Karlsruhe Institute of Technology

Institute for Industrial Production

Annual Report 2018

Chair of Energy Economics

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Preface

This fourth 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 2018. 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. We are currently around 30 research and 4 administrative staff, roughly divided equally between these four groups.

During 2018, we worked on around 25 ongoing national and international research projects and started about 10 new projects. We published around 20 peer-reviewed journal articles, and 5 PhD 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

Distributed Energy Systems and Networks Group

Head of research group: Dr. Armin Ardone

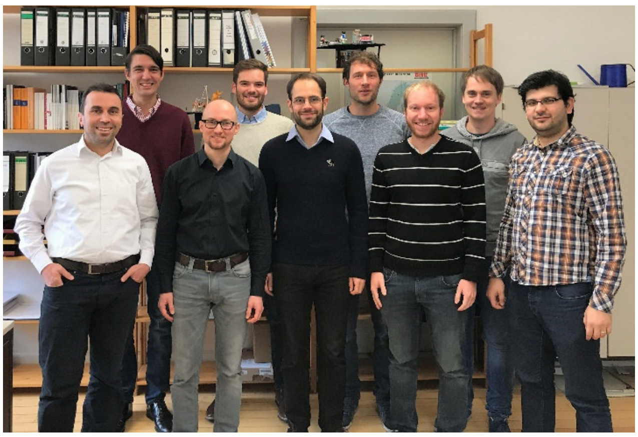
Members of the research group (fltr): Nico Lehmann, Rafael Finck, Armin Ardone, Max Kleinebrahm, Manuel Ruppert, Christoph Nolden, Viktor Slednev. Not in the picture: Hannes Schwarz.

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.

Energy Markets and Energy System Analysis Group

Head of research group: Dr. Dogan Keles



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

The sustainable design of energy systems under consideration of environmental, economic, social and security aspects is not only an important, but also a complex task. On the one hand, the task requires strong political governance with a broad view for possible future developments. On the other hand, the task is dependent on decisions and the behaviour of different actors in the sectors of energy generation, trade, supply and usage. The goal of the research group *Energy Markets and Energy System Analysis (EMESA)* is the formulation and application of mathematical models to analyse the implications of political and economic framework conditions as well as technological trends onto the future development of energy systems.

The main research topics include

- market design,
- investments in flexibility options,
- diffusion of energy storage and its impact on the electricity market,
- decarbonisation of the energy sector,
- sector coupling and
- price forecasting and analyses.

Normative issues, considering the overall economic perspective, are considered in the analyses of these topics 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.

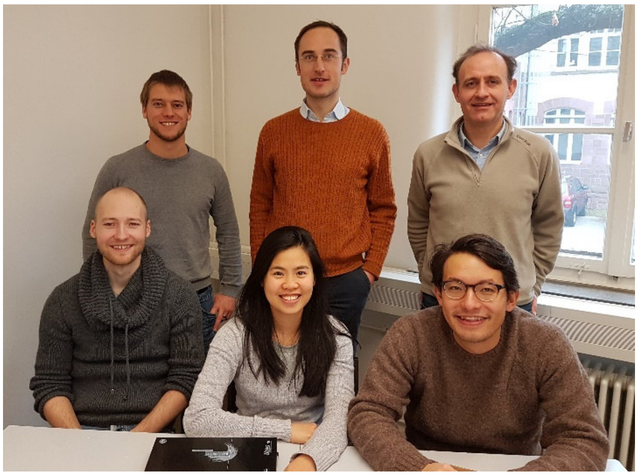
Renewable Energy and Energy Efficiency Group

Head of research group: Dipl.-Wi.-Ing. Kai Mainzer

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 (RE³ASON) 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 RE³ASON 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 methods for improving renewable energy generation forecasts, the model-based analysis of municipal energy autonomy, the economic assessment of battery storage in industrial applications, 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.



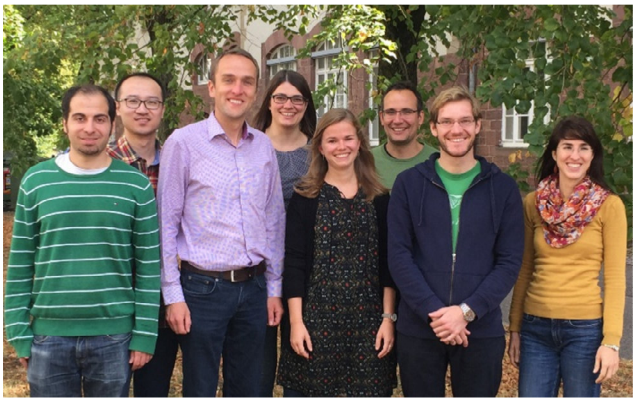
Members of the research group (from t.l. to b.r.): Kai Mainzer, Russell McKenna, Javier Parrilla Martinez, Jann Michael Weinand, Phuong Minh Khuong, Fritz Braeuer.

Transport and Energy Group

Head of research group: PD Dr. Patrick Jochem

Most discussions on the energy transition focus still mainly on the electricity sector and its decentralization. The transport sector, however, is widely ignored even though its challenges concerning energy efficiency, oil dependency, and several negative environmental impacts lead to an urgent need for extending the energy transition by a mobility transition. 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 in energy efficiency and a shift in fuels: from oil dominated to a high diversification potential via the energy carrier electricity. Furthermore, they accelerate the interactions of the transport and the electricity system ("sector coupling"), which is the main focus of the research group "Transport and Energy".

Consequently, the overriding objectives of the group are to analyse the market development of PEV in main car markets and to determine the impacts of PEV on (decentral) energy systems and material flows. For this, we apply highly interdisciplinary approaches from business economics, economics, sociology, electrical engineering, 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, econometrics 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 impact of PEV on distribution grids as well as on energy markets. Service-related topics in our field of research are allocated to our associated eMobility Lab 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): Thomas Dengiz, Zongfei Wang, Patrick Jochem, Katrin Seddig, Alexandra Märtz, Axel Ensslen, Christian Will, Sabrina Ried.

Research Projects

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

Dogan Keles, Christoph Fraunholz, Kai Mainzer

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

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2016 to 2019

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

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

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

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

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

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

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

BEAM-ME Project

Hasan Ümitcan Yilmaz, Rupert Hartel, Dogan Keles

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

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2017 to 2019

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

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

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

Another focus of the project is to analyse model reduction approaches. These approaches are very commonly used and effective due to the reduction of the size of the optimization problem, which means less variables and constraints. One of the KIT's objective is to reduce production- and demand-related time series without losing their energy-relevant key features. First results show that clustering input data and using representative samples from each cluster is an appropriate way to reduce the time series.

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

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by the German Bundestag**

Carsharing Study for Six European Cities

Patrick Jochem, Axel Ensslen

Partner: Karlsruhe Service Research Institute (KIT-KSRI), car2go

Funding: car2go

Duration: 2017 to 2018

The carsharing study for six European cities was carried out in cooperation with colleagues from KSRI between September 2017 and June 2018. The research activities were funded by car2go.

The aim of the study was to comprehensively analyse and evaluate the effects of car2go on vehicle ownership, modal shift, vehicle kilometres travelled and CO_2 emissions. Therefore, a survey was carried out in Berlin from March to April 2018. The survey was conducted among persons who used the car2go service three times or more within the last 91 days. The Berlin sample comprises 1,280 persons. Our analysis based on this sample shows that customers regularly using car2go in Berlin sold a total of 4,616 vehicles - mainly small, older cars - due to the carsharing service available in the city. This corresponds to 4.4 cars per carsharing vehicle used by car2go. Around 75 percent of Berlin users who sold their car, have sold their only vehicle and, as a result, no longer own a private vehicle. The publication of the whole study is planned for next year.

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

Armin Ardone, Dogan Keles, Nico Lehmann, Emil Kraft, Sabrina Ried

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

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

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2016 to 2020

C/sells intends to create a cellular structured energy system. Geographically limited technical solutions ("Cells") are developed which are the core of the project. The supply, use, distribution, storage and other infrastructure services within the individual cells, e.g. properties, districts and cities, are optimized mostly autonomous in accordance with the principle of subsidiarity. The interaction of the cells to form a network furtherly allows a secure and robust energy system. An infrastructure information system (IIS) supports the exchange of energy at a local and regional level by making information available. Examples for such information are flexibility potentials of the cells, different types of forecasts or technical aspects to control individual devices within the cells. New economic opportunities are provided for citizens by giving them the opportunity to participate in new business models ("sells"). Participation thus further increases acceptance of the energy transition. The diverse stakeholder structure, which encompasses all stages of the cellular energy system's value-added chain, offers ideal conditions for the development and implementation of new cooperation models. C/sells enables a smooth transition from demonstration to mass capability.

Within the framework of C/sells, the Chair of Energy Economics will analyze and evaluate existing market structures and new market design options. For this purpose, marketing opportunities for energy and flexibility on the various existing and possible future markets are investigated in order to obtain optimal trading strategies, especially for control power markets. These trading strategies are then implemented into the existing agent-based simulation model PowerACE to include control power markets in the model. With regard to the further progress of the project, new market structures and concepts will be considered in order to integrate (decentralized) flexibility and renewable energies into the existing energy system as effectively and efficiently as possible. Hereby, regionalized trading and aggregation of decentralized energy resources will be in the scope of work.

Supported by:

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by the German Bundestag

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

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

Partner: Fraunhofer ISI

Funding: Umweltministerium Baden-Württemberg

Duration: 2016 to 2018

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

The European Union and national governments foster the transition from a fossil-fuel-based energy system to an energy system dominated by renewable energies to achieve environmental and climate targets without compromising security of supply and economic efficiency. Therefore, it is not only aimed to convert the electricity sector to a renewable-based system, but also to decarbonize the transport, industrial and heating sector. This is supposed to be achieved, among other means, by increasing the use of electricity from renewable energy sources in these sectors. The increase of electricity demand in the other sectors due to the introduction of new technologies, such as electric vehicles and heat pumps, raises the following question: How will this increase affect security of supply, especially in southern Germany, taking into account that at the same time fossil-fueled power plants might be closed faster (than typical lifetimes of conventional plants), e.g. because of political measures. To analyze this research question, a model concept has been developed and applied to investigate the development of electricity demand and the optimal portfolio of generation technologies. The model concept takes into account technical, economic and climate policy restrictions. The two demand side models (FORECAST and eLoad) synthesize scenarios for the development of electricity demand and its shape (load curve). On the supply side, optimization models are applied to determine both the regional distribution of fluctuant renewable energies (PERSEUS-RES) and the need for flexible technologies (PERSEUS-ADQ), taking into account stochastic failures and planned outages in the power plant portfolio. The models allow dividing Germany into two regions, Germany-South and Germany-North. The outcome of these models (including PERSEUS-EU to determine to expenditure-minimal share of technologies) with regard to capacity expansion is then applied as an input to PERSEUS-NET for the unit commitment with grid restrictions. The PERSEUS-NET model analyses then whether a stable grid operation is possible with the calculated power plant capacities and demand can be served at all system nodes.

The analysis using the model concept shows that the use of electricity in the heating and transport sector will have a significant impact on electricity demand and its structure. In the short- and mid-term (until 2030), the additional demand from the heating and transport sectors can be compensated by exploiting energy efficiency potentials of traditional electricity devices. In the long term, however, demand for electricity is expected to increase by up to 30% compared to the 2015 level. However, additional demand peaks can be compensated, for example, by flexible control of heat pumps and intelligent charging of electric vehicles.

The analysis of the expected demand for new power plant capacity is carried out for two different scenarios, "Low-Flex" and "High-Flex", which differ in the amount of heat pumps and electric cars available for load shifting. For the Low-Flex scenario, the new capacity demand is determined again for two cases: first, by a purely regional self-sufficiency requirement, without the possibility of electricity imports. Second, the demand for new capacity is calculated in a European cooperative scenario, i.e. the possibility of electricity imports is given, which corresponds to the current political objectives with regard to the "Energy Union". The results indicate that a large amount of new capacity (approx. 11 GW) would already be needed in 2020 in Germany-South to achieve regional self-sufficiency. In the European cooperative scenario, however, the demand for new flexible power plants will be quite low until 2025 if the projects of the so-called "Ten Year Network Development Plan" are realized in time. By 2050, however, the cumulative capacity requirement over the entire period will increase to around 23 GW of secured capacity in each of the two German model regions. The new capacity determined by the model initially consists of combined cycle gas power plants and gas turbines. In the later years (after 2035), only gas turbines are expected to be built in Germany-South. Including pumped storage power plants and the existing power plants remaining in the market, the availability of approximately 70 GW of flexible capacity (in Germany) is a prerequisite over the entire planning period to ensure that demand is met with the pre-defined level of security of supply.

A further scenario called "CoalPhaseOut" is also investigated to consider a coal phase-out in Germany and some European countries and a delay in grid expansion. In contrast to the initial scenario Low-Flex, in this scenario Germany already requires around 10 GW new capacity in 2025 (approx. 3 GW in Germany-North and approx. 7 GW in Germany-South). The need for additional power plant capacity increases over time, but the difference between the two scenarios remains almost constant (46 GW in 2050 in the Low-Flex scenario and 55 GW in the CoalPhaseOut scenario). This difference is due to the fact that in case of a phase-out policy, no coal-fired power plant capacity at all will be available in Germany in 2050.

The analyses with the PERSEUS-NET model show that stable grid operation is possible in the short term (until 2025) and in the long term (until 2050). The security of supply is guaranteed also under grid restrictions across various scenarios, but it is necessary that inner German lines are expanded according to the "Grid Development Plan" and the TYNDP is implemented without significant delays. However, it is worth to mention that to a certain extent the expansion of fluctuating renewable energies must be regionally and technologically diversified, that the above-mentioned regional capacity requirements must be met and that European electricity exchange must not be hindered.

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

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

Thomas Dengiz, Hasan Ümitcan Yilmaz, Patrick Jochem

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

Funding: Deutsche Forschungsgemeinschaft (DFG)

Duration: 2016 to 2020

The design of future energy systems, which can cope with fluctuating supply and flexible demand, is an important societal concern. An essential aspect is the consumption of energy, particularly of complex systems such as factories or IT infrastructures. Important points are the flexibilization of energy consumption, so that the share of locally generated 'green' energy increases, robustness of energy provisioning, or the efficient design of new energy systems serving these purposes.

ENERGY STATUS DATA
COLLECT • ANALYSE • UTILISE

(Source: http://www.energystatusdata.kit.edu)

To accomplish this, a core prerequisite is a structured collection, storage and analysis of energy status data. Energy status data describes the provisioning of energy, its storage, transmission and consumption, be it the outcomes of measurements, be it metadata such as the extent of fatigue of batteries, be it other relevant data such as electricity rates.

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

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.

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

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

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

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

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

ENRES - Research Training Group Energy Systems and Resource Efficiency

Daniel Fett, Rafael Finck, Jann Weinand

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

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

Duration: 2016 to 2019

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

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

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

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

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

In May 2018, Daniel Fett, Rafael Finck, both KIT and Verena Weiler and Sally Köhler from Hft Stuttgart, participated in the „Zero Carbon Cities“ Summer School in New York. Approx. 35 students and PhD students from i.a. New York University, City University of New York, Hochschule für Technik Stuttgart and Karlsruhe Institute of Technology worked for one week together to analyze the GHG reduction potential in cities. The results are planned to be published in 2019.

Moreover, the members of the training group came together in several workshops in 2018, to present their progress and discuss their PhD projects with each other and the supervising professors.

ENSURE – New Energy grid StructURes for the German Energiewende

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

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

Funding: Federal Ministry of Education and Research (BMBF)

Duration: 2016 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 the coordinator in the project, which includes 23 further project partners from science, industry and society, among which are RWTH Aachen, E.ON SE, TenneT TSO GmbH, Siemens AG, ABB and other partners. The project aims to answer questions raised by the energy transition such as: How much electricity grid is needed? What is the optimal structure that satisfies technical, economic and social aspects and which degree of centralised and decentralised generation is appropriate? The project will cover three project stages from fundamental research to demonstration and testing with an overall time horizon of ten years. The first phase of the project is funded until 2019.

The Chair of Energy Economics at the IIP contributes to the research about future power grid structures performed in the System Structures Cluster. The focus of the Chair's work lies on economic aspects of future grid structures, namely analysing market elements for the future market design (e.g. effects of capacity markets on power grid utilisation, regulatory framework for decentralised generation by residential PV-battery systems) and potential business models in this context. The German-wide self-consumption potential and its impact on the household electricity price was analyzed considering different changes in the regulatory framework (e.g. the abolishment of feed-in tariffs and different allocation schemes for the grid charges). Furthermore, cloud- and community tariffs for prosumers were evaluated from a household perspective. Another main field of research is the techno-economic assessment of scenarios for the future transmission grid as well as the new technical concepts identified by the partners. In future scenarios, energy autonomous municipalities that are completely decoupled from the grid could also play an important role. A municipal typology was developed to assess the implications of this development. Especially rural municipalities with a high potential for renewable energies could be suitable for energy autonomy. The next step is to determine the optimal energy system for these municipalities. Another research focus in the project is the techno-economical assessment of the transition of the transmission grid. In this context, a multi-criteria approach to determine a cost-efficient congestion management with low carbon impact and low market disruption is applied in order to analyse future grid structures.

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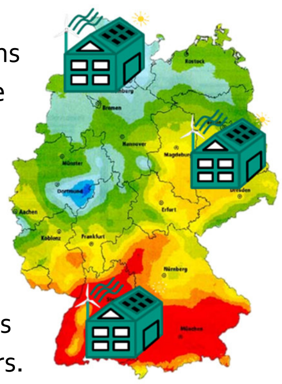
Energy Systems Integration

Max Kleinebrahm, Armin Ardone, Florian Zimmermann

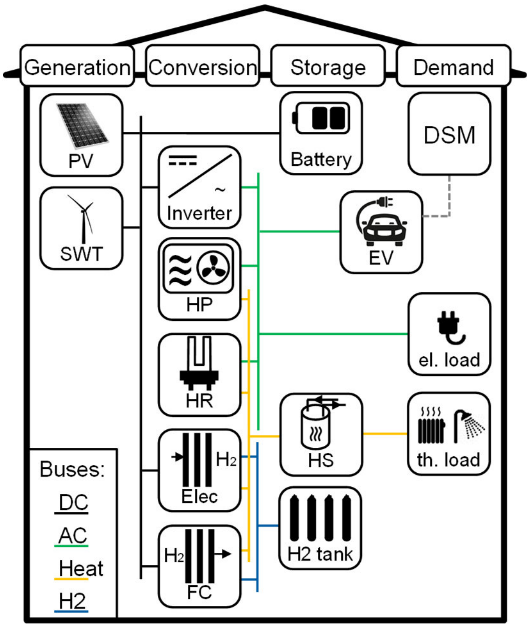
Partner: Forschungszentrum Jülich (FZJ), German Aerospace Centre (DLR), Max-Planck-Institute for Plasma Physics (IPP), Helmholtz-Zentrum Berlin (HZB), Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Helmholtz-Zentrum Potsdam German GeoResearchCentre (GFZ), Karlsruhe Institute of Technology (KIT)

Funding: Helmholtz Association

Duration: 2017 to 2020



The project "Energy Systems Integration" deals with those aspects of the energy system that make all individual components form a whole, i.e. all physical and IT-based interconnections as well as their structures and behaviors. It is incorporated in the broader challenge to



coherently manage the resources energy, materials, and the natural environment. The cross-sectoral interaction between the various components of the energy system, such as producers, storage facilities, consumers and different transport systems, has not yet been sufficiently taken into account. For this reason, the focus is on the technological and economic interactions of energy system components. The aim of the research project is to design an environmentally sound, viable, flexible, stable and resource-efficient energy system by integrating and combining individual technologies and sectors.

Interactions within the energy system are represented by models, simulated for a variety of scenarios and verified by real data sets. The modelling from the component level to the process level up to the level of the energy systems leads to in-depth knowledge and applicable tools. For the development of robust scenarios, the trend towards individual and independent energy supply is analyzed. Therefore, the effects of self-sufficient residential buildings on the future energy system are examined in the Group "Distributed energy systems and networks". In addition to technologies already existing on the market (PV, batteries, biofueled heating systems, heat pumps), technologies under development, such as hydrogen storage systems are also taken into account. Initial studies have shown that 100% renewable energy-based electricity and heat supply is possible for single-family houses, taking into account technologies such as small wind turbines and long-term storage systems (Kleinebrahm et al. 2018). In the further course of the project, the effects of different geographical conditions on the dissemination of self-sufficient residential buildings will be investigated.

HELMHOLTZ ASSOCIATION

eUrban – Impacts from electric vehicles on urban areas

Patrick Jochem, Alexandra Märtz, Rupert Hartel

Partner: KIT-IIP, KIT-IfV, Uni Stuttgart – IER, HS Esslingen – INEM

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

Duration: 2018 to 2019

The Project eUrban is funded by the Ministry of the Environment, Climate Protection and the Energy Sector Baden-Württemberg within the context of the "Strategiedialog Automobilwirtschaft Baden-Württemberg" and is realized by four project partners.

Due to the growing traffic volume, urban areas have to rise to new challenges. For this reason, the project focuses on the impacts from electric vehicles on the distribution network in urban areas. Therefore, the project partners evaluate the level of market penetration of battery-powered vehicles for motorised private transport, public bus transport and freight transport and investigate future mobility and charging behavior taking into account the charging infrastructure and various vehicle parameters such as range and charging time. Based on a simulation of the Stuttgart region with mobiTopp, an agent-based, microscopic traffic

demand model, the mobility behavior of the approx. 2.5 million inhabitants within one week as well as all movement patterns of the vehicles including charging processes can be analysed. Thus, the regional distribution of the electric vehicles as well as the associated energy demand can be determined temporally and spatially.
Based on the identified mobility and charging behavior, a network analysis is implemented to identify critical network situations and bottlenecks. Therefore, a suitable network will be implemented in MATPOWER and the network will be analyzed within a load flow calculation. The network analysis also takes into account the spatial and temporal penetration of EV as well as the network restrictions. The obtained results are discussed and to support a cost-effective integration of EV into the distribution grids some indications for main policy implications will be obtained.

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

strategiedialog automobilwirtschaft BW

Grid-Control – Advanced Decentral Grid Control

Johannes Schäuble, Axel Ensslen, Patrick Jochem, Sabrina Ried

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

Funding: Federal Ministry for Economic Affairs and Energy (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 was carried out from July 2015 to December 2018. The goal of the project was 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 at KIT was used to investigate the provision of ancillary services in a decentralized controlled network segment. In field experiments, the coordination of interactive energy management systems was tested. Real hardware systems in critical grid situations were used to analyse what cannot be done in laboratory experiments. In order to investigate decision making for capacity management applications, an agent-based energy system model for capacity management applications was developed.

grid-control

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

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. However, since the questions are strongly interconnected with each other the aim is also to provide an interdisciplinary environment in which the PhD students come into a close exchange and are able to support each other. From spring 2012 on, in two periods of three years, in total nearly fifty PhD students can take part in the programme.

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

IILSE – Inductive and Interoperable Charging Systems for Electric Vehicles

Patrick Jochem, Alexandra Märtz

Partner: KIT-DFIU, KIT-IEH

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

Duration: 2015 to 2019

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. It distinguishes between two project terms.

In the first project term (2015 – 2017), four institutes DFIU, IEH, AIFB and ZAR from KIT were working together to support the international cooperation to harmonize charging infrastructure standards. In a bi-national exchange with Japanese partners, the focus was placed on inductive and fast charging. In addition, we scientifically evaluated the topics of inductive charging and international e-roaming.

At IIP/DFIU we have evaluated important aspects for an appropriate charging infrastructure. In order to investigate the research question of how acceptance of inductive charging can be explained, a theory-based structural equation model was developed and empirically tested based on data from an online survey (Fett et al., 2017).

In the current second project term (2018 – 2019), the consideration of electricity networks is now gaining significantly in importance. Due to the increasing market penetration of electric vehicles, there is a need for a more detailed analysis of the future influence of the additional electricity demand by electric vehicles on the different voltage levels in order to identify bottlenecks in time. Therefore, the additional electricity demand and the related higher load from electric vehicles will be investigated with a focus on distribution grids. In a first step, different relevant scenario parameter will be identified and analysed. After model implementation of the different scenarios, the impacts on the grid from charging processes will be evaluated by means of a load flow calculation. Based on the results achieved policy recommendations will be derived.

Supported by:

Federal Ministry of Economics and Technology

on the basis of a decision by the German Bundestag

ELEKTRO POWER II

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

Russell McKenna, Fritz Braeuer

<u>Partner:</u> Fraunhofer Institute for Solar Energy Systems, ISE, KIT Institute of Fluid Machinery, FSM, KIT Building Science Group (Fachgebiet für Bauphysik & technischen Ausbau), fbta, University Freiburg INATECH, Department of Sustainable Systems Engineering, various housing companies, various technology partners

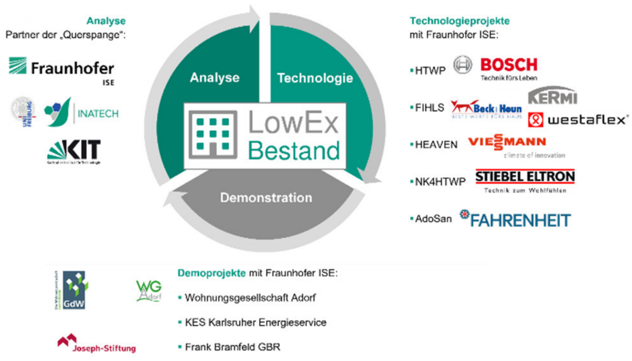
<u>Funding</u>: Federal Ministry for Economic Affairs and Energy (BMWi)

<u>Duration:</u> 2016 to 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 CO2 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 CO2 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.



http://www.lowex-bestand.de

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.

Supported by:
Federal Ministry of Economics and Technology
on the basis of a decision by the German Bundestag

Living Lab Walldorf

Hans Schermeyer, Sabrina Ried, Armin Ardone, Christoph Nolden

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

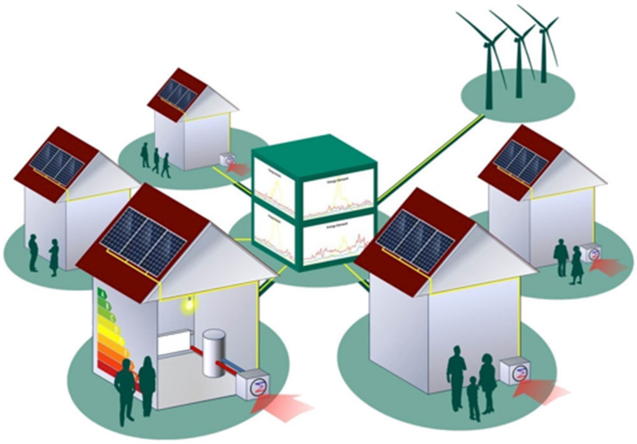
Funding: Ministry of Environment, Climate Protection and Energy Sector Baden-Württemberg

Duration: 2015 to 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 until 07/2019. 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.

LiLa Walldorf
Living Lab



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.

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

New Approaches for an Integrated Energy System and Power Grid Modelling

Viktor Slednev, Armin Ardone

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

Funding: Deutsche Forschungsgemeinschaft (DFG)

Duration: 2017 to 2018

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

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

For modelling the coupled transmission network expansion planning (TNEP) and generation expansion planning (GEP) problem, in the first step, exogenous model inputs such as the distribution and profile of future consumers and renewables generators at potential buses of the central European power system are generated. In this context, an optimal allocation planning of renewables is performed. In order to ensure the security of supply, furthermore, national minimum capacity expansion targets are defined within a preceding optimization based on a European Monte Carlo simulation of generator unavailability within 15 weather years.

In the next step, an Augmented Lagrangian decomposition approach is chosen in order to solve a coupled TNEP and GEP, focusing on a decoupling between time steps and between binary and continuous decision variables. Afterwards, the same decomposition approach is applied to validate the solution within a security constrained unit commitments problem optimization. Finally, the non-linear power flow restrictions, which where linearly relaxed based on the DC-approach up to this point, are taken into account by solving the DOPF problem based on the found grid topology and power plant dispatch. In this context, a developed parallel iterative approach for solving linear equation systems based on the dual weighted residual method is applied.

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Parameterization of the azimuth and inclination of PV systems using GIS-based approaches (PANGIS)

Kai Mainzer

Partner: FhG-ISE

Funding: TenneT TSO

Duration: 2018 to 2019

The location, orientation and inclination of photovoltaic (PV) systems significantly influence the profile of their respective power generation. However, the energy industry lacks exact knowledge about these parameters, which in turn leads to inaccurate forecasts and to an increase in balancing power demand.

The aim of this project is to determine these parameters using building data and satellite images of a given region. By adapting and employing image recognition algorithms, both PV systems on building roofs as well as freestanding systems can be automatically identified, which in turn allows the determination of the size, shape and orientation of these PV systems.

First results indicate that the identification of existing PV systems from aerial images works with reasonable accuracy.

Source: Own depiction with data from Google Maps

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

Florian Zimmermann, Joris Dehler-Holland, Russel McKenna, Dogan Keles

Partner: Paul Scherrer Institute (PSI), Switzerland

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 operational 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 an optimal control model to determine the operational profitability of the hydro storage power plants based on 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.

The results show that factors affecting the electricity prices of neighbouring countries also influence the development of the Swiss electricity price according to the correlation analysis. Market coupling and the large trading capacities between the markets play a crucial role in this regard. Results indicate that in times with very high peaks the French load and the Swiss electricity price strongly interact. Furthermore, strong correlations in spring and summer between electricity prices in Germany, France and Switzerland are examined. It is further observed that the German electricity generation from wind and solar power is a significant driver for the Swiss prices, while its role decreases in the autumn and winter months. In winter, the Swiss electricity prices follow the Italian and French electricity price. In addition, the Italian price curve serves as kind of upper threshold for the Swiss prices.

The ABM model PowerACE also shows the strong dependency on neighbouring countries' electricity prices for Switzerland's electricity wholesale market. Regarding the investments, the activity in Switzerland differs depending on the implemented electricity market designs in the neighbouring countries. There are less investments in Switzerland in a scenario with capacity remuneration mechanisms (CRM) in France, Italy and Germany, as it is possible to rely on imports due to the CRM incentivized generation capacity in the neighbouring countries.

Independently from the new installed capacity in Switzerland, the Swiss hydropower provides sufficient energy in times of scarcity and can even supply electricity to other countries in many hours. This leads to a successful market clearing in Switzerland in all simulated hours. Subsequently, this means that the model results show no need for a capacity remuneration mechanism in Switzerland to ensure market clearing and generation adequacy.

Nevertheless, prices are expected to rise in the long term (due to e.g. rising carbon certificates and fuel prices as well as increasing demand), which will increase the operational profitability of hydropower plants, because hydropower receives these high prices. The operational profitability is higher in a scenario where Switzerland is neighboured by energy only markets (EOMs) than by countries implementing a CRM due to a higher price level in a scenario with EOMs. However, the results show also that for seasonal storage hydropower plants the operational profitability are very similar in both scenarios until 2030 and approximately equals to double value as of today.

With a price increase to more than 100 EUR/MWh in 2040 and beyond, it is very likely that hydropower plants are profitable independently from the market design changes in neighbouring countries. For this reason and due to the fact that generation adequacy is ensured in our investigation, the adaption of the Swiss market design is, according to our results, currently not required.

Regarding RES-support volume, a decline can be observed in the mid-term because of increasing wholesale prices together with the changes from a support scheme with fixed feed-in tariffs to a system with direct marketing. However, in the long-term an increase in the total subsidy volume can be expected caused by the targets for installed RES capacities in the future energy market, in particular due to a disproportionate growth of solar power.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE
Office fédéral de l'énergie OFEN

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

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

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

Funding: European Commission, Horizon 2020

Duration: 2016 to 2019

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

For this purpose, REFLEX brings together the comprehensive expertise and competences of known European experts from six different countries. Each partner focuses on one of the research fields techno-economic learning, fundamental energy system modelling or environmental and social life cycle assessment. To link and apply these three research fields in a compatible way, an innovative and comprehensive energy models system (EMS) is developed, which couples the models and tools from all REFLEX-Partners. It is based on a common database and scenario framework.

The results from the EMS will help to understand the complex links, interactions and interdependencies between different actors, available technologies and impact of the different interventions on all levels from the individual to the whole energy system. In this way, the knowledge base for decision-making concerning feasibility, effectiveness, costs and impacts of different policy measures will be strengthened, which will assist policy makers and support the implementation of the SET-Plan. Stakeholders will be actively involved during the entire project from definition of scenarios to dissemination and exploitation of results via workshops, publications and a project website.

This project is funded by the European Union

Helmholtz Portfolio Initiative "Safety and Security"

Kai Mainzer, Russell McKenna, Hasan Ümitcan Yilmaz

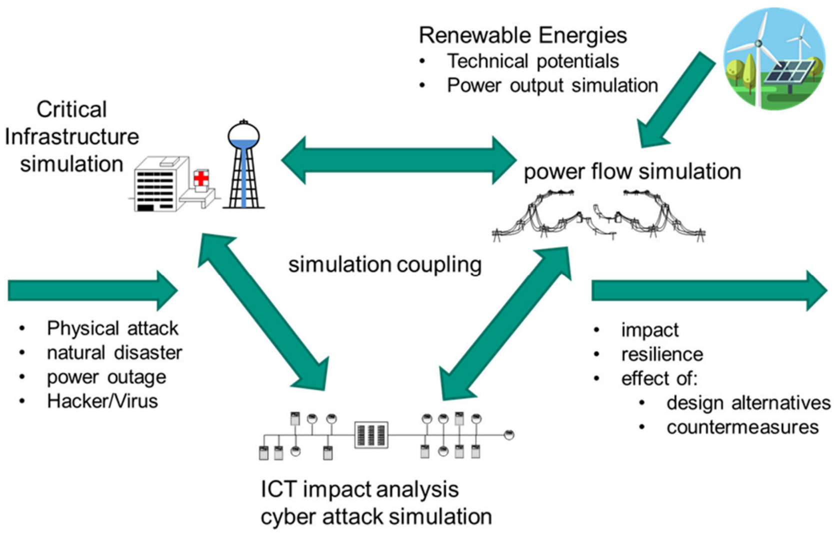
Partner: KIT-IKET, KIT-IPD

Funding: Helmholtz Association

Duration: started in 2013, ongoing

As part of the energy transition, power generation in Germany is changing from a centralised to a decentralised structure in which variable renewable energies dominate power generation. Among others, higher demand flexibility through intelligent load management as well as smart grid technologies at the distribution grid level shall help to cope with the increased complexity of the supply task. This will lead to an increasing diffusion of information and communication technologies (ICT) in the electricity sector in the future (e.g. via "smart meters"). The essential objective of the Helmholtz Portfolio Initiative "Safety and Security" is to develop future threat scenarios, which may arise in the context of the progressive networking, and to conduct model-based security assessments of critical infrastructures.

The focus is on the analysis of disruptions with possible cascade effects in electricity and communication networks as well as on the investigation of effects on other critical infrastructures such as health care and water supply.



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

Christoph Nolden, Hannes Schwarz, Armin Ardone, Joris Dehler-Holland, Thorben Sandmeier

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 Program (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.

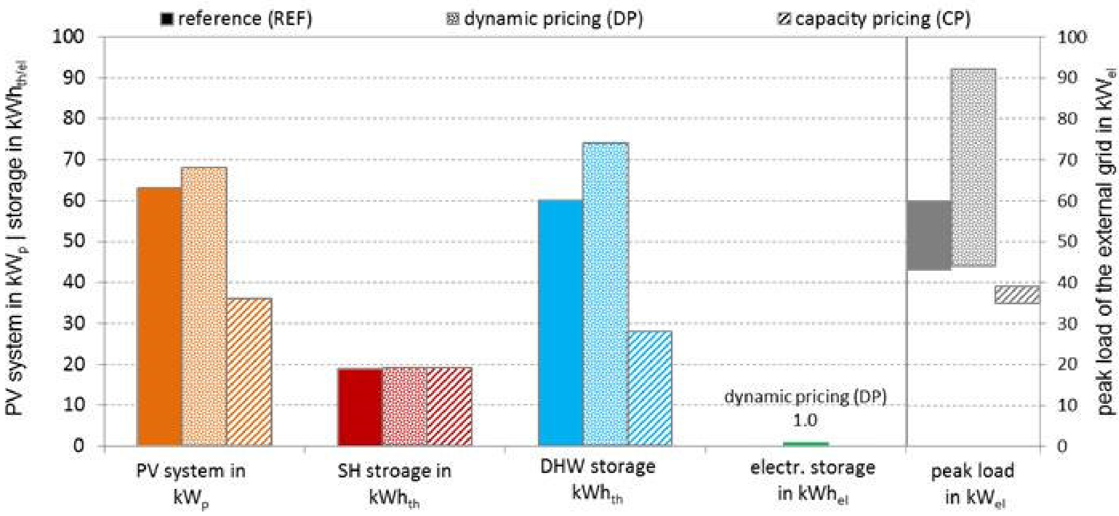
2) Efficient infrastructures, which address the upcoming challenges of energy transmission and distribution.

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. One aspect is the analysis of technologies for decentralized energy systems with electrical and thermal storage units under consideration of uncertainties using stochastic programming. Therefore, we consider a residential quarter using photovoltaic (PV) systems, heat pumps and storage units. To account for the interdependent uncertainties of energy supply, demand and electricity prices, we use a module-based framework including Markov processes and a two-stage stochastic mixed-integer program (Schwarz et al. 2018a).

Furthermore, we analyze the impact of different tariffs on the investment and operation decisions in this residential quarter and its interaction with the external grid. The considered tariffs include a standard fixed per-kilowatt-hour price (REF), a dynamic pricing scheme (DP) and a capacity pricing scheme (CP). The following figure shows the optimal investment in the residential quarter's components for the three different tariffs considered (Schwarz et al. 2018b).



Our results show that the integration of a PV system is economically advantageous for all considered tariffs with a self-consumption rate between 58 and 75 %. Dynamic prices results in the largest PV system that is built. However, the peak load from the external grid is doubled under this tariff without any incentive for reduction. In contrast, the peak load is reduced by up to 35 % when capacity pricing is applied. Considering uncertainties, thermal storage units in such systems are generally larger, i.e. stochastic optimization can help to avoid insufficient setup decisions. Moreover, we find that the storage is more profitable for domestic hot water than for space heating. Electrical storage units rather play a subordinate role under the current conditions (Schwarz et al. 2018a, 2018b).

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Schwarz, H, Schermeyer, H, Bertsch, V & Fichtner, W (2018b), „Self-consumption through power-to-heat and storage for enhanced PV integration in decentralised energy systems", Solar Energy, vol. 163, pp. 150–161.

SEES – Scientific Evaluation of Energy Services

Patrick Jochem, Russell McKenna, Fritz Braeuer, Hasan Ümitcan Yilmaz, Carmen Schiel, Sabrina Ried

Partner: KIT-ENTECHNON

Funding: BMW Group

Duration: 2017 to 2020

BMW Energy Services develops innovative digital energy services for business and private customers. As part of a joint project, KIT is researching various business models from a market perspective as well as from a techno-economic and ecological perspective. BMW Energy Services' products and services are researched for the following customer groups:

- BMW manufacturing plants
- Medium-sized companies
- Residential areas
- Private customers

During a first phase of the project, methodological principles were developed. The aim of the second phase of the project is to conduct scientific research into various business models at BMW Energy Services. The business models address the planning and operation of local energy systems for the various customer groups, which in addition to energy consumers also include renewable energy systems, battery storage, and electric vehicles.

At the Institute for Industrial Management and Industrial Production (IIP), four research groups work on the evaluation of business models from the customer's point of view. The evaluation is carried out using quantitative methods and model-based calculations based on economic efficiency and ecological sustainability. Possible effects on the German electricity system from the large-scale application of the business models are also assessed, using the PERSEUS program package developed at the IIP.

SuMo-Rhine - Sustainable mobility in the Upper Rhine region

Jérémy Rimbon, Patrick Jochem, Katrin Seddig

Partner: Institute of Economics (KIT-ECON), Centre for Renewable Energies (University of Fribourg), European University of Manoecology, Institute of Environmental Sciences (University of Koblenz-Landau), Image, City, Environment Laboratory (University of Strasbourg and Centre National de la Recherche Scientifique), Research Institute of Computer Science, Mathematics, Automatics and Signal (University of Haute-Alsace), Chair "Innovative Metropolitan Mobility" (École Nationale Supérieure d'Architecture de Strasbourg); City of Lörrach

Funding: European Regional Development Fund (ERDF) under the INTERREG V Upper Rhine Programme

Duration: 2018 to 2020

The project "SuMo-Rhine - Sustainable mobility in the Upper Rhine region" is coordinated by the French-German Institute for Environmental Research (DFIU) of the Karlsruhe Institute of Technology (KIT). Ten other financed partners from Germany and France are represented in the project consortium. The European Union is supporting the project with a total of 1.36 million euros from the

European Regional Development Fund (ERDF). The aim of the project is to comprehensively analyse and evaluate the cross-border transport systems existing on the Upper Rhine, using the conurbations of Strasbourg and Lörrach as examples. In the course of this, the project partners want to set up a novel "decision support system". Via a web application, the system makes measurable indicators for sustainable mobility accessible. Thus, cities, municipalities, mobility offices and mobility service providers should be able to identify potentials for improving the transport offer with low environmental impact and for increasing the market share of alternative modes of transport much more precisely than before.

SuMo-Rhine

Supported by:

Fonds européen de développement régional (FEDER)
Europäischer Fonds für regionale Entwicklung (EFRE)

interreg Oberrhein Rhin Supérieur

Awards

- Dr. Dogan Keles has been awarded a Senior Research Fellowship by the Durham University, which is cofunded by Durham University and European Union's Seventh Framework Programme (EU MSCA-COFUND programme). He will visit Durham University between April and August 2019 to strengthen international collaboration and to work on the topic "Price impact of renewable energies and carbon policy in the UK and German electricity market".

- PD Dr. Russell McKenna received the price of the KIT Department of Economics and Management for interdisciplinary research.

- PD Dr. Russell McKenna has accepted the position of Professor (MSO) at the Technical University of Denmark (DTU).

- Regina Rabl received the Bachelor price of the GOR association for Operations Research for her Bachelor thesis with the title: "Comparison of two approaches for the linearization of non-linear functions at the example of heat pump technologies". The work was supervised by Fritz Braeuer, Russell McKenna and Wolf Fichtner.

Completed PhD Dissertations and Habilitations

PhD dissertation: "An analysis of current and future electricity production from biogas in Germany"

David Balussou

With the development of renewable energy sources in Germany the use of biogas for electricity and heat production has rapidly expanded since the year 2000. This expansion has been encouraged by several Federal governmental incentives and in particular by the electricity Feed-In-Tariffs introduced in the Renewable Energy Sources Act (EEG). Agricultural plants valorizing energy crops now constitute almost 80% of total biogas installations. However, volatile energy crops and electricity prices, combined with continuously evolving framework conditions, are a source of uncertainty for German plant operators. In this context, investment decision making for biogas plant projects is a difficult task that requires the development of decision support tools.

In order to provide an assistance to plant operators two models are developed in this work. The first one deals with the analysis of the current electricity production from biogas in Germany (simulation model) and the second one with mid-term developments up to the year 2030 (optimization model).

The simulation model is based on a process modelling approach, which calibrates and simulates reference biogas plant types by considering a variable and differentiated biomass input. The analysis concerns the three major installation types in Germany valorizing energy crops, biowaste and manure. An integrated economic evaluation tool leads to the identification of the most profitable biogas plant sizes taking into account various subsidy schemes. Under EEG 2014 a paradigm shift is observed. Small-scale manure and large-scale biowaste plants appear as the most profitable installations whereas agricultural plants are no longer profitable mainly due to the cut in the subsidy for energy crops implemented in 2014.

The optimization model based on a plant operator perspective aims to determine the economically optimal capacity development for the three main installation types at the Federal State level and under various scenarios. The results highlight the influence of regional biomass potentials, revenues and electricity production costs as well as plant flexibilization and decommissioning. Future capacity expansion should mainly concern small-scale manure plants and biowaste installations rather than agricultural plants which, on the contrary, should undergo only modest development.

Based on the model results recommendations for plant operators and policy-makers are formulated. Maintaining current subsidy levels for biowaste and small-scale manure installations appears necessary in order to ensure the profitable and sustainable development of German biogas plants. Strategy planning and flexible plant operation as well as the increased valorization of residues in agricultural plants represent key challenges. An improved mobilization of biowaste potentials combined with better heat valorization would contribute to the creation of local and circular bio-economies in line with the planned national energy transition. The transferability of the methodological framework used in this work to other countries and bioenergy pathways is further analyzed. A model implementation is possible especially in countries showing stable legal framework conditions for bioenergy (e.g. Feed-In-Tariffs) and benefiting from lessons learned and best practices from past projects.

PhD dissertation: "The Impact of Electric Cars on Oil Demand and Greenhouse Gas – Emissions in Key Markets"

Jonatan J. Gómez Vilchez

This thesis explores the extent to which electric cars might reduce oil demand and greenhouse gas emissions in key markets: China, France, Germany, India, Japan and the United States. To meet this objective, a dynamic model capable of simulating the market evolution of nine powertrain technologies between 2000 and 2030 is developed.

The model consists of an econometric sub-model, soft-linked with a system dynamics sub-model. The purpose of the time-series econometric sub-model is to project country-specific total car stock. To this end, six single-equation regressions based on autoregressive integrated moving average or autoregressive distributed-lag techniques are estimated. The purpose of the system dynamics sub-model is to represent feedback processes and facilitate policy analysis. The effects of six policy measures are examined: emission standards, energy taxation, electric car purchase subsidies, investment in recharging stations, investment in hydrogen refuelling infrastructure and desired car occupancy. The dynamic hypothesis of the model captures feedback loops that may stimulate the market development of electric cars. The six countries are interlinked to simulate technological progress concerning the electric vehicle battery. In particular, its cost, price and capacity, together with the resulting electric range of the car, are investigated. Two scenarios are constructed: under the Alternative Scenario, the market uptake of electric cars is faster due to a favourable policy package. This leads to a decline in oil demand and direct greenhouse gas emissions as well as to an increase in electricity demand from cars compared to the Reference Scenario.

The methodological linkage of econometrics and system dynamics, together with the endogenisation of the electric vehicle battery price evolution by explicitly modelling six major car markets, is the main contribution of this study. Its major limitations prompt further research along a particular line: expansion of the model boundaries by representing supply-side aspects (i.e. battery and vehicle manufacturers) using alternative methods such as agent-based modelling.

PhD dissertation: "Analysis and Optimization of urban Energy Systems: Development and Application of a transferable modelling toolbox for sustainable system design"

Kai Mainzer

Many cities and municipalities are aware of their importance for the success of the energy transition and pursue their own sustainability goals. However, especially in smaller communities, there is a lack of the required know-how to quantify local potentials and identify a suitable combination of measures to achieve these goals.

Therefore, the RE³ASON (Renewable Energies and Energy Efficiency Analysis and System OptimizatioN) model has been developed as part of this work, which allows these communities to perform automated analysis, e.g. to determine the energy demand and the potential for renewable energies. In the subsequent optimization of the respective energy system, various objectives can be pursued – e.g. the minimization of discounted system expenditures while taking into account additional emission reduction targets. The optimization includes both investment and operational planning for energy conversion technologies on the supply and demand side.

The implementation of this model employs various methods, including methods from the fields of geoinformatics, radiation simulation, economics, machine learning and mixed-integer linear optimization. One of the main focuses of the work is determining the costs and potential for the generation of electricity and heat from photovoltaic, wind power and biomass plants. Particular emphasis was placed on the transferability of the developed methods which enables them to be used by as many cities and communities as possible. For this purpose, various publicly available open-data sources were used and combined with each other to generate the necessary input data for the analysis of the urban energy system.

The application of the model in the context of several German and international case studies shows, among other things, that especially in smaller communities there is significant potential for supplying the energy demand on the basis of renewable energies. It could also be demonstrated, that the transformation of the urban energy system to use local and sustainable energy resources can be the preferred alternative from the point of view of the community representatives. From these results, recommendations for action can be derived for urban decision-makers. A point of criticism is that due to the chosen system boundary, the model results do not allow conclusions on the scale of national energy economics.

PhD dissertation: "Optimization of the value chain of the existing free potentials of wood resources for power generation in Baden-Württemberg"

Javier Parrilla

The energy mix of Baden-Württemberg – one of the most wooded regions of Germany – might be diversified through the optimal utilisation of the existing free potentials of forest residues and landscape wood raw material (circa 17 PJ). For this reason, an optimisation of the value chain of wood resources for power purposes is accomplished for this federal state in order to identify the most cost-efficient utilisation pathways. Each unexploited potential of wood resources for up to ten different types is estimated at district level. Next, the stages of felling, extraction, debranching, moving and chipping of wood resources are modelled into four specific logistic chains on the basis of the type of forest ownership, the steepness of slope and the variety of tree. In addition, ten types of chipped wood resources are assigned unit costs based on two different cost allocation procedures. Then, a singular conclusion is drawn according to which gasification is for each particular capacity under same operation conditions more cost-efficient than combustion – except for co-firing. Hence, the fluidised bed gasification coupled to a gas engine or a combined cycle and the direct co-firing of wood resources at a 10% fraction are preselected on account of their higher cost-effectiveness. Lastly, a new MILP model (BioESyMO) is created for the intended analysis. This optimising tool contains a unique mathematical constraint aiming at assuring profitability of investments within each utilisation pathway.

A scenario-based analysis is developed for the wood resources based bioenergy system of Baden-Württemberg. A combined heat and power cogeneration process consisting of a fluidised bed gasification process coupled to a gas engine of 20 MW_e renders electricity production costs of 10.1-13.8 €cent/kWh_e. The co-firing option for the existing coal fired power plants with bio-based capacities up to 84.3 MW_e generates lower electricity production costs of 6.6-11.7 €cent/kWh_e. When a fluidised bed gasifier is connected to a combined cycle (210/340 MW_e), this technology turns out to be the most cost-efficient with electricity production costs in the order of 5.6-7.1 €cent/kWh_e. These costs ranges can be intentionally reduced by appropriately decreasing remunerations. This way, cheaper bioenergy configurations based on co-firing arise, thus incurring lower production costs of up to 5.6 €cent/kWh_e. Leveraging such cost reduction potentials, the introduction of suitable energy policy instruments for the promotion of carbon-neutral baseload power generation via both centralised conversion technologies is strongly recommended in view of Germany's nuclear and coal phase-out. Thereby, although the quality of the results generated by this study is basically conditioned by uncertainty and the high spatial aggregation level, the performed optimisation analysis provides a solid starting point for gaining insight into new energy generation structures that may contribute to the initiated energy transition in Baden-Württemberg and the whole of Germany.

PhD dissertation: "Congestion management in power grids with a high share of renewable energies"

Hans Schermeyer

The expansion of electricity generation capacities on the basis of renewable energies (RE) within the framework of the German energy transition is leading to structural changes in the power flows through the electricity grid. Increasingly, grid bottlenecks are occurring and it is necessary for the grid operator to curtail renewable electricity generation. Against this background, this work contributes to the further development of congestion management at distribution grid level. The contribution includes the development of a techno-economic energy system model that is able to map the interaction of bottlenecks and regulation in the grid area under consideration. The central research question deals with the conception and application of a congestion management system in which costs are taken into account. Furthermore, the quantitative investigation of the expansion and use of plants for the coupling of the sectors electricity and heat (SzW) in connection with district heating systems is a central objective of the work.

For the first time in the present study, an algorithm is formally presented, which represents the current congestion management regime of a distribution network operator in Germany and which is consistently compared with historical data. The weaknesses of the currently used congestion management are pointed out and an alternative algorithm is developed with the cost-based congestion management. The algorithm is formally presented as an optimization program and applied as a case study for a real network area, thus closing a significant research gap in the existing literature. For the first time, a concrete methodology for the improvement of congestion management in the distribution network is presented, which considers the feedback with wholesale prices and allows a direct influence on the balancing between costs and regulation. Furthermore, for the first time the presented dissertation contains the investigation of SzW plants with regard to their potential for congestion management, integrated into the model of a real distribution network.

In the context of the dissertation, a significant risk for cost increase is uncovered, if the current congestion management regime should be maintained. For cost-based congestion management, it is shown that costs can be significantly reduced and recommendations for the further development of the current congestion management regime are derived. With regard to sector coupling, the study comes to the conclusion that at most district heating locations only little can be contributed to congestion management in the distribution network under consideration. The development of decentralized SzW plants is recommended, which have considerable potential at the alternative locations shown, to reduce costs as well as regulation and greenhouse gas emissions.

Staff as of December 2018

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)

Josiane Folk (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)

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

Dipl.-Wi.-Ing. Kai Mainzer – Renewable Energy and Energy Efficiency

Doctoral Researchers and their PhD-topics

Giacomo Benini*: Economic and environmental consequences of oil demand decrease due to electric vehicles market penetration

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

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

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: Socioeconomic analyses on electric mobility considering user experiences

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

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

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

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

Emil Kraft: Analysis and modelling of balancing power markets.

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

Alexandra Märtz: A techno-economic analysis of impacts from electric vehicles on distribution grids

Christoph Nolden: Integration of Power to Gas Facilities into the German Power System until 2050

Sabrina Ried: Sector coupling of electricity and mobility and implications on the curtailment of renewable energies

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

Thorben Sandmeier

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 with photovoltaic supply under consideration of 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*: CO_2-neutral charging of electric vehicles: a techno-economic analysis from OEM-perspective

Hasan Ümitcan 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

International Collaboration

Location: Davis, California, USA

Who: Christian Will

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

Period: October 2017 to January 2018

Until the start of the year, Christian Will has researched electric vehicle charging services during a research visit at the Plug-in Hybrid & Electric Vehicle Research Center at the ITS. A series of interviews were conducted to assess customers' understanding and demand for renewable electricity for their electric vehicles. A joint publication is in progress. The findings from these interviews laid the foundation for consecutive representative studies in Germany, which are currently under way. Furthermore, Christian has collaborated in discussing customers' driving and charging behavior as well as renewable energy markets in the United States.

Location: Dublin, Ireland

Who: Manuel Ruppert

Host: Prof. Valentin Bertsch, The Economic and Social Research Institute (ESRI)

Period: March 2018 to June 2018

Manuel Ruppert is researching optimal redispatch in congested electricity transmission grids, considering economic and environmental impacts. In 2018, he spent four months as a visiting researcher at the Economic and Social Research Institute in Dublin, Ireland, working on a multi-criteria approach considering multiple objectives in redispatch simulations. The collaboration findings are in the process of publication. During his stay in Dublin, Manuel Ruppert also presented his work at the University College Dublin and the Power Systems Computational Conference 2018 (PSCC).

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 ~70 students
Prof. Dr. rer. pol. W. Fichtner

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

Renewable Energy – Resources, Technologies and Economics ~120 students
PD Dr. R. McKenna

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

Energy Policy ~35 students
Apl. Prof. Dr. rer. pol. M. Wietschel

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

Liberalised Power Markets ~40 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.

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.

Heat Economy ~15 students

Prof. Dr. rer. pol. W. Fichtner

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

Energy Systems Analysis ~40 students

Dr. rer. pol. A. Ardone

M. Sc. Thomas Dengiz

Dipl.-Inform. Hasan Ümitcan Yilmaz

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. In computer exercises the basics of the modelling language GAMS are taught. The students use the modelling language to define optimisation problems for answering simple energy related research questions.

Smart Energy Infrastructure ~20 students

Dr. rer. pol. A. Ardone

Prof. Dr. Dr. A. M. Pustisek

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

Efficient Energy Systems and Electric Mobility ~40 students

PD Dr. R. McKenna

PD Dr. rer. pol. P. Jochem

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

Energy and Environment ~45 students
Apl. Prof. Dr. rer. nat. U. Karl

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

<table>
<tr><th colspan="2"><u>Teaching at the Chair of Energy Economics</u></th></tr>
<tr><td colspan="2"><u>BSc-Module „Energy Economics“</u>
Introduction to Energy Economics (SS, 5,5 ECTS)
Renewable Energy – Resources, Technologies and Economics (WS, 3,5 ECTS)
Energy Policy (SS, 3,5 ECTS)</td></tr>
<tr><td><u>MSc-Module „Energy Economics and Energy Markets“</u>
Liberalised Power Markets (WS, 3 ECTS)
Energy Trade and Risk Management (SS, 4 ECTS)
Simulation Game in Energy Economics (SS, 3 ECTS)
Quantitative Methods in Energy Economics (WS, 3 ECTS)</td><td><u>MSc-Module „Energy Economics and Technology“</u>
Efficient Energy Systems and Electric Mobility (SS, 3,5 ECTS)
Energy and Environment (SS, 4,5 ECTS)
Energy Systems Analysis (WS, 3 ECTS)
Heat Economy (SS, 3 ECTS)
Smart Energy Infrastructure (WS, 3 ECTS)</td></tr>
</table>

Publications

University Publications

Balussou, D. (2018): An analysis of current and future electricity production from biogas in Germany. Dissertation. Karlsruhe. doi:10.5445/IR/1000084909

Killinger, S. (2018): Anlagenscharfe Simulation der PV-Leistung basierend auf Referenzmessungen und Geodaten. Dissertation. Fraunhofer, Stuttgart. doi:10.5445/IR/1000082916

Merkel, E. (2018): Analyse und Bewertung des Elektrizitätssystems und des Wärmesystems der Wohngebäude in Deutschland. Dissertation. KIT Scientific Publishing, Karlsruhe. doi:10.5445/KSP/1000066148

Schermeyer, H. (2018): Netzengpassmanagement in regenerativ geprägten Energiesystemen. Dissertation. Karlsruhe. doi:10.5445/IR/1000086513

Peer-Reviewed Journals

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