Energy Working Group
Arbeitskreis Energie (AKE)

Hardo Bruhns
Meliesallee 5
40597 Düsseldorf
ake@bruhns.info

The programme of the Energy Working Group comprises sessions which deal with energy technologies based on geological, biological, chemical and physical research in conjunction with engineering developments. A major part is devoted to renewable energies. Novel developments are presented both for silicon based photovoltaics and new classes of organic, colloidal nanocrystal and hybrid semiconductors, perovskite type materials in particular. In this context also the plenary talk on Friday should be noted. - For concentrating solar thermal power routes towards cost and concept optimizations are analyzed. - The discussion of geothermal energy focuses on deep fluid reservoir technology and the physico-chemistry for optimized utilization of the hot saline fluids. - Energy from biomass has an important role. In the long term novel concepts of designing a biological metabolism for enhancing direct hydrogen production at the expense of biomass production could open very substantial new options. - The energy challenge can be reduced by energy savings which is a wide topic. Here progress is presented in developing energy efficient building envelopes.
The internationally unbroken trend of dominant fossil fuel use progressively implies unconventional fossil fuel extraction. As a consequence, however, also options for carbon capture and geological storage must receive due attention. - Forecasts see fission power as a provider of at least a constant fraction of the world electricity supply over the forthcoming decades, these technologies continue therefore to be of high significance. - Fusion energy is the only known further clean option for non-fossile electricity generation. Systematically different from the other energy sources it could offer a large potential of non-fluctuating electricity generation if research will be successful. Both magnetic and inertial confinement fusion research are being addressed.
A substantial part of the programme is devoted to various aspects of energy storage which is a crucial prerequisite both for electromobile applications (ex. Li-Ion batteries) and for large-scale fluctuating grid electricity (ex. Power-to-Gas). Mitigating and managing the fluctuating nature of electricity generation dominantly from wind and photovoltaics is the dominant challenge. After assessing the corresponding implications on a European-wide statistical basis and with regard to the impacts on conventional technology, there are joint sessions regarding analysis and modeling of fluctuating generation and consequent backup and storage requirements as well as the requirements for the electricity (smart) grid and consumer integration. A further joint sessions extends into the area of sustainability and human nature interaction. - Last but not least, the integral assessment of electricity generation systems, incorporating external cost, is discussed with a view to identifying and optimizing instruments for energy policy.
Submitted talks complement the invited talks. The sequence of sessions reflects to some extent the agenda of speakers and the boundary conditions for designing the joint sessions.

Overview of Invited Talks and Sessions

Invited Talks

AKE 1.1	Mon	9:30–10:00	A 151	**Perspectives and challenges of thin-film crystalline silicon solar cells on glass** — •Bernd Rech, Daniel Amkreutz, Jan Haschke, Stefan Gall, Christiane Becker, Onno Gabriel, Rutger Schlatmann
AKE 1.3	Mon	10:15–10:45	A 151	**Neue optoelektronische Materialien und Verfahren für die Photovoltaik** — •Christoph Brabec
AKE 2.1	Mon	11:30–12:00	A 151	**Konzepte zur Kostensenkung solarthermischer Kraftwerke** — •Robert Pitz-Paal
AKE 3.1	Mon	12:00–12:30	A 151	**Deep geothermal fluid resources: Energetic use and beyond** — •Harald Milsch

AKE 4.1	Mon	15:00–15:30	A 151	**Nuclear fission energy: new build, operation, fuel cycle and decommissioning in the international perspective** — •Stefan Niessen
AKE 5.1	Mon	15:30–16:00	A 151	**Wendelstein 7-X , ein Konzept für ein stationäres Fusionsplasma** — •Robert Wolf, W7-X Team
AKE 5.2	Mon	16:00–16:30	A 151	**Laserfusion: status and concepts for new laser drivers and ignition physics** — •Bjorn Manuel Hegelich
AKE 6.1	Mon	16:45–17:15	A 151	**"Fracking"- Routine oder Risikotechnologie?** — •Michael Kosinowski
AKE 6.2	Mon	17:15–17:45	A 151	**Geological carbon storage: processes, risks and opportunities** — •Holger Ott
AKE 7.1	Tue	9:30–10:00	A 151	**Optionen und Trends der Biomassenutzung: Perspektiven für die Bioenergie 2050** — •Jens Ponitka, Daniela Thrän
AKE 7.2	Tue	10:00–10:30	A 151	**Rational design of cyanobacteria for hydrogen production** — •Sascha Rexroth
AKE 8.1	Tue	10:45–11:15	A 151	**Energiespeicher für die Elektromobilität - Perspektiven und Limitierungen** — •Margret Wohlfahrt-Mehrens
AKE 9.1	Tue	14:00–14:30	A 151	**Power to Gas - an economic approach ?** — •Manfred Waidhas
AKE 10.1	Wed	9:30–10:00	A 151	**Neue Materialien und Komponenten für Energieeffiziente Gebäudehüllen** — •Ulrich Heinemann, Helmut Weinläder, Hans-Peter Ebert, Stephan Weismann
AKE 11.1	Wed	10:15–10:45	A 151	**Ganzheitliche Bewertung von Stromerzeugungssystemen** — •Rainer Friedrich, Markus Blesl
AKE 12.1	Wed	11:15–11:45	A 151	**Electricity by Intermittent Sources** — •Friedrich Wagner
AKE 13.1	Wed	15:00–15:30	A 151	**Fluctuations from photovoltaic and wind power systems** — •Detlev Heinemann, Gerald Lohmann, Mohammed Reza Rahimi Tabar, Mehrnaz Anvari

Sessions

AKE 1.1–1.4	Mon	9:30–11:00	A 151	**Photovoltaics**
AKE 2.1–2.1	Mon	11:30–12:00	A 151	**Solarthermal Energy Systems**
AKE 3.1–3.1	Mon	12:00–12:30	A 151	**Geothermal Energy**
AKE 4.1–4.1	Mon	15:00–15:30	A 151	**Nuclear Fission Energy**
AKE 5.1–5.2	Mon	15:30–16:30	A 151	**Nuclear Fusion Research**
AKE 6.1–6.2	Mon	16:45–17:45	A 151	**Fossile Energy Systems**
AKE 7.1–7.2	Tue	9:30–10:30	A 151	**Bioenergy**
AKE 8.1–8.6	Tue	10:45–12:30	A 151	**Energy Storage I, Mobility, Materials**
AKE 9.1–9.4	Tue	14:00–15:15	A 151	**Energy Storage II**
AKE 10.1–10.2	Wed	9:30–10:15	A 151	**Energy efficient Building envelopes**
AKE 11.1–11.1	Wed	10:15–10:45	A 151	**Integral Assessment of Electricity Generation Systems**
AKE 12.1–12.3	Wed	11:15–12:15	A 151	**Implications of Fluctuating Electricity Generation**
AKE 13.1–13.5	Wed	15:00–16:30	A 151	**Fluctuating Electricity Supply: Modelling of Generation, Backup and Storage (joint Session AKE / DY / SOE)**
AKE 14.1–14.6	Wed	16:45–18:30	MA 001	**Physics of Sustainability and Human-Nature Interactions I (joint with DY, jDPG, BP, AKE) - session accompanying the sympoisum SYPS**
AKE 15.1–15.12	Thu	9:30–12:45	BH-N 243	**Energy Systems (joint session DY/ AKE /SOE)**

Annual General Meeting of the Energy Working Group

The annual general meeting of the energy group will take place during the AKE spring meeting in the Physikzentrum at Bad Honnef on 16 April 2015.

AKE 1: Photovoltaics

Time: Monday 9:30–11:00 Location: A 151

Invited Talk AKE 1.1 *(7)* Mon 9:30 A 151

Perspectives and challenges of thin-film crystalline silicon solar cells on glass — •Bernd Rech[1], Daniel Amkreutz[1], Jan Haschke[1], Stefan Gall[1], Christiane Becker[2], Onno Gabriel[3], and Rutger Schlatmann[3] — [1]Institut Silizium Photovoltaik, Helmholtz-Zentrum Berlin, 12489 Berlin, Germany — [2]Nachwuchsgruppe Nano-Sippe, Helmholtz-Zentrum Berlin, 12489 Berlin — [3]PVcomB, Helmholtz-Zentrum Berlin, 12489 Berlin, Germany

Silicon is an abundant, non-toxic material which has evolved to be the dominating raw material for photovoltaic PV devices today. The world-wide market share of solar cells based on multi- or monocrystalline silicon wafers exceeds 80% in a strongly growing market. However, the high energy demand and costs for the production of silicon wafers gave rise to other silicon solar cell technologies aiming at high conversion efficiencies while using much less high quality crystalline silicon. Only recently, the liquid phase crystallization (LPC) of amorphous or nanocrystalline silicon thin-films directly on a glass substrate has received increased attention for photovoltaics. By using an electron-beam line source or a line shaped laser moving across the substrate the entire silicon precursor film is molten and subsequently recrystallizes. We will present our latest progress in fabricating high quality crystalline silicon thin film solar cells on glass highlighted by efficiencies of 12 % and open-circuit voltages Voc well above 600 mV with a maximum value of 656 mV. So far, such high Voc values have only been achieved on wafer-based silicon solar cells.

AKE 1.2 *(13)* Mon 10:00 A 151

Computational studies of material properties in $CuInSe_2$ photovoltaic solar cell material — Laura Oikkonen[1], Maria Ganchenkova[2], •Ari Paavo Seitsonen[3,4], and Risto Nieminen[1,5] — [1]COMP Centre of Excellence, Department of Applied Physics, Aalto University, Espoo, Finland — [2]Department of Materials Science, National Research Nuclear University, Moscow, Russia — [3]Institut für Chemie, University of Zürich, Switzerland — [4]Département de Chimie, École Normale Supérieure, Paris, France — [5]Dean's Office, Aalto University, Finland

$CuInGaSe_2$ (CIGS) is considered as a highly efficient material in thin film solar cells. In recent years we have performed several studies of the properties of the $CuInSe_2$ (CIS) material, ranging from point defects [1], importance of Se-related defects [2], mass transport in CIS [3], incorporation of Na into CIS [4], and clustering and diffusion of defects [5]. We discuss the relation of our results with the experimental findings and the overall material properties of CIGS.

[1] LE Oikkonen, MG Ganchenkova, AP Seitsonen and RM Nieminen, Journal of Physics: Condensed Matter 23 (2011) 422202
[2] *ibid*, Physical Review B 86 (2012) 165115
[3] *ibid*, Journal of Applied Physics 113 (2013) 133510
[4] *ibid*, Journal of Applied Physics 114 (2013) 083503
[5] *ibid*, Journal of Physics: Condensed Matter 26 (2014) 345501

Invited Talk AKE 1.3 *(10)* Mon 10:15 A 151

Neue optoelektronische Materialien und Verfahren für die Photovoltaik — •Christoph Brabec — iMEET @ Friedrich Alexander University Erlangen Nürnberg

Lösungsprozessierte Halbleiter finden immer mehr Bedeutung in der Entwicklung von optoelektronischen Bauteilen. Diese Klasse von Halbleiter umfasst die organischen Halbleiter, kolloidale Nanokristalle und Nanopartikel als auch hybride Halbleitersysteme. Die gezielte Optimierung der einzelnen Materialsysteme führte zu einer beachtlichen Qualitätssteigerung in diesen Materialklassen, die sich eindrucksvoll in der Effizienzkurve für photovoltaische Bauelemente widerspiegelt. Organische lösungsprozessierte Solarzellen als auch kolloidale Nanopartikelkomposite erreichen Effizienzen von 9 - 11%, hybride lösungsprozessierte Halbleiter wie die Perovskite erreichen Effizienzen von über 20 %. Die kontinuierliche Verbesserung der Halbleiter wird begleitet durch neue Architekturen als auch durch innovative Konzepte in der Lichteinkopplung bzw. Lichtmanipulation, so dass eine weitere stetige Verbesserung in der Performance von gedruckten Solarzellen zu erwarten ist. In diesem Vortrag werden die opto-elektronischen Eigenschaften dieser neuen Halbleitersysteme und deren Verwendung in der Photovoltaik diskutiert. Neue Solarzellen Architekturen, die speziell für die Lösungsprozessierung entwickelt wurden, werden vorgestellt. Erste Applikationen versuchen die Alleinstellungsmerkmale dieser Technologie zur Geltung zu bringen - Eigenschaften wie Transparenz und die Farbgebung spielen hier eine große Rolle.

AKE 1.4 *(20)* Mon 10:45 A 151

Recent progress in organic photovoltaics — •Johannes Widmer, Christian Koerner, and Karl Leo — IAPP (Institut für Angewandte Photophysik), TU Dresden, Germany

Organic solar cells are today manufactured as flexible, light weight "solar films". These modules can be designed in various colors, and they are optionally available as semi-transparent foils. These properties illustrate some of the advantages which organic photovoltaics have over their established inorganic counterparts. And though absolute efficiencies of organic photovoltaics are still below those of silicon solar cells, they have reached a level where their unique characteristics start to make them interesting for commercial applications.

In this contribution, we give a compact overview over the scientific and technological specifics of organic photovoltaics. We outline prevailing topics and challenges in research and development, and discuss promising application scenarios. Thereby we illustrate, why organic solar cells might soon be found in places where today we do not think about photovoltaics yet.

AKE 2: Solarthermal Energy Systems

Time: Monday 11:30–12:00 Location: A 151

Invited Talk AKE 2.1 *(30)* Mon 11:30 A 151

Konzepte zur Kostensenkung solarthermischer Kraftwerke — •Robert Pitz-Paal — DLR, Institut für Solarforschung, Köln, Deutschland

In solarthermischen Kraftwerken werden konzentrierenden Kollektoren dazu verwendet die Hochtemperaturwärme für den Kraftwerksblock bereitzustellen. Es existiert eine Vielzahl von unterschiedlichen Konzepten, in den das Wärmträgermedium entweder direkt im Kraftwerkskreislauf verwendet wird (z.B. Wasserdampf), oder alternativ zunächst in einem Sekundärkreislauf zirkuliert (z.B. Thermoöl).

Bisher sind vor allem Parabolrinnensysteme, die Thermööl als Wärmeträgermedium verwenden, kommerziell erfolgreich. Es werden aber vermehrt auch alternative Ansätze verwendet, die sowohl andere Konzentratorgeometrien (Linear Fresnel Systeme, Turmkraftwerke) als auch andere Wärmeträgerfluide verwenden. Der Vortrag stellt eine Reihe von unterschiedlichen Konzepte vor und versucht diese einzuordnen indem er technologischen Stärken und Schwächen diskutiert.

AKE 3: Geothermal Energy

Time: Monday 12:00–12:30 Location: A 151

Invited Talk AKE 3.1 *(2)* Mon 12:00 A 151
Deep geothermal fluid resources: Energetic use and beyond — •Harald Milsch — GFZ German Research Centre for Geosciences, Telegrafenberg, D-14473 Potsdam, Germany

Unlike countries with or close to volcanic areas Germany is not blessed with high temperature geothermal resources at shallow depths. However, also there deep geothermal energy can yield a significant contribution to the future renewable energy mix once a number of scientific and technical challenges have been overcome. Apart from improved exploration strategies required to drill into productive reservoirs these challenges predominantly relate to characterizing and appropriately handling the energetic resource itself, the geothermal fluid. This fluid, rarely, is simply pure water but rather a compositionally complex aqueous solution containing various dissolved solid and gaseous species at high concentrations that can range up to 300 g/L and several Nm3, respectively. Consequently, a number of fluid-rock-materials interactions may occur when hot fluids are produced from the reservoir, their heat is extracted at the surface, and the cooled fluids are injected back into the formation during a geothermal energy cycle. In this contribution these interactions, the related physico-chemical processes, and ways to control these will be reviewed. Also, it will be discussed to what extent the fluid is valuable beyond heat energy as it relates to the dissolved elements and compounds it contains.

AKE 4: Nuclear Fission Energy

Time: Monday 15:00–15:30 Location: A 151

Invited Talk AKE 4.1 *(8)* Mon 15:00 A 151
Nuclear fission energy: new build, operation, fuel cycle and decommissioning in the international perspective — •Stefan Niessen — AREVA GmbH, Erlangen, Germany

Over 60 nuclear power reactors are in construction today and over 400 are connected to the grid. The presentation will show where. A nuclear new build project involves a team of several thousand people. Some pictures from ongoing new build projects will illustrate this. Using concrete examples from the AREVA group, the nuclear fuel cycle from uranium mines in Niger, Kazakhstan or Canada to chemical conversion, enrichment and fuel manufacturing will be explained. Also the recycling of used fuel and the fabrication of MOX fuel is addressed. The presentation closes with an overview on decommissioning and final storage projects.

AKE 5: Nuclear Fusion Research

Time: Monday 15:30–16:30 Location: A 151

Invited Talk AKE 5.1 *(6)* Mon 15:30 A 151
Wendelstein 7-X , ein Konzept für ein stationäres Fusionsplasma — •Robert Wolf und W7-X Team — Max-Planck-Institut für Plasmaphysik, Wendelstein-Str. 1, 17491 Greifswald

Ziel der internationalen Fusionsforschung ist die Entwicklung der Grundlagen für ein erstes Fusionskraftwerk. Wichtige Elemente dieser Entwicklung sind die Fusionsexperimente ITER und Wendelstein 7-X. ITER soll erstmalig ein brennendes Fusionsplasma mit einer positiven Leistungsbilanz erzeugen. Wendelstein 7-X beruht auf dem Stellarator-Prinzip, welches für den magnetischen Einschluss eines Hochtemperaturplasmas, anders als beim Tokamak ITER, ohne einen toroidalen Plasmastrom auskommt und damit intrinsisch stationär betrieben werden kann. Ziel dieses weltweit am weitesten entwickelten Stellarator-Experiments ist nachzuweisen, dass die Vorteile des stationären Einschlusses mit der Einschlussqualität eines Tokamaks kombiniert werden können. Nach Abschluss der Montage wird Wendelstein 7-X derzeit auf den experimentellen Betrieb vorbereitet. Erste Plasmaexperimente sind Mitte 2015 geplant. Bis 2019 soll Wendelstein 7-X schrittweise ausgebaut und auf Plasmen mit 10 MW Heizleistung und Pulsdauern bis zu 30 Minuten vorbereitet werden. Der Vortrag erklärt die technische Inbetriebnahme von Wendelstein 7-X, erläutert die Planung erster Experimente und diskutiert abschließend die Perspektiven für ein Fusionskraftwerk auf Basis des Stellarator-Prinzips.

Invited Talk AKE 5.2 *(11)* Mon 16:00 A 151
Laserfusion: status and concepts for new laser drivers and ignition physics — •Bjorn Manuel Hegelich — University of Texas at Austin, Austin, TX, USA

Laser Fusion or more generally, Inertial Confinement Fusion (ICF) is one of the two big options for energy from controlled fusion in the laboratory and ultimately a power plant and its successful development would be a game changer with regards to the world*s energy challenges. Coordinated, large laser fusion / ICF programs are underway in several countries, including the USA, France, China, and Russia, and have encountered both progress and setbacks in the recent years. Several large dedicated fusion laser facilities have been constructed worldwide or are currently under construction, such as the National Ignition Facility (NIF) in the US, the Laser MegaJoule (LMJ) in France, the Shenguan-III and *IV lases in China as well as a 2.8MJ laser system in Russia. At the same time, laser technology is making rapid progress in many sub-fields, especially direct diode pumping of ceramic laser media and offers new possibilities for laser drivers for both research installations and power plant concepts. This talk will give an overview over the status and trajectory of the different laser fusion programs worldwide as well as highlight recent challenges, open questions and new concepts in both ignition physics and driver development.

AKE 6: Fossile Energy Systems

Time: Monday 16:45–17:45 Location: A 151

Invited Talk AKE 6.1 *(9)* Mon 16:45 A 151
"Fracking"- Routine oder Risikotechnologie? — •Michael Kosinowski — Bundesanstalt für Geowissenschaften und Rohstoffe Hannover

Die "hydraulische Bohrlochbehandlung" ist genau genommen ein Verfahren zur Behandlung des Gesteins außerhalb des Bohrlochs. Bei diesem Verfahren wird ein Fluid mit so hohem Druck in das Gestein gepresst, dass die Gesteinsfestigkeit überschritten wird und sich Risse bilden. Über diese Risse können Gase und Flüssigkeiten aus den Gesteinsporen in das Bohrloch fließen. Wenn die Risse groß genug sind und die Porenfüllung hinreichende Zuflüsse ermöglichen, können so Erdgas, Erdöl oder warmes Wasser für Heizzwecke in wirtschaftlich interessanten Mengen aus Gesteinen gewonnen werden, deren natürliche Durchlässigkeit dafür zu gering wäre.

Unter dem Namen Fracking ist die hydraulische Bohrlochbehandlung in das öffentliche Interesse und in die Kritik geraten. Während die Befürworter angesichts einer seit Jahrzehnten üblichen Technologie von routinemäßigen Anwendungen sprechen, sehen die Kritiker darin

ein hohes Risiko. Kann es gelingen, zwischen diesen beiden Positionen zu vermitteln?

Invited Talk AKE 6.2 *(5)* Mon 17:15 A 151
Geological carbon storage: processes, risks and opportunities — •Holger Ott — Shell Global Solutions International B.V., 2288 GS Rijswijk, The Netherlands — Imperial College London, London SW7 2AZ, United Kingdom

Due to the growing global demand for energy and the relatively slow transition to a sustainable energy source, the combustion of carbon-based fuels will remain our major energy source for the coming decades. In order to achieve climate targets, transition technologies are required to reduce CO_2 emissions during this period. Carbon Capture and Storage (CCS) is such a technology with a high potential to reduce greenhouse-gas emissions, and potentially even achieve a negative CO_2 footprint – i.e. an active transfer of CO_2 into the long-term carbon cycle. While for CO_2 capture and transport, cost efficiency is the main issue, subsurface storage is focused on storage capacity and storage safety. With this in mind we are investigating plume migration and trapping mechanisms in the confined pore space of deep saline aquifers and depleted hydrocarbon reservoirs in order to assess the performance and risks of injection operations. In the presentation, CCS will be discussed in relation to energy demand, ongoing injection operations and 'Clean Fossil Fuels'. The presentation will illustrate the relevant subsurface fluid-displacement and trapping mechanisms, and how the investigation of subsurface processes and the support of operations are addressed through industrial/academic R&D collaboration.

AKE 7: Bioenergy

Time: Tuesday 9:30–10:30 Location: A 151

Invited Talk AKE 7.1 *(12)* Tue 9:30 A 151
Optionen und Trends der Biomassenutzung: Perspektiven für die Bioenergie 2050 — •Jens Ponitka[1] und Daniela Thrän[1,2] — [1]Deutsches Biomasseforschungszentrum gemeinnützige GmbH — [2]Helmholtz-Zentrum für Umweltforschung - UFZ

Vor dem Hintergrund weltweiter Trends wird sich auch weiterhin zunehmend die Energieversorgung umstellen müssen. Bioenergie ist derzeit und gilt auch zukünftig als ein wichtiges Element erneuerbarer Energieversorgung mit hohem Treibhausgasminderungspotenzial, sie steht jedoch wie keine andere erneuerbare Option im Spannungsfeld der öffentlichen Debatte aufgrund vielfältiger Anforderungen und Konkurrenzen.

Der Beitrag gibt einen Überblick über die globale energetische Biomassenutzung. Am Beispiel verschiedener Bioenergiebereitstellungsketten werden Einblicke in technische, logistische und organisatorische Aspekte und Spannungsfelder der Bioenergie bezüglich der Biomassebereitstellung, des Transports, der Konversion und Endnutzung gegeben. Anschließend wird am Beispiel der Biokraftstoffproduktion auf das Problem der direkten und indirekten Landnutzungsänderungen eingegangen. Globale Trends, aber auch national unterschiedliche, politische Rahmenbedingungen oder auch die lokalen Gegebenheiten können zukünftig die Prioritäten, Möglichkeiten und Grenzen der Biomassenutzung verschieben. Mit Ausblicken auf andere stofflich-industrielle Nutzungen und weiter zu erforschenden und umzusetzenden Synergieeffekten werden im Beitrag die wichtigsten Eckpunkte für eine integrierte Bioenergiebereitstellung abgeleitet.

Invited Talk AKE 7.2 *(3)* Tue 10:00 A 151
Rational design of cyanobacteria for hydrogen production — •Sascha Rexroth — Lehrstuhl für Biochemie der Pflanzen, Ruhr-Universität Bochum, Bochum, Germany.

The solar-driven hydrogen production has tremendous potential as renewable and carbon-neutral energy source, since the substrate, water, and the energy source, sunlight, are virtually unlimited. Cyanobacteria, which perform oxygenic photosynthesis, can under certain conditions produce hydrogen using electrons extracted from water. Our goal is to improve the efficiency of hydrogen generation at the expense of biomass production. An important part is the efficient coupling of the linear photosynthetic electron transport from water to an imported, engineered hydrogenase. For this coupling the photosynthetic electron metabolism has to be engineered in many individual steps towards this goal. Engineering of ferredoxin-dependent pathways is a decisive step for re-routing electrons from water for hydrogen production instead of CO2-fixation. Optimization of photobioreactor systems and improved fermentation conditions are integral parts of the process design. Optimal culture conditions can be found and kept constant for several months by using continuous cultivation techniques which allow the systematic optimization of each individual parameter. Provided such systems are optimized both on the individual cell level and on the systems level, a more than 100-fold increase of hydrogen production in comparison with the most productive natural systems existing to date can be estimated, which would be a promising basis for an economically competitive H2 production.

AKE 8: Energy Storage I, Mobility, Materials

Time: Tuesday 10:45–12:30 Location: A 151

Invited Talk AKE 8.1 *(31)* Tue 10:45 A 151
Energiespeicher für die Elektromobilität - Perspektiven und Limitierungen — •Margret Wohlfahrt-Mehrens — ZSW - Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Baden-Württemberg, D-89081 Ulm

Die Verfügbarkeit leistungsstarker, bezahlbarer, umweltfreundlicher und sicherer elektrischer Energiespeicher ist eine Schlüsseltechnologie sowohl für die Elektromobilität als auch für die Zwischenspeicherung regenerativer Energien. Stand der Technik sind Lithium-Ionen-Batterien, die bisher noch nicht vollständig den Anforderungen der Anwender entsprechen. Eine signifikante Erhöhung der Energiedichte und eine weitere Reduktion der Kosten sind dabei zentrale Stellhebel für eine breitere Anwendung dieser Technologie im Fahrzeugmarkt. Es ist allgemein akzeptiert, dass weitere Technologiedurchbrüche nur durch koordinierte, ganzheitliche und interdisziplinäre Herangehensweisen erreicht werden können. Der Vortrag gibt einen Überblick über den Stand der Technik, Perspektiven und Limitierungen elektrischer Energiespeicher und den daraus abgeleiteten Forschungs- und Entwicklungsbedarf.

AKE 8.2 *(21)* Tue 11:15 A 151
Understanding the conversion reaction in Cu_3P anode material of Li-ion batteries — •Jatinkumar Rana[1], Marian Stan[2], Richard Kloepsch[2], Jie Li[2], Gerhard Schumacher[1], Martin Winter[2], and John Banhart[1,3] — [1]Helmholtz-Zentrum Berlin — [2]MEET Battery Research center, Münster — [3]Technische Universität Berlin

We investigate structural changes in Cu_3P anode material by X-ray Absorption Spectroscopy (XAS). The material was synthesized via a wet mechanochemical route and demonstrated a satisfactory electrochemical performance. XAS data were recorded at various states of charge and discharge of the Cu_3P/Li cell. The overall electrochemical reaction can be represented by: $Cu_3P + 3Li \leftrightarrow Li_3P + 3Cu$. During discharge, lithium insertion into the Cu_3P phase is observed to occur by substituting Cu^+ in the structure with Li^+, giving rise to the formation of a series of intermediate phases such as $LiCu_2P$, Li_2CuP and finally Li_3P and nano particles of elemental copper. During subsequent charge, oxidation of elemental copper occurs and the resultant Cu^+ displaces Li^+ in the structure, giving rise to the reformation of the original Cu_3P phase. The close structural resemblance between Cu_3P and the end member Li_3P and the formation of extremely small-sized copper particles, are believed to be the reasons for the reversible nature of the conversion reaction in the material.

AKE 8.3 *(18)* Tue 11:30 A 151

Plasma-assisted synthesis of hydrogenated TiO2 for energy storage and conversion — Yong Yan, •Dong Wang, and Peter Schaaf — Chair Materials for Electronics, Institute of Materials Engineering and Institute of Micro- and Nanotechnologies MarcoNano, TU Ilmenau, Gustav-Kirchhoff-Str. 5, 98693 Ilmenau. Germany

In this study, hydrogenated TiO2 (H-TiO2) with distinct physical and chemical properties are controlledly synthesized through hydrogen (H2) plasma treatment, which exhibit excellent performance in the application for lithium ion batteries, photocatalysis, and photothermal conversion. Moreover, the microstructure of H-TiO2, and their dependence on the application performance of H-TiO2 are comprehensively investigated. It is believed that these research is highly favorable for the development of high-performance and versatile TiO2 materials for energy storage and conversion devices.

AKE 8.4 *(16)* Tue 11:45 A 151

Study of polymerization of Acetonitrile as a probable ageing mechanism in supercapacitors — •Nasim Tavakoli[1,2], Alexander. M. Bittner[1,3], and Monika Goikoetxea[1] — [1]CICnanoGUNE, Donostia-San Sebastiań, Spain — [2]University of Basque Country (UPV/EHU), Donostia-San Sebastiań, Spain — [3]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

Supercapacitors are electrochemical double layer capacitors which have much higher specific energy than conventional electrolytic capacitors and also significantly larger specific power than rechargeable batteries. Although supercapacitors have a very high number of cycle life, ageing mechanisms will eventually decrease their capacity and consequently increase the equivalent series resistance of the system. One of the various probable ageing mechanisms is polymerization of acetonitrile. Acetonitrile is used as the solvent in the structure of the supercapacitors. In this work we intend to investigate the production of polyacetonitrile in a controlled replicated environment and it's role in the ageing of supercapacitors.

AKE 8.5 *(17)* Tue 12:00 A 151

Photoluminescence and hydrogen storage properties of gallium nitride hexagonal nano-sheets — •Ghulam Nabi[1,2], Yong Lei[1], and Abdul Majid[2] — [1]Institute of Physics & Institute of Micro- and Nanotechnologies (ZIK MacroNano), Technische Universität Ilmenau, 98693 Ilmenau, Germany — [2]Department of Physics, University of Gujrat, Gujrat, Pakistan

A novel morphology of gallium nitride (GaN) hexagonal nano-sheets (HNSs) have been synthesized by chemical vapor deposition (CVD) method at 1200 °C. Photoluminescence (PL) and hydrogen storage capabilities of hexagonal nano-sheets (HNSs) at different temperatures have been investigated first time. Maximum hydrogen storage capacities of 1.45wt%, 1.71wt% and 2.12 wt% have shown an increasing trend of hydrogen absorption capacity with increasing temperature at a fixed pressure of 5MPa. During desorption process under ambient pressure, about 79%, 79% and 78% releasing of the stored hydrogen has been noted at 100 °C, 200 °C and 300 °C respectively. Highly reversible absorption/desorption results exhibited by GaN HNSs are encouraging and promising for hydrogen storage applications. The PL spectrum has exhibited strong near-band-edge emission at 367 nm (3.38 eV). Defects related broad yellow band emission at 553 nm (2.24 eV) has also been observed, which plays significant role in the hydrogen absorption. The effect of hydrogen absorption on PL properties of GaN HNSs has also been studied that showed H2 absorption has a passivation effect on the point defects or impurities.

AKE 8.6 *(1)* Tue 12:15 A 151

Energie, Mobilität und Umwelt — •Klaus Hofer — Uni Bielefeld, W.-Bertelsmannstr. 10, 33602 Bielefeld

Umweltverschmutzung, Erderwärmung und Naturkatastrophen sind die unübersehbaren Folgen unseres maßlosen Konsum- und Mobilitätsverhaltens. Anstatt dieser dramatischen Entwicklung endlich entgegenzuwirken, werden weiterhin neue Autobahnen und Flughäfen gebaut, damit sich das Verkehrsaufkommen in den nächsten zehn Jahren verdoppeln kann. Dabei wird selbst von Experten allzu gerne verdrängt, dass sich dieser ökologischer Wahnsinn weder mit regenerativer Energieerzeugung, intelligenten Netzen, alternativen Wasserstoff- und Batteriesystemen noch mit Hybridantrieben oder durch Effizienzsteigerung der Komponenten stoppen lässt. Der Schlüssel für einen nachhaltigen Umgang mit unserer Umwelt liegt daher ausschließlich in der konsequenten Umsetzung der ökologischen Formel *Je langsamer, leichter und spartanischer ein Fahrzeug ist, desto umweltfreundlicher sind seine Herstellung und sein Betrieb*. Aus diesen Gründen ist der drastische Verzicht auf Geschwindigkeit, Gewicht und Luxus die einzige Alternative gegen den gegenwärtigen Raubbau an der Umwelt. Doch ökologisches Denken und Handeln setzt voraus, dass man die Grenzlinie zwischen umweltfreundlicher und umweltschädlicher Fortbewegung kennt und umsetzt. In diesem Beitrag wird dieses wichtige Umweltkriterium exakt in Kilowattstunden pro Strecke und Person hergeleitet. Für die Berechnung werden sowohl der personenbezogene Energieverbrauch einiger gängiger Verkehrsmittel als auch der ökologische Fußabdruck verschiedener Länder herangezogen.

AKE 9: Energy Storage II

Time: Tuesday 14:00–15:15 Location: A 151

Invited Talk AKE 9.1 *(32)* Tue 14:00 A 151

Power to Gas - an economic approach ? — •Manfred Waidhas — Siemens AG, PD LD HY, 91058 Erlangen, Germany

The reduction of CO2 emissions is clearly linked with the extension of renewable energies (RE). However, due to the volatile character of its power generation there will be an increasing mismatch between generation and demand. The storage of excess production will become essential in the future in order to prevent increasing curtailment of wind and PV installations and to enable an economic viable scenario with renewables.

It is very clear that grid extension and demand side management will come prior to energy storage. But the estimated storage demand in a 85 % RE scenario - as targeted for Germany in 2035 - will be in the TWh range.

There are many concepts and technologies to store electric energy. Among the three options for large- scale storage * pumped hydro, compressed air and hydrogen - hydrogen is the only viable option to address capacities >10 GWh. Enabling component is the electrolyzer technology, converting electrical energy into hydrogen, a multifunctional chemical energy carrier.

This concept - power to gas - has raised big resonance on one side, but contradictory discussions on the other hand. This presentation addresses all the disputed arguments. It will illustrate the technology, its pros and cons and its limitations. Stress will also be laid on the economic viability in the current and future power generation market.

AKE 9.2 *(19)* Tue 14:30 A 151

CO_2 Methanation with different gas mixtures — •Fabian Rachow, Johannes Israel, Carola Schwiertz, Evgenia Charlafti, Klaus Müller, and Dieter Schmeisser — Brandenburg University of Technology, Applied Physics and Sensors, Konrad-Wachsmann-Allee 17, 03046 Cottbus, Germany

A key issue in the Energiewende in Germany is the storage of excess energy, as it enables energy management systems to react to fluctuating sources and enhances the flexibility of an energy mix. Power to Gas may be the most reasonable approach to store the energy in the form of hydrogen or synthetic natural gas.

We study the direct conversion of CO_2 by the Sabatier reaction to gain a methane based mixture which can replace natural gas in CHP plants and gas motors and can help to partially reduce the CO_2 emission. In laboratory scale we investigated the performance (with IR and QMS) of Ni-based catalyst for different sources of CO_2 like clean CO_2, CO_2 emitted as flue gas from an Oxyfuel power plant or a synthetic mixture with O_2, N_2 and SO_2 in concentration typical for conventional power plants. Measurements from an up-scaled system are also presented, showing data important for a technical application. Here, we are able to convert more than 200kg CO_2/day with conversion rates up to 90%.

AKE 9.3 *(15)* Tue 14:45 A 151

Ionic Conductivity of Sodium based Electrolytes — •Kaustubh Bhat, Stefan Blügel, and Hans Lustfeld — Pe-

ter Grünberg Institut (PGI-1) and Institute for Advanced Simulation (IAS-1), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany

Sodium ionic conductors (SICs) are currently receiving renewed attention in the search for electrolytes that possess better ionic conductivity than the materials presently in use. Owing to their lower cost and abundant availability, SICs offer significant advantages over lithium ion batteries for application in large scale energy storage systems. The class of sodium phosphates and thiophosphates (Na_3PO_4, Na_3PS_4) and the class of NASICON materials are known from experiments to contain electronic insulators with good ionic conductivities [1]. To get an insight into the mechanism of ionic transport we determine in particular the energy barriers of ionic hopping for the following situations: i) several pathways, ii) several pressures [2], and iii) replacement of sodium ions by potassium ions. The aim is to detect from these results materials that have smaller energy barriers, and thus better ionic conductivity.

[1] M. Guin and F. Tietz, J. Power Sources **273**, 1056 (2015).
[2] J. A. Hirschfeld and H. Lustfeld, Phys. Rev. B **84**, 224308 (2011).

AKE 9.4 *(24)* Tue 15:00 A 151

Self restriction oft the Sabatier reaction in large scale — •Johannes Israel, Fabian Rachow, Carola Schwiertz, Evgenia Charlafti, Klaus Müller, and Dieter Schmeisser — Brandenburg University of Technology, Applied Physics and Sensors, Konrad-Wachsmann-Allee, 03046 Cottbus, Germany

A main goal for a sustainable energy supply is a long term energy storage system. One opportunity in this research field is the power to gas concept, where the produced gas can be fed in the existing network of natural gas. Here we show in a technical scale how the direct CO_2 conversion to methane according the Sabatier reaction, $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$, is self organized. At a certain limit of gas flow, a steady state equilibrium of exothermic heat production and thermal flow is reached and the reaction needs no further external annealing. We find for the maximum volume rate at the steady state equilibirum a shift of around 250 °C above the optimized temperature of the catalytic supported chemical equilibrium. It is shown that also with this setup the used catalyst works with a stable conversion higher than 80 % under the reached temperature and given pressure conditions.

AKE 10: Energy efficient Building envelopes

Time: Wednesday 9:30–10:15 Location: A 151

Invited Talk AKE 10.1 *(29)* Wed 9:30 A 151

Neue Materialien und Komponenten für Energieeffiziente Gebäudehüllen — •Ulrich Heinemann, Helmut Weinläder, Hans-Peter Ebert und Stephan Weismann — Bayerische Zentrum für Angewandte Energieforschung, Am Galgenberg 87, 97074 Würzburg

Energieeffizienzmaßnahmen in Wohngebäuden setzen vor allem an einer Reduzierung der Transmissionswärmeverluste der Gebäudehülle an. Neben dem verstärkten Einsatz konventioneller Dämmmaterialien können neue Materialien und Komponenten weitergehende Lösungen bieten, die insbesondere unter dem Gesichtspunkt des hierfür benötigten Raums effizienter sind, aber auch neue technische und gestalterische Möglichkeiten eröffnen.

Der durch einen Temperaturgradienten hervorgerufene Wärmetransport setzt sich zusammen aus dem Wärmetransport durch Konvektion, Wärmeleitung und Infrarotstrahlungstransport. Konvektion, ein sehr effektiver Wärmetransportmechanismus, wird auch von konventionellen Dämmmaterialien bereits hervorragend unterdrückt. Bei der Wärmeleitung sind zu unterscheiden die Beiträge über das Festkörpergerippe und durch das Gas. Da ruhende Luft im Vergleich zu Festkörpern eine sehr niedrige Wärmeleitfähigkeit aufweist, sind Dämmstoffe im Allgemeinen hochporös. Der Gesamtwärmetransport wird jedoch wesentlich bestimmt und dominiert von der Wärmeleitung dieses ruhenden Gases. Verbesserungen der Dämmeigenschaften setzen insbesondere an einer Verringerung der Gaswärmeleitfähigkeit an.

Verbesserungs- und Optimierungsansätze werden anhand neuer Systeme erläutert.

AKE 10.2 *(14)* Wed 10:00 A 151

City Density and CO2 Efficiency — •Ramana Gudipudi[1], Till Fluschnik[1], Anselmo Cantu[1], Carsten Walther[1], and Juergen Kropp[1,2] — [1]Potsdam Institute for Climate Impact Research, Potsdam 14473, Germany — [2]University of Potsdam, Department of Geo- and Environmental Sciences, Potsdam 14469, Germany

Previous research on the relationship between population density and greenhouse gas (GHG)emissions often yielded mixed results majorly because of the ambiguity in defining the city boundaries and the emission inventories used. In this paper we suggest a methodology for calculating this relationship using the gridded CO2 emissions data and the City Clustering Algorithm (CCA). We found sublinear relationship between population density and the total emissions (sum of on-road and building emissions) on a per capita basis where ß value ranges between -0.62 to -0.88 depending on the land use data used and the threshold distance in the CCA which means doubling the population density will improve the CO2 efficiency by atleast 35%. Furthermore, we found out that population density impacts on-road emissions more than the emissions from buildings which are more influenced by the local climate. At a county scale within selected MSA*s, we found out that building emissions increased and on-road emissions decreased pointing out towards a potential threshold density beyond which the building emissions surpass the emissions from on-road emissions on a per capita basis. Our results suggest that decreasing urban population density worldwide will lead to an increase in on-road energy consumption.

AKE 11: Integral Assessment of Electricity Generation Systems

Time: Wednesday 10:15–10:45 Location: A 151

Invited Talk AKE 11.1 *(4)* Wed 10:15 A 151

Ganzheitliche Bewertung von Stromerzeugungssystemen — •Rainer Friedrich und Markus Blesl — Inst. für Energiewirtschaft und Rationelle Energieanwendung Universität Stuttgart

Energiepolitisches Handeln sollte die Verbesserung der Erhaltung der natürlichen Lebensgrundlagen sowie der wirtschaftlichen und sozialen Entwicklung simultan anstreben. Da hierbei häufig Zielkonflikte auftreten, ist eine Gewichtung bzw. Abwägung von Zielerfüllungsgraden erforderlich. Tatsächlich werden energiepolitische Entscheidungen allerdings meist intuitiv getroffen, dabei wird das multikriterielle Entscheidungsproblem stark vereinfacht, wodurch suboptimale Entscheidungen entstehen. Hier wird dagegen vorgeschlagen, Methoden zur ganzheitlichen Bewertung (integrated assessment) zu verwenden, um energiepolitische Entscheidungen zu unterstützen. Dabei werden Klima-, Umwelt- und Gesundheitsschäden durch Umwelteinwirkungen zunächst abgeschätzt und dann monetär bewertet. Im Ergebnis erhält man soziale Kosten, diese umfassen als Summenindikator sowohl die Kosten als auch Umwelt-, Gesundheits- und Klimaschäden eines Energiesystems. Die Methode wird hier zur ganzheitlichen Bewertung von Stromerzeugungssystemen genutzt. Es ergibt sich eine Rangfolge der verschiedenen Stromerzeugungstechnologien hinsichtlich ihres Beitrags zur nachhaltigen Entwicklung; zusätzlich wird der optimale Mix der Technologien ermittelt. Ein besonders effizientes energie- und umweltpolitisches Instrument zur Umsetzung ist die Internalisierung externer Effekte über Steuern.

AKE 12: Implications of Fluctuating Electricity Generation

Time: Wednesday 11:15–12:15 Location: A 151

Invited Talk AKE 12.1 *(26)* Wed 11:15 A 151
Electricity by Intermittent Sources — •Friedrich Wagner — Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

We describe the major characteristics of an electricity supply system being predominantly composed of the scalable renewable energy (RE) forms wind and photovoltaic power. The analysis is mostly based on the actual production data of 2013 from the German electricity system. The 2013 data will be scaled to larger shares of RES in the electricity production up to the 100% case where RES integrally generate as much electricity as consumed during a year. The 100% case is then analysed according to the proper mix of wind and PV power, the extent of installed power, the remaining residual back-up power, the dynamics of the back-up system, the size of storage, the conditions for demand-side-management, the CO2-reduction in comparison to other supply forms and finally with regard to some cost issues. Similar analyses are carried out for some European countries using only their national RE-power field. A rough picture emerges on the viability of using RES in Europe. Finally, an EU-wide RE power field is constructed from the superposition of the national contributions. This allows to assess the reduction of the degree of intermittency and the necessary interconnection capacity to benefit from this effect.

AKE 12.2 *(28)* Wed 11:45 A 151
Transient stability of conventional power generating stations during times of high wind penetration — •Marios Zarifakis[1] and William T. Coffey[2] — [1]Electricity Supply Board, Generation, Asset Management, Dublin, Ireland — [2]Department of Electronic and Electrical Engineering, Trinity College, Dublin, Ireland

The requirement to increase the level of energy produced from sustainable sources resulted in wind turbine generators and solar photo voltaic installations becoming major contributors into the energy pool. However, studies, recent measurements and experience in the island of Ireland show that the increase of these generation sources influences the ability of the frequency in the transmission and distribution system to remain stable after a transient disturbance. This weakening of the grid frequency strength is observed by an increase of the Rate of Change of Frequency (ROCOF). Furthermore, the frequency of the transmission system oscillates in a higher frequency range which triggers further oscillations in transmission connected synchronous generators. The development of an understanding of the behaviour of synchronous generators, connected to such a system with high wind penetration during transient disturbances, required a new modelling technique. A mechanical analogy and model was developed and verified using electromagnetic models in MATLAB and proven by comparing it with actual measurements on various generators. It highlights limitations to the operational range of synchronous generators and also limits to the amount of grid connected non synchronous generators used in wind turbine and solar PV installations.

AKE 12.3 *(22)* Wed 12:00 A 151
On the Improvement of Numerical Weather Prediction by Assimilation of Wind Power Data — •Stefan Declair, Klaus Stephan, and Roland Potthast — Deutscher Wetterdienst, Frankfurter Straße 135, 63067 Offenbach, Germany

It is a demanding task for the transmission system operators (TSOs) to predict the amount of weather dependent renewabe energy in terms of net stability and power supply safety. In the BMBI funded project EWeLiNE, the German Weather Service and the Fraunhofer Institute on Wind Energy and Energy System Technology strongly support the TSOs by developing innovative weather- and power forecasting models and tools for grid integration.

With focus on wind energy, this contribution sketches the way of using wind power data from the growing amount of wind farms in Germany to improve the wind forecast in the planetary boundary layer via data assimilation (DA). This part of the atmosphere is important to observe, since it is heavily underobserved by conventional observation networks. Additionally, it is difficult to describe the strong spatiotemporal fluctuations in the numerical weather prediction (NWP) model properly. The concept of DA provides an improved initial atmospheric state for the subsequent NWP model integration in terms of a best-fit according to observations and model background and is a crucial part in NWP.

After a short introduction, the DA system is shortly introduced and first results of improved wind forecasts from impact experiments are discussed.

AKE 13: Fluctuating Electricity Supply: Modelling of Generation, Backup and Storage (joint Session AKE / DY / SOE)

Time: Wednesday 15:00–16:30 Location: A 151

Invited Talk AKE 13.1 *(27)* Wed 15:00 A 151
Fluctuations from photovoltaic and wind power systems — •Detlev Heinemann[1], Gerald Lohmann[1], Mohammed Reza Rahimi Tabar[2], and Mehrnaz Anvari[2] — [1]Universität Oldenburg, Institut für Physik, AG Energiemeteorologie & ForWind — [2]Universität Oldenburg, Institut für Physik, AG TWiSt & ForWind

Solar and wind resources vary considerably in time and space, and changes in their magnitude are almost immediately translated into output power variations of wind and solar power plants. Analyzing the stochastic properties of wind and solar resources in different temporal and spatial scales is therefore a necessary step towards a proper representation of these contributions to large scale power systems.

This presentation describes known stochastic properties of wind and solar resources as well as reports on current studies of (i) their conditional probability distribution functions in different time lags and (ii) increment statistics of large-scale wind and solar production.

Conditional distribution functions show severe deviations from Gaussian statistics and possess positive skewness, while the risk of flickering events in both wind and solar generally increases with parameters as wind speed and solar elevation, respectively. Spatial averaging significantly influences this behavior. The comparison of wind and solar power fluctuations is strongly affected by the presence of a deterministic contribution in the solar part. Applying a detrending approach for the solar data results in an significant improvement of the solar increment statistics.

AKE 13.2 *(33)* Wed 15:30 A 151
Facing Europe: Revised wind power upscaling algorithms — •Bruno Schyska, Lüder von Bremen, and Alexander Kies — University Oldenburg - ForWind, Oldenburg, Germany

In the wind energy sector, upscaling models are used to estimate the total wind energy production within a certain region from a small number of reference sites. Each reference site is considered to be representative for a certain sub-region. Upscaling models therefore include selection schemes for the reference sites as well as statistical, partly non-linear, models to estimate the energy production in the sub-regions. Until now, upscaling models are mainly used on country level. For larger areas such as Europe no operational model and no research model exist.

In this study, revised upscaling models for the estimation of near real-time wind energy production in Europe are presented. These models include different approaches for the estimation of the energy production in the sub-regions as well as different selection schemes for the reference sites using cluster analyses. Cluster analyses are based on wind speed data from the MERRA reanalysis data set as well as on the geographical distribution of installed wind energy capacities in Europe. From the comparison, the selection scheme, which requires the minimal number of reference sites, is selected for long-term investigations of the wind energy production in Europe.

AKE 13.3 *(23)* Wed 15:45 A 151
Backup flexibility classes in complex renewable energy net-

works — •David Schlachtberger[1], Sarah Becker[1], Stefan Schramm[1], and Martin Greiner[2] — [1]Frankfurt Institute for Advanced Studies, Uni Frankfurt, Frankfurt am Main, Germany — [2]Department of Engineering, Aarhus University, Aarhus, Denmark

How large will be the demand for more flexible backup plants in an European power system with an increasing share of fluctuating renewable energies? We use eight years of high resolution weather-based wind and solar power generation data to split the backup systems required to cover the residual load into three flexibility classes for daily, weekly, and seasonal time-scales. They are distinguished by the maximum rates of change of their power output. We find that a large fraction of seasonally and weekly flexible backup systems can no longer be reasonably integrated above a penetration of renewables of around 50% and 90% of the mean load, respectively. We also find that the total required backup capacity can only be reduced if countries share their excess generation and backup power.

AKE 13.4 *(34)* Wed 16:00 A 151

Dimensioning the Minimal Storage Needs in Renewable Power Systems — •Stefan Weitemeyer, David Kleinhans, and Carsten Agert — NEXT ENERGY · EWE Research Centre for Energy Technology at the University of Oldenburg, Germany

Integrating a high share of electricity from non-dispatchable Renewable Energy Sources (RES) in a power supply system is a challenging task; it will likely require large-scale installations of costly storage capacities.

We present a modelling approach to investigate which storage characteristics are most adequate for scenarios with high shares of RES. Adapted from an optimization approach, the model allows to systematically study the influence of important storage parameters (size, efficiency, power) on the integration of RES. In particular, the implications of simultaneously using multiple storage classes in combination with fossil back-up power plants can be investigated.

Applying our model to data for Germany, our simulations show how an extensive integration of RES requires different storage characteristics during different phases of the pathway towards a 100% RES scenario. The results also imply that a balance between installing storage capacities and additional generation capacities is required.

AKE 13.5 *(25)* Wed 16:15 A 151

The temporal development of storage needs in the European energy transition — •Alexander Kies, Lüder von Bremen, and Bruno Schyska — ForWind, Universität Oldenburg, Oldenburg

Europe is on the way towards a highly renewable energy system. In 2012 23.5% of the gross electricity consumption in the EU-28 was produced from renewable sources. This share is expected to increase further up to very high penetration levels close to 100% in the next decades. To ensure reliability and stability of the power system several solutions to the generation-load-mismatch problem have been proposed like over-installation of renewables, transmission capacity extensions and the use of storages. In this work we investigate the development of storage needs in 34 European countries for different transmission grid scenarios until 2050. A large weather data set with a spatial resolution of 7 x 7 km and a hourly temporal resolution covering Europe is used to model the fluctuating feed-in from the renewables, i.e. wind, photovoltaics, hydro, concentrated solar power and wave. Additionally the controllable renewable generation types biomass and geothermal were considered. Starting from the renewable shares in the year 2012 we model the increase in renewable capacities in a linear and a logistic way until levels of 100% in 2050 for different transmission grid scenarios and calculate the storage needs for every year. The remaining generation shares to cover the load are assumed to come from conventional generation. We show that storage needs are unlikely to grow rapidly until 2030, but thereafter are of high importance. However, this process can be slowed down considerably by transmission grid extensions.

AKE 14: Physics of Sustainability and Human-Nature Interactions I (joint with DY, jDPG, BP, AKE) - session accompanying the sympoisum SYPS

Time: Wednesday 16:45–18:30 Location: MA 001

Topical Talk AKE 14.1 *(43)* Wed 16:45 MA 001

The Industrial Society's natural Sustainability — •Hans G. Danielmeyer and Thomas Martinetz — Institut für Neuro- und Bioinformatik, Uni Lübeck

Human nature and industrial engineering form a predictable macrosystem with six S-functional variables and biologically stabilized parameters [1]. S-functions display storing lifetimes with time shifts like Sinus functions with phase shifts. Since 18th century UK the real GDP per capita increased 100-fold; only a factor of 2.7 yields for the G7 the biologic limit of 118 years for the life expectancy.

This is orders of magnitude below all earlier predictions. The industrial society will be materially sustainable. But the present financial system is unsustainable because saturating growth and interest rates dry out saving, life insurances, and pension funds. This caused the Great Depression and the crash of 2008, not neoclassical excuses [2]. The only cure is bringing finance in line with human biology: return to the sustainable income distribution between Word War II and 1980; increase retirement age; continue innovation; and defend the G7 position globally. Believing in the Neoclassical Paradigm of exponential growth is already Chinas problem because it wastes resources with unsustainable investments.

[1] H. G. Danielmeyer and T. Martinetz, An exact theory of the industrial evolution and national recovery, www.inb.uni-luebeck.de, 2009 pdf. [2] C. Teuling and R.Baldwin, Secular Stagnation: Facts, Causes & Cures, CEPR London 2014, www.voxeu.org/sites/default/files/Vox_secular_stagnation.pdf

AKE 14.2 *(20)* Wed 17:15 MA 001

The decoupling of CO2 emissions and human development — Kai Kornhuber[1], Dominik Reusser[1], •Luis Costa[1], Jürgen Kropp[1,2], Rybski Diego[1], and Schellnhuber Joachim[1,3] — [1]Potsdam Institute for Climate Impact Research, Potsdam, Germany — [2]University of Potsdam, Potsdam, Germany — [3]Santa Fé Institute

Evidence of a decoupling between greenhouse gas emission and socioeconomic development would benefit international climate negotiations in two ways. First, it would communicate to emerging countries that socioeconomic progress is not strictly connected with ever-growing emissions. Secondly, it informs developed economies on reduction targets that do not jeopardize progress. Using the Environmental Kuznets Curve as background and country-panel data between 1990 and 2013, a model was established to test postulated relationships between socioeconomic progress (measured using the Human Development Index (HDI)) and CO2 emissions from fossil fuels. An inverted U-curve with a time-dependent maximum moving towards higher HDI and lower per capita CO2 mission was established as the relationship delivering the lower fitting error. Extrapolating the global decoupling trend until 2050 returns global cumulative emissions of CO2 that are incompatible with meaningful with long-term climate protection targets. Individual countries presented remarkable differences in their decoupling dynamics. Further insights and implications of the analysis will be discussed, as well as future research needs.

AKE 14.3 *(50)* Wed 17:30 MA 001

The size distribution, scaling properties and spatial organization of urban clusters: a global and regional perspective — •Till Fluschnik, Steffen Kriewald, Anselmo García Cantú Ros, Bin Zhou, Dominik Reusser, Jürgen Peter Kropp, and Diego Rybski — Potsdam Institute for Climate Impact Research (PIK)

Human development has far-reaching impacts on the surface of the globe. The transformation of natural land cover occurs in different forms and urban growth is one of the most eminent transformative processes. We analyze global land cover data and extract cities as defined by maximally connected urban clusters. The analysis of the city size distribution for all cities on the globe confirms Zipf's law. Moreover, by investigating the percolation properties of the clustering of urban areas we assess the closeness to criticality. We study the Zipf-exponents as a function of the closeness to percolation and find a systematic decrease with increasing scale, which could be the reason for deviating exponents reported in literature.

AKE 14.4 *(63)* Wed 17:45 MA 001

Limits and opportunities of a regionalized food production for cities: A global analysis — •Steffen Kriewald, Anselmo García Cantú Ros, Till Sterzel, Prajal Pradhan, and Jürgen P. Kropp — Potsdam Institute for Climate Impact Research, Potsdam, Germany

The massive ongoing urbanisation in the 21st century is a major challenge for societies and therefore crucial developments towards a sustainable future will take place in cities. Together with many other issues a proper food supply is essential. Today, the necessary transport of food, especially the increasing transport by plane due to the global food supply chain, leads to a significant amount of greenhouse gas emissions. A reorganisation of cities in terms of their food allocation could save a considerable amount of emissions. We provide a global overview of the potential of peri-urban agriculture based on land-use, population, yield and dietary datasets. Our analysis indicates that up to 2 billion city dwellers can be fed by local grown products. However, Climate Change will drastically decrease the possibility of a local food supply for many regions.

AKE 14.5 *(29)* Wed 18:00 MA 001

Food demand and supply under global change: need for sustainable agricultural intensification — •Prajal Pradhan[1], Dominik Reusser[1], Matthias Lüdeke[1], and Juergen Kropp[1,2] — [1]Potsdam Institute for Climate Impact Research, Potsdam — [2]University of Potsdam, Dept. of Geo- and Environmental Sciences, Potsdam

Global food demand is expected to increase by 60–110% between 2005 and 2050. Meeting growing food demand along with reducing agricultural environmental impacts is a global sustainability challenge. We investigated diet shifts, emissions, livestock feed, local food, and yield gaps to address this challenge. Globally, we identified sixteen dietary patterns. Diets common in developed world, exhibit higher emissions. Currently, 40% of global crops is fed to livestock. Two billions people are self-sufficient within 5′ grid, while 1 billion Asians and Africans require inter-continental trade. However, they can become self-sufficient by closing yield gaps. By 2050, the global agricultural emissions will approach 7–20 Gt $CO_{2eq.}$/yr and feed demand may increase up to 1.3 times. The number of trade dependent people will range 1.5–6 billion which may be further increased by 4–16% due to climate change. In future, diet shifts will significantly increase crop demand, emissions, and trade. These can be reduced by technological change, consuming local food, and closing yield gaps. Sustainability of inputs and management required to close yield gaps depends on how options are chosen and implemented. Hence, a combination of sustainable intensification, expansion, trade and diet shifts is required to feed growing population.

AKE 14.6 *(9)* Wed 18:15 MA 001

Sustainabilty for a Warming Planet — •Humberto Llavador[1,2], John Roemer[3], and Joaquim Silvestre[4] — [1]Universitat Pompeu Fabra (Barcelona) — [2]Barcelona GSE — [3]Yale University — [4]University of California, Davis

A clean biosphere is a resource in jeopardy due to man-made GHG emissions. What is the fair way to share this scarce global resource across present and future generations, and across regions of the world? This study proposes that the guiding ethics should be sustainability and egalitarianism. Sustainability is interpreted as a pattern of economic activity over time that sustains a given rate of growth of human welfare indefinitely; in doing so, the atmospheric concentration of carbon must be capped at some level not much higher than exists today.

Human welfare depends not only upon consumption, but also upon education, knowledge, and a clean biosphere. The analysis shows that we should be investing more in education and substantially more in knowledge creation than is currently the case.

International cooperation is vital in capping global greenhouse gas emissions at a sufficiently low level. We propose that solving the bargaining problem between developing and developed nations requires recognizing the relationship between economic growth and the climate problem. We propose that the dates at which developing countries converge in living standards to those of developed countries should not be altered by the agreement. This principle, along with sustainability, suffices to determine how emissions should be allocated across regions and time.

AKE 15: Energy Systems (joint session DY/ AKE /SOE)

Time: Thursday 9:30–12:45 Location: BH-N 243

AKE 15.1 *(80)* Thu 9:30 BH-N 243

Decentral Smart Grid Control — •Benjamin Schäfer[1], Moritz Matthiae[1], Dirk Witthaut[1,3,4], and Marc Timme[1,2] — [1]Network Dynamics, Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen — [2]Institute for Nonlinear Dynamics, Faculty of Physics, University of Göttingen, 37077 Göttingen — [3]Forschungszentrum Jülich, Institute for Energy and Climate Research (IEK-STE), 52428 Jülich — [4]Institute for Theoretical Physics, University of Cologne, 50937 Köln

Stable operation of complex flow and transportation networks requires balanced supply and demand. For the operation of electric power grids - due to their increasing fraction of renewable energy sources - a pressing challenge is to fit the fluctuations in decentralized supply to the distributed and temporally varying demands. Common smart grid concepts suggest to collect consumer demand data, centrally evaluate them and send price information back to customers. Besides restrictions regarding cyber security, privacy protection and large required investments, it remains unclear how such central smart grid options guarantee overall stability.

Here we propose a Decentral Smart Grid Control, where the price is directly linked to the local grid frequency at each customer. The grid frequency provides all necessary information about the current power balance such that it is sufficient to match supply and demand without the need for a centralized IT infrastructure. We analyze the performance and the dynamical stability of the power grid with such a control system and determine its stability conditions.

AKE 15.2 *(269)* Thu 9:45 BH-N 243

Dynamical Models of Power Grids: Identifying and Curing Weak Links — •Martin Rohden and Hildegard Meyer-Ortmanns — Jacobs University Bremen, Canpus Ring 8, 28759 Bremen

The inclusion of more and more renewable energy sources into modern power grids leads inevitably to drastic changes of the topology of power grids [1]. Nevertheless it is not known to date what an optimal network topology for power transport and robustness could be. Adding simply new transmission lines can induce long-ranged alterations on the power flow [2]. Here we use the recently introduced novel criteria of redundant capacities to identify weak links in power grids. We propose new strategies to cure these critical links and show their advantages over possible alternatives. Our results may serve as a step towards optimal network topologies in real-world power grids.

[1]: M. Rohden, A. Sorge, D. Witthaut and M. Timme, Chaos **24**, 013123 (2014)

[2]: D. Labavic, R. Suciu, H. Meyer-Ortmanns and S. Kettemann, Eur. Phys. J. Special Topics (EPJ ST), **223**, pp 2517-2525 (2014)

AKE 15.3 *(370)* Thu 10:00 BH-N 243

The induced feedback of Demand-Side Management in the German power market and grid — •Sabine Auer[1,2], Jobst Heitzig[1], and Jürgen Kurths[1,2,3,4] — [1]Potsdam Institute for Climate Impact Research, D-14412 Potsdam, Germany — [2]Department of Physics, Humboldt University Berlin, D-12489 Berlin, Germany — [3]Institute for Complex Systems and Mathematical Biology, University of Aberdeen, AB24 3UE Aberdeen, UK — [4]Department of Control Theory, Nizhny Novgorod State University, Gagarin Avenue 23, 606950 Nizhny Novgorod, Russia

The integration of Variable Renewable Energy (VRE) into the German power system becomes increasingly challenging with growing wind and solar power capacities. To prevent negative energy prices and to secure future energy supply, a debate about redesigning the German power market has aroused. Two competing solutions, a capacity market and an optimized spot market, are under consideration, so far [1]. Either using demand as negative capacities or real-time market pricing will

increase the price elasticity of demand and therefore, create a feedback loop between physical loads and power pricing [2].

In our research, we study these feedbacks in regard to power market and grid, especially in terms of stability [3]. Will these new concepts increase system stability by smoothing price evolution or rather provoke highly non-linear dynamics?

[1] BMWi. Ein Strommarkt für die Energiewende (2014). [2] M. Roozbehani et. al. (2012), IEEE, 27(4), 1926-1940. [3] P. Menck, J. Heitzig, N. Marwan J. & Kurths (2013). Nature Physics, 9(2), 89-92.

AKE 15.4 *(375)* Thu 10:15 BH-N 243

Flow tracing in renewable electricity networks — Mirko Schäfer[1], •Bo Tranberg[2], and Martin Greiner[2] — [1]Frankfurt Institute for Advanced Studies — [2]Aarhus University

Renewable electricity networks are defined as power grids with a large penetration of fluctuating renewable power generation. Flow tracing algorithms track the renewable power as it flows from the generation nodes through the network to the consumption nodes. This allows for fair pricing schemes of future transmission investments. A new analytical expression is presented and applied to the pan-European transmission grid.

AKE 15.5 *(373)* Thu 10:30 BH-N 243

Large-deviation study of the maximum-disturbance stability of power grids — •Alexander K. Hartmann[1], Timo Dewenter[1], Wiebke Heins[2], and Benjamin Werther[2] — [1]Institut of Physics, University of Oldenburg — [2]Institut for Electrical Energy Technology, Technical University of Clausthal

We study numerically the distribution of "maximum-disturbance" stability of power grids. The model is based on networks of oscillators. Here, we consider different ensembles of random networks, like standard Erdös-Renyi and two dimensional spacial networks. To access the distribution down to very small probabilities, we use specific large deviation techniques [1]. The stability is given by a conservative estimation of an asymptotic stability boundary, which is well known in stability theory [2,3]. The starting point is the matrix $\mathbf{A}$ defined by $\mathbf{J^T A} + \mathbf{AJ} = \mathbf{E}$, $\mathbf{J}$ being the Jacobean Matrix. By calculating the maximum disturbance of $\mathbf{x}$, which results in the quadratic form $V = \mathbf{x^T A x} = \epsilon(\mathbf{x})$ not being a Lyapunov-function of the system any longer, the boundaries for the stability can be found.

For comparsion, for the given networks also simple stability measures beased on shortest paths [4], on the eigenvalues of the Jacobi matrix and on a linearized power-flow model [5] are obtained.

[1] A.K. Hartmann, Eur. Phys. J. B **84**, 627-634 (2011)
[2] R. Unbehauen, Systemtheorie (Vol. 2), Oldenbourg, Munich (1998)
[3] E.J. Davison and E.M. Kurak, Automatica **7**, 627-636 (1971)
[4] A.K. Hartmann, Eur. Phys. J. B **87**, 114 (2014)
[5] T. Dewenter and A.K. Hartmann, preprint arXiv:1411.5233 (2014)

AKE 15.6 *(374)* Thu 10:45 BH-N 243

Impact of network topology on decentral frequency-based smart grid control — •Carsten Grabow[1] and Jürgen Kurths[2] — [1]Potsdam Institute for Climate Impact Research, Potsdam, Germany — [2]Potsdam Institute for Climate Impact Research, Potsdam, Germany

Replacing conventional power sources by renewables in power grids poses a big challenge nowadays. In particular, a stable operation of the power grid requires new methods and ideas in aligning the arising fluctuations in decentralised supply to the temporally varying demands. In this context, a decentral Smart Grid Control has been proposed recently in order to directly link the price information to the local grid frequency. Principally, it has been shown that this approach leads to an efficient decentralized strategy for matching supply and demand in a dynamically stable way. However, first results are restricted to simple small and regular networks. In our talk, we will extend the local and global stability analysis of the decentral Smart Grid Control to the collective dynamics of small network motifs, in particular, star-like networks and regular grid motifs. For larger networks, we numerically investigate decentralization scenarios finding additional phenomena that have to be considered to support power grids in exhibiting a stable state.

15 min. break

AKE 15.7 *(369)* Thu 11:15 BH-N 243

Detours around basin stability in power networks — •Paul Schultz[1,2], Jobst Heitzig[1], and Jürgen Kurths[1,2,3,4] — [1]Potsdam Institute for Climate Impact Research, D-14412 Potsdam, Germany — [2]Department of Physics, Humboldt University Berlin, D-12489 Berlin, Germany — [3]Institute for Complex Systems and Mathematical Biology, University of Aberdeen, AB24 3UE Aberdeen, UK — [4]Department of Control Theory, Nizhny Novgorod State University, Gagarin Avenue 23, 606950 Nizhny Novgorod, Russia

To analyse the relationship between stability against (large) perturbations and topological properties of a power transmission grid, we employ a statistical analysis of a large ensemble of synthetic power grids, looking for significant statistical relationships between the single-node basin stability measure and classical as well as tailor-made weighted network characteristics. Especially, we propose a strategy to directly estimate a power grid's stability - even on short time scales - to omit the need of costly simulations. The focus lies on the identification of grid nodes that appear critical for stability, using for example a version of Newman's current flow betweenness. This method enables us to predict poor values of single-node basin stability for a large extent of the nodes, offering a node-wise stability estimation at low computational cost.

Further, we analyse the particular function of certain network motifs to promote or degrade the stability of the system. Here we uncover the impact of so-called detour motifs on the appearance of nodes with a poor stability score and discuss implications for power grid design.

AKE 15.8 *(322)* Thu 11:30 BH-N 243

Network Measures for Power Grid Stability in Practice — •Frank Hellmann — Potsdam-Institut für Klimafolgenforschung, Potsdam, Deutschland

A key challenge for the emerging future grid infrastructure is the dynamical stability of the power grid in the presence of fluctuating power sources and changing topologies.

I show how tools based on novel as well as existing network topology measures can help with identifying vulnerable points in the power grid and can guide the design of the future grid in practice.

AKE 15.9 *(368)* Thu 11:45 BH-N 243

Predicting critical links in complex supply networks — •Xiaozhu Zhang[1], Dirk Witthaut[1,2,3], Martin Rohden[1,4,5], Sarah Hallerberg[1], and Marc Timme[1,6] — [1]Network Dynamics, Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen, Germany — [2]Forschungszentrum Jülich, Institute for Energy and Climate Research - Systems Analysis and Technology Evaluation (IEK-STE), 52428 Jülich, Germany — [3]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany — [4]IIIrd Institute of Physics, Faculty of Physics, Georg August University, 37077 Göttingen, Germany — [5]School of Engineering and Science, Jacobs University, 28759 Bremen, Germany — [6]Institute for Nonlinear Dynamics, Faculty of Physics, Georg August University, 37077 Göttingen, Germany

It has been observed that most large-scale outages in power grids can be traced back to single transmission line failures [1]. Yet, identifying which infrastructures in power grids and other supply networks are critical remains an open challenge, with severe consequences for network planning and stability. In this work we propose that the critical links can be reliably predicted from the network structure and the normal operation state prior to edge failure. Numerical simulations of a variety of flow network models confirm that the topological edge redundancy as well as renormalized linear response theory provide general key indicators for network robustness.

[1] Pourbeik et al., Power and Energy Magazine, IEEE 4.5 (2006): 22-29.

AKE 15.10 *(376)* Thu 12:00 BH-N 243

Modelling the Dynamical Formation of Coalitions of Power Grid Operators to Reduce Needs for Backup Capacity — •Jobst Heitzig[1] and Sarah Becker[2] — [1]Potsdam Institute for Climate Impact Research, Potsdam, Germany — [2]Frankfurt Institute for Advanced Studies, Frankfurt, Germany

Power grid operators face an increasing need for backup capacity due to a raising amount of volatile renewable energy production. This need may be decreased by extending transmission capacities between several neighbouring grids and then pooling their backup capacities. Due to the physical properties of electricity transmission grids, extending a line between two grids may however also reduce the backup capacity needs of a third connected grid, and may do so even more than

when the third grid's connection were extended as well. These physical effects generate complex and interesting strategic incentives for individual grid operators to join a backup capacity sharing coalition or not. In this talk, we'll use a model of dynamic coalition formation to show which grids may form coalitions in which order, using real-world example data.

AKE 15.11 *(343)* Thu 12:15 BH-N 243

Short-Time Stochastic Characterization of the Offshore Wind Profile — •Christian Behnken, Pedro Lind, Matthias Wächter, and Joachim Peinke — ForWind, Institute of Physics, Carl-von-Ossietzky University, 26111 Oldenburg, Germany

Currently descriptions of vertical wind profiles are mostly performed by using standard logarithmic or power law approaches. Especially for short time scales ($1\,s \leq t \leq 10\,min$) the dynamics of the profile strongly influence the load situations and the energy conversion of wind turbines. Since these short-time dynamics are not considered when using the standard techniques, a more detailed approach is presentend in this work. Firstly, PDFs of spatial and temporal velocity increments, estimated from offshore wind speed data, are fitted by using a superposition of Gaussian distributions with a varying standard deviation. It is shown that the empirical PDFs follow a heavy-tailed distribution which matches the proposed theoretical distribution. Furthermore, drift and diffusion coefficients for two-dimensional systems of Langevin equations are estimated directly from wind speed data to investigate dynamic coupling along the profile. This approach gives a first insight into the dynamics of wind profiles on short time scales.

AKE 15.12 *(184)* Thu 12:30 BH-N 243

intermittency and synchronization in wind farm — •mehrnaz anvari and joachim peinke — Institute of Physics and Forwind, Carl von Ossietzky University, 26111 Oldenburg, Germany

The renewable wind and solar sources and their share in electricity production have been increased constantly in recent years. These sources have new stochastic characteristics such as intermittency and non-Gaussian behavior, which may cause instability in power grids in very short-term time scales.

In this work, we focus on wind power that influenced by atmospheric turbulence. Hence frequent extreme fluctuations in power output of wind turbines are detectable. This intermittent behavior also, is present in cumulative power of the total wind field, even for a country-wide installation. To understand the origin of such extreme events, we consider the interactions between wind turbines and for this purpose, we evaluate the phase synchronization in wind farm. We conclude that, the existence of partial phase synchronization between turbines in specific time intervals can explain the origin of extreme events in this complex system. We found that higher synchronized wind turbines will produce higher intermittent power output.