



Preface to the special issue of the Division Energy, Resources and the Environment at vEGU2021: Gather online

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Abstract. The European Geosciences Union (EGU) is one of the leading global bottom-up societies that promotes earth, planetary and space sciences. In its annual general assemblies, EGU brings together experts from all over the world to discuss cutting-edge research and implementation of findings in its respective disciplines and thus offers a unique forum for scientific exchange, science-policy interaction, and joint development of strategies for future research endeavours.

This special issue in *Advances in Geosciences* comprises a collection of contributions from the Division Energy, Resources and the Environment (ERE) of the EGU, which were presented at the General Assembly 2021, vEGU2021: Gather online. It was held entirely online for the second time after EGU2020 from 19 to 30 April 2021.

1 Introduction

The EGU General Assembly 2021 was held from 19 to 30 April 2021. Due to various restrictions caused by the COVID-19 pandemic, the conference was run as vEGU2021: Gather online. In contrast to the General Assembly 2020, vEGU2021 was scheduled as a two week-long series of online activities with Union-wide lectures in week one and division-specific sessions in the subsequent week. Participation was open to anyone and moderate fees were charged to allow for a considerably large share of conference fee

waivers (approximately one third of all participants) for low-income regions and early career researchers.

The online format was innovative and successful, despite some minor technical glitches on the first day of the second week. In total, 18 172 registered participants formed the programme in 642 scientific sessions, five Union symposia, and 32 Medal and Award Lecture sessions. During the second conference week, each session was organized as a Zoom meeting with live or pre-recorded contributions followed by a live discussion with presenters and a subsequent text-based chat. Several networking events offered the geosciences community the chance to meet online, share their research, build or strengthen relationships within or beyond their own expertise or just taking the opportunity to get-together with colleagues and friends.

The division “Energy, Resources and the Environment” (ERE) is one of 22 divisions that helps organise the EGU scientific activities. In 2021, it led 22 sessions (including two inter-and transdisciplinary sessions) with 466 presentations and co-organised another five sessions (other divisions with leading role) with 84 presentations (EGU, 2021). Consequently, 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 April 2021 and hereby continues a series of eight 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, 2020).

2 ERE program at vEGU2021: Gather online

The ERE division program for vEGU2021 consisted of six sub-program groups, namely:

- Integrated studies
- Renewable energy
- Fossil energy
- Geo-storage
- Raw materials, and
- Process coupling and monitoring related to geoenery applications.

In addition, ERE organized a session dedicated to two division outstanding early career scientists (ECS) award lectures, one delivered by Estanislao Pujades on “Underground pumped storage hydropower (UPSH) and its interaction with the saturated subsurface medium: effects of the water exchanges on the environment and the plant efficiency” (Pujades, 2021) and the other by Giorgia Dalla Santa on “Deformations and permeability variations in fine sediments induced by freezing-thawing cycles caused by borehole heat exchangers” (Dalla Santa et al., 2021). The division meeting is reserved for reporting to and receiving feedback from the community, as well as approving official functions of division officers and for discussion of general matter. It took place on Thursday, 29 April 2021. Two further ERE networking events were organized, one specifically for early career scientists using GatherTown as a platform and an additional, general networking event back-to-back with the division meeting.

2.1 Integrated studies

The traditional introductory session “Energy, Resources and the Environment” aims at providing an overview on interdisciplinary studies that are needed to tackle the challenges of energy generation, resources management and its implications on the environment, and hence addressing several of the United Nations’ Sustainable Development Goals (UN, 2015). The broad scope of the session clearly demonstrated the interdisciplinary nature of the ERE division.

As a consequence of the requirement to adopt national energy and climate plans in the period 2021–2030 within the European Union, 45 national and regional Geological Survey Organisations from 32 European countries have joined forces to develop 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” discussed key results from the European geoscience services and illustrated how these outcomes provide advice and data in response to a more sustainable and efficient management of resources with

a focus on geo-energy, groundwater and raw materials, and the cross-thematic online information platform required to provide open access. It also presented current activities of continuously improving a Geological Service for Europe related to issues within the five mission areas of Horizon Europe and the four main themes for a Geological Service for Europe: Resourcing Europe, Climate Change and Decarbonisation, Europe’s Digital Twin and Safety, Security and Well-being.

The session “Carbon emissions/removals estimates under Land use, Land-use change and Forestry (LULUCF) sector: field measurements, remote sensing and modelling” discussed contributions on national and subnational carbon budget estimates (past, present, and future) under different land-use scenarios (forests, crops, grasslands, urban areas) using multiple data sources and different calculation methods. National forest inventory (NFI)-based, remote sensing and modelling studies on carbon stocks and/or fluxes in different ecosystem pools (live biomass, dead wood, litter, or soil) were among the key topics. The aim was to provide an extensive overview of different methodological approaches that can be used for national scale estimates and to highlight main issues regarding data integration and model calibration, as well as the validation process of such models.

The transition towards low-carbon and renewable energy systems has significantly accelerated within the last decade. The session “Impacts and co-benefits of the energy transition on terrestrial ecosystems – implications and prospects for Natural Capital and Ecosystem Services” brought together expertise on ecological, technological, and societal research and thus gathered new evidence and insights from around the world on the effects of the low-carbon energy transition on terrestrial ecosystems relating to natural capital (NC) and ecosystem services (ES). This session also addressed innovative methods to enhance the ecosystem sustainability of the low-carbon energy transition.

Land is a finite resource that is under competing uses and claims. The organizers of the session “Land use dynamics, land degradation and insights for land sustainability in agriculture and forest landscapes” invited authors to discuss the spectrum of land use dynamics and insights to be gained for theory and for promoting resilient landscapes that ensure ecosystem integrity, stop, or reverse the degradation of ecosystems, and support human wellbeing in the light of achieving various Sustainable Development Goals (SDGs).

A slightly broader approach was chosen in session “Navigating the Anthropocene: Human agency in global society-environment interaction assessments and modelling approaches”, as it addressed not less than the general interaction between humanity and the environment, which has to be seen as an integrated system when dealing with current challenges. Main topics addressed were:

- i. How to navigate the humanity in the Anthropocene?
- ii. What are the relevant dimensions of human agency to study human-environment system interactions?
- iii. Which concepts and research methods are relevant for the research on human agency?
- iv. How to operationalize human agency in global human-environmental system modelling efforts?

The session “Towards a net-zero world: remaining carbon budgets, climate response to different emission pathways, and implications for policy” contributed to our understanding of the climate response under different emission scenarios, with particular focus on emission pathways towards net-zero targets, and the advancement of knowledge on associated carbon budgets consistent with various levels of warming. A variety of tools was discussed, including fully coupled Earth System Models, Integrated Assessment Models, and simple climate model emulators.

Food traceability is an important issue in food security and quality control. The session “Geochemical and isotopic methodologies for traceability and food security” focused on methods of tracing the origin of food stuff, as it is playing an increasingly important role at the legislative level worldwide, as a tool that allows judgement on product authenticity.

2.2 Renewable Energy

Most renewable sources of energy, such as wind and solar power, hydro, tidal, and wave are intermittent, because they directly depend on weather and/or climate. Modelling and measurement for resource assessment, site selection, variability analysis and operational forecasting for horizons ranging from minutes to decades are therefore an important foundation for strategic decisions in renewable energy systems planning and implementation. 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 inter-annual variability of solar and wind resources as well as tools for urban area renewable energy strategic planning and control. A further important aspect was the challenge of matching current infrastructure (electrical grids) with rising shares of intermittent energy generation.

Parts of the issues discussed in the above-mentioned session were further elaborated in the session “Spatial and temporal modelling of renewable energy systems”. Topics ranged from the improvement of our understanding how climate data can be used to model renewables to implementation issues, such as the development of integrated scenarios of energy systems with high shares of renewable energy. The session provided a comprehensive insight into recent advances in renewable energy systems modelling.

Geothermal energy is considered a low-carbon energy solution that is not directly affected by weather and climate, but the availability is restricted to certain areas. It 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 and applied research topic.

The session “Shallow geothermal systems for building heating and cooling: geoscience and engineering approaches” included contributions about shallow geothermal energy applications, such as 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 energy and thermo-(hydro)-mechanical performance of energy geostructures.

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 achieve this and to comply with national and international regulations, the production efficiency from conventional and unconventional systems needs to be improved to sustain the global energy production demand, and to ensure resilience. 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 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 a key mechanism in the green shift, in particular for dealing with intermittent energy sources and to achieve decarbonisation in energy and heat generation. Secure subsurface storage requires geologi-

cal knowledge and sound risk evaluations, which in turn are essential for obtaining public acceptance of these technologies. The session “Secure subsurface storage for future energy systems” covered a wide field of topics, from characterization of storage formations, to monitoring and modelling approaches, systems integration (coupling of different energy storage types) to questions of public perception and acceptance.

The scientific research on geo-storage did not originate from recent pressure towards decarbonisation and increasing the share of renewable energy systems. The most pressing environmental challenges in several countries worldwide is currently the successful implementation of safe deep geological disposal of spent fuel, high-level waste and other long-lived radioactive waste. Site exploration and assessment are primarily geoscientific tasks that require interdisciplinary collaboration of different geoscientific fields. 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

The rise and fall of civilizations, cultural heritage and societal development are inherently linked with ornamental stones and the construction of historical monuments. The session “Global Heritage Stone Resource: The sustainable way forward” dealt with the interesting interface between cultural heritage, historical research, conservation and increasing public awareness. It demonstrates another highly interdisciplinary domain of the ERE division.

The Sustainable Development goals (UN, 2015) emphasise on the importance of equally balancing economic prosperity, environmental protection, and social equity. The session “Sustainability as a challenge to face and a goal to reach: interdisciplinary approach to support raw materials and energy supply” thus focused on the interdisciplinary approaches to guarantee a sustainable supply of raw materials and energy. Among the thematic areas sustainable mining, energy supply and circular economy, topics such as “resource efficiency”, “environmental and human health risk”, “climate change adaptation”, “market challenges and social acceptance” and “legislation and political issues” were discussed.

Mineral resources are the basis of our modern society, and the backbone for the ongoing energy transition. Innovative technologies are sought to assure a safe and sustainable supply of an increasing demand of mineral resources and par-

ticularly rare earth elements. The session “Mineral exploration for the XXI Century” therefore brought together geoscientists from all sectors of mineral exploration to discuss cutting-edge science, including new methods of exploration, use of artificial intelligence and machine learning and potential synergies between academia and industry, among others.

A systems approach towards mineral deposits was presented in session “Mineral deposits: systems, settings and processes”. As mentioned above, climate policies and the consequent rise of modern and green technologies lead to an increasing demand of scarce mineral resources. Topics along the entire supply chain were discussed, from processes of component sequestration at the source region, to mining, formation of economic commodity to transport and chemical barriers for further industrial use.

Antimony is a critical element for the European Union, due to its high demand and low availability in Europe. The session “Antimony and associated elements: from mineralisation to the environment” focused on environmental legacies from mining operations in the 19th and 20th centuries on one hand and potential strategies for sustainable future mining strategies on the other hand.

Legacies of mining operations are likely to increase due to a growing global demand of mineral resources. Environmental, societal, and technological challenges on the mining value chain are therefore imposed. Exploitation and processing lead to large volumes of residues. Although these residues, such as waste rock, tailings, slags and fly ashes often hold impressive residual mineral values that have the potential to be converted to secondary raw materials and mineral resources, we face further challenges to characterize and model waste deposits to realistically assess the prospects for sustainable exploitation. The session “Towards an environmentally sustainable transformation of tailings and mine waste: circular economy and future vision” therefore assessed the potentials of residues characterization and use, including the development of respective policies, modelling and life cycle assessment.

2.6 Process coupling and monitoring related to geoenergy applications

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.

Faults and fracture zones are fundamental features of geological reservoirs that control the physical properties of the rock. The presence of fractures modifies the bulk physical properties of the original media by many orders of magnitudes, and they often introduce a strongly nonlinear behaviour. Numerical modelling of such systems is especially challenging and often requires creative new ideas to solve, for example the use of stochastic models. Understanding the hydraulic and mechanical properties of fractures and fracture networks thus is crucial for predicting the movement of any fluid such as water, air, hydrocarbons, or carbon dioxide. The session “Faults and fractures in geoenery applications 1: Numerical modelling and simulation” focussed on modelling, simulation and deterministic or stochastic approaches for structural construction of fractured media. Important inputs and validation of such models requires experiments and monitoring. The sister-session “Faults and fractures in geoenery applications 2: Monitoring, laboratory and field work results” therefore discussed fieldwork approaches, monitoring, and laboratory experiments.

Most of all telecommunication data (99 %) transit through submarine and land-based fibre-optic cables. Global networks of cables encircle the Earth and cover the most remote regions of the continents and oceans. At the same time fibre-optic cables are being used as distributed sensors to measure temperature or strain for a variety of objectives (e.g. fault detect) and environments (e.g. land, marine). The session “Advances in fibre-optic technologies for geophysical applications” discussed novel approaches to utilize experimental and commercial fibre optic cables as sensors for microseismic, local and teleseismic earthquakes, volcanic events, and ocean dynamics.

Thermal, hydraulic and mechanical processes in aquifers are of increasing interest for hydrogeological analysis for development of innovative field and laboratory experiments. Both in research and in practice, accurate characterization of subsurface flow and heat transport, observations of induced or natural variations of the thermal regime. Understanding the interaction of hydraulic, thermal and mechanical processes is a major challenge in modern hydrogeology. Deep underground constructions, tunnels, carbon dioxide storage, hydro- and enhanced geothermal applications are prominent subjects. The session “Thermal energy applications and associated processes in porous and fractured aquifers” provided an overview of the current and future research in the field, covering any temporal or spatial scale, and addressed both separate and coupled processes.

Dissolution, precipitation and chemical reactions between infiltrating fluid and rock matrix alter the composition and structure of the rock, either creating or destroying flow paths. Dissolution and precipitation processes are relevant

in many industrial processes, such as dissolution of carbonate rocks by carbon dioxide-saturated water can reduce the efficiency of carbon dioxide sequestration, mineral scaling reduces the effectiveness of heat extraction from thermal reservoirs, and acid rain that degrades carbonate-stone monuments and building materials. However, natural processes are also strongly affected by chemical reactions at mineral surfaces, e.g. networks of caves and sinkholes in karst area, wormholes induced by the acidization of petroleum wells, and porous channels that are being created during the ascent of magma through peridotite rocks. The session “Reactive transport, mineral dissolution and precipitation in fractured and porous rock: experiments, models and field observations” discussed reactive flow processes through interdisciplinary work combining experiments or field observations with theoretical or computational modelling.

3 Conclusion

The EGU General Assembly 2021 was held as vEGU2021: Gather online, a two weeks-long series of online activities, in April 2021. The Division on Energy, Resources and the Environment hosted 22 sessions with 466 presentations and co-organised another five sessions with 84 presentations. With this special issue in *Advances in Geosciences*, we are pleased to present a collection of contributions from the ERE division 2021 session program.

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