Karlsruhe Institute of Technology

Institute for Industrial Production

Annual Report 2016

Chair of Energy Economics

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Preface

This second 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 2016. 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 2016, we worked on around 25 ongoing national and international research projects, as well as beginning about 10 new projects. We published around 25 peer-reviewed journal articles, and 3 PhDs as well as 1 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

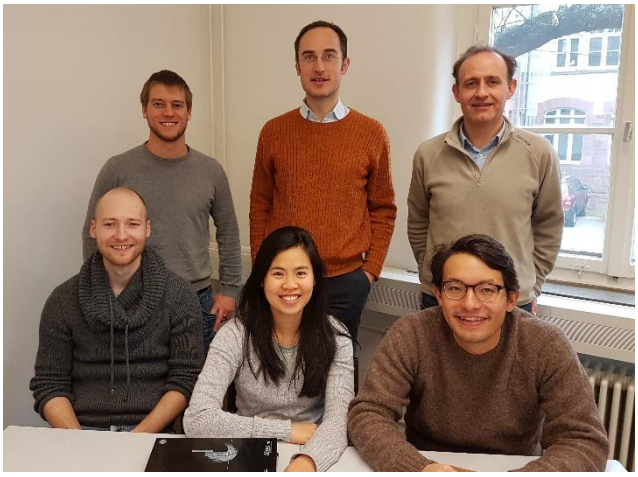
Renewable Energy and Energy Efficiency Group

Head of research group: 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^{3}ASON) 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^{3}ASON 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, Andreas Bublitz, Florian Zimmermann, Rupert Hartel, Christoph Fraunholz, Joris Dehler, Daniel Fett, Hasan Ümitcan Yilmaz.

The sustainable design of energy supply 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

So far, discussions on the energy transition focus 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 the 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, 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). 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.

Research Projects

CIVIS Project

Russell McKenna, Erik Merkel

Partner: Universita degli Studi di Trento (UNITN), Aalto-korkeakoulusaatio (AALTO), Fondazione centro studi enel (EF), Imperial College of Science, Technology and Medicine (Imperial College), Instituto Superior Tecnico (IST), Kungliga Tekniska Hoegskolan (KTH), Santer Reply Spa (REPLY), Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek – tno (TNO), Technische Universiteit Delft (TU DELFT), Fondazione Bruno Kessler (FBK)

Funding: The CIVIS project is funded by the European Commission in the FP7 framework.

Duration: 10/2013 to 09/2016

CIVIS's aim is to contribute to the design of a fairer, more sustainable, energy-optimised smart city. The project focuses on the ICT-enabled social dimension to harness the potential of innovation of individuals and collectives with respect to energy prosumption.

CIVIS will link energy, ICT and society to achieve significant impacts in terms of CO_2 reduction and new forms of social innovation.

CIVIS will implement a distributed ICT system to:

- Manage communities' energy needs
- Negotiate individual and collective energy services agreements and contacts
- Raise awareness about the environmental impacts of collective energy use
- Allocate energy production resources more efficiently

Accompanying research to "*Wettbewerb Energieeffiziente Stadt*" ("Energy-Efficient City Competition")

Kai Mainzer, Russell McKenna, Patrick Jochem

Partner: LEE (Lehrstuhl für Energiesysteme und Energiewirtschaft, Ruhr-Universität Bochum), KIT BLM (Building Lifecycle Management), IZT (Institut für Zukunftsstudien und Technologiebewerung, Berlin), B.&S.U. (Beratungs- und Servicegesellschaft Umwelt, Berlin)

Funding: Bundesministerium für Bildung und Forschung (BMBF)

Duration: 2011 to 2016

The five cities in the project Energy Efficient City Competition (Delitzsch, Essen, Magdeburg, Stuttgart, Wolfhagen) use different model-based planning tools, which support decision making by evaluating measures to increase energy efficiency and devising strategies to decrease greenhouse gas emissions. This includes models that balance energy flows and greenhouse gas emissions as well as energy system models that employ simulation and optimization methods. The IIP was tasked with the characterisation and the analysis in terms of transferability for these models. The final objective was the development of methods that might overcome the identified obstacles of transferability.

During the analysis of the developed models, it was found that the availability of the required input data is most critical for the transferability of models. Subsequently, methods that can automate the data acquisition and preparation for urban energy system modelling have been developed. These methods have been coupled with a new urban energy system optimization model (RE^{3}ASON).

The model has been tested in a number of case studies. The results indicate that it can provide the required base data, e.g. local renewable energy potentials, as well as decision support for the required investments in order to accomplish sustainability objectives for arbitrary communities (cf. Ebhausen case study).

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Federal Ministry of Education and Research

Reference number 03SF0415B

Integration of fluctuating renewable energy sources by the convergent use of electricity and gas grids (KonStGas)

Christoph Nolden

Partner: Karlsruher Institut für Technologie (KIT) - DVGW Forschungsstelle am Engler-Bunte-Institut, DBI-Gastechnologisches Institut gGmbH Freiberg, Forschungszentrum Jülich - Institut für Energie- und Klimaforschung, Systemforschung und Technologische Entwickung, Fraunhofer Institut für Umwelt-, Sicherheits- und Energietechnik, Fraunhofer Institut für Windenergie und Energiesystemtechnik, Gas und Wärme Institut Essen e.V., Hochschule Regensburg - Forschungsstelle Energieversorgungsnetze & Energiespeicher, ONTRAS - VNG Gastransport GmbH, Ruhruniversität Bochum - Lehrstuhl Energiesysteme und Energiewirtschaft, RWE Deutschland AG, RWTH Aachen - Institut für Elektrische Anlagen und Energiewirtschaft, TU Clausthal - Lehrstuhl für Gasversorgungssysteme, TU Dresden - Lehrstuhl für Energiewirtschaft, Wuppertal Institut für Klima, Umwelt, Energie, 50 Hertz Transmission GmbH

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 08/2013 to 09/2016

The high volatility and limited predictability of renewable electricity generation lead to an increasing decoupling of electricity production and consumption. The energy system is rapidly changing from a supply-driven to a consumption-driven structure. Taken as a whole, the difference between the rising generation of fluctuating renewable energy sources and the reduced capacity of conventional power plants covering electricity supply gaps will cause problems in maintaining the security of supply in future.

Therefore, the crucial point is the development of cost-effective energy storage technologies and capacities with minimal energy losses. Within the KonStGas project, 13 research institutions and three grid operators have joined forces under the leadership of the DBI Gastechnologisches Institut in Freiberg, Germany. The consortium investigated, technically and economically, the opportunities that arise from the coupling of electricity and gas grids. The project partners analysed the electricity and gas grid in order to identify the advantages and potentials of a coupling of the two transport systems for energy storage. The research focus was on the integration of capacities for converting electricity from renewable energy sources into renewable gas into the energy supply system.

The KonStGas project investigated two scenarios with different shares of RES-E capacities. In the first scenario, the development of RES-E capacities is based on the Renewable Energy Sources Act. To ensure this aim of 80% RES-E in 2050, the RES-E share rises to 92% of the net electricity demand (before curtailment). The economic analyses show

an integration of about 5 GW_{el} of Power-to-Gas (PtG) facilities until 2050. This integration basically reduces the curtailment of RES-E, but on a very low level. To investigate a complete electricity supply from renewable energies in the second scenario, the RES-E share increases up to 130%. The results show an integration of about 38 GW_{el} of PtG facilities. The production of about 90 TWh renewable gas is used in times of a low RES feed-in by conventional gas power plans which can be therefore decarbonized.

The KonStGas project was funded by the Federal Ministry for Economic Affairs and Energy. It ran from August 2013 to September 2016. The results were presented at a public workshop in Berlin on September 22nd 2016.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Decentralized Energy Systems, Market Integration, Optimization

Phillip Ringler, Hans Schermeyer, Manuel Ruppert, Marian Hayn, Valentin Bertsch, Dogan Keles

Partner: -

Funding: Stiftung für Energieforschung Baden-Württemberg

Duration: 2012 to 2015

The increasing electricity generation from renewable energy sources (RES) as a result of the German "Energiewende" leads to the expansion of distributed generation capacities of various technologies. This trend is expected to continue and causes major challenges for the traditional electricity sector, which was originally designed for large generation units and low fluctuations.

In this study we develop a flexible modelling toolbox for decentralized electricity systems with an agent-based simulation approach at its core. Two RES-E generation models for wind and PV, each with a high temporal and spatial resolution, are presented and approaches to model specific aspects of the demand side in detail are introduced. The implementation of an AC load flow algorithm is described and the concept of a market-based congestion management mechanism based on market price signals is outlined. Our main findings can be briefly summarized as follows:

- In order to decide if an available time series of renewable supply is useful for the analysis of decentralized energy systems, the gradients, maximum amplitudes and the spatial volatility of the input data is key. We develop three corresponding indicators measuring future input data: MARS; MGRS and spatial volatility.

- We present a methodology to simulate spatially and temporally correlated renewable supply time series. Our copula-based approach simulates irradiation at nine locations and reveals substantial differences to an approach simulating only one stochastic process.

- We evaluate the increasing stress on the electricity grid infrastructure through decentralization of renewable generation and a more flexible demand. Dynamic electricity prices down to the household level can lead to more or less congestion with the tariff setup being crucial to the results. In different systems, we find an increase in critical grid situations when RES-E feed-in as well as demand flexibility is increased and the price signals are only based on wholesale market prices for electrical energy.

- When analysing decentralized systems, the complexity strongly increases through the heterogeneity of stakeholders and the higher resolution of data. This challenges the application of optimization models, common in energy systems analysis, and makes simulation approaches, such as the agent-based simulation presented in this work, more and more promising.

AVerS - Analyse der Versorgungssicherheit in Süddeutschland unter Berücksichtigung der europaweiten Kopplung der Strommärkte (Analysis of the security of supply in southern Germany under consideration of couppled European electricity markets)

Dogan Keles, Christoph Fraunholz

Partner: Fraunhofer ISI, TU Dresden, ESA² 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 ESA² 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

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)

Rupert Hartel, Hasan Ümitcan Yilmaz, Viktor Slednev

Partner: Fraunhofer ISI

Funding: Umweltministerium Baden-Württemberg

Duration: 2016 to 2017

Due to the ambitious European and national climate protection targets, Germany is undergoing a transformation of its energy supply. This transformation is about to ensure the decarbonisation of the power sector and should thereby incorporate aspects of high security of supply as well as a cost-efficient energy supply. Simultaneous and extensive decarbonisation of the power sector can jeopardize the security of supply in

south Germany, as renewable generating capacities are predominantly located in the north, whereas big demand centres are concentrated in the southern part of Germany.

The overall objective of this research project is to examine the long-term effects on the security of supply in south Germany while taking economically and environmentally indicated power plant shutdowns in other European countries into account. Resulting congestions in the German transmission system are likewise analysed with respect to security of supply. Special consideration will be given to the population's acceptance, load-flexibility measures, storage technologies and the development of demand for electricity, which can increase in the case of sectoral coupling by the spread of Power-to-X-technologies and electro-mobility. For the extensive and detailed analysis of the security of supply three models from Fraunhofer ISI and KIT-IIP are going to be linked with each other. Robust results can be computed by conducting multiple iterations of these models that, amongst other things, contain an extension of capacities alongside the accompanying fortification of the grid. On this basis, assessments for the security of supply in south Germany and recommendations for actions will be derived.

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 flexibilisation 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 inter-disciplinary 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 behaviour 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.

Another 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.

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

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.

Ebhausen Energy Concept

Russell McKenna, Kai Mainzer, Jann Weinand

Partner: Valentin Bertsch, Economic and Social Research Institute (ESRI) and Department of Economics, Trinity College Dublin, Ireland

Funding: none – just for fun!

Duration: 02/2016 to 12/2016

In Germany over 700 energy cooperatives were established since 2006 and about 46% of installed renewable energy can be referred to as "community energy". Although decentralised community energy resources are often abundant in smaller, more rural communities, these often lack the resources to exploit them. According to projections, these communities will be most strongly affected by a future reduction in population (e.g. ageing, migration). Energy system analysis can offer useful insights in this context, but many energy system models possess the weakness that they focus on technical and economic aspects, without considering social aspects such as acceptance for renewable energies and individual preferences. Much research in previous years has therefore attempted to link social aspects and energy system models, often by employing a combination of energy system analysis and multi-criteria decision analysis (MCDA) tools. The general approach employed in the present contribution is oriented towards the "target triangle" of German energy policy, which includes the three sometimes conflicting criteria of economic viability, environmental sustainability and security of supply, in this case augmented by the fourth criterion of public acceptance. For one exemplary municipality in the region of Baden-Württemberg (south-west Germany), stakeholder workshops are combined with energy system modelling and MCDA. The overall objective is to develop energy scenarios in line with the preferences of the local stakeholders, which will be assessed along the lines of the four above criteria. The novelties of the approach include the active involvement of the community in the iterative development of alternative scenarios focusing on the four above criteria of local energy policy, as well as the explicit consideration of the uncertainties associated with the stakeholder preferences as well as those relating to the scenario formulation itself. In addition, cost-potentials for renewable energies are determined automatically based largely on open-source data such as Open Street Map and satellite images (see Figure 1). Results indicate significant potentials to improve energy efficiency and reduce carbon dioxide emissions but also highlight the trade-offs faced by the community between partly conflicting objectives such as cost and emissions.

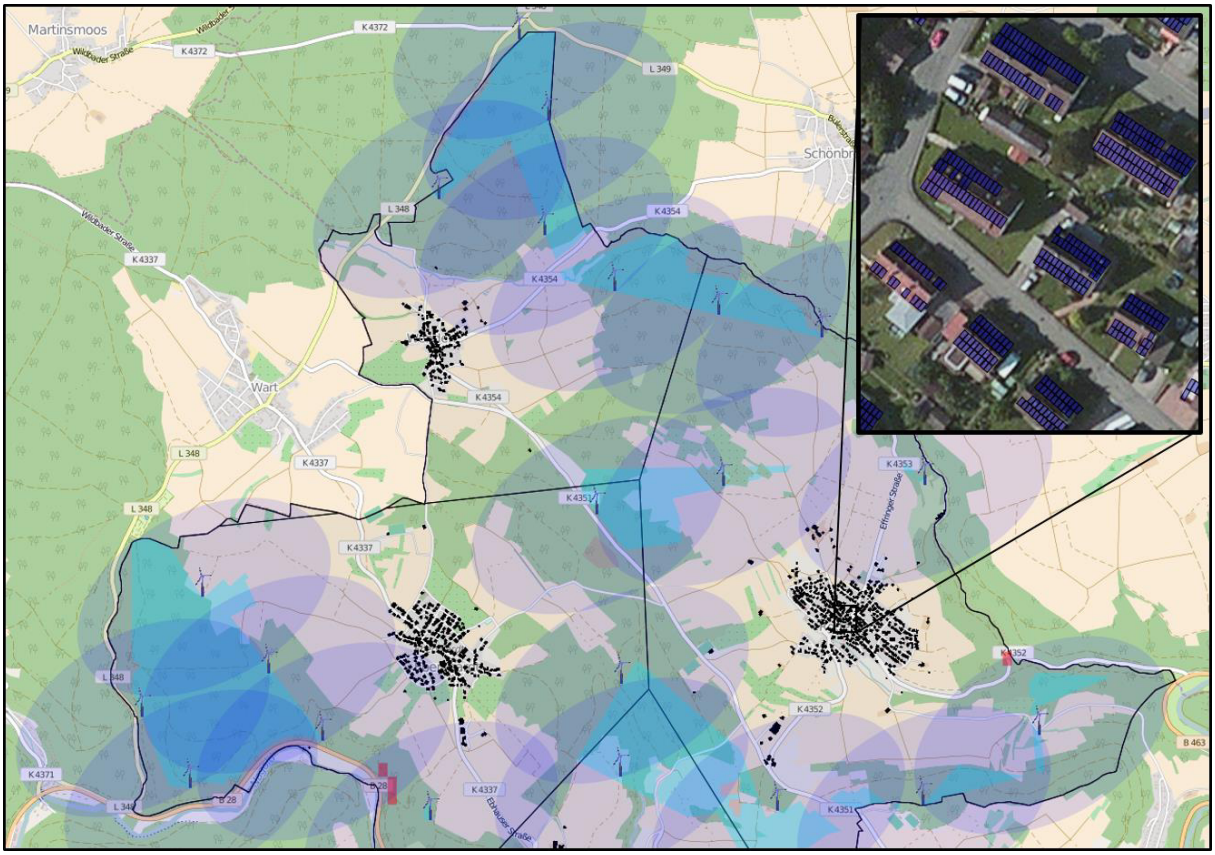

Figure 1: Wind and PV module placement in the district of Rotfelden (source: own depiction with image data from Bing Maps)

ENRES - Kooperatives Promotionskolleg Energiesysteme und Ressourceneffizienz (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 – Neue Energienetzstrukturen für die Energiewende (New Power Grid Structures for the Energy Transition)

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

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

Funding: Federal Ministry for Education and Research

Duration: 2016 to 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 a core partner in the project which includes in 15 further project partners, 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 grid capacity is needed? Or: 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 phases 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 network structures. The focus of the Chair's work lies on economic aspects of future grid structures, namely the future market design (e.g. grid-based price signals or investment incentives, regulatory framework for decentralised generation) and the repercussions on the grid, possible business models in the context of new grid structures and the techno-economic assessment of scenarios for the future grid as well as the new technical concepts identified by the partners.

Grid-control – Advanced Decentral Grid Control

Johannes Schäuble, 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

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.

http://www.projekt-grid-control.de/

Helmholtz Portfolio Initiative "Safety and Security"

Manuel Ruppert, Kai Mainzer

Partner: KIT-IKET, KIT-IPD, KIT-IKS, Deutsches Zentrum für Luft- und Raumfahrt, Forschungszentrum Jülich GmbH

Funding: Helmholtz Association

Duration: 01/2013 to 12/2015

The design of the future energy system is one of the most important problems of our society. In Germany, the development of the energy system is driven by efforts to prevent global climate change. As one contribution to emission reduction, the share of renewable energy sources increased significantly and is planned to further increase. With the growing importance of electric mobility and a further increase of renewable feed-in from wind and photovoltaic power generating units, it is foreseeable that the existing electrical power grid will not meet future requirements.

The essential objective of the Helmholtz Energy Alliance "Technologies for the Future Power Grid" is the development of solutions and the conduction of systems analyses aimed at improving flexibility and system management of the electrical distribution and transmission grids. Thereby, gas networks for energy storage will be taken into account in addition to purely electrical storage systems. Key topics in the field of technology development are intelligent system management in distribution grids, system management and system stability of a hybrid transportation grid as well as the integration of storages into the future power grid.

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 Mai 2017 the four Institutes DFIU, IEH, AIFB and ZAR from KIT are working together to support the international cooperations 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 the IIP we evaluate two important aspects for an appropriate charging infrastructure. First we evaluate electric vehicle users' acceptance of inductive charging (wireless power transfer - WPT) by carrying out surveys. One important result concerns stated willingness to pay for inductive charging systems. About 40% of our samples' electric vehicle users and fleet managers are willing to pay more than the current price for inductive charging systems, which are available for less than 2,000 Euros. Second, 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.

ELEKTRO POWER II

Supported by:

Federal Ministry of Economics and Technology

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 francais 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

INSIGHT_E is a European, scientific and multidisciplinary think-tank for energy which informs the European Commission and other energy stakeholders. It supports energy policy at the European level by providing advice on policy options and assessing their potential impact.

The key task of the think tank is the provision of objective, transparent and unbiased advice of decision makers on an EU level. The focus of consultancy activities is the analysis and assessment of consequences of different policy options to reach the European climate targets. The effects and the sustainability of different options are analysed under consideration of environmental, economic, social and safety aspects. Founded on a broad data base, different models and methods for system analysis are applied. Additionally, the awareness of decision makers to new technological developments and different behaviours and motives of energy-related actors is raised through the expertise of the think tank members. For this purpose, innovative methods of stakeholder engagement and an *observatory* online platform are applied and installed.

An Energy think tank informing the European Commission

INSIGHT_E

Living Lab Walldorf

Hans Schermeyer

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

Funding: Ministry of Environment, Climate Protextion and 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

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

Funding: Deutsche Forschungsgemeinschaft (DFG)

Duration: 2014 to 2016

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.

Profilregion Mobilitätssysteme Karlsruhe (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 will be 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 will be exploited and a mutual cross-institutional exchange of knowledge will be 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

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.

Power-to-Gas-Konzepte mit hoher gesellschaftlicher Akzeptanz für eine effiziente und flexible Speicher- und Energieinfrastruktur zur Integration Erneuerbarer Energien in Baden-Württemberg (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.

Reallabor 131 ("field tests 131"): KIT findet Stadt

Kai Mainzer, Russell McKenna

Partner: EIFER (European Institute for Energy Research), KIT-IEB (Fachgebiet Bauphysik & Technischer Ausbau)

Funding: Ministerium für Wissenschaft, Forschung und Kunst Baden-Württemberg - IQF-Programm „Reallabore, BaWü-Labs, für eine Forschung für Nachhaltigkeit in Baden-Württemberg"

Duration: 10/2015 to 11/2016

The Urban Transition Lab focuses on four topics, identified as the bottom line of two different perspectives: the objectives of Karlsruhe's citizens which were developed in a participatory process on the one hand and the expertise of KIT on the other hand.

- Energy concept in the district Oststadt
- Mobility and consulting
- Social networks and aspects of urban planning
- Sustainable consumption

The IIP is involved in the subproject of energy concepts, more specifically in the calculation of photovoltaic potentials and heat demand. Subsequently, this data can be used for the derivation of goal-orientated measures for energy savings.

The IIP has focused on the calculation of calculation and geographical mapping of heat demand in residential buildings in the Oststadt. In order to do this, the building stock in the Oststadt has been analysed during a student seminar, which led to the creation of a tailored building typology based on these observations and the IWU typology. By combining this tailored typology with local climate data, a high-resolution heat demand map has been developed.

Horizon 2020 Project "REFLEX" – Analysis of the European energy system under the aspects of flexibility and technological progress"

Dogan Keles, Andreas Bublitz, Christoph Fraunholz, 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.

Storage and Cross-linked Infrastructures (SCI)

Christoph Nolden, Hannes Schwarz

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.

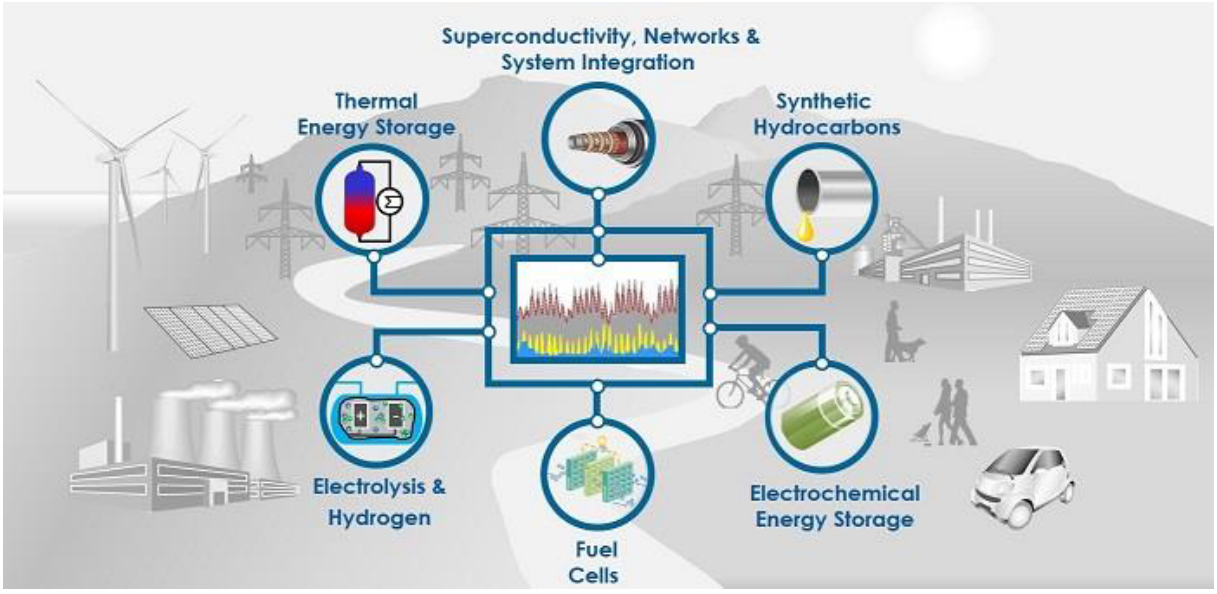

Figure 2: Topics of the SCI Project

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.

Due to the increasing profitability of photovoltaic-battery systems in private households in Germany, the objective of the proposed PhD project is an interdisciplinary analysis of the impact from increasing autonomy of private households in Germany.

The applied methodology might be agent based modelling (ABM), which allows a representation of heterogeneous private households and their different electricity demand and technical specifications (especially batteries, PV systems and electric vehicles). The simulation should consider 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. Furthermore, the simulation should include several profitable

combinations of battery storages, electric vehicles and photovoltaic systems in private households in the German electricity system.

Awards

- Jonathan Gómez Vilchez received the WCTRS Young Researcher's Award on July, 14th 2016 for his Prestige Grant Paper entitled "Car technologies and their impact on climate - A system dynamics approach". https://www.wctrs-society.com/wctrs-y-initiative/
- Qingxin Li received a Bundeskanzlerstipendium from the Alexander von Humboldt Foundation. She holds a PhD degree from Tsinghua University and is conducting research at IIP on the field of Energy Process Engineering.
- The CROME Research Project - CROss-border Mobility for EVs was awarded the second prize at the German-French-innovation competition 2016.

Completed PhD Dissertations and Habilitations

Habilitation: "Electric Mobility and Energy Systems - A techno-economic impact analysis of electric vehicles on the energy system"

Patrick Jochem

Transport is one of the main contributors to climate change and responsible for a fast growing share of about 23% of total energy-related CO_2 emissions worldwide. Most forecasts assume a doubling of the global passenger fleet and therefore a corresponding doubling of greenhouse gas emissions from transport until 2050. An electrification of this fleet has the potential to decrease CO_2 emissions and oil dependency, but may also contribute to an accelerated integration of fluctuating electricity feed-in by renewable energy resources, such as photovoltaic or wind. A multi-methodological techno-economic analysis of this issue and the endorsement of a synergetic integration of electric vehicles to the energy system have been undertaken.

For this purpose, plug-in electric vehicles (PEV) are characterized and contextualized with other alternative drive train technologies for a low-carbon energy system of the future. Furthermore, relevant dimensions for measuring and methods for analysing the impact from PEV to the energy system are discussed. This comprises an overview of different energy system modelling approaches as well as of methods to analyse the future market penetration of PEV. Here, the consideration of the user acceptance becomes evident: The car purchase decision is based on heterogeneous rules and the user preferences differ significantly. Consequently, the market success of PEV not only relies on the technological development of batteries, but also on user acceptance.

From an energy economics perspective, the charging process is of high interest. Here, again the user patterns, but also the willingness to adapt the charging process is of key relevance to provide load flexibilities according to the status and requirements of the electricity system. Theoretically, the load shifting potential from electric vehicles is significant and might lead to an increasing integration of volatile electricity generation such as from wind and solar into the future electricity system. However, this is strongly dependent on the underlying assumptions. Hence, the papers included in the cumulative Habilitation deal with all these aspects and are structured in the following categories:

- **Market penetration of electric vehicles** is considered by four papers. First, a simple market forecast model (which is applied by the German advisory council "national platform electric mobility, NPE") is presented. Second, a complex system dynamic model, evaluates several jurisdictions. Third, the focus is turned to commercial transport and, finally, the optimal allocation of fast charging stations is addressed.
- **Impact from PEV on the national electricity system** is subdivided into two subsections. The first includes three papers on the load shift potential of PEV: They focus on the initial identification of load shifting potentials from PEV in general, on the identification of these potentials in different European countries, and on business model specifications of smart charging managers to integrate PEV into electricity markets. The second subsection focuses on the indirect CO_2 emissions from PEV and comprises two papers: One on the calculation of marginal CO_2 emissions from power plants and the other on a hypothetical extension of the European Emission Trading System (EU-ETS) to include road transport.
- **Integration of PEV on the decentralized level and the interaction with smart grids** is subdivided in three subsections. First, the issue of user acceptance and load shifting potential of PEV in smart homes is addressed in a paper, which focuses on the user-acceptance of load shifts in a smart grid-environment. Then, households with photovoltaic, stationary storages and PEV are considered before a section on private households with combined heat and power units and PEV are addressed.

The Habilitation ends with a comprehensive conclusion and outlook section on further efforts in this research field.

PhD Dissertation: "Model based analysis of new electricity tariffs for households in consideration of demand-orientated levels of supply security"

Marian Hayn

The increase of demand flexibility can contribute to a better integration of renewable energies in energy systems. Set against this background, this thesis develops and analyses empirically, as well as based on models, new electricity tariffs for households, including a performance price component.

The developed electricity tariff belongs to the category of load variable tariffs and allows suppliers to reduce the power consumption of customers in case of supply shortfall by an amount agreed in advance. Due to increasing contract complexity, explicit agreements must be reached regarding the expected service quality within the so-called Service Level Agreements. Hence, to describe the developed tariff, this dissertation will define four specific indicators (Service Level Indicators) and subsequently impose empirical as well as model-based target values (Service Level Objectives).

On the basis of an online survey conducted in the course of this thesis, representative for German households with about 1,100 valid datasets, the fundamental acceptance for the developed tariff concepts as well as the design of the Service Level Objectives have been determined. Moreover, by using statistical methods, conclusions on potential tariff distinction for various groups of customers can be drawn.

In addition, a developed bottom-up model is introduced to simulate und optimize profiles of household loads considering different tariff concepts. The model can create power consumption profiles for different household which differ in their tariff use and their household equipment with a resolution of 15 minutes. By using linear as well as mixed-integer optimization, the model can illustrate a minimal cost equipment use as well as one that is linked to the developed tariff concept. The load profiles modelled for various customer groups are used for plausibility checks of empirically surveyed Service Level Objectives as well as for the comparative assessment of the influence of various tariff concepts on the demand flexibility of households.

The results show that the acceptance and design of the developed tariff concepts mostly depend on the size of the households as well as the environmental attitude of the interviewees.

PhD Dissertation: "Analysis and assessment of the electricity and heat systems in residential buildings in Germany"

Erik Merkel

The dissertation investigates the evolution of the electricity system and the heat system of the residential buildings in Germany until 2050. The aim of the research work relates to the analysis of the temporal evolution of the investigated energy systems as well as of the potential of innovative technologies at the interface of electricity and heat along with the assessment of the goals of climate and energy policy in the heat system of the residential sector.

For the analysis, a model-based approach is established. Therein a coupling of two models is realised developing and combining the national energy system model TIMES-HEAT-POWER which encompasses the electricity system and the residential heat system and an optimisation model of decentralised heat supply systems. Whereas the first aims at the investigation of the energy system from a societal perspective determining the optimal technology choice as well as the capacity and dispatch under cost minimality the second has a specific focus on the heat system within the system boundaries of a building taking into account a high level of technical detail of the technologies and also determining the optimal energy system under least cost. Further central aspects of the modelling approach relate to the methodological extension of TIMES-HEAT-POWER in order to avoid the technology mix effect known from production theory as well as the development of a decomposition approach for the solution of complex instances of the optimisation model of decentralised heat supply systems.

The established approach thus allows for an in-depth analysis of the evolution of the electricity system and the heat system of the residential buildings as well as the assessment of climate and energy targets of the latter in an optimising system context. Likewise, a level of detail in modelling the heat system is attained that is significantly elevated in comparison to related work.

PhD Dissertation: "Production security and welfare in coupled electricity markets – studies by means of an agent-based simulation model for the region Central-Western Europe"

Philipp Ringler

This thesis deals with the development of an agent-based simulation model for electricity wholesale markets. The model is applied to analyse the development of electricity markets regarding generation adequacy and welfare as well as various design options of electricity markets. It is applied to a case study in the region of Central-Western Europe (Germany, France, Belgium, the Netherlands) in the period of 2012-2030.

The model of the spot market for electric energy includes implicit auctions for cross-border congestion management between interconnected market regions (market coupling). During their investment planning, power plant operator agents verify various strategic real options (i.e. power plant decommissioning due to economic considerations). To measure the development of electricity systems, two target dimensions of energy policy, namely profitability and production security will be evaluated by a microeconomic welfare analysis or by an event-by-default approach. Besides the energy-only-market, the strategic reserve is analysed as an additional market design option. In the framework of a Monte-Carlo simulation, data uncertainties (i.e. electricity demand or feed-in from wind and PV power plants) can be taken into account. This thesis describes a new method combination consisting of an agent-based simulation as model framework, multiple optimization problems (i.e. linear programming), a stochastic simulation (i.e. use of discrete Fourier transformation and an Ornstein-Uhlenbeck process) and particular game-theoretical as well as econometric approaches (i.e. estimation of linear regression models by recursive least-square-algorithms). The model is implemented in the programming language Java and can be parameterized in various ways. To evaluate the case study of the Central-Western Europe region, extensive input data are investigated. The model is characterized by the hourly resolution as well as detailed modelling of conventional power plants with multiple techno-economical parameters.

In terms of results (i.e. development of production security, welfare distribution, and wholesale prices for electricity), various conclusions concerning energy economics and political as well as methodical aspects can be drawn. To create an electricity internal market, inter alia, market coupling must be intensified in Europe. Furthermore, the decline of production security in Central-Western Europe from 2022 onwards as identified in the case study can be an indication that the energy-only market design does not provide sufficient production security. On a higher level, a unification in terms of European electricity market design or at least a gradual alignment or adjustment of national solutions should be strived for.

Staff as of December 2016

Head of the Chair of Energy Economics

Prof. Dr. Wolf Fichtner

Administrative Staff

Michaela Gantner-Müller

Corinna Feiler (also working for the Chair of Business Administration, Production and Operations Management)

Liana Blecker (also working for the Chair of Business Administration, Production and Operations Management)

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

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: Flexibility in industrial production

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

Thomas Kaschub: Profitability of battery storage in households with photovoltaics, electric vehicle and demand response

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

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

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

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*: CO2-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

International Collaboration

Location: Shanghai, China
Who: Kai Mainzer
Host: Prof. Huijuan Dong, Shanghai Jiao Tong University (SJTU), School of Environmental Science and Engineering
Period: September 2016

Short description of stay: During his visit to Shanghai for the Urban Transitions Global Summit 2016 conference, Kai Mainzer met with Huijuan Dong and a couple of her colleagues in order to discuss synergies between their research and to talk about possible joint projects. First steps have been taken towards determining the cost and potentials for renewable energies in the Shanghai area.

Location: London, United Kingdom
Who: Dr. Russell McKenna
Host: Prof. Neil Strachan, University College London (UCL) Energy Institute,
Period: August to September 2016

Short description of stay: Following on from his four month stay at the UCL Energy Institute in the context of a WholeSEM Fellowship in summer 2015, Russell McKenna returned there for three weeks in summer 2016. During his stay there he presented and discussed a current project focussing on community-scale energy systems (see Research Projects). He also visited the Environmental Change Institute at the University of Oxford, where he held a similar seminar. This short stay enabled some stimulating discussions with colleagues at both institutions who are working on similar topics.

Location: Vancouver, Canada
Who: Hannes Schwarz
Host: Prof. Dr. Holger Hoos, University of British Columbia (UBC), Computer Science Department (CS), Bioinformatics, Theoretical and Empirical Algorithms (BETA) Laboratory
Period: Jan-May 2016

Short description of stay: Hannes Schwarz spent a total of 4 months at the UBC with a focus on the optimisation of decentralised energy systems under uncertainty. Within this collaboration, he searched for an improvement of the optimisation process to reduce the computational effort. Therefore, he attempted to:
a) use the sequential model-based algorithm configuration (SMAC) developed by the UBC that automatically tunes the parameters of the employed MILP solver, CPLEX, and
b) substitute the time-consuming optimisation approach of CPLEX by a machine learning approach: decision tree learning.

As a result, the computational effort of the optimisation process can be reduced by up to 50% in case a). A final outcome of the collaboration is a joint journal publication that will be submitted to the Computers & Operations Research (COR) journal.
In case b), the substitution of the MILP solver by a machine learning approach was not sufficient and needs more research activities. Therefore, a subsequent longer cooperative research project of UBC and KIT is considered. The involved institutions are looking to continue collaboration through further exchanges of students and researchers.

Location: Villigen, Switzerland
Who: Florian Zimmermann
Host: Paul Scherrer Institute (PSI)
Period: November 2016

Short description of stay: In November 2016, Florian Zimmermann stayed at the Paul Scherrer Institute (PSI) in Villigen, Switzerland. The institute is a partner in the project "Powerdesign: Impact of different market designs in the CWE market area on electricity prices and on the competitiveness of Swiss hydropower".
The aim of this stay was to intensify the collaboration between the Energy Economics group at PSI and the Chair of Energy Economics at KIT. Further data research for Switzerland and the transfer of methodologies for the models were discussed and a joint publication was elaborated.

Location: Boston, Massachusetts, USA
Who: Hans Schermeyer
Host: Prof. Ignacio Pérez-Arriaga, MIT Energy Initiative, Massachusetts Institute of Technology (MIT)
Period: 04-08 2016

Short description of stay: From April until August 2016 Hans Schermeyer spent a few months abroad on a research exchange with the MIT Energy Initiative in Boston, USA. During his stay Hans collaborated with the group of Prof. Pérez-Arriaga working in the field of distributed generation and networks. He had the opportunity to gain a deeper understanding of locational marginal pricing to account for network constraints in power systems analysis. A concrete publication is under preparation and the research partners already applied for future funds to continue the cooperation.

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

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.

Basics of Liberalised Energy 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.

Strategical Aspects of Energy Economy ~ 30 students
Dr. rer. pol. A. Ardone

This course deals with the fundamentals of energy supply especially electrical power supply and different power plant types. Insights into the cost of electricity generation are given examining the different cost types (CAPEX, OPEX, variable cost). Another focus is on energy system planning where optimization approaches and mathematical models for decision support, system planning and market modelling are examined.

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 ~30 students
Dr. rer. pol. V. Bertsch

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.

Efficient Energy Systems and Electric Mobility ~40 students
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.

Teaching at the Chair for Energy Economics

BSc-Module „Energy Economics"

- Introduction to Energy Economics (SS, 5,5 ECTS)
- Renewable Energy – Resources, Technologies and Economics (WS, 3,5 ECTS)
- Energy Policy (SS, 3,5 ECTS)

MSc-Module „Energy Economics and Energy Markets"

- Basics of Liberalised Energy Markets (WS, 3 ECTS)
- Energy Trade and Risk Management (SS, 4 ECTS)
- Gas Markets (WS, 3 ECTS)
- Energy Policy (SS, 3,5 ECTS)
- Simulation Game in Energy Economics (SS, 3 ECTS)
- Quantitative Methods in Energy Economics (WS, 4 ECTS)

MSc-Module „Energy Economics and Technology"

- Strategical Aspects of Energy Economy (WS, 3,5 ECTS)
- Technological Change in Energy Economics (WS, 3 ECTS)
- Heat Economy (SS, 3 ECTS)
- Energy Systems Analysis (WS, 3 ECTS)
- Energy and Environment (SS, 4,5 ECTS)
- Efficient Energy Systems and Electric Mobility (SS, 3,5 ECTS)

Publications

Peer-Reviewed Journals

Babrowski, S.; Jochem, P.; Fichtner, W. (2016): How to model the cycling ability of thermal units in power systems? Energy, 103, 397-409. doi:10.1016/j.energy.2016.02.142

Babrowski, S.; Jochem, P.; Fichtner, W. (2016): Electricity storage systems in the future German energy sector: An optimization of the German electricity generation system until 2040 considering grid restrictions. Computers & Operations Research, 66, 228–240. doi:10.1016/j.cor.2015.01.014

Balussou, D., McKenna, R., Möst, D., Fichtner, W. (2016): A model-based analysis of the future capacity expansion for German biogas plants under different legal frameworks, accepted in Waste and Biomass Valorization

Bertsch, V.; Hall, M.; Weinhardt, C.; Fichtner, W. (2016): Public acceptance and preferences related to renewable energy and grid expansion policy: Empirical insights for Germany. Energy, 114, 465-477. doi:10.1016/j.energy.2016.08.022

Ensslen, A.; Schücking, M.; Jochem, P.; Steffens, H.; Fichtner, W.; Wollersheim, O.; Stella, K. (2016): Empirical Carbon Dioxide Emissions of Electric Vehicles in a French-German Commuter Fleet Test, Journal of Cleaner Production 142, 263-278, doi: 10.1016/j.jclepro.2016.06.087

Fichtner, W.; Bertsch, V. (2016): A participatory multi-criteria approach for power generation and transmission planning. Annals of operations research, 245 (1), 177–207. doi:10.1007/s10479-015-1791-y

Heinrichs, H.; Jochem, P. (2016): Long-term impacts of battery electric vehicles on the German electricity system, European Physical Journal Special Topics 225, 581-591, doi: 10.1140/epjst/e2005-50115-x

Jäger, T.; McKenna, R. C.; Fichtner, W. (2016): The feasible onshore wind energy potential in Baden-Württemberg: A bottom-up methodology considering socio-economic constraints. Renewable Energy, 96, 662-675. doi:10.1016/j.renene.2016.05.013

Jochem, P.; Brendel, C.; Reuter-Oppermann, M.; Fichtner, W.; Nickel, S. (2016): Optimizing the allocation of fast charging infrastructure along the German autobahn. Journal of Business Economics, 86 (5), 513–535. doi:10.1007/s11573-015-0781-5

Jochem, P.; Doll, C.; Fichtner, W. (2016): External costs of electric vehicles. Transportation Research Part D: Transport and Environment, 42, 60–76. doi:10.1016/j.trd.2015.09.022

Jochem, P.; Rothengatter, W.; Schade, W. (2016): Climate Change and Transport, Transportation Research Part D (Editorial) 45, 1-3, doi: 10.1016/j.trd.2016.03.001

Kaschub, T.; Jochem, P.; Fichtner, W. (2016): Solar energy storage in German households: profitability, load changes and flexibility. Energy Policy, 98, 520-532. doi:10.1016/j.enpol.2016.09.017

Keles, D.; Bublitz, A.; Zimmermann, F.; Genoese, M.; Fichtner, W. (2016): Analysis of design options for the electricity market: The German case. Applied Energy, 183, 884-901. doi:10.1016/j.apenergy.2016.08.189

Keles, D.; Scelle, J.; Paraschiv, F.; Fichtner, W. (2016): Extended forecast methods for day-ahead electricity spot prices applying artificial neural networks (ANN), Applied Energy, 162, 218-230. doi: 10.1016/j.apenergy.2015.09.087

Killinger, S., Braam, F., Müller, B., Wille-Haussmann, B., McKenna, R. (2016): Projection of power generation between differently-oriented PV systems, Solar Energy, 136, 15 October 2016, 153–165. doi: 10.1016/j.solener.2016.06.075

McKenna, R.; Bertsch, V.; Jochem, P.; Genoese, M.; Fichtner, W. (2016): Infrastrukturelle und nachfrageseitige Herausforderungen für die Energiewirtschaft: eine Aufgabe für die Energiesystemanalyse, Betriebswirtschaftliche Forschung und Praxis.

McKenna, R.; Hofmann, L.; Merkel, E.; Fichtner, W.; Strachan, N. (2016): Analysing socioeconomic diversity and scaling effects on residential electricity load profiles in the context of low carbon technology uptake. Energy Policy, 97, 13–26. doi:10.1016/j.enpol.2016.06.042.

McKenna, R.; Merkel, E.; Fichtner, W. (2016): Energy autonomy in residential buildings: a techno-economic model-based analysis of the scale effects, Applied Energy (in press). doi: 10.1016/j.apenergy.2016.03.062

McKenna, R.; Ostman v. d. Leye, P.; Fichtner, W. (2016): Key challenges and prospects for large wind turbines, Renewable and Sustainable Energy Reviews, 53, 1212-1221. doi:10.1016/j.rser.2015.09.080

Merkel, E.; Kunze, R.; McKenna, R.; Fichtner, W. (2016): Modellgestützte Bewertung des Kraft-Wärme-Kopplungsgesetzes 2016 anhand ausgewählter Anwendungsfälle in Wohngebäuden, accepted in Zeitschrift für Energiewirtschaft, December 2016

Merkel, E.; McKenna, R.; Fehrenbach, D.; Fichtner, W. (2016): A model-based assessment of climate and energy targets for the German residential heat system, Journal of Cleaner Production, in press. doi: 10.1016/j.jclepro.2016.10.153

Paraschiv, F.; Hadzi-Mishev, R.; Keles, D. (2016): Extreme Value Theory for Heavy-Tails in Electricity Prices, Journal of Energy Markets, accepted. doi: 10.21314.JEM.2016.141

Ringler, P.; Keles, D.; Fichtner, W. (2016): Agent-based modelling and simulation of smart electricity grids and markets – A literature review, Renewable & Sustainable Energy Reviews, accepted. doi: 10.1016/j.rser.2015.12.169

Rodenhausen, M.; Moser, W.; Hülsmann, C.; Bergemann, C.; Könker, M.; McKenna, R. (2016): Prüfung der Standorteignung für Windenergieanlagen: Ein pragmatischer Ansatz, Bautechnik, in press, doi: 10.1002/bate.201600027

Ruppert, M.; Hayn, M.; Bertsch, V.; Fichtner, W. (2016): Impact of residential electricity tariffs with variable energy prices on low voltage grids with photovoltaic generation, International Journal of Electrical Power and Energy Systems, 79, 161–171. doi:10.1016/j.ijepes.2016.01.017

Conference Proceedings and Working Papers

Dehler, J.; Zimmermann, F.; Keles, D.; Fichtner, W. (2016): Der Einfluss der Nachbarländer auf den Schweizer Strommarkt. Proceedings des 14. Symposium Energieinnovationen, 10.02. - 12.02.2016, Graz, Austria.

Ensslen, A.; Gnann, T.; Globisch, J.; Plötz, P.; Jochem, P.; Fichtner, W. (2016): Willingness to Pay for E-Mobility Services: A Case Study from Germany. Proceedings of Karlsruhe Service Summit Workshop, 25.-26. February 2016, Karlsruhe, Germany.

Ketelaer, K.; McKenna, R.; Fichtner, W.; Kuckshinrichs, W.; (2016): How do companies differ in their investment behaviour for energy efficiency? Analysing energy intensive industries with survey results, presentation at the IAEE International Conference, June 19-22, Bergen, Norway.

Ketelaer, K.; McKenna, R.; Fichtner, W.; Kuckshinrichs, W. (2016): How do companies differ in their investment behaviour for energy efficiency? Comparing the iron & steel and cement sectors with survey results, presentation at the ENERDAY 2016, April 8th, 2016, Dresden, Germany.

Killinger, S.;Müller, B.; Saint-Drenan, Y.-M. (2016): Towards an improved nowcasting method by evaluating power profiles of PV systems to detect apparently atypical behavior, Conference Paper, 43rd IEEE PVSC, June 2016, Portland, Oregon. doi: 10.13140/RG.2.1.3741.9120

Mainzer, K.; Schlund, D.; Killinger, S.; McKenna, R.; Fichtner, W. (2016): Rooftop PV Potential Estimations: Automated Orthographic Satellite Image Recognition Based on Publicly Available Data. In: Proceedings of EU PVSEC. 32nd European Photovoltaic Solar Energy Conference and Exhibition, June 20-24, 2016, Munich, Germany. doi: 10.4229/EUPVSEC20162016-7EO.2.3

McKenna, R.; Mainzer, K.; Bertsch, V.; Fichtner, W. (2016): Combining local preferences and linear optimisation with multi-criteria decision analysis to develop feasible energy concepts in small communities, presentation at the Herbsttagung der wissenschaftlichen Kommission Nachhaltigkeitsmanagement (NaMa 2016), 5-7 October, Dresden, Germany.

McKenna, R.; Bertsch, V.; Mainzer, K.; Fichtner, W. (2016): Combining local preferences with multi-criteria decision analysis and linear optimisation to develop feasible energy concepts in small communities, IIP Working Paper Series in Production and Energy, 16, November 2016, http://www.iip.kit.edu/downloads/WP16_Nov16.pdf, checked 30.11.2016

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Ried, S.; Reuter, M.; Jochem, P.; Fichtner, W. (2016): Zur Berücksichtigung von Batteriespeichern in Dimensionierungsmodellen für dezentrale Energiesysteme. Einsatz von OR-Verfahren zur Analyse von Fragestellungen im Umweltbereich: Tagungsband zum Workshop der GOR-Arbeitsgruppe „OR im Umweltschutz" am 20./21. und 25./26. Februar 2015 in Aachen. Hrsg.: E. Merkel et al., 59-76, Shaker, Aachen, Germany.

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Zimmermann, F.; Bublitz, A.; Keles, D.; Dehler, J.; Fichtner, W. (2016): An analysis of long-term impacts of demand response on investments in thermal power plants and generation adequacy. 13th International Conference on the European Energy Market (EEM), June 6 - June 9, 2016, Porto, Portugal, 1-5, IEEE, Piscataway, NJ. doi:10.1109/EEM.2016.7521216

Books and Book Chapters

Ensslen, A.; Jochem, P.; Rometsch, M.; Fichtner, W. (2016): Adoption of EV in the French-German context. Cross-border Mobility for Electric Vehicles: Selected results from one of the first cross-border field tests in Europe. Eds.: J. Schäuble; P. Jochem; W. Fichtner, 141-171, KIT Scientific Publishing, Karlsruhe.

Ensslen, A.; Paetz, A.-G.; Babrowski, S.; Jochem, P.; Fichtner, W. (2016): On the road to an electric mobility mass market - How can early adopters be characterized? Markets and Policy Measures in the Evolution of Electric Mobility, 21-51, Springer, Cham. doi:10.1007/978-3-319-24229-3_3

Hayn, M.; Bertsch, V.; Zander, A.; Nickel, S.; Fichtner, W. (2016): The impact of electricity tariffs on residential demand side flexibility. Karlsruhe.

Hofmann, L.; McKenna, R.; Fichtner, W. (2016): Development of a multi-energy residential service demand model for evaluation of prosumers' effects on current and future residential load profiles for heat and electricity. Karlsruhe.

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