Adv. Geosci., 54, 1–5, 2020
https://doi.org/10.5194/adgeo-54-1-2020

Advances in Geosciences
Open Access
EGU

Preface: Special issue from the Division on Energy, Resources and the Environment at EGU2020: Sharing geoscience online

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Received: 3 August 2020 – Published: 3 September 2020

Abstract. Since 2004, the European Geosciences Union (EGU) brings together experts from all over the world into one annual event covering all disciplines of the Earth, planetary and space sciences. This special issue in Advances in Geosciences comprises a collection of contributions from the Division on Energy, Resources and the Environment (ERE) which were presented at EGU2020: Sharing Geoscience Online.

1 Introduction

The EGU General Assembly 2020 was held from 4 to 8 May 2020. Due to the COVID-19 pandemic, the conference was run as EGU2020: Sharing Geoscience Online, a week-long series of online activities. Participation was open to anyone interested in geosciences and free of charge.

The online format was an exciting experiment and a great success. In total, 18 036 abstracts formed the programme with 701 scientific sessions. During the conference week, each session hosted a live, text-based chat for community exchange and discussion on their presentations. A total of 26 219 individual users joined 721 live text chats and posted 200 400 messages. Furthermore, Union Symposia, Great Debates, Townhall Meetings, and Short Courses were successfully organised, and several networking events offered the geosciences community the chance to meet online and share their research and ideas.

The ERE Division is one of 22 divisions that helps organising the EGU scientific activities. In 2020, the ERE division led 21 sessions with 545 presentations and co-organised another 15 sessions with 395 presentations (EGU, 2020). Based on that, this volume of Advances in Geosciences spans a wide range of topics in the fields of energy, resources and the environment which were presented in May 2020 and hereby continues a series of seven ERE special issues over the course of the last years (Kühn et al., 2013, 2015, 2016; Juhlin et al., 2014; Martens et al., 2017, 2018, 2019).

2 ERE program at EGU2020: Sharing Geoscience Online

The scientific program of the ERE division included the following subprograms:

- Integrated studies,
- Renewable energy,
- Fossil energy,
- Geo-storage,
- Raw materials,

- Process coupling and monitoring related to geoenergy applications,
- Nexus approaches and applications.

2.1 Integrated studies

With the subprogram "Integrated studies", the ERE division hosted the session "Energy, Resources and the Environment" which gave an overview on interdisciplinary studies that are needed to tackle the challenges of the future in line with several United Nations' Sustainable Development Goals (UN, 2015).

In total, 45 national and regional Geological Survey Organisations from 32 European countries have joined forces to develop "Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe (GeoERA)". The session "GeoERA: Towards integrated European geoscience services for today's and future generations" addressed integrated European geoscience services that will provide advice and data to Europe towards a sustainable subsurface management, integrating geo-resources (energy, water, raw materials) and environmental conditions, supported by a cross-thematic online information platform.

The session "The Environment and Smart Circular Economy and Cities: A New Geo management Approach" addressed studies on new economic models and business concepts. Green-economy, bio-economy, and smart and circular economy, are the most recent models that have proven to lead to a more sustainable development. Among others, it was discussed, whether the models are competing or supplementing each other and what opportunities the most recent models of the smart circular economy bring to environmental protection.

2.2 Renewable energy

By their very nature, wind and solar power, as well as hydro, tidal, wave and most other renewable forms of energy generation are dependent on weather and climate. Modelling and measurement for resource assessment, site selection, variability analysis and operational forecasting for horizons ranging from minutes to decades are of paramount importance. Hence, the session "Energy Meteorology" focused on various aspects of weather dependent renewable power generation, e.g. wind conditions on short and long-time scales for wind power development, long-term analysis of interannual variability of solar and wind resource as well as tools for urban area renewable energy strategic planning and control.

The session "Spatial and temporal modelling of renewable energy systems" provided an insight into recent advances in the field of renewable energy system models. Contributions included studies which model the characteristics of future renewable energy systems and assess the characteristics of the past performance and characteristics of renewable energies.

Marine renewable energy includes offshore wind, wave, tidal range, tidal-stream energy, as well as technologies such as ocean thermal energy conversion, salinity gradients and desalination. Understanding the environment these marine renewable energy devices are likely to operate in is vital when designing efficient and resilient devices. Accurate characterisation of the resource is of clear importance, whilst interactions with the environment, and between other "blue economy" developments, is essential for the development of the industry and marine spatial plans. The session "Marine renewable energy; resource characterisation, interactions and impacts" shared information on new research techniques and methods to better understand the resource and the environment, including mapping tools, numerical modelling approaches and observations.

With an increasing demand for low-carbon energy solutions, the need of geothermal resources utilisation is accelerating. Geothermal energy can be extracted from various, often complex geological settings, e.g. fractured crystalline rock, magmatic systems or sedimentary basins. A sustainable use of geothermal resources requires advanced understanding of the properties of the entire system during exploration and monitoring. Challenges are, among others, exploration of blind systems, reservoir stimulation, induced seismicity and problems related to scaling processes. The integration of analogue field studies with real-life production data, from industrial as well as research sites, and their organisation and the combination with numerical models, are a hot topic worldwide. The session "Exploration, utilisation and monitoring of conventional and unconventional geothermal resources" gathered experts to stimulate discussion in this multi-disciplinary applied research field.

Characterisation of geothermal energy systems requires advanced understanding of the dominant thermal, hydraulic, mechanical and chemical (THMC) processes and properties of the geothermal systems. Thus, the session "Characterization and modelling of (coupled) THMC processes for geothermal energy" offered a platform to present and discuss the use of modelling, analogue and numerical, for the development of geothermal energy.

The session "Shallow geothermal systems for building heating and cooling: geoscience and engineering approaches" included contributions about shallow geothermal energy applications, e.g. traditional closed- and open-loop borehole heat exchangers as well as so-called energy geostructures (e.g. thermo-active foundations, walls, tunnels). Different types of analysis and approaches were relevant to this session, spanning from the evaluation of ground thermal properties to mapping of shallow geothermal potential, from energy storage and district heating to sustainability issues and consequences of geothermal energy use, from the design of new heat exchangers and installation techniques to the energy and thermo-(hydro-)mechanical performance of energy geostructures.

A large-scale introduction of renewable energy systems is vital for climate change mitigation. At the same time, the 17 Sustainable Development Goals (SDGs) proposed by the United Nations address society's common global challenges. Among these, increasing human well-being by ending poverty and hunger (SDG 1 and 2) while at the same time delivering affordable and clean energy (SDG 7), protecting biodiversity (SDG 14 and 15) and mitigating climate change (SDG 13) are key goals. Land use management is a core theme, as the effects of introducing different renewable energy systems on SDGs may vary dependent on spatial location and scale of implementation. The session "Rethinking the energy transition in light of the Sustainable Development Goals: Maximizing synergies and minimizing trade-offs" linked renewable energy systems deployment to one or more SDGs. A variety of methods, models and tools were of interest, among others, environmental analyses, life cycle analyses, regional climate and earth system modelling, energy system models, policy relevant analyses, and integrated assessment.

2.3 Fossil energy

A cleaner and more efficient use of carbon resources will be necessary during the energy transition from nuclear power and coal to renewable energies. To do that, a focus needs to be on improving the production efficiency from conventional and unconventional system. The session "Petroleum exploration and production and their impact on the environment" presented and discussed the latest advances in oil and gas exploration and production technologies, e.g. new geophysical monitoring methods and modelling approaches as well as well as their associated environmental risks and economic benefits.

2.4 Geo-storage

Storage of energy and carbon dioxide in subsurface geological formations has been identified as key for future systems relying on renewable energy systems and heat generation. All subsurface storage systems rely on the properties and integrity of the reservoir and its confining units under thermal, mechanical, hydraulic and chemical stress. Natural analogues have provided evidence for the feasibility of long-term containment of methane and carbon dioxide in geological formations and may offer similar insights for energy and heat storage. The session "Versatile subsurface storage for future energy systems" addressed storage of fluids in geological systems at all scales, from laboratory experiments to full-scale storage projects.

The successful implementation of safe deep geological disposal of spent fuel, high-level waste and other long-lived radioactive waste is one of the currently most pressing environmental challenges in several countries worldwide. Site exploration and assessment are primarily geoscientific tasks that require interdisciplinary collaboration of different geoscientific fields, such as geophysics, hydrogeology, (hydro-)geochemistry, mineralogy, geomechanics, and geological as well as coupled thermal, hydraulic, mechanical and chemical modelling. As for other subsurface technologies, barrier integrity is a crucial aspect for the assessment of nuclear waste disposal. Different technical concepts in diverse geological candidate formations are being discussed. Numerical simulations, in conjunction with experimental studies are an integral part of safety and environmental-impact assessment concepts involving barrier integrity as a key component. Aside from these geoscientific and technological aspects, the session "Towards a safe nuclear waste repository – assessment of barrier integrity, geoscientific, technological, societal and regulatory challenges and approaches" also addressed social and regulatory challenges.

2.5 Raw materials

At present, constructional geomaterials make the largest (by volume) group of extracted mineral raw materials. Despite their low unit price, they significantly contribute to the economy in many ways. Ongoing worldwide development of infrastructure, rapid urbanisation and the need for maintenance of the existing structures exert enormous pressure on the environment due to the extraction of new materials from natural resources, along with their processing and transportation. As the knowledge of many aspects of these materials is still rather limited, the session "Constructional GeoMaterials: Resources, Properties, Uses, and Environmental Interactions" addressed, e.g. a comparison of natural and anthropogenic decay of constructional geomaterials as well as interactions and material compatibility between traditional construction materials and modern restoration products.

Natural stones are an integral part of the architectonic heritage built over the centuries and, thus, reflect close cultural affiliation with society. The session "Heritage Stones: Global relevance vis-à-vis architectonic heritage" discussed the use of heritage stones in different civilizations over the period of time, their impact on human culture, geoheritage, geoarchaeology and architectonic relevance.

Mineral resources are used in larger quantities than ever before in history and are the basis of our modern society. The safe and sustainable supply of mineral resources is fostering a demand for innovative actions to cover the foreseeable future industry and human demands. The session "State-of-the-art in mineral exploration" brought together scientists from various disciplines, in order to discuss, among others, new methods of exploration, imaging, conceptual modelling and quantification of deposits and mineral systems, scale-up and replicability as well as industry-academia synergies.

Solid waste deposits from the extractive industry, i.e. extractive waste and municipal solid waste landfills can be an environmental threat through groundwater or surface water contamination in addition to the human health risks they

might pose. In line with Europe's Circular Economy Action Plan, several strategies emerged aiming for sustainability regarding the use of natural resources, a responsible consumption/production, dynamic landfill management and the recovery/reuse of waste produced during exploitation and processing activities. Hence, there is a large demand of innovative techniques for the characterization and monitoring of disposal sites. In particular, reliable information about the composition and geometry of waste depositions, as well as their biogeochemical status is needed. The session "Sustainable mining and circular economy: waste characterization and exploitation supported by geophysical methods" discussed, among others, waste characterization and monitoring approaches as well as case studies for the detection and assessment of environmental pollution associated to the disposal of solid waste.

2.6 Process coupling and monitoring related to geoenergy applications

Modelling of geological subsurface utilisation in terms of chemical or thermal energy storage as well as hydrocarbon production and storage are required to ensure a safe and sustainable energy supply. However, utilisation of the geological subsurface may induce changes in the recent hydraulic, thermal, mechanical and chemical regimes. The session "Process quantification and modelling in subsurface utilisation" aimed at the integration of experimental and numerical modelling methods for quantification and prediction of the potential impacts resulting from geological subsurface utilisation. Topics included acquisition and interpretation of site-specific geological and process data, integration of experimental data into static and dynamic models, model coupling as well as methods for risk assessment, among others.

Numerous cases of induced/triggered seismicity have been reported in the last decades, directly or indirectly related to anthropogenic activity for geo-resources exploration. Induced earthquakes felt by the local population can often negatively affect public perception of exploration and may lead to the cancellation of promising projects. Furthermore, large earthquakes may jeopardize wellbore stability and damage surface infrastructure. Thus, understanding the processes which are leading to fault reactivation is critical to developing effective and reliable forecasting methodologies during deep underground exploitation. The session "Induced/triggered seismicity in geo-energy applications: monitoring, modelling, mitigation, and forecasting" addressed the complex interaction between injected fluids, subsurface geology, stress interactions and covered both theoretical and experimental aspects of induced and triggered seismicity at multiple spatial and temporal scales.

Fractures are discontinuities in rocks that are present in almost all geological settings and at any scale. They may represent small-scale fissures or comprise large scale faults. The presence of fractures modifies the bulk physical properties of the original media by many orders of magnitude. Fractures also provide the main flow and transport pathways in hard rock aquifers, dominating over the permeability of the rock matrix, as well as creating anisotropic flow fields and transport. Hence, understanding the hydraulic and mechanical properties of fractures and fracture networks is crucial for predicting the movement of any fluid such as water, air, hydrocarbons, or CO_2. Consequently, fractures are of great importance in various disciplines such as hydrogeology, hydrocarbon reservoir management, and geothermal reservoir engineering. The session "Fractures: Breaking the Laws" discussed novel ideas and concepts on treating the challenges related to the generic understanding, the characterization and the modelling of fractured geological media.

2.7 Nexus approaches and applications

The session "Multi-scale water-energy-land nexus planning to manage socio-economic, climatic, and technological change" was organised as an inter- and transdisciplinary session (ITS). The aim of an ITS is to either link disciplines within the geosciences in a novel way to address specific and often new problems (interdisciplinary session) or to link the geosciences to other disciplines (transdisciplinary session).

The world's energy, water, and land systems are in transition and rapidly integrating, driven by forces such as socioeconomic, demographic, climatic, and technological changes as well as policies intended to meet SDGs and other societal priorities. These dynamics weave across spatial scales, connecting global markets and trends to regional and subregional economies. At the same time, resources are often locally managed under varying administrative jurisdictions closely tied to the inherent characteristics of each component, such as river basins for water, grid regions for electricity and land-use boundaries for agriculture. Local decisions in turn are critical in deciding the aggregate success and consequences of national and global policies. Thus, there is a growing need to better characterize the energy-water-land nexus to guide robust and consistent decision making across these scales. This session focused on exploring energy-water-land dynamics, trade patterns, policy interventions as well as infrastructure planning and uncertainty characterization across variable spatial boundaries.

3 Conclusion

The EGU General Assembly 2020 was held as EGU2020: Sharing Geoscience Online, a week-long series of online activities, in May 2020. The Division on Energy, Resources and the Environment hosted 21 sessions with 545 presentations and co-organised another 15 sessions with 395 presentations. With this special issue in Advances in Geosciences, we are pleased to present a collection of contributions from the ERE division.

Special issue statement. This article is part of the special issue "European Geosciences Union General Assembly 2020, EGU Division Energy, Resources & Environment (ERE)". It is a result of the EGU General Assembly 2020, 4–8 May 2020.

Acknowledgements. We would like to thank all participants for their contributions to EGU2020: Sharing Geoscience Online. Our special thanks go to the conveners – without their support, EGU2020 would not have been the success that it was. We would also like to thank all reviewers for their effort and time put into the reviews of the papers.

Financial support. The article processing charges for this open-access publication were covered by a Research Centre of the Helmholtz Association.

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