Karlsruhe Institute of Technology

Institute for Industrial Production

Annual Report 2019

Chair of Energy Economics

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Preface

This fifth 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 2019. 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 2019, we worked on around 20 ongoing national and international research projects and started about 7 new projects. We published around 25 peer-reviewed journal articles, and 4 PhDs 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

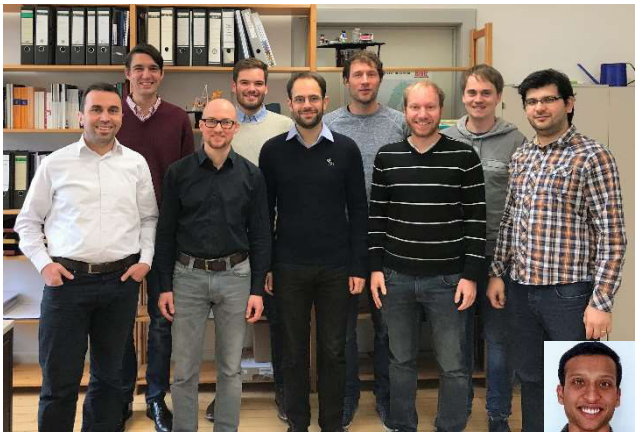
Members of the research group (fltr): Viktor Slednev, Max Kleinebrahm, Nico Lehmann, Armin Ardone, Manuel Ruppert, Rafael Finck, Thorben Sandmeier.

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, Anthony Britto

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.

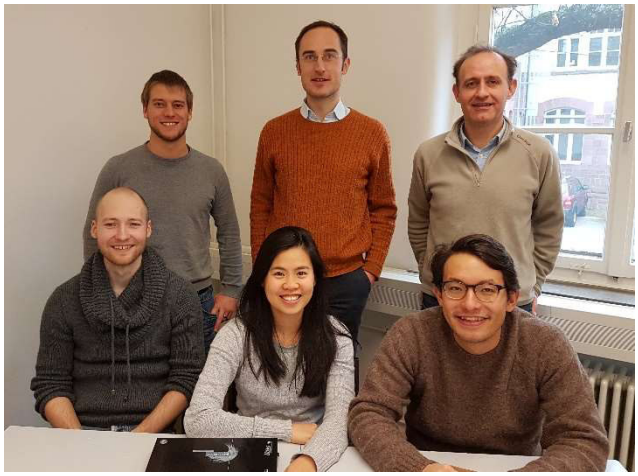
Renewable Energy and Energy Efficiency Group

Head of research group: Dr.-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.

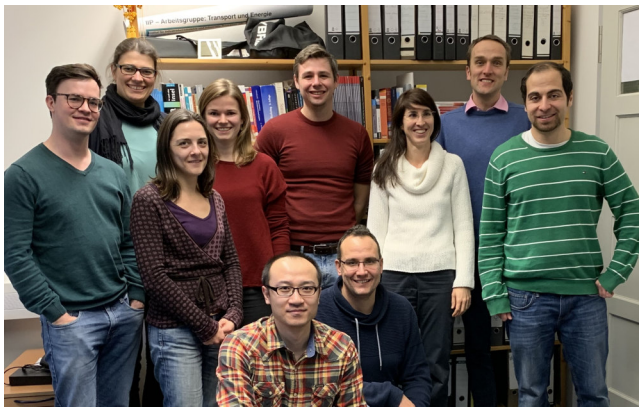
Transport and Energy Group

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, and 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 (from left to right): Uwe Langenmayr, Katrin Seddig, Nora Baumgartner, Alexandra Märtz, Zongfei Wang, David Pflegler, Axel Ensslen, Sabrina Ried, Patrick Jochem, Thomas Dengiz

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, ESA² GmbH

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2016 to 2019

The project AVerS, which is funded by the Federal Ministry for Economic Affairs and Energy, aims to analyse generation adequacy in (Southern) Germany given the phase out of nuclear and coal power and the increasing share of intermittent renewable energy generation. The research expertise of KIT, Fraunhofer ISI, TU Dresden and ESA² GmbH is combined in this 3-year project (06/2016 – 08/2019).

Driven by the phase out decisions of nuclear and coal power in Germany, substantial amounts of generation capacity, mainly located in Southern and Western Germany will be decommissioned in the upcoming years. At the same time, electricity generation from wind power in Northern Germany has increased significantly over the past years and is expected to continue to do so. However, the industrial load centers with a rather inflexible demand structure are mainly located in Western and Southern Germany. In the last years, this locational mismatch between generation and consumption as well as the lack of sufficient transmission capacity has led to an increasing number of hours where the market result had to be corrected by redispatching and curtailment of renewables. Moreover, low wholesale electricity prices provide poor incentives for investments in new conventional generation capacity or utility-scale storage units.

Against this background, the main objective of AVerS is a comprehensive analysis of medium- and long-term security of supply in (Southern) Germany. Regarding the development of domestic power plant capacities, the trend towards a Single European Electricity Market and the introduction of capacity mechanisms in Germany's neighboring countries have an immense impact. Also in Germany itself, the discussion about whether some kind of capacity mechanism might be required to ensure generation adequacy is still ongoing. Furthermore, the planned HVDC grid expansion between Northern and Southern Germany as well as a flexibilisation of the electricity demand are important drivers when assessing security of supply in Germany.

Starting with a reference scenario, three different instruments to preserve security of supply were analysed in detail. Firstly, splitting the German market area into a Northern and Southern price zone and the related long-term effects on investment incentives and transmission grid. Secondly, the introduction of a capacity mechanism in Germany with a particular focus on investment incentives and supply shortages. Thirdly, the long-term influence of demand side management on the electricity market and the transmission grid.

In order to adequately capture all essential aspects mentioned above, the analyses carried out in AVerS are based on a coupling of different established energy models from the project partners. The demand models FORECAST and eLOAD (Fraunhofer ISI) are used to generate future electricity demand profiles with and without consideration of demand side management in Germany and its neighboring countries. The resulting hourly demand profiles are then integrated into the electricity market simulation model PowerACE (Karlsruhe Institute of Technology) in order to investigate investments in conventional power plants and utility-scale storage units under different market designs in Germany and to simulate the electricity market in Germany and the neighboring countries until 2050. Ultimately, the development of the power plant

fleets and the hourly market results are transferred to the optimal power flow model ELMOD (TU Dresden) to analyse the respective effects in the transmission grid, such as curtailment of renewables, redispatching measures and load shedding. ELMOD is also used to determine an optimal splitting of the German price zone by clustering nodal prices.

The major results of AVerS can be summarized as follows:

- Electricity-based processes and innovative production methods can lead to a strong increase in electricity demand in the industrial sector. If ambitious CO_2 reductions targets are to be reached, these developments require an enormous expansion of renewable energies.
- Given the phase out of nuclear and coal power as well as delays in the planned HVDC grid expansion, there will be a substantial need for new conventional power plant capacity in Germany in the upcoming years.
- While grid expansion is essential in the short-term, further flexibilities such as utility-scale storage units and demand side management will be required in the long-term. However, it is questionable, whether the current market design is able to incentivize these flexibility options.
- If implemented on a sufficiently large scale, demand side management can significantly contribute to the system integration of renewable energies and substitute substantial amounts of conventional power plant capacity that would otherwise be needed.
- A capacity mechanism with a regional component can incentivize new generation and utility-scale storage capacities and place them at the desired locations.
- Regional price signals can be a useful complement to further grid expansion. However, although splitting the German market area is likely to reduce required congestion management measures in the medium-term, it also entails new risks in the long-term.

During a successful final workshop held in Stuttgart, the findings of AVerS were presented to the interested public. Further dissemination activities, such as the final project report and journal publications are still ongoing.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

BDL – Bidirectional Charging Management

Sabrina Ried, Patrick Jochem, Axel Ensslen, Fritz Braeuer, Kira Schumacher

Partners: BMW, TenneT, Bayernwerk, KOSTAL, Forschungsstelle für Energiewirtschaft, Universität Passau

Funding: BMWi

Duration: 2019 to 2022

Under the consortium leadership of BMW, the BDL project aims at developing electric vehicles and the supportive hard- and software for bidirectional charging ("Vehicle-to-Grid", or V2G) and testing those for different use cases in a field test. The

flexibility and storage capacity of electric vehicles (EVs) should be optimally integrated into the energy supply system both from a system's and from the integration of renewable energies is analysed based on a grid model. In order to identify the opportunities and risks for BDL from both an energy system and user perspective, KIT is also involved in

user acceptance research and thus supports holistic accompanying research.

Supported by:

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 Federal Ministry funds the BEAM-ME project (Implementation of acceleration strategies from mathematics and computational sciences for optimizing energy system models) 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 (ESMs).

One of the KIT's objective was to reduce the input time series of the ESMs without losing their energy-relevant key features. We developed a carefully engineered data-processing pipeline to reduce energy time series. We cluster the input data and use the "representative days" from each cluster instead of the entire time series. We use self-organizing maps, a special kind of neural network for clustering. The method outperforms the existing ones with respect to the quality of ESM results, and leads to a significant reduction of ESM execution times.

Furthermore, KIT developed a methodology to model hydro storage power plants with rolling horizon in power plant dispatch planning models. With this approach, the Pearson correlation in hourly dispatch results between historical data and model results is more than 90% for each modelled country.

In a final approach, KIT used the fix-and-relax method to reduce the execution time of the mixed integer ESMs. The method reduces the execution time of an exemplary model instance by a factor of 5 and degrade the quality of the ESM results by only 0.1%.

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by the German Bundestag

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, Kai Mainzer, 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:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

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

Anthony Britto, Thomas Dengiz, Patrick Jochem, Hasan Ümitcan Yilmaz, Dogan Keles

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

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

Another distinctive feature of the research agenda graduates have to deal with as part of their education 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.

ENERGY STATUS DATA
COLLECT • ANALYSE • UTILISE

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

-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.

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 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. 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 prosumer's 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. In a next step, the optimal energy system of these municipalities was determined. This revealed that energy autonomy is associated with a high cost increase in most municipalities compared to the optimised reference system with grid connection. In municipalities with a high potential for base-load renewable energy technologies, energy autonomy is achievable with low cost increases of about 5%. To identify the interdependencies between prosumers and electricity markets, PV battery storage systems were integrated in an electricity market model. The number was determined by a Bass diffusion model. Then, a net present value based heuristic was used to determine the optimal system configuration for the prosumers. The resulting household energy demand was used to determine adjusted electricity prices which in turn influence the investment choice of the households. 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 was applied in order to analyse future grid structures. The transmission needs in the central European transmission grid were analysed for four storylines, developed within the project (Reference, ambitious climate action, European oriented energy transition with ambitious climate goals, decentral energy transition with ambitious climate goals). The power grid for Germany and the electrical neighbours except Denmark where considered as well as the electricity market integration with 15 other European countries. The necessary congestion management to resolve grid congestions in Germany was calculated using a multi-criteria optimisation model to determine the solution space regarding the targets minimal cost, minimal greenhouse gas emissions as well as minimal volume of congestion management measures. 91 combinations were calculated in hourly resolution for the year 2030. The results are published in a joint study of the involved project partners, where the impacts of the different scenarios in the storylines on the German power system are discussed.

SPONSORED BY THE

Energy Systems Integration

Max Kleinebrahm, Armin Ardone

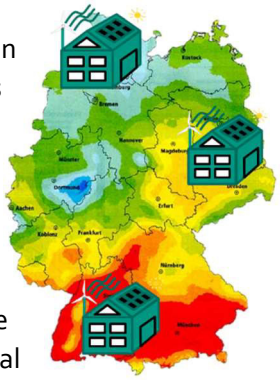
Partner: Forschungszentrum Jülich (FZJ), German Aerospace Centre (DLR), Max-Planck-Institute for Plasma Physics (IPP), Helmholtz-Zentrum Berlin (HZB), Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Helmholtz-Zentrum Potsdam German GeoResearchCentre (GFZ), Karlsruhe Institute of Technology (KIT)

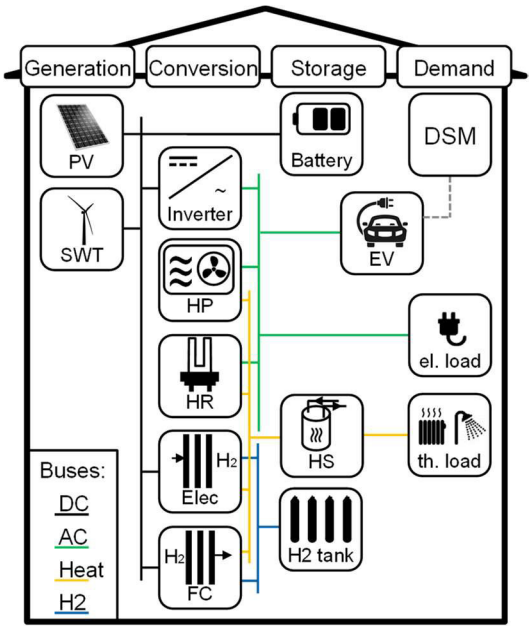
Funding: Helmholtz Association

Duration: 2017 to 2020

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

Interactions within the energy system are represented by models, simulated for a variety of scenarios and verified by real data sets. The modelling from the component level to the process level up to the level of the energy systems leads to in-depth knowledge and applicable tools. For the development of robust scenarios, the trend towards individual and independent energy supply is analysed. Therefore, the effects of self-sufficient residential buildings on the future energy system are examined in the Group "Decentralized 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). Considering different location factors such as country-specific regulatory conditions, weather conditions and comfort levels, big differences can be seen in the dimensioning of self-sufficient building energy systems. In the further course of the project, the dissemination of self-sufficient residential buildings under various conditions will be investigated.





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 five project partners.

Due to the growing traffic volume, urban areas have to rise to new challenges. For this reason, the project focused on the impacts from electric vehicles on the distribution network in urban areas. Therefore, the project partners evaluated 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 were analysed. Thus, the regional distribution of the electric vehicles as well as the associated energy demand was determined temporally and spatially.

Based on the identified mobility and charging behavior, a network analysis was implemented to identify critical network situations and bottlenecks. Therefore, a suitable network was implemented in MATPOWER and the network were analyzed within a load flow calculation. The network analysis also took into account the spatial and temporal penetration of EV as well as the network restrictions.

In the investigated grid area no thermal or voltage-related overloads could be identified. However, this conclusion cannot be generalized due to the different network topologies.

Within the framework of the project, however, it was shown that it is not the additional amount of energy of the grid that poses new challenges, but the newly emerging load peaks. However, intelligent charge management has the potential to smooth out peak loads.

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

strategiedialog automobilwirtschaft BW

flexQgrid: Practice-oriented implementation of the quota-based grid light concept for flexibility use in and from the distribution grid

Armin Ardone, Nico Lehmann

Partners: 9 partners from industry and science: Netze BW GmbH, Entelios AG, PSI Software AG, University of Stuttgart, Karlsruhe Institute of Technology (KIT), BlockInfinity GmbH, Fichtner IT Consulting GmbH, FZI Forschungszentrum Informatik

Associated partners: PREdistribuce, a.s.,

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2019 to 2022

The flexQgrid project is intended to make a significant contribution both to the realization of flexibility utilization in the distribution grid and to the provision of flexibility for upstream voltage levels.

In flexQgrid, the approaches developed in the grid-control project (www.project-grid-control.de) for a quota-based grid light concept are further developed and tested. With an intraday implementation of the quota model and the establishment of secondary trading, further flexibility potential can be used in the distribution grid. It is essential that asset operators (private individuals and market participants) are willing to provide flexibility. For this reason, appropriate incentives for providing flexibility are being investigated and stakeholders are being involved. In addition, the technical framework conditions that have to be considered before and during the implementation of a quota model are also examined. Finally, the compatibility of the quota model with the legal and regulatory framework is examined and adjustment options are elaborated.

The developed solutions are field-tested. The aim is to use the infrastructure of smart meters like those that are currently being installed in Germany. In addition to battery storage and power generation systems, sector-coupling flexibility options (heat pumps, electric vehicles) and other flexible consumers are to be integrated. In order to ensure a reliable supply of flexibility, the dynamic behavior of these facilities is investigated in simulations and laboratory tests. On the basis of the knowledge gained, recommendations for action are derived and a roadmap with the necessary steps for the use of the quota-based grid light concept is developed.

Within the framework of flexQgrid, the Chair of Energy Economics will investigate the incentives necessary for providing flexibility in the low-voltage grid. The price/quantity combinations on the supply and demand side of flexibility are largely unknown and have to be assessed exemplarily before introducing a quota model. Instruments are developed, e.g. surveys and expert interviews, which make it possible to ascertain the preferences of flexibility providers and thus quantify the socio-economic constraints. The aim is to achieve reliable and valid results and to include these results in the market simulations. In this way, market behavior can be observed and conclusions can be drawn on the market design.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

IILSE – Inductive and Interoperable Charging Systems for Electric Vehicles

Patrick Jochem, Alexandra Märtz, Axel Ensslen

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 phase of the project (2015 - 2017) the acceptance of inductive charging of electric vehicles was intensively investigated. In order to investigate the research question of how the 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. In the second phase of the project (2018 - 2019), the consideration of networks gained significantly in importance. The increasing market penetration of electric vehicles resulted in the need for a more detailed analysis of the future influence of the additional electricity demand by electric vehicles on the distribution networks in order to identify network bottlenecks in good time.

In the second phase, the additional electricity demand and the associated higher grid load from electric vehicles should be analyzed with a focus on distribution grids. In a first step, various relevant scenario parameters were identified, analyzed and future-oriented scenarios created. In particular, the simultaneity of the charging processes was taken into account. Since peak loads can mainly lead to critical network situations, the simultaneity on which the network analyses are based plays a decisive role. For this purpose, a tool was developed within the framework of the project which calculates the maximum simultaneous charging processes as a function of the households located in the network. After model implementation, the network effects of the charging processes were analyzed by means of a load flow calculation taking into account the calculated simultaneity. The analyses were based on different network types (rural, village and suburban networks). The different networks were analyzed with regard to the different scenarios and examined for thermal and voltage-related overloads. In order to highlight the regional differences, the network types were also compared.

Supported by:

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by the German Bundestag

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

Russell McKenna, Fritz Braeuer

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

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

Duration: 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 CO_2 emissions of buildings is a major climate policy goal of the German Federal Government.

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

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

The demonstration part will comprehensively observe and scientifically evaluate the operation of various heat pump systems and components in

http://www.lowex-bestand.de

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.

Living Lab Walldorf

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.

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

MODEX-EnSAVes: Model Experiments – Development paths for new power applications and their effects on critical supply situations

Florian Zimmermann, Dogan Keles, Patrick Jochem

Partner: TU Dresden, Fraunhofer ISI, ESA², University of Duisburg-Essen, M-FIVE

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2019 to 2021

In the context of the energy turnaround, a completely new energy landscape is developing in Germany with increasing interconnection and the resulting interactions between the numerous actors and new technologies. Model-based energy system analyses are an important instrument for understanding these complex interrelationships and mechanisms of action. On this basis, specific impulses can be set which should drive system development in the desired direction. For this purpose, a wide variety of model approaches have been developed over the past decades, which now have a very broad methodological spectrum. In order to investigate the function and effects of the different methods, to increase the transparency in system analysis and to promote the continuous improvement of the models, comparisons of model approaches should be pursued at regular intervals. Therefore, MODEX-EnSAVes is a methodologically oriented model comparison study, which is carried out on the basis of a specific use case.

The aim of the model comparison is to compare the results of different model approaches for the market rollout of new power applications and its

effects on supply security. On the demand side, the model experiment focuses on the areas of e-mobility and heat pumps in residential buildings, for which the consortium applies various detailed models with a particular focus on the analysis. Since the investment decisions for passenger cars (i.e., modelled by TE3) and building heating systems are made by different actors, there are various influencing factors which are represented differently in the individual models. At the same time, the development dynamics in this area are crucial for the path towards an "All-Electric-Society", as is often proposed with regard to the implementation of climate protection goals.

At the same time, increased electrification is also expected to have an impact on supply security, and the question arises in particular as to how critical supply situations such as situations with no wind in cold winter nights can be handled in the future. Therefore, the models for demand development are to be coupled with electricity market models (i.e., PowerACE). The latter should be used specifically for an analysis of future generation security, i.e., the adequacy of generation, backup capacities, demand side management, or reserve power plants for dealing with periods of high residual load. For this purpose, possible load curves for the new electricity applications will be derived from the demand models and used as input for the electricity market models. By iterating the models to be coupled, it will also be possible to reflect influencing factors such as the electricity price back to the demand models in order to consider mutual dependencies of the market launch with regard to e-mobility and heat pumps.

These are then used to investigate whether and how electricity demand can be met in the future by exploiting the flexibility potentials of the generation plants and demand applications. In particular, the focus will be on a year with extreme weather conditions. In this case, the weather year 2012 with comparably low temperatures at the beginning of February can be considered. By comparing the results of different electricity market models, it will be possible to determine in particular the impact of flexibility potentials on generation security.

Supported by:

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Modex-NET

Thomas Dengiz, Rafael Finck, Patrick Jochem, Armin Ardone

Partner: Forschungszentrum Jülich, Deutsches Zentrum für Luft- und Raumfahrt, Forschungsstelle für Energiewirtschaft, Öko-Institut, RWTH Aachen University, Technische Universität Dortmund, Technische Universität Dresden

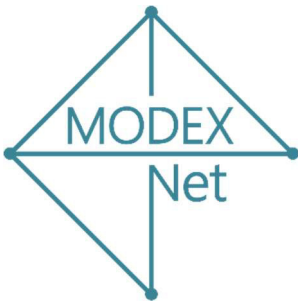
Funding: Bundesministerium für Wirtschaft und Energie (BMWi)

Duration: 2019 to 2021

Due to the increasing share of renewable energy sources in the European energy system, models of the transmission grid become more and more important for analyzing questions like the grid stability and the security of supply in future. To this end, many different transmission grid models exist. However, the used methodologies for modelling the transmission grid and the used input data for the model runs are quite diverse.

The goal of the project Modex-Net is to compare eight energy system models of the European transmission grid. The differences between the models are going to be identified and analyzed based on several case studies. The analysis comprises the methodological basics, the grid topologies and the used input data for the models. A special focus will be given to the used flexibilities

for both the generation and the demand side. General recommendations for the adjustment and development of transmission grid models should be made based on the results of the analysis to foster the significance of transmission grid models for the energy transmission.



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

Analysis of the optimal and technology-specific storage mix for Germany and Europe in case of a complete conversion of the power supply to renewable energies by 2050 (OptTech)

Daniel Fett, Dogan Keles, Viktor Slednev, Hasan Ümitcan Yilmaz

Funding: Stiftung Energieforschung B-W

Duration: 2019 to 2021

The OptTech project investigates how a secure power supply can be achieved through 100 % renewable energies (RE) by the year 2050 if fossil fuels are abandonded, and which storage technologies are required to compensate for fluctuations in the renewable energies. In particular, analyses what an economically reasonable composition of long-term and short-term storage technologies looks like for Germany and Europe until 2050 and to what extent both technologies complement or hinder each other in terms of capacity utilisation. This study will therefore examine the diffusion and optimal composition of different storage technologies under different energy policy scenarios.

First, the diffusion of decentralised PV battery storage systems based on microeconomic optimisation of households is predicted. Based on this, the European energy system model PERSEUS-EU is used to calculate the cost-minimal composition of renewable energies and central storage technologies as well as the resulting total system costs.

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

Profilregion Mobilitätssysteme Karlsruhe

Patrick Jochem, Axel Ensslen

Partner: FZI, Fraunhofer ICT, Fraunhofer IOSB, Fraunhofer ISI, Fraunhofer IWM, HsKA IEEM, HsKA IKKU, KIT ECON, KIT ETI, KIT FAST, KIT FAST, KIT IAM-WK, KIT IESL, KIT IFAB, KIT IFKM, KIT IfV, KIT IHE, KIT IIP, KIT IKFT, KIT IPEK, KIT IRS, KIT ITAS, KIT ITIV, KIT ITIV, KIT KASTEL, KIT KSRI, KIT MRT, WBK

Funding: Ministry of Science, Research and the Arts Baden-Württemberg (MWK)

Duration: Phase 1: 01/2016 – 12/2017; Phase 2: 03/2019 – 12/2020

Within the „Profilregion Mobilitätssysteme Karlsruhe", the research expertise and the development competence in the field of mobility systems available and located at Karlsruhe is combined and linked with industry. The project is funded by the federal state of Baden-Württemberg. Several institutes at KIT, Fraunhofer, Hochschule Karlsruhe and FZI (Forschungszentrum Informatik) are involved in the project and combine interdisciplinary research expertise.

Joint projects permit the partners to collaborate even closer, exploit synergy potentials and initiate a mutual and cross-institutional exchange of knowledge.

In Phase I IIP was part of the initialization projects "Transportation and Mobility in a changing society" and "Mobility in an urban environment – needs-oriented infrastructure solutions in future cities" with a focus on electric mobility topics.

In Phase II, IIP participates in the sub-project "Urban Mobility in Transition". Analyses focus on topics in the field of alternative drive trains and mobility concepts in the context of urban mobility solutions, related socio-economic implications as well as on analyses of potentials for electrifying Karlsruhe's taxi service.

In the reporting period, the adoption, diffusion and charging of electric vehicles including load shifting potentials were simulated taking into account aspects of user acceptance for France and Germany. In addition, CO_2 emissions specific to electric

vehicles for France and Germany have been investigated and the effects of car sharing in 11 European cities have been analyzed. In addition, the effects of electric vehicle specific emissions on parts of the Stuttgart distribution network have been analyzed. As part of the "Strategiedialog Automobilwirtschaft" a charging matrix for the year 2030 was developed during workshops with experts from industry and politics. In order to measure sustainable mobility, an indicator system is developed within the framework of the SuMo-Rhine project. This indicator system will be applied to the East City of Karlsruhe.

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, 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

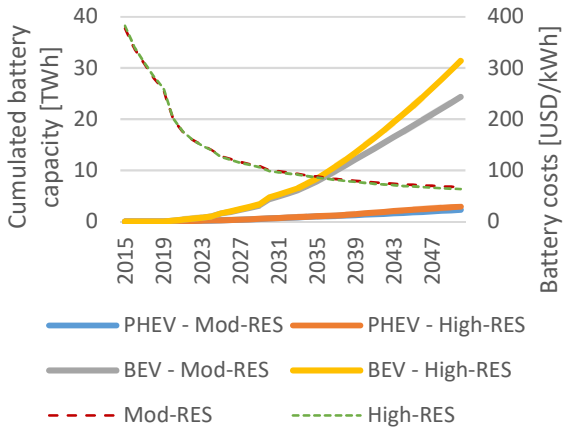
The future energy system is challenged by the intermittent nature of renewables and requires therefore several flexibility options. Still, the interaction between different options, the optimal portfolio and the impact on environment and society are unknown. It is thus the core objective of REFLEX to 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.

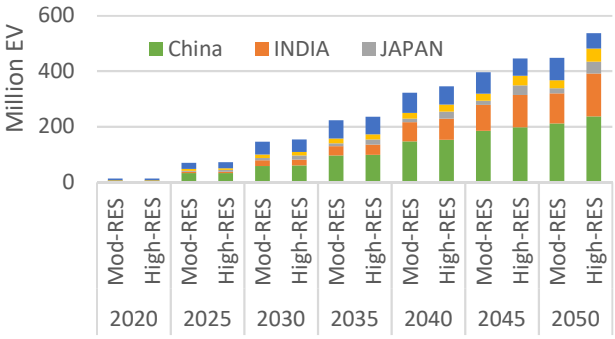
KIT is the leader of work package 5, dealing with market design options and policy measures. In this context, the electricity market model PowerACE was applied in order to investigate the long-term cross-border effects of several European countries recently starting to implement capacity remuneration mechanisms (CRM) as an extension to the energy-only market (EOM). More specifically, three different market design settings were analysed, namely a European EOM, national CRM policies and a coordinated CRM. The introduction of CRMs generally proved to be an effective measure substantially shifting investment incentives towards the countries implementing the mechanisms. However, CRMs increase generation adequacy also in the respective neighboring countries, indicating that free riding occurs. A coordinated approach therefore seems preferable in terms of both lower wholesale electricity prices and generation adequacy.

In the transport sector the coupling of the two models, ASTRA (for the European market) and TE3 (for the main non-European car markets), in order

to consider 34 countries in detail (and therewith more than 90% of current EV sales) allows analysing the interrelations of global battery costs and the individual market shares endogenously. Experience curves are endogenously implemented for battery and plug-in hybrid EV. As a core result, it turns out that battery prices, which rely strongly on the learning rate, have a strong impact on global EV sales. The key non-European countries have a higher impact on the development of battery prices through a high contribution to the cumulative battery capacity due to their higher overall car stock compared to the European countries.



The results from the EMS 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 is strengthened, which assists policy makers and support the implementation of the SET-Plan. Stakeholders were actively involved during the entire project from definition of scenarios to dissemination and exploitation of results via workshops, publications and a project website. A final book comprising project results from all partners as well as additional journal publications are currently in preparation.

This project is funded by the European Union

reFuels – rethinking fuels

Patrick Jochem, Simon Glöser-Chahoud, Uwe Langenmayr, Paul Heinzmann, David Pflegler

Partner: Daimler, Audi, Porsche, MiRO, MWV, Ineratec, EnBW, Bosch, BorgWarner, Eberspächer, Freudenberg, L'Orange, Mahle, CAT, Kolbenschmidt, Mann+Hummel

Funding: Ministerium für Verkehr des Landes Baden-Württemberg

Duartion: 2019 to 2020

The utilization of renewable produced fuels (reFuels) is one of the main actions next to electric mobility on the way to CO_2 neutral mobility. These fuels use carbon-containing residues of agriculture and forestry, as well as, industry and municipality waste. Other fuel-generation processes compound CO_2 with hydrogen produced from the electrolysis process. All these fuels form the group of reFuels.

The project consortium comprises several institutes of the KIT and other partners from the industry. The aim of the project is to assess the complete value chain, from the production of the fuels to the application in the vehicle, of these fuels. The Institute for Industrial Production, on one hand, examines the impact of the production processes on the energy system of Baden-Württemberg and Germany. The focus of this task is the assessment of the additional flexibility of these processes, the CO_2 savings in the mobility sector and the increasing integration of renewable energy sources. On the other hand, a techno-economic analysis of the different production processes is conducted. This task aims to deliver deeper understanding of investment volumes and the cost structure of different process constellations. This includes aspects of logistics and necessary infrastructure, which have an additional impact on the final integration costs of the processes. Finally, the implementation of a pilot plant at the facility of one project partner will be simulated and assessed. The project results support deeper insights on reFuels, their production processes and useful applications. Furthermore, they help to further decrease the greenhouse gas emissions in the mobility sector.

RES-TMO – Regionale Konzepte für eine integrierte, effiziente und nachhaltige Energieversorgung und Speicherung in der Trinationalen Metropolregion Oberrhein [Regional Concepts for an Integrated, Efficient and Sustainable Energy Supply and Storage in the Trinational Metropolitan Region Upper Rhine]

Joris Dehler-Holland, Dogan Keles, Kira Schumacher

Partner: KIT DFIU, University of Freiburg, badenova, University of Strasbourg, Centre national de la recherche scientifique – CNRS, University Haute Alsace, TRION-climate e.V.

Funding: Interreg Oberrhein

Duration: 2019 to 2021

The RES-TMO project develops regional concepts for an integrated, efficient and sustainable energy supply in the Upper Rhine region. The holistic nature of the concept is a particular focus. Through the multidisciplinary approach of the project different aspects of social acceptance, regulatory framework, economic feasibility and last but not least data security can be examined. The IIP contributes its many years of experience in energy system analysis. In the course of the project, various development scenarios for the expansion of

renewable energies in the Upper Rhine region will be developed.

The scenarios will then be mapped in the PERSEUS model developed at the institute. Among other things, the study focuses on the interaction between the local expansion of renewable energies and the European energy system. Particular attention must be paid to how the European infrastructure will develop in the coming years.

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

Helmholtz Portfolio Initiative "Safety and Security"

Kai Mainzer, Russell McKenna, Hasan Ümitcan Yilmaz

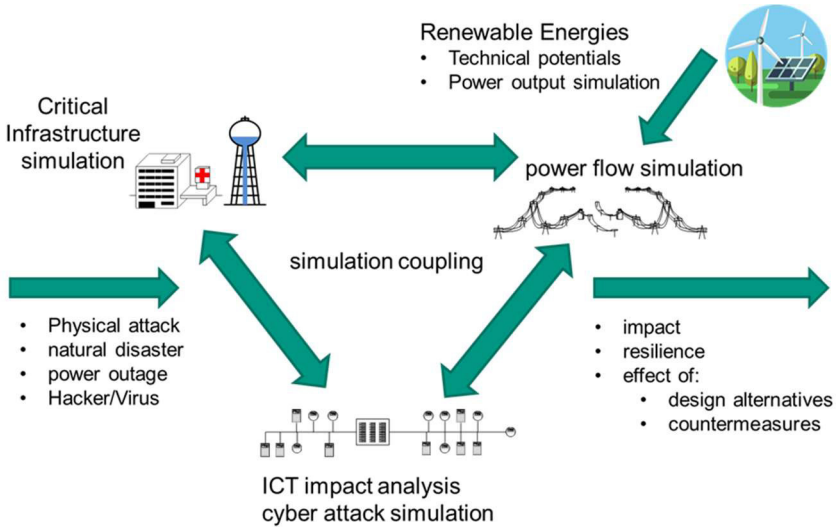
Partner: KIT-IKET, KIT-IPD

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

Hannes Schwarz, Armin Ardone, Joris Dehler-Holland, Thorben Sandmeier, Rafael Finck, Jann Weinand

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.

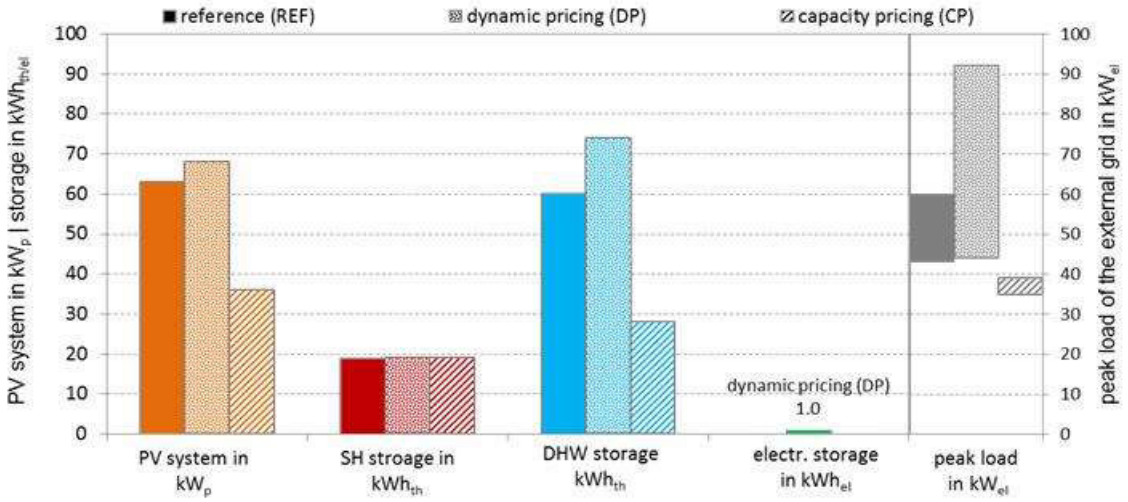
2) Efficient infrastructures, which address the upcoming challenges of energy transmission and distribution.

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.

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.

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.

SEES – Scientific Evaluation of Energy Services

Patrick Jochem, Russell McKenna, Fritz Braeuer, Hasan Ümitcan Yilmaz, Sabrina Ried, Kira Schumacher

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

Kira Schumacher, Katrin Seddig, Patrick Jochem, Nora Baumgartner

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 2021

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). Eight 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.

In March 2019 the kick-off event of the trinational SuMo-Rhine research project took place. The about 110 participants were welcomed by Gabriela Mühlstädt-Grimm, President of the Karlsruhe Vice Government, Dr. Frank Mentrup, Mayor of Karlsruhe, and Prof. Dr. Thomas Hirth, Vice President for Innovation and International Affairs at KIT. Afterwards, Prof. Dr. Wolf Fichtner presented the contents of the project. Next, project partners from municipalities, research and companies presented innovative concepts and exemplary initiatives for sustainable mobility in the Upper Rhine region and offered a good basis for discussions and expansion of the various networks.

In November 2019 the first participative Workshop

"Municipal Perspectives" of sustainable mobility in the Upper Rhine region will take place. In this first participatory workshop, the first results and the indicators will be presented and discussed with the target group. Participants in the interactive format are invited to share their needs and experiences with the researchers from a community perspective, thereby improving the practicality of this field decision support tool.

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

Awards

- Katrin Seddig received a teaching award for her teaching activities of the Energy and Environment tutorial during the summer semester 2019. Her tutorial was rated as one of the five best lectures during this semester.
- Emil Kraft received the Best Paper Award for his paper “Forecasting of Frequency Containment Reserve Prices Using Econometric and Artificial Intelligence Approaches“, submitted to the 11th International Energy Economics Convention (Internationale Energiewirtschaftstagung) at TU Vienna.
- Dr.-Ing. Sven Killinger was honored for his dissertation “Anlagenscharfe Simulation der PV-Leistung basierend auf Referenzmessungen und Geodaten” with the “Sparkassen-Umweltpreis”.
- Dr.-Ing. Hans Schermeyer was awarded the “EEX Group Exellence Award” for his dissertation “Netzengpassmanagement in regerativ geprägten Energiesystemen – Untersuchungen zur Abregelung Erneuerbarer Energien und zur Sektorenkopplung in einem deutschen Verteilnetz”.
- Dr.-Ing. Kai Mainzer was honored for his dissertation “Analyse und Optimierung urbaner Energiesysteme” with the “GOR dissertation price”.
- Dr.-Ing. Kai Mainzer was awarded the “UMSICHT science price” for his dissertation “Analyse und Optimierung urbaner Energiesysteme”.

Completed PhD Dissertations and Habilitations

PhD dissertation: "Socioeconomic analyses on electric mobility considering user experiences"

Axel Ensslen

The electrification of road transport is part of national strategies to reduce greenhouse gas, particulate matter and nitrogen oxide emissions. Research activities in the field of electric mobility have been supported in recent years by publicly funded projects, also within the framework of living labs. The aim of this dissertation is to analyze socio-economic aspects of electric mobility in the context of living labs on different levels (micro, meso, and macro) and across the levels in the energy context.

This dissertation is based on four articles. The first article is dedicated to the micro-level. The main focus of the analyses is on acceptance of electric vehicle use in living labs in the French-German metropolitan region of the Upper Rhine. Results of the analyses show that an electric vehicle friendly environment can positively influence acceptance through an advantageous acceptance context. The second article is dedicated to the meso-level. As part of a living lab in Southwest Germany, the business model "electric mobility from one provider" is analyzed by evaluating costs and benefits of electric vehicle specific product service systems in organizations. On average, the higher total costs of ownership of electric vehicles compared to internal combustion engine vehicles are compensated by non-monetary benefits. However, the costs of charging infrastructure and services exceed the associated benefits of many organizations. The third article assesses the impact of electric vehicle use at the macro level. CO_2 emissions that occur during charging phases in France and Germany are assigned to individual charging processes collected in a living lab. The results on electric vehicle specific CO_2 emissions of cross-border commuters show considerable differences depending on national electricity generation mixes. The fourth article pursues a cross-level assessment approach. An agent-based electricity market simulation model (meso level) is extended by electric vehicle charging service providers enabling the analysis of controlled charging and related effects on electricity markets (macro level) taking into account user requirements (micro level). The coupling between the micro- and meso-level is carried out via an innovative electric vehicle specific electricity tariff intending to stimulate the provision of flexibility potentials taking into account individual requirements concerning the use of electric vehicles. Charging service providers use the flexibility potentials provided by electric vehicle users for their bids on electricity markets within the scope of their business activities.

Future developments of agent-based electricity market simulation models could be oriented more towards user-centered, socio-economic paradigms. Cross-level analyses could be carried out taking into account preferences for innovative electric vehicle specific electricity tariffs, which could be analyzed in further living labs.

PhD dissertation: Capacity remuneration mechanisms for electricity markets in transition

Andreas Bublitz

The necessity to remunerate the provision of electrical capacity is intensively discussed among stakeholders in the electricity sector, as concerns about generation adequacy are growing due to an increasing share of intermittent renewable energies. Around the world and most recently in particular in Europe, different capacity remuneration mechanisms have already been implemented or are about to be introduced. These developments entail new challenges for regulators as well as market participants, yet it is still disputed whether capacity remuneration mechanisms are indeed needed.

In this dissertation, it is examined to which extent the expansion of renewable energies is linked to a decline in prices and restrained investments. It is shown that the drop in wholesale electricity prices in European markets is partly attributable to an increase in renewable production. However, the development of fuel prices, emission allowances prices, and the decommissioning of power plants are equal or even stronger factors. Notwithstanding, the profitable operation of state-of-the-art thermal power plants, i.e., combined cycle gas-fired units, remains difficult with the ongoing increase of renewable capacities, thus making it likely that the debate about capacity remuneration mechanisms will further intensify. Against this backdrop, an up-to-date overview of the debate on the necessity for capacity remuneration mechanisms is provided, and initial experiences with real-world implementations are discussed. In addition, the current state of research on capacity remuneration mechanisms is analyzed. While most studies agree that capacity remuneration mechanisms have certain advantages, for example, investment cycles can be dampened, and the adverse effects of the abuse of market power can be mitigated, no consensus is found on other issues, for example, the optimal design or cross-border effects.

PhD Dissertation: "Optimierung der Investitions- und Einsatzplanung dezentraler Ernergiesysteme unter Unsicherheit"

Hannes Schwarz

Energy supply is continuously moving from a centralized to a decentralized supply, with significant expansion occurring in fluctuating renewable energy. In the fundamental, structural rearrangement of the energy supply, the investment and operational planning of decentralized energy systems is subject to a variety of uncertainties. Motivated by this development, a comprehensive, module-based framework is developed for investment and operation planning optimization in order to consistently model and take account of those uncertainties and their interdependencies.

Beginning with the generation of meteorological input data using Markov processes, these are then transformed into the required data for the optimization. Finally, a two-stage stochastic mixed-integer linear program optimizes the investment decision and operational management of the decentralized energy system. To this purpose, the large-scale program is decoupled by fixing connecting variables into sub programs and performed in parallel on high-performance computing systems. The computational effort is reduced by up to 75 % through an upstream scenario reduction and an optimized solver setting using automatic algorithm configuration. The fixed variables in the master program are optimized by a derivative-free hill-climbing algorithm, which robustly and reliably finds the (local) optimum in a few iterations. In a case study, the optimal investment and operation for the energy system of a residential quarter in Karlsruhe is determined endogenously. Possible system components include a PV system, heat pumps as power-to-heat applications as well as thermal and electrical storage units. The results indicate that the PV system is generally economical as a decentralized energy supply in such a system. Heat storage units are generally larger when uncertainties are taken into account, i.e. stochastic optimization can help to avoid insufficient investment planning. With a separated heating system, hot water storage units are more profitable than space storage units, the value of which is rather in reducing the risk of not covering heat demand in cold winters. Due to their higher investment needs, electrical storage units play a marginal role in comparison to thermal storage units and are only essentially required in the case of complete self-sufficiency bridging certain weeks in the year. The scalability analysis and the comparison with a state-of-the-art dual decomposition method reflect a good performance in the developed approach for the considered problem type. The added value of taking uncertainties into account in optimization, including the resulting computational effort, is shown and justifies the approach.

PhD Dissertation: "Fleets of electric vehicles in the local energy system with photovoltaic supply under consideration of uncertainty"

Katrin Seddig

Electric vehicles (EV) represent a promising technology for a sustainable transport sector with reduced CO_2 emissions, especially if the EVs are charged with electricity from renewable energy sources (RES). However, the fluctuating generation of RES and the driving patterns of EV users are subject to several uncertainties.

In the context of this thesis, a model is developed, which can be used to identify the load shifting potentials (LSP) of electric vehicle fleets with special consideration of the integration of photovoltaic (PV) generation and uncertainties. Concluding from this, approaches for the implementation of possible business models are identified, as for example an EV aggregator could use them to sell the LSP resulting from the charging processes on electricity markets.

To answer the underlying questions of the work, different approaches are developed using simulation, deterministic optimization and stochastic optimization to plan the charging process of three different electric vehicle fleets (commuter, opportunity and commercial fleet) at a common charging infrastructure under uncertainty. In a car park case study, several technical constraints are taken into consideration when evaluating the LSP of the electric vehicle fleets in order to minimize charging costs and maximize the use of locally generated electricity by PV. The two-stage stochastic mixed-integer optimization problem is solved by a sample average approximation method based on Latin Hypercube. Uncertainties in the generation of electricity by the PV system are taken into account by three different forecasting options and the mobility characteristics of electric vehicle fleets are modelled with a non-parametric probability density function (Kernel Density Estimation). In addition, a Monte Carlo simulation is applied to all approaches in order to map the underlying stochastic profiles of PV generation, electricity prices, departure and arrival times, and the driving distances of the EV. By comparing the different approaches with the deterministic optimum, the results of the methods can be compared.

The differences in charging costs and the utilization of electricity by locally generated PV are identified and discussed when applying the three approaches. The numerical results illustrate the load shift potential of different electric vehicle fleets in a car park with a common charging infrastructure at different signals, taking into account both technical constraints as well as uncertainties.

Staff as of December 2019

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

Dr.-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

Nora Baumgartner: Development of a modular system of intervention measures to increase the acceptance in the mobility context

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

Anthony Britto: Manifestations of the energy-efficiency gap

Joris Dehler-Holland: 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

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

Ruppert 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.

Uwe Langenmayr: Sector coupling of electricity and mobility – Comparison of Power-to-Liquid, Power-to-Gas and Electric Mobility

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

David Pflegler: Assessment of the possibilities of a meaningful integration of different infrastructures in the context of PtX technologies in terms of storage, flexibility and transport of "indirect electricity" for instance liquid fuels based on PtL or hydrogen/methane based on PtG.

Thorben Sandmeier: Evaluation of flexible network elements in electrical transmission grids

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

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: University of Auckland, New Zealand

Who: Patrick Jochem

Host: Dr. Andrea Raith, Senior Lecturer in the Department of Engineering Science

Period: June 2019

Patrick Jochem visited the Engineering Science department of University of Auckland. His stay was funded by the Research Alliance for Logistics and analytics in Primary care and Emergency Services (ReAL PrimES). In his research stay he focused on two research foci. First, the electrification of touristic mobility flows in New Zealand, and second, the electrification of taxi services. Within the second topic a Julia-based simulation tool was developed, which allows a profitability analysis of inductive charging systems at taxi ranks. This model has been presented at a VHB workshop at RWTH Aachen in October 2019.

Location: Durham University

Who: Dogan Keles

Host: Prof. Tooraj Jamasb, Department of Economics

Period: April – August 2019

Dogan Keles' Fellowship was funded by the EU COFUND program. He gave different talks/presentations at Durham University institutions, such as the two talks about "Transformation towards Sustainable Energy Systems – Lessons learned from the German transition". Another presentation was about the topic "Cross-border Effects of Capacity Remuneration Mechanisms: The Swiss Case" organized at the Durham Business School for both, doctoral students and academic staff. As a Member of the Durham University Business School (DUBS), he was able to visit talks and presentations organized by members of the school, such as the talk of the Nobel Prize holder Vernon L. Smith with the title "The Human Factor in Economics: From Adam Smith to Artificial Intelligence". With Prof. Tooraj Jamasb and Dr. Manuel Llorca from Durham University, who now moved to Copenhagen Business School, Dogan started the work for two journal publications, one about energy systems integration, the other about the merit order effect in different European countries. Further topics for joint work have been also identified, for instance, modeling of decentralized systems and energy sector coupling.

Location: Wharton Business School

Who: Hasan Ümitcan Yilmaz

Host: Professor Steven Kimbrough of the Department of Operations, Information and Decisions

Period: March – June 2019

Hasan Ümitcan Yilmaz had a research stay at the Wharton Business School in the USA from March 1 to June 30. Professor Steven Kimbrough of the Department of Operations, Information and Decisions hosted his stay and the Karlsruhe House of Young Scientists (KHYS) financed his scholarship. During his research stay, Hasan Ümitcan Yilmaz mainly worked on assessing and hedging of the volatility risk of gas prices, deep decarbonisation of the European electricity system and techniques to obtain robust results from energy system models.

Location: Massachusetts Institute of Technology (MIT), United States

Who: Florian Zimmermann

Host: Prof Carlos Batlle, MIT Energy Initiative

Period: July 2019

Florian Zimmermann was granted the KHYS networking grant for visiting Carlos Batlle at the MIT Energy Initiative in Cambridge for two weeks. During the stay, Florian Zimmermann presented this research topics concerning cross-border effects of capacity remuneration mechanisms, and an agent-based electricity market simulation model approach. This short stay enabled some stimulating discussions with Carlos Batlle, who is working on different aspects of energy market modelling and capacity remuneration mechanisms.

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 nine 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 90 bachelor and master theses per year.

Introduction to Energy Economics ~110 students

Prof. Dr. rer. pol. W. Fichtner
PD Dr. rer.pol. P. Jochem
M. Sc. T. Sandmeier

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 ~100 students

PD Dr. rer. pol. P. Jochem
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 ~40 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 ~30 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 ~15 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 ~15 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.

Energy Systems Analysis ~20 students

Dr. rer. pol. A. Ardone
Dr. rer. pol. D. Keles
M. Sc. T. Dengiz
Dipl.-Inform. H. Ü. 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 ~15 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 ~20 students

PD Dr. rer. pol. P. Jochem
PD Dr. R. McKenna

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 ~65 students

Apl. Prof. Dr. rer. nat. U. Karl
PD Dr. rer. pol. P. Jochem
M. Sc. K. Seddig

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

Teaching at the Chair of Energy Economics

BSc-Module „Energy Economics"

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

MSc-Module „Energy Economics and Energy Markets"

- 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)

MSc-Module „Energy Economics and Technology"

- 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)

Publications

University Publications

Ensslen, A. (2019). Sozioökonomische Analysen zur Elektromobilität unter Berücksichtigung von Nutzungserfahrungen. PhD dissertation. Karlsruhe.

Parrilla-Martinez, J. (2019). Optimization of the value chain of the existing free potentials of wood resources for power generation in Baden-Württemberg. PhD dissertation. Karlsruhe. doi:10.5445/IR/1000099390/v2

Bublitz, A. (2019). Capacity remuneration mechanisms for electricity markets in transition. PhD dissertation. Karlsruhe. doi:10.5445/IR/1000096476

Gómez Vilchez, J. J. (2019). The Impact of Electric Cars on Oil Demand and Greenhouse Gas Emissions in Key Markets. PhD dissertation. Karlsruhe. doi:10.5445/IR/1000095249

Mainzer, K. (2019). Analyse und Optimierung urbaner Energiesysteme - Entwicklung und Anwendung eines übertragbaren Modellierungswerkzeugs zur nachhaltigen Systemgestaltung. PhD dissertation. KIT, Karlsruhe. doi:10.5445/IR/1000092481

Schwarz, H. (2019). Optimierung der Investitions- und Einsatzplanung dezentraler Energiesysteme unter Unsicherheit. PhD dissertation. KIT Scientific Publishing, Karlsruhe. doi:10.5445/KSP/1000092368

Peer-Reviewed Journals

Yilmaz, H. Ü.; Fouché, E.; Dengiz, T.; Krauß, L.; Keles, D.; Fichtner, W. (2019). Reducing energy time series for energy system models via self-organizing maps. Information technology, 61 (2-3), 125–133. doi:10.1515/itit-2019-0025

Plötz, P.; Gnann, T.; Jochem, P.; Yilmaz, H. Ü.; Kaschub, T. (2019). Impact of electric trucks powered by overhead lines on the European electricity system and CO_2 emissions. Energy policy, 130, 32–40. doi:10.1016/j.enpol.2019.03.042

Ensslen, A.; Will, C.; Jochem, P. (2019). Simulating Electric Vehicle Diffusion and Charging Activities in France and Germany. World electric vehicle journal, 10 (4), Art.-Nr.: 73. doi:10.3390/wevj10040073

Weinand, J. M.; McKenna, R.; Mainzer, K. (2019). Spatial high-resolution socio-energetic data for municipal energy system analyses. Scientific data, 6 (1), 243. doi:10.1038/s41597-019-0233-0

Xu, L.; Fuss, M.; Poganietz, W.-R.; Jochem, P.; Schreiber, S.; Zoephel, C.; Brown, N. (2020). An Environmental Assessment Framework for Energy System Analysis (EAFESA): The method and its application to the European energy system transformation. Journal of cleaner production, 243, 118614. doi:10.1016/j.jclepro.2019.118614

Gómez Vilchez, J. J.; Jochem, P. (2019). Simulating vehicle fleet composition: A review of system dynamics models. Renewable & sustainable energy reviews, 115, Article: 109367. doi:10.1016/j.rser.2019.109367

Weinand, J. M.; McKenna, R.; Kleinebrahm, M.; Mainzer, K. (2019). Assessing the contribution of simultaneous heat and power generation from geothermal plants in off-grid municipalities. Applied energy, 255, 113824. doi:10.1016/j.apenergy.2019.113824

Held, M.; Schücking, M. (2019). Utilization effects on battery electric vehicle life-cycle assessment: A case-driven analysis of two commercial mobility applications. Transportation research / D, 75, 87–105. doi:10.1016/j.trd.2019.08.005

Weinand, J. M.; McKenna, R.; Karner, K.; Braun, L.; Herbes, C. (2019). Assessing the potential contribution of excess heat from biogas plants towards decarbonising residential heating. Journal of cleaner production, 238, 117756. doi:10.1016/j.jclepro.2019.117756

Hone, C.; Weeber, M.; Braeuer, F.; Sauer, A. (2019). Techno-economic analysis of battery storage systems for demand responds application in manufacturing. Procedia manufacturing, 33, 359–366. doi:10.1016/j.promfg.2019.04.044

Fett, D.; Keles, D.; Kaschub, T.; Fichtner, W. (2019). Impacts of self-generation and self-consumption on German household electricity prices [in press]. Journal of business economics. doi:10.1007/s11573-019-00936-3

Jochem, P.; Szimba, E.; Reuter-Oppermann, M. (2019). How many fast-charging stations do we need along European highways?. Transportation research / D, 73, 120–129. doi:10.1016/j.trd.2019.06.005

Weinand, J. M.; Kleinebrahm, M.; McKenna, R.; Mainzer, K.; Fichtner, W. (2019). Developing a combinatorial optimisation approach to design district heating networks based on deep geothermal energy. Applied energy, 251, 113367. doi:10.1016/j.apenergy.2019.113367

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