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## Interdisciplinary Approaches in Resource and Energy Research to Tackle the Challenges of the Future

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### Abstract

The Division Energy, Resources & the Environment (ERE) of the European Geosciences Union (EGU) provides an international platform for scientists from a wide range of fields with the common denominator that their research topics have high societal relevance. The ERE community develops approaches for the solution of global economic prosperity, environmental quality and political stability based on interdisciplinary research on adequate and reliable supplies of affordable energy and other resources in environmentally sustainable ways. This special issue presents contributions of the ERE division at the EGU General Assembly in 2016.

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## 1. Introduction

The EGU General Assembly 2016 was held under the conference theme “Active Planet” from 16-22 April 2016 in Vienna, Austria. The program consisted of 619 unique scientific sessions and 321 side events. A total of 16,300 contributions were presented in the form of posters (64%), oral presentations (30%) and interactive content (PICO, 6%). The 13,650 participants originate from 109 countries, of which the majority were early career scientists (53%) and students (25%). Over the last decade, EGU has expanded in terms of number of scientific contributions (62% increase) and number of participants (57% increase).

The scientific program of the Division Energy, Resources & the Environment (ERE) was organized around six main groups of sessions: (1) integrated studies, (2) impact of energy and resource exploitation on the environment, (3) non-carbon based energy, (4) carbon based energy, (5) geo-storage for a sustainable future, and (6) geo-materials from natural resources. The division hosted 19 sessions and co-organized further 13 with others. In total, 458 presentations came from ERE, corresponding to almost 3% of all contributions of the EGU General Assembly 2016.

This special issue presents some of the current and coming applied research topics within the fields of energy, resources and the environment, and also documents the ERE activities at the recent EGU General Assembly. Below, a brief description of the scientific program [1] is given, sorted with respect to the six main groups of sessions. Comparable overview issues were published in Energy Procedia in previous years [2-4].

## 2. Integrated studies

### 2.1. Energy, resources and the environment

Integrated studies within the fields of energy, resources and the environment have the common objective to address current and future societal needs. Adequate and reliable supplies of affordable energy and other resources, obtained in environmentally sustainable ways, which will be essential to economic prosperity, environmental quality and political stability around the world.

### 2.2. Energy and environmental system interactions – policy and modelling

The transition to a low-carbon energy regime to mitigate greenhouse gas emission and combat climate change, together with the need to meet future demands and security of energy supply, presents a challenge for many governments. Meeting these challenges would require significant changes to the whole energy system including the deployment of new technologies, expansion of power generation capacity and significant levels of demand-side management. These projected changes in the energy system will inevitably result in changes to the level of appropriation of environmental resources, particularly land and water, what will have wider implications for environmental sustainability, and may affect other sectors of the economy.

### 2.3. Fracture, mechanics and flow in tight reservoirs

The presence of fractures, whether natural or induced, has become increasingly important in recent years in the exploitation of Earth's natural resources. Especially in rocks with low matrix permeability, the presence of fractures is critical for reaching flow rates sufficient for economic heat extraction from geothermal reservoirs and hydrocarbon production. Better prediction of subsurface fracture arrangements and their mechanical and flow response has become an increasingly relevant field of research.

## 3. Impact of energy and resource exploitation on the environment

### 3.1. Petroleum exploration and production and their impact on the environment

Recent decreases in the world's oil and gas reserves imply that energy producers and consumers are facing a major challenge. Therefore, an enhanced exploration and production strategy needs to be carried out to sustain the

world energy production level. To ensure sufficient energy production levels, new advances in oil and gas exploration and production technologies are required, as well as an improved understanding of their associated environmental risks and economic benefits.

#### **4. Non-carbon based energy**

##### *4.1. Energy meteorology and spatial variation of resources*

Wind and solar are the predominant new sources of electrical power in recent years. Solar power reached a milestone of providing 50% of demand in Germany during one hour in 2012, and wind power during one hour in 2015 exceeded 140% of demand in Denmark. By their very nature, wind and solar power, as well as hydro, tidal, wave and other renewable forms of generation are dependent on weather and climate. Modelling and measurement for resource assessment, site selection, long-term and short-term variability analysis and operational forecasting for horizons ranging from minutes to decades are of paramount importance.

The success of wind power means that wind turbines are increasingly put in sites with complex terrain or forests, with towers extending beyond the strict logarithmic profile, and in offshore regions that are difficult to model and measure. Major challenges for solar power are notably accurate measurements and the short-term prediction of the spatio-temporal evolution of the effects of cloud field and aerosols. For both solar and wind power, the integration of large amounts of renewable energy into the grid is another critical research problem due to the uncertainties linked to their forecast and to patterns of their spatio-temporal variabilities. Of particular interest these days is the relatively new field of urban meteorology applied to the renewable energy sector. There are several “Smart Cities” and “Smart Grids” projects in Europe, focusing on urban measurement development for forecasts or high-resolution resource mapping.

##### *4.2. Development of strategies towards a sustainable intensive thermal use of the shallow subsurface*

In consideration of the on-going transition towards energy supply from renewable sources, the thermal use of the shallow subsurface including heat generation, cooling and thermal energy storage is increasingly gaining importance. Spatial planning of the subsurface is needed to prevent overexploitation of the shallow geothermal potential and to avoid conflicts with other subsurface usages. To achieve this, the shift from shallow geothermal regulation to management will be essential. However, this step preconditions a thorough geothermal process and system understanding, especially in urban areas.

##### *4.3. Exploration, development and production of geothermal resources*

Energy from deep geothermal resources plays an increasing role in many countries in their efforts to increase the proportion of renewables in their energy portfolio. Deep geothermal heat and electric power have a high load factor, are sustainable and environmentally friendly. Even regions with moderate geothermal gradients are considered to have a high geothermal potential today; however, deep drilling is required to reach temperatures high enough for economic exploitation of a geothermal reservoir. Substantial research efforts are needed to ensure the safe, sustainable and economic development of deep geothermal resources, especially in less favourable regions.

##### *4.4. Numerical modelling in geothermics*

A wide range of numerical modelling is applied in geothermics in order to study deep geothermal processes and near-surface applications. Models can come from all phases of geothermal projects: prediction of geothermal potentials, optimization of borehole locations as well as the study of processes in existing geothermal installations. They can encompass all areas relevant for geothermics such as thermal, hydraulic, mechanical and chemical processes, as well as models about fracturing processes for enhanced geothermal systems. There are ongoing advances as well as unresolved difficulties in modelling geothermal processes, which stimulate new ideas for future work.

#### 4.5. Uncertainties in geothermal systems

Geothermal systems are commonly investigated with numerical simulations and these simulations are subject to uncertainties. In recent years, many methods have been developed to address the analysis of uncertainties in simulations. Several of these methods can directly be applied to the analysis of geothermal systems, but often, specific additional problems emerge, for example, related to the consideration of boundary conditions, the complexity of coupled processes and flow in fractured porous media. Recent developments and applications of suitable methods from the areas of model calibration, inversion, stochastic modelling, optimization and subsequent analyses of uncertainty quantification with applications to the broad range of geothermal systems were presented. Nonlinearities and the associated parameter sensitivities were in addition of specific interest, as well as approaches for history matching in engineered or operating systems.

#### 4.6. Sustainable biomass for raw materials, energy and GHG mitigation

The greenhouse gas (GHG) balance of biomass utilization is poorly understood, due to the underlying complexity of the processes involved. In contrast, the understanding of GHG emissions caused by fossil fuel combustion is better understood, because they can be measured via fuel consumption statistics. Renewable resources, such as biomass, represent an important tool in reducing GHG emissions, but understanding the net GHG impact of the production and utilization of biomass is crucial to make informed, metrics-based policy decisions and to incentivize changes in transportation and land use patterns. New approaches of thermal utilization of biomass are emerging and have the potential to further decrease GHG emissions via bio-energy and carbon capture and storage. Improved quantifications of GHG emissions on various scales help researchers to better assess aspects of biomass production and utilization at different scales, dealing with potential consequences of land-use change on soils, water and atmosphere. Further assessments are required, that take into account the effects of climate change, dynamics of socio-economic developments, new technologies and boundaries of natural ecosystems to provide services (e.g. biomass production) on sustainable scales. This would allow policy makers to elaborate on informed, metrics-based decisions and to incentivize changes towards a safe introduction of a bio-economy.

#### 4.7. Renewable energy and environmental systems: modelling, control and management for a sustainable future

There is an urgent demand to develop methods to manage the environmental systems to accommodate the increasing variability of climate and growing society. Topics to consider are: existing and emerging modelling, control and optimization methods for managing environmental systems, in particular renewable energy resources and to demonstrate their application in real-world applications and their performance for present and/or future contexts. Special attention should be given to:

- inclusion of forecasts and uncertainty estimates in models, optimization and control
- quantification of space-time dependences between wind/solar/tidal energies, water cycle, hydropower and energy demand
- optimization of resource use in environmental systems
- societal and economic aspects related with renewable energy use and development for a sustainable future.

### 5. Carbon based energy

#### 5.1. Unconventional hydrocarbon resources: advances and new technologies

The demand for unconventional hydrocarbon resources such as shale gas and tight sands has increased in the last decade. The production strategies for these unconventional resources differ significantly from that applied in conventional reservoirs in terms of exploration, exploitation and production techniques (e.g. drilling, fracking) as well as with respect to the environment. Advances in existing technologies and development of new technologies are therefore needed for their exploitation and exploration.

## 6. Geo-storage for a sustainable future

### 6.1. Geo-energy and urban future: a sustainable energy transition and safe energy exploitation

Global demand for energy is soaring, while CO<sub>2</sub>-induced climate change is a recognized issue. Securing future energy supply is becoming a concern at both, the global and local scales. However, energy production, removes the Earth's subsurface from its natural equilibrium, both chemically and physically. This frequently induces reservoir compaction, surface subsidence, induced (micro-)seismicity, among other economic and societal issues. At the same time, attempts are being undertaken to reduce CO<sub>2</sub> emissions via a sustainable energy transition from high-carbon fossil fuels, such as oil and coal, towards cleaner energy production using geothermal energy and natural gas. The understanding of the underlying physical and chemical processes, which control the behaviour of the subsurface, is of crucial importance for better understanding production-induced effects and mitigation options.

### 6.2. Field methods and analysis of field data for CO<sub>2</sub> geological storage

Application of existing and development of new field methods and analysis of field data are of fundamental importance for safe and sustainable site characterization and monitoring of CO<sub>2</sub> geological storage. Issues of importance include: (1) regional and local characterization of storage formations and their behaviour during CO<sub>2</sub> injection and storage; (2) identification and determination of key site parameters for CO<sub>2</sub> storage, such as parameter for its long-term trapping; and (3) characterization of cap-rocks and their properties.

### 6.3. Process quantification and modelling in subsurface utilization

Modelling of geological subsurface utilization is needed to support the design and safe and sustainable energy supply. The subsurface may be used for chemical or thermal energy storage as well energy production (e.g., hydrocarbon production). Utilization of the geological subsurface induces changes in the hydraulic, thermal, mechanical and chemical regimes. Various types of integration of experimental and numerical modelling methods are needed for quantification and prediction of potential impacts, resulting from geological subsurface utilization, including:

- site characterization and determination of site-specific geological and process data
- development of static geological models
- integration of experimental data into static and dynamic models as well as application of numerical models for experimental design and interpretation
- development and benchmarking of modelling tools
- model and parameter upscaling techniques
- model coupling addressing the interaction of thermal, multi-phase flow, geochemical and geomechanical processes in the fluid-rock system
- application of modelling tools for site characterization and prediction of potential impacts
- methods for risk assessment and efficient site operation.

## 7. Geo-materials from natural resources

### 7.1. Geo-materials in construction: resources, properties, performance and environmental interactions

Our society is using various types of geo-materials for construction, including for example, natural stone, aggregates, bricks, cement, lime and clay. These materials have widely varying properties and history, both from a genetic and a technological point of view. Most of the geo-materials have been also used in important monuments of the World Cultural Heritage. However, our knowledge of many aspects of these materials is still rather limited and attention from the scientific community is needed due to their long-term use, importance for the society and sensitivity to the environment.

## 7.2. Natural stone research and heritage stone designation

A Global Heritage Stone Resource (GHSR) is under construction to raise the interest in stone built heritage among the wide public and policy-makers to encourage the use of local natural stone and ensure the availability of the natural stone required for the maintenance of the built heritage and the quality of new buildings. The aim of GHSR is to build a formal designation with natural stone of local, regional or/and other different geographical levels importance.

## 8. Conclusions

Within this issue, we present highly applied results from innovative research and development projects. The common theme is focused on basic societal needs and challenges: how to obtain adequate supply of energy and resources in a sustainable way for the environment? These basic societal demands have to be met in order to ensure economic prosperity, environmental quality and political stability on a global scale. Interdisciplinarity, as provided by the ERE division, is a key approach to tackle the challenges of the future.

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