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UFZ EnergyDays 2015

Book of abstracts

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Keynote lectures

Renewable Electricity Policies: Rationales, Controversies and Policy Design

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In the European Union – and elsewhere – governments provide direct support for the diffusion of renewable electricity technology such as wind and solar power. However, the views on the rationale for these policies often differ among researchers as well as among policy makers, and such ambiguities concerning the underlying rationale make it difficult to evaluate the implemented support schemes. The purposes of this presentation are to: (a) discuss the economic rationale for supporting renewable electricity generation; and (b) how different policy rationales will influence the efficient choice of support scheme. The analysis emphasizes the role of renewable electricity support schemes as second-best climate policy instruments and not the least as tool for promoting technology learning. The latter typically calls for technology-specific support schemes that can adequately address the relevant learning processes.

EU Climate and Energy Policy 2030: another step towards a science-based transformation?

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The European Union claims to follow a science-based climate policy, guided by a long-term transformation pathway for the European energy system. But a closer look at the 2030 energy/climate headline target negotiations, the start of the EU's second transformation phase, shows a highly politicized process, which will continue with the implementation of the new headline targets. This keynote will explore how to qualify the actual role of scientific knowledge in EU energy and climate policy: "evidence-based policy-making", or rather "policy-based evidence-making", or both?

Session A1: Renewable Energy technology - Concepts and assessment

Session coordinator: **Marcus Eichhorn**

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Variable renewable energy sources (wind and photovoltaic) are and will remain the main pillars of sustainable power generation. However, the intermittent nature of these sources makes it challenging to ensure security of supply and maintain system integration. Within this session, we address energy system modelling, system friendly technology options, economics of adaptive measures and environmental impacts of renewable sources. In detail we discuss important questions like how to assess future power generation capacities with renewable fractions (by using the energy system model REMIX). We concentrate on impacts of technological adaptations of wind and photovoltaic for reducing feed-in variability and minimizing the generation of excess energy. Further, this topic is then lighted in terms of economics by estimating costs of such technical adaptations. We also discuss the role of flexible bioenergy in a renewable dominated power system. Environmental impacts of wind power and some possible approaches for mitigation are finally presented.

Economic assessment of system friendly technologies

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Previous studies find that the economic value of electricity ($/MWh) generated by wind and solar power drops as the penetration rate of these technologies increases. This “value drop” potentially compromises future competitiveness of wind and solar power – a challenge to power system transformation and decarbonization. There are many possibilities throughout the power system to mitigate the value drop, including electricity storage, flexible conventional plants, transmission expansion, and demand response. This study assesses another option: a different design of wind and solar plants themselves. “Advanced” wind turbines that are higher and have a larger rotor compared to generator size (lower specific rating) generate electricity more constantly than “classical” turbines. The same is true for “advanced” solar modules that are more oriented towards east and west. More constant electricity generation can have three major economic benefits, especially under high shares of wind and solar power: increased revenues from electricity sales (spot market value), reduced grid costs, and reduced costs for balancing forecast errors. This study discusses all three benefits, but focusses on the first. Model-based analysis in central Europe shows that advanced wind turbine design can increase the spot market value substantially. At a wind penetration rate of 30% in energy terms, the value of electricity from advanced turbines is estimated to be 22% higher than the value of electricity from classical turbines. Extensive sensitivity tests indicate that this finding is remarkably robust: in most cases, the value increase is in the range of 13 – 25%. Reduced costs for electricity grids and balancing services might increase the socioeconomic value of advanced wind power further, although these effects are likely to be smaller.

System friendly technologies

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The on-going energy transition in Germany aims at a power system dominated by renewable energy sources (RES) with more than 80% in 2050. With the mainstay of future RES expected to be provided by inherently variable sources like wind and solar photovoltaics (PV), the temporal mismatch in demand and supply is becoming a mayor issue for a secured power supply. Under currently insufficient storage capacity and rapidly increasing power installations from variable renewables like wind and solar PV, options for the integration of increasing shares of vRES are urgently needed. As a consequence, we investigated different technological and organizational options improve the volatile power production characteristics of wind and solar energy among a variety of options available. System friendly layouts of vRES and optimal mixes of wind and solar PV capacities were identified as major assets with a huge potential for the integration of large shares of vRES into the power supply system in the near to medium term.

Flexible Bioenergy - Generation technologies

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Bioenergy is today one of the main pillars of the German renewable energy provision in the power sector. In future the potential for a quantitative growth of bioenergy is limited and solar and wind become a formative roll. Due to this upcoming development, fluctuations of intermittent generation are increasing and the demand to balance these fluctuations, which are today mostly served by fossil units, have to be provided by renewable sources and innovative approaches. The large amount of already installed capacities in biomass driven generation units, represent a large basic stock which could be adapted to a flexible mode of operation. The challenge to develop flexibility in the bioenergy sector is determined on technical and economical constrictions. At the moment the most favorable technology to serve flexibility, is cogeneration in biogas plants. For this technology important interdependencies are described, to show the limits of theoretical potentials.

Clean energy, dead birds? An attempt to create bird friendly wind turbines across the federal state of Brandenburg, Germany

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Wind energy may offer an excellent means to reduce greenhouse gas emissions, but not without costs for biodiversity. Wind energy facilities have become an increasing cause for conservation concern, especially with respect to their impacts on bats and birds. To identify the major factors responsible for bird mortality at wind farms, we combined species distribution modeling with assessments of bird mortality data estimated by carcass surveys around wind turbines in the federal state of Brandenburg, Germany. We quantified these mortality detections in sets of 5 broad taxonomic groups, in relation to sets of independent ecogeographical features: climatic, topographic and habitat (land-use) variables. Using the random forest algorithm in addition with variable selection based on optimization of the area under the receiver operating characteristic curve (AUC) of the technique, we developed spatial models to determine turbine related vulnerable zones for the avian fauna in the federal state. Our results affirm that bird vulnerability at wind-farms combine all types of eco-geographical factors, but the respective natures of these impacts differ; different taxa show vulnerability towards different times of the year and are affected by different land-uses. Additional differences were found in their response towards different topographic factors. The spatial model indicated that, across all taxa, highly vulnerable areas occurred across the central-western and eastern regions of Brandenburg, while Passerines showed an additional vulnerability towards the south-eastern sector. An overlay of these results against the European network of protected areas, namely Natura 2000 (and Important Bird and Biodiversity Areas within them), show that many protected sites coincide with high vulnerability areas, or occurs in their vicinity. Our approach and the subsequent results can be used to direct future expansion of protected sites to reduce this risk, as well as to direct wind turbine installations based on both potential benefits and associated risks based assessment, thereby, minimizing the conflict between renewable energy and biodiversity protection.

Session A2: Power-to-X: Enabling technologies for the energy transition

Session coordinator: **Sabine Kleinsteuber**

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Temporal variability leading to an intermittent, stochastic and not fully predictable availability is an inherent problem of major renewable energy sources such as wind and solar power. Moreover, such variable renewable energy sources (vRES) are characterized by a spatial mismatch between demand and supply. With the envisaged increasing share of vRES in power production, there is an urgent need for higher storage and grid capacities to cope with these spatial and temporal mismatches. Instead of waiting for mature battery technologies, the Power-to-Gas approach (P2G) provides an opportunity for large-scale storage based on the existing gas grid infrastructure and flexible use of vRES for power, heat and fuel supply. Besides P2G, excess power from vRES can be utilized to produce liquid fuels and bulk chemicals (Power-to-Liquids). Power-to-X technologies using catalytic, biochemical or electrochemical conversion processes will be discussed in this session.

Power to gas and the need for establishing a pan-European understanding of admissible hydrogen concentrations in the natural gas system

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The generation of green gases by water electrolysis using surplus electrical energy is a promising opportunity for integrating renewable energy sources. This approach enables existing energy infrastructures as power and gas grids to contribute to the integration of renewable energy. Using the gas grid in this way enhances the flexibility of energy utilization. Green gas can be used for heat and power generation and as vehicle fuel to assist in fulfilling emission targets. Important criteria for establishing the power to gas (P2G) technology are reasonable production costs and the tolerance of the gas infrastructure to green gases, especially H2. The decision between two feasible options, the direct H2 injection or further conversion of H2 to CH4, requires a location specific assessment. Direct H2 injection offers lower capital and operational expenditures but is limited by the existing gas infrastructure which is optimized for natural gas. These challenges remain to be addressed as previous experience with H2 in town gas is not fully transferable to the current situation. Previous R&D did not yet cover all components in the gas grid that may be H2 sensitive. Research projects on H2 tolerance show that most parts of the gas grid are compatible with up to 10% H2. Porous underground gas storage, steel CNG vehicle tanks, and gas turbines and engines are sensitive components which require further research to determine their tolerance to H2 admixtures. DBI has initiated a network HIPS-NET to gather and share the available and expected research results and to develop a European

understanding of the gas grid tolerance to H2. About 30 international partners from various industries as well as research institutes have joined HIPS-NET so far, revealing the strong interest in closing the existing knowledge gaps on H2 tolerance of the existing gas grid. Gaining and sharing this knowledge is an important precondition to include P2G in a sustainable and renewable energy system.

Biocatalytic methanation of carbon dioxide and hydrogen in a trickle bed process – a suitable technology for power to gas

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Renewable energies, especially wind and solar power, are important to obtain a shift away from reliance on fossil fuels. However, due to the inadequate development of the electricity network, energy input and distribution are limited. Electricity can be stored as hydrogen by the electrolysis of water. Further conversion to methane allows the storage and transfer in the natural gas grid. The biologically catalyzed methanation occurs at moderate temperatures and has a higher resistance to contaminants such as H2S, organic acids and ammonia compared to the chemical conversion. The efficiency of this approach can be increased using a novel anaerobic trickle-bed reactor. This reactor differs from all other reactor types used for biogas production, such as liquid tensed or classical fixed-bed reactors. Due to the high surface suitable for material transfer from the gas phase to the liquid phase, a high productivity is reached. With this patented anaerobic trickle-bed process, a methane concentration of up to 98% is achieved. A methane productivity of 1.5 m^3 CH4/m^3d for a loading rate of 6 m^3 H2/m^3d was established. This methane quality and yield from gaseous substrates (CO2/H2) has never been reached in bioreactors so far. The methane production is controllable and flexible since the achievement potential was immediately restored after a suspension of substrate input. Thus, the reactor can be operated independently of the substrate availability. As the methane is nearly of the same quality as natural gas, it can be fed into the gas grid after minimal upgrading. Therefore the process is applicable in a P2G strategy. As CO2 source, the reactor can be fed with biogas which will be enriched in methane content. Thus, the trickle-bed reactor is applicable as downstream methane enrichment step in which no by-products accumulate. Currently, the scale up to a pilot plant takes place and a feasibility study for an industrial scale will be done.

Electrocommodities & Electrofuels: technology challenges and economic considerations of (microbial) electrochemical synthesis of fine chemicals and fuels

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Electrochemistry is the key science for any power-to-x technology. Electrochemistry as well as microbial electrochemistry allows converting electric energy into chemical energy carriers (commodities and fuels) and vice versa. This presentation will provide a short introduction into the broad fields of i) electrochemical synthesis and ii) microbial electrosynthesis from the viewpoint of sustainable synthesis of commodities and fuels. Thereby the principle potential will be highlighted on two selected examples and technical hurdles for component and system development will be addressed. Finally, in order to provide an incentive to overcome these hurdles the energetic and economic potential of (microbial) electrosynthesis will be highlighted.

Session A3: Biomass material streams for energy and the bioeconomy

Session coordinator: **Alberto Bezama**

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The competition among industrial sectors for using the available biomass resources is addressed in various national and international bioeconomy strategies. These have on the one hand established a strategic hierarchy for an appropriate use of these resources, and on the other hand fostered the integration of the industrial sectors for optimizing the use of the biomass resources. In particular, wood resources will receive an increasing future demand, as their physic-chemical characteristics allow the production of a wide range of energetic alternatives, being at the same time an interesting alternative raw material for the materials and chemical industries. This session will provide an analysis of the bioeconomy strategy, mainly based on the lessons learned in the wood-based bioeconomy. The session will be oriented to technology developers and practitioners, as well as for scientists dealing with challenges associated to assessing the new value-added chains in a regional context.

BioEconomy Policy Strategies in the 22 IEA Bioenergy Member Countries

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The transition from an economy based on fossil raw materials to a sustainability-oriented bio-economy obtaining its raw materials from renewable biological resources requires concerted efforts by international institutions, national governments and industry sectors, and prompts for the development of bioeconomy policy strategies. The progress and priorities of such strategies worldwide are summarized in the following as result of a survey on bioeconomy strategies in the 22 member countries of the IEA Bioenergy Implementing Agreement IA (A, AU, BE, BR, CA, CH, DK, DE, FI, FR, GB, HR, IE, IT, JP, KR, NL, NO, NZ, SE, US, ZA). The focus of the survey was on official governmental bioeconomy strategies, with regional and industry strategies serving as additional evidence for the current state of bioeconomy development in a country. Strategy documents provided and partly translated by IEA Bioenergy country representatives were analyzed in a framework of questions to compare patterns as the definition and scope of bioeconomy, vision and (measurable) targets, economic sectors in the focus of the strategies, current focus of implementation, and the position of bioenergy in a future bioeconomy. This survey was commissioned by the IEA Bioenergy Executive Committee and performed by JOANNEUM RESEARCH in cooperation with ITABIA with the support of national representatives in the IEA Bioenergy Implementing Agreement.

Challenges for implementing the bioeconomy strategy in a regional scale

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The establishment of the European bio-based economy strategy in Germany entails an enormous challenge, which should be overcome by the technical development and implementation of integrated concepts (i.e. the implementation of the cascade and coupled use concepts) that optimize the utilization of the available biomass resources. Nonetheless, the actual impacts of implementing this shift from “value-added chains” to “value-added networks” will be observed first on a regional level: although technically feasible, the required integration will certainly bring along several further challenges to the existing industrial infrastructures in terms of technological flexibility as well as with the internal and external logistics of the participating industries. In addition, an increasing attention will be paid for practitioners to manage their processes and resources in a standardized sustainable way, accordingly to the local strategies and conditions. This manuscript aims to identify and to analyze the most relevant aspects to be incorporated in an appropriate management concept of the upcoming transition towards the implementation of the bioeconomy strategy in Germany. A particular focus will be given to the life cycle based methodologies and tools that must be developed or enhanced in order to optimize the technological design of the involved processes, to appraise the regional-specific socio-economic added value of the intended industrial integration, and to evaluate the sustainability trade-offs of the resulting material flow management concepts.

Organosolv fractionation of beech wood at pilot scale

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One important aim of biorefinery concepts is to allow for a complete material usage of renewable feedstock. This can be achieved by a proper fractionation of heterogeneously composed natural materials. At the Fraunhofer Center for Chemical-Biotechnological Processes - CBP lignocellulosic feedstock is pretreated by an organosolv process at pilot scale. Beech wood is fractionated into cellulose, hemicellulose and lignin using ethanol-water pulping at elevated temperatures. The products are promising raw materials for the development of bio based materials such as plastics, adhesives, resins, carbon fibers and various fermentation products. In order to enable a systematic optimization of the pulping conditions the process kinetics are investigated. Furthermore lignin obtained at different process times and conditions is analyzed using for example GPC analysis. The results will be used for the adaptation of the process conditions in order to improve the product qualities required for various different potential uses and to optimize the process.

Sustainability monitoring of cross-sectoral integration options in emerging bioeconomy regions

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Cross-sectoral co-production between bio-based industry sectors promises a variety of synergies for creating added value by efficient utilization of by-products. Simultaneously it may lead to a series of trade-offs by resource competition and other biophysical limitations such as critical loads for environmental media or allocation constraints for utilities and production sites. Therefore multi-sector cooperation in emerging bioeconomy regions requires extensive elicitations for assessing future utilization strategies of underutilized by-products, in order to monitor the sustainability performance of the newly created industrial networks. Additionally the extended cascade use of bio-based secondary raw materials gives the option to minimize resource competition by gradually broadening the resource base of companies. However this is adding further degrees of complexity into strategic decision making as the realization of intensified cascade use requires the development of new recycling friendly products designs and new feedstock flexible treatment technologies. As both of these strategies, the integration of co-production systems and the cascade use, have to be implemented in parallel but with different timing constraints, there is a need for structuring and prioritizing R&D efforts and technology implementation plans and for monitoring the degree of progress in fulfillment of efficiency and sustainability goals. The development of a sustainability monitoring system by means of a well-adjusted and calibrated multi criteria analysis has been proposed and outlined in its basic functionalities and methodological steps. The presentation will give an insight ranging from the identification of relevant efficiency and sustainability goals within defined system boundaries over the calibration of suitable indicators to practical examples for assessment cases.

Session B1: Sociology of the subterranean - Perception and framing of subsoil energy technologies

Session coordinator: **Alena Bleicher**

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The rather positive image geothermal energy enjoyed in Germany has recently begun to change following several unfavorable events such as the “Staufen accident” or seismicity in Basel and Landau. Furthermore links have been established in public debates between hydraulic stimulation for shale gas production and critical discussions on geothermal energy utilization. So far too little scientific knowledge is available on how the underground in general is perceived and framed by different societal groups, on factors of perceptions, risk attributions and decision making. Existing studies show significantly varying perceptions between subsoil technologies. We invite researchers who approach the issues of perception and acceptance of different subsoil technologies from a social science perspective (e.g. sociology, psychology, geography). The session is a step towards a more integrated understanding of patterns and structures in perceptions of, and debates on, subsoil technology.

CCS: Concentrating, Construction and Distribution of Risks - Societal reasons why CCS failed in Germany

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The CCS technology could whether develop a convincing technical utopia in the wider frame of the German ‘Energiewende’ nor establish a coalition of actors, which was able to enforce the implementation of the technology. For this “failure” the following societal reasons are discussed: the perception of risks and underground uncertainties, the discussion of environmental justice and the distribution of risks and benefits, the connection of the debate to the issue of lignite and the missing proof of economic feasibility.

Framing shale gas for policy making in Poland

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Despite huge enthusiasm about new gas reserves in Poland, shale gas has not come to Poland without controversies. This study examines how shale gas has been framed as a public issue by political and business elites, experts, local communities and civil society organizations. Through the application of frame analysis, it is shown that three main frames about shale gas exist in Poland: “shale gas as an economic resource”, “shale gas as a strategic resource for state security” and “shale gas as a source of threat”. However, it is noticed that only the first two frames, which have been proposed by political and business elites, have shaped the policy process so far. The third frame, constructed by local actors and civil society groups, has had no impact on the policy process. Exclusion of the third frame is explained by the deficit model of risk communication which is reproduced by Polish experts, business and political actors during interactions with local groups. The deficit model of communication says that non-experts are not competent in debating technological controversies. By excluding the “incompetent actors”, the third frame positing “shale gas as a source of threat” is excluded from policy processes.

Market perception versus society perception in deep geothermal energy

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In this session we present the result of diverse national analyses, which allow us to find out how people assess geothermal energy as well as how people discuss geothermal energy in the internet and which target groups discuss on different internet platforms. The analysis of facebook allows us to collect specific personal data. Interviews with geothermal experts, associations and business surveys allow to describe the industries view on geothermal energy. These analyses are the background to compare the perception of the geothermal market with the perception of the society for geothermal development. With this comparison we get results what are the differences between the geothermal industry and the population. In the last part of the presentation we outline the role of the culture of acceptance for the development of geothermal energy and the possibility of culture of acceptance for other subsoil technologies. The main target of the culture of acceptance is to find the perfect acceptance concept for the population and for the project developer. One result can be a realization of the project, but it also can be the stop of the project. Culture of acceptance is an open-ended tool for the project, which means under which conditions would it be possible to realize a project. This could be either a subsoil project, but it can be also an infrastructure project for example.

Session B2: Thermal use of the shallow subsurface

Session coordinator: **Thomas Vienken**

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The rather positive image geothermal energy enjoyed in Germany has recently begun to change following several unfavorable events such as the “Staufen accident” or seismicity in Basel and Landau. Furthermore links have been established in public debates between hydraulic stimulation for shale gas production and critical discussions on geothermal energy utilization. So far too little scientific knowledge is available on how the underground in general is perceived and framed by different societal groups, on factors of perceptions, risk attributions and decision making. Existing studies show significantly varying perceptions between subsoil technologies. We invite researchers who approach the issues of perception and acceptance of different subsoil technologies from a social science perspective (e.g. sociology, psychology, geography). The session is a step towards a more integrated understanding of patterns and structures in perceptions of, and debates on, subsoil technology.

Sustainable thermal use of subsurface urban heat islands

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Temperatures in shallow urban ground are typically elevated. They manifest as subsurface urban heat islands that are observed worldwide in different metropolitan areas and have a site-specific areal extent. In most cases these thermal anomalies are caused by anthropogenic heat fluxes into the subsurface. The objective of this study is to quantify the spatial distribution of these fluxes and the thermal power they transport into the urban subsurface. Furthermore, the possible implications on thermal groundwater use are investigated by comparing the annual thermal recharge of anthropogenic heat fluxes into the subsurface with the residential space heating demand. Thus, the potential of the subsurface urban heat island as a sustainable source of thermal energy is evaluated.

Development of a thermal tomography to enhance shallow geothermal energy exploration

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As a large share of the primary energy consumption in Germany is used for heat generation, a high potential lies in using the shallow subsurface as alternative source for heating, cooling and heat storage. Nevertheless there is a lack of methods describing heat-transport parameter distribution within the vadose zone, which is especially suitable for heat storage due to decreased convective loss. This work intends to close this gap by using the similarity in mathematical description of conductive heat-transport and hydraulic-flow. Of special interest herein is the hydraulic-tomography, which allows a high-resolution spatial hydraulic conductivity estimation. The experiment design and analysis techniques are transferred from groundwater hydraulics to conductive heat-transport to gain thermal-conductivity distributions. Using Fiber-Optic Distributed-Temperature-Sensing as temperature sensor allows for spatial and temporal high-resolution temperature data as input for analysis. With finishing this work, a method for describing the shallow subsurface in terms of distribution of conductive heat-transport will be provided; yielding an exploration tool for future geothermal-energy and storage projects to ensure sustain and economical use of the shallow subsurface.

Concepts for the sustainable development and use of shallow geothermal energy on neighborhood scale

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An ongoing technological enhancement in the heat pump technology drives a raised interest in using shallow geothermal energy for heating and cooling applications. Especially urban areas show an increasing system density. However, these systems are in many cases planned on an individual, property based scale. This planning is in many cases solely based on geological maps, drilling databases, and literature references. Due to financial restrictions, no site-specific measurements are conducted to characterize the subsurface. To increase the planning safety and promote the use of renewable energies in the domestic sector, this study investigates a novel concept for an enhanced geothermal development of residential neighbourhoods. This concept is based on a site-specific characterization of subsurface conditions and the implementation of demand-oriented geothermal usage options. Therefore, non-invasive exploration methods detecting the lateral subsurface structure are combined with minimal-invasive high resolution vertical profiling tools. The results of this study show that the application of this improved investigation concept enables a more precise design of shallow geothermal systems as well as a reliable prediction of induced long-term changes in groundwater temperatures. Three different options for the thermal development of residential neighbourhoods were deduced to guarantee the financial feasibility and practicability.

Session B3: Dynamics of fluids in the course of underground storage

Session coordinator: **Carsten Vogt**

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This session deals with strategies and challenges linked to the underground storage of energy carrier and end products, focusing on (i) the development of sensitive and innovative monitoring concepts for the detection and source identification of fluids in the subsurface as well as (ii) putative impacts of microbial processes on underground fluid dynamics.

Potential effects of hydrogen on the microbiology of underground gas reservoirs

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The increasing utilisation of solar or wind sources for energy supply in Europe leads to a high fluctuation in energy production which can be adapted to the actual demand by converting the energy to chemical energy sources such as hydrogen or methane and subsequent storage. Large volumes of storage capacities are required for this issue which most likely can be solved by underground storage in geological formations. Despite microbial life has been evidenced in underground storage reservoirs, less attention has been given to study the impact of microbial processes on the geochemical conditions and the gas composition in an underground reservoir. From an economic point of view, microbial activities can lead to a loss of stored gas accompanied by a pressure decline in the reservoir, damage of technical equipment by biocorrosion, clogging processes through precipitates and biomass accumulation, and reservoir souring due to a deterioration of the gas quality. In close cooperation with energy groups and the Federal Institute for Geosciences and Natural Resources – BGR, we study the interactions between storage gas and microbial processes in reservoir samples. We aim 1) to reveal the structure, function and activity of indigenous microbial communities inhabiting different geological formations and 2) to elucidate potential stimulation effects on microbial activities if neat hydrogen or natural gas blended by hydrogen would be introduced into geological formations.

Short-Term Energy Storage in Artificial Salt Caverns

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Clean energy production from sun or wind resources causes fluctuating energy outputs. To compensate those fluctuations and to guarantee energy supply, the conversion of excessive energy into gases is a promising technique for energy storage. However, those power-to-gas applications require huge storage volumes. Utilizing geologic formations as storage sites for artificial gases is the focus of many recent research projects. Besides pore-space storage such as saline aquifers, artificial salt caverns show a large storage capacity. Gas storage causes variations in the pressure and temperature conditions of the subsurface, which influence the mechanical condition of the host rock. In our work, we develop a mathematical model of the storage process to determine stresses, strains, and temperatures in the cavern and its host rock. The model is used to study the influence of temperature on the rock salt and to provide the evidence of cavern stability.

Carbon Capture and Storage (CCS) technology and the requirement for appropriate assurance monitoring approaches

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In recent years, global concerns about greenhouse gas emissions have stimulated considerable interest in carbon capture and storage (CCS) as a climate change mitigation option which can be used to reduce man-made CO_2 emissions. This is achieved by separating and capturing CO_2 from emission sources, then injecting and storing it in the subsurface. However, a successful monitoring needs to cover different areas at different scales to enable detection of any significant irregularities concerning subsurfaceCO_2 migration and the potential occurrence of leakages at the ground surface. The presentation gives an introduction into the MONACO project which aims in the application and validation of a multi-scale near-surface monitoring concept to enable reliable detection of CO_2 migration and seepage. The project focuses on the development of assurance monitoring techniques - especially in the atmosphere, at surface level and in the vadose or saturated zone. Results and lessons learned from the MONACO approach, presented here, were primarily obtained by applying the integrative monitoring concept at a natural CO_2 degassing site.

Growth and activity of reservoir microorganisms under carbon capture and storage conditions

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Carbon capture and storage is a technology to decelerate global warming by reducing CO2 emissions into the atmosphere. To ensure safe long-term geological storage of CO2 microbial activity in reservoirs needs to be considered, which can lead to the formation of acidic metabolites, H_2S or carbonates which then might affect injectivity, permeability, pressure build-up and long-term operability. Our research focused on the effect of high CO2 concentrations on growth and activity of selected thermophilic fermenting and sulphate-reducing bacteria isolated from deep reservoirs. Experiments with supercritical carbon dioxide at 100 bar completely inhibited growth of respective microorganisms. This effect was not observed in control cultures with 100 bar of hydrostatic pressure. However, when provided with a surface for attachment, CO2-inhibited cells restarted growth after CO2 release. The same was observed for organisms able to form spores. Further experiments will examine physiological and molecular properties of the model organism allowing for prediction of its sensitivity and/or adaptability to carbon dioxide in potential future storage sites.

Microbial communities in natural gas fields in the context of carbon capture and storage (CCS)

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Depleted natural gas fields have been discussed as a main target for the storage of anthropogenically produced CO2, though the suitability of the prevailing geological formations is still unclear. In this context, we were interested in the potential contribution of indigenous microorganisms to the integrity of these geological formations and of the cap rocks. The experimental approach taken hereby involved the analysis of the indigenous microbial community in formation fluids of the natural gas field Schneeren (Lower Saxony, Germany). Following the isolation of a novel strain of the genus Petrotoga from the same formation fluids we tested it as representative member of the indigenous microbial community for its cellular response to high CO2 concentrations presumed to occur upon carbon sequestration. Using flow-through experiments on various geological cores we went on to assess the possible contribution of indigenous microorganisms to the integrity of the geological formation. Again, we evaluated both as inoculum, samples of formation fluid from the gas field Schneeren and Petrotoga as representative species and assessed changes in core permeability.

Session C1: Spatiality of energy systems – Implications from a land-use perspective

Session coordinator: **Franziska Taubert**

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The resource land is scarce and limited. In the course of the energy transition towards sustainably energy systems, effects of spatiality have been unattended up to now. This raises the central question: Which role plays spatiality in renewable energy landscapes? The regulatory framework addresses different aspects of the energy system acting at various spatial scales. In part tremendous ecological, social and economic consequences can be the result, for which reliable and adequate multi-criteria assessment tools are required. In this session, we want to highlight in a series of presentations methodological approaches for a prematurely assessment of consequences of the regulatory framework on allocation decisions and, in turn their impacts on land-use.

Impact of the German market premium scheme on the actors of the electricity market – an ABM analysis

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In the year 2012 the German government introduced the market premium for supporting the direct marketing of electricity from renewable energies. The AMIRIS agent-based simulation model allows testing and analysing the impacts of the market premium on the involved market actors (e.g. renewable power plant operators and direct marketers) on the micro level as well as effects on the macro level (energy exchange prices and market structure) of the energy market system. Results show that an important factor for economic success is the quality of output forecast that directly influences the costs for balancing energy. The declining management premium (the decline was decided in 2012) affects smaller direct marketers with a lower quality forecast and smaller portfolio. Therefore a market concentration seems likely in the years after full degression. Concerning power plant operators, the wind power plant operators profit clearly from direct marketing and the market premium, as bonus payments of the direct marketers are high due to the relative high management premium for intermitted RES compared to the corresponding feed-in-tariffs. By taking part in the balancing power market, the direct marketing becomes lucrative for solid fuel plants as well as for big biogas plants. The importance of participating at the balancing power market is even raised by the expected degression of the relative market value of biomass plants. Assuming an increase of the installed power of PV power plants, peak prices at noon will strongly decrease until 2020, so that the relative market value of biomass plants operating only a simplified day-night cycle falls below 100%. This effect indicates the importance of considering interdependencies between the feed in of different renewables when analyzing market potentials.

Large-scale optimization of the spatial allocation of renewable energy plants

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Wind and solar power are the most important resources for renewable electricity (RE) production in Europe. An important prerequisite for the success of the energy transition in Germany and elsewhere is that the expansion of RE sources is carried out cost-effectively, and under consideration of potential social conflicts. We used a genetic algorithm to generate candidate landscapes for the cost-effective and socially acceptable spatial allocation of wind and solar energy plants. We considered physiogeographical and legal restrictions for the allocation of RE

plants, as well as site-specific wind speed and solar radiation data for the estimation of energy potentials. Using questionnaires, we estimated the willingness to pay (WTP) for increased distance of RE plants to settlements to determine optimum distances. Finally, we performed optimizations to find pareto-optimal spatial allocation schemes that minimize electricity production costs and maximize the fairness of the spatial distribution of electricity production capacity. We found that the optimal spatial allocation largely depends on the future development of photovoltaic investment costs. While under current investment costs wind energy is dominating the solutions, a shift to solar energy occurs under investment costs of 30-40% compared to current costs (expected around 2020). The optimization of the distances to settlements resulted in only a small increase compared to current legal restrictions, due to low WTP. Synchronous optimization for cost-effective electricity production and fair spatial distribution showed that a maximum of fairness can be achieved with a cost increase of only 0.3 ct/kWh. With this study we are able to show how physiogeographical, economic and social aspects can be integrated into the optimization of the spatial allocation for RE sources. The results allow us to identify consequences of regulatory measures regarding the energy transition in Germany.

Changes in agricultural landscapes induced by the allocation of energy infrastructures - Methodological insights from an agent-based model

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The allocation of additional energy infrastructures for supplying, converting, transporting or using energy or energy carriers can cause indirect side-effects such as a secondarily induced land use change with strong impacts on large areas. Access to infrastructures for the use of renewable resources for bioeconomic purposes with energetic relevance, for instance, can alter land use decisions concerning crop cultivation with environmental implications that are not fully understood so far. For example, changes in composition and configuration of agricultural landscapes may affect biodiversity and the provision of ecosystem services. Land use decisions, however, are also influenced by physical site-conditions and market-related policy instruments. Understanding the functional relationship between the distribution of energy infrastructures, induced land use patterns, and resulting environmental impacts is crucial for identifying options for fostering synergies and mitigating side-effects. We present a spatially-explicit agent-based model to investigate these issues. Based on hypothetical landscapes, the emergence of macro-level land use patterns from individual land use decisions, which are influenced by existing energy infrastructures, as well as economic determinants and physical site-conditions, is explored. Resulting land use patterns and thereby the regulatory framework as driver are assessed from an ecological perspective. At this, the concept of landscape metrics is used to determine the ecological value with regard to biodiversity aspects.

Smart Spatial Model: spatial land-use optimization for a sustainable renewable energy production

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The exploitation of Renewable Energy Sources (RES) has gained an increasing interest during the last decades. However, the site selection among various renewable energy allocation projects is a complex task involving numerous decision makers, taking into account different technological, environmental, economic and social criteria. Accordingly, in order to deal with this complexity the Smart Spatial Model (SSM), a GIS-based tool was developed in order to support political decision in sustainable spatial planning. The objective is to optimize land-use by building different scenarios for RES development. For this purpose three different kinds of modules (GIS-based layers) are developed. Firstly, the theoretical and the technical RES potentials are defined. On the one hand, the theoretical potential describes the theoretically usable energy supply and is only determined by the physical properties. On the other hand, the technical potential is only a percentage of the theoretical one and depends significantly on the specific technical requirements for different power plants. Secondly, restrictions areas of RES exploitation in terms of mandatory (legally established) and recommended (planning practice) exclusion areas are identified for selecting suitable area for the exploitation of RES. Thirdly, sensitivities of the landscape are considered by including ecological criteria during the selection of best location for RES. The proposed model is tested in a case study concerning the exploitation of wind, solar and biomass energy, located in the Hanover region, Germany. The results demonstrate that the technical potentials and their combinations are strongly limited by the actual availability of land for RES-generation considering legally and environmental restrictions.

Session C2: Challenges for the spatial organisation of the energy transition

Session coordinator: **Jana Bovet**

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The ambitious aims of Germany's energy transition (at least 80% of electricity supply from renewables in 2050) call for a radical transformation of the energy system. Already today, with 25% renewables at overall electricity supply, spatial consequences and challenges of this transformation become palpable. While the Renewable Energies Act has proven to be very successful in increasing the deployment of renewables, it failed to adequately address the spatial allocation of production capacities. This lead to several systemic imbalances and, in consequence, created potential areas of conflict. In particular, the following challenges need to be resolved:

- Spatial disparity between the most important centers of production and consumption
- Lack of coordination within Germany's federally organized political system
- Land-use conflicts arising from production capacities and transmission grids

Several approaches are currently discussed as possible solutions to these issues: market-based approaches would rely on economic incentives to steer the spatial allocation of energy infrastructure (e.g., market splitting so as to incentivize a more appropriate allocation of production capacities). Improved policy coordination between the different levels of government could avoid mismatches between existing policy targets and instruments. Moreover, adequate planning procedures could alleviate the problems associated with large-scale energy infrastructure projects (e.g., protests against new transmission lines). Since a variety of heterogeneous stakeholders contributes to the energy transition and/or is affected by the transition, finding appropriate regulatory solutions will be far from trivial. Thus, the workshop aims to analyze the different approaches and their interactions in more detail. Improved coordination of the diverse regulatory approaches will be crucial in addressing the spatial challenges of the energy transition. By assessing the approaches' benefits and drawbacks, the workshop seeks to indicate possible non-intended consequences.

Session C3: Market and system integration of renewable power supply: The role of future power market and RES support design in Germany

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The German government aims at increasing the share of renewable energy sources (RES) in final electricity consumption to 50% by 2030 and 80% by 2050. So far, government efforts to actually reach these goals have been quite effective, reaching a share of 25% in 2013. That notwithstanding, this success has also raised public debates as to the challenges that are associated with the transition from fossil- and nuclear-fueled to renewable power generation. The discussion focuses on two major issues: the costs and the reliability of power supply (next to community acceptance and spatial land use conflicts, which are addressed in a separate session). Thanks to the Renewable Energy Sources Act (EEG), RES generation is fed into power grids with priority and largely irrespectively of power demand. The remuneration for RES generation is determined by an administratively set feed-in tariff. First, this raises concerns that RES plants are not installed and operated in a cost-effective manner. Second, the volatility of RES feed-in – more than half of it stems from wind and solar plants – may also impair the reliability of power supply under the current framework conditions. Fossil power plants have to adapt even more flexibly to changes not only in power demand but also in power supply – while they are losing market shares and revenues at the same time. In order for the German energy transition to succeed, it is thus a decisive question how the governance framework can be modified to address these challenges properly. Avenues may particularly include regulatory approaches to integrate RES generation into the current power market and power system – but also to adapt power market design and power system characteristics to better accommodate volatile renewables. Potential regulatory approaches may range from modifications in RES policy design (premiums, tenders) and complementary measures, such as capacity mechanisms, modified regulation of power grids and demand-side management, to a fundamental reform of the power market design. This session is meant to provide an overview of potential governance avenues, and to discuss corresponding strengths and weaknesses. The discussion in this session will be informed by 5-minute inputs by which three invited experts in this research field introduce their key theses related to future power market design.

System and markets adaption to high shares of renewable power supply

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Electricity supply is a service of general interest. Hence the regulator has certain objectives regarding its provision. The overall ambition of the German 'Energiewende' could be summarized as follows: 'Achieving the environmental objectives to the lowest cost possible while maintaining security of supply.' Before evaluating institutional design options to achieve RES-E system and market integration, it has to be clarified, how those different types of integration are related to the 'Energiewende' objectives.

- RES-E system integration: The more investment and operational decisions accommodate system requirements, is the lower system costs are. Thus RES-E system integration could be considered as a sub-ordinate objective to the cost objective. Although system integration has to be understood as an issue of mutual adaption, i.e. all other system components and the institutional framework have to adapt to the new circumstances as well.

- RES-E market integration: First of all, what does market integration mean? Squeezing RES-E into existing markets (which were designed for a different system) hardly seems to be a sustainable strategy. A reasonable interpretation of 'market integration' as a goal could rather be: Confronting private investors and operators with market risks wherever a coordination of these decentral actors leads to more desirable outcomes than regulatory determinations.

So the question rises which publicly discussed policy options are − in accordance with the foregoing specification − helpful in order to create a well-functioning institutional framework for a RES-E based system?

The general benefits of RES-E direct marketing obligations still remain vague, while cost increases are likely. Although the EEG market premium approach could be evaluated as an eligible instrument for influencing dispatch behavior of existing RES-E plants operators. Yet it appears to be an unnecessarily expensive instrument for providing curtailment incentives for new installations. Advanced premium models can be assessed as promising instruments for inducing system compatible RES-E investment and operational decisions. However developing an effective and efficient design proves to be a challenging task and currently proposed concepts contain several pitfalls.

As the RES-E generation share rises, the localization of RES-E plants will gain importance. Thus spatial steering mechanisms will sooner or later be relevant. In this context there is some good reason for limiting the complexity of the incentive system for influencing site selection. Moreover RES-E will face additional responsibilities for delivering system services in the future. A participation in services markets appears to be unnecessary though. By the time the system moves close towards final RES-E target capacities, there even might be a stronger case for using tender mechanisms to regulate new investment. Currently the disadvantages of applying tenders outweigh the advantages.

The system transformation also goes along with increased requirements on attributes and capabilities of residual load covering units. An energy only market (EOM) itself does neither guarantee security of supply, nor does it deliver some desired technology mix. Additional measures (like reserve schemes or regulatory restrictions) can address these shortcomings, however the EOM model still remains a cost-intensive approach. Especially costs of capital can be reduced by providing secure streams of income to investors. But certainly that requires a determination of which projects will get access to the corresponding remuneration schemes. At this point in time there is a high uncertainty or at least little consensus about which technology options are suited best in order to achieve the objectives of the ‘Energiewende’. Taking this into account it should be one of the regulator’s top priorities to develop know-how and ressources. By doing so he will at least be able to identify ‘no-regret’ segments of the technology mix, for which he can offer low risk contracts. The complementary part of the residual load coverage portfolio should be addressed by more output-related requirements to allow for a wide range of competition.