Karlsruhe Institute of Technology

Institute for Industrial Production

Annual Report 2017

Chair of Energy Economics

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Preface

This third annual report from the Chair of Energy Economics at the Institute for Industrial Production (IIP), Karlsruhe Institute of Technology (KIT) presents an overview of our main activities during 2017. The four research groups "Transport and Energy", "Renewable Energy and Energy Efficiency", "Energy Markets and Energy System Analysis", and "Distributed Energy Systems and Networks" have been working on numerous projects on a regional, national and international level, to provide decision support in the field of energy economics. As shown in the picture below, we are currently around 30 research and 4 administrative staff, roughly divided equally between these four groups.

During 2017, we worked on around 25 ongoing national and international research projects, as well as beginning about 10 new projects. We published around 22 peer-reviewed journal articles, and one PhD as well as one Habilitation were completed.

My staff and I hope that we can arouse your interest in our research activities with the brief report. We look forward to receiving any comments and suggestions you may have.

Prof. Dr. Wolf Fichtner, Chair of Energy Economics

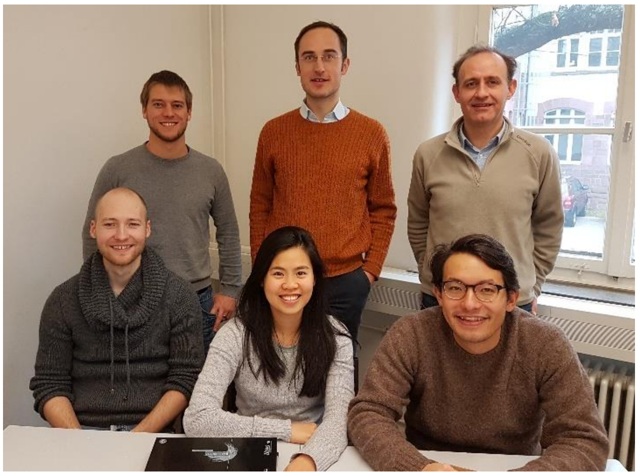
Renewable Energy and Energy Efficiency Group

Head of research group: PD Dr. Russell McKenna

The *Renewable Energy and Energy Efficiency (REEE)* group carries out technical, economic and environmental model-based analysis of energy-efficient and renewable policies and technologies, as well as their potentials.

To offer decision support for different planning activities, several optimization models have been developed and are employed, in particular the TIMES-HEAT-POWER (THP) model framework and the Renewable Energies and Energy Efficiency Analysis and System OptimisatioN (RE^3ASON) model. THP is a linear optimization model of the German electricity and domestic heating sectors, and is employed to analyse technologies such as micro-CHP and heat pumps at the interface of heat and electricity sectors. The RE^3ASON model, on the other hand, is a highly transferable linear optimisation model for community-scale energy systems, which mainly employs publicly-available data.

The current research foci in the REEE group lie in the development of cost-potential methods for renewable energies, the model-based analysis of energy systems in residential buildings and municipalities, the analysis of the links between urbanisation and energy efficiency in southeast Asian countries, and the application of these methods in the context of real-world case studies.



Members of the research group (from t.l. to b.r.): Kai Mainzer, Russell McKenna, Javier Parilla Martinez, Jann Michael Weinand, Phuong Minh Khuoung, Fritz Braeuer.

Energy Markets and Energy System Analysis Group

Head of research group: Dr. Dogan Keles

Members of the research group (fltr): Dogan Keles, Rupert Hartel, Christoph Fraunholz, Emil Kraft, Daniel Fett, Joris Dehler, Florian Zimmermann, Andreas Bublitz, Hasan Ümitcan Yilmaz.

The sustainable design of energy systems under consideration of environmental, economic, social and security aspects is not only an important, but also a complex task. On the one hand, the task requires strong political governance with a broad view for possible future developments. On the other hand, the task is dependent on decisions and the behaviour of different actors in the sectors of energy generation, trade, supply and usage. The goal of the research group *Energy Markets and Energy System Analysis (EMESA)* is the formulation and application of mathematical models to analyse the implications of political and economic framework conditions as well as technological trends onto the future development of energy systems. Normative issues, considering the overall economic perspective, are considered as well as the specific perspectives of different actors which include the behaviour and motives of different market participants. Recipients of the model based analyses of EMESA are decision makers from politics, economics and industry.

Transport and Energy Group

Head of research group: PD Dr. Patrick Jochem

Most discussions on the energy transition focus still mainly on the electricity sector and its decentralization. The transport sector, however, is widely ignored even though its challenges concerning energy efficiency, oil dependency and several negative environmental impacts lead to an urgent need for extending the energy transition to this sector. Currently, one promising alternative in this regard is the electrification of passenger road transport by plug-in electric vehicles (PEV), i.e. plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV). They come along with a significant increase of energy efficiency and a shift in fuels: from oil dominated to a high diversification potential via the energy carrier electricity. Furthermore, they accelerate the interactions of the transport and the electricity system ("sector coupling"), which is the main focus of the research group "Transport and Energy".

Consequently, the overriding objectives of the group are to analyse the market development of PEV in main car markets and to determine the impacts of PEV on (decentral) energy systems and material flows. For this, we apply highly interdisciplinary approaches from business economics, economics, sociology, logistics and other environment-related disciplines and with strong cooperation with electrical engineers and computer scientists. Our main methods are based on energy system models, such as optimisation tools, agent-based simulation as well as other socio-economic or mathematical models. These models are applied in different fields from service science and psychology to decentralized electricity systems and electricity markets. Currently, a focus is on the profitability of electro-chemical mobile and stationary storages (in combination with photovoltaic and battery degradation) as well as the impact of PEV on the distribution grid. Service-related topics in our field of research are allocated to our associated group eMobility services at the Karlsruhe Service Research Institute (KSRI). We have a comprehensive exchange with international partners from academia and industry. Our main funding comes from German ministries, Deutsche Forschungsgemeinschaft (DFG), European Commission, Helmholtz Association, local ministries, and industry.

Members of the research group (fltr): Axel Ensslen, Katrin Seddig, Sabrina Ried, Zongfei Wang, Christian Will, Thomas Dengiz, Maximilian Schücking, Thomas Kaschub, Patrick Jochem, Johannes Schäuble, Jonathan Gomez Vilchez.

Distributed Energy Systems and Networks Group

Head of research group: Dr. Armin Ardone

The promotion of renewable energy sources (RES) and combined heat and power (CHP) generation leads to an increasing decentralisation of energy systems and brings about new challenges. Especially in Germany, the realisation of the ambitious targets concerning the expansion of RES necessitates an extensive structural rearrangement of the system. For instance, large amounts of electricity need to be transported from the wind farms in the north to the large load centres in southern and western Germany. As a consequence, the grid load in the system will rise to an extent that is hardly manageable with existing power grid capacities. Furthermore, decentralised power generation installations (e.g. solar PV) need to be integrated into the lower voltage power grids without violating grid-safety constraints. In this context, different market design options for distributed energy systems, including appropriate demand response mechanisms, are currently being intensively discussed. However, the consequences of these structural changes for the system's stability and resilience are not yet well understood.

In addition, the number of players in the market recently increased in consequence of the decentralisation and this number is expected to further increase. Since the different players typically pursue different objectives and have different preference perceptions, multiple and usually conflicting targets need to be considered. As a result, decision and evaluation processes need to be designed in a participatory way. Moreover, a purely economic optimisation is no longer sufficient to support decision making in energy systems since the importance of ecological, technical and socio-psychological criteria steadily increases.

Members of the research group (fltr): Viktor Slednev, Hans Schermeyer, Manuel Ruppert, Hannes Schwarz, Armin Ardone, Christoph Nolden, Qingxin Li, Rafael Finck. Not in the picture: Max Kleinebrahm, Nico Lehmann.

Research Projects

AVerS - Analysis of the Supply Adequacy in Southern Germany under Consideration of Coupled European Electricity Markets

Dogan Keles, Christoph Fraunholz

Partner: Fraunhofer ISI, TU Dresden, ESA^2 GmbH

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2016 to 2019

The project "AVerS", which is funded by the Federal Ministry for Economic Affairs and Energy, aims to analyse generation adequacy in (southern) Germany given the phase out of nuclear energy and the increasing share of intermittent renewable energy generation. The research expertise of KIT, Fraunhofer ISI, TU Dresden and ESA^2 GmbH is combined in this 3-year project (06/2016 – 05/2019).

An essential part of the study is to incorporate the development towards a Single European Electricity Market and the introduction of capacity mechanisms in Germany's neighbouring countries. These developments have an enormous impact on the total domestic, but also regional generation capacities.

Previous analyses on generation adequacy are extended by three major aspects:

- The impact of different market design options in Germany and its neighbouring countries on generation adequacy in (southern) Germany,
- The impact of European market coupling mechanisms on generation adequacy in (southern) Germany,
- The contribution of demand side management to generation adequacy.

Different modelling approaches from the project partners, each having their specific strengths, are coupled in order to address the research questions of generation adequacy in a proper manner. The coupling of these established models delivers detailed insights on aspects of generation adequacy in southern Germany, that have so far not been analysed.

The study serves to derive policy recommendations to design an electricity market for Germany that preserves a sustainable, cost-efficient and secure supply of electricity.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

BEAM-ME Project

Hasan Ümitcan Yilmaz, Ruppert Hartel, Dogan Keles

Partner: German Aerospace Center (DLR), Technical University of Berlin, Technical University of Denmark, Institute of Energy Economics at the University of Cologne, University of Duisburg-Essen, GAMS Software GmbH

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2017 to 2018

The BEAM-ME project (Implementation of acceleration strategies from mathematics and computational sciences for optimizing energy system models) is funded by the Federal Ministry for Economic Affairs and Energy (BMWi) within the 6th Energy Research Programme of the Federal Government.

Within BEAM-ME a consortium of researchers from different research fields (system analysis, mathematics, operations research and informatics) develop new strategies to increase the computational performance of energy system models (ESM) and to transform ESMs for usage on high performance computing clusters (HPC).

The main objective of the IIP within the project is to analyse and demonstrate the general application of acceleration techniques, on the PERSEUS-EU model. The focused acceleration technique is the application of ESMs to HPCs. Therefore, together with some other ESMs, PERSEUS-EU will be applied to a HPC to provide a thorough analysis of different parallelization methods and benchmark analysis of these methods between the models.

Afterwards, the identified efficient strategies and general standards for increasing computational performance and for applying ESMs to high performance computing will be documented in a best-practice guide.

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C/sells: The Future Energy System in the Solar Arc of Southern Germany.
A Project within the Support Programme "Smart Energy Showcases - Digital Agenda for the Energy Transition (SINTEG)"

Armin Ardone, Dogan Keles, Nico Lehmann, Emil Kraft

Partner: 56 partners, among them: a) Industrial partners: DB Energie GmbH, devolo AG, EAM GmbH & Co. KG, Flughafen Stuttgart GmbH (Stuttgart Airport), MVV Energie AG, Netze Mittelbaden GmbH, Next Kraftwerke GmbH, Power Plus Communications AG, Seven2one Informationssysteme GmbH, Stadtwerke München Services GmbH, TenneT TSO GmbH, TransnetBW GmbH.

b) Academic partners: Deutsches Zentrum für Luft- und Raumfahrt (DLR), FfE Forschungsstelle für Energiewirtschaft e.V., Fraunhofer IAO, Fraunhofer ISE, Fraunhofer ISI, FZI Forschungszentrum Informatik, Hochschule Offenburg, Hochschule Ulm, International Solar Energy Research Center Konstanz, TU München, Universität Stuttgart.

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2016 to 2020

C/sells intends to create a cellular structured energy system. The supply, use, distribution, storage and other infrastructure services within the individual cells, e.g. properties, districts and cities, are optimised as autonomously as possible in accordance with the principle of subsidiarity. The interaction of the cells to form a network also allows a secure and robust energy system. An infrastructure information system (IIS) supports the exchange of energy at a local and regional level by making information available. Examples for such information are flexibility potentials of the cells, different types of forecasts or technical aspects to control individual devices within the cells.

Geographically limited technical solutions ("Cells") are developed which are the core of the project and, by doing so, new economic opportunities are provided for citizens by giving them the opportunity to participate in new business models ("sells"). Participation thus further increases acceptance of the energy transition. The diverse stakeholder structure, which encompasses all stages of the cellular energy system's value-added chain, offers ideal conditions for the development and implementation of new cooperation models. C/sells enables a smooth transition from demonstration to mass market.

Southern Germany is predestined for this project because of its high solar power generation, which is the top value in Germany. Furthermore, its complex grid structure with over 420 distribution grid operators, the combination of industrialised metropolitan areas with rural, sparsely populated regions, its Energiewende-enthusiastic citizens, politicians and investors as well as its central location in the European energy transmission network makes it the perfect place to proof the feasibility of C/sells.

Within the framework of C/sells, the Chair of Energy Economics will analyse and evaluate existing market structures and new market design options. For this purpose, the existing control power markets will be modelled in a first step and integrated into the existing simulation model PowerACE. With regard to the further progress of the project, new market structures and concepts will also be considered in order to integrate (decentralised) flexibility and renewable energies into the existing energy system as effectively and efficiently as possible.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Decarbonisation of the Energy System through Increased Use of Renewably Generated Power in the Heating-, Transport-, and Industry Sector during Ongoing Decommissioning of Power Plants (DESK)

Dogan Keles, Armin Ardone, Hasan Ümitcan Yilmaz, Rupert Hartel, Viktor Slednev

Partner: Fraunhofer ISI

Funding: Umweltministerium Baden-Württemberg

Duration: 2016 to 2017

The project „DESK“, funded by the BWPLUS research program, combines the expertise of KIT and Fraunhofer ISI. The project „DESK” aims mainly to analyze the effects of a simultaneous shut down of power plants for economic and environmental reasons on the security of supply in Southern Germany.

Due to the ambitious European and national climate protection targets, Germany is currently undergoing a restructuring of its energy system. This process is supposed to guarantee the decarbonisation of the electricity sector while taking into account the security of supply and a cost-efficient energy production. A broad decarbonisation of the energy sector combined with the phase out of nuclear energy can endanger the security of supply in southern Germany. While most of the renewable electricity production is located in northern Germany, a large proportion of demand is located in the south. Therefore, the overarching goal of this research project is the analysis of the security of supply in southern Germany in the long-term with consideration of the interaction with other European countries, economic and climate policy related shutdowns of power stations and possible bottlenecks in the European transmission grid. The acceptance of the population, demand side management, storage technologies and the development of electricity demand, which can increase due to the propagation of Power-to-X technologies and electric mobility, are taken into account. For the extensive and detailed analysis of security of supply, three models developed by Fraunhofer ISI and IIP are combined. Through various iterations of these models, robust results can be produced regarding capacity and grid expansions amongst others. On this basis, the security of supply in southern Germany is evaluated drawing policy recommendation and actions.

DFG Graduate School 2153 Energy Status Data – Informatics Methods for its Collection, Analysis and Exploitation

Thomas Dengiz, Hasan Ümitcan Yilmaz, Patrick Jochem

Partner: KIT-IPD, KIT-IAI, KIT-ITI, KIT-ITEP, KIT-ZAR, KIT-AIFB, KIT-IPE, KIT-IISM, KIT-KSRI

Funding: Deutsche Forschungsgemeinschaft (DFG)

Duration: 2016 to 2020

The design of future energy systems which can cope with fluctuating supply and flexible demand is an important societal concern. An essential aspect is the consumption of energy, particularly of complex systems such as factories or IT infrastructures. Important points are the flexibilization of energy consumption, so that the share of locally generated 'green' energy increases, robustness of energy provisioning, or the efficient design of new energy systems serving these purposes. To accomplish this, a core prerequisite is a structured collection, storage and analysis of energy status data. Energy status data describes the provisioning of energy, its storage, transmission and consumption, be it the outcomes of measurements, be it metadata such as the extent of fatigue of batteries, be it other relevant data such as electricity rates.

This Research Training Group targets at the handling of such data. To this end, an interdisciplinary approach (computer science, engineering, economics, law) is indispensable. It reveals new scientific challenges we will confront PhD students with as part of their education. For instance, we have observed that different planning and control purposes require data of different temporal resolution and at different aggregation levels. This varying granularity leads to the question how to find outliers in such data at the right level of abstraction. Other graduates benefit from new approaches that detect such outliers. They can now work more efficiently, e.g., can identify shortcomings of existing models of energy systems systematically. An example of such a model would be one describing the behavior of Li-Ion batteries. The infrastructure for energy research of the KIT Helmholtz sector such as the EnergyLab 2.0 will be subject/object of our Research Training Group to a significant extent; the persons responsible for these facilities are part of the group of applicants of this Research Training Group.

An other distinctive feature of the research agenda graduates have to deal with as part of their education with us is the comprehensive treatment of the life cycle of energy status data, which consists of the phases 'collection', 'analysis' and 'deployment'. It yields a significant added value, compared to stand alone PhD work that otherwise would have to cover that entire life cycle by itself: For instance, PhD topics falling into an early phase of the life cycle might tailor specific methods of collecting energy status data if it is known how it will be used. Topics from the phase 'deployment' in turn, which want to design better energy systems in a data-driven fashion, can work with data of exactly the right quality.
(Source: http://www.energystatusdata.kit.edu)

The PhD students of the IIP focus on the following topics:

- Quantification and utilization of load flexibility potentials in German households focusing on Power-To-Heat: Heat demand data of the German building stock has to be used to predict the future demand and to optimize the run time of Power-To-Heat-Systems. By doing so future energy systems should be capable of dealing with the increasing infeed of electricity from volatile renewable energy sources.

- Modelling Intermittent Renewable Power Generation in the European Energy System Considering Model Complexity Challenges: The main focus of the study is to analyse the impacts of the uncertainties in renewable energy production on the future European power plant park. However, modelling the intermittent character of the renewable energy technologies in energy system models is increasing the complexity which has already reached the boundaries of computational power. Finding ways to reduce the execution time using among others decomposition and parallel computing approaches is at the core of the study

- Time Series Reduction: One way of decreasing the computational time of Energy System Models is to reduce the data input. In Energy System Models, a. o. the operation of power plants for several years are modelled, therefore various intra-annual data are used as input. Instead of using data of a whole year, using representative weeks or days would reduce the data input. Thus, we aim to investigate different clustering methods for finding representative weeks/days. Especially the applicability of Self-Organizing-Maps (special types of Artificial Neural Networks) for this purpose is tested. To this end, we set up an interdisciplinary research group collaborating with researchers from the Faculty of Computer Science and the Faculty of Electrical Engineering.

E-SAVE: European Electricity Market Coupling and its Impact on Security of Supply with increasing Shares from Renewable Energies

Dogan Keles, Joris Dehler, Florian Zimmermann, Christoph Nolden

Partner: -

Funding: Stiftung Energieforschung Baden-Württemberg

Duration: 2015 to 2017

The energy and climate change policy targets for a stronger use of renewable energies for electricity generation in Europe present new challenges for the electricity markets. At the same time, the establishment of a European electricity market is being pursued in order to make the energy system more efficient throughout Europe. Corresponding measures include, among other things, a better and more efficient coupling of national electricity markets (e.g. via the so-called "market coupling").

In liberalized electricity markets, security of supply depends on investment decisions made by electricity market participants, in particular power plant operators. Energy policy can provide an appropriate framework for the actors through an adequate design of the electricity markets. Accordingly, the anticipated decisions of the market participants regarding the electricity market design must be taken into account. The roles played by the expansion of renewable energies, the interconnection of electricity markets in Europe and their interaction in electricity pricing and the resulting long-term investments in power plant capacities is a question which has so far hardly been questioned. Moreover, different market configurations in the national electricity markets may cause undesirable interactions.

The overriding aim of the present research project is thus the investigation of the long-term security of supply, taking into account the interactions between the coupling of electricity markets and the expansion of the renewable energies. Here, also the current configuration of the national electricity markets will be considered. For long-term analysis of current systems with their techno-economic properties and a wide range of interactions, the energy system analysis is basically suitable. In particular, the agent-based simulation has proven itself in this regard in order to examine market situations with several, heterogeneous actors. In the research project, an agent-based electricity market simulation model, which is focussed on Germany, is therefore being further development into a European model.

Helmholtz Portfolio Initiative "Safety and Security"

Kai Mainzer, Manuel Ruppert, Russell McKenna

Partner: KIT-IKET, KIT-IPD

Funding: Helmholtz Association

Duration: started in 01/2013, ongoing

As part of the energy transition, power generation in Germany is changing from a centralised to a decentralised structure in which renewable, volatile generation capacity dominates the thermal power plant fleet. Among others, higher demand flexibility through intelligent load management as well as an expansion of smart grid technologies at the distribution grid level shall help to cope with the increased complexity of the supply task. This will lead to an increasing diffusion of information and communication technologies (ICT) in the electricity sector in the future (e.g. "smart meters").

The essential objective of the Helmholtz Portfolio Initiative "Safety and Security" is to develop future threat scenarios, which may arise in the context of the progressive networking, and to conduct model-based security assessments of critical infrastructures. The focus is on the analysis of disruptions with possible cascade effects in electricity and communication networks as well as on the investigation of effects on other critical infrastructures such as health care and water supply.

Energy Systems Integration

Max Kleinebrahm, Armin Ardone

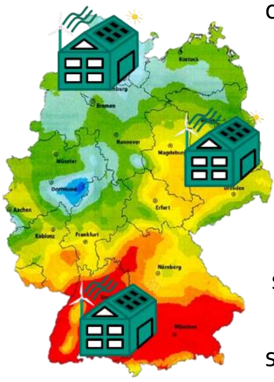
Partner: Forschungszentrum Jülich (FZJ), German Aerospace Centre (DLR), Max-Planck-Institute for Plasma Physics (IPP), Helmholtz-Zentrum Berlin (HZB), Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Helmholtz-Zentrum Potsdam German GeoResearchCentre (GFZ), Karlsruhe Institute of Technology (KIT)

Funding: Helmholtz Association

Duration: 2017 to 2020

The project "Energy Systems Integration" deals with those aspects of the energy system that make all individual components form a whole, i.e. all physical and IT-based interconnections as well as their structures and behaviours. It is incorporated in the broader challenge to coherently manage the resources energy, materials, and the natural environment. The cross-sectoral interaction between the various components of the energy system, such as producers, storage facilities, consumers and different transport systems, has not yet been sufficiently taken into account. For this reason, the focus is on the technological and economic interactions of energy system components. The aim of the research project is to design an environmentally sound, viable, flexible, stable and resource-efficient energy system by integrating and combining individual technologies and sectors.

Interactions within the energy system are represented by models, simulated for a variety of scenarios and verified by real data sets. The modelling from the component level to the process level up to the level of the energy systems leads to in-depth knowledge and applicable tools. For the development of robust scenarios, the trend towards individual and independent energy supply is analysed. Therefore the effects of self-sufficient residential buildings on the future energy system are examined in the Group "Distributed energy systems and networks".



ENRES - Research Training Group Energy Systems and Resource Efficiency

Daniel Fett, Rafael Finck, Jann Weinand

Partner: KIT-ITAS, Hochschule Pforzheim – INEC, Hochschule für Technik Stuttgart – zafh.net

Funding: Landesgraduiertenstiftung, Ministerium für Wissenschaft, Forschung und Kunst Baden-Württemberg

Duration: 2016 to 2019

Together with partners at the KIT, the Hochschule Pforzheim and the Hochschule für Technik Stuttgart, the IIP has set up a Research Training Group for doctoral students.

This joint undertaking focuses on the integrated analysis of energy systems and resource efficiency, regarding both the technological and the socio-economic aspects. In this project the IIP cooperates with the Institute for Technology Assessment and Systems Analysis (also KIT), the Centre for Sustainable Energy Technology at the Hochschule Stuttgart and the Institute of Industrial Ecology at the Hochschule Pforzheim.

The four research institutes of the participating universities offer a total of 12 doctoral scholarships for three years which are funded by the Ministry of Science, Research and Arts (MWK) Baden-Württemberg in line with the State's support for PhD students. The focus at IIP is on three topics:

- Impacts of the increasing diffusion of PV-battery storage systems on the (central) electricity markets
- Municipal energy autonomy: a model-based analysis of the technical, economic and environmental impacts from a micro- and a macroeconomic perspective
- Analysis of the impact of increasing generation from renewable sources in the European electricity market on transmission grids considering flow-based market coupling

Starting in July 2016, this program shall provide the opportunity to investigate innovative research topics and support the professional and transdisciplinary exchange of its members for the next three years. The participating institutes also offer joint events for the doctoral students.

ENSURE – New Energy grid StructURes for the German Energiewende

Manuel Ruppert, Daniel Fett, Rafael Finck, Jann Weinand, Mirish Thakur, Armin Ardone

Partner: KIT, RWTH Aachen University, Schleswig-Holstein Netz AG, TenneT TSO GmbH, Siemens AG, ABB AG, Bergische Universität Wuppertal, Christian-Albrechts-Universität zu Kiel, Friedrich-Alexander Universität Erlangen-Nürnberg, Leibniz Universität Hannover, TU Darmstadt, TU Dortmund, DVGW, ewi Energy Research and Scenarios gGmbH, FGH e.V., Fraunhofer-IWES, Maschinenfabrik Reinhausen GmbH, Nexans Deutschland GmbH, OFFIS e.V., Öko-Institut e.V., Stadtwerke Kiel, Deutsche Umwelthilfe e.V., Germanwatch

Funding: Federal Ministry of Education and Research (BMBF)

Duration: 2016-2019

The ENSURE Consortium is one of four "Kopernikus Projects for the Energy Transition", funded by the Federal Ministry for Education and Research to combine economic, social, political and technological research questions for the sustainable and long-term future development of energy systems. The KIT is the coordinator in the project which includes in 23 further project partners from science, industry and society, among which are RWTH Aachen, E.ON SE, TenneT TSO GmbH, Siemens AG, ABB and other partners. The project aims to answer questions raised by the energy transition such as: How much electricity grid is needed? What is the optimal structure that satisfies technical, economic and social aspects and which degree of centralised and decentralised generation is appropriate? The project will cover three project stages from fundamental research to demonstration and testing with an overall time horizon of ten years. The first phase of the project is funded until 2019.

The Chair of Energy Economics at the IIP contributes to the research about future power grid structures performed in the System Structures Cluster. The focus of the Chair's work lies on economic aspects of future grid structures, namely analysing market elements for the future market design (e.g. effects of capacitiy markets on power grid utilisation, regulatory framework for decentralised generation by residential pv-battery systems) and potential business models in this context. Another main field of research is the techno-economic assessment of scenarios for the future transmission grid as well as the new technical concepts idenditified by the partners.

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Grid-control – Advanced Decentral Grid Control

Johannes Schäuble, Sabrina Ried, Patrick Jochem

Partner: EnBW AG, Forschungszentrum Informatik (FZI), Landis+Gyr, Fichtner IT, Seven2one, ads-tec, University of Stuttgart, PREdistribuce

Funding: Federal Ministry of Economics and Technology (BMWi)

Duration: 2015 to 2018

grid-control

Within the scope of "Grid-Control – Advanced Decentral Grid Control", industrial and scientific partners have teamed up in order to push forward the research, development and practical demonstration of sustainable power grids. This research project is part of the funding initiative "Zukunftsfähige Stromnetze" by the German Federal Ministry for Economic Affairs and Energy and is financially supported with a total amount of EUR 10 million. The project is being carried out from July 2015 to June 2018. The goal of the project is to specify, develop, install, test and evaluate holistic concepts of sustainable power grids. Within the framework of grid-control the existing Energy Smart Home Lab will be used at KIT to investigate the provision of ancillary services in a decentralized controlled network segment. In laboratory examinations the coordination of interactive energy management systems is tested. Real hardware systems in critical grid situations are used to analyse what cannot be done in field tests. In order to investigate decision making for capacity management applications, an agent-based energy system model for capacity management applications is being developed.

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on the basis of a decision by the German Bundestag

IILSE - Inductive and Interoperable Charging Systems for Electric Vehicles

Patrick Jochem, Axel Ensslen, Johannes Schäuble, Thomas Kaschub

Partner: KIT-DFIU, KIT-IEH, KIT-ZAR, KIT-AIFB

Funding: Federal Ministry of Economics and Technology (BMWi), Elektro Power II

Duration: 2015 to 2017

The project IILSE (inductive and interoperable charging systems for electric vehicles) is part of the funding program "ELEKTRO POWER II: Electric Mobility – Positioning along the Value Chain" and is funded by the German Federal Ministry for Economic Affairs and Energy. In the project term from June 2015 until December 2017 the four institutes DFIU, IEH, AIFB and ZAR from KIT are working together to support the international cooperation to harmonize charging infrastructure standards. In a bi-national exchange with Japanese partners the focus is placed on inductive and fast charging. In addition, we scientifically evaluate the topics of inductive charging and international e-roaming.

At IIP/DFIU we have evaluated two important aspects for an appropriate charging infrastructure. First, we have evaluated electric vehicle users' acceptance of inductive charging (wireless power transfer - WPT) by carrying out surveys.

Results indicate a high degree of acceptance for wireless charging. Even individuals with lower degrees of acceptance are willing to use wireless charging within car-sharing or commercial fleets. Furthermore, the collaborative charging infrastructure for apartment buildings or residential districts is analysed with an optimization model. First results show the benefits of collaborative charging. Especially with controlled charging fewer charging points are needed.

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on the basis of a decision by the German Bundestag

Insight_E - An Energy Think Tank informing the European Commission

Dogan Keles, Joris Dehler, Hasan Ümitcan Yilmaz

Partner: KTH Royal Institute of Technology, University College London, University College Cork, KIC InnoEnergy, Institut français des relations internationales, Paul Scherrer Institute, Energy Institute Hrvoje Pozar, University of Stuttgart, Enerdata, E4SMA, Stakeholder Forum for a Sustainable Future

Funding: European Commission

Duration: 2014 to 2017

Between 2014 and 2017, twelve European research institutions in the disciplines of engineering, economics, environment and law formed "Insight_E", an independent energy think tank in the form of a network of experts from the energy sector. The task of the think tank was to provide objective, transparent and impartial advice to policy makers at European level. The main focus of the consulting activities was the investigation and impact assessment of political options for action to achieve the climate policy objectives. The effects and sustainability of individual options for action with regard to ecological, economic, social and security aspects were examined. This was done based on a well-founded database and suitable models or methodical approaches for system analysis. In addition, policy-makers' attention was also drawn to the development of new technical trends and the actions and motives of key players. In addition, innovative methods of stakeholder engagement and an "Energy Observatory" were used to determine trends.

In addition to a large number of publications on the INSIGHT_E platform, selected results were also be published in a scientific framework: "Europe's Energy Transition - Insights for Policy Making" summarizes the main results of the project. The main challenges for European energy policy in the coming years (decades) will be to decarbonise the energy system and increase efficiency by designing appropriate market mechanisms, while consumers' needs for affordable energy must not be neglected. The IIP was able to contribute to a deeper insight into these three challenges with various analyses:

The controversial proposal of a coal exit was analysed using the Perseus Electricity System Model. A premature phase-out at the country level has a minor impact on CO_2 emissions in Europe and would lead to higher imports and exports and the phenomenon of carbon leakage in Germany. However, CO_2 would be saved at country level.

Further contributions of the IIP include the analysis of different design options for the electricity market. Particular attention must be paid to the extent to which generation from renewable energies can be integrated.

An analysis of the technical and political framework conditions reveals the ambivalences of the increasing own consumption of solar power and the use of batteries in home systems. While a system-useful battery control can have advantages at the system level, uncontrolled charging leads to additional costs. The financial incentive to own-consume generated electricity arises from the difference between the final consumer price, which in turn consists of taxes and levies, in particular the EEG levy. Assuming the current structure of electricity prices, increased own-consumption could lead to a redistribution of the costs of the electricity system to customers who cannot afford the combination of solar system and storage tank.

Living Lab Walldorf

Hans Schermeyer, Armin Ardone

Partner: BEEGY GmbH, MVV Energie AG, Stadtwerke Walldorf, FZI Forschungszentrum Informatik, KEO GmbH.

Funding: Ministry of the Environment, Climate Protection and the Energy Sector Baden-Württemberg

Duration: 12/2015 to 01/2019

The project Living Lab Walldorf ("LiLa Walldorf") is funded by the Ministry of the Environment, Climate Protection and Energy Sector Baden-Württemberg over the period 12/2015 till 01/2019. The goal of the project is the evaluation of various innovative regulation schemes for the electricity sector. By considering different research scenarios, the impact of – even disruptive – changes of the German regulatory framework in the electricity sector is investigated. To this end, optimization methods focusing on economic and environmental objectives are developed and evaluated for a pool of controllable loads, generators and storage devices. In addition, concepts of new market models, consumer acceptance and consumer participation are examined.

The project is structured in several sub-projects, which are closely interlinked. Starting with the development of a set of specifications and scenarios (TP1), macroeconomic effects of different regulatory and market approaches are investigated by using large-scale multi-agent simulation models (TP2). TP3 focuses on the design of efficient algorithms for scheduling the operation of the pool devices for improving the integration of a large share of volatile renewable generators. In parallel, socio-scientific studies (TP4) investigate acceptance and interest in participation of customers in the field study. TP5 and TP6 comprise implementation, installation and realisation of the field study. The main objective of this field test is investigating the real-world potential, requirements and restrictions of flexibility utilization, e.g. by a prototypical implementation of the meter reading balancing procedure. The evaluation (TP7) is based on both simulations and the

field test in order to reach theoretical and practical evidence and to derive concrete recommendations for action.

The expected benefits of the project are widespread and affect the consumers resp. prosumers as well as network operators, balancing group managers, market makers, new stakeholders and guide future regulation and policy decisions.

LiLa Walldorf
Living Lab

LowEx-Concepts for Heat Supply of Existing Multi-Family Buildings: Joint Project "Analyse und Demonstration" (Analysis and Demonstration)

Russell McKenna, Fritz Braeuer

Partner: Fraunhofer Institute for Solar Energy Systems, ISE, KIT Institute of Fluid Machinery, FSM, KIT Building Science Group (Fachgebiet für Bauphysik & technischen Ausbau), fbta, various housing companies, various technology partners

Funding: Federal Ministry for Economic Affairs and Energy (BMWi)

Duration: 06/2016 to 05/2020

The building sector plays a key role in Germany's energy consumption. Regarding greenhouse gas emissions, this sector takes up the biggest role after electricity production and traffic. Hence, the substantial reduction of CO_2 emissions of buildings is a major climate policy goal of the German Federal Government.

The massive decarbonisation of the heating sector represents the main lever to achieve these goals. Electric as well as gas powered heat pumps have a significant potential to reduce the specific CO_2 emissions of a building's heat supply depending on various heat sources and sinks.

The aim of this collaborative project is to analyse and demonstrate different concepts of LowEx-systems, particularly heat pumps, in existing multi-family buildings (MFBs). In the analysis part of the project, the combination of different technological concepts and different types of MFBs are reviewed and evaluated. A special consideration is given to the thermal comfort of the inhabitants, the economic aspects as well as the emission reduction potential.

The demonstration part will comprehensively observe and scientifically evaluate the operation of various heat pump systems and components in pilot-refurbishment-projects in combination with selected heat sources, storages and transport systems. The demonstration projects are undertaken by a larger joint collaboration project named "LowEx-Bestand-Konzepte" (LowEx-Existing-Building-Stock-Concepts) where technology producers as well as housing companies are involved.

The tasks at IIP are:

- Techno-economic evaluation of various LowEx-system concepts in conjunction with specific building and settlement types.
- Identification of energy efficiency levers in existing multi-family buildings.
- Model-based national system optimisation of the heat supply mix in residential housing with a special focus on the existing stock of multi-family buildings.

New Approaches for an Integrated Energy System and Power Grid Modelling

Viktor Slednev, Armin Ardone

Partner: KIT-IEH (Institut für Elektro-energiesysteme und Hochspannungstechnik), EMCL (Engineering Mathematics and Computing Lab, Heidelberg)

Funding: Deutsche Forschungsgemeinschaft (DFG)

Duration: 2017 to 2018

The rapid expansion of decentralized renewable energy sources (RES) in many European countries necessitates an extensive structural rearrangement of the power system. In particular, since many of these new RES facilities will be located far from the load centres (in particular new wind parks), an expansion of the transmission grid is necessary to meet the resulting transport capacity requirements. To support decision making in this context, models are needed which allow for a long-term, regional operation and expansion planning for electricity generation and transmission. The consideration of grid constraints in energy systems models therefore becomes increasingly important. An integrated energy system and power grid modelling, however, requires new approaches concerning the mathematical modelling and its efficient solution.

The development of efficient numeric methods for solving the dynamic optimal power flow (DOPF) problem forms the basis for an adequate consideration of technical and physical grid restrictions within long-term energy system models. Within the scope of the DFG-funded project an approach for solving the DOPF problem based on the decoupling into several smaller sub problems was found to be well suited for the problem at hand. Especially a temporal decoupling was found to outperform existing solution approaches or decoupling approaches between power plant dispatch and load flow restrictions.

For modelling the coupled transmission network expansion planning (TNEP) and generation expansion planning (GEP) problem, a decomposition approach based on Bender was chosen and parametrised with spatial and temporal highly resolved input parameters. The first steps for implementing the developed parallel iterative approach for solving linear equation systems within the integrated TNEP and GEP problem were taken.

Profile Region Mobility Systems Karlsruhe

Patrick Jochem, Axel Ensslen

Partner: KIT, Fraunhofer (ICT, IOSB, ISI, IWM, NAS), University of Applied Sciences Karslruhe (IEEM, IKKU), Forschungszentrum Informatik (FZI)

Funding: Ministerium für Wissenschaft, Forschung und Kunst (MWK) of Baden-Württemberg

Duration: 2016 to 2017

Within the "Profilregion Mobilitätssysteme Karlsruhe" (01/2016-12/2017), the research expertise and the development competence in the field of mobility systems available and located at Karlsruhe are combined and linked with the industry. The project is funded by the federal state of Baden-Württemberg. Several institutes at KIT, Fraunhofer, University of Applied Science Karlsruhe and FZI (Forschungszentrum Informatik) are involved in the project and combine interdisciplinary research expertise. Seven initialization projects are supposed to bring the different partners closer together. Within the project synergies with the local partners are exploited and a mutual cross-institutional exchange of knowledge has been initialized. IIP is part of the initialization projects "Transportation and Mobility in a changing society" and "Mobility in an urban environment – needs-oriented infrastructure solutions in future cities" with a focus on electric mobility topics.

PROFILREGION
MOBILITÄTSSYSTEME
KARLSRUHE

The research activities of IIP notably focus on identifying and analysing user requirements for potential future electric mobility solutions and optimizing the allocation of fast charging infrastructure along the German autobahn. Further information about the seven initialization projects are available at: http://www.profilregion-ka.de or http://www.profilregion.kit.edu/26.php.

Baden-Württemberg
MINISTERIUM FÜR WISSENSCHAFT, FORSCHUNG UND KUNST

Baden-Württemberg
MINISTERIUM FÜR WIRTSCHAFT, ARBEIT UND WOHNUNGSBAU

Powerdesign: Impact of Different Market Designs in the CWE Market Area on Electricity Prices and the Competitiveness of Swiss Hydropower

Dogan Keles, Joris Dehler, Florian Zimmermann, Russel McKenna

Partner: Paul Scherrer Institute

Funding: Swiss Federal Office of Energy

Duration: 2015 to 2018

This project in cooperation with the *Paul Scherrer Institute (PSI)* is funded by the *Swiss Federal Office of Energy SFOE* and it aims to assess the impact of changes in the neighbouring energy markets on the competitiveness of hydropower and on support schemes for renewable energies (RES) in Switzerland. Therefore, the price effect of changes in the market design and support schemes in Switzerland and neighbouring countries will be analysed. Based on this the profitability of hydropower and the value of RES will be analysed to determine the required support.

To carry out the analysis a sequential approach will be applied. Firstly, an econometric analysis will identify the main drivers of the Swiss electricity prices and the ones of the neighbouring countries. Then, the determined drivers will be captured by the agent-based market model PowerACE and used for building stochastic scenario trees from the prices derived in the market model. The agent-based model simulates the future capacity development of power plants and the resulting electricity prices for different market design assumptions. The resulting prices will be used to analyse the required RES subsidies due to alternative support schemes and RES scenarios. Subsequently, the generated stochastic scenario trees will be used for the stochastic optimization of the dispatch of Swiss hydropower storage plants.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE
Office fédéral de l'énergie OFEN

Power-to-Gas Concepts with high Social Acceptance for an Efficient and Flexible Storage and Energy Infrastructure for the Integration of Renewable Energies in Baden-Württemberg

Russell McKenna, Tobias Jäger, Quentin Bchini

Partner: DVGW-EBI (DVGW-Forschungsstelle am Engler-Bunte-Institut am KIT), KIT-IEH (Institut für Elektroenergiesysteme und Hochspannungs-technik), Fraunhofer ISI (Institut für System- und Innovationsforschung), Hochschule Biberach – IGE (Institut für Gebäude – und Energiesysteme), Stadtwerke Karlsruhe Netze GmbH, IREES (Institut für Ressourceneffizienz und Energiestrategien)

Funding: Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg (BWPLUS)

Duration: 11/2013 to 03/2017

The increasing penetration of renewable energies will make new storage technologies indispensable in the future. Power to Gas (PtG) is one long-term storage technology that exploits the existing gas infrastructure. However, this technology faces technical, economic and environmental challenges and questions. This large research project attempted to address and provide answers to some of these questions for Baden-Württemberg (south west Germany).

Three energy scenarios out to 2040 were defined, one oriented towards the Integrated Energy and Climate Concept of the Federal State Government and two alternatives. Timely-resolved load profiles for gas and electricity for 2015, 2020, 2030 and 2040 have been generated at the level of individual municipalities. The profiles include residential and industrial electrical load, gas required for heating (conventional and current-controlled CHP), as well as gas and electricity demand for mobility. The installation of rooftop PV-plants and wind power plants is projected based on bottom up cost-potential analyses which account for some social acceptance barriers. Residential load profiles are derived for each municipality. In times with negative residual load, the PtG technology could be used to convert electricity into hydrogen or methane.

The detailed analysis of four structurally-different model regions delivered quite different results. While in large cities, no negative residual load is likely due to the continuously high demand, rural areas with high potentials for renewables could encounter several thousand hours of negative residual load. A cost-effective operation of PtG would only be possible under favourable conditions, including high full load hours, a strong reduction in costs and a technical improvement of efficiency. Whilst these conditions are not expected to appear in the short to mid-term, they may occur in energy systems with very high shares of renewable energy sources.

Horizon 2020 Project REFLEX – Analysis of the European Energy System under the Aspects of Flexibility and Technological Progress

Dogan Keles, Andreas Bublitz, Christoph Fraunholz, Katrin Seddig, Jonathan Gomez, Patrick Jochem

Partner: Technical University of Dresden, AGH – Krakow University of Science and Technology, ESA² - Energy System Analysis Agency, Fraunhofer ISI, KTH – Royal Institute of Technology, TEP Energy, TRT TRASPORTI E TERRITORIO srl, Universiteit Utrecht

Funding: European Commission, Horizon 2020

Duration: 2016 to 2019

The future energy system is challenged by the intermittent nature of renewables and requires therefore several flexibility options. Still, the interaction between different options, the optimal portfolio and the impact on environment and society are unknown. It is thus the core objective of REFLEX to analyse and evaluate the development towards a low-carbon energy system with focus on flexibility options in the EU to support the implementation of the SET-Plan. The analysis is based on a modelling environment that considers the full extent to which current and future energy technologies and policies interfere and how they affect the environment and society while considering technological learning of low-carbon and flexibility technologies.

For this purpose, REFLEX brings together the comprehensive expertise and competences of known European experts from six different countries. Each partner focuses on one of the research fields techno-economic learning, fundamental energy system modelling or environmental and social life cycle assessment. To link and apply these three research fields in a compatible way, an innovative and comprehensive energy models system (EMS) is developed, which couples the models and tools from all REFLEX-Partners. It is based on a common database and scenario framework. The results from the EMS will help to understand the complex links, interactions and interdependencies between different actors, available technologies and impact of the different interventions on all levels from the individual to the whole energy system. In this way, the knowledge base for decision-making concerning feasibility, effectiveness, costs and impacts of different policy measures will be strengthened, which will assist policy makers and support the implementation of the SET-Plan. Stakeholders will be actively involved during the entire project from definition of scenarios to dissemination and exploitation of results via workshops, publications and a project website.

SEES – Scientific Evaluation of Energy Services

Patrick Jochem, Russell McKenna, Fritz Braeuer, Carmen Mayer, Sabrina Ried

Partner: KIT-ENTECHNON

Funding: BMW Group

Duration: 2017 to 2020

Between June 2017 and May 2020, KIT evaluates the market opportunities of renewable energies, battery storages, and electric vehicles in different applications. Based on these potentials, IIP assesses the ecological impact of those business cases on the German electricity system.

Storage and Cross-linked Infrastructures (SCI) – for the Renewable Energy Age

Christoph Nolden, Hannes Schwarz, Armin Ardone, Joris Dehler

Partner: Forschungszentrum Jülich (FZJ), German Aerospace Centre (DLR), Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), Helmholtz-Zentrum Dresden-Rossendorf (HZDR), and Karlsruhe Institute of Technology (KIT)

Funding: Helmholtz Research Programme (PoF III)

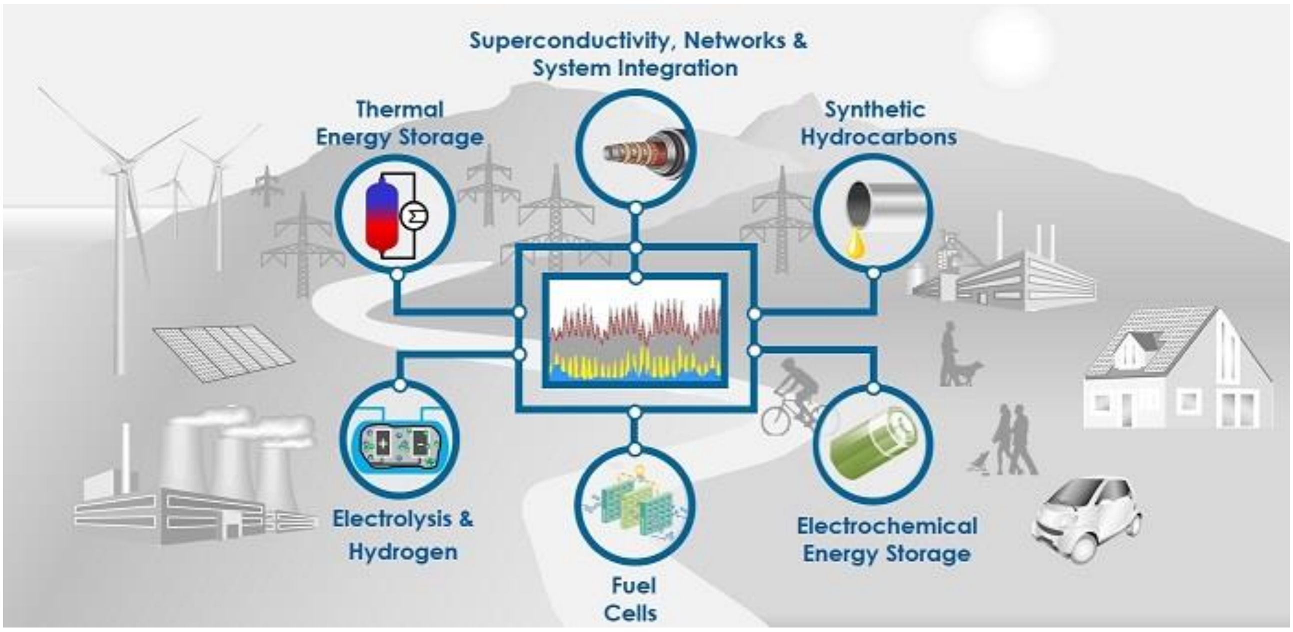
Duration: 2015 to 2019

The project focuses the challenges which are attended by the German "Energiewende" in the field of energy storage systems and efficient infrastructures. The rising share of electricity generation from renewable energy sources requires three important new technical solutions:

1) Adequate energy storage systems which compensate the volatile generation and bridge seasonal fluctuations in supply and demand.

2) Efficient infrastructures which address the upcoming challenges of energy transmission and distribution.

3) A cross-sector coupling (e. g. power-to-gas) to increase the energy systems' flexibility, efficiency and profitability and to secure reliable, flexible, efficient, and economic energy supply.



The whole project is divided into 6 thematic areas. The chair of Energy Economics is involved in Topic 6 *Superconductivity, Networks & System Integration*. One focus is the future development of the German transmission grid, in particular the interaction between the allocation of RES-E capacities and necessary transmission grid expansions. Another focus lies on future (regional) market designs and coordination.

Helmholtz Research School on Energy Scenarios

Zongfei Wang, Patrick Jochem

Partner: KIT-ITAS, KIT-IfP, Fraunhofer-ISI, University of Stuttgart (IER and ZIRIUS), German Aerospace Center (DLR) Institute of Engineering Thermodynamics (TT)

Funding: Helmholtz Association

Duration: 2011 to 2018

The Helmholtz Research School on Energy Scenarios provides a structured educational programme for international PhD students who address challenges connected with energy scenarios in their research. Three pillars, constituting the "life-cycle" of energy scenarios, form the topical focus of the programme: New methods for the construction of energy scenarios are developed in order to address the complex transformation of the energy system. The impacts of scenarios on energy policy and public debate are investigated from an empirical perspective and methods to systematically assess and compare various energy scenarios are developed. The research school offers a broad lecture programme which supports the PhD students in coping with these demanding questions. But since the questions are strongly interconnected with each other the aim is also to provide an interdisciplinary environment in which the PhD students come into a close exchange and are able to support each other. From spring 2012 on in two periods of three years in total nearly fifty PhD students can take part in the programme.

The current topic at the IIP deals with an optimal control of electric vehicle charging patterns. The analysis considers uncertainties due to the measurement of data, price forecasts, demand and supply prognosis (including weather) methods, technical issues (blackouts of system components) and changes of user patterns.

energy
scenarios
school

HELMHOLTZ
ASSOCIATION

Awards

- Emil Kraft received the BestMasters Award of Springer Gabler for his Master thesis on “Analysis and Modelling of the French Capacity Mechanism”, which was supervised by Florian Zimmermann, Dogan Keles and Wolf Fichtner.
- Patrick Jochem received the “Wissenschaftspreis” of the KIT Department of Economics and Management for his Habilitation “Electric mobility & energy systems: a techno-economic impact analysis of electric vehicles on the energy systems”.

Completed PhD Dissertations and Habilitations

Habilitation: Decentralised low-carbon energy systems: cost-potential methods and energy systems analysis, May 2017

Russell McKenna

The characteristics of renewable energy resources, especially their low power density and spatially-distributed nature, mean that much of their installed capacity is decentralised. An ongoing strong trend towards so-called 'community energy' involves the investment in and operation of low carbon technologies (LCT) by mainly private individuals and farmers. Within this context, buildings account for about 40% and 36% of the total European end energy consumption and greenhouse gas (GHG) emissions respectively. In particular, residential buildings make up around 75% of the total European building floor area, where the bulk (up to 80%) of energy use and emissions in Germany is related to heating applications (i.e. space heating and hot water). In addition, currently around 87% of heat supply in European buildings is generated in or near to the object it supplies. The characteristics of heat and electricity systems means that decisions made at the individual, building (e.g. household or commercial premises) and municipality scale all have strong interactions with one another and between energy vectors. The characteristics of these (electricity and heat) systems means approaches are needed that consider these interactions between systems and levels.

This cumulative Habilitation takes these characteristics as its starting point, by developing and applying methods that provide decision support to key stakeholders, including researchers, policy-makers and investors in this field. The common thread that connects this diverse body of work is the techno-economic and model-based analysis of decentralised LCTs and energy systems, with a focus on methods to analyse the optimal allocation of resources based on different criteria and perspectives. The Habilitation has two main foci, namely the cost-potential and integration analysis of LCTs, and energy system modelling of decentralized heat and power systems in residential buildings and urban areas.

1. In the field of cost-potential analyses for LCTs, the following three work streams are presented:
    a. Methods for the cost-potential assessment of onshore wind energy have been developed. Appropriate turbines are selected and allocated to areas (combinations of land use categories and wind speeds) based on their suitability and a minimization of their LCOEs. Such novel methods have been applied to Baden-Württemberg, Germany and the whole of Europe (McKenna et al. 2012, 2014b, 2015b). These methods have been extended to consider the aesthetic appreciation of the local landscape and the local planning process, and to individually place and cluster wind turbines and parks (Jäger et al. 2016).
    b. Highly-transferable methods for cost-potential assessments of wind and PV have been developed, both at the national scale, based on publicly available data at the municipal level (Mainzer et al. 2015) and the local scale, to determine PV cost-potentials at the building level (Mainzer et al. 2016).
    c. Upon the basis of the above methods, model-based analyses have been carried out to determine the scope for realizing these local potentials for PV and wind, and optimizing these potentials according to diverse energy-political criteria (Killinger et al. 2014).
2. In the field of model-based analysis of decentralized LCTs in residential buildings and urban areas, the following contributions have been made:
    a. A methodological framework for modelling decentralised heat supply at the national level was developed, including the TIMES-HEAT-POWER model itself, which includes the German electricity and residential buildings sectors at a level of detail until now unseen in such models (Merkel et al. 2017). The model was applied to analyse the potential for thermal load management with virtual power plants (Fehrenbach et al. 2014) and extended to consider the technology mix effect (Merkel et al. 2014).

b. Methods to analyse decentralised heat and power supply at the building level were developed, including an optimisation model for decentralised CHP setup and dispatch and the application of this model to analyse CHP plants in a UK context (Merkel et al. 2015). This model was subsequently extended and applied to analyse the effects of scale on the economic case for energy autonomy in residential buildings (McKenna et al. 2016b).
c. Integrated approaches were developed, which combine several methods and/or models, to analyse decentralised heat and power supply at the neighbourhood and municipality level. The model in 2.b. was combined with stochastic heat and electricity profile generators, household and neighbourhood archetypes, in order to analyse the effects of socioeconomic diversity on the possible penetration of LCTs at the neighbourhood level (McKenna et al. 2016c, 2017). Further, an integrated participative approach combining cost-potential analyses, optimisation, stakeholder workshops and MCDA in order to develop feasible energy concepts for small municipalities was developed and applied (McKenna et al. 2016d).

The cumulative Habilitation concludes with an outlook over further research. In the field of cost-potential analyses, further research should consider the costs of network connection/extension associated with the development of LCTs, as well as the system costs resulting from the required integration measures, and should attempt to account for softer socioeconomic factors such as acceptance of these technologies. In the area of modelling decentralised LCTs for heat and power supply, further research should attempt to consider the economic and environmental trade-offs between centralised and decentralised heat supply options. Also in this area, a superior reflection of user behaviour in residential buildings is required, as some studies have already attempted. The availability and analysis of increasingly available smart meter data promises to make inroads in this respect. Finally, in the area of energy autonomy, a holistic definition and assessment framework is required in order to assess the system-level consequences of many energy-autonomous municipalities (McKenna 2018).

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PhD Dissertation: "Battery storage in households considering photovoltaics, electric vehicles and demand response"

Thomas Kaschub

The developments of lithium-ion batteries are enabling competitive products such as electric vehicles (EV) or battery storage for households with a photovoltaic (PV) roof-top system. These products can support transforming the energy system and help reducing greenhouse gas emissions and air pollutants.

The objective of this work is to investigate the economic efficiency of stationary battery systems (SBS) in combination with a PV system and EV in households. The load-shifting potentials of EV and SBS are analyzed as well as the effects of various electricity tariffs and general conditions.

Therefore an optimization model (mixed integer linear program) was developed. It endogenously determines the system sizes of PV and SBS system and maximizes their net present values. The model considers all household expenditures for electricity and the investments for PV system and SBS over a period of 20 years. Relevant technical restrictions of the analyzed systems are considered. This includes simplified constraints of cycle and calendar lifetime of the SBS. The model determines the optimal charging and discharging scheduling of SBS and EV for a whole year in quarterly hour time resolution.

Empirical data such as measured household curves, mobility profiles based on the German Mobility Panel and weather data are used to calculate the results. On basis of these and further input data, future developments and scenarios, like different electricity tariffs, were calculated. In each case, different integration strategies of the EV were evaluated comparatively. In addition sensitivity analyzes were performed.

Together with a further decrease of the investment costs for PV system and SBS, the results show that positive net present values (NPV) of an SBS in combination with a PV system can be expected within a few years – even without subsidies. However, these results are highly sensitive to investment costs, electricity prices and interest rates. Depending on the personal mobility behavior an EV significantly increases the household's electricity demand. Controlled charging of EV enables to increase the self-coverage rate of households to an average of about 50% and to reduce accordingly the household's CO_2 emissions compared to the German electricity mix. The considered technologies fundamentally change the household's electricity consumption and the grid feed-in of surplus electricity from PV system. SBS and EV enable relevant demand response measures. For example, peak loads can be reduced by introducing a demand charge or a tariff with dynamic load limits.

Staff as of December 2017

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Prof. Dr. Wolf Fichtner

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Michaela Gantner-Müller

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Josiane Folk (also working for the Chair of Business Administration, Production and Operations Management)

Heads of Research Groups

Dr. Armin Ardone – Distributed Energy Systems and Networks

PD Dr. Patrick Jochem – Transport and Energy

Dr. Dogan Keles – Energy Markets and Energy System Analysis

PD Dr. Russell McKenna – Renewable Energy and Energy Efficiency

Doctoral Researchers and their PhD-topics

David Balussou*: An analysis of current and future electricity production from biogas in Germany

Andreas Bublitz: An agent-based model of the electricity market to analyse market dynamics and energy and climate policy instruments

Fritz Braeuer: Economic optimization of demand side flexibility through thermal and electric storage in the industrial and residential sectors

Joris Dehler: The policy driven diffusion of renewable energy technologies considering social dynamics

Thomas Dengiz: Quantification and utilization of load flexibility potentials in German households focusing on Power-To-Heat

Axel Ensslen: Model-based analysis of integrating electric vehicles into the energy systems in France and Germany

Daniel Fett: Impacts of the increasing diffusion of PV-battery storage systems on the (central) electricity market

Rafael Finck: Analysis of the impacts of increasing generation from renewable sources in the European electricity market on transmission grids considering flow-based market coupling

Christoph Fraunholz: The influence of market design on diffusion and operation of flexibility options in the electricity market

Jonathan Gomez Vilchez: The impacts of electric vehicles on global oil demand and CO_2 emissions

Rupert Hartel: Model-based analysis of the development of pollutant emissions from the European electricity sector until 2050

Phuong Minh Khoung: Energy intensity in ASEAN countries: a retrospective decomposition analysis of the effects of urbanization and a model-based analysis of future developments

Sven Killinger*: High temporal and spatial resolution simulation of PV power output

Max Kleinebrahm: Analysis of renewable based energy supply systems for energy self sufficient households.

Emil Kraft: Analysis and modelling of balancing power markets.

Nico Lehmann: Development and assessment of new market designs which enable bidirectional trading of flexibility on a cellular level.

Kai Mainzer: Development of a transferrable model for the optimization of urban energy systems by exploitation of renewable energy and energy efficiency potentials

Christoph Nolden: Optimal allocation of renewable energy expansion in Germany considering transmission grid constraints

Javier Parrilla: System optimization of the value chain of wood residues for power generation in Baden-Württemberg

Alexandra-Gwyn Paetz*: Demand Response – an interdisciplinary analysis of intelligent control mechanisms of residential electricity demand

Sabrina Ried: Dynamic economic battery dispatch considering battery degradation

Manuel Ruppert: Analysis of regional investment incentive schemes in congested electricity markets

Johannes Schäuble: Agent-based simulation of local electricity markets

Hans Schermeyer: Congestion Management based on distribution locational marginal pricing: How to curtail less renewables

Maximilian Schücking*: Optimization model for commercial electric fleets considering uncertainties

Hannes Schwarz: Optimisation of decentralised energy systems under uncertainty

Katrin Seddig: Fleets of electric vehicles in the local energy system under consideration of the integration of renewable energies and uncertainty

Viktor Slednev: Integrated generation and transmission planning modelling in large scale power systems with a high RES share

Mirish Thakur: Development of a database for the transmission grid on a European scale

Zongfei Wang: Uncertainties in energy demand of future private households (with a focus on stationary storages, electric vehicles and photovoltaic systems)

Jann Michael Weinand: Municipal energy autonomy: a model-based analysis of the technical, economic and environmental impacts from a micro- and a macroeconomic perspective

Christian Will*: CO_2-neutral charging of electric vehicles: a techno-economic analysis from OEM-perspective

Hasan Ümitan Yilmaz: Modelling intermittent renewable power generation in the European energy system considering model complexity challenges

Florian Zimmermann: Assessment of different design options for the European electricity market and their impacts on various national energy markets

*external researchers

Visiting Researchers

Dr. Qingxin Li: Electric Power Planning & Engineering Institute (EPPEI) and Southwest Electric Power Design Institute, China

Katharina Karner: Institute for energy, transport and environmental management, FH JOANNEUM university of applied sciences

International Collaboration

Location: Reading and Lancaster, United Kingdom

Who: PD Dr. Russell McKenna

Host: Prof. Jacopo Torriti, University of Reading, and Prof. Gordon Walker, Lancaster University

Period: November 2017 to March 2018

In the context of the DEMAND research project, coordinated from the http://www.demand.ac.uk/ at Lancaster University, Russell McKenna will visit the School of the Built Environment at the University of Reading, for two weeks at the end of 2017. He will also spend a further two weeks at the DEMAND Centre in Lancaster in the spring of 2018. The purpose if the visits is to develop collaborations with the two institutions, especially within the general field of residential energy use.

Location: Paris, France

Who: Johannes Schäuble

Host: Prof. Dr. Christian de Perthuis, Chaire Economie du Climat (Paris Dauphine)

Period: January to July 2017

The main purpose of Johannes Schäuble's stay was to increase the experience and quality of his future work: this was achieved through the numerous discussions, evaluations, presentations and conferences beyond expectations. Paris is home to a number of high-ranking universities and offers a highly interesting research community: Johannes Schäuble has been able to build a network of French researchers specialising in energy-related topics.

The visibility of his research (and that of the KIT in general) could benefit from his stay, as he was able to present his work during the numerous small internal colloquia, congresses and conferences in Paris.

The hosting organization of the Chaire Economie du Climat is conceived as a research platform, academically recognized and open to the economic and political world. The research programme focuses on the economics of climate change. This concept of the research platform with all its resources has therefore strengthened his knowledge, especially in this area.

Location: Davis, California, USA

Who: Christian Will

Host: Prof. Dan Sperling, Institute of Transportation Studies (ITS), University of California, Davis (UC Davis)

Period: October 2017 to January 2018

During his research visit at the Plug-in Hybrid & Electric Vehicle Research Center at the ITS in mid-October, Christian Will has been researching electric vehicle charging services. A series of interviews are in progress to assess customers' understanding and demand for renewable electricity for their electric vehicles. The findings from these interviews lay the foundation for consecutive representative studies on this topic to be conducted in Germany. Furthermore, Christian collaborates in discussing customers' driving and charging behavior as well as renewable energy markets in the United States.

Location: Santiago, Chile

Who: Sabrina Ried

Host: Prof. Matías Negrete, Prof. Daniel Olivares, Prof. Alvaro Lorca, OCM-Lab, Pontificia Universidad Católica de Chile (PUC), Prof. Guillermo Jiménez, Prof. Rodrigo Moreno, Centro de Energía, Universidad de Chile

Period: March to April 2017

Sabrina Ried spent two weeks with each institute, aiming at establishing a cooperation in the field of stationary batteries for energy systems. Together with the Energy Optimization, Control and Markets Lab of the PUC, she started investigating the possibilities of integrating batteries in energy system modelling. A common publication is currently under preparation. Together with the Centro de Energía, Sabrina analysed the opportunities for integrating higher shares of renewable energies into the Northern Chilean transmission grid by applying a stationary battery.

Location: Austin, TX, United States

Who: Joris Dehler

Host: Prof Varun Rai, University of Texas at Austin, Lyndon B. Johnson School of Public Affairs

Period: July 2017

Joris Dehler was granted the KHYS networking grant for visiting Varun Rai and his research group in Austin. During the stay, Joris Dehler presented his research topics concerning the diffusion of renewable energy technologies, different aspects of agent based models, and empirical research. He got the chance to work with the models proposed by Varun and to compare the two approaches. This short stay enabled some stimulating discussions with colleagues at both institutions who are working on similar topics.

Teaching Activities

The Chair of Energy Economics offers several modules in the fields of Energy Economics, Energy Markets and Technology. For undergraduate students the module Energy Economics contains three lectures. Moreover, the chair offers twelve courses in the context of the two Master modules "Energy Economics and Energy Markets" and "Energy Economics and Technology". Furthermore, the chair offers several seminars in Energy Economics where current developments are addressed. The chair supervises on average about 100 bachelor and master theses per year.

Introduction to Energy Economics ~80 students

Prof. Dr. rer. pol. W. Fichtner

This lecture aims to make students familiar with basic concepts of energy economics. The main contents are the different energy carriers gas, oil, coal, lignite and uranium. The terms of reserve and resource are introduced as well as associated technologies. Subsequently the final carrier electricity and heat are introduced and other forms of final energy carriers (cooling energy, hydrogen and compressed air) are presented. The lecture aims to enable the students to characterize and evaluate the different energy carriers and their peculiarities and conveys a fundamental understanding of contexts related to energy economics.

Renewable Energy – Resources, Technologies and Economics ~120 students

PD Dr. R. McKenna

This lecture introduces the basics of renewable energies starting with a general introduction on the global situation and the energy balance of the earth followed by the different renewable forms hydro, wind, solar, biomass and geothermal. The promotional concepts of renewable energies are presented and the interactions in the systemic context are examined. The course includes an excursion to the "Energieberg" in Mühlburg.

Energy Policy ~45 students

Apl. Prof. Dr. rer. pol. M. Wietschel

This course deals with material and energy policy of policy makers and includes the effects of policies on the economy as well as the involvement of industrial and other stakeholders in policy design. At the beginning, neoclassical environment policy is discussed. Afterwards the concept of sustainable development is presented and strategies how to translate the concept in policy decision follows. In the next part of the course an overview of the different environmental policy instruments, classes, evaluation criteria for these instruments and examples of environmental instruments like taxes or certificates will be discussed. The final part deals with implementation strategies of material and energy policy.

Liberalised Power Markets ~50 students

Prof. Dr. rer. pol. W. Fichtner

After presenting the liberalisation process in the European energy market this course examines pricing and investment mechanisms in liberalised power markets. The power market and the corresponding submarkets are discussed. Moreover, the course deals with the concept of risk management and market power in liberalised energy markets. It concludes different market structures in the value chain of the power sector.

Energy Trade and Risk Management ~30 students

Dr. sc. techn. C. Cremer

Dr. rer. pol. D. Keles

This lecture on energy trading introduces the major energy carrier markets such as gas, oil or coal. Different pricing mechanisms are discussed. In terms of methods, evaluation techniques from financial mathematics and key risk analysis approaches are presented.

Gas Markets ~30 students

Prof. Dr. Dr. A. M. Pustisek

This course starts by introducing technical and economic principles of the natural gas industry. The natural gas value chain, local and international market places are presented and the structure of commodity contracts is analysed. Subsequently the course deals with possibilities for natural gas transportation and storage. The course concludes on selected regulatory aspects, risk management, new technologies relevant for the natural gas industry.

Simulation Game in Energy Economics ~15 students
Dr. rer. pol. M. Genoese

This course is structured in a theoretical and a practical part. In the theoretical part, the students are taught the basics to carry out simulations themselves in the practical part which comprises amongst others the simulation of the power exchange. The participants of the simulation game take a role as a power trader in the power market. Based on various sources of information (e.g. prognosis of power prices, available power plants, fuel prices), they can launch bids in the power exchange.

Quantitative Methods in Energy Economics ~20 students
Dr. rer. pol. D. Keles
Dr. rer. nat. P. Plötz

Energy economics makes use of many quantitative methods in the exploration and analysis of data as well as in simulations and modelling. This lecture course aims at introducing students of energy economics to the application of quantitative methods and techniques as taught in elementary courses to real problems in energy economics. The focus is mainly on regression, simulation, time series analysis and related statistical methods as applied in energy economics.

Technological Change in Energy Economics ~30 students
Apl. Prof. Dr. rer. pol. M. Wietschel

This lecture gives insights into innovation theory, innovation economy and innovation systems. Different quantitative methods for the forecast of technology change such as technology cycle models, optimisation and simulation models are examined to provide the students with a toolset to evaluate important technological developments in the energy sector from a techno-economic perspective.

Heat Economy ~20 students
Prof. Dr. rer. pol. W. Fichtner

After introducing the principle of heat economics, this lecture provides insights to CHP technologies and heat systems including profitability calculations. Further, the distribution of heat, the demand for space heating as well as thermal insulation measures and possibilities for heat storage are highlighted. The legal framework conditions for heat economy conclude the theoretical part of the lecture. A laboratory experiment with a compression heat pump gives the students the opportunity to apply the acquired theoretical knowledge.

Energy Systems Analysis ~40 students
Dr. rer. pol. V. Bertsch
Dr. rer. pol. A. Ardone

This lecture gives an overview of different system modelling approaches for energy system modelling. Scenario techniques are introduced, the concept of unit commitment of power plants and interdependencies in energy economics are examined. Scenario-based decision making in the energy sector is highlighted and insights into visualisation and GIS techniques for decision support in the energy sector are given.

Smart Energy Infrastructure ~20 students
Dr. rer. pol. A. Ardone
Prof. Dr. Dr. A. M. Pustisek

This lecture provides insights into the topic of infrastructures for energy transport, particularly the transport of natural gas and electricity, and the underlying economics. In the field of energy infrastructure, the keyword "smart" is becoming increasingly important. The lecture treats concepts of smart electricity transmission, as well as future infrastructure challenges in an energy system with an increasing share of renewable electricity generation. In the field of gas, possibilities for transportation and storage of natural gas are discussed.

Efficient Energy Systems and Electric Mobility ~40 students
PD Dr. R. McKenna
PD Dr. rer. pol. P. Jochem

This lecture series combines two of the most central topics in the field of energy economics at present, namely energy efficiency and electric mobility. The objective of the lecture is to provide an introduction and overview to these two subject areas, including theoretical as well as practical aspects, such as the technologies, political framework conditions and broader implications of these for national and international energy systems. The energy efficiency part of the lecture provides an introduction to the concept of energy efficiency, the means of affecting it and the relevant framework conditions. Further insights into economy-wide measurements of energy efficiency and associated difficulties are given with recourse to several practical examples. The problems associated with market failures in this area are also highlighted, including the Rebound Effect. Finally, and by way of an outlook, perspectives for energy efficiency in diverse economic sectors are examined. The electric mobility part of the lecture examines all relevant issues associated with an increased penetration of electric vehicles including their technology, their impact on the electricity system (power plants and grid), their environmental impact as well as their optimal integration in the future private electricity demand (i.e. smart grids and V2G). Besides technical aspects the user acceptance and behavioural aspects are also discussed.

Energy and Environment ~50 students
Apl. Prof. Dr. rer. nat. U. Karl

This lecture examines the environmental impacts of fossil fuel conversion and related assessment methods. After introducing the fundamentals of energy conversion the focus is set on air pollution and conversion efficiency. Assessment methods include Life Cycle Assessment of selected energy systems, integrated assessment models, cost-effectiveness analyses and cost-benefit analyses.

<table>
<tr><th colspan="2"><u>Teaching at the Chair for Energy Economics</u></th></tr>
<tr><td colspan="2"> <u>BSc-Module „Energy Economics“</u>

Introduction to Energy Economics (SS, 5,5 ECTS)
Renewable Energy – Resources, Technologies and Economics (WS, 3,5 ECTS)
Energy Policy (SS, 3,5 ECTS)
</td></tr>
<tr><td> <u>MSc-Module „Energy Economics and Energy Markets“</u>

Liberalised Power Markets (WS, 3 ECTS)
Energy Trade and Risk Management (SS, 4 ECTS)
Gas Markets (WS, 3 ECTS)
Simulation Game in Energy Economics (SS, 3 ECTS)
Quantitative Methods in Energy Economics (WS, 4 ECTS)
</td>
<td> <u>MSc-Module „Energy Economics and Technology“</u>

Efficient Energy Systems and Electric Mobility (SS, 3,5 ECTS)
Energy and Environment (SS, 4,5 ECTS)
Energy Systems Analysis (WS, 3 ECTS)
Heat Economy (SS, 3 ECTS)
Smart Energy Infrastructure (WS, 3 ECTS)
Technological Change in Energy Economics (WS, 3 ECTS)
</td></tr>
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Publications

Books and Book Chapters

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Dehler, J.; Keles, D.; Telsnig, T.; Fleischer, B.; Baumann, M.; Fraboulet, D. et al. (2017): Self-Consumption of Electricity from Renewable Sources. In: Europe's energy transition: insights for policy making: Elsevier, Amsterdam, S. 225–236.

Hüttenrauch, J.; Müller-Syring, G.; Krause, H.; Fichtner, W.; Nolden, C. et al. (2017): Integration fluktuierender erneuerbarer Energien durch konvergente Nutzung von Strom- und Gasnetzen – Konvergenz Strom- und Gasnetze (KonStGas). Abschlussbericht. http://www.dbi-gruppe.de/files/PDFs/Projekte/00_Abschlussbericht_KonStGas_2017.pdf.

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Ensslen, A.; Schücking, M.; Jochem, P.; Steffens, H.; Fichtner, W.; Wollersheim, O.; Stella, K. (2017): Empirical carbon dioxide emissions of electric vehicles in a French-German commuter fleet test. In: *Journal of cleaner production* 142 (1), S. 263–278. DOI: 10.1016/j.jclepro.2016.06.087.

Hu, J.; Fichtner, M.; Baricco, M. (2017): Preparation of Li-Mg-N-H hydrogen storage materials for an auxiliary power unit. In: *International journal of hydrogen energy* 42 (27), S. 17144–17148. DOI: 10.1016/j.ijhydene.2017.06.021.

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