil province, which stretches across Austria, Slovakia and the Czech Republic. There are positive indications of good potential for CO$_2$-EOR for this field, and production schemes will be further optimised during the ENOS project, taking into account economic considerations.

For exploitation of this site, cross-border coordination is also needed. The field itself is close to state borders (*Figure 2*), which means that the storage complex boundaries need to be carefully evaluated, includ-

ing, among others, the pressure footprint and risk scenarios of possible leakage of fluids from the storage reservoir below spill points. Moreover, the closest suitable industrial point source of CO$_2$ is in Slovakia, at a distance of ca. 120 km from the storage site.

Based on the existing understanding of the LBr-1 field, CO$_2$-EOR followed by storage is not only capable of generating more oil. Such a combination can actually result in more CO$_2$ stored in the field than is generated from utilisation of hydrocarbons that have been and will be produced from this field.

Figure 3 shows the CO$_2$ balance for one

of the simulated CO$_2$ injection scenarios (called "combined case") at LBr-1. The scenario starts from the current status quo situation that takes into account the historical hydrocarbon production from 1957 to present and the corresponding CO$_2$ emissions produced by combustion of the oil and gas produced. In 2020 pilot CO$_2$ injection will start and then continue until 2026. This will be followed by three years of oil production, until 2029. The three-year production period was selected based on the results of other simulations for this reservoir, that show that approximately 50% of the additional oil will be recovered during first three
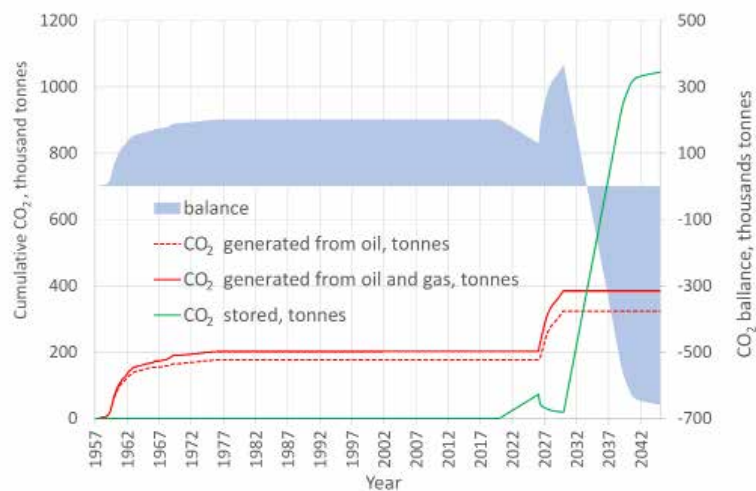

Figure 3: CO$_2$ balance of one of the initial simulations for the LBr-1 field. On the horizontal (time) axis we can identify the historical phase of conventional oil production, the long relaxation period after site abandonment, and the potential future CO$_2$-EOR and CO$_2$ storage phases.
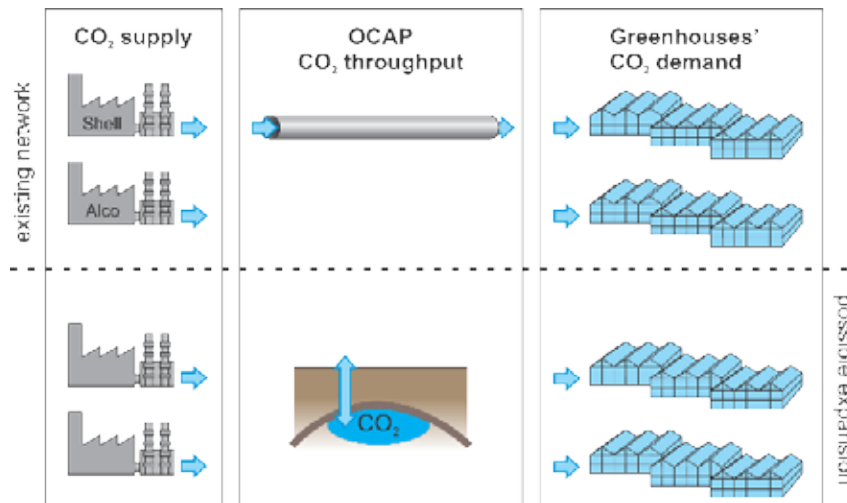
Figure 4: The existing network includes two CO_2 suppliers in the Rotterdam harbour area that deliver CO_2 to a pipeline, which transports it to several areas to be used in greenhouses (top). The lower illustration shows potential elements for expanding the network, such as additional suppliers and consumers, but the current bottleneck is the buffering capacity of the network.

years, followed by production decline. After the three years of oil production the reservoir is to be closed and the pure CO_2 storage phase will be started, which is scheduled to last until 2040.

The CO_2 balance (blue shaded area in the graph) is expected to improve quickly after the oil production is stopped and the field starts serving as a pure storage site. Five years after production termination the overall balance is predicted to be zero (= no net emission), after which it becomes markedly negative.

The importance of carbon negative solutions, extended here to hydrocarbon fields that over their lifetime can be carbon neutral or even negative, has been stressed since the CCOP 21 in Paris for meeting the 2°C climate change mitigation target. While hydrocarbons could be phased out as an energy source in the years to come, they will remain a vital resource for the petrochemical industry.

Q16-Maas

In the Netherlands, a utilisation network for CO_2 for reducing the CO_2 emissions from the horticulture is operational. The standard practice of Dutch greenhouses that are not connected to the CO_2 grid is to produce CO_2 through burning natural gas in co-generation units. In winter both heat and CO_2 are used, while in summer only CO_2 is needed.

These emissions are partially avoided by distributing CO_2 from the industrial area around Rotterdam to the greenhouses, using a reconverted pipeline as backbone.

The CO_2 is obtained from two industrial sources, the Shell Pernis refinery and the Alco bio-ethanol plant, which have dedicated scrubber installations in place. The central body OCAP is the distributor and guarantees continuous supply (*Figure 4*). The pipeline is operated at low pressure, meaning that CO_2 is gaseous throughout the transport chain. An additional environmental benefit is that the availability of CO_2 is compatible with the use of geothermal energy to heat greenhouses, which is indeed increasingly the case in this area.

The success of this network is such that it has currently reached its limits: over 400 kt of CO_2 are delivered to connected greenhouses. While the pipeline can still accommodate additional capacity, the first bottleneck is the CO_2 suppliers. During summer, which is the growth season with high CO_2 usage by the greenhouses, the limits of the capture installations are reached. In order to expand the network to additional users, temporary geological storage has been proposed to buffer seasonal demand and continuous production (*Figure 4*).

The quantities of CO_2 to be stored are too large to consider storage at the surface. A more realistic option is offered by the Q16-Maas gas and condensate field just off-shore of Rotterdam. It is one of the most recent fields, but also very small, and is near depletion. The total capacity for CO_2 is currently estimated at around 2.1 Mt, which is small for traditional storage, but possibly the ideal scale for a buffer reservoir.

Developing the Q16-Maas into a CO_2 buffer offers sufficient advantages to consider it as an investment opportunity. Inte-

grating a geological element in an already complex chain is, however, a challenge. In this case a geological buffer with converted injection, production and potential scrubber installations would be linked to the existing distribution network through a new pipeline segment to double the capacity for delivering CO_2, including potentially new CO_2 sources and consumers. Implementation depends on assessing the reliability and economics of the upscaled project, even when there are still significant geological uncertainties that remain unresolved.

The methodological approach for studying this buffer is one of the first to be based on the principles of geological economics. The integration of a reservoir model into an economic analysis allows the intricacies of working with subsurface data to be taken into account, such as widely varying degrees of uncertainty.

Because traditional reservoir simulations are calculation intensive, these are not suitable for integration in Monte Carlo-based economic assessments. In the first step of a speed-optimised solution, dynamic reservoir models will provide results for the most important parameters, injection and production pressures and fluid composition, for a limited number of cases and parameter variations (~15). In the second step, a set of continuous reservoir response curves will be interpolated based on these data, including uncertainty ranges. These results, called reservoir response curves, serve as direct input for the economic assessment.

The economic viability of integrating the Q16-Maas field as a buffer in the existing CO_2-utilisation network will be investigated, starting from the current network configuration. The greenhouses will be presented with different options for CO_2 and heat supply, including the OCAP network, CHP, geothermal and external CO_2 supplied by truck. The choices are made on a quarterly basis with limited foresight, which allows the buffer to be addressed on a seasonal basis if desired, with a realistic outlook uncertainty (*Figure 5*). This approach allows us to determine the conditions under which buffer storage provides added value.

Conclusions

The ENOS project is a unique gathering of expertise covering all aspects needed for tackling the existing knowledge gaps concerning the geological storage of CO_2 in onshore settings. A broad range of approaches is necessary to enable onshore geological storage in Europe, which is given dedicated attention in current and realistic future pilot

sites. The benefits of CO_2 geological storage are not necessarily restricted to climate and environment. In two of the cases, it is integrated into schemes that also improve the regional socio-economic matrix.
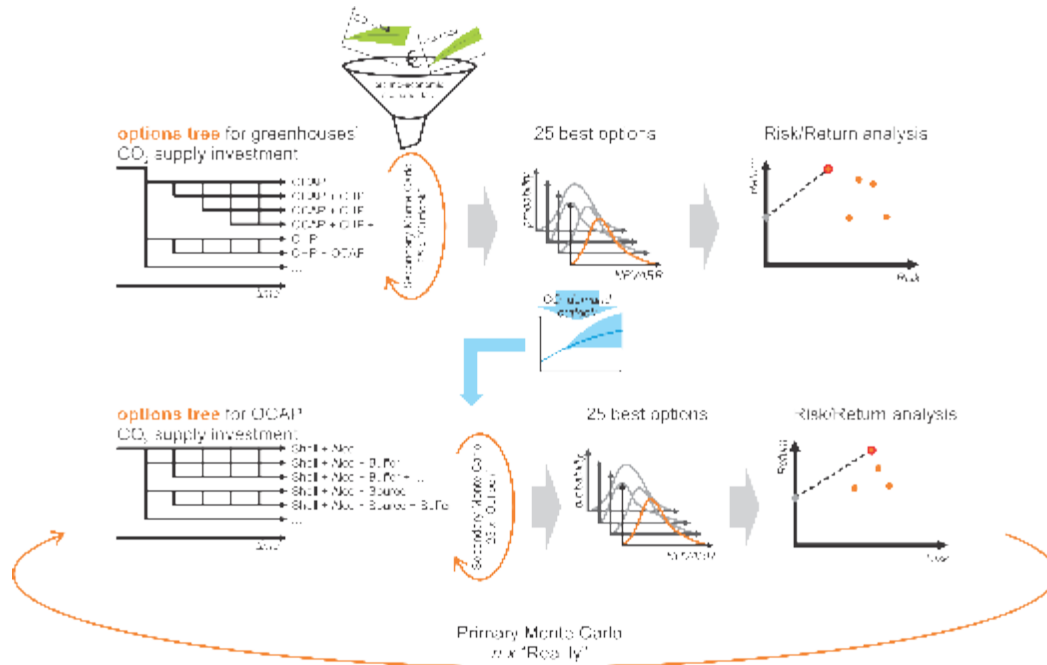
Figure 5: This schematic presentation of the techno-economic methodology shows how the predictions of the model are based on the simulating the behaviour of two actors: the greenhouse farmers (top) and the utility company OCAP (bottom). Both make realistic investment choices under uncertainty that interact with each other.

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Resources for future generations – understanding earth and people

John Thompson*, Lana Eagle and Oliver Bonham

Earth's growing population requires resources for the basics of life and increasing standards of living. Energy from many sources, numerous minerals and water are critical for human existence, and are increasingly linked in the context of sustainability. For future generations, resources must be discovered and cleanly exploited, even as efforts to improve efficiency and increase recycling continue. To succeed, we must fully understand the earth, from the critical processes that concentrate resources to the environment and climate that support life. Simultaneously, we must engage broadly with people to fully understand needs and concerns, inform effective policy, and provide the knowledge to support future generations. The Resources for Future Generations 2018 conference will bring together geoscientists, engineers, members of civil society, and young people to learn, discuss and debate these issues.

L'augmentation de la population sur terre requiert des ressources suffisantes pour satisfaire les besoins vitaux de base et l'accroissement du niveau de vie. L'énergie tirée de nombreuses sources, un grand nombre de minéraux ainsi que l'eau sont indispensables à l'existence humaine et sont de plus en plus liés au contexte du développement durable. Pour les générations futures, les ressources doivent être découvertes et exploitées proprement, même si des efforts continus contribuent à une amélioration de l'efficacité et à un recyclage croissant. La réussite passe par une totale compréhension des caractéristiques terrestres, depuis les processus incontournables de concentration des ressources jusqu'aux conditions régulant l'environnement et le climat, supports de vie. Simultanément, nous devons nous mettre pleinement à la disposition se la population, pour la compréhension totale des besoins et des inquiétudes actuelles, celle d'une politique pertinente et la diffusion des connaissances utiles aux générations futures. La Conférence (2018) concernant les Ressources pour les Générations Futures réunira géologues, ingénieurs, membres de la société civile et aussi les jeunes qui pourront ainsi apprendre, discuter et débattre à propos de ces questions.

El crecimiento de la población de la Tierra requiere recursos tanto para las necesidades básicas sus habitantes como para el incremento del nivel de vida. La energía procedente de varias fuentes, numerosos minerales y el agua son elementos críticos para la existencia humana, y están cada vez más vinculados en el contexto de la sostenibilidad. Los recursos deben descubrirse y explotarse de forma limpia para las generaciones futuras, aun cuando continúen los esfuerzos para mejorar la eficiencia y aumentar el reciclaje. Para tener éxito, debemos comprender la tierra en su conjunto, desde los procesos críticos que concentran los recursos hasta el medio ambiente y el clima que sustentan la vida. Al mismo tiempo, tenemos que involucrarnos firmemente con las personas para comprender las necesidades e inquietudes, elaborar políticas efectivas y proporcionar el conocimiento para apoyar a las generaciones futuras. La conferencia Resources for Future Generations 2018 reunirá a geocientíficos, ingenieros, miembros de la sociedad civil y jóvenes para aprender, discutir y debatir estas cuestiones.

The human population is anticipated to grow well into this century. Currently around 3 billion people lack some or all of the basic ingredients of life – clean water, sanitation, nutrition, heat or electricity – and the number without adequate resources will likely increase with population growth. Freeing these people from poverty, desperate circumstances, and lack of a meaningful future requires natural resources, particularly energy, minerals and water.

At the same time, humans increasingly and appropriately expect a clean and protected environment. The world is embracing new technologies that enhance our lives and provide alternatives for power generation and transportation that reduce greenhouse gas emissions. Delivering these technologies requires the supply of numerous minerals; extracting and processing these minerals requires energy and water, a necessity that may compete with other users.

This picture translates into increasing demand for energy, minerals and water over the coming decades, and rapid changes in demand for some commodities as new technologies emerge. How will we meet this demand in a responsible manner that attempts to satisfy global and local sustainability goals? What is the mix of technical and social challenges, and who will provide the solutions?

To address these and many related questions, geoscientists and engineers from around the world, in academia, government and industry, along with Indigenous people, policy experts, members of civil society and young people — students and early career professionals — will meet in Vancouver, Canada, in June 2018 for the Resources for Future Generations conference (*Figure 1*). The conference seeks broad engagement and a multidisciplinary effort to fully examine the nature of Earth, the distribution of resources and how new sources can be found, and the important sustainability issues related to resource extraction. We invite you to attend! For more information, see *www.rfg2018.org* or follow the conference on twitter *#RFG2018*.

Earth and natural resources

The Earth is a remarkable planet. Over its history, our planet has seen the growth and amalgamation of supercontinents, the building of mountain ranges many thousands of kilometers in length, constant

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Figure 1: Resources for Future Generations conference.

delivery of massive quantities of sediment from landmasses into adjacent sedimentary basins, and occasionally, disruptive and hazardous events such as earthquakes, volcanic eruptions and violent storms. These major events are driven by plate tectonics, and some argue that plate tectonics is also the fundamental driver of life.

Perhaps not as obvious, numerous geological processes, most of which are broadly linked to plate tectonics, have moved and concentrated metals, minerals, hydrocarbons, and water to varying extents throughout Earth's history. The formation of economic concentrations of natural resources, such as mineral deposits and petroleum reservoirs, resulted from combinations of factors linked to large-scale global processes such as magmatism, sedimentation, continental collision, the presence of water, the composition of the atmosphere, and microbiological activity. At the site of concentration, local-scale processes – such as crystallization, structure, permeability, pressure and temperature, fluid-rock-mineral interaction, and erosion rate contributed to the creation and preservation of identifiable and economic resources. Understanding these processes, and the many related aspects of Earth science that underpin the way in which they operate, is critical to our ability to find natural resources and exploit them successfully.

Humans and natural resources

The concentration of metals and minerals, both by primary processes and in many cases by secondary weathering, produced deposits that were so obvious that ancient humans recognized and started to exploit them more than 10,000 years ago. From these early days, natural resources had a profound influence on human development

including agriculture, trade by land and sea, and military power. Inevitably, ownership of natural resources also became a source of conflict.

In the last 250 years, the availability of natural resources, particularly energy and minerals, fueled the industrial revolution, and subsequent mass production, transportation and consumerism. While many of the resulting changes were positive for human welfare and led to improved living conditions, land disturbance and environmental degradation were commonly related to resource development.

Fast forward to the modern era where technological innovation is integrated into everything from healthcare to space travel to global communications and the shared economy. Perhaps the most exciting applications of technology involve innovations intended to create a cleaner and greener planet and redress the unintended consequences of accelerating population growth and resource extraction. The two most cited examples of major innovations related to reducing our reliance on fossil fuels are renewable energy and electric vehicles. While welcome, these rapidly evolving sectors require abundant natural resources such as copper for electric motors and turbines, lithium, cobalt and nickel for batteries, and silicon, gallium, indium, and tellurium for solar panels. It will take considerable amounts of these and other natural resources to get us through the emerging sustainability revolution. Recycling will play an increasingly important role, but a serious resource gap needs to be filled before recycling alone can meet the long-term needs of a growing population.

The availability of water has also influenced human history and has an increasing impact on the modern world. While many in the developed world take water

for granted, the importance of this most vital of natural resources has become more obvious with the depletion of aquifers, climate change, and local pollution. Water is also intimately linked to the production of energy and minerals, either as key part of production processes, or as a potential carrier of contamination in effluent from active or legacy sites. The need for water in the development of natural resources may also lead to conflict with people in the region who rely on it for habitation, agriculture or recreation. In some cases, modern technology has come to the rescue, particularly in arid regions with limited available water, where the reuse of surface water, desalination or direct use of seawater for processing, and treatment of saline ground water have become important. All of these changes, however, require significant additional energy and critical materials derived from mineral resources, further reinforcing the energy-minerals-water nexus.

Challenges for natural resources

How do we meet the resource demands of the future? First and foremost, we must discover new resources, preferably those with high concentrations of the critical commodities that we need. Over the past few decades, extraction of many natural resources has become more difficult. Many current mines have lower concentrations or grades of metals and minerals than in the recent past, hydrocarbons are extracted from more complex, lower-permeability host rocks, and deeper aquifers must be tapped for water. As a result, we expend more energy, disturb more land, and spend more per unit of production than in the past.

The discovery of new high-quality, high-value deposits can reverse this trend, allow-

ing increased efficiency of extraction per unit of commodity. Making such discoveries is challenging, but recent history demonstrates that there is considerable potential for more discoveries, especially at modest depths. In spite of rapid increases in the use of all natural resources, the extractive industries have kept up with demand, and economic reserves of most commodities have remained constant (Arndt *et al.*, 2017).

The odds of making new discoveries are improved when we fully understand the critical Earth processes that work separately and collectively to form and concentrate resources of different types. Furthermore, we have to translate this knowledge into new approaches, techniques, and models to decipher existing deposits, and to be able to define the areas with the greatest potential for new discoveries. Cooperation among geoscientists from many disciplines and global regions is needed to tackle this daunting task.

Discovering new natural resources is vital, but equally important is how we extract the contained material of economic importance. The extractive industries are not viewed well by many people, which is hardly surprising given past examples of poor practices, environmental damage, and limited distribution of benefits. These industries, however, have changed significantly over the last 30-40 years, and will continue to advance by using more effective

technologies, reducing energy consumption, recycling water, and applying more stringent measures to reduce pollution and other detrimental impacts on the environment. More needs to be done, particularly to make resource extraction more selective by recovering a higher proportion of valuable products from less rock, by reducing the amount of waste, and by managing the waste more effectively. The drive to increase efficiency and decrease impact is greatly assisted by new materials of construction, new processes, the use of sensors, and integration of digital data for real-time decision-making. The technologies facilitating many of these changes incorporate specialty metals, and the availability of these metals from mines and other extractive sources is therefore a prerequisite.

Efficient and clean resource extraction requires a full understanding of the rocks and minerals that host the commodities of interest. Natural resources are highly variable, both within deposits and reservoirs, and between ones of the same type. Geoscientists understand natural variability and increasingly we have the tools to quantify variation at multiple scales. The challenge, however, is to communicate this knowledge to engineers of many disciplines and to project managers. Encouraging dialogue among those involved in energy, minerals and water with many different specialties will allow new approaches for evaluation,

development and enhanced environmental performance to be exchanged and advanced.

Over the long term, advances in resource extraction will be built on a profound understanding of the Earth, including surface processes, water, climate and biodiversity. Geoscience and geoscientists play major roles in understanding global change, as well as assessing local and regional landscapes. This allows us to evaluate site-specific, regional, and potential cumulate impacts at a range of scales. Government geological surveys have traditionally generated regional geoscientific data, but a broader remit for understanding all aspects of landscape from rocks, to fauna and flora, and to human habitation, may become an appropriate mandate for these agencies. Ultimately, the geoscience community will need to apply knowledge at multiple scales to identify and mitigate negative consequences from resource extraction.

Natural resources and society

Geoscience integrated with engineering and environmental management clearly provides the technical underpinning for delivering resources for the future. But technical advances in resource operations have limited potential if the people who are most at risk from the extractive process see few of the benefits. The relationship of

Figure 2: Interplay among energy, minerals and water, from Earth science to the needs of people and goal of sustainability.

extractive industries to society, from jurisdictions to local communities, is critical for the development of new resource projects, and increasingly involves many specialists in companies, governments and civil society. Seeking operating permits through a defined regulatory process is challenging, but achieving a social license to operate can be much harder. Failure in both these areas may ultimately have more impact on resource supply than the geological availability of resources and related discovery challenges.

Indigenous people have relationships to the land and associated resources that have evolved over time periods vastly exceeding recent industrial resource use. Understanding Indigenous knowledge and community needs is a pre-requisite for future responsible resource extraction, and while other communities do not have the same longevity, their concerns must also be heard. Successful engagement requires the interplay between the technical and non-technical world, and the interface between geoscience and engineering, and social and political science. Many technically minded people are uncomfortable bridging the gap to social science, and yet building collaboration across this divide is critical for future resource development that is designed to meet global sustainability goals.

The relationship of natural resource extraction to people living in remote settings is different to those living in cities. People in remote areas may benefit directly from resource operations. They may be employees at mines and extractive facilities, and may own related service businesses, or in some cases, a share in the operation. City dwellers are the dominant consumers of resource products, and yet they are commonly against or uninformed about resource extraction. Lack of understanding poses challenges for society when faced with complex choices. Engaging young people in the debate around natural resources, from the materials in the ground to extraction and their use in the products that they depend on daily, is critical for the future clean supply of energy, minerals and water.

RFG2018

The interplay among energy, minerals and water, from Earth science to the needs of people and goal of sustainability are depicted in *Figure 2*. This is the context for the Resources for Future Generations – RFG2018 – conference, a global forum for discussing the future of natural resource. The conference was conceived by the IUGS – the International Union of Geological Sciences – and is being organized by several Canadian associations with support from over 40 global partners.

The conference, to be held June 16-21, 2018, will include numerous sessions covering the major technical themes — Earth, Energy, Minerals and Water — as well as nontechnical themes, including Resources & Society and Education& Knowledge. Complex and challenging issues will be debated, and efforts will be made to draw delegates from across the boundaries among the themes and disciplines. Indigenous people will demonstrate their leadership in the resource debate and will bring their unique perspective to the issues most critical for remote communities. Considerable focus will be given to young people – early career and students – who represent "Future Generations." This will include pop-up pitch sessions, career workshops, mentoring opportunities, and focus group discussions, as well as opportunities to speak in broad thematic and specific technical sessions.

Vancouver, Canada provides an excellent venue for the conference. Canada is a vast country rich in natural resources, and there is considerable national interest in the future role that resource businesses will play locally, regionally and nationally. Furthermore, Canadian companies are involved globally in all natural resources and considerable expertise resides in the country. Canada wants to be seen as an innovative leader in responsible resource development, as do many other nations with similar endowments. The conference provides a venue to develop a path forward, led by young people who will be responsible for important future decisions around the extraction and use of natural resources.

Geological processes support life, and these processes also concentrated natural resources that have aided human development for over 10,000 years, and especially in the last 250 years. It is critical that we understand this relationship, the nature of Earth in all its complexity, and the role that humans will play in maintaining the supply of critical resources while exploiting them more cleanly for the benefit of all. We must work collectively to empower future generations to take on the natural resource challenge in all its aspects. The Resources for Future Generations – RFG2018 – conference is an important step to address natural resource opportunities and challenges, and hence build a path to long-term human sustainability.

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Future Mining – Thoughts on Mining Trends

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Even though mining for energy resources is likely to decrease, mining activities generally will increase. The demand for metal resources will rise in the next decades. The question is, what will mining look like in the future? Mines have to be dug even deeper and processing has to mill even smaller because ore is getting more complex. One possibility is automation, which may be a solution for mines with certain conditions, e.g. where heat and gas levels (NO_x and CO) are a major concern. However, automating an underground mine is a very complex task. The relevant influencing factors are introduced and discussed in this paper, with brief descriptions of some investigations into different approaches and technologies for handling these situations.

Même si les ressources énergétiques d'origine minière sont appelées à décroître, l'activité minière globale va augmenter. La demande en ressources métalliques va s'accroître au cours des prochaines décades. La question posée est : à quoi va ressembler la mine dans le futur? Les gisements miniers doivent encore être atteints à plus grande profondeur et le traitement par broyage doit être aussi plus fin car la nature du minerai devient plus compliquée. Une possibilité est l'automatisation qui peut être une solution pour des gisements dans certaines conditions, c'est-à-dire lorsque les niveaux de chaleur et de gaz (NO_x et CO) représentent un danger réel. Cependant, automatiser une mine souterraine est un travail très complexe. Les facteurs d'influence significative sont précisés et font l'objet d'un débat dans cet article avec une brève description de certaines recherches concernant les diverses approches et technologies mises en œuvre pour faire face à ces situations.

Si bien es probable que disminuya la extracción de recursos energéticos, las actividades mineras generalmente aumentarán. La demanda de recursos metálicos aumentará en las próximas décadas. La pregunta es, ¿cómo se verá la minería en el futuro? Las minas tienen que cavarse aún más y el procesamiento debe reducirse aún más porque el mineral se vuelve más complejo. Una posibilidad es la automatización, que puede ser una solución para minas que cumplen con ciertas condiciones, por ejemplo donde los niveles de calor y gas (NO_x y CO) son una gran preocupación. Sin embargo, la automatización de una mina subterránea es una tarea muy compleja. Los factores de influencia relevantes se presentan y discuten en este articulo, con breves descripciones de algunas investigaciones sobre diferentes enfoques y tecnologías para manejar estas situaciones.

The most recent *Exploration Review*, edited by Karl and Wilburn (2017) from the U.S. Geological Survey, again shows decreased expenditure for exploration activities in 2016 (*Figure 1*). With this trend present since 2012, it cannot be expected that efforts in mineral extraction will increase in the near future. In general, with rising demands for raw materials on the world market, suppliers of the mining industry are expecting higher sales of their products. However, with today's situation, this scenario is not yet likely. Suppliers should use the time of recession to invest in research and development for new products and new concepts in order to be able to meet future demands in quality. As this task is very complex, companies with different profiles should work together.

What are future demands? What will future products look like and what will concepts be about? To answer these questions, it is important to first discuss expected advancements and to define the parameters of influence. Besides technological aspects, social changes and new ideologies also have to be considered. The world of future mining will be interconnected and operating with more flexible approaches. Relevant influencing factors are discussed in this paper.

Thinking about future technology, automation is of major interest. However, the simple idea of automating a mine comes with a range of demands regarding the mine and the technology itself. Automating a mine means automating the entire mine, requiring a great deal of research and development to be done. Of course, it is possible to copy strategies and technologies of other industries that are at high levels of automation already. However, it is highly questionable whether they will meet mining standards. Sensors, for example, might not be designed for mine environments. If sensors cannot work adequately, they may deliver false data. Analysing false data will lead to wrong conclusions. Will it be possible to solve these problems, for example, with a local remote sensing survey to define the position of each limber of a drilling jumbo, rather than fitting each limber with individual sensors (as in *Figure 2*)? Also, sensors should be maintenance free and have a lifespan similar to the lifespan of the machine they are surveying. Could drones be an adequate solution? Such technology could be used to survey
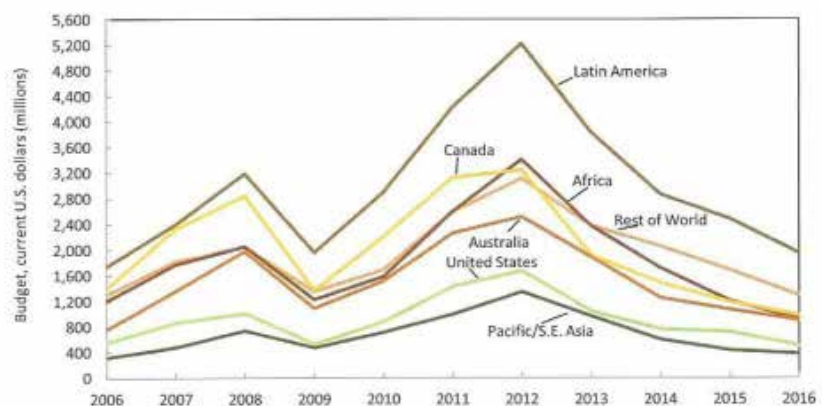
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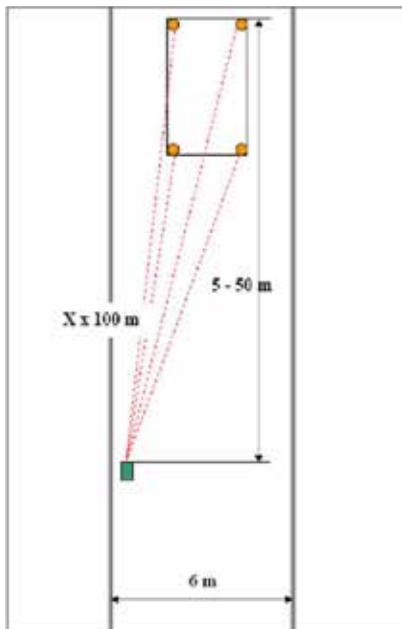Figure 1: Known investments in exploration by region, 2006 to 2016 (Karl & Wilburn, 2017).

Figure 2: Remote sensing for drilling jumbos (Mining Institute, Clausthal University of Technology, 2009).
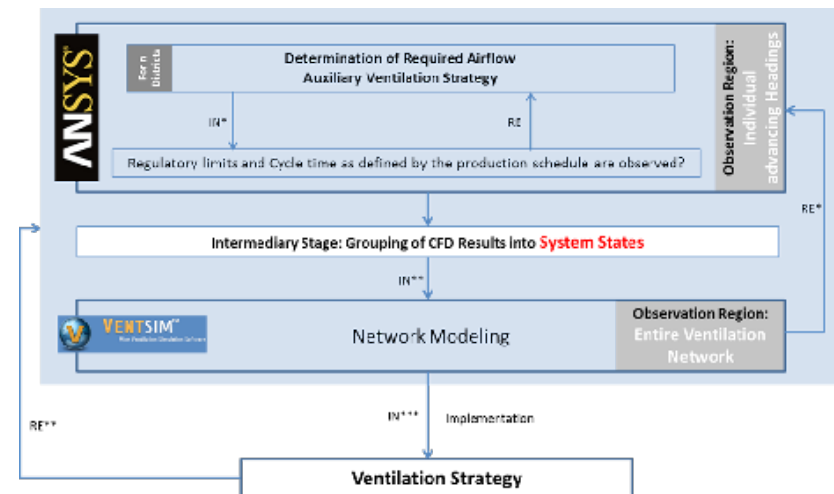

Figure 3: Ventilation on Demand – CFD multiphase and analytical ventilation network, Mining Institute, Clausthal University of Technology (Clausen & Langefeld, 2013).

large cavities or inaccessible sections. By fitting drones with additional sensors, they could also deliver data that is needed for automation.

The provision of an extensive network is the main basis for any automation process, as information must be exchanged between the sensor and machine. This then requires the installation of a mine-wide communication system (e.g. using fibre optic cables) and information technology. In the first step, data that was collected by the sensors must be reduced to the information that is needed for the process. For solving this 'big data problem', adequate software is required. The data must be saved and guarded by a data protection system. All of these are major tasks to be solved for the mining industry before automation can be implemented.

Besides automation, safety will be a major concern in future mining. "Vision Zero', the aim of achieving a system producing no fatalities or injuries, is no longer a vision, but a goal. Today, the industry is still far from reaching this goal and much is yet to be done. Public opinion of mining reflects this, as the mineral sector is still judged as dangerous, dirty and dark. Improving this image will be a milestone on the way to establishing faith and trust in the mining industry. The most effective approach is by communication and honesty. 'Do good, and spread it into the world' can be seen as a guiding principle. In these terms, it is clear that accident numbers have to be further reduced – worldwide.

One opportunity for advancing safety in underground mines is 'Ventilation on Demand' (VoD) (Clausen & Langefeld, 2013), meaning a controlled and energy-efficient supply of mine areas with the needed amounts of air (*Figure 3*). Generally, with no people in the mines, automation can lead to a significant decrease in accident numbers. Heat and gas levels (NO_x and CO) will not be major concerns. Ventilation would be needed mainly to remove the heat from machinery and to support it with oxygen if it has a combustion engine. In my opinion, these goals can be achieved within the next ten to fifteen years. However, this will require systems that are highly integrated and fitted with adequate communication opportunities. Finally, fully automated mining systems will be a requirement for deep-sea mining and sky mining.

Linking all relevant data and machines is also of high importance for future mines. The comprehensive planning of a mine, respecting a hierarchical and thorough approach, can help to establish an efficient network (Clausen, 2013; *Figure 4*). Goals must be defined clearly and exactly for machines to understand the tasks. Also, geological and tectonic data of the deposit should be considered. All relevant data, such as amount and quality of conveyed material, must be measured at all tipples or handling points, and must then be compared to expected data from the planning stage. Planned data can then be corrected accordingly, forming an in-time flexible system with self-learning and self-adjusting capabilities.

However, this idea is not a recent one. The German *Ruhrkohle AG* began analysing core drills from general mine surveys in the past (*Figure 5*) (Langefeld *et al.,* 2000; 2001). The ability to analyse the rock can be used for simulating possible shothole spacings and blasting patterns to find an optimum for the downstream haulage and processing system (in terms of chip size, etc.). Especially in cave mining, this can be very important.

Even more sensors will be required to allow an online and real-time analysis, for example sensors that gather information on type of ore, grades and other properties of the rock during transportation (Vraetz *et al.*, 2017) or the drilling process ('measurement while drilling'). Will it be possible to analyse a rock's tectonics from the resistances while percussion drilling? Questions like this express a high and urgent demand for research and development, as only with complete data analysis will automation be successful.

Flexibility in terms of reacting to measured data is another important aim of sensor development and data analysis. As mentioned in the example above, real-time data can be used to improve drilling and blasting operations and thus for optimisation of the mining process. A requirement for this is that reporting and evaluation of measured data must be available immediately. Developing deeper and more complex mines increases the need for available systems. Also, with the present trend on the raw materials supply market, secondary deposits are drawing increased attention. One example is tailing ponds, as focused on in the REWITA project, funded by the German Ministry of Research and Education. Concentrating on evolving strategies for mining and processing, this project uses tailing ponds of an abandoned ore mine in Goslar, Germany. Besides technical questions, social and environmental aspects of utilising secondary deposits also have to be respected.

Furthermore, post-mining is an important aspect. It is more than only securing in terms of subsidence and back stowing.

Developing a concept for using the sites of a mine after the phase of mineral production can be included in the planning even before mining activities start. This guarantees matching mine development regarding the post-mining usage, e.g. energy production. 'Blue Mining' (*Figure 6*) is a concept being developed at the Clausthal University of Technology since 2013, covering the aspects of post-mining opportunities (Langefeld & Kellner, 2013). From 2008 to 2011, in cooperation with the German Ministry for the Environment and Nuclear Safety, the university also worked out a strategy for using abandoned mines for storing wind power, presented in an 864-page report (Beck & Schmidt, 2011).

In addition, reliability and maintenance are important aspects of automation. Machines that require regular repair and that have inadequate lifespans will not be suitable for automation. Suppliers will have to rethink and focus on quality rather than on spare parts supply. The point of time for replacing spare parts should then be defined by software from information gathered by the fitted sensors. Only then is automation reasonable.

Regarding technology in terms of the machinery itself, two aspects are vital. With the ambition of 'zero emission', new methods of engineering will change mining machinery. Electric engines, powered by batteries, are rising in importance. With batteries, new concepts for fire prevention and control will apply that are still in their design phase. But battery powered vehicles change the mining methods and the sequences, e.g. more infrastructure is needed for the battery handling. The other important aspect is the cutting of the rock. Drilling and blasting will be employed in future mining, but cutting holds some advantages. For example, noise emission and vibrations are reduced and no fumes are produced. However, cutting in hard rock is still problematic and should be granted more attention in research. Thus, a new network of researchers is forming these days to solve these problems.

In addition to all of the technological demands of future relevance that I have mentioned, the most important of all is rather a social one, defined by industrial standards, sustainability and communication. The framework conditions are subject to change. Today, stricter pollution levels are forcing the industry to react and introduce cleaner technologies, but it is more than likely that allowed pollutant levels will be further decreased in the future. Today's society is enlightened and aware of environmental and safety hazards. One alteration is that, whereas personal information was strictly kept secret in the past, people
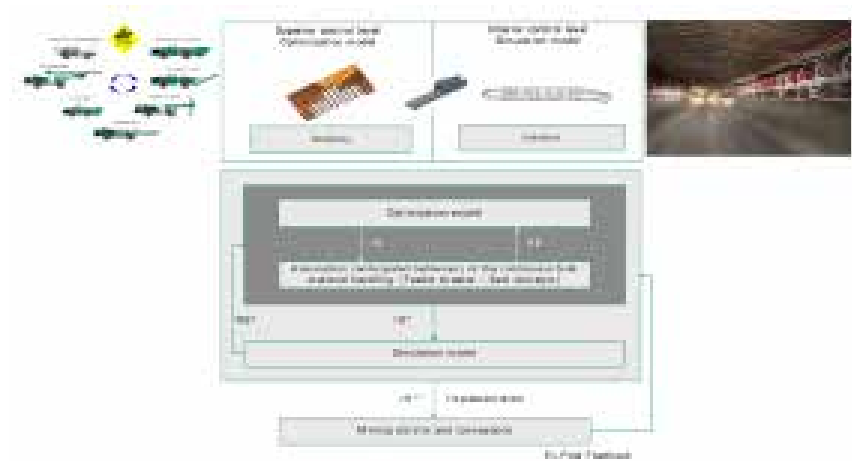

Figure 4: Hierarchy of planning, Mining Institute, Clausthal University of Technology (Vraetz et al., 2017).
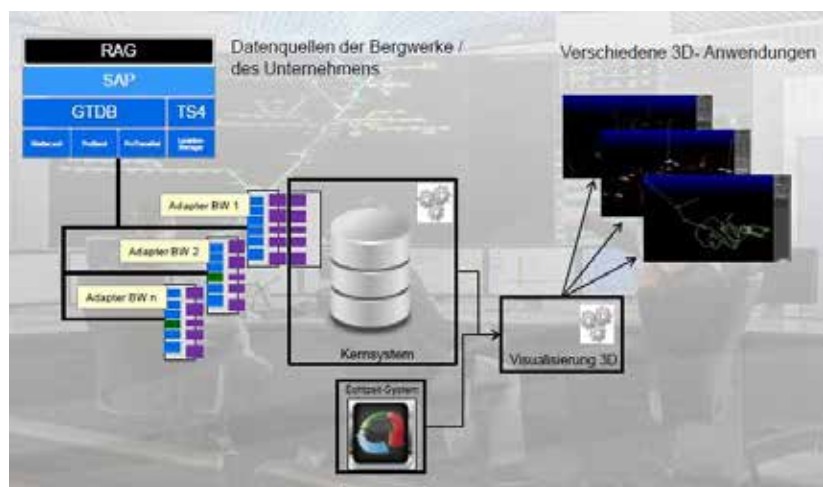
Figure 5: Census of data during the production process (Junker, Martin RAG Mining Solution).

provide it today if they feel they can profit from it. In the 1970s, everyone was afraid of "Big Brother is watching you". Nowadays, a situation in which "everyone is watching you" is no reason to feel uncomfortable and people are willing to impart information for a bonus in a customer loyalty programme or a smartphone app. This shows the importance of passing on information. People need to know how they can benefit from a situation. The mining industry has to involve the public, discuss as equals and provide all relevant information to build up confidence.

Also, as today's society is characterised by flexibility and individualism, companies will have to react accordingly in their human resource policies. Beyond race, gender and spiritual beliefs, also ideology, lifestyle and workplace morale must be respected, in particular in team work. To further define required action in this field, universities and EIT Raw Materials are currently working on a cooperative project on the topic 'Diversity in the EU's Raw Materials Sector'. With automation in the future, this will remain a relevant topic. Automation will allow fully mechanised

processes in extraction and conveying, but other activities, such as in repair shops, will still require personnel. If underground, relevant locations will also need auxiliary ventilation.

With increasing demands for sustainable development, mining companies, suppliers, research institutes and related organisations will have to rethink. Along with the concept of Zero Emission, this also means focusing on renewable energies and reducing waste production.

All aspects, as a foundation for a successful mining economy in the future, must be included in education. Universities that teach mining classes have to arrange their educational principles in a way that all graduates satisfy the high level of demand that is present in any employment. Besides basic technical skills, methodological and soft skills are gaining in importance. A good example of a successful implementation of these requirements in the fields of study is the Master programme "Mining Engineering" offered by the Clausthal University of Technology. Held in English, this programme includes modern teaching and CDIO methodology (see

Figure 6: Blue Mining Concept – planning of post-mining use prior to mining (Langefeld & Kellner, 2013).
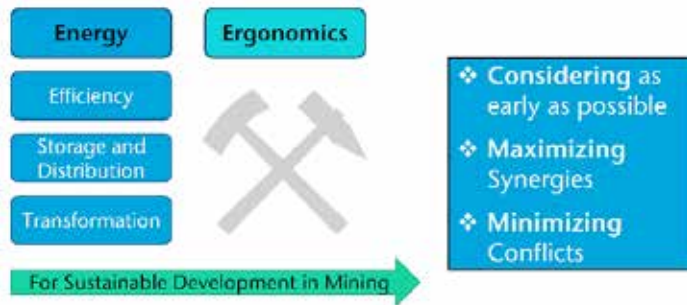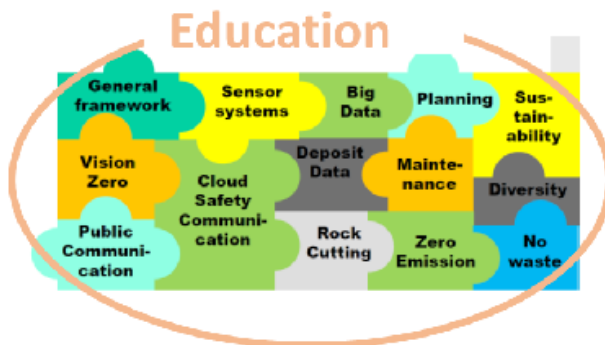

Figure 7: System of connecting disciplines for future mining activities.

http://www.bergbau.tu-clausthal.de/en/studies/study-courses/mining-engineering-master/). CDIO is an initiative for internationally orientated study plans for optimal training of future engineers (for more information, see http://www.cdio.org/about). Currently (as of May 2017), 60 students are registered in the Mining Engineering programme. Some 70% are from non-German-speaking countries, in fact 15 different countries in total, which allows all students to gather cross-cultural experience by learning together and which opens new opportunities for conducting the lectures. In addition to international experience, also the Rammelsberg teaching and research mine in the nearby city of Goslar is part of the study plan. Here, authentic teaching is possible and a range of research opportunities are available for the students (Clausen & Binder, 2017).

With its international composition, the mining study course attracts well educated bachelor-degree holders from foreign countries to Germany and offers a wide range of opportunities for employment on the German market after finishing the course. As many graduates remain in Germany and receive employment there, the study course also supports Germany's national economy. The first contact between students and possible employers is gained during field trips. Here, both German and international students get to know different mining companies and suppliers and may be offered internships or research opportunities.

For the establishment of a successful and socially accepted mining industry in the future, all of the aspects discussed in this paper must be respected. Germany shows high potential to be successful in this progress, as competences are available in the country. However, success is also a question of combining these competences and working together among the variety of disciplines to ensure the best project outcomes. In this, universities are very appropriate partners (*Fig. 7*) in efforts to proactively adapt to trends in the future of mining.

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Landslide susceptibility mapping using the Rock Engineering System approach and GIS technique: an example from southwest Arcadia (Greece)

Nikolaos Tavoularis*, Ioannis Koumantakis, Dimitrios Rozos and Georgios Koukis

The purpose of this study is to prepare a susceptibility map in a landslide-prone area in Greece using Rock Engineering System (RES) and a geoprocessing tool called Model Builder. The implementation of RES is achieved through an interaction matrix, where ten parameters were selected as controlling factors for the landslide occurence. The validation of the developed model was achieved by using field-verified data, showing excellent correlation between the expected and existing landslide susceptibility level. In conjunction with Model Builder, which can overlay different layers and produce landslide susceptibility maps, RES can act as a tool for calculating the instability index and getting a prognosis of a potential slope failure in relation to sustainable development planning processes in landslide susceptible areas.

L'objet de cette étude est la réalisation d'une carte de prédisposition au risque, dans un secteur sujet aux éboulements, en Grèce, en utilisant le système RES (Rock Engineering System) et un outil de traitement géologique nommé Model Builder. La mise en œuvre du RES est réalisée grâce à une matrice interactive avec sélection de dix paramètres en tant qu'éléments de contrôle d'une occurrence d'éboulement. La création de ce modèle a été validée en utilisant des données de vérification terrain qui ont montré une excellente corrélation entre les niveaux de prédisposition aux éboulements, attendus et constatés. En conjonction avec le Model Builder qui peut concerner différentes couches de terrain et produire autant de cartes de prédisposition aux éboulements, RES peut agir comme un outil de calcul de l'indice d'instabilité et de pronostic de rupture potentielle de pente en relation avec les processus de planification de développement durable dans les secteurs propices aux éboulements.

El propósito de este estudio es preparar un mapa de susceptibilidad en un área propensa a deslizamientos en Grecia utilizando Rock Engineering System (RES) y una herramienta de geoprocesado llamada Model Builder. La implementación de RES se logra a través de una matriz de interacción, donde se seleccionaron diez parámetros como factores de control para la probabilidad de deslizamiento. La validación del modelo desarrollado se logró mediante el uso de datos verificados en el campo, que muestran una excelente correlación entre el nivel de susceptibilidad al deslizamiento esperado y existente. En conjunto con Model Builder, se pueden superponer diferentes capas y producir mapas de susceptibilidad a deslizamientos, RES puede actuar como una herramienta para calcular el índice de inestabilidad y obtener un pronóstico de un posible derrumbe de taludes en relación con procesos de planificación sostenibles en áreas susceptibles a deslizamientos.

1. Introduction

Over the last two decades, many studies of landslide susceptibility assessment have been made. It is believed that the accuracy of landslide susceptibility mapping increases when all determining parameters are included in the analytical process. Rock Engineering System (RES), which is a semi-quantitative rock engineering approach and the basic tool for representing the parameters and their interaction mechanisms, can thus be useful in decision making regarding land use and development planning processes in landslide susceptible areas by providing a

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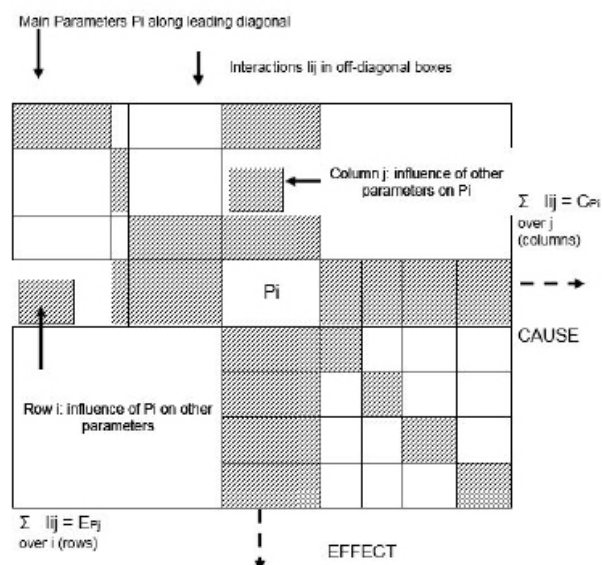

Figure 1: Summation of coding values in the row and column through each parameter to establish the cause and effect co-ordinates (after Hudson, 1992).

tool for zoning landslide hazard. It is based on an interaction matrix which represents the key parameters as leading diagonal terms and their binary interaction mechanisms as off-diagonal terms (*Figure 1*).

RES was developed by Hudson (1992) to determine the interaction of a number of parameters in rock engineering design and calculate an instability index for rock slopes. In this study, an attempt is made to prove that RES can be implemented with the same efficiency in forecasting landslides, which are related to a variety of geomaterials [for instance soils, soft rocks, flysch formation (intercalation of different geological formations, etc.)].

Here, the RES approach was used for landslide susceptibility mapping in the wider area of Megalopis, located in southwest Arcadia, which is part of the administrative region of Peloponnese, Greece. In the first stage, 21 landslide locations were identified in the study area from the literature field surveys and interpretation of satellite pictures. Secondly, ten data parameters (layers) were used as landslide conditioning and triggering factors for susceptibility mapping.

Next, the examined area was analysed using the RES methodology in conjunction with Geographical Information Systems (GIS), which facilitated the manipulation of these ten selected landslide data layers. To be more specific, a geoprocessing GIS function called "Model Builder" from ArcGIS (ESRI) was applied, providing automatic preparation of the landslide susceptibility map. The results of the RES analyses proved the instability of the field-verified landslide locations. Moreover, the verification results showed not only excellent correlation between the susceptibility map produced and the existing data of the 21 historical landslide locations but also indicated that many more potential slope failures could be taken place in the wider region of Megalopis in the future. In conclusion, this contribution (the combination of RES with Model Builder resulting in landslide susceptibility mapping) provides originality to this study.

Table 1: Interaction matrix of the RES method.

				INTERACTION MATRIX							
P1	0	3	1	0	1	0	3	0	0	5	
3	P2	3	1	4	3	0	4	4	4	24	
4	0	P3	1	0	1	0	2	2	1	11	
2	1	2	P4	1	2	2	2	2	1	15	
3	1	3	1	P5	4	0	4	2	3	23	
2	0	2	3	1	P6	0	2	1	1	11	
4	0	3	0	2	4	P7	4	0	0	17	
3	0	2	0	0	3	0	P8	1	2	11	
2	0	1	3	1	4	0	2	P9	1	14	
3	0	3	1	1	4	0	3	2	P10	17	
26	2	22	12	10	26	2	26	14	13		160
				(Effect - E)						153	

P1	Distance from roads	P2	Tectonic regime	P3	Slope inclination	P1	Slope orientation
P5	Lithology	P6	Hydrogeological conditions	P9	Rainfall	P11	Thickness of weathering mantle
P9	Distance from rivers			P10	Distance from tectonic elements		

Parameters	C	E	C+E	[(C+E)/(ΣC+E)]·100%	Maximum rating	Weighted coefficient a_i
P1	8	26	34	11.1	4	2.8
P2	28	2	28	9.2	4	2.3
P3	11	22	33	10.8	4	2.7
P4	15	12	27	8.8	4	2.2
P5	21	10	31	10.0	4	2.7
P6	11	26	37	12.1	4	3.0
P7	17	2	19	6.2	4	1.8
P8	11	26	37	12.1	4	3.0
P9	14	14	28	9.2	4	2.3
P10	17	13	30	9.8	4	2.5
	ΣC=160	ΣE=160	306	100.0		

2. Materials and methods

2.1 Establishing the interaction matrix and matrix coding

The RES approach, which is based on an expert's judgement, uses an interaction matrix in which the main parameters thought to govern a particular circumstance (e.g. slope failure) are selected and the interactions between them are considered (Hudson, 1992). This enables a comprehensive assessment of the factors and interactions, the advantage being that all potential influencing factors can be included initially. RES methodology reduces uncertainty because study of the interactions between the factors indicates the degree of influence of the factors in the system being considered – which are dominant and which have a much lesser or insignificant contribution – thus reducing the uncertainty.

The interaction matrix (*Table 1*) shows in its main diagonal cells the principal parameters considered responsible for controlling the potential instability of the examined slopes, while its off-diagonal cells contain the coded expressions of all possible binary interactions. For the purpose of the present work, a range of possible interactivity from 0 to 4 was adopted (Koukis and Ziourkas, 1991), where 'none' is coded 0 to indicate the most stable conditions, and other interactions are ranked 'weak' (coded 1), 'medium' (coded 2), 'strong' (coded 3) or 'critical' (coded 4 – the most favourable condition for slope failure).

By coding the interaction matrix components and then summing the values in the row and column through each parameter, "cause" and "effect" co-ordinates are generated, indicating a parameter's interaction intensity (*Figure 2*).

The influential role of each parameter on slope failure (weighted coefficient influence) is revealed from a Cause [C] versus Effect [E] diagram (*Figure 3*), while the role of the system's interactivity is expressed from the histogram of the interactive intensity (C+E) (*Figure 4*). The C+E values will be transformed into a percentage form acting as weighting coefficients, which express the proportional share of each parameter (as a failure-causing factor) in slope failure and are normalised by dividing by the maximum rating (4), giving the a_i percentage.

The next step is to compute the instability index (Ii) for the considered slope using the following equation:

$$I_i = \Sigma a_i \times P_{ij},$$

where i refers to parameters (from 1 to 10), j refers to the examined slope and a_i is
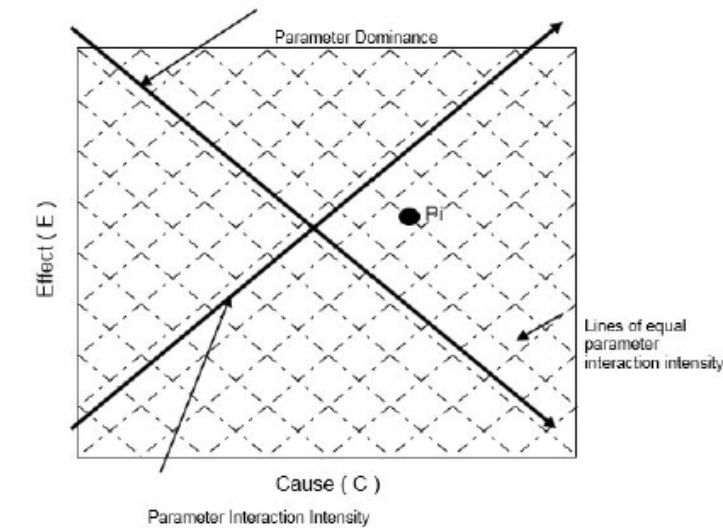
Figure 2: Parameter interaction Intensity and Dominance (after Hudson, 1992).
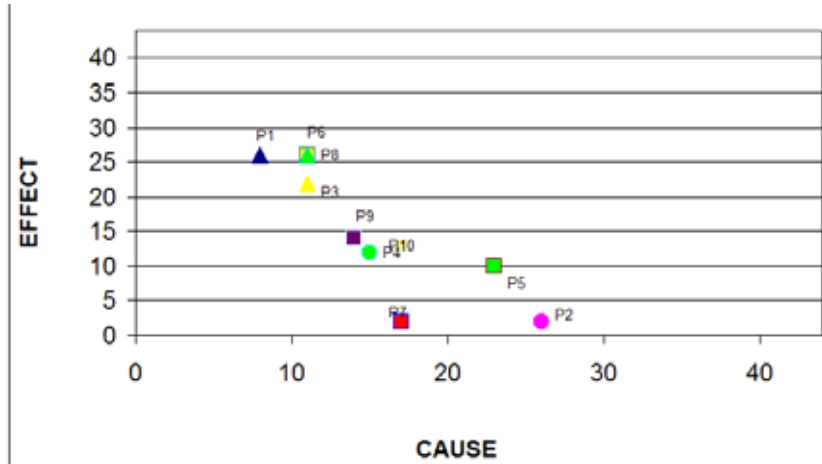
Figure 3: Cause-Effect diagram for the 10 parameters of the Megalopolis study area.
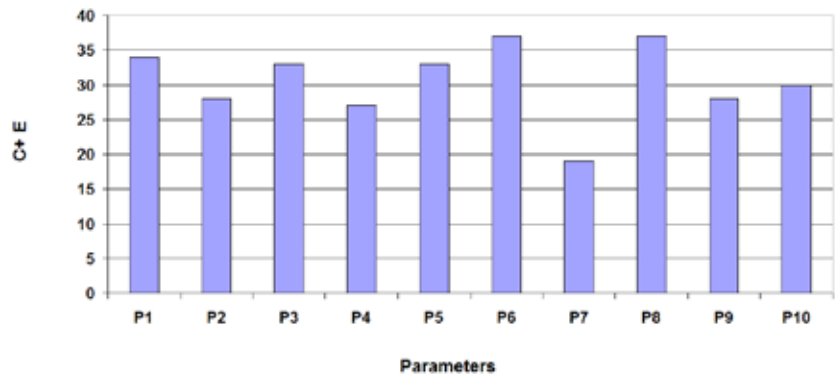
Figure 4: Interactive intensity of parameters.

the weighting coefficient of each parameter given by the formula:

$$a_i = 1/4 * [(C+E)/(\Sigma_i C + \Sigma_i E)]\%,$$

scaled to the maximum rating of P_{ij} (maximum value=4). P_{ij} is the rating value assigned to the different category of each parameter's separation, which also fits better to the conditions related to the parameter in question regarding the examined slope failure (Rozos *et al.*, 2008). The instability index is an expression of the inherent potential instability of the slope, where the maximum value of the index is 100 and refers to the most unfavourable conditions.
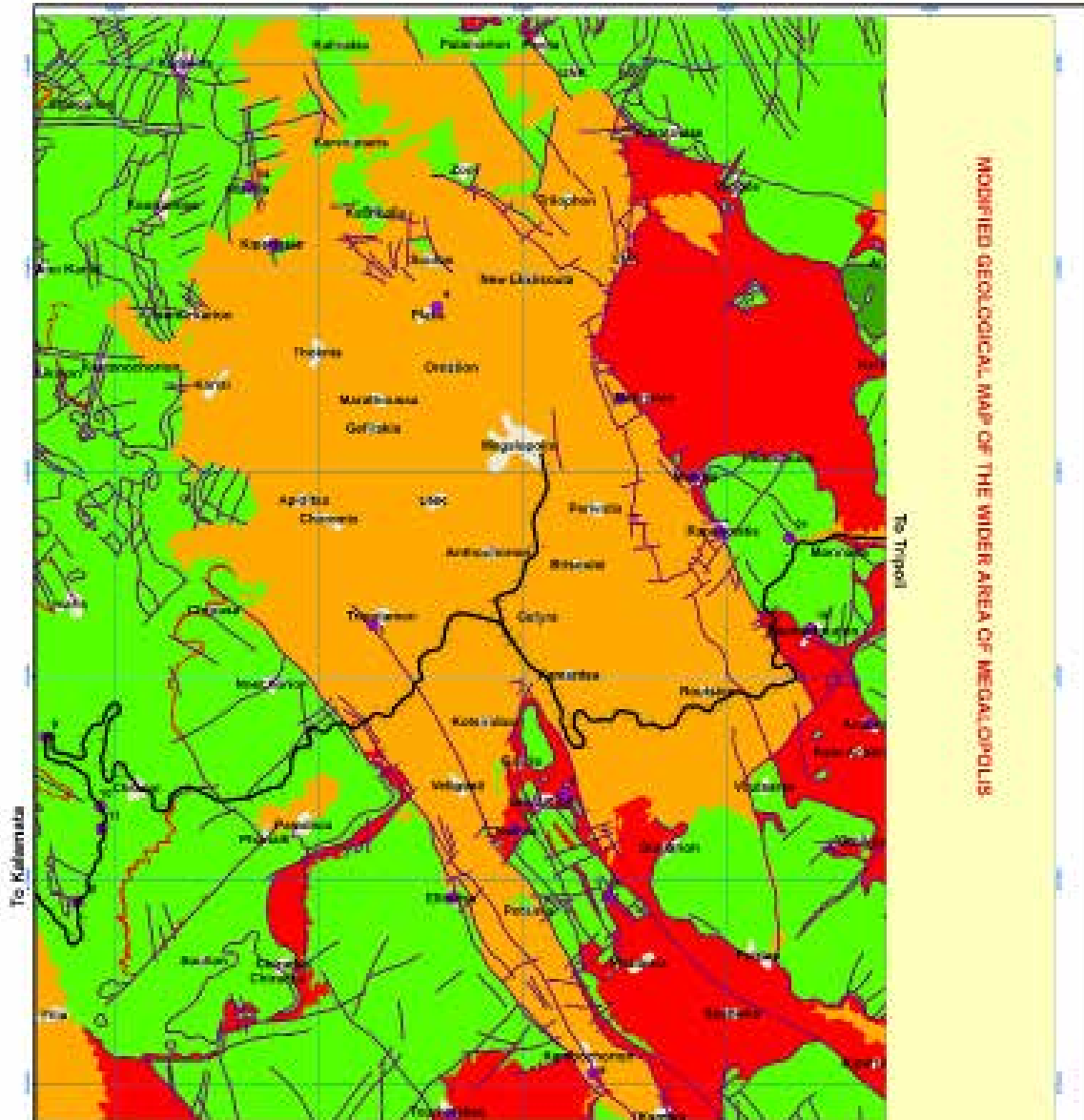
Figure 5: Modified geological map of Megalopolis area, scale 1:100,000 (Tavoularis, 2017).

2.2 Geological setting of the study area

The study area is located in Greece and specifically in the southwestern part of Arcadia in Peloponnese (*Figure 5*). In this particular region two alpine geotectonic units of the external Hellenides are present, namely (i) the Tripolis unit (shallow – water carbonates, Triassic – L. Eocene and flysch, L. Eocene – E. Miocene), and (ii) Pindos unit (pelagic limestones, radiolarites, the so-called "first flysch", thin-bedded limestones, L. Cretaceous and flysch, Danian-Eocene). Pindos units overthrust Tripolis units, forming successive thrust sheets with movement direction from east to west. The neotectonic macrostructure of the broader area (SW Peloponnese) is characterised by the presence of large grabens and horsts bounded by wide fault zones, striking N-S and E-W (Ladas *et al.*, 2007). In addition, this area was affected by the great Neogene phase of crustal extension.

The examined area is included in the 1:50,000 Geological Map of Megalopolis and has an extent of 614 km². The main rivers are the Alfios and Elisson. The mean annual rainfal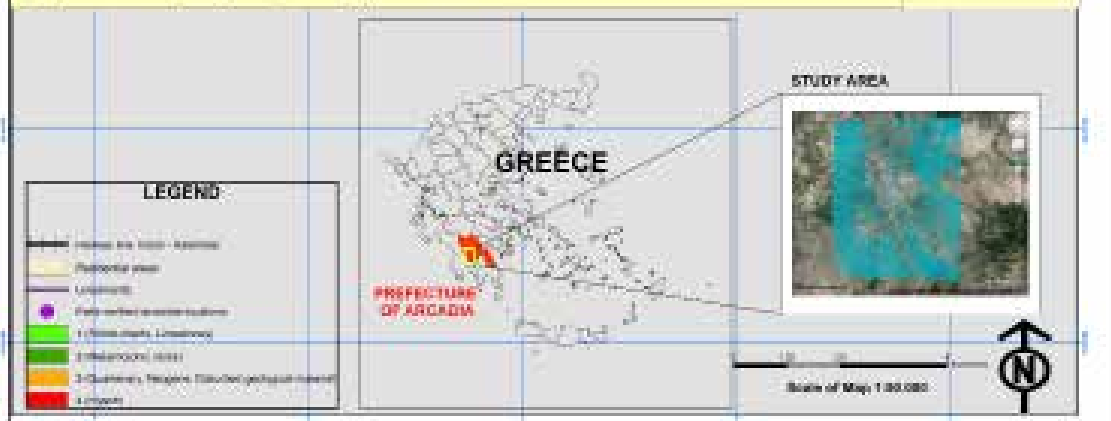l is around 1000 mm, while the maximum precipitation falls between November and March. Altitude values in the study area vary between 88 to 1340 m (Tavoularis, 2017).

2.3 Selection of the appropriate parameters controlling the slope failures

The majority of such studies follow five basic concepts for the chosen parameters, specified by Ayalew and Yamagishi (2005). Parameters should:

- be representative of the entire study area,
- vary spatially,
- be measurable,
- not account for double consequences in the final result,
- have a certain degree of affinity with the dependent variable (the presence or absence of landslides).

In the above case study area, ten parameters were selected as independent controlling factors for the landslide occurrence and each factor was classified into 5 classes. The factors utilised for the RES methodology were:

P1 - distance from roads,
P2 - tectonic regime,
P3 - slope inclination,
P4 - slope orientation (aspect),
P5 - lithology,
P6 - hydrogeological conditions,
P7 - rainfall,
P8 - thickness of weathering mantle,
P9 – distance from rivers and
P10 - distance from tectonic elements.

The geodata were adjusted to the local conditions of Megalopis area and rated for construction of the interaction matrix (Tavoularis, 2017). These parameters can be quantified more easily than more time- and money-consuming ones (*Table 2*).

Table 2: The selected parameters and their rating.

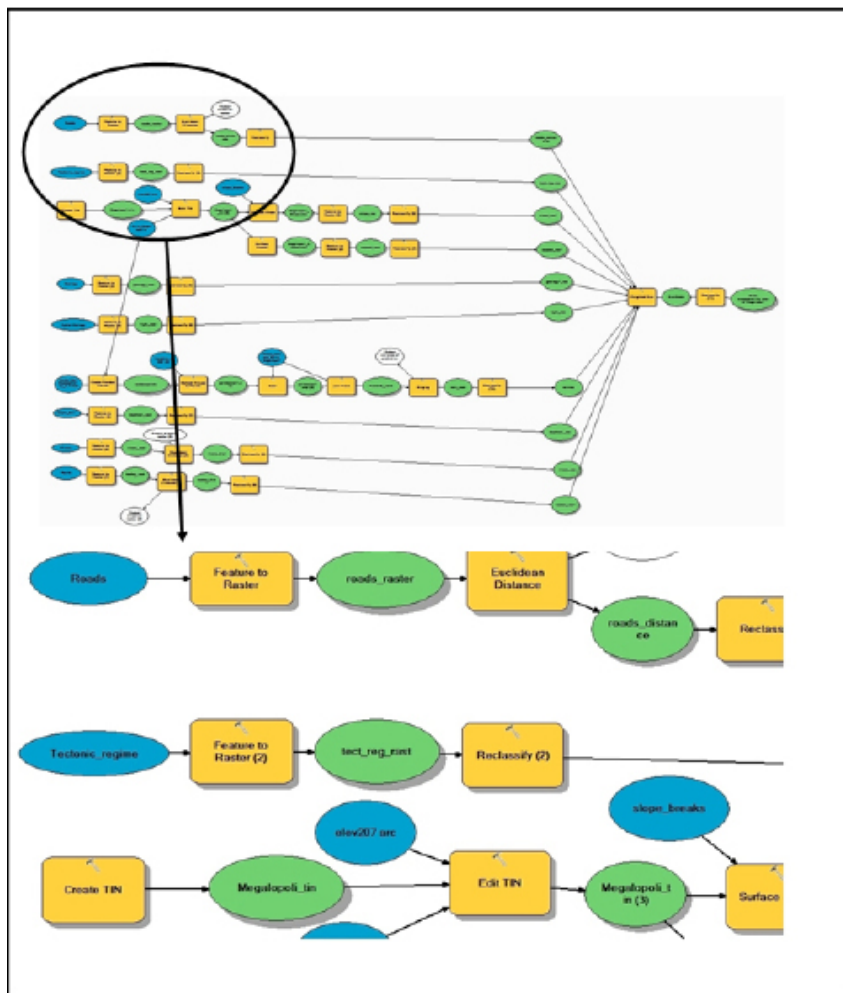| PARAMETERS	RATING	PARAMETERS	RATING
1. Distance from roads		**7. Rainfall**	
Distant (>200 m)	0	<400 mm	0
Moderately distant (151–200 m)	1	400–600 mm	1
Immediate (101–150 m)	2	600–1000 mm	2
Less immediate (51–100 m)	3	1000–1400 mm	3
Close (0–50 m)	4	>1400 mm	4
2. Tectonic regime		**8. Thickness of weathering mantle**	
Weak: is not connected with a significant tectonic event	0	None	0
Moderate: presence of schistocity	1	Very small (0.00–0.50 m)	1
Strong: is associated with the presence of faults and discontinuities	2	Small (0.– 1.50 m)	2
Very strong: with high-fractured zones	3	Medium (1.5– 3.0 m)	3
Intense: represents up thrusts and over thrusts	4	Significant (>3.00 m)	4
3. Slope's inclination		**9. Distance from rivers**	
0–5°	0	Distant (>200 m)	0
6–15°	1	Moderately distant (151–200 m)	1
16–30°	2	Immediate (101– 150 m)	2
31–45°	3	Less immediate (51–100 m)	3
>45°	4	Close (0-50 m)	4
4. Slope's orientation		**10. Distance from tectonic elements**	
225° –275°	0	Distant (>200 m)	0
45°– 90°	1	Moderately distant (151–200 m)	1
90°–135°, 275°– 315°	2	Immediate (101–150 m)	2
315°– 0°	3	Less immediate (51–100 m)	3
0°– 45°, 135°–225°	4	Close (0–50 m)	4
5. Lithology		Note: Paramaters rating is based on: Rozos et al. (2008) & (2011) and Koukis and Ziourkas (1991) for the period 1949–1991. In addition, concerning slope inclination, even though based on Koukis and Ziourkas (1991) the higher landslide density is in the class of 16°–30°, in this study the higher rating was given to slopes with the higher inclination, due to the fact that in nature, slopes consisting of soil or hard soil to soft rocky formations and having high angle fail almost immediately after the formation giving lower slope angles (Rozos et al., 2011).	
Volcanic rocks	0		
Cherts, schists	1		
Limestone, marbles	1		
Metamorphic formations exhibiting schistocity	2		
Old landslide / disturbed geomaterial (alluvial, etc.)	3		
Flysch	4		
6. Hydrogeological conditions		**RATING**	
None		0	
Fractured formations characterised as having low to negligible permeability (Flysch, schists)		1 (Restricted: refers to solution and leaching of soil materials as well as to degradation of fine-grained and coarse-grained materials)	
Alluvial deposits, carbonate formations having low to medium permeability		2 (Moderate: is associated with the freezing of water in the joints, clays swelling and the action of water in discontinuities and cavities)	
Debris with medium permeability		3 (Increased: refers to erosion by water courses)	
Carbonate formations with medium to high permeability		4 (Extensive: is connected to the loading caused by snow, rainfall and springs but also to the increase of pore water pressure)	

Figure 6: View of Megalopolis model builder.

2.4 Application of Model Builder in landslide susceptibility mapping

The susceptibility approach was designed by the USGS in the 1960s as a qualitative way to prepare landslide maps or to delineate zones affected by landslides, assessing the propensity of a given slope unit to generate a landslide based on spatial data (Brabb *et al.*, 1972). Naturally, any landslide susceptibility prediction has a level of uncertainty. Sources of uncertainty include:

- errors and incompleteness in the landslide and thematic information to complete the analysis,
- an imperfect understanding of landslide processes and their geographical and temporal evolution;
- limitations in the techniques used to determine the susceptibility,
- the inherent natural variability of landslide phenomena.

Determining the errors associated with the geomorphological, geological and other thematic information is of primary importance. Improving the understanding of the landslide processes is feasible, but requires time and resources often not available to landslide investigators (Guzzetti *et al.*, 2006). Consequently, some parameters will have to be rated from the beginning. To overcome these difficulties, in this study Model Builder, an application of ArcGIS (ESRI), is used for the automatic preparation of a landslide susceptibility map by modifying each parameter easily and quickly at any time.

Model Builder is a visual programming language for building geoprocessing workflows that allows multiple processes to be combined. The model is represented as a diagram that links together sequences of processes and geoprocessing tools, using the output of one process as the input to another process. It enables the user to visualise work flow (in the form of flow chart diagrams) and author and automate geoprocessing tasks that would normally be executed in single steps in ArcMap. It also

has the resultant advantage of allowing the user to document the steps involved in the development of a model. While the development of the initial version of a model might take a little more time than conducting the steps manually, it is extremely useful when conducting multiple runs of a model – the model can be run on different data or small changes in the model can be made and the model rerun to examine model alternatives and assumptions (National Land Service of Lithuania, 2008). By using this application, it becomes easier to test the susceptibility model (*Figure 6*).

2.5 Data analysis

The following step was the production of the landslide susceptibility map through the construction of different thematic maps associated with landslide-related variables. The data used for the preparation of these layers were obtained from the Hellenic Military Geographical Service topographical sheets (scale 1:50,000) and IGME geological map (Megalopolis, scale 1:50,000). All data layers were digitised either from the original thematic maps or derived from spatial GIS calculations and finally were converted into grids with cell size 30 × 30 m.

The next step was to assign weights and rank values to the raster layers (representing factors) and to the classes of each layer respectively. This was realised with the use of RES. Finally, the weighted raster thematic maps with the assigned ranking values for their classes were multiplied by the corresponding weights and added up (through the ArcGIS tool of weighted sum) to yield a simple map where each cell has a certain landslide susceptibility index value. After reclassification this map represents the final susceptibility map of the study area (*Figure 7*).

3. Results and discussion

3.1 Implementation of RES in Geological map of Megalopolis (scale 1:50,000)

RES was implemented in the area defined by the geological map of Megalopolis, taking into account the interactions of the examined principal parameters and the calculation of their weighting coefficients. This resulted in the determination of an instability index for each examined slope of the study area. The RES matrix shown in *Table 1* provides interactions of the chosen parameters based on the ratings outlined in *Table 2*.

For example, regarding the effect of rainfall on the thickness of the weathering
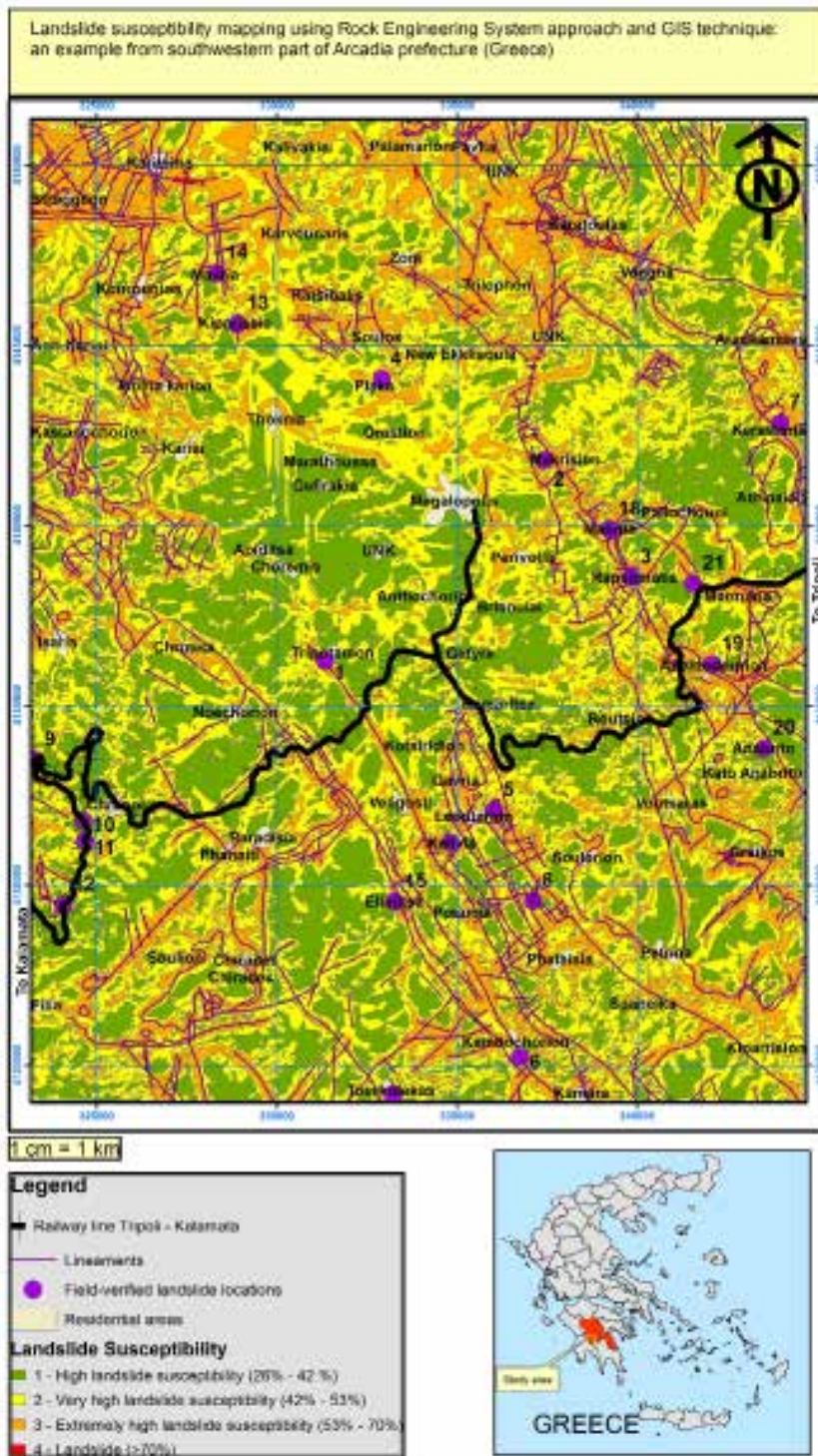
Figure 7: Landslide susceptibility map of Megalopolis area scaled in 1:100,000 (Tavoularis, 2017).

From *Table 1*, it can be seen that hydro-geological conditions and thickness of the weathering mantle are the most interactive parameters (C+E=37), while rainfall is the least interactive (C+E=19). This suggests that rainfall does not depend on the influence of the other parameters but is an independent agent, concerning the whole system.

Based on the above, the landslide susceptibility index (LSI) values in the resulting susceptibility map vary within the range of 0 and 100. LSI values were classified into seven categories, namely "Negligible", "Low", "Middle", "High", "Very high", "Extremely high" and "Landslide", according to the classification for landslide susceptibility shown in *Table 3* (Brabb *et al.*, 1972). The higher the LSI, the more susceptible the area is to landslides. In this study, the critical zones were those corresponding to an instability index higher than 49%, the "Very High" and "Extremely high" zones.

3.2 Validation of the landslide susceptibility map

In order to test the performance of the produced susceptibility map, it was compared with the distribution of the major landslide events that had occurred in the study area and the predicted map showed very satisfactory results. To be more specific, in the landslide susceptibility map of Megalopolis, 5% of the locations of actual landslides correspond to the "Very high" and 95% are associated with "Extremely high" landslide susceptibility (*Figure 7, Table 4*)". The susceptibility map shows that slope failure incidents were located in areas where flysch formations, schist-cherts and Neogene sediments outcrop on slopes near major fault zones and thrust surfaces. Moreover, in order to examine the potential landslide risk in respect to settlements, villages and cities of the study area were overlaid on the susceptibility-hazard map. This correlation suggests that 45 settlements are entirely or partially located within "Very high" or "Extremely high landslide susceptibility" zones".

4. Conclusions

In this paper, landslide susceptibility was assessed by examining ten landslide parameters using RES and a GIS geoprocessing tool called Model Builder. Based on the selected parameters, all interactions that

mantle, the runoff erodes the surface soil and weakens rock formations. Also, the infiltrated water increases the pore water pressure, alters the weathering of the existing surface (and subsurface) geomaterials and consequently increases the thickness of the weathering mantle (rating: 4). On the other hand, the thickness of the weathering mantle does not influence rainfall at all (rating: 0).

Table 3: Classification for relative landslide susceptibility proposed by Brabb et al. (1972).

% Failed area	0 - 1	2 - 8	9 - 25	26 - 42	43 - 53	54 - 70	100
Relative Susceptibility	I	II	III	IV	V	VI	L
	Negligible	Low	Middle	High	Very high	Extremely high	Landslide

Table 4: Calculation of Instability Index of Megalopolis area.

Parameter Landslide location	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Instability Index	RSH	Landslide susceptibility
1	3	0	1	2	3	2	2	4	4	4	66	VI	Extremely high landslide susceptibility
2	4	2	1	6	1	1	5	1	4	1	61	VI	Extremely high landslide susceptibility
3	4	2	1	4	1	1	1	1	1	4	60	VI	Extremely high landslide susceptibility
4	4	2	1	4	1	1	4	1	0	0	54	VI	Extremely high landslide susceptibility
5	4	2	3	4	4	1	2	2	1	1	67	VI	Extremely high landslide susceptibility
6	1	2	4	2	1	1	4	1	1	4	66	VI	Extremely high landslide susceptibility
7	1	4	2	2	1	1	2	1	4	4	62	VI	Extremely high landslide susceptibility
8	4	2	1	4	4	1	2	2	2	4	66	VI	Extremely high landslide susceptibility
9	4	4	2	4	1	2	2	2	4	0	62	VI	Extremely high landslide susceptibility
10	4	4	2	4	1	2	2	2	4	0	63	VI	Extremely high landslide susceptibility
11	4	4	2	4	1	2	5	2	4	0	63	VI	Extremely high landslide susceptibility
12	4	4	2	2	1	2	5	2	2	4	64	VI	Extremely high landslide susceptibility
13	4	1	1	2	1	2	4	1	1	1	60	VI	Extremely high landslide susceptibility
14	4	4	1	4	1	2	4	2	1	1	63	VI	Extremely high landslide susceptibility
15	4	2	1	4	1	4	2	1	4	1	66	VI	Extremely high landslide susceptibility
16	4	2	1	4	4	1	2	2	1	0	67	VI	Extremely high landslide susceptibility
17	4	2	2	2	1	1	2	2	1	1	61	VI	Extremely high landslide susceptibility
18	4	2	2	2	4	1	2	2	1	1	66	VI	Extremely high landslide susceptibility
19	4	4	2	2	1	4	2	1	1	1	63	VI	Extremely high landslide susceptibility
20	4	2	1	0	4	1	1	2	4	0	49	V	Very high landslide susceptibility
21	4	4	2	4	1	4	2	1	2	1	67	VI	Extremely high landslide susceptibility
Maximum rating	4	4	4	4	4	4	4	4	4	4			
$\sum(HG)/\sum(HG)\times100\%$	11.1	8.2	10.6	6.6	16.6	12.1	6.2	12.1	8.2	9.8	100.0		
Weighted coefficient (Wj)	2.6	2.1	2.7	2.2	2.7	1.0	1.6	4.0	2.5	2.5			

were revealed have been implemented through an interaction matrix. The outcome of this procedure produced the final susceptibility map for the southwestern part of Arcadia in Greece. The validity of this approach was tested using the slope failures that had occurred in this particular region. The instability index of all those slopes was found to be larger than 49 (out of 100), proving their instability (e.g. 21 out of 21 landslides were observed in either the "Very high susceptibility" or "Extremely high susceptibility" zone). In addition, it became clear that many more potential landslides could take place in the wider region of Megalopolis in the future.

Based on these positive results, we are confident in saying that the adaptability of RES to local conditions and to the given characteristics of existing geodata allow the use of an efficient tool in estimating landslide susceptibility hazard by adopting parameters that can be quantified more easily compared to other more expensive and time-consuming techniques. Moreover, experts (geologists, engineers) can use the RES approach before site investigations (geological–geotechnical) take place without knowing in advance if any slope failure has occurred in this area already.

As a consequence, RES could be an inexpensive and effective tool in ranking the instability in natural and man-made slopes and be useful in decision making regarding land use and development planning processes for zoning areas of potential landslide phenomena, such as those of southwest Arcadia.

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Resource sustainability - Geology is the solution

Eamonn F. Grennan* and John A. Clifford

The question of resource sustainability was developed during the late 1960s and lies at the core of a number of alarmist reports compiled at that time, none of which had a geological perspective. The public perception of geology is that it has little, if any, impact on their everyday lives. This is, of course, a fallacy. Geology is one of the central factors that impacts, and needs to be considered, across a range of public policy issues and it is noteworthy that in all of these reports exploration risk is never considered. At present Europe is dependent on imports of raw materials from countries which do not necessarily have good environmental standards. If Europe really wants a quality environmental future, it must encourage the discovery of its own resources and not develop policies that inhibit their development. Europe can only ensure a secure, and sustainable, supply of raw materials for its industrial base by doing this.

La question de la durabilité des ressources naturelles s'est développée à la fin des années 1960 et est présente au cœur de nombreux rapports alarmistes établis alors, dont aucun ne mentionne la moindre perspective géologique. La perception géologique auprès du public est celle d'un très faible impact sinon d'aucun impact sur leur vie au quotidien. Ceci est, naturellement, une erreur. La géologie est l'un des facteurs principaux qui intervient et doit être considéré parmi une série de questions de politique publique et il est à noter qu'au sein de tous ces rapports, la notion de risque en exploration n'est jamais mentionnée. Actuellement, l'Europe dépend de l'importation de matières premières venant de pays qui n'ont pas nécessairement de réglementation environnementale valable. Si l'Europe désire réellement vivre dans un environnement futur de qualité, elle doit encourager la découverte de ses propres ressources et s'abstenir de développer des politiques qui freinent leur développement. C'est en faisant cela que l'Europe peut seulement garantir l'approvisionnement sécurisé et durable de matières premières, indispensables à ses besoins industriels de base.

El tema de la sostenibilidad de los recursos se desarrolló a fines de los años sesenta en relación con una serie de informes alarmistas compilados en esta época, ninguno de los cuales tienen una perspectiva geológica. La percepción pública de la geología es que tiene poco o ningún impacto en su vida cotidiana. Esto es, por supuesto, un error. La geología es uno de los factores centrales que tiene un impacto, y debe ser tenida en cuenta en un amplio rango de asuntos de política pública, por el contrario es importante mencionar que en ningún informe se considera el riesgo de exploración. Actualmente, Europa depende de las importaciones de materias primas procedentes de países que no tienen necesariamente buenas normas medioambientales. Si Europa realmente quiere un futuro con calidad medioambiental, debe apoyar al descubrimiento de sus propios recursos en lugar de propiciar políticas que impiden su desarrollo. Solo así, Europa puede garantizar un suministro seguro y sostenible de materias primas para su estructura industrial.

As with many scientific arguments, the actual starting date and the person, or persons, responsible for the idea of 'resource sustainability', is usually a matter of great debate. We propose to use just four principal references. Our starting point is "A Report for the Club of Rome" (Meadows *et al.* 1972), using the abstract established by Pestel (no date). Their model "was built specifically to investigate five major trends of global concern", including "the depletion of non-renewable resources". The latter statement goes to the core of the sustainability debate.

As a matter of fact, the Earth is of a certain size with a fixed amount of materials. Thus, from a fundamentalist point of view, the extraction, use and discarding of non-renewable raw materials lessens the amount available for future use. This is a fundamentalist position based primarily

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on the supposition that all resources have been discovered. To take just one example, the total amount of gold produced in the world is about 187 kt (World Gold Council website 2017). No one is suggesting that we are running out of gold. No, geology is not the problem.

Over the past 50 years we have witnessed many transient shortages of materials such as germanium, gold, zinc, rare earths, and even iron, as well as those others listed in the Critical Raw Materials (CRM) reports. In parallel with this is the changing demand for materials and the use of substitutes, e.g. hematite was substituted for 20% of the barite in drilling mud, fluorspar was in high demand in the steel industry during the 1970s and mines opened and closed due to major price variations. In the latter case, due to recent increase in demand, fluorspar is now designated as a CRM. Demand for, and the price of, gold has fluctuated widely during the past 50 years; copper prices rose

and fell with economic activity; iron ore prices rose rapidly for a period in the late 20th century due to demand, principally, from China; all are examples of supply and demand.

We concur with the CRM report that "Raw materials are fundamental to Europe's economy, growth and jobs and are essential for maintaining and improving our quality of life" (CRM, 2014:7). However, only "around 9% of raw material supply is indigenous to the EU" (p.30) **"largely due to industrial minerals production"** (p.8, authors' emphasis). The CRM notes that "total supply across all twenty raw materials can be estimated at less than 3%, with over half having no, or very limited, production within the EU" (p.30).; with 14 of the 20 imported from China.

The rationale behind the CRM 2010 Report was refined in the 2014 report suggesting that while "most of these metals and minerals will continue to be imported from

sources outside Europe; others can, and should be produced domestically" (CRM, 2014:8). In implementing such an action, we agree with Brundtland (1981) that the ecological ramifications must be considered at the same time as the economic, trade, energy, agricultural and other dimensions. As is pointed out in the CRM (2014), the problem is that the environmental considerations now have a veto on resource development in Europe to the detriment of the environment and sustainable development of Less Developed Countries (LDCs).

Shortages/sustainable supply

It would seem from study of the CRM document that the primary issue for the EU is to secure a sustainable, reliable and continuous supply of resources without a discordant pricing policy. As enunciated in the ERA-MIN (2017), and reflecting Brundtland (1981), the question of finite resources is a non-issue and the objective should be to "secure sustainable supply of raw materials, increasingly from European sources." This is in accordance with the aim of the European Industrial Policy (EIP). There are of course a number of supply problems, the rate of discovery for some materials may not be fast enough or the difficulties, be they metallurgical, financial, environmental, or administrative, may not be resolved in a timely manner.

We agree with Brundtland (1981) that efficiencies and recycling technological advances are important with the caveat that in many instances such advances will involve the use of different raw materials, which are as yet undiscovered. In addition, it is likely that the sophisticated chemistry required in the production of the newer materials will probably lessen their suitability for recycling.

Thus, Brundtland (1981) is correct in arguing that "the integration of environment and development is required in all countries, rich and poor" (Ch. 1, para. 48) and in pointing out that "economic growth always brings risk of environmental damage" (Ch. 1, para. 50). Those risks can be, and are being, addressed in all new mining ventures, which require a closure plan as part of the development application. We must recognize however that, as Commissioner Hogan has stated in another context, "you cannot make an omelette without breaking eggs"!! (Hogan, 2014). What we must argue against is that Europe is exporting the mining industry to LDCs, importing the raw materials and then selling the end product back to the LDCs.

Geology, exploration, and risk

Fundamental to a sustainable supply of raw materials for manufacturing industry is a mining industry; fundamental to a sustainable mining industry is a vibrant exploration industry; fundamental to a vibrant minerals exploration industry is geology. The real problems of the technical and financial risk attaching to mineral exploration, and the importance of geology, are rarely discussed.

To take just one simple example: Ireland is a major zinc concentrate producer in Europe and is in the world's Top 15 (E. Doyle *pers. comm.* 2017). All of the deposits which have contributed to this achievement have been discovered within 100 m of the ground surface. During the process of mining, the deposits have been extended to greater depths, some in excess of 300 m. Nobody is seriously suggesting that discovery depths of 100–200 m will not happen. Of course, the cost of discovery will be

greater and indeed such is the confidence in making another discovery that expenditure on exploration in Ireland in the period 2012–2016 was nearly EUR 100 million (E. Doyle *pers. comm.* 2017), over 90% of which was directed to zinc.

There are two principal reasons why exploration tends to be ignored in all of this debate. Firstly, the high risk of no success - exploration success in Ireland is around 5,000 to 1. Most people, especially those in government service or in academia, rarely understand why anyone would undertake such risks. This is why there is a special section within the Stock Exchanges for such high risk companies. Secondly, having succeeded in finding a viable deposit, the extent of the regulatory obstacles put in the way of development is enormous, and costly. They can be ameliorated, but the environmental lobby has totally captured the administrative system.

Some countries in Europe, including within the EU, had a vibrant metals exploration and mining industry until the early 1960s. Today, however, the mining of metals has virtually ceased in most countries in the geographic core of Europe and has continued elsewhere only at a low ebb. This, we suggest, is a result of policy changes at both EU and corporate level. This is highlighted by the global distribution of exploration expenditure over the past 20 years, demonstrating the unsustainable low level of exploration investment in Europe relative to other regions (*Figure 1*).

This point becomes even more obvious when it is realised that 50% of the European exploration expenditure is focused on just three countries – Finland, Sweden and Serbia – with a further 25% in the next four countries – Spain, Ireland, Poland, and Portugal (*Figure 2*). It is more than coincidence that significant new base metal discoveries, or extension to existing operations, have been made in each of those countries during the past decade.

Principally within English speaking countries, minerals exploration and mining are two distinct sectors. Both have major financial risks - does the deposit being sought exist? – and the world is full of examples of mining projects which went wrong for a wide variety of reasons including, *inter alia*, poor timing, substitution by other commodities and over-extended loans. Within centrally controlled economies and most of the non-English speaking countries in the EU, exploration is undertaken either by a State agency or a mining company, either directly or by funding a junior partner. So the true cost of explora-
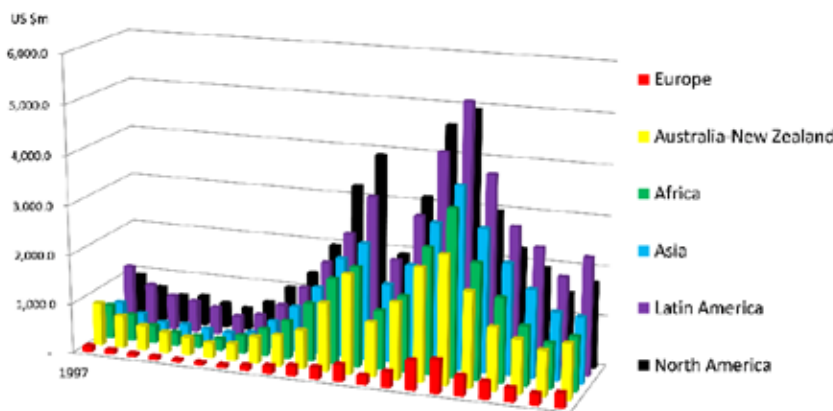
Figure 1: Global Distribution of Exploration Expenditure, 1997 –2017 (SNL Database).
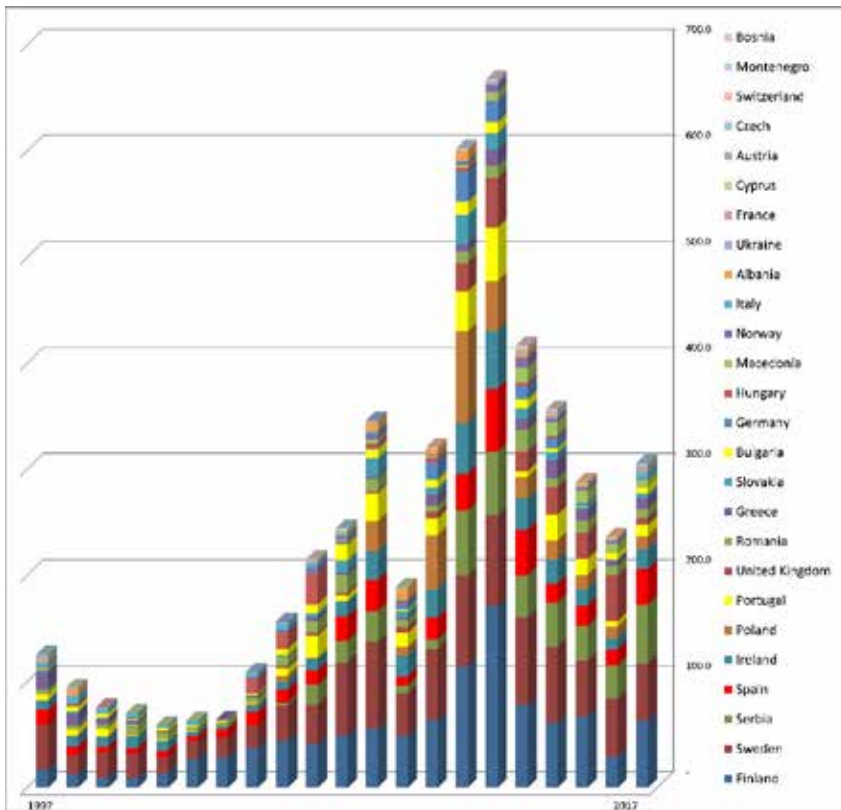
Figure 2: European Exploration Expenditure (million USD) Distribution, 1997–2017 (SNL Database).

tion and the very high risk attaching to it is not appreciated.

An understanding of the need for a separate high risk exploration psyche is essential for the discovery of new deposits. We consider that the excellent admonition of the need to incentivise European production of critical raw materials (20th May 2014 Press Release accompanying the publication of the CRM) is fundamental to finding the answer to a sustainable supply, with the caveat that "production" captures both the exploration and mining industries.

It has been argued that the best, and most efficient, way to find a deposit is to allow small exploration companies to flourish, whereby they can raise high risk finance and/or obtain exploration funding from major mining companies. Whilst it is undoubtedly true that exploration costs are rising, the real escalation in costs is in the post-discovery pre-development phase. Few geologists will argue against an increase in environmental and reporting standards, and inevitably the smaller company cannot sustain the costs and is typically taken over by the larger partner. The major company, through social and regulatory pressure accedes to the environmental/cultural/administrative lobby. This in turn leads to increased costs being imposed both

directly and indirectly on the developer, which leads to lower profits, and thus lower tax payments, resulting in the self-fulfilling prophecy that such companies avoid paying tax. This does not have to be the case, as is shown by the recent Australian case studies, such as the Nova and DeGrussa deposits, which went from discovery to production in 2 and 3 years respectively.

The INTRAW Report (2017) on Industry and Innovation suggests that new discoveries will likely be at depths in excess of 200 m, that new geological concepts and exploration technologies will be required to detect them, and this at a time when European universities and research institutes are either closing, or have declining interest in the geosciences. This view is further reflected by ERA-MIN (2013) which stresses that "research is vital to explore for deeper-seated deposits". We agree with these opinions, but note that "deep" in this context can mean "blind", in that new discoveries, such as Sakatti (Coppard, 2011), will be made beneath peat bogs and cover rocks, often at depths significantly less than 200 m.

Europe needs an exploration industry that is likely to succeed in discovering an economically exploitable resource. There exist sufficient data today in general geology, structural geology, geochemistry or

geophysics. These should be made available to small companies and within a system that gives the explorer rights.

Geologists, research and education

With some notable exceptions, geologists are poor communicators, and rarely participate in public policy debate. Indeed, even within corporate structures they are seldom heard outside of their chosen profession. Thus, when major over-arching studies are being compiled they are seldom if ever on the steering committee and often do not make it onto the important consultative committees. This lies at the root of many of the exaggerated statements of dwindling resources, and of the failure in communication of the value that geology brings to society.

Fortunately, this problem of public engagement has been recognized by certain geological organisations, of which the EFG is one, and which is also being addressed by some excellent television specials, as for example the Iain Stewart presentations on the BBC. However, more needs to be done.

In Ireland, the government is proactive through the Science Foundation Ireland in sponsoring, with a 5-year, EUR 25 million grant, to iCRAG - a geological research centre, and also in funding the Geological Survey of Ireland (GSI) to carry out a nationwide geochemical and airborne geophysical programme, code named TELLUS. Both of these initiatives will bear fruit in the future and reflect the ERA-MIN recommendations on the support required by the **traditional** and high-technology industries in Europe.

Unfortunately, at the very time when specialist and well-honed skills are required, the greying of the exploration community and a trend for new, graduate geologists to preferentially choose careers in sectors of the geosciences which do not require extended field time, mean that there is increasing loss of 'corporate knowledge' and the mentoring required in the passing on of critical exploration and mining skills.

Further, the majority of ERA-MIN activities are restricted to the academic and government domains, while links with the private sector are, with some notable exceptions, poorly developed, thus resulting, we contend, in a lack of research focus.

SMEs generally do not have a record of implementing high cost exploration. Such programs, which often require major academic input, only suit large companies. A similar issue applies to the exploration for deep deposits. In this respect, it can be

stated that the so-called traditional methods have not been systematically applied over much of Europe.

To address this problem, grant aid programmes need to have a grant level below which the administrative procedures are relaxed for SMEs. The concept of taxation credits to facilitate the initial evaluation of prospective areas is another idea worthy of consideration.

Way forward

The lingering negative perception of mining is a matter that must be addressed. In addressing it, it needs to be emphasized that successful exploration is a pre-requisite for a mining project. Interestingly the opponents of mining are far more cognisant of this fact and this is why they lobby against any incentives for exploration. In the absence of such incentives there will be no exploration.

The recent removal of environmental protection over part of the Amazon Basin was greeted with horror by the environ-mental community. This decision, at least in part, is an unintended consequence of the EU's outsourcing of its raw material requirements, rather than developing indigenous sources of supply, and thereby results in the exporting of the problem of mine waste management. As pointed out by Brundtland (1981) environmentalists must recognize that their policies can have adverse consequences.

Under a series of EC generated Directives, most Member States have adopted a series of environmental regulations which make it very difficult or even virtually impossible, to develop a mineral deposit. There is no balance, only the environmental aspects are given a veto; whilst the broader benefits for society are not given the same weight or credence. Thus, the EUs industrial heartland, built on hundreds of years of mining and manufacturing, now exists only as a manufacturing hub. It is worth recording that some 30 million jobs in the EU are directly reliant on access to raw materials (CRM, 2014).

The ERA-MIN roadmap lists four key areas that need to be addressed - exploration; mining/quarrying; mineral processing and metallurgy; mine closure and rehabilitation. If the ERA-MIN roadmap objectives are to be realised in the exploration sector then we need: access to lands to carry out exploration; new geological, geophysical and geochemical data to support that exploration, and financial incentives to attract mobile exploration funding.

One of the oft quoted sentences from Brundtland (1981) is "humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs". **This goes to the core of what is required in Europe; we must develop our own sustainable resources.**

Acknowledgements

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Multi-source data integration of Lower Cretaceous units with geothermal potential in Lisbon region, Portugal, to support geological modelling

Ana Ramada, Rayco Marrero-Diaz and João Carvalho*

The Lisbon region, the urban area with the highest population density and energy demand in Portugal, presents a favourable geological environment for geothermal purposes. The objective of this study was to integrate all the information known from different sources to support the construction of a geological model of the Lower Cretaceous units, which reveal the geothermal potential. The methodology developed in this study allows the integration of data from different sources into a single georeferenced and refined database. The eastern sector of the city of Lisbon, identified as the most promising area for geothermal applications, shows a lack of geological information at depth. However, a future junction of existing seismic profiles with the data obtained in the present study could resolve this issue.

La région de Lisbonne, zone urbaine avec la densité de population et la demande d'énergie, les plus élevées du Portugal, offre un environnement géologique favorable du point de vue énergie géothermique. Le but de cette étude fut d'intégrer l'ensemble des informations disponibles et venant de différentes sources pour soutenir la création d'un modèle géologique rapporté aux horizons du Crétacé inférieur qui représentent un potentiel géothermique certain. La méthode développée dans cette étude permet d'intégrer les données d'origines diverses en une base de données unique, géo référencée et épurée. Le secteur oriental de la ville de Lisbonne, identifié comme le plus prometteur au niveau applications géothermales est assorti d'un défaut de données géologiques profondes. Cependant, la future adjonction de profils sismiques existants aux données obtenues lors de cette étude, serait à même de résoudre ce défaut.

La región de Lisboa es la zona urbana con mayor densidad de población y demanda de energía en Portugal, presenta un entorno geológico favorable para la geotermia. El objetivo de este estudio fue integrar toda la información conocida de diferentes fuentes, para apoyar la construcción de un modelo geológico de las unidades del Cretácico Inferior, que revela el potencial geotérmico. La metodología desarrollada en este estudio permite la integración de datos de diferentes fuentes en una sola base de datos georreferenciada y filtrada. La zona este de Lisboa, identificada como la zona más prometedora para aplicaciones geotérmicas, muestra una falta de información geológica de profundidad. Sin embargo, una futura unión de perfiles sísmicos existentes con los datos obtenidos en el presente estudio podría resolver este problema.

1. Introduction

It is widely known that large sedimentary basins are favourable for the existence of deep aquifers which, with a medium or even smaller geothermal gradient, are also susceptible to be exploited as low-enthalpy geothermal reservoirs. The Lisbon region, located in the western Meso-Cenozoic sedimentary basin (Rassmussen *et al.*, 1998; Dias *et al.*, 2013) presents deep aquifers in sedimentary formations, very favourable for geothermal purposes (Correia *et al.*, 2002; Marrero-Diaz *et al.*, 2015). Within the lithostratigraphic units identified in the Lisbon region, the geothermal potential of

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the Lower Cretaceous stands out with its relatively low mineralised water (salinity <1 g/l) and with a temperature of 50 °C at 1,500 m depth. These units were already being exploited in the 1990s for geothermal purposes in two concrete cases (Carvalho & Cardoso, 1994).

The main objective of the present study was to obtain a methodology to support the construction of three-dimensional geological models aiming to estimate representative surfaces of the lithostratigraphic units of the Early Cretaceous in order to infer their geometry in the Lisbon region. For this purpose, all known information from various sources – geology, hydrogeology and geophysics – was integrated with the intent of filling the lack of data in depth and identifying the most promising sites for geothermal purposes.

The region of Lisbon, with approximately 960 km^2, is the urban area with the highest population density in Portugal (corresponding to about 19 % of the inhabitants of the country), which results in a strong demand for energy; in this way, geothermal energy could be seen as a possible environment-friendly energy source in this area.

2. Study area

From a tectonic-sedimentary point of view, the Lisbon region is part of the southern sector of the Western Meso-Cenozoic border, with formations that belong to the Lusitanian Basin, partially overlain by Cenozoic sediments of the Baixo Tejo Basin (*Figure 1*). The Lusitanian Basin, deposited in a tectonic pit originated by the tilting of the Hercynian Massif, has been constituted by a >3 km thick normal sequence of sediments since the Triassic until today

(Rasmussen *et al.*, 1998). The Baixo Tejo Basin represents a normal sedimentary sequence with a thickness of about 1,500 m from the Paleogene until today (Dias *et al.*, 2013).

Due to the vast number of geological formations identified in the Lisbon region, only 8 lithostratigraphic units were chosen to simplify and group (*Table 1*).

From all the lithostratigraphic units identified, Lower Cretaceous units, namely the *Grés de Almargem* and *Barremian-Berriasian units* (*Table 1*), have the greatest interest considering their geothermal potential (Marrero-Diaz *et al.*, 2015). The *Grés de Almargem* lithostratigraphic unit is mainly constituted of ferruginous sandstones, pellets and conglomerates, interbedded with limestones and calcareous marls (Rey, 1993; LNEG, 2011). Generally, it is a sequence of sandstones, carbonates and sandstones again that has an average thickness in the order of 100 m, with relatively significant lateral variations. The *Barremian-Berriasian* unit groups several sedimentary formations composed essentially of limestones, marls, sandstones and pellets, with an average thickness of 200 m (LNEG, 1993).

According to Marrero-Diaz *et al.* (2015) and references therein, the *Grés de Almargem* unit behaves as a multi-layered semi-confined, often artesian, dual-porosity aquifer with coexisting intergranular and fracture circulation and effective porosity between 7 and 18 %, allowing exploration flow rates up to 50 l/s. The statistical study of 76 groundwater wells exploiting *Grés de Almargem* unit in the Lisbon region shows thicknesses between 60 m and 229 m with a mean value of 135 m, and transmissivities between 1 and 386 m^2/d with a mean of 26 m^2/d.

3. Multi-source data integration

3.1. Pre-processing

In an initial phase, a survey and selection of all the geological, hydrogeological and geophysical information available in the Lisbon region was carried out, from which the data summarised in *Table 2* was selected.

3.2. Processing

The second phase consisted of the organisation and integration of previously selected data into a single georeferenced database using the ArcGIS ESRI platform, through the steps described below:
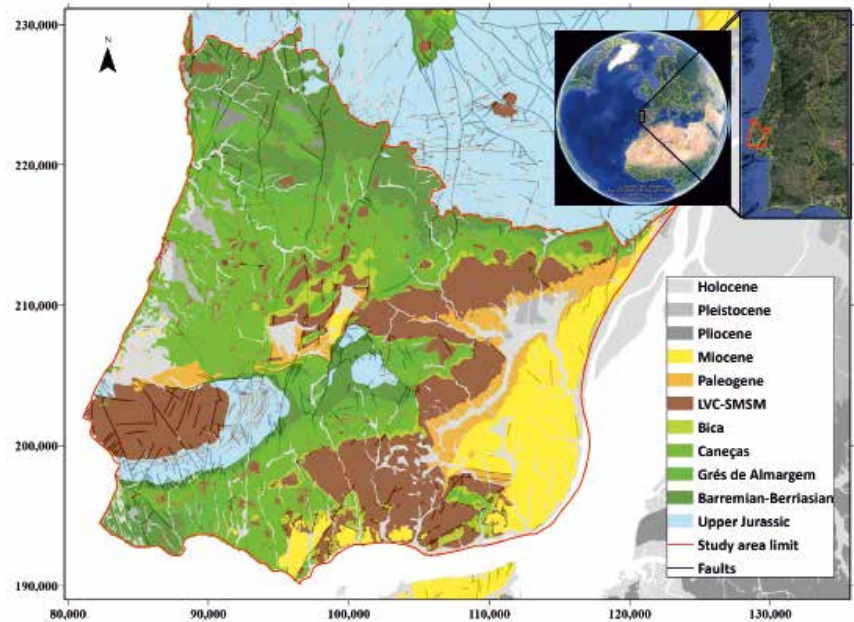

Figure 1: Geological map of the study area, with the study area limit in red, obtained from the junction of Sheets 34A, 34B, 34C and 34D of the Geological Map of Portugal at 1:50,000 scale (LNEG, 1993, 2011, 1999, 2006). Coordinate system Lisboa Hayford Gauss IGeoE used here and in all maps below.

Table 1: Lithostratigraphic units grouped in the study area and acronyms of the formations considered from Sheets 34A, 34B, 34C and 34D of the Geological Map of Portugal at 1:50,000 scale (LNEG, 1993, 2011, 1999, 2006).

| Unit (Age)	Sheet	Acronyms
Miocene (Idem)	34A	$M^3l + M^3m$
	34B e 34D	$M_{Mv} + M_{BP} + M_{CR} + M_{QC} + M_{Xa} + M_{Gr} + M_{Mu} + M_{VC} + M_{Es} + M_{Ec} + M_{FT} + M_{QB} + M_{CV} + M_{Pm} + M_{Pr}$
	34C	$M^e_{III} + M^1_{II} + M^1_{I}$
Paleogene (Idem)	34A	$\varnothing$
	34B e 34D	Φ_{Bf}
	34C	Φ
LVC - SMSM Lisbon Volcanic Complex – Subvolcanic Massif of Sintra-Mafra (Santonian)	34A and 34C	β^1
	34B and 34D	B
Bica (Turonian)	34A and 34C	C^3_C
	34B and 34D	$C^2_{Bi} + C^2_{Fa}$
Caneças (Cenomanian – Upper Albian)	34A and 34C	C^2_{AC}
	34B	C^2_{GC}
	34D	C^2_{Cn}
Grés de Almargem (Lower Albian – Upper Barremian)	34A and 34C	$C^1_{AS} + C^1_A + C^1_{Ba}$
	34B	$C^1_{Ro} + C^1_{Cr} + C^1_{Re}$
Barremian-Berriasian (Idem)	34A	$C^1_{HBa} + C^1_{Hc} + C^1_{Ht} + C^1_V + C^1_{Be}$
	34B	$C^1_{VL} + C^1_{SC} + C^1_{RR} + C^1_{Se}$
	34C	$C^1_{HBa} + C^1_H + C^1_V + C^1_{Be}$
Upper Jurassic (Idem)	34A, 34B and 34C	$J^3_{Ab} + J^3_{Am} + J^3_{So} + J^3_{Ar} + J^3_{So} + J^3_{Fr}$
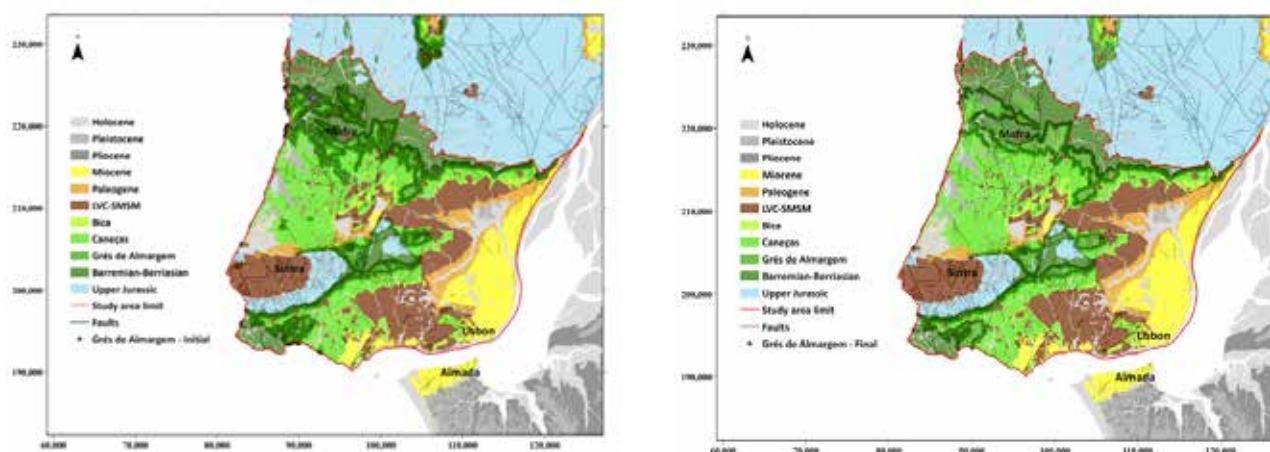
Figure 2: Grés de Almargem points before (left) and after (right) the refinement of boundaries.

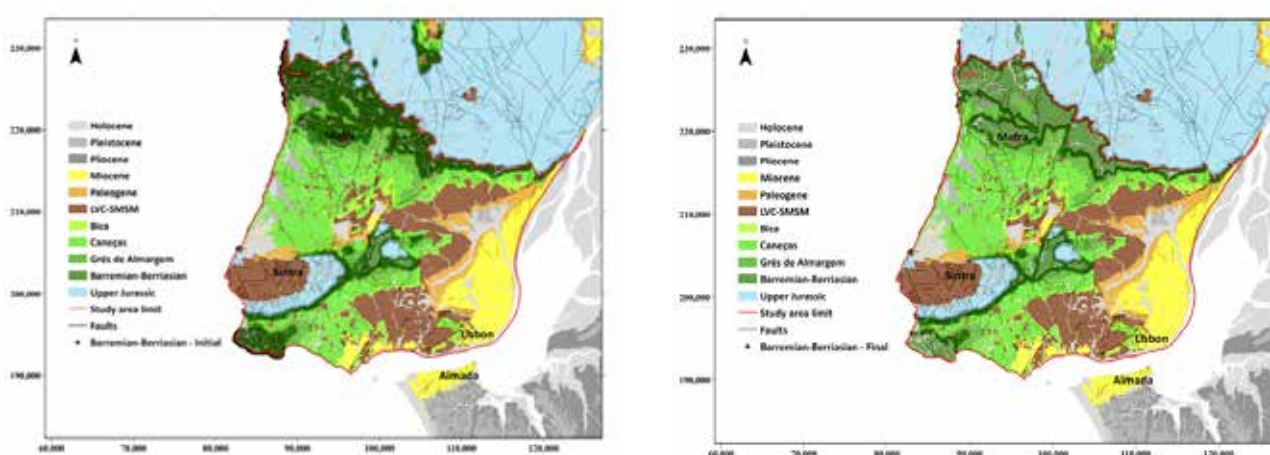
Figure 3: Barremian-Berriasian points before (left) and after (right) the refinement of boundaries.

Table 2: Bibliographic summary of selected data.

Source kind	Type of data	Data format	Data specifications	Issuing organisation
Geological	Sheets 34-A, 34-B, 34-C and 34-D of the Geological Map of Portugal at 1:50,000 scale	Digital (vector)	Boundaries of lithostratigraphic units and tectonic structures (faults)	National Laboratory of Energy and Geology (LNEG)
Hydrogeological	Groundwater wells reports	Printed (paper) and digital (pdf)	251 Logs from groundwater wells: lithostratigraphic sequence, static and dynamic piezometric levels, volumetric flow rates, water chemistry	LNEG; Portuguese Environment Agency (APA)
Geophysical	Reflection seismic profiles: AR12-81; AR16-81; AR17B-81; AR28.	Printed (paper) and digital (vector)	Position of reflectors indicating the litho-logical changes related to the tops of lithostratigraphic units	National Entity for the Fuel Market (ENMC)

3.2.1. Geological data integration

The geological data integrated in the database belong to the geological mapping of Portugal at 1:50,000 scale (*Table 2*). This data was analysed, interpreted and treated using the ArcGIS ESRI platform and various automated ArcToolbox tools.

Conversion of the polygons of lithostrati-graphic units into points

The respective cartographic boundaries of the Grés de Almargem and Barremian-Berriasian units were unified and exported as polygons, which were later subdivided into points. Longitude (x) and latitude (y) in the Lisboa Hayford Gauss IGeoE system were assigned to each point thus obtained,

and, finally, the elevation (z) was also assigned, based on the digital global elevation model (Aster GDEM) with approximately 30 m of spatial resolution.

Refinement of boundaries

In order to identify correspondence points with top and bottom of the lithostratigraphic units, a new field, desig-
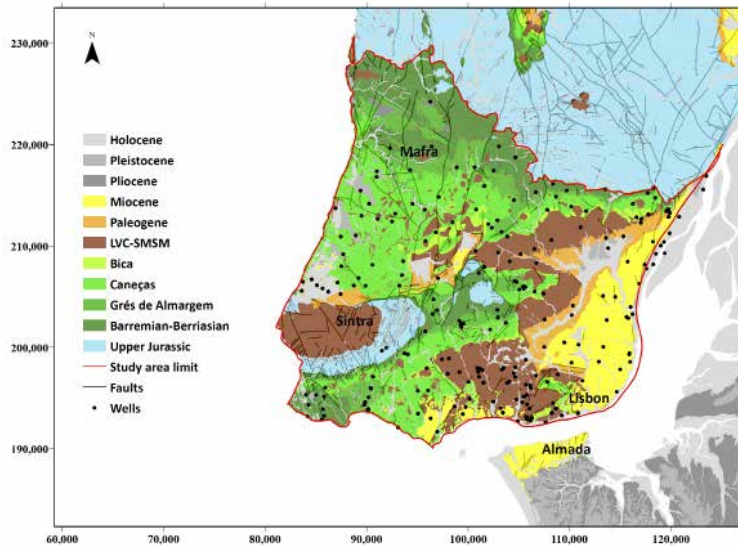
Figure 4: Location of groundwater wells with information from the top and bottom of the various units in the study area.
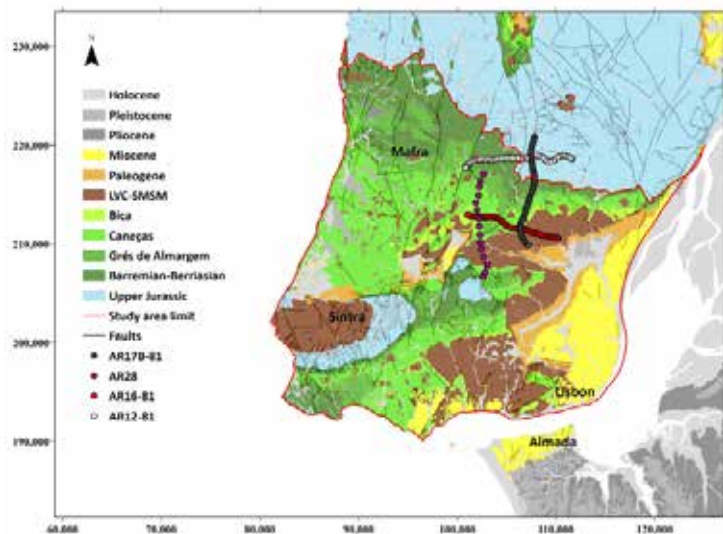

Figure 5: Location of seismic profiles in the study area.

nated as horizon, was added to the georeferenced database obtained from the previous steps. The coding assigned was 1 for the top, and 2 for the bottom.

There are points that do not correspond with the boundaries of top or bottom of the lithostratigraphic units; to solve this incongruence a refinement of the boundaries was manually performed through the ArcGIS ESRI platform, removing less representative points from the georeferenced database, for example, those coincident with contacts with volcanic extrusives or Holocene alluvial deposits. *Figures 2 and 3* show *Grés de Almargem* and *Barremian-Berriasian* points before and after their refinement.

3.2.2. Hydrogeological data integration

For the present study, more than 500 reports of groundwater wells were consulted and analysed in the study area. After a critical review of each report, based on the geological and hydrogeological knowledge of the surrounding area, 251 wells were considered reliable and interesting for the present study (*Figure 4*).

A geological correspondence was proposed between the lithology crossed by the groundwater wells and the top and bottom of the lithostratigraphic units under study, as well as of the other units present in the region (*Table 1*). It should be noted that errors may exist in the proposed geological correspondence, due to the repetition of lithological sequences and the existence of

asynchronous formations or lateral variations. Thus, the presented selection may be improved in the future with the introduction of new knowledge.

Analogously to the geological data integration described previously, codification (1 - top; 2 - bottom) was also assigned to each limit. Additionally, codes 0.5 and 1.5, corresponding to the top and base of the groundwater well, were assigned and denominated "Relative top" and "Minimum bottom", respectively. These new horizons force the model to incorporate the information from the wells, but it should be noted that they are not real boundaries.

3.2.3. Geophysical data integration

Multiple 2D seismic reflection profiles acquired for hydrocarbon prospection in the northern zone of the Lisbon region are available (Rasmussen *et al.*, 1998; Carvalho *et al.*, 2005). However, only 4 reflection seismic profiles are within the study area (*Figure 5*). These seismic profiles were acquired by Veritas in 1963 (AR-28 profile) and by the company Petróleos de Portugal (Petrogal) in 1981 (AR12-81, AR16-81 and AR17B-81 profiles) and initially interpreted by Walker (1983).

Interpretation of the seismic profiles

The interpretation started with the seismic to well tie using well data in the study area and also using previously established seismic-stratigraphy packages identified by other authors in other seismic profiles outside the study area (Carvalho *et al.*, 2005; 2011) that intersect the profiles used in this study. Afterwards, the interpretation proceeded by checking the intersections between each seismic profile and using geological surface information such as geological contacts, faults, etc. Available gravimetric and magnetic data (Carvalho *et al.*, 2011) was also used in the interpretation, which allowed the identification of salt domes, igneous structures and the pre-Mesozoic basement.

Analysis of seismic profiles

Resolution of the seismic information is a crucial parameter for correct analysis of the seismic profiles. Considering an average propagation velocity of the P-waves of 2,500 m/s (corresponding to the homogenisation velocity identified in the considered profiles) and a frequency of 10 Hz, an average vertical resolution of 60 m was obtained.

Strong lithological subsurface contrasts

are traduced in the seismic profiles by a strong reflector. However, chronological contacts do not always correspond to strong reflectors if the chronological boundary represents a continuous depositional episode and/or does not correspond to a sharp lithological boundary (Carvalho *et al.*, 2005). To complement and calibrate this information, tops of the horizons of the *Grés de Almargem* and *Barremian-Berriasian* units (and of the other units present in the region) were also represented in the seismic profiles (*Figure 6*). These horizon tops were obtained from intersecting seismic profiles previously reprocessed and reinterpreted by Carvalho *et al.* (2005; 2011) and from nearby groundwater wells (considering a buffer of 200 m between the wells and the seismic profiles).

Since the vertical scale of the seismic profiles corresponds to the traditional two-way travel time of the reflected waves, this last task involved the depth-time conversion of the groundwater well information. Due to the lack of check-shots and/or velocity logs in the wells that would allow the accurate knowledge of propagation velocities, the adopted criterion was to consider a homogenisation velocity of 2,500 m/s above the seismic datum (0 milliseconds – corresponding to approximately 150 m depth) and different velocities below 0 milliseconds obtained through the use of well data (Carvalho *et al.* 2005).

Next, a preliminary structural interpretation was performed, and several probable faults were identified, some of them with no surface correspondence in the geological maps of the study zone (*Figure 6*), though most of the major faults that were identified could be matched in the geological surface maps.

Finally, the top horizons of *Grés de Almargem* and *Barremian-Berriasian* units in time were depth-converted using seismic velocities obtained from well data outside the study area for geological units similar to those found inside the region of interest.

3.3. Database enhancement

Finally, the database was refined, creating a single file using Microsoft Office Excel. Each point from different sources has associated coordinates of x, y and z, and horizon code (1 - top, 2 - bottom, 0.5 - relative top, 1.5 - minimum bottom). Thereafter a selection of the most representative data concerning the top of Grés de Almargem and Barremian-Berriasian units was performed (*Table 3*).

This database, constituted by 6,035 points from the diverse data sources considered,
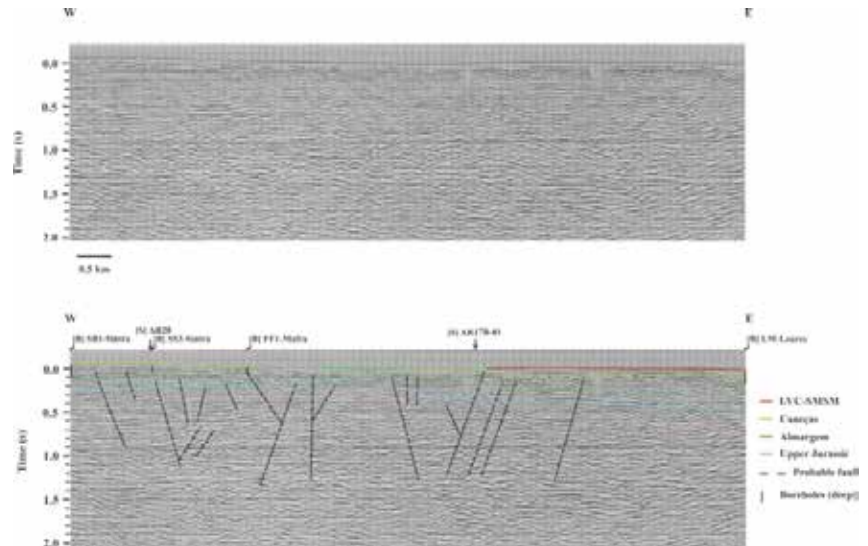

Figure 6: Reinterpretation of the reflection seismic profile AR16-81 showing interpreted probable faults and top horizons corresponding to the distinct lithostratigraphic units.
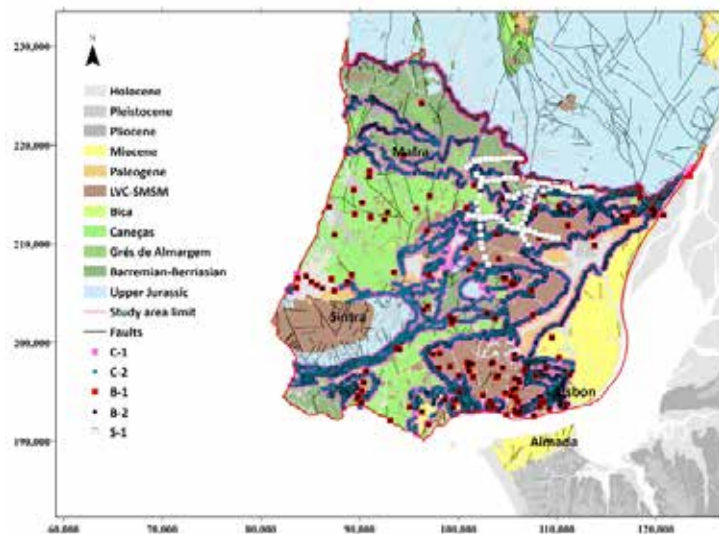

Figure 7: Location of top and bottom points (grouped by horizons) obtained from the geological (C: cartography), hydrogeological (B: boreholes) and geophysical (S: seismic) data.

Table 3: Enhanced database summary.

Source	Type of data	Number of points corresponding to the top horizon of the Lower Cretaceous units
Geological	Geological mapping	5,897
Hydrogeological	Reports of wells	89
Geophysical	Reflection seismic profiles	49

is the potential input for the future three-dimensional geological modelling of the area (*Figure 7*).

4. Discussion and conclusion

This study has shown a methodology for integrating data from different sources into a single georeferenced database, which will allow the future construction of a three-dimensional geological model of the Lower Cretaceous units in the Lisbon region. *Figure 8* presents a flowchart with the phases of the work.

In the eastern part of the study area, where a strongly demand for energy exists and predictably Lower Cretaceous units are deeper (and thus a higher temperature
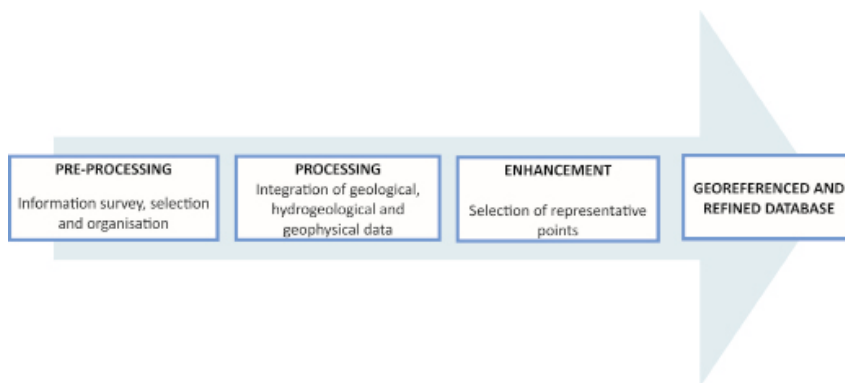
PRE-PROCESSING	PROCESSING	ENHANCEMENT	GEOREFERENCED AND REFINED DATABASE
Information survey, selection and organisation	Integration of geological, hydrogeological and geophysical data	Selection of representative points	

Figure 8: Flowchart showing the distinct phases of the work.

of groundwater is expected), there is still a scarce amount of data (*Figure 7*). Groundwater wells in this sector usually exploit shallower formations, namely the Miocene and Paleogene units, and there are no seismic profiles. However, seismic profiles previously reprocessed and reinterpreted by Carvalho *et al.* (2005; 2011) exist at Tagus estuary. Therefore, in order to complete the gaps, the next step would be a junction of those profiles with the data obtained in the present study.

Finally, it is important to note the dynamic feature of this methodology, which in the future may be improved with new data and adopted for other geosciences applications besides geothermal purposes (e.g. structural geology, hydrogeology, CO_2 storage, etc.).

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The KINDRA project – towards Open Science in Hydrogeology for higher impact

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Groundwater knowledge and research in the European Union is often scattered and non-standardised. Therefore, KINDRA is conducting an EU-wide assessment of existing groundwater-related practical and scientific knowledge based on a new Hydrogeological Research Classification System (HRC-SYS). The classification is supported by a web service, the European Inventory of Groundwater Research (EIGR), which acts not only as a knowledge repository but also as a tool to help identify relevant research topics, existing research trends and critical research challenges. These results will be useful for producing synergies, implementing policies and optimising water management in Europe. This article presents the work of the project during the first two years in relation to a common classification system and an activity for data collection and training delivered by the EFG's National Associations in 20 European countries.

Les connaissances et la recherche concernant les eaux souterraines au sein de l'Union Européenne sont souvent disparates et non standardisées. KINDRA a donc comme objectif une évaluation extensive, au niveau européen, des connaissances scientifiques et pratiques touchant les eaux souterraines, basée sur un nouveau système de classification de recherche hydrogéologique dénommé HRC-SYS. La classification s'appuie sur un service web, l'Inventaire Européen de Recherche des Eaux souterraines (EIGR) qui fonctionne non seulement comme une mine de renseignements mais aussi comme un outil d'aide à l'identification des orientations actuelles de la recherche, des thèmes pertinents de recherche, et des défis exigeants auxquels la recherche doit faire face. Ces résultats seront utiles pour réaliser des synergies, rendre effectives les politiques et optimiser la gestion de l'eau en Europe. Cet article présente le travail accompli par le projet, pendant les deux premières années, en relation avec un système commun de classification et les actions de collection de données et de formation mises en œuvre par les Associations nationales membres de la FEG, dans vingt pays européens.

El conocimiento y la investigación de las aguas subterráneas en la Unión Europea a menudo están dispersos y no estandarizados. Por esta razón, KINDRA está llevando a cabo una evaluación a escala europea sobre el conocimiento científico y práctico relacionado con las aguas subterráneas, basado en un nuevo Sistema de Clasificación de Investigación Hidrogeológica (HRC-SYS). La clasificación cuenta con el apoyo de un servicio digital, el Inventario Europeo de Investigación de Aguas Subterráneas (EIGR), que actúa no solo como un repositorio de conocimientos sino también como una herramienta para identificar temas de investigación relevantes, tendencias de investigación existentes y desafíos de investigación críticos. Estos resultados serán útiles para producir sinergias, implementar políticas y optimizar la gestión del agua en Europa. Este artículo presenta el trabajo del proyecto durante los primeros dos años en relación con el sistema de clasificación común y la actividad de recopilación de datos y formación desarrollada por las Asociaciones Nacionales de FEG en 20 países europeos.

The objective of the KINDRA project is to help achieve a better understanding of the societal challenges relating to groundwater by providing an overall view of the scientific knowledge that exists across Europe and classifying this in an open repository. This will also hopefully raise the awareness of citizens of how science affects their daily lives.

Therefore, the KINDRA project is creating a unique knowledge inventory, i.e. a database of groundwater research results, activities, projects and programmes deemed essential for the identification of the state-of-the-art as well as future perspectives and research gaps in the groundwater field.

This project is in line with the European policy for Open Science. The deliverables for sharing scientific knowledge, research

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projects, articles and data represent a concrete manifestation of Open Science in practice at the European level. The same database is open for use by researchers, policy makers and the public at large. The classification of data has been elaborated in a user-friendly way in order to optimise the use of a wide range of stakeholders. It has been widely accepted and welcomed by the scientific and broader community in hydrogeology. In this sense, the KINDRA project is a reference project in implementing Open Science that could be replicated by other scientific areas.

These achievements would not have been possible without the active support of the national associations of Geology throughout Europe. These associations have connected to the community of geologists and the professionals in hydrogeology in each country. This has facilitated comparable and consistent data across Europe as well as scientific and professional peer review

of the progress and the objectives of the KINDRA project. This common effort has enabled networking, mutual recognition, trust and visibility across the hydrogeology communities in European Member States.

In this sense, the KINDRA project is a concrete manifestation of a bottom-up European construction opening up for a closer collaboration between countries in Europe tackling common societal challenges such as the access to clean water.

1. A common classification system

The KINDRA project proposes a comprehensive approach with a new classification system in hydrogeology tested and approved by the research community, the professional community in geology and the wider public at large. It is a multi-step venture from a well-defined thematic categorisation to the complete roll-out as an open searchable service (*Figure 1*).
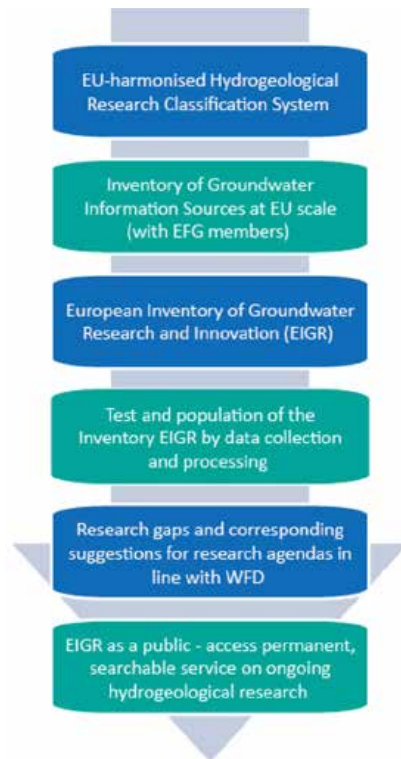
Figure 1: The methodology line.

The first year of the project focused its efforts on developing the concept of a Harmonized Terminology and Methodology for Classification and Reporting Hydrogeology-Related Research in Europe (HRC-SYS).

For classifying groundwater research and knowledge, the KINDRA project group has defined the categorisation of all groundwater research according to three main categories:

1. Horizon 2020 societal challenges,
2. Operational Actions and
3. Research Topics.

Each of these three main categories includes five overarching groups, allowing for an easy overview of the main research areas.

Horizon 2020 defines seven main Societal Challenges (SCs) for which research programmes for 2014-2020 will be defined and developed according to identified research needs. Groundwater research may be conducted under all of these SCs except for SC 4 (Smart, green and integrated transport), which is not relevant. Furthermore, we consider SC6 (Europe in a changing world - inclusive, innovative and reflective societies) and SC7 (Secure societies - protecting freedom and security of Europe and its citizens) similar in scope, as both consider issues related to the development of secure and prosperous societies and EU policies to ensure such a development. Therefore SCs 6 and 7 are grouped into

one SC with the title "Policy, Innovation and Society". The resulting final five societal challenges selected as overarching themes for categorisation of groundwater research are therefore: 1. Health; 2. Food; 3. Energy; 4. Climate, environment and resources; 5. Policy, innovation and society.

The five main Operational Actions adopted as overarching actions or activities – intended to include all identified activities in the identified keywords – are based partly on literature searches in the Web of Science, Scopus (SciVal) and Google Scholar, and their results on the number of papers published in each category, and partly based on expert judgment, used to determine how the different Operational Actions are related. The five overarching activities covering all operational actions, taking into account the results of an end-user survey performed during the project, have been identified as: 1. Mapping, 2. Monitoring, 3. Modelling, 4. Water Supply, 5. Assessment & Management.

The research topics constitute by far the largest group of keywords, and it was impossible to identify five of them as overarching research topics that include all of the more than 150 identified keywords. Based on the understanding that hydrogeology or groundwater research is a natural science discipline and generally relates to one or more of the other main natural science disciplines, the following five overarching groundwater research topics have been selected: 1. Biology, 2. Chemistry, 3. Geography, 4. Geology, 5. Physics & Mathematics.

The identification of the three main categories (Societal Challenges, Operational Actions and Research Topics) and the sub-

division of each of these into five overarching groups give us the tree hierarchy classification shown in *Figure 2*. The adopted merged list of keywords consisting of about 240 terms has also been organised in a tree hierarchy, where the overarching groups represent Level 1, followed by Levels 2 and 3. Subsequently, items from the complete merged list of keywords have been distributed under pertinent categories.

The classification system depicted in *Figure 2* previews the interaction among the three main categories through a 3D approach, where along each axis the five overarching groups are indicated. Societal Challenges (SC) as put forward by the EC policy priorities of the Europe 2020 strategy are represented by the vertical (z) axis in *Figure 2*, while Operational Actions (OA), which are instrumental actions required for implementing groundwater related activities (e.g. implementation of the Water Framework directive and the development of river basin management plans), correspond to one of the horizontal axes (x). Finally, Research Topics (RT) – identified from (a) the EC policy documents, the Water Framework Directive and its daughter the Groundwater Directive, and (b) the scientific literature – are represented by the other horizontal axis (y).

This also results in a 2D representation for each of the Societal Challenges, where Operational Actions and Research Topics intersect in a 5×5 matrix. The 2D structure of each one of the five Societal Challenges allows for a 2D analysis and report of the relationships between the three main categories. Taking for instance *Figure 3*, let us consider one of the five selected Societal Challenges, say, Health (SC1); it is then pos-
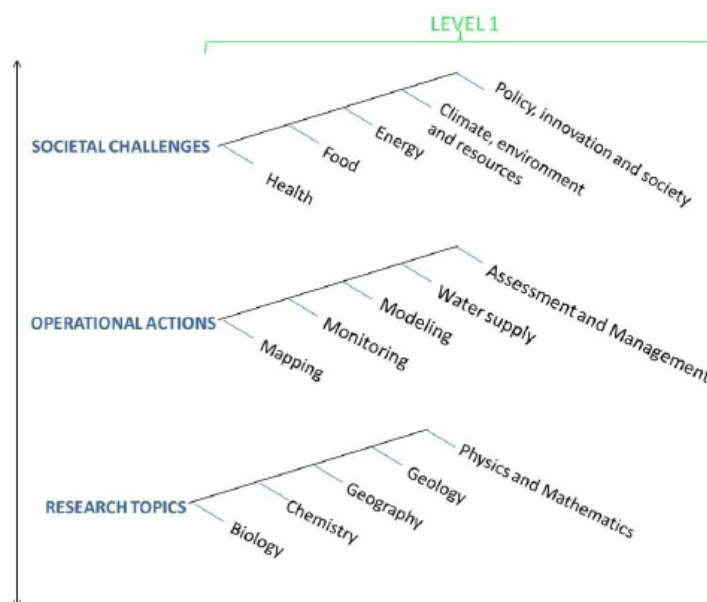

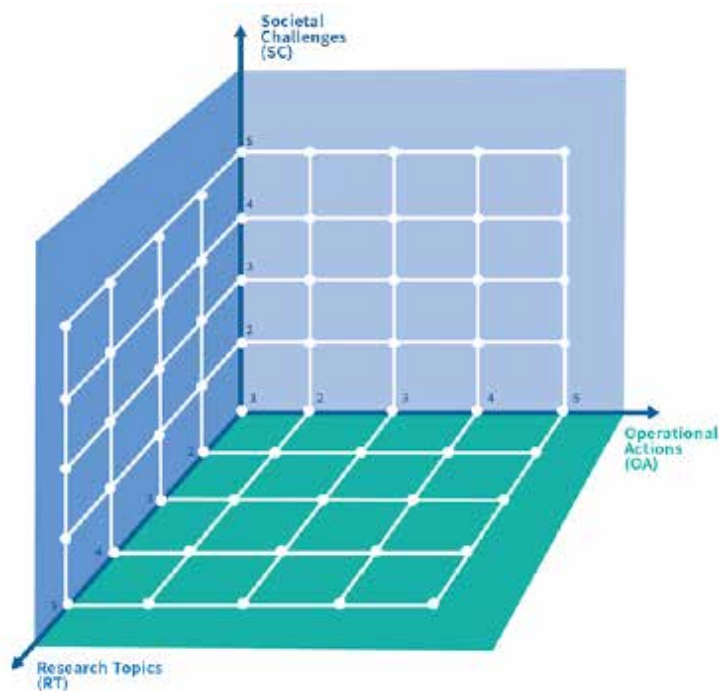*Figure 2: Tree hierarchy diagram.*

Figure 3: Three-dimensional representation of the HRC-SYS.

sible to identify all possible intersections for 'Operational Actions' and 'Research Topics' within this layer. Each sub-category on Research Topics and Operational Actions for the same Societal Challenge SC1 Health can be represented and analysed at a more detailed level.

2. Training and data collections

The KINDRA European Inventory on Groundwater Research (EIGR) is a tool for inventorying information sources regarding Hydrogeological Research Knowledge and Information. It follows the principles defined by the KINDRA project Harmonised Terminology and Methodology for Classification and Reporting Hydrogeology-Related Research in Europe (HRC-SYS).

The KINDRA European Inventory of Groundwater Research, EIGR, is a collection of information sources related to Hydrogeological Research Knowledge, including papers, reports, maps, databases, etc., scattered around Europe and elsewhere at international and national levels. The EIGR provides metadata identifying various information sources from which data can be collected, added and stored, to be available as open access.

The EIGR is intended to be used in three different ways:

i. for insertion of information pertaining to groundwater research and other available knowledge by experts;
ii. for consultation during and after the project by people and organisations dealing with groundwater research, but also possibly by non-experts;
iii. for analysing collected and stored information to identify trends, challenges and gaps in groundwater research, by the KINDRA partners during the project period and policy makers in the future.

The EIGR is intended to be a permanent resource, publicly available after the end of the KINDRA project.

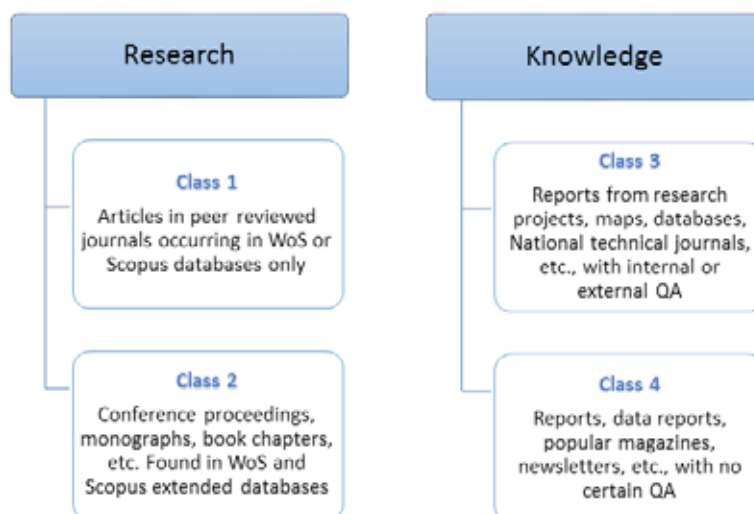The EIGR will not contain data itself, but rather metadata, referring and providing links to research that has been performed in Europe since 2000, and at the same time allowing their classification under the uniform proposed HRC-SYS. The EIGR allows for the insertion of different information products. In the process of inserting information in the EIGR, users are guided to classify the uploaded information and distinguish between 'research' and 'knowledge' according to four different classes of "knowledge" and "research" identified by the level of the performed quality assurance the uploaded work has received.

In order to have a quality assessment (QA) of the resources, KINDRA has classified the work according to Research and Knowledge classes. *Table 1* presents the definition of the 4 classes used in the KINDRA project.

The aim of the KINDRA project – to carry out a Europe-wide assessment of existing groundwater-related practical and scientific knowledge focusing on international (in EU dimensions), national and regional scientific activities – would not have been possible without the active support of professional associations in geology in EU Member States and beyond. In fact, the data collection and assessment have been implemented with the help of the member National Associations of the European Federation of Geologists. They take part in the project as EFG Linked Third Parties. Based on the data provided, the European Inventory (database) of Groundwater Research (EIGR) has been provided with data (populated) in the form using a web service.

In total there were 20 countries participating in the KINDRA Inventory population: Belgium, Croatia, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Poland, Portugal, Serbia, Slovenia, Spain, Switzerland, the UK and Ukraine (see *Figure 4*).

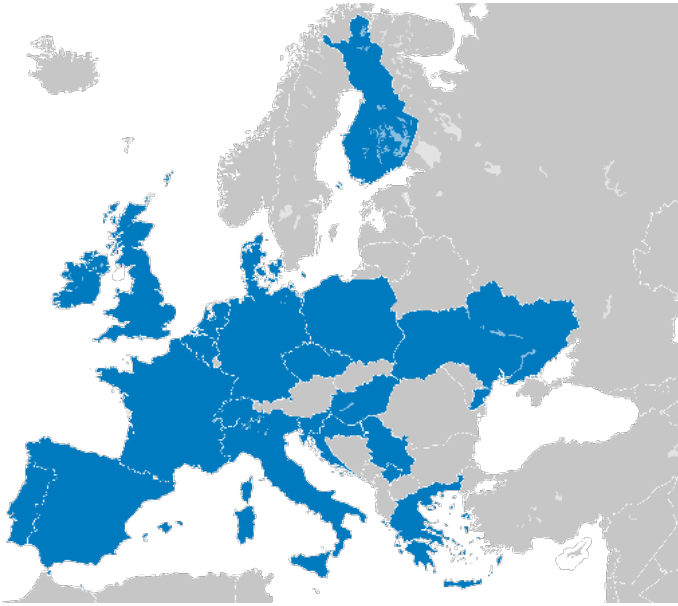*Table 1: Definition of research and knowledge classes 1 to 4.*

Figure 4: Countries participating in KINDRA data collection.

publications and data sources that are not already available through the well-known and most appreciated research databases (i.e. Web of Science and Scopus).

The LTPs experts grouped the resources they entered into EIGR into the following 7 data types or resource categories. The type of the resources included in this wide range of information with different accessibility and formats are:

a. National databases
b. National and local reports containing facts and data;
c. Hydrogeological maps;
d. Technical reports, guidelines, manuals, etc.;
e. Books and book chapters;
f. Position papers and/or important papers on PR journals;
g. Others

Figure 7 shows the distribution of data type/resource category in the EIGR entries. The most dominant resource category is the "National and local reports containing facts and data" with 47.9 % of the metadata. The "Position papers and/or important papers in peer reviewed journals" data type has also a significant number of entries, with 26 %. The remaining 26.1 % is distributed between the "National databases" (2.9 %), "Hydrogeological maps" (4 %), "Technical reports, guidelines, manuals, etc."(2.9 %), "Books and book chapters" (6.4 %) and topics classified as "Other" (9.9 %).

3. Dissemination at national level

The research and methodology of the KINDRA project requires insight into past and ongoing hydrogeological research in Europe. Project dissemination on the national level is crucial. To facilitate this work, EFG Linked Third Parties (LTPs) participating in the project organised hydrogeology-related national workshops. The objective of the workshops was to facilitate interaction among stakeholders and come to a common understanding of the key research priorities in each particular country. Mapping the practical and scientific knowledge related to hydrogeology had already started before the event, while the workshops provided platforms for stakeholder interaction and the dissemination of project objectives and facilitated national-level networking.

The LTPs were encouraged to organise the workshop within the frame of a larger event (e.g. international conferences or annual meetings of the NA) or in co-organisation with other national and international organisations, if possible, in order to

Before collecting data about the existing practical and scientific knowledge on groundwater research, it should be clarified where the information comes from. That is why an inventory of information sources has been created concerning national and international projects, documents, databases, initiatives, reports and scientific publications. The data were gathered by a survey in collaboration with the EFG's National Associations in 20 European countries.

An orientation workshop was organised with the participation of experts from the 20 European countries representing EFG's Linked Third Parties (National Associations) in the KINDRA project (*Fig. 5*). The aim of the workshop was to train the experts participating in data collection on groundwater research at a national level, during the second year of the project, and who will populate the European Inventory for Groundwater Research (EIGR). During the workshop the EIGR was tested and detailed guidelines for populating the EIGR were provided. The response of the participants was very positive and valuable suggestions were given to improve the EIGR's user functionalities.

The metadata insertion to the EIGR was implemented by the National Experts

Figure 5: KINDRA workshop for EFG's Linked Third Parties.

assigned by the European Federation of Geologists Linked Third Parties (LTPs), the 20 National Associations participating in the project.

The National Experts used different sources on regional, national and international levels to collect the relevant information for their EIGR entries. The LTPs were asked to classify their sources of information into the following groups:

- institutions dealing with groundwater research/surveying;
- groundwater monitoring, availability of data;
- journals/archives focused on hydrogeology.

The most important sources were the national databases, reports and journals, responsible governmental bodies, universities and national geological surveys. The LTPs' experts classified the information they gathered according to the previously defined research and knowledge classes (*Table 1*). As illustrated in *Figure 6*, most of the data from universities and research institutes were ranked as Class 1 or Class 2 and the information gathered from regional authorities usually placed into Class 3 and Class 4. In total, 45.6 % of the metadata are related to Class 4. The number of peer-reviewed articles in scientific journals (Class 1) and the number of reports from research projects and publications in national technical journals (Class 3) has a similar occurrence, 23% and 24.2% respectively. The Class 2 resources have the lowest number of EIGR records inserted by LTPs, only 7.2% were classified into Class 2. The reason for that is that the LTPs focus on
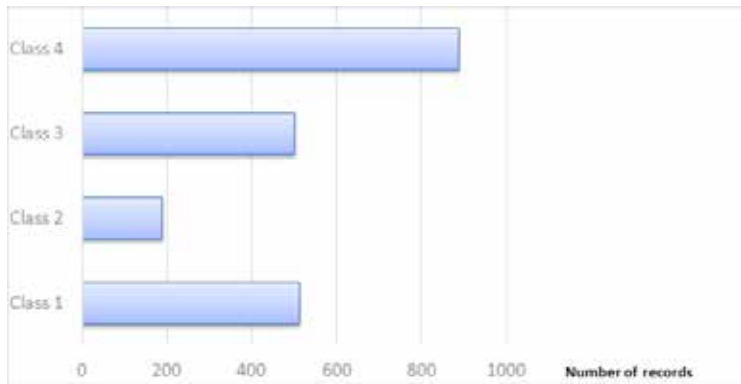
Figure 6: Quality assessment class of the records inserted in the EIGR up to January 2017.
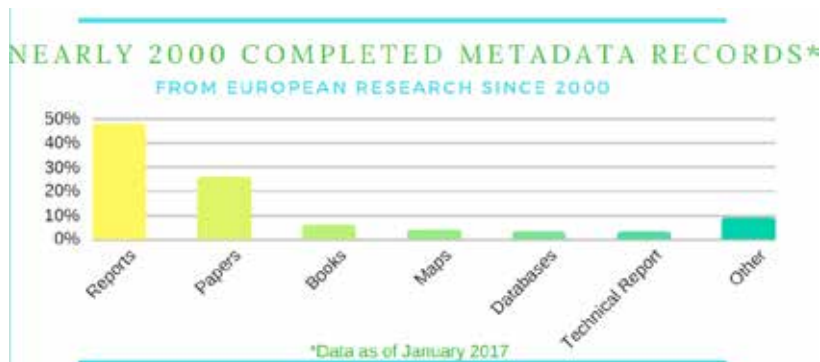

Figure 7: Metadata insertion as of January 2017.

increase the visibility of the project and have higher dissemination impact. This was the case for 10 National Associations (Greece, Serbia, Hungary, Germany, France, Poland, Belgium, Croatia, Denmark and Portugal). The rest of the workshops were organised in the National Association headquarters.

Although the overall scope was the same, the size of the workshops considerably varied, as EFG covers small and large European countries as well. The total number of the participants in the 20 European countries was over 600.

The workshops served as a platform for disseminating the project at a national level and at the same time facilitated interaction and discussion between workshop participants and KINDRA national experts. All of the participants were very interested in the KINDRA project and pointed out the importance of establishing a database of hydrogeological research and accessibility of data online on a European, but also on a national level. Participants from Denmark indicated that it would be really nice if the EIGR would be THE database with all groundwater information in Europe, including material on Research Gate, Scopus and Web of Science. Some participants were concerned about the data and platform maintenance in the future (Greece, Belgium, Spain, Serbia) and pointed out that the platform should also be communicated to the general public as a means of access to reliable scientific information on

hydrogeology. The importance of pursuing roadmaps aimed at supporting policies that will enable the simplest access possible to hydrogeological knowledge by technicians, researchers and professionals was stressed (Italy), since quality and effectiveness of interventions and scientific research (aimed at both use and protection of groundwater) rely on data availability and reliability.

Participants discussed the involvement of the EU Member States related to the implementation policy according to recommendations of the Water Framework Directive in the field of works on the protection of groundwater resources and improvement of water quality. During discussion the degree of national involvement in the implementation of policy of sustainable development also was also assessed.

The general conclusions of the workshops were that the first two steps of the project (i.e. Classification and Inventory) had been completed and that the upcoming months would be mainly dedicated to the dissemination, as all technical content and results will be finally adapted into outreach materials that will help the general public to understand the relevance of groundwater in daily life. In order to achieve this, close cooperation between the public and private sector is necessary.

4. KINDRA European Inventory on Groundwater Research Open Science

On 24 April 2017 the KINDRA European Inventory on Groundwater Research (EIGR) was opened to the public. European hydrogeologists were invited to insert their data with the aim of showcasing their research to other European professionals working in the water sector.

There is a clear added value to presenting the research in the KINDRA EIGR. Three main dimensions of value can be distinguished:

1. providing visibility in the first online tool exclusively focused on groundwater research and knowledge;
2. allowing like-minded professionals to find each other;
3. classifying the research, products, papers and projects;
4. making research accessible to database analysis for EU Policy support and water directive implementation.

KINDRA EIGR has published 2,102 records from 20 countries (as of September 2017).

The record of the KINDRA inventory (EIGR), based upon the KINDRA Classification (HRC-SYS), illustrates that research and knowledge on Societal Challenge (SC) category Climate and Environment are highly represented. In total, Climate, Environment and Resource represent 87 % of the groundwater research and knowledge compilation. The societal impact of groundwater has a close relation with climate and environmental challenges. This is due to the fact that there is a close correlation between this knowledge and the daily challenges of citizens, households, industry and cities.

The Research Topic (RT) Geology has also a very high representation, 75 % of the records. In this case the explanation is the fact that most of the experts in charge of popular inventories are hydrogeologists. In the Operational Actions (OA) category, Assessment and Management is the most represented action, with 53 % of the records in this category.

Figure 8 presents a 2D representation of the research topic on Geology of the Societal Challenges, where Operational Actions and Societal Challenges intersect in the categories in each axis 5×5. This type of figures illustrates in a visible manner the societal challenges and operational actions correlate in the inventory. If the geographic areas, local, regional or national data are added, then a comparative analysis is facilitated. It becomes possible to detect which knowledge areas need additional efforts

and in which areas knowledge is already available. When a temporal dimension is added, it is also possible to visualise trends and changes over time.

Conclusions – the value of KINDRA in the broader EU policy frame

The KINDRA project has a large societal impact, given the extensive use of groundwater for our households, industry and cities. An open-science approach in the field of hydrogeology strengthens this societal impact, since it increases the quality and the relevance of hydrogeology research outcomes while allowing for the broader awareness of citizens.

The new open-science approach also increases the rate of return on public investment in hydrogeology research. First, the investment in science is gathered in a comprehensive, open and Europe-wide database of broad use and visibility. Second, the common classification enables researchers and stakeholders to detect gaps or duplication of efforts in research, while stimulating new areas of research inspired by the comprehensive state of the art provided by the open database. In this way, public investments in research in hydrogeology will have a higher return in terms of the quality and relevance of scientific outcomes.

The KINDRA project has opened up for a bottom-up European construction in the
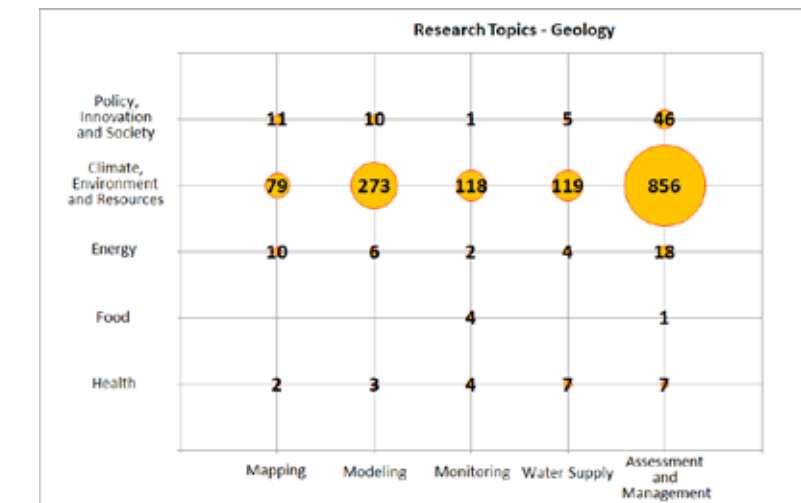

Figure 8: 2D representation of the number of resources available in the intersections of Societal Challenges and Operational Actions for the Research Topic on Geology.

field of hydrogeology. It has created trust and reinforced networks between professionals and researchers in hydrogeology across European countries. This achievement is even more important given the relevance of groundwater and clean water to citizens and societies in Europe and beyond.

Acknowledgement

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How to increase future mineral supply from EU sources

D. Rokavec, K. Mezga* and S. Miletić

Europe's insufficient mineral production and increasing industrial demands are reflected in high dependency on imported raw materials. Although exploration and exploitation of Europe's mineral raw materials are essential activities, the land available for extraction is constantly diminishing. To improve the sustained mineral supply from European deposits, access to mineral deposits needs to be ensured and they need to be protected from potential sterilisation. Mineral deposits need to be properly evaluated, taking into account the geological setting and the viability of exploitation in accordance with other land-user and environmental requirements. Their incorporation into spatial plans will be of key importance. In the near future, each Member State needs to identify and protect the access to its selected significant mineral deposits within its national legislation framework. This paper presents a list of mineral deposits in Slovenia that should be protected and discusses criteria for their selection.

La production minière européenne, insuffisante, et les demandes croissantes de l'Industrie sont le reflet du haut niveau de dépendance des matières premières importées. Bien que l'exploration et l'exploitation des matières premières minérales en Europe représentent une activité essentielle, le terrain disponible pour l'extraction minérale se réduit de façon constante. Pour améliorer l'approvisionnement durable en matières minérales à partir de gisements européens, l'accès à ces ressources doit être garanti et il est nécessaire de les protéger d'une disparition potentielle. Les gisements miniers doivent faire l'objet d'une évaluation soigneuse, prenant en compte les conditions géologiques et la viabilité des conditions d'exploitation en accord avec les exigences des autres utilisateurs du terrain et les lois environnementales. Les incorporer aux cartes et plans d'exploitation aura une importance cruciale. Dans un proche futur, chaque pays membre doit identifier et protéger ses accès aux gisements miniers choisis comme significatifs, au sein de son cadre législatif national. Cet article présente la liste de gisements miniers en Slovénie qui méritent d'être protégés et débat des critères qui ont mené à leur sélection.

La producción insuficiente de minerales en Europa y la demanda industrial creciente se reflejan en una gran dependencia de las materias primas importadas. Aunque la exploración y explotación de las materias primas minerales en Europa son actividades esenciales, la superficie de terreno disponible para la extracción disminuye constantemente. Para mejorar el suministro sostenible de minerales en Europa, se debe garantizar el acceso a los depósitos minerales, los cuales deben protegerse de la esterilización potencial. Los depósitos minerales deben evaluarse de manera adecuada, teniendo en cuenta el entorno geológico y la viabilidad de la explotación de acuerdo con otros requisitos de gestion territorial y ambientales. Su incorporación en los planes espaciales será muy importante. En un futuro cercano, cada Estado miembro deberá identificar y proteger el acceso a los depósitos minerales importantes seleccionados dentro de su marco de legislación nacional. Este documento presenta una lista de depósitos minerales en Eslovenia que deberían protegerse y analiza los criterios para su selección.

In recent decades, the increasing global demand for mineral raw materials has been driven by the growth of emerging economies and their mineral consumption. Insufficient production within the EU causes increases in imports of raw materials from third countries. This manifests itself as mineral supply dependency. While the mineral consumption is increasing, available areas for potential mineral extraction are running short and therefore domestic supply is put at risk. Mineral deposits are often neglected in land-use planning, while some land uses, e.g. nature preservation, infrastructure building, water resources protection, and others receive preferential treatment.

In November 2008, the European Commission (EC) launched the "Raw Materi-

als Initiative — meeting our critical needs for growth and jobs in Europe" (RMI). The RMI (European Commission, 2008) is based on three pillars: (1) Ensuring the fair and sustainable supply of raw materials from international markets, promoting international co-operation with developed and developing countries; (2) Fostering sustainable supply of raw materials from European sources; and (3) Reducing consumption of primary raw materials by increasing resource efficiency and promoting recycling. By identifying mineral deposits for safeguarding and securing access to them, the second pillar is supported.

The RMI and the European Innovation Partnership's (EIP) Strategic Implementation Plan (SIP) (European Commission, 2013) highlight access to mineral deposits as a common challenge to be targeted by Member States. Therefore, national geological surveys endeavouring to designate mineral deposits for safeguarding reflect the above-mentioned initiatives' aims. The

work and activities of geological survey experts contribute to better communication between the minerals sector and land-use planners. Current land-use planning fails to address potential mineral resources areas. Temporary land-use for mineral extraction is neglected as well (e.g. surface extraction of clays). Constructive dialogue between the different land-use interests and planners needs to be strengthened.

Recent EU statistics show that every newborn infant will need a lifetime supply of 300 kg of lead, 280 kg of zinc, 560 kg of copper, 1,350 kg of aluminium, 12,200 kg of iron, 9,950 kg of clay, 1,500 kg of salt and 448,000 kg of stone, sand, gravel, and cement.[1] Therefore, the sustainable exploitation of minerals in Europe is an indispensable activity and must ensure that the present and future needs of the European society can be met. This requires free access

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1 Euromines: Sustainable Development Issues (*http://www.euromines.org/what-we-do/sustainable-development-issues*).

to mineral deposits. Also potential mineral deposits (also taking into account abandoned mines and historical mining sites) should be considered with respect to and in balance with other land uses, such as agriculture, forestry, natural preservation, building, and infrastructure.

Mineral supply depends on advanced land-use planning that respects environmental and socio-economic criteria. Some deposits of metals, industrial minerals, and construction materials should be considered of 'public importance' (energy minerals are already adequately treated in Europe). 'Public importance' is a term used when information demonstrates that sustainable exploitation could provide economic, social, or other benefits to the EU or the Member States or a specific region/municipality.[2]

In parallel with geological definitions, a harmonised European regulatory framework for sustainable access and mineral supply will need to be developed. It should include the 'sustainability principle' for exploration and mineral extraction (Shields & Šolar, 2004). The concept of mineral safeguarding will need to be incorporated into the broader policy-making.

Slovenian case-study

Slovenia lies in the narrow area between the Adriatic Sea, the Alps and the Pannonian Basin. Compared to other EU countries, Slovenia has the largest relative proportion (~37%) of Natura 2000 sites, not counting

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2 MINATURA2020 Project (*http://minatura2020.eu/*)

other protected areas (13.29%).[3] However, in the country's small territory some considerable deposits of mineral raw materials are to be found. Although the extraction of metallic mineral raw materials became non-profitable, the extraction of aggregates and non-metals is still quite active. In 2016 there were 144 exploitation right holders operating 189 pits and quarries. They target 26 different mineral commodities. Slovenia has around 200 sites of metallic mineral deposits and occurrences, and several dozen closed or abandoned metal mines. Today, after a long period of mining all metal mines are closed; however, ore reserves that could be exploited in the future remain. The extraction of mineral resources concentrates on aggregates for the construction industry and a few industrial minerals whose annual production is around 12.6 million tons (aggregates, dimension stone, clays, chert, quartz sand, etc.), not taking into account energy minerals (lignite and hydrocarbons) (GeoZS, 2017).

Mineral safeguarding in Slovenia is partly regulated by the Mining Act[4], in which strategic mineral resources are considered to be of public interest. Extraction areas with a mining concession are incorporated into spatial plans. Moves towards the protection of access to mineral deposits have been

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3 ARSO (Ministry of the Environment and Spatial Planning, Slovenian Environment Agency), 2017. Nature conservation. (*http://www.arso.gov.si/narava/zavarovana%20obmo%C4%8Dja/*)
4 Official Gazette of the Republic of Slovenia, No. 14/14 (*https://www.uradni-list.si/glasilo-uradni-list-rs/vsebina/116414*)

active for some time but are still waiting for implementation.

Methodology description

The second pillar of the 'Raw Materials Initiative' promotes the intention of safeguarding mineral deposits from sterilisation. Each Member State should identify and protect access to their selected significant mineral deposits in accordance with its national legislation.

Slovenia currently exploits only non-metal and energy resources. Energy resources are already of strategic importance and are adequately treated; therefore, this survey was focused on non-energy minerals (industrial minerals and aggregates). A list of areas suggested for safeguarding of mineral deposits has been created for Slovenia along with a relevant map (Rokavec & Mezga, 2017) with the view of protecting the access to deposits and ensuring sustained mineral supply in the future. The deposits were selected due to their uniqueness, rareness or importance for existing industries and traditional housing.

Considering the entire relevant legislation and legal entities on all levels is crucial for the preparation of such list and the eventual implementation of a protection policy for such areas. A short review of the existing minerals policy in Slovenia is given in the following.

In cooperation with the ministry responsible for mining/minerals management (currently the Ministry for Infrastructure) the Geological Survey of Slovenia (GeoZS)

Table 1: List of designated safeguarding areas for mineral deposits – summary data by country (SI-Slovenia, IT-Italy, PT-Portugal, HU-Hungary, SE-Sweden, UK-United Kingdom and PL-Poland) (Rokavec & Mezga, 2017).

| Country	Province	No. of potential areas of safeguarded mineral deposits	Level	Type of mineral endowment		
				metals	non-metals	aggregates
SI	entire state territory	30	national		X	
		max 50	local/regional			X
IT	Emilia Romagna Region	11	regional			X
PT	north and north-eastern regions of Portugal	38	national	X		
	Rio Maior municipality	1	local		X	
HU	Borsod-Abaúj-Zemplén, Hajdú-Bihar, Heves, Szabolcs-Szatmár-Bereg Counties	402	regional		X	X
SE	Norrbotten County	24	national	X	X	
UK	South West England & South Wales (on shore)	40	regional	X	X	X
	South West England & South Wales (off-shore in Celtic and Irish seas)	10	regional	X		X
PL	Lower Silesia	142	regional	X	X	X
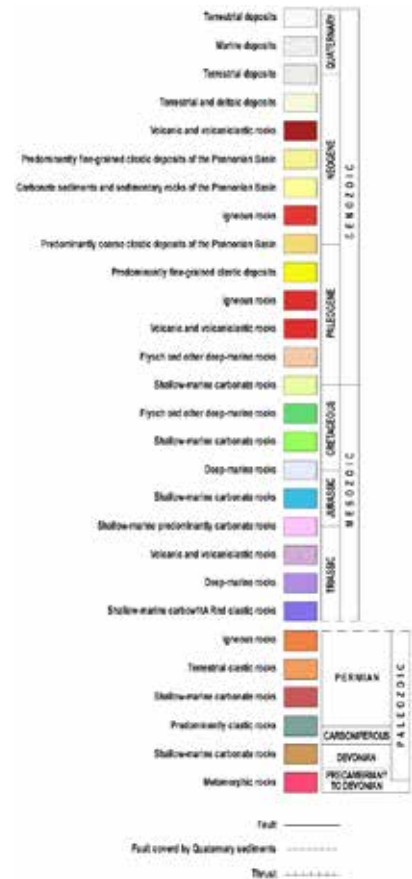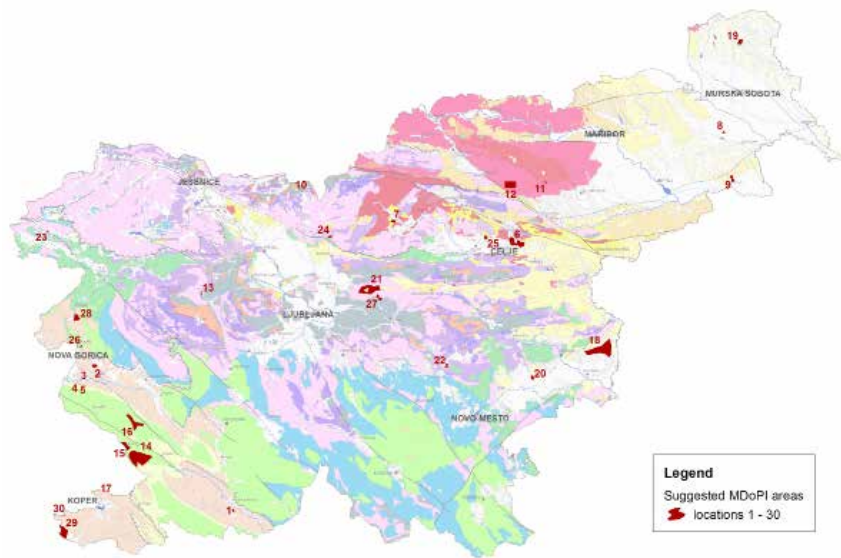
Figure 1: Suggested areas of Mineral Deposits of Public Importance (MDoPI) in Slovenia (based on Geological Map of Slovenia (1:1 000 000) with legend (right) after Bavec et al., 2013) (Rokavec & Mezga, 2017).

runs a Public Mining Service in order to manage minerals data through a modern geological information system. To achieve sustainability in mineral resources management, GeoZS joined the Knowledge and Innovation Community (KIC) EIT Raw Materials. GeoZS is also a coordinator or partner in several EU- financed projects dealing with sustainable mineral supply (e.g. MINATURA2020, MineService and others).

Slovenia is in the process of adopting a National Mining Strategy. Until then, the National Mineral Resource Management Programme – the General Plan is in force (Government of the Republic of Slovenia, 2009). Its goals include enabling access to resources for future generations and minimising negative environmental impacts. It ensures a sustainable minerals supply for Slovenia.

Results

Slovenia applies a safeguarding regulative concept in which mineral deposits are included in land-use plans only through a licencing process, meaning that only areas with mining rights are automatically safeguarded. There is no open door for 'potential deposits' that do not have mining rights yet. However, according to the Slovenian Mining Act, exploration and exploitation of minerals are in the public interest if their deposits are in areas where the exploitation could encourage economic and social development, reduce transport costs, and stabilise the minerals market.

In Slovenian practice, certain natural resources are properly safeguarded (e.g. water, forests and agricultural land), while minerals, although non-renewable, are rather neglected. Therefore, an adequate regulatory regime should be established to treat mineral resources equally. Since Slovenia is preparing a Mining Strategy, it is an excellent opportunity to improve the current minerals status in terms of safeguarding minerals and their deposits on a national level.

In the scope of such aspirations, a list of and a respective map of suggested mineral areas in Slovenia were prepared (***Fig. 1***; Rokavec & Mezga, 2017). The total surface of suggested safeguarding areas for mineral deposits in Slovenia is approximately 95 km², which is less than 0.5% of the State's territory. Aggregates are not included, but would also need to be safeguarded. In land-use plans, they often overlap forest, agricultural, or built-up areas. Some of the mineral areas even extend into protected areas (e.g. Natura 2000, ecologically important areas, valuable natural features, landscape parks, etc.).

At national level, 30 areas of non-metal deposits (industrial minerals) were designated, containing clays (brick and ball clay), dimension stone (limestone, travertine, tonalite, and cizlakite, a flysch sandstone), quartz sand, chert, chalk, calcite, bentonite, tuff, and raw materials for the lime and cement industry. Due to their geological settings, these deposits should be designated in land-use plans.

At the local/regional level, fewer locations of aggregate supply centres per statistical region were considered. For all 12 Slovenian regions, up to 50 extraction sites were suggested as aggregates supply cen-

tres, which are quarries for crushed stones (mostly limestone and dolomite) and sand and gravel pits.

The list of safeguarded mineral deposits and the borders of mineral deposits under evaluation are not final; rather, they are dynamic and should be adapted, reflecting new geological knowledge and future social needs. The mineral deposits should be incorporated into spatial plans and thus safeguarded for the needs of future generations. Mineral deposits are bound to a specific area, while most human activities can be moved (e.g. industrial facilities and housing). Even the Natura 2000 Directive (Habitats Directive 92/43/EEC) does not exclude or even prohibit mineral exploration and extraction, but sets certain limits and requirements (European Commission, 2010).

The Horizon 2020 project "Developing a concept for a European minerals deposit framework" (MINATURA2020, ***www. minatura2020.eu***) offers the opportunity to develop a concept for safeguarding certain mineral deposits from sterilisation. Seven case-study countries, i.e. the United Kingdom, Italy, Slovenia, Sweden, Portugal, Hungary and Poland, were selected, considering differences in the territorial size, types of mineral endowment, and national mineral policies. All case-study countries

have designated potential areas of mineral deposits for safeguarding within at least one province or a region, while Slovenia has prepared such a list of the entire national territory (*Tab. 1*).

Conclusions

In order to ensure sustainable mineral supplies within the EU for future generations, it is of great importance to properly safeguard mineral deposits and foster sustainable mineral supply from European sources.

For the existence and development of the European economy and the achievements of its civilisations, the safeguarding of European mineral deposits is a key requirement. Access to mineral deposits should be secured in order to permit mineral exploration and exploitation, if viable. It is of great importance that current mineral extraction does not endanger the supply of future generations. The mineral deposits should be properly evaluated, considering geological knowledge, the technical and economic dimensions, competing land uses, and the societal dimension. Delineation of mining areas in co-ordination with other land uses is challenging, but necessary to avoid conflicts and meet societal needs.

The EU is preparing the fundamental concept for defining and subsequently safeguarding mineral deposits of public importance. Current spatial planning treats certain other land uses preferentially, e.g. nature preservation, infrastructure building, water resources protection, etc., while mineral deposits are often neglected. Relevant mineral deposits need to be identified and properly designated on the national and local levels to facilitate their incorporation into spatial plans. In this context, a list and a map of proposed safeguarding areas for mineral deposits in Slovenia have been prepared. At a national level, 30 mineral deposits of non-metals have been designated as well as up to 50 aggregate supply centres at the local/regional level. Less than 0.5% of the national territory might be dedicated to future mineral safeguarding. The list is not final but dynamic, and will be updated according to new geological research results and knowledge of deep geological structures, as well as market conditions and societal needs. Even some abandoned and closed mines could be of significance in the future.

Slovenia is in the process of adopting a new National Mining Strategy, which provides an opportunity to improve the current mineral status in terms of safeguarding mineral deposits at a national level.

The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the view of any institution.

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Clearing the sky from the clouds – The Mineral Intelligence Capacity Analysis (MICA) project

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MICA develops the EU-RMICP with an innovative visualization interface that guides the user to a 'recipe' for how to find answers to particular mineral raw material related questions. This is different from a database providing pre-formulated answers to questions: MICA offers an expert-designed pathway towards answers by means of an exhaustive catalogue of data sources and peer-reviewed information with relevance to the user question. Thus, MICA enables the user to explore data, acquire information and build up knowledge, rather than being given narrow, pre-formulated answers. The MICA Platform endeavours to cater for professional as well as general public stakeholders.

MICA développe la Plateforme européenne intégrée et intelligente consacrée aux matières premières, avec une interface innovante et conviviale. La plateforme fournit à l'utilisateur final une interface de visualisation qui guide l'utilisateur vers une formule "recette" permettant de trouver une réponse à toute question spécifique liée aux matières premières minérales. Ceci est différent des approches habituelles pour lesquelles une base de données ne répond qu'à des questions pré-formulées : MICA offre une approche de type expert avec, par l'intermédiaire d'un catalogue exhaustif de sources de données et d'information vérifiée collégialement, des réponses pertinentes aux questions posées par l'utilisateur. MICA permet donc à l'utilisateur d'étudier les données, d'acquérir une information qui nourrit la connaissance plutôt que de recevoir des réponses étroites et pré-formulées. La Plateforme MICA s'efforce de faire face aux exigences des professionnels comme des parties prenantes du secteur public.

MICA desarrolla la Plataforma Europea de Capacidad Inteligente de Materias Primas con una interfaz innovadora y sencilla. La plataforma proporciona al usuario final una interfaz de visualización que le orienta a una 'receta' sobre cómo encontrar respuestas a preguntas particulares relacionadas con materias primas minerales. Esto es diferente de los enfoques habituales, donde una base de datos proporciona únicamente respuestas a preguntas preformuladas: MICA ofrece un camino hacia las respuestas diseñado por expertos, mediante un catálogo exhaustivo de fuentes de datos e información relevante, revisada y contrastada, responde a la pregunta del usuario. Por lo tanto, MICA le permite al usuario explorar datos, adquirir información y acumular conocimiento, en lugar de recibir respuestas ceñidas y preformuladas. La Plataforma MICA tiene el objetivo de servir tanto a los profesionales como al público en general.

Introduction

This paper aims to outline the Mineral Intelligence Capacity Analysis (MICA) project for developing the European Union-Raw Materials Intelligence Capacity Platform (EU-RMICP). Mineral raw materials are fundamental to Europe's economy and further development. The MICA project represents a response to previous raw material initiatives (COM(2008)699[1], the "Report on criti-

1 COM(2008)699 final. "On the Implementation of the Raw Materials Initiative", Communication from the Commission to the European Parliament and the Council, {SEC(2008)2741}, 04.11.2008, *http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52008DC0699*

*Centre for Minerals and Materials (MiMa), Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, 1350 Copenhagen, Denmark, em@geus.dk
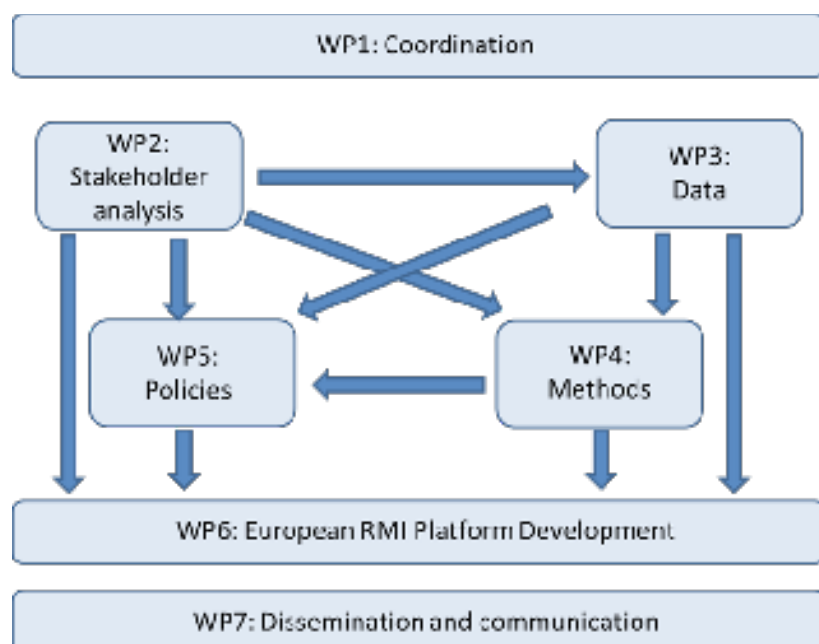
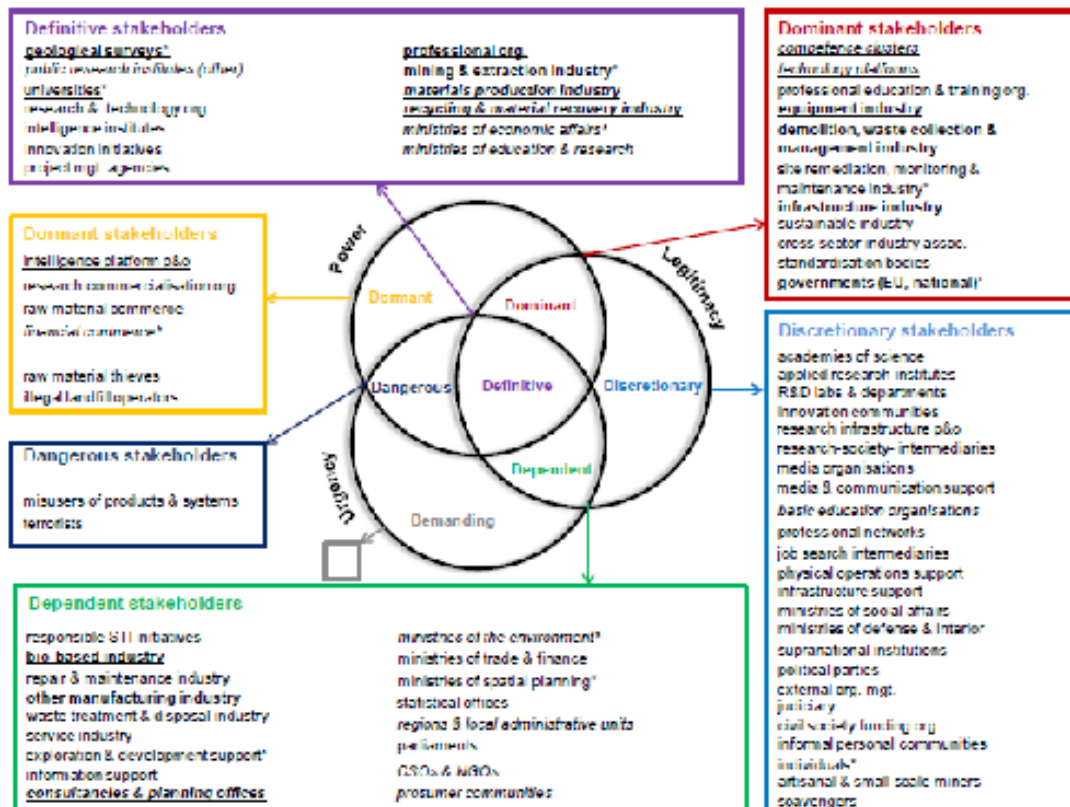*Figure 1: Outline of the MICA project structure.*

Figure 2. Ninety stakeholders mapped to six stakeholder groups. Types of treatment: surveys (in bold), stakeholder workshop (underlined) and interviews (in italics). Indirect appraisal in the surveys is marked with an asterix (*).

cal raw materials for the EU" (EC, 2010[2]; 2014[3]), COM(2011)21[4], COM(2011)25[5], as well as COM(2012)82[6]). Various projects

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2 EC (2010) "Critical Raw Materials for the EU. Report of the Ad-Hoc Working Group on Defining Critical Raw Materials", *https://ec.europa. eu/growth/tools-databases/eip-raw-materials/ en/system/files/ged/79%20report-b_en.pdf,* accessed 12.09.17.
3 EC (2014) "Report on the Critical Raw Materials for the EU. Report of the Ad Hoc Working Group on Defining Critical Raw Materials", *http://www.catalysiscluster.eu/wp/wp-content/ uploads/2015/05/2014_Critical-raw-materials- for-the-EU-2014.pdf*, accessed 12.09.17.
4 COM(2011)21 final. "A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy", Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, 26.1.2011, *http://eur-lex.europa.eu/legal-con- tent/EN/TXT/?uri=CELEX:52011DC0021*
5 COM (2011)25 final. "Tackling the challenges in commodity markets and on raw materials", Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Com- mittee of the Regions, 2.2.2011, *http://www. europarl.europa.eu/meetdocs/2009_2014/ documents/com/com_com(2011)0025_/com_ com(2011) 0025_en.pdf*
6 COM (2012)82 final. "Making raw materials available for Europe's future well-being. Pro-

posal for a European Innovation Partnership on Raw Materials (EIP-RM)", Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, 29.2.2012, *http://eur-lex.europa.eu/procedure/ EN/201383*

related to mineral raw materials, all of which contribute towards the development of the EU-RMICP and the EU-RMIS, have been funded in EU Framework Programmes as a result of this increased awareness, notably ProMine, EuroGeoSource, EURare, Min- ventory, Minerals4EU, ProSUM, I²Mine,

EO-Miners, MINATURA2020 and others, and most recently the Knowledge and Inno- vation Community, EIT KIC Raw Materials was set up. MICA aims to synthesise the outcomes of previous projects and other initiatives into a stakeholder-tailored ser- vice – the "European Raw Materials Intel- ligence Capacity Platform" (EU-RMICP).

Project structure

MICA has a total project duration of 26 months (1 December 2015 to 31 January 2018) and a budget of EUR 2 million. A

Of all project partners, 16 partners are direct beneficiaries - namely the Geological Surveys of the UK (BGS), Germany (BGR), France (BRGM), Slovenia (GeoZS), Denmark (GEUS), Finland (GTK), as well as the European Federation of Geologists (EFG), EuroGeoSurveys (EGS), and the Joint Research Centre (JRC) of the European Commission, alongside Fraunhofer-ISI, the La Palma Research Centre (LPRC), Minpol GmbH, the Norwegian University of Science and Technology (NTNU), University College London (UCL), Joseph Fournier University, Grenoble (UJF) and the University of Leiden's Institute of Environmental Sciences (UL-CML). Another 15 linked third parties support the project, namely the Geological Surveys of Albania (AGS), Romania (GIR), Belgium (GSB), Cyprus (GSD), Ireland (GSI), Croatia (HGI-CGS), Institute of Geology and Mineral Exploration (IGME-Greece), Spain - the Institute of Geology and Mineral Exploration (IGME), the Instituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA, Italy), the Laboratorio Nacional de Energia e Geologia I.P. (LNEG, Portugal), and geological research organisations in Hungary (MBFSZ), Norway (NGU), Poland (PGI-NRI), Sweden (SGU) and Switzerland (Swisstopo).

total of 31 partners are working on the project (see box, previous page). The project is structured into seven work packages (WP) that are interwoven and feed into each other (*Figure 1*). The project management is undertaken in WP1 (led by GEUS); WP2 (led by Fraunhofer-ISI) identifies and defines stakeholder groups and their Raw Material Intelligence (RMI) requirements; WP3 (led by BGS) consolidates relevant data on primary and secondary raw materials; WP4 (led by UL-CML) determines appropriate methods and tools to satisfy stakeholder RMI requirements; WP5 (led by Minpol) investigates RMI-options for European mineral policy development; WP6 (led by BRGM) develops the EU-RMICP integrating information on data and methods/tools with a user interface capable of satisfying stakeholder needs; and WP7 (led by EGS) disseminates the project's results.

Stakeholder identification and stakeholder needs

As of today, a range of outputs ('deliverables') have been produced in MICA, as summarised below. A systematic inventory was undertaken that mapped *90 stakeholder groups* (Erdmann *et al.*, 2016) according to three criteria legitimacy, power, and urgency of their issues (see *Figure 2*). The so-called 'definitive' stakeholders include, among others, those formally involved in the MICA project such as the geological surveys, public research institutes, universities, research and technology organisations, as well as intelligence institutes, professional organisations, industry (mining and extraction, production, recycling and material recovery, etc.), innovation initiatives, project management agencies, and ministries (economic affairs, education and research). 'Dominant' and 'dependent' stakeholders were considered in the comprehensive survey of raw material information needs. The manufacturing industry and governments represent dominant stakeholders. Business sectors that could potentially be affected by minerals RMI, such as e.g. the tourism industry or the bio-based industry, as well as civil society organisations e.g. environmental NGOs and human rights NGOs, are examples of dependent stakeholders.

MICA provided an *empirical appraisal of RMI needs of stakeholders* (Erdmann *et al.*, 2017) through three online surveys: one was conducted by EuroGeoSurveys reaching almost two thirds of its member geological surveys, another one by EFG to enhance the knowledge and understanding of raw material information needs of professional
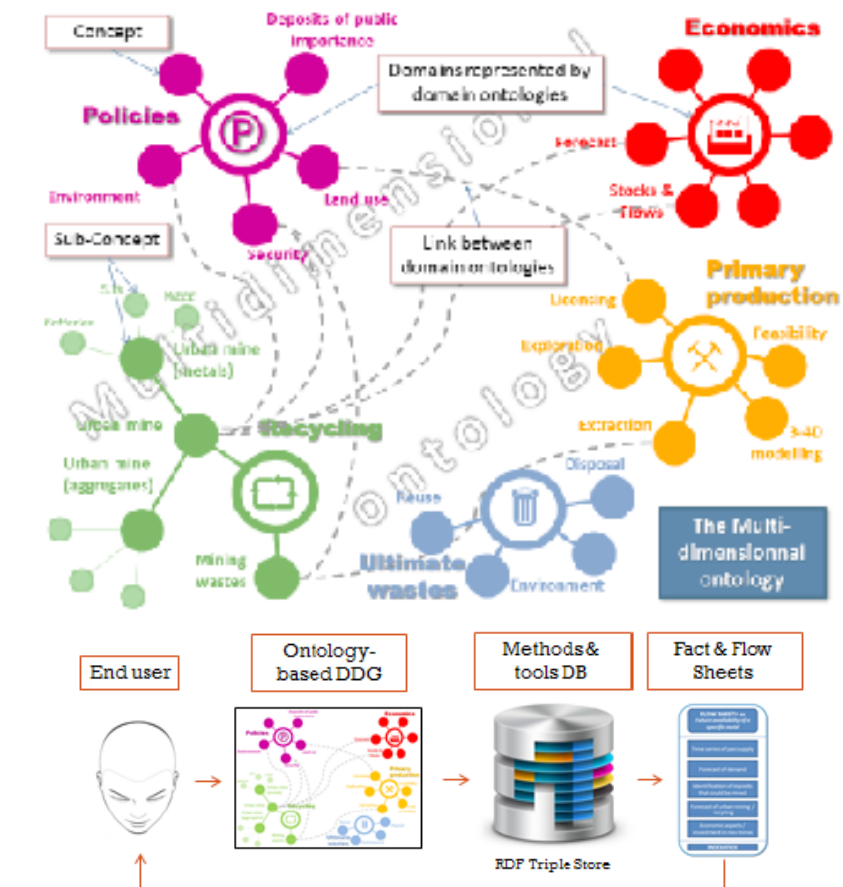

Figure 3: The multidimensional ontology to support the DDG.

Figure 4: Domains used by the MICA ontology.

geologists as potential users of EU-RMICP, and a third industry survey reached out to strategic management of industry associations, covering large parts of the material supply chain from raw materials processing to recycling. A stakeholder workshop and 20 interviews with representatives from NGOs and industry, EU agencies, minis- tries, cities, finance, education, and consumers were also conducted. The outcome of these surveys, the stakeholder workshop and interviews were condensed into a map of stakeholder needs in RMI that facilitated the finalisation of the 'MICA ontology', which is tailored towards the identified stakeholder topics of interest.

The ontology

In MICA, the *Main Multi-dimensional Ontology* represents the domain of questions end users may have about mineral resources/raw materials, see *Figure 3* (Cassard *et al.*, 2016). It is used for supporting a *Dynamic Decision Graph (DDG)* which allows the end users to navigate and visualise the MICA database content and the relationships between the different techniques, and to search for the most appropriate method(s) and tool(s) to use for resolving the user query (Cassard *et al.*, 2016). Depending on the users' preference or skills, a more or less 'visualised' and 'assisted' approach to their research is supported.

The ontology consists of seven domains, as presented in *Figure 4*, with about 300 concepts and sub-concepts (Cassard *et al.*, 2016). The main ontology and transversal 'generic' ontologies were developed collaboratively and interactively within the project, based on a survey performed by WP2 during the project kick-off meeting and drawing on experts from the project. To ensure that the main ontology represents end user (e.g., politicians, representatives of the EC, from governmental agencies, NGOs, academia and the general public) expectations or questions, it was informed by surveys undertaken in WP2, 3, 4 and 5, and thus its perimeter and depth/granularity improved. The main ontology is accompanied by three transversal, more 'generic' ontologies covering 'Value/Supply chains', 'Space/Time', and 'Commodities' that allow the end user to specify some fundamental 'search' parameters in order to speed up the discovery of the answer: where in the supply chain, which commodities, and where geographically (i.e., EU level, national level) and when (past/present/future).

Raw materials data inventory

Data and information are the foundation of any decision-making process, as they enable the creation of knowledge and intelligence and therefore are essential to the knowledge management system (EU-RMICP) that MICA develops. The 'Data – Information – Knowledge – Intelligence' (DIKI) hierarchy shown in *Figure 5* represents a conceptual framework for defining the terms and describing the levels of interpretation and analysis needed to move from data to intelligence. RMI depends very much on asking the right questions, and having the right underlying knowledge to act and move forward with decision-making. Although data, information, knowledge and intelligence are presented in a hierar-
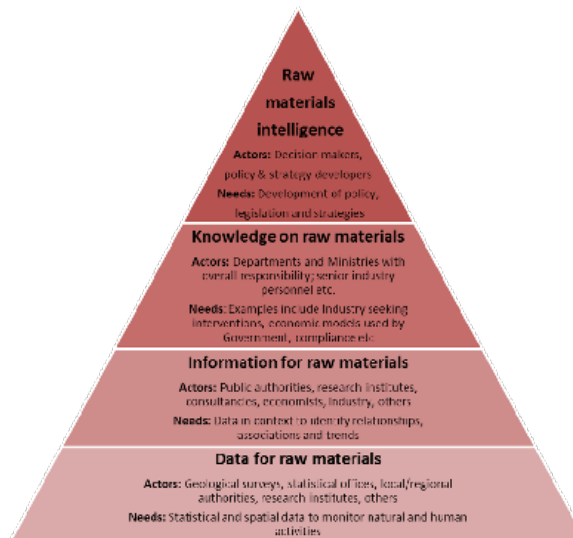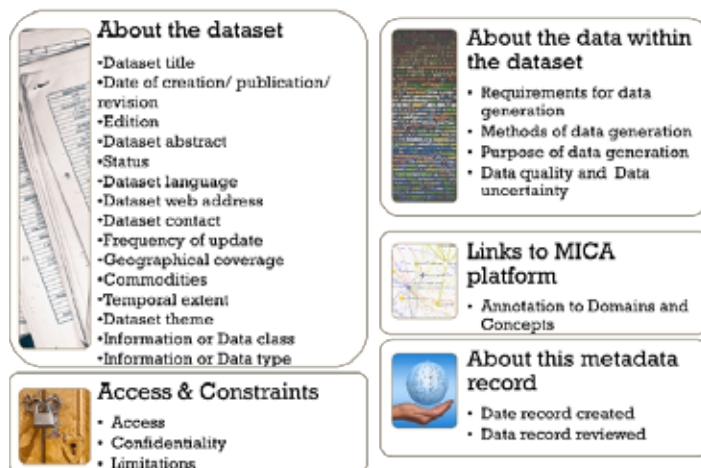
Figure 5: From data to intelligence.

Figure 6: The fields of the metadata template used in MICA.

chical order, in reality iterative processes operate throughout the process to enable movement from the lowest level of the pyramid to the top.

MICA delivers an inventory of raw materials data, which consists of approximately 408 metadata records that give descriptive information on datasets. The development of the metadata structure and template, as well as the final inventory, the relationships between data and methods, and work undertaken on data uncertainty are described in the WP3 deliverables (see Petavratzi *et al.*, 2016; Petavratzi and Brown, 2017). The data inventory communicates with the EU-RMICP and therefore users can gain access to data tailored to their needs through the platform by navigating to topics of interest. An online data portal will also be available (*http://metadata.mica-project.eu/*), which includes metadata information about various datasets and inventories (e.g. geoportals, life cycle analysis databases), contextual information (e.g.

reports), articles from scientific journals, legal documents, maps and projects, among others. The metadata template (*Figure 6*) is based on ISO 19115 (2014) and is aligned with the INSPIRE Directive requirements and implementing rules for metadata (EC-JRC, 2013).

(In)visible guidance of users by experts

Based on the stakeholder needs elucidated in WP2 and expert opinions, mineral raw materials relevant knowledge is condensed into documents, the so-called 'FactSheets' and 'DocSheets'. These will be the end point at which a user query will arrive and will provide the user with essential supporting information, data and knowledge. These FactSheets/DocSheets cover a variety of methods by which RMI can be gathered as well as topics of interest aligned to identified stakeholder needs.

WP4 workshop "Methods and Tools for Raw Materials Intelligence" MICA workshop 27 September 2016
Mapping research questions to methods and tools

Research question	Methods to identify and assess geological and anthropogenic (urban) stocks					Methods to assess society's metabolism and its environmental impacts					Methods to assess the economic aspects of the use of resources							Methods to forecast or estimate future use of resources					
	Geological mapping	Remote sensing	Geochemical analysis	Ground investigation	Resource estimation	Material flow accounting	Material flow modelling	Life cycle assessment	Environmentally extended Input Output Analysis	Risk Assessment	Footprinting	Cost Benefit Analysis	Life cycle costing	Input output analysis	Criticality assessment	Econometrics	General Equilibrium Modelling	Bottom up forecasting	Top-down forecasting	Backcasting	Horizon scanning	Tech watch/best practice	scenario storylines
1. What is the estimated size of resources (economic, reserve base, ultimate earth crust) over the past 50 years and where are they located?	■	■	■	■	■	●	■					●											
2. What is the estimated size of resources in urban stocks (i.e. stocks-in-use) over the past 50 years and where are they located?		●	●	■	■	■	■					●	●	●									
3. What was the extraction of raw materials over the past 50 years and where were they extracted?						■								■									

Figure 7: Excerpt from contribution of methods to answering stakeholder questions.

Methods for data use

The *FactSheets of methods* for RMI are essential to put data into context within the EU-RMICP (van der Voet *et al.*, 2016a). They address methods to identify and assess geological and anthropogenic (urban) stocks (including geological mapping methods also applicable to secondary stocks e.g. landfills or underground hibernating stocks). The methods comprise two categories: a) to account for stocks in use, and b) to follow them through society together with their impacts, e.g. Material Flow Analysis (MFA); Life Cycle Assessment (LCA) within the context of Life Cycle Sustainability Analysis for the life-cycle of materials, environmental footprinting, economic aspects of resource use (Cost Benefit Analysis; Econometric and Computable General Equilibrium models; criticality assessment), as well as scenario analysis for future resource use. These methods have been assessed as to their usefulness to help answer stakeholders' questions; see excerpt from the exercise in *Figure 7* (van der Voet *et al.*, 2016b).

In addition, *more than 100 other FactSheets and DocSheets* on identified topics are being elaborated by project collaborators with particular knowledge and expertise. These sheets undergo a peer-review process and are then revised. The documents therefore represent a unique and qualified source of information in EU-RMICP.

The so-called *FlowSheets* are in essence recipes that come into play upon specific queries by the end user and prescribe the flow of data and information, e.g., which DocSheets/FactSheets and which datasets should be used, following a certain order, to solve the query of the end user. The content
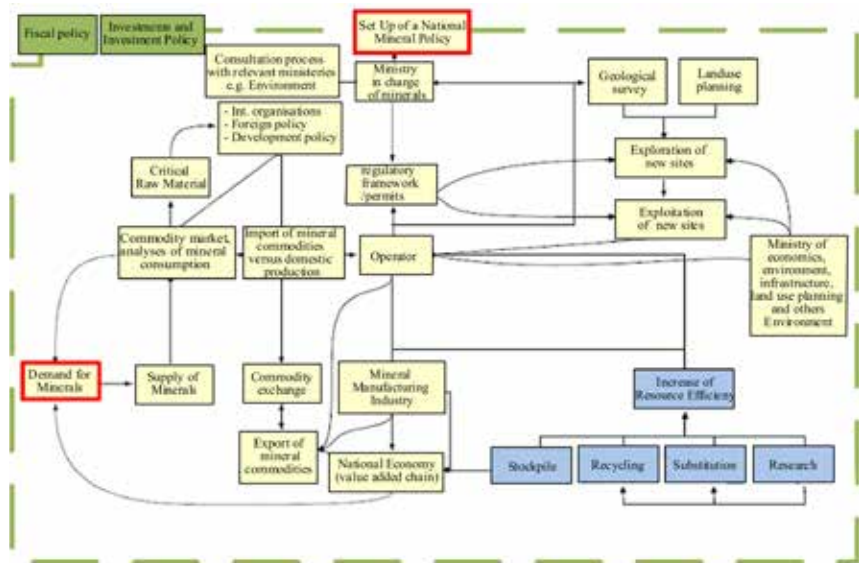
Figure 8: Mechanisms of minerals policy framework. Source: Tiess, 2011, adapted 2017.

of the FlowSheets will be visible to the end user and reflects expert knowledge that was at play when these were designed.

Policy relevance and foresight

MICA also delivered a discussion and summary of RMI tools and methods, including an assessment of the EU Raw Material Initiative, which provides a general framework for a mineral policy but lacks systematic RMI in the EU (Falck *et al.*, 2016). A multi-dimensional matrix serves to outline the various RMI dimensions, the main dimensions being the minerals policy frameworks and their governing principles at national, European, and global level, stakeholder needs and expectations (e.g., the mechanisms of minerals policy frameworks) (see *Figure 7*), and methods and strategies to predict future development in the use, demand, and supply of minerals.

Furthermore, a *foresight logframe* was elaborated (Konrat Martins and Bodo, 2016) that reviews international foresight case studies based on an inventory structured into three classes: quantitative, macro-environmental, and a methods–combination–suitability matrix. The quantitative classification addresses measurable aspects, such as the number of people and institutions involved. The macro-environmental classification outlines large-scale environmental factors that were the object of study, while the matrix of methods, combinations and suitability reviews the methods observed in the study.

Outreach

The MICA *graphical identity* is used in *promotion material* distributed at numerous events including the EGS MREG meeting 2015, the 7th session of the UNECE Expert

Group of Resource Classification, and the World Circular Economy Forum 2017, in accordance with its *communication strategy and dissemination plans* (Delfini *et al.*, 2016). Information about MICA's progress can be obtained also via various social media (Delfini, 2017): Twitter (*@micaproject2015*), LinkedIn (*www.linkedin.com/company/7957049/*), and Facebook (*www.facebook.com/micaproject2015*). News and deliverables are available from the MICA project website: *www.mica-project.eu.*

Conclusions

By project completion in January 2018, a raw materials data and methods strategy and a conceptual framework for the transformation of data into knowledge will have been delivered with the EU-RMICP. The ambition of the EU-RMCIP is to help stakeholders find answers to raw materials related questions, even if they have no experience and knowledge of using one of the spatial geoportals, raw materials databases, or other related tools and methods. It

is hoped that this will help stakeholders to better understand how data, methods and raw materials-related decisions will impact their daily life.

Acknowledgements

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UNEXMIN: a new concept to sustainably obtain geological information from flooded mines

Luís Lopes*, Norbert Zajzon, Stephen Henley, Csaba Vörös, Alfredo Martins and José Miguel Almeida

The UNEXMIN project is developing an autonomous robotic system that can explore and map flooded underground mines, gathering new geological data from locations that are now inaccessible for human exploration and that can be used in future sustainable applications. The robotic system – UX-1 – will have specifically designed tools for the challenging environment. Among these there are the water sampler, magnetic field unit and SLS ("Structured Light Sensor"). In the on-going development phase software and hardware tools for navigation, 3D mapping and data processing are being created. Post-processing software is being developed to provide optical and sonar imaging as well as geochemical, hydrological, geophysical, and mineralogical information from the variety of instrumentation to be carried by UX-1.

Le projet UNEXMIN développe un système robotique autonome qui peut explorer et cartographier les mines souterraines inondées, rassemblant des données géologiques nouvelles, tirées d'endroits qui sont maintenant inaccessibles à l'exploration humaine, et qui peuvent être utilisées pour des applications futures et durables. Le système robotique - UX-1 - comportera des outils de conception spécifique pour faire face aux défis environnementaux. Parmi ceux-ci, on note un échantillonneur d'eau, un capteur de champ magnétique et le SLS (capteur à lumière structurée). Au cours de la phase de développement actuel d'outils de navigation (logiciel et matériel), la cartographie 3D et le traitement de données sont des outils en voie de création. Un logiciel de post-traitement est développé pour fournir des informations de type image optique et sonar tout autant que géochimique, hydrogéologique, géophysique et minéralogique, à partir de la diversité des programmes de mesure qui seront réalisés par UX-1.

El proyecto UNEXMIN está desarrollando un sistema robótico autónomo que puede explorar y mapear minas subterráneas inundadas, recopilando nuevos datos geológicos de lugares que ahora son inaccesibles para la exploración humana y que pueden ser utilizados en futuras aplicaciones sostenibles. El sistema robótico - UX-1 - utilizará herramientas diseñadas específicamente para este entorno desafiante. Entre otros se encuentran la recogida de muestras de agua, la unidad de campo magnético y el SLS ("Structured Light Sensor", Sensor de Luz Estructurado). En la fase de desarrollo han sido creados, herramientas de software y hardware para la navegación, el mapeo 3D y el procesamiento de datos. Actualmente se está desarrollando un software de postprocesamiento para proporcionar imágenes ópticas y sónicas, así como información geoquímica, hidrológica, geofísica y mineralógica a partir de la variedad de instrumentos que transportará el UX-1.

Concept and approach

UNEXMIN (**Un**derwater **Ex**plorer for Flooded **Min**es) is an EU project funded under the Horizon 2020 Framework Programme that is a direct response to the H2020 Call SC5-11d-2015 on (1) "New sustainable exploration technologies and geomodels", part of an effort for (2) "Ensuring the sustainable supply of non-energy and non-agricultural raw materials", based on the raw materials needs envisaged by the European Commission in recent years. The first topic links to a major challenge identified by the EU: to reduce the dependency on the import of raw materials and solve issues in their entire value chain. Geological uncertainty, technological and economic feasibility of mine development and the growing costs of exploration (including exploration in extreme conditions and challenging environments) are problems for which the EU is actively trying to find a solution. These bottlenecks were first identified by the EIP on Raw Materials (EIP on Raw Materials, 2013). The second link is the aim to improve the knowledge base on raw materials, while also finding "innovative solutions for the cost-effective, resource-efficient and environmentally friendly exploration, extraction, … and recovery of raw materials and for their substitution by economically attractive and environmentally sustainable alternatives with a lower environmental impact" (Programme description, *http://cordis.europa.eu/programme/rcn/664407_en.html*).

UNEXMIN intends to help solve these problems and it will form the necessary bridge between the geosciences and engineering through robotics development (e.g. with autonomous systems). Bugmann *et al.* (2011) identified many possible roles robotics can play in sustainability: (1) exploration of resources, (2) recycling, (3) reducing waste, (4) enhancing product repairability, (5) monitoring soil, plant and animal conditions and (6) monitoring water contamination, air quality and other environmental measures, among others. UNEXMIN can contribute to several of these aspects: the robotic technology being developed will help in exploring resources in flooded

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mines and other non-easily accessible locations, and can monitor water contamination and other environmental aspects in underwater environments (e.g. temperature, pH). The UNEXMIN project is, thus, connecting geosciences, engineering and sustainability, to be applied to benefit modern society.

In Europe, there are a considerable number of closed mine sites – around 30,000 (ISRM, 2008) and many of these may still contain valuable quantities of mineral raw materials, which usually are minerals that were disregarded during the operational lifetime of the mines due to low commercial value that made their further exploitation economically unfeasible. A classic example of this is fluorite which until recent decades was considered a waste mineral in many lead-zinc mines but is now on the EU list of critical raw materials. With the general increase in prices of most mineral commodities and the huge societal demand presently seen, what was considered unprofitable to exploit decades ago can be regarded today as economically feasible to exploit. With this new vision, the re-opening of closed mine sites in Europe has become a hot topic, with ever-growing interest, as it creates a way to provide a sustainable supply of raw materials and thus reduce the dependence on imports that European industry faces.

A big opportunity for the re-opening of closed mine sites resides in former underground mines: high commodity prices and demand can make their exploitation feasible again. The problem that arises is that the majority of these mines are now flooded, a normal process that occurs when dewatering pumps are switched off after cessation of mining activities, and in most cases information regarding their status and layout has not been preserved, has been lost or was not even prepared.

Knowing what resources are (still) present underground can be the first step for a more sustainable supply and use of mineral raw materials inside the EU, which is one of the EU's major goals for the near future. UNEXMIN will use sustainable methods – environmentally non-invasive and non-damaging – for exploration. By using an autonomous system, like the one being developed, and by following the premise of sustainable exploration, it will be possible to create geomodels for more sustainable exploration scenarios in the future. The novel UNEXMIN technology will perform without the need for using common intrusive exploration methods such as drilling, sampling, tethered equipment or even humans (as divers), that usually have a negative impact on the environment (e.g. damaging nature and the site, using exces-

sive resources such as water and oil, etc.) or can even be considered as dangerous (the risk of losing human lives).

The overall concept and workflow of the UNEXMIN project can be seen in *Figures 1 and 2*, respectively.

Sustainable future applications for the UNEXMIN technology

Although the main objective for the development of UNEXMIN is autonomous exploration and mapping of flooded underground mines, the steps made towards such a novel technology can lead to the emergence of other technologies that can also be applied with sustainable objectives. Particularly, UNEXMIN aims to (1) place the EU at the forefront of sustainable minerals surveying and exploration technologies, (2) provide a better, more efficient solution to evaluate abandoned mines for their mineral potential and (3) offer technology to document and safeguard unique mining heritage that would be otherwise lost or permanently inaccessible.

When fully developed, the technology can potentially be used in a series of sustainable applications in unusual environments that will greatly benefit society, and particularly the geoscience community, in many ways: (1) providing information about min-
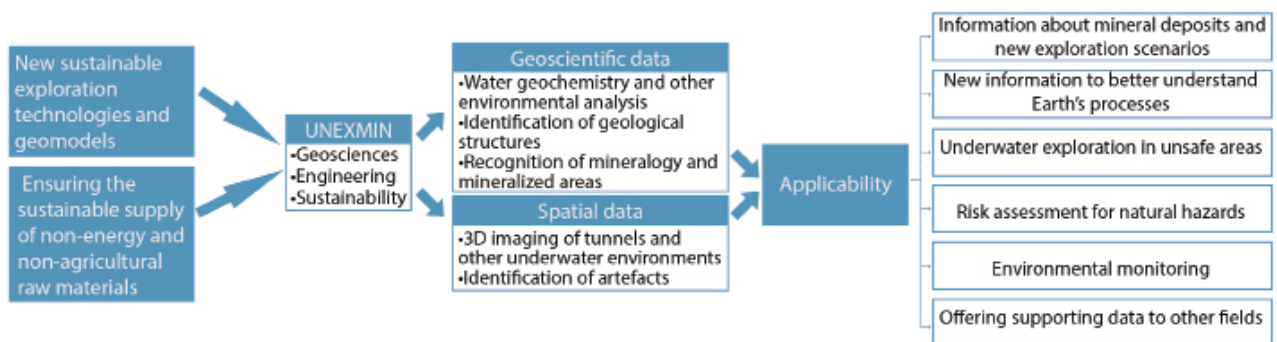

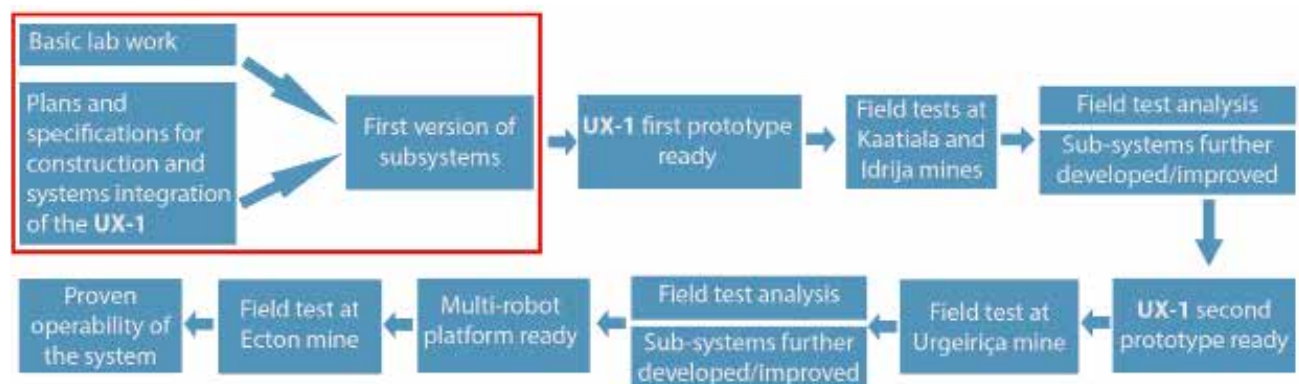*Figure 1: General concept of the UNEXMIN project.*

Figure 2: General workflow of the UNEXMIN project.

eral deposits and opening new sustainable exploration scenarios for raw materials, (2) giving access to new, otherwise inaccessible, information necessary to better understand Earth's processes and help to map actions towards a sustainable future, (3) carrying out underwater exploration in unsafe areas (nuclear accidents, toxic spills, surveying of unstable underwater environments – after earthquakes or other catastrophes, etc.), (4) enabling risk assessment of natural hazards (e.g. sinkholes and similar geotechnical problems), (5) environmental monitoring and (6) offering supporting data for fields such as energy efficiency, resource management, archaeology or civil engineering, for instance in the examination and monitoring of underground water reservoirs without the need to drain them.

Development of instrumentation

The surveyor – UX-1 – is designed to employ technologies and equipment derived from state-of-the-art autonomous control and navigation, deep sea robotics and 3D mapping (as a basis). The instrumentation that the robot will carry can be roughly divided into (1) equipment necessary for basic robotic functions such as navigation, control, autonomy or environmental perception and (2) scientific instruments that will generate valuable geological and spatial data. The first group includes thrusters, optical and acoustic cameras, a structured light system (SLS) including laser and white light, pendulum and buoyancy control systems, batteries, a computer and a pressure hull. The second group contains a water sampler, conductivity and pH measuring units, a sub-bottom profiler, a magnetic field measuring unit, UV fluorescence imaging and multispectral imaging units.

The software and hardware tools are being developed, tested and adapted specifically for flooded underground mine environments, where an uncommon combination of conditions must be overcome (e.g. low visibility, confined space, obstacles, water chemistry, etc.). Due to the special

environmental characteristics, it is not possible to use methods that require direct contact with the surroundings to collect geoscientific data. Instead, indirect methods will be used such as imaging, geophysical and water sampling methods.

The instruments that are required for some of these methods are described below. Data post-processing is also mentioned, as it is one of the most important processes in geological interpretation.

a) Water sampler unit

A water sampler will collect samples from mine waters and has the final purpose of yielding information about their chemical, biological, radiological and physical characteristics, either through in-situ analysis or a posteriori analysis in accredited laboratories. Some of the most important parameters that can be studied from water analysis are temperature, pH, conductivity (from measurements performed during the missions) and ionic composition (measurements performed after the missions).

The UX-1 unit (*Figure 3*) is designed as a complex storage tank with capacity for 16 different water samples, with each of the samples amounting to 6.8 cm^3. Depending on the pressure, it can take up from 40 seconds to less than 5 seconds to fill a sample task using the power of ambient water pressure. Two independent chambers will be set up in the water sampler: one is the sampling section, filled with sampled water; the other is at atmospheric pressure and contains mainly electrical components and other parts necessary to make the system work, which do not have adequate internal pressure and their own pressure protection.

b) SLS imaging unit

The robot will be equipped with a custom developed set of laser-based structured light systems (SLS) that will provide both 3D morphological information of the scanned environment and imaging (*Figure 3*). Each SLS sensor comprises a laser/light projector

unit and a dedicated camera. The camera unit integrates not only the camera itself but also a dedicated embedded processor responsible for the projected laser line detection and triangulation – essential to obtain 3-dimensional data. The laser line projector is mounted in a rotating axis, thus allowing for area sweep even when the robot is motionless. Each image produces a 3D line of points that can then be recorded as a point cloud in the mine's global coordinate system – analysed with post-processing.

The use of multiple SLS sensors in the robot allows the system to be able to simultaneously scan a large volume of its surroundings and thus to build a coherent map of the environment. In an underground flooded environment, this is crucial not only for navigation purposes but also to obtain relevant morphology information on the environment itself.

One relevant characteristic of the sensor is that the LED illumination wavelength can be chosen, and, in particular, different LED wavelengths can be used in different pulses. The UNEXMIN SLS systems have white illumination for standard images and also UV LEDs that can be used to obtain fluorescence images. These indicate the fluorescence properties of some minerals, helping in their identification (e.g. scheelite).

c) Magnetic field measuring unit

The main objective of geomagnetic methods is to explore subsurface geology; they are used in situations such as ground exploration, borehole investigation or aeromagnetic surveys. They are essential to identify magnetic anomalies that can indicate the presence of orebodies or gangue minerals associated with ferromagnetic ore deposits. In UNEXMIN the magnetic field measurements will help to identify possible orebodies, imaging geology and fault structures, or to locate artefacts such as pipes, tanks and other archaeological material of importance inside the flooded mines. Regarding ore bodies, magnetic field measurement
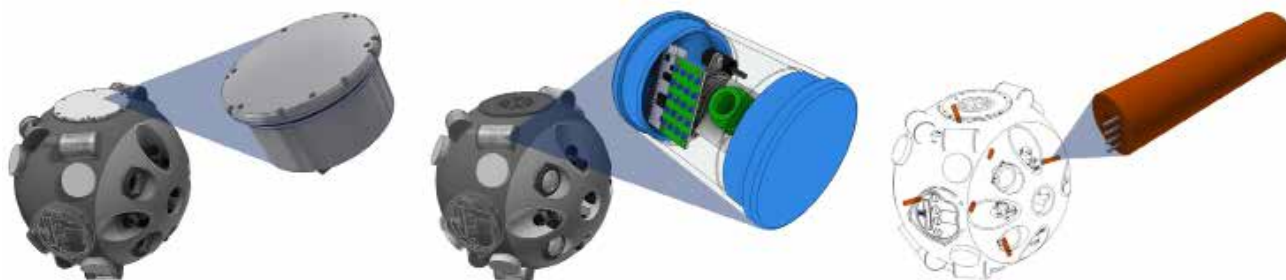

Figure 3: Part of the scientific equipment and their position in UX-1: left – water sampler unit; centre – SLS imaging unit; right – Magnetic field measuring unit.

can help to discriminate massive sulphide bodies – magnetite, hematite, etc. – that usually contain high amounts of commodities (e.g. iron, nickel or copper).

The flux gate sensor system was chosen to measure the magnetic field intensity and direction and is an instrument that collects the data, composed by 6 sensor pieces arranged in three pairs, thus it is three-dimensional sensitive (*Figure 3*). The sensors will be mounted in a perpendicular manner that allows for better measurements of the magnetic field, including very specific local changes. However, it is necessary to compensate the effect of the different electromagnetic equipment built into the UX-1 such as thrusters and cooler fans. Therefore, a compensation process will be applied during data conversion or post-processing to make the data meaningful and valuable.

d) Post-processing software

Post-processing software is used to transform (interpret) the raw data collected by the different instruments into a common database format (e.g. processing of the point-cloud captured by the SLS unit), ultimately allowing creation of usable 3-dimensional geometric and geological models of the flooded mine environments. UX-1 will use miniaturised optical systems to obtain spatial data plus a combination of geophysical and geochemical methods to yield detailed information about environmental parameters (e.g. pH, temperature, conductivity, and concentration of metallic ions of interest in water) as well as multispectral data that will give clues to the composition of the rock faces, and sub-bottom sonar to give an indication of

the depth of silt or mud in the mine as well as some clues to the structure of the solid rock below it. Together, it will be possible to identify mineralised areas, which can help in the development of metallogenic models.

Data visualisation will require high-resolution 3D displays supported by fast software algorithms. The data can then be used to learn about the actual status of abandoned underground flooded mines, which could, in turn, support economic assessments for potential re-opening of mining activities. Results from the visualisation software will be presented on computer screens, using virtual reality headsets, and as 3D printed models.

Joint efforts by UNEXMIN partners University of Miskolc and Resources Computing International show that although complex data analysis is needed, it may well be possible to identify or classify wall-rock mineral compositions from the multispectral data. Key software applications for this will include principal components and factor analysis, linear programming optimisation and multiple discriminant analysis.

Field trials

After instrumentation tests in both the laboratory and the field, the UX-1 prototype will be assembled, tested and consequently improved with four trials in flooded underground mines around Europe: the Kaatiala pegmatite mine in Finland, the Idrija mercury mine in Slovenia, the Urgeiriça uranium mine in Portugal and the Ecton copper mine in the UK. The tests will take place from mid-2018 to mid-2019 and will serve as trials in real life conditions, representing increasingly difficult mission

objectives in terms of mine layout, geometry and topology. The process will prove the total operability of the system in a set of pilot sites with typical mine characteristics, which can be representative of most flooded mines around Europe. The final and most ambitious trial, to be held in the Ecton underground mine in the UK, aims to resurvey the entire flooded section of the mine, which nobody has seen for over 160 years.

Next steps

The UNEXMIN project is still in its development phase related to the instrumentation, with software and hardware tools for navigation, 3D mapping and data processing being constantly improved and adapted to flooded mine environments. The first UX-1 robotic prototype will be fully functioning and ready by mid-2018 in time for the Kaatiala mine trial. For the period of one year the prototype will be further developed and improved based on the results of the various field tests. In the last test site, in Ecton Mine, we expect to deploy a multirobotic system formed by three UX-1 robots that will work simultaneously, sharing the workload during their mission.

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The ¡VAMOS! Sustainable Underwater Mining Solution

Edine Bakker*, Gorazd Žibret and Jenny Rainbird

¡VAMOS! – Viable Alternative Mine Operating System – is a research project funded by the H2020 program which is building a prototype underwater mining system that will provide a novel way of exploiting inaccessible inland mineral resources that lie beneath the water table. The project is developing a submerged remotely controlled mining vehicle prototype with associated launch, recovery and ore collecting equipment. The system is also equipped with cutting-edge technology for environmental data collection and real-time grade control. The ¡VAMOS! technology is expected to provide major advantages in the fields of environmental sustainability and safety with respect to conventional mining methods. Two separate field trials will prove the environmental integrity and economic viability of the concept.

¡VAMOS! (Système d'opération minière alternative, viable) est un projet européen de recherche, de création commune, sous forme d'un prototype de système d'exploitation minière sous marine qui procurera un nouveau moyen d'exploitation des ressources minières continentales, présentes en-dessous du niveau statique. Le projet développe un prototype de véhicule minier immergé, avec contrôle distant, démarrage associé, équipement de récupération et de collecte du minerai. Le système est également équipé d'une technologie en pointe pour la saisie des données environnementales et le contrôle de leur qualité en temps réel. On attend de la technologie VAMOS, des avancées majeures dans les domaines de l'environnement durable et de la sécurité, tout en respectant les méthodes minières conventionnelles. Deux expérimentations séparées vont attester de l'intégrité environnementale et de la viabilité économique de ce concept.

¡VAMOS! – Viable Alternative Mine Operating System – es un proyecto de investigación financiado conjuntamente por la Unión Europea que está construyendo un prototipo de sistema de minería submarina que proporcionará una forma novedosa de explotar los recursos minerales inaccesibles, ubicados debajo del nivel freático. El proyecto está desarrollando un prototipo de vehículo de minería sumergido, controlado a distancia, con equipamiento asociado al lanzamiento, a la recuperación y a la recolección de minerales. El sistema también está equipado con tecnología puntera para la recopilación de datos ambientales y el control de posición en tiempo real. Se espera que la tecnología de ¡VAMOS! brinde mayores ventajas en los campos de sostenibilidad ambiental y de seguridad con respecto a los métodos de minería convencionales. Dos ensayos de campo separados demostrarán la integridad ambiental y la viabilidad económica del concepto.

Introduction

Europe is highly dependent on imports of raw materials that are needed to support its industries. Securing a reliable supply of minerals that are essential for the European quality of living and economy has been a top priority for the EU in the past years (European Commission, 2017). Mineral raw materials have been mined over many centuries in Europe. However, many mines that have been closed because they could not be economically operated in the past still contain valuable raw materials. Modern mining and processing techniques make mining of previously uneconomic deposits possible today, since the economically exploitable average grade of present-day operating mines has continu-

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ously decreased over time. Many mineral deposits in Europe are also submerged, either through flooding of mines after they were abandoned or in unmined deposits that lie below the water table.

¡VAMOS! is developing a new mine operating system that allows minerals to be extracted in an underwater open-pit environment. The ¡VAMOS! mining technique will enable re-opening of these abandoned open-pit mines, extend the lifetime of opencast mines which are limited by stripping ratio or hydrological and geotechnical issues, and will allow the opening of new mines with limited environmental impacts in the EU. The ¡VAMOS! solution was developed in response to a Horizon 2020 Research and Innovation call for 'New solutions for sustainable production of raw materials' by 17 partners from 10 European countries.

The ¡VAMOS! mining technology

The ¡VAMOS! system consists of several components (*Figure 1*). A remotely-controlled underwater mining vehicle is equipped with a cutter-head that will cut rocks to fragments of about 50 mm. The resulting mined material will be fed into a dredge suction mouth by a rotating auger, and a grill over the suction mouth will prevent blockage of the piping by large rock fragments. The mined slurry will be pumped up to the surface through a riser to an anchored launch and recovery vessel (LARV) and then through a hose system to an on-land dewatering facility, where the mined material will be separated from water before further processing and the excess water will be returned to the mine pit. The LARV also serves to launch and recover the mining vehicle from the water and provides the surface link for the communications and
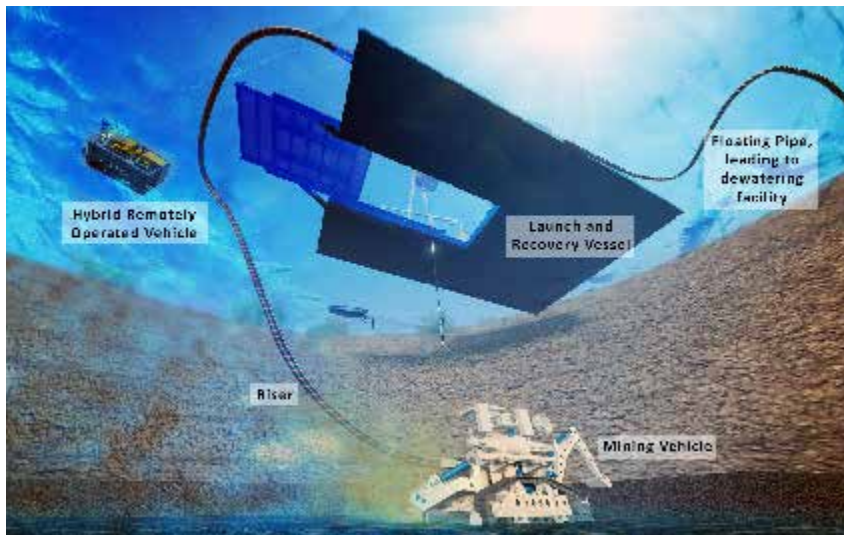
Figure 1: Artist's impression of the ¡VAMOS! technology in action (Damen Dredging).

power tether. The entire system will run on electricity, which can be provided by diesel generators or from the electrical grid.

The exact positioning and navigation of the mining vehicle and situational awareness of its environment will be accomplished with a tether-less hybrid remotely operated autonomous underwater vehicle (HROV/AUV) that will operate in parallel with the mining vehicle. It will collect visual and sonar information for situation modelling, obstacle avoidance data and vehicle positioning and orientation data.

The mining machine positioning is obtained by a localisation solution that fuses Short Base Line acoustic positioning (with a set of transponders fixed on the LARV) with an on-board inertial motion unit providing orientation information. Assisted by this data, all machinery can be controlled and operated via a 3D virtual reality human-machine interface onshore.

In addition, the mining vehicle also carries a set of sensors providing situational awareness, which allows safe and efficient remote operation. The sensors consist of a multibeam sonar system and an underwater camera (and lights) mounted on a pan-tilt unit, on several cameras and lights located at relevant machine points and in a set of custom developed laser-based structured light systems (SLS). These systems provide not only standard visual information, but also, when the water turbidity conditions allow, 3D point cloud measurements of the environment. This 3D information together with the range data from the sonar is fed into the mine map that is produced in real-time and used in the virtual reality environment.

The autonomous underwater vehicle is also equipped with a multibeam sonar and set of SLS sensors to gather precision 3D environment information. Its positioning is obtained with the aid of an inverted (Ultra) Short Baseline acoustic solution and on-board inertial navigation sensors. An acoustic communications link is established with the surface for low rate telemetry and teleprogramming. In addition, a custom developed short range underwater electromagnetic communication system is used for direct teleoperation when required (and within range) and for high bandwidth information transfer (such as images or sonar data).

The HROV is used in different stages of the mining operation. Initially it surveys the mine pit and produces an initial bathymetric map that can be used in the mine planning operations. During mining operations, the HROV is used both for gathering 3D data and updating the map and for additional situational awareness, providing a freely controllable viewpoint for the operations.

The mining vehicle will also be equipped

with laser induced breakdown spectroscopy (LIBS) for real-time grade control. This system is attached to a small diversion on the slurry circuit and produces a high rate set of spectroscopy measurements of the slurry. These are correlated with pre-existing calibrated responses from the minerals expected to be present at particular location allowing real-time ore grade monitoring and obtaining of production statistics. This allows for more efficient mining operation and reduces the cutting of waste.

Application and expected environmental sustainability

Because the ¡VAMOS! technology is completely new and has yet to be field tested (as of September 2017), scientific data is still required to confirm the best application domain and the potential environmental impacts. It is also crucial to answer the question where exactly iVAMOS! technology is a more cost-effective extraction method in comparison to conventional in-land mining. One of the major economic advantages of the technology is that groundwater does not need to be pumped out of the mine continuously. The resulting lower energy consumption is not only more cost efficient, but will lower the carbon footprint of the operation as well. Another big environmental advantage is that the local water table will not be affected, limiting the effects of the mining operation on surrounding hydrological systems, vegetation, and ecosystems. Considering that the extraction will be located underwater, there will be no significant noise or dust emissions, and due to hydrostatic effects less energy will be required to transport ore to the surface. It is also expected that ¡VAMOS! technology will allow lower stripping ratio, since sidewalls are expected to be more stable underwater than in dry conditions (*Figure 2*). The reasons for this are that there will be no blast over-break, ground
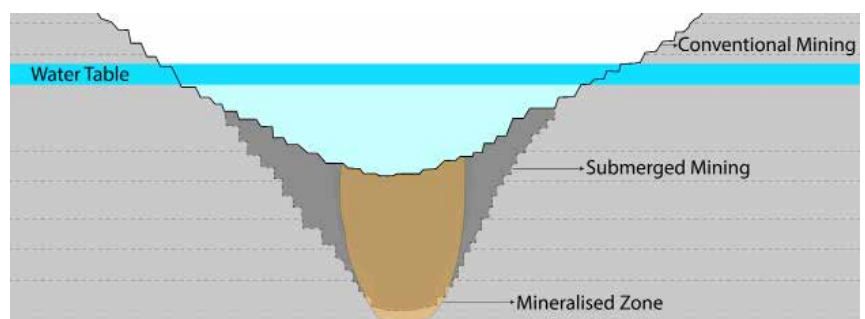

Figure 2: Sketch of a conventional opencast mining operation, requiring dewatering and the removal of large volumes of waste rock, compared to submerged mining with a lower stripping ratio due to more stable sidewalls in hydrostatic conditions.

Table 1: Comparison of key components of mining in open-pits, off-shore and in the ¡VAMOS! concept according to their economic importance.

Economic factor	Conventional in-land open-pit mining	Off-shore mining	¡VAMOS! concept
Dewatering	Related to climate and depth of operation, risk of flooding; it is often the limitation factor for further development of mine	No need for dewatering	No need for dewatering, pit semi-immune to flooding
Crushing	Depending on the ore hardness and extraction type; generally after blasting ore is transported and crushed in primary and secondary ore crushers	Ore is primarily crushed during extraction	Ore is primarily crushed during extraction
Productivity	Depending on the extraction technology; open-pit mining allows very large operations	Limited by size and quantity of the machinery	Limited by size and quantity of the machinery
Equipment needed	Excavator, hauling trucks or conveyor belts, primary and secondary crusher, extractive waste and tailings deposits, equipment for lowering the water table, accommodation for workers; equipment cost is relatively easy to determine	Production support vessel with control room, ore pumping and dewatering unit, accommodation units, power generating units and risers for different subsea cutters, transport vessels, generators; cost of equipment could be high	Modular submerged cutter(s), riser and positioning barge with pumps, dewatering station, control room, accommodation for workers, generators (in case of remote location), cost of equipment not yet defined
Energy requirements	Liquid fuels for trucks and excavators, electricity provided by grid or diesel generators, explosives for blasting	Electricity provided by diesel generators	Electricity from grid or provided by diesel generators
Sidewall stability	Defined by the geotechnical properties of host rock and geological conditions; often a limiting factor for further mine development	Since ores are mined on the sea floor there is no problems with sidewall stability	Better stability can probably be expected compared to conventional open-pit mining: no erosion, no freezing, balanced hydrostatic pressure, no adverse phreatic surfaces, no weakening due to blast vibrations;
Hauling	Trucks or conveyor belts; significant amount of energy and equipment is required	Ore is transported in suspension, lower energy requirements due to hydrostatic effects	Ore is transported in suspension, lower energy requirements due to hydrostatic effects
Workforce and safety	A larger number of workers with different skills are needed, but this depends on the level of automation in the mine; many requirements to assure worker health & safety	Moderate to low numbers of workers (special training required for some positions), no need to work in dangerous places due to remote control of the machinery, lower requirements to assure worker health & safety	Moderate to low numbers of workers, (special training required for some positions), no need to work in dangerous places due to remote control of the machinery, lower requirements to assure worker health & safety
Environmental impacts	Emissions of dust and gases, noise, visual impact on landscape, changes in water table, release of sediments, risks of acid mine drainage, tailing, oil, chemical and lubricant spills, erosion of sidewalls, discharge of mine water, vibrations because of blasting, impacts on biota	Impacts on marine biota, dispersion of sediments, risk of fuel, chemical and lubricant spills	Smaller risk of fuel, chemical and lubricant spills than in conventional mining, possible impacts on groundwater chemistry, only sidewalls above water table are subject to erosion, lower visual impact on landscape than conventional mining; low water pH can limit use of ¡VAMOS! machinery
Suitability for different deposit types	All types of in-land ore deposits, provided there is a sufficient amount of ore close enough to the surface	Sedimentary deposits on continental shelves, SEDEX & polymetallic ore deposits on ocean floor	Vertical/semi-vertical orebodies, deformed sedimentary deposits, possibly also hydrothermal deposits in veins near surface and other deposits in areas of high groundwater levels; ore hardness could be a limiting factor due to the reduced weight and size of excavators and related hydrostatic effects
Social acceptance	Depends on the operation and locality; could be a limiting factor for mine development.	Not known	High social opposition is not likely, since the main purpose of ¡VAMOS! technology is the exploitation of resources in abandoned flooded open-pit mines, where land is already degraded

vibrations will be reduced, no toe seepage or erosion of softer rocks due to equalised water pressure, no oxidation of materials in side walls, no differential water pressures in the pit and no frost damage underwater, and since people will not work at the site of extraction there will be no need for very high safety measures. However, the sidewall stability of submerged sediments, tilted layered rocks or tectonically fractured rocks might be reduced in underwater environments compared to above water conditions. However, these are hypothetical assumptions that still need to be confirmed in real-environment tests. If ¡VAMOS! proves that it will lower the stripping-ratio of a mining operation, then less waste rock will need to be removed, further reducing the environmental impact and increasing the cost and energy efficiency of the mining operation.

Table 1 provides a preliminary analysis that has been carried out to provide a comparison between the ¡VAMOS! concept, conventional in-land open-pit mining, and off-shore mining with regards to economic exploitability.

Field trials

Two field trials are planned within the iVAMOS! project, taking place in October 2017 and in spring 2018. The first trial is scheduled for Lee Moor, Devon, UK, at a disused flooded kaolin open-pit extraction site that ceased operation in 2008 (*Figure 3*). The host rocks of the kaolin deposit are Variscan granite intruded into surrounding Carboniferous slates and gritstones. The kaolinite is derived from the alteration of the host rock's feldspar component by multi-stage alteration processes by superheated and meteoric fluids and gasses (Dominy, 1993). The depth of the lake in the open pit does not exceed 25 m. Besides extraction of very soft kaolinite, the ¡VAMOS! machines will also be tested on extracting harder adjacent side walls composed of granitic host rocks.

The second test site is the abandoned open-pit iron mine Smreka in Vareš, Bosnia and Herzegovina (*Figure 4*). The ore minerals are massive and layered siderite and hematite which are locally silicified (Operta and Hyseni, 2016). The iron-rich layers dip steeply towards the north. This deposit formed as a hydrothermal replacement of the host rocks – limestone and dolomite. The hydrothermal fluids entered the area through a strike-slip fault of regional importance. The southern footwall of the ore body is breccia limestones of Jurassic age, while the north wall is composed of siliceous slates, shales, and slates ("Werfen

Figure 3: Site preparation for the first field trials in Lee Moor, Devon, UK (September 2017, photo by James Kinsman).

Figure 4: Smreka open pit iron mine in Vareš, Bosnia and Herzegovina, the second ¡VAMOS! test site (photo by Gorazd Žibret).

formation"). The uniaxial compressive strength of rocks found in Smreka pit varies between 44 and 80 MPa.

Besides testing the equipment in real environments, the purpose of the site trials is also to measure different operating parameters. They will be needed to evaluate this newly developed equipment for its potential usefulness for economical exploitation of mineral resources and to compare it with conventional mining techniques. Since one of the most important factors affecting the production rates in mining or civil engineering projects is the performance of the mechanical excavators

(Tumac et al., 2007), special focus will be put on determining the excavator productivity (m³/h) for different types of rocks. In addition to productivity, several other key parameters will be measured, including the determination of typical:

- working hours needed to assemble, operate, maintain and disassemble the ¡VAMOS! equipment;
- power, fuel and lubricant usage;
- machine productivity and net cutting rate for different ores and rock types;
- equipment wear and overhaul costs;
- ore suspension dewatering costs;

- environmental impacts: impacts on water chemistry, suspended particulate matter levels, sediment dispersion, vibrations and noise emissions, etc.;
- social perception of mining when using ¡VAMOS! equipment;
- other relevant parameters.

From the results of the field trials, it will be possible to estimate the industrial viability of the ¡VAMOS! equipment and market up-take possibilities, with special focus on where exactly (what type of deposits and geo-environments) the ¡VAMOS! technology performs better than conventional mining technologies.

Conclusions

¡VAMOS! provides a new mining technique that is expected to be used for reopening of abandoned and flooded open-pit mines because it will allow ore extraction underwater. The reduced stripping ratio due to expected increased wall stability will decrease the surface footprint of a mining operation and require lower energy use, as less unwanted material needs to be removed. The highly automated system functionality significantly reduces safety risks. As there is no need for haul trucks and blasting and because the machinery largely works underwater, there will be less noise and and almost no dust emissions. Less oil and fuel is needed for the operation, reducing the risk of spillages. Energy consumption is reduced as there is no need for constant dewatering and the local water table around an operation will not be affected. All these factors combined make rehabilitation easier at the end of mining operation. Field trials, expected to take place in October 2017 and spring 2018, will provide information on the exact conditions and type of environments where ¡VAMOS! would be preferred option for mineral extraction and will demonstrate the environmental integrity and economic viability of the system.

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News corner:
Compiled by Isabel Fernández Fuentes and Anita Stein, EFG Office

Horizon 2020 projects

Horizon 2020 is the biggest EU research and Innovation programme ever, with nearly 80 billion euros of funding available to secure Europe's global competitiveness in the period 2014–2020. EFG is currently involved in eight Horizon 2020 projects: INTRAW, KINDRA, MINATURA2020, ¡VAMOS!, UNEXMIN, CHPM2030, MICA and FORAM. Some of these projects have been presented in detail in this issue of European Geologist. Below you will find descriptions of the topics and aims of the other projects.

INTRAW

642130 - INTRAW
International cooperation on Raw materials
START DATE: 1 February 2015
DURATION: 36 MONTHS

INTRAW, which started in February 2015, aims to map best practices and develop new cooperation opportunities related to raw materials between the EU and technologically advanced countries (Australia, Canada, Japan, South Africa and the United States) in response to similar global challenges. The outcome of the mapping and knowledge transfer activities conducted in the first two years of the project are used as a baseline to set up and launch the International Raw Materials Observatory as a permanent raw materials knowledge management body.

EFG's role:

The European Federation of Geologists (EFG) is the coordinator of a consortium of 15 partners from different European countries including also Australia, the United States and South Africa. Most of EFG's members are also part of the consortium as EFG Linked Third Parties.

Current status:

In a truly cooperative approach, the INTRAW project has elaborated, in a series of workshops run in 2016, three scenarios that describe the world of raw materials in 2050. Given the current uncertainties that global politics have to deal with, scenarios are indeed an excellent means to prepare for the future and to safeguard against developments that are not desirable, but yet still plausible. The final scenarios, named "Unlimited Trade", "Sustainability Alliance" and "National Walls", are now available on the INTRAW website at http://intraw.eu/the-world-of-raw-materials-2050/ and are presented in more detail in a new brochure that you may download at *http://intraw.eu/media-corner/.*

The next step ahead for the project consortium is the launch of the International Raw Materials Observatory during the European Commission's Raw Materials Week (6–10 November 2017). The Observatory is a new independent, apolitical, international not-for-profit organisation, set up to support international cooperation on mineral raw materials. The launch of the Observatory provides a glimpse of the services the Observatory will be offering to its members, namely foresight dialogues with key influencers and match-making services for organisations active along the minerals materials value chain. Two major events are scheduled during the Raw Materials Week: the official launch of the Observatory during the EU-Advanced Mining Countries conference on 7 November 2017 and an open roundtable on the challenges of international cooperation on 8 November 2017.

For more information: *www.intraw.eu*

CHPM2030

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

The CHPM2030 project aims to develop a novel, pilot-level technology that 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 for manipulating metal-bearing geological formations with high geothermal potential at a depth of 3–4 km in order to make the co-production of energy and metals possible; potentially this could be optimised according to market demands in the future. Led by the University of Miskolc (Hungary), the project will be implemented through the cooperation of 12 partners from 10 European countries.

EFG's role:

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) have 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 have also collected data on the national geothermal potential. Guidelines and templates for data collection were provided by EFG.

During the second year, EFG is supporting the road mapping and preparation for Pilots (WP6). EFG's Linked Third Parties will assess 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 will combine these data with the outcomes of the most recent predictive metallogenic models. Only exist-

ing datasets will be utilised; no new surveys will be carried out.

EFG also leads the Work Package on dissemination.

Current status:

Recently laboratory investigations have been carried out on metal content mobilisation using mild leaching techniques. Functionalised carbon nanoparticles are used for target-specific mobilisation,. The particles are characterised before and after metal

adsorption or complexation. Laboratory experiments are also made on the recovery of the metal content by high-temperature, high-pressure geothermal fluid electrolysis and by gas-diffusion electro-precipitation and electro-crystallization. Investigations on salinity gradient power from pre-treated geothermal fluids started in June 2017.

A workshop on "Geochemistry of geothermal fluids" was held in Miskolc, Hungary, on 26 and 27 October 2017. It brought together all running geothermal projects

funded by the Horizon 2020 program. The aim of this workshop was to provide a glimpse into the geochemical aspects of geothermal fluids, promoting cross-fertilization between different projects, providing a forum for the exchange of scientific knowledge and facilitating synergies between the projects.

More information: *http://chpm2030.eu*

FORAM

730127 – FORAM
Towards a World Forum on Raw Materials
START DATE: 1 November 2016
DURATION: 24 MONTHS

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 and enhance the international cooperation on raw material policies and investments. This platform will work 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. Synergies with relevant EU Member State initiatives will be explored and fostered. Particularly, the project will seek to engage the participation of G20 member countries and other countries

active in the mining and other raw materials sectors, so that experiences will be shared and understanding of all aspects of trade in raw materials will be increased.

The FORAM project is coordinated by the World Resources Forum Association (WRFA) and supported by eleven additional leading organisations (EuroGeoSurveys, European Federation of Geologists, United Nations University, Leiden University, University of Kassel, Clausthal University of Technology, ESM/Matsearch, Gondwana Empreendimentos e Consultorias, Servicio Geológico Colombiano, MinPol GmbH and La Palma Research Centre for Future Studies SL), which compose the FORAM consortium.

EFG's role:

EFG leads 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 will define and present a long-term vision and its strategic positioning, as well as an

appropriate framework to measure performance and to respond to geopolitical, technological and economic changes.

The report on "Strategic Planning" was presented on 30 September 2017, as deliverable D3.3 of FORAM. It defines the strategic position that should be considered in the design and launch of a World Forum on Raw Materials, i.e. how the Forum should face competition and serve its stakeholders. The definition of stakeholders encompasses the various communities related to the non-energy abiotic raw materials value chain, from mining/extraction, processing, product development, design and substitution up to re-use/recycling and substitution.

More information: *http://foramproject.net/*

EFG's upgraded Code of Ethics: constant work towards an ethical European family of geologists

Excelling in a profession involves the demonstration of many professional and personal qualities. And if there is one that the EFG holds to a particular high standard when it comes to supporting the professional development of its members, it is their contribution to the ethical exemplarity of the European family of geologists.

The promotion of best practices is therefore a central part of the EFG's missions and it is notably achieved through the promo-

tion of the "Code of Ethics", a guide that prescribes acceptable behaviour for each individual member and for European Geologists and establishes a common ground of principles that apply to all. By doing so, the code therefore provides a means of professional self-regulation, a necessary condition to guarantee the quality and the legitimacy of the work of geologists.

Conscious that a set of principles only grows stronger the more it reflects the profession's as well as society's realities and changes, EFG made a point of constantly upgrading its "Code of Ethics" and published in spring 2017 its newest version, which includes an amendment relating to

the working environment. This updated version was unanimously approved by the EFG Council, whose members all agreed on the necessity to align with recent initiatives taken by several scientific societies, including the American Geophysical Union (AGU), who published last year the "Draft Organizational Principles for Addressing Harassment", following several recent cases of harassment in the field of sciences.

With this updated "Code of Ethics", EFG therefore joins other scientific societies in taking a strong stand in favour of a respectful and safe working environment.

New EFG member: EurAsian Union of Experts in Subsoil in Subsurface Management (EUES)

EFG is glad to welcome a new member, the EurAsian Union of Experts in Subsoil in Subsurface Management (EUES). EUES is a non-profit organisation operating in accordance with Russian legislation and was established in February 2016. It is a voluntary association of experts aiming to present and protect the professional interests.

EUES was unanimously elected as a new EFG member during the association's summer Council meeting held in Santorini, Greece, on 20 and 21 May 2017.

EFG now has two Russian members, with the National Association for Subsoil Auditing (NAEN) continuing to be a member.

EFG Medal of Merit: Iain Stewart, a multi-faceted career, a unique personality

A passionate geologist, an inspiring professor, a charismatic science broadcaster. Iain Stewart is one of those rare people whose personality, and resume, stands out with its richness and uniqueness. It then comes as no surprise that this Scottish geologist, currently Professor of Geoscience Communication at the University of Plymouth (UK), was appointed Member of the Order of the British Empire in 2013 for popularising geography and earth sciences.

And it then comes as no surprise, but with much honour and excitement, that the EFG has decided to award Iain Stewart with the Medal of Merit for his outstanding contribution in elevating the profile of geology around the world. The official ceremony will take place in Brussels during EFG's Council Meeting on 11 November 2017. A special day to celebrate the work of a very special Geologist.

EAGE/EFG Photo Contest 2017

The theme of the Photo Contest 2017 was again 'Geoscientists at work'. All EAGE members and members of EFG's national associations were invited to submit their photos relating to the following five subcategories:

- Education & training
- Landscapes & environment
- Fieldwork
- Energy
- Women Geoscientists

EAGE and EFG members then voted online for their favourite photograph among nearly one hundred entries. The 12 most stunning photographs have been printed and exhibited during the 79th EAGE's Annual Conference & Exhibition 2017 (12–15 June, Paris, France). They will also be included in a desktop calendar for 2018 that will be available in the EAGE Bookshop. Pre-order now by sending an e-mail to *photocontest@houseofgeoscience.org.*

More information: *http://www.houseofgeoscience.org/entries*

Top 3 winners, from left to right: First place - "Reservoir modeling is fun" by Sofiana Sulaiman, Second place - "How to confuse a geoscientist" by Daniel Bücken, Third place - "Hills! Sorry, ripples" by Lukas Becker.

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:
EFG Office
Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: *info.efg@eurogeologists.eu*

Note

All information published in the journal remains the responsibility of individual contributors. The Editorial Board is not liable for any views or opinions expressed by these authors.

Subscription

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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.

EFG is the Voice of European Geologists

The European Federation of Geologists (EFG) is a not-for-profit professional organisation focused on the promotion of excellence in the application of geology and in raising public awareness on the importance of geosciences for the society. EFG is based in Brussels, was established in 1980 and includes today 26 national association members.

EFG adheres to the principles of professional responsibility and public service and certifies the competence, integrity and ethical conduct of professional geologists. Professional geologists, from the EFG national association members, contribute with their expertise in education, research and applied practice in industry and for governments in a wide range of activities that are vital to society and to protection of the public.

The EFG delivers its objectives through activities relating to:
• EU policies & environmental protection;
• Education & outreach;
• Free movement & professional titles;
• Professionalism & ethics;
• Supporting EFG Members.

EFG Members

UBLG - Belgium-Luxembourg	IGI - Ireland	CHGEOL – Switzerland
BGS - Bulgaria	ANGI/CNG - Italy	TAEG - Turkey
CGS - Croatia	KNGMG – Netherlands	UAG - Ukraine
CAGME - Cyprus	Polish Association of Mineral	GSL - United Kingdom
CAEG - Czech Republic	Asset Valuators - Poland	
GSD - Denmark	APG - Portugal	Associated members: AIG –
YKL - Finland	NAEN - Russia	Australia, CCPG – Canada, GSSA
SGF - France	SGS - Serbia	- South Africa and AIPG – USA
BDG - Germany	SGD - Slovenia	
AGG - Greece	ICOG - Spain	
MFT - Hungary	SN - Sweden	