Karlsruhe Institute of Technology

Institute for Industrial Production

Annual Report 2021

Chair of Energy Economics




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Preface

This 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 2021. The four research groups "Distributed Energy Systems and Networks", "Energy Markets and Energy Systems Analysis", "Energy Policy", and "Transport and Energy" 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.

[1]

During 2021, we worked on around 20 ongoing national and international research projects and started 2 new projects. We published around 20 peer-reviewed journal articles. Furthermore, 5 dissertations were completed and 3 theses were defended.

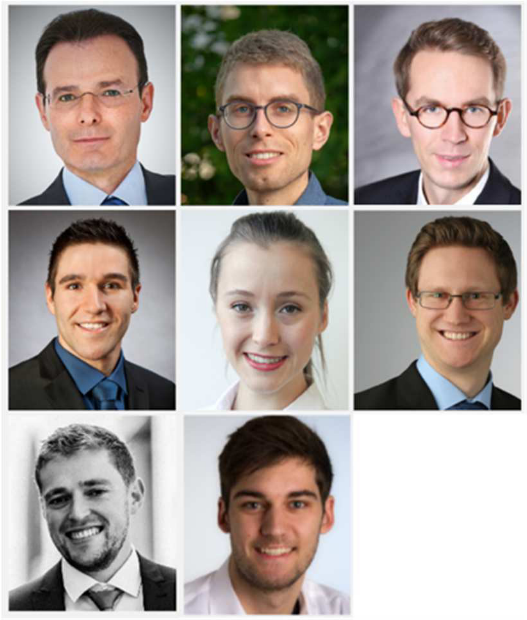
My staff and I hope that we can arouse your interest in our research activities with the brief report. We look forward to receiving any comments and suggestions you may have.

Prof. Dr. Wolf Fichtner, Chair of Energy Economics

[1] Disclaimer: this picture has been taken in 2019. All following pictures have been taken considering the infection protection laws at the time.

Distributed Energy Systems and Networks Group

Head of research group: Dr. Armin Ardone



Members of the research group (fltr): Armin Ardone, Daniel Sloot, Max Kleinebrahm, Nico Lehmann, Leandra Scharnhorst, Rafael Finck, Viktor Slednev, 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 Systems Analysis Group

Head of research group: Christoph Fraunholz

Members of the research group (fltr): Emil Kraft, Christoph Fraunholz, Daniel Fett, Florian Zimmermann. Missing in the picture: Kim Miskiw, Malin Lange.

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.

For the analyses on these topics, both, the overall economic perspective and the market participants' individual perspectives are taken into account. The targeted audience for the model-based analyses of the research group EMESA are decision-makers from politics, business and industry.

Energy Policy Group

Head of research group: Joris Dehler-Holland

Members of the group (fltr): Joris Dehler-Holland, Phuong Minh Khuong, Anthony Britto, Hasan Ümitcan Yilmaz Missing in the picture: Stephanie Stumpf.

Achieving ambitious climate protection targets requires extensive social, economic and technological change. Due to high greenhouse gas emissions, the energy sector is particularly challenged. Political decision-makers have various tools at their disposal to stimulate sustainable change.

The focus of the Energy Policy Research Group is on policy measures to promote or sanction energy technologies and their economic and societal impacts. Since policy instruments do not emerge independently from political actors, the research group focuses on political processes and their influence on policy measures. Statistical methods for data analysis and economic models are used, but also surveys on the acceptance of technologies.

Transport and Energy Group

Head of research group: Manuel Ruppert

Members of the research group (fltr): Christian Perau, Zongfei Wang, Nora Baumgartner, Tim Signer, Manuel Ruppert, Alexandra Märtz, Thomas Dengiz, Uwe Langenmayr.

The ongoing decarbonisation of the energy sector and its increasingly rapid transformation pose a variety of complex questions for research. While questions with a strong focus on the electricity sector have traditionally been investigated in the field of energy system analysis, questions concerning the optimal system design across the individual sectors (sector coupling) are currently particularly relevant. In the context of these questions, the working group Transport and Energy at the Chair of Energy Economics performs research on coordinated emission reduction strategies in the sectors electricity, gas, heat and transport. A special focus is on the mobility transition through increasing electrification of the transport sector. Currently, one promising alternative in this regard is the electrification of passenger road transport by electric vehicles (EV). 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, which is a central area of research within the group. Another special field of interest in this context is the coupling of the electricity and the gas sector using power-to-X technologies and the subsequent link to transportation when producing renewable fuels (power-to-liquid).

The group currently follows three central questions of research: First, the market development of EV is investigated concerning market penetration and impact of smart charging methods on the local and national power system. Second, the feasibility of energy storage and power-to-X technologies in the future energy system is being analysed on both local (distribution grid) and central (transmission grid) level. Third, mobility patterns, user behaviour and user acceptance analyses of (technological) innovations in the transportation sector are performed. For answering the research questions, 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 modelling, such as optimisation tools, agent-based simulation, econometrics as well as other socio-economic or mathematical models. These models are applied in different fields from service science and psychology to decentralised electricity systems and electricity 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. The funding comes from various research projects for German ministries, the European Commission, Helmholtz Association, local ministries, and industry.

Research Project

BDL – Bidirectional Charging Management

Sabrina Ried, Fritz Braeuer, Nora Baumgartner, Tim Signer, Manuel Ruppert

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

Funding: Federal Ministry for Economic Affairs and Energy (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 with 50 BMW i3. 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 stakeholders' perspectives. For this reason, KIT investigates the interaction of bidirectional charging management with electricity markets and grids in the BDL project. To this end, an existing energy system model has been extended to research the effects of V2G on the European electricity market. The findings of the pilot phase, where 50 EVs are tested in different V2x use cases, will be included in the energy system model. In addition, the potential of V2G for improved integration of renewable energies has been 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. Specifically, surveys were conducted on the user acceptance of a possible design of EV's planned charging control by distributed system operators (§14a EnWG).

Another topic that is dealt with in the context of user acceptance research relates to tariff design and determination of the willingness to pay for controlled charging management tariffs.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

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

Anthony Britto, Joris Dehler-Holland, Leandra Scharnhorst

Partners: 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 2025

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

Within the scope of this graduate college, Anthony Britto focuses on the economic puzzle of the *energy-efficiency gap*, which is the idea that the energy-conservation technology diffuses more slowly than its profitability would indicate. The focus of this research is a micro-economic modelling of different demand sectors in order to investigate the causes and possible solutions to this issue.

Energy System Design (ESD)

Armin Ardone, Christoph Fraunholz, Max Kleinebrahm, Thorben Sandmeier, Leandra Scharnhorst

Partner: Forschungszentrum Jülich (FZJ), German Aerospace Centre (DLR), HELMHOLTZ Center Berlin (HZB), Max Planck Institute for Plasma Physics (IPP) and Karlsruhe Institute of Technology (KIT)

Funding: Helmholtz Research Program (PoF IV)

Duration: 2021 to 2027

The primary objective of the Program is to provide the necessary expertise to enable the success of the energy transformation on system level. There are two broad, inter-linked strands to the Program: Topic 1 examines different transformation pathways for the energy system embedded in their full technical, economic, environmental, societal and political contexts, while Topic 2 provides methods and technologies for the detailed design and operation of future integrated energy systems. Both Topics cover a time horizon up to the year 2050 with an indicative outlook beyond. The objectives are:

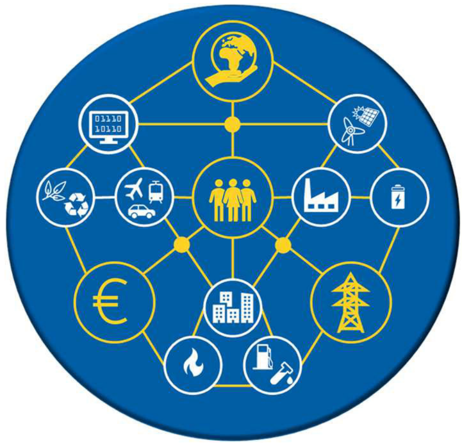
- to establish a set of three to five different but internally-consistent and plausible qualitative and quantitative scenarios for the energy transformation, so that they can provide system knowledge down to the technical requirements. (Topic 1)
- to use these transformation scenarios to develop decision support tools for policymakers and to investigate them in societal real-world laboratories and with other inter- and transdisciplinary tools. (Topic 1)
- to develop detailed methods and technologies on a systems level to plan and operate resilient, decentralized and integrated energy systems. Systems technologies will be demonstrated and validated in smart energy system laboratories under close to real conditions. (Topic 2)
- to identify the technical pre-conditions for the feasibility of the energy system in 2050 in both the national and international contexts, while demonstrating this feasibility using the real-

world implementations of the different technical solutions. (Topic 2)

The IIP is involved in subtopic 2.2 "Design, operation and digitalization of future energy grids" and subtopic 2.3 "Smart areas and research platforms". In 2.2 we participate in the efforts to develop new models for future energy grids. In this context modern optimization algorithms for solving large-scale power grid simulations shall be developed and applied and the role of flexible network elements like FACTS, PST and battery storage systems in a world of rising renewable energy generation shall be evaluated. Additionally, the needed market design options in order to ensure that the technical solutions regarding the new system challenges can be build, financed and operated based on economic sound decisions will be analyzed.

In 2.3 the IIP is using the Energy Smart Home Lab, a residence building which is part of the Energy Lab 2.0. It is equipped with modern technical equipment like a PV-system, a battery storage system and a combined heat and power generator, measuring systems for all the power and heat flows and an energy management system. In our research, we investigate topics such as strategies for rewarding flexible use of energy and energy efficiency improvements, the economic value of security of supply, the interoperability between a smart home energy management system and smart grids or the interactions between self-sufficiency and electromobility. In practice, we conduct long-term residential periods with up to two external persons in a close to real life environment. During these experiments, we provide the inhabitants with

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES



information, messages and incentives and observe their reactions via smart meter data, surveys and interviews. Based on the data the user behavior and acceptance is evaluated. Furthermore, we will provide the collected quantitative data to our partners.

En4U - Entwicklungspfade eines dezentralen Energiesystems im Zusammenspiel der Entscheidungen privater und kommerzieller Energieakteure unter Unsicherheit

Daniel Fett, Joris Dehler-Holland, Stephanie Stumpf

Partner: Deutsches Zentrum für Luft- und Raumfahrt (DLR), KIT - Institut für Operations Research (IOR)

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 04/2021 to 03/2024

The En4U project investigates uncertainties in the energy market and their impact on household energy decisions using three technologies with different market diffusion (PV battery storage systems, electric vehicles, and heat pumps).

The aim of the project is to analyse and understand the influences of uncertainties on the operation and investment decisions of households regarding these three technologies. In this course, the project partners also want to evaluate the effects on the operation and investment of portfolios of modern conventional and renewable power plants in combination with storage capacities. First, the uncertainties of the energy actors are explored and quantified. This includes not only economic, meteorological or political uncertainties, but also societal and qualitative aspects, which are often neglected in energy market research. Building on this, the future adoption of the aforementioned technologies will be analysed using diffusion models. By developing and applying suitable methods of stochastic optimization, uncertainties for operators of conventional as well as renewable power plant portfolios are modelled and their decisions optimized.

The focus of this research is on the diffusion of the technologies considered and the expected transformation pathways for the development of conventional and renewable power plant capacities.

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ENSURE 2 – New Electrical Grid Structures for the energy transition

Manuel Ruppert, Christian Perau, Christoph Fraunholz, Emil Kraft, Kim Miskiw, Daniel Fett

Partners: ABB Power Grids Germany AG, Bergische Universität Wuppertal, CAU, DUH, DVGW-EBI, EWI, FAU, FGH, FH Westküste, Germanwatch, KIT, Maschinenfabrik Reinhausen, OFFIS, Öko-Institut, RWTH Aachen, SH Netz, Siemens AG, SWKiel Netz GmbH, TenneT, TU Dortmund, TU Ilmenau

Funding: Federal Ministry of Education and Research

Duration: 09/2019 to 01/2023

The project ENSURE examines and demonstrates technical solutions for the energy networks of the future over a period of ten years and three project phases as part of the funding initiative Kopernikus-Projects for the energy transition. The research work in the second phase will contribute to making the energy system transformation economically successful. The project aims in particular to answer three questions:

- How will the supply tasks change beyond 2030, taking into account future and changing social, economic and ecological conditions?
- What technical challenges will result from the changing supply tasks for energy infrastructures?
- What network structures and technologies should be used to meet these challenges?

At the IIP, in ENSURE 2 questions in the subprojects "Socio-economic analysis" and "Integrated system structures" are investigated. This involves investigating the effects of different market designs on the investment and bidding decisions of various actors and the interactions with the operations in congestion management of the electrical transmission network. Furthermore, generation and load time series with regionally and technically high-resolution for different scenarios in the electricity system of the future were simulated at the IIP on a European scope. In addition to the above-mentioned question, these simulations also form the basis for investigations by other project partners at the transmission and distribution network level.

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FlexKälte – Flexibilisierung vorhandener Kälteanlagen und deren optimierter Einsatz in einer Realweltanwendung

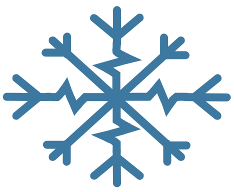
Thomas Dengiz, Manuel Ruppert

Partners: KIT-IAI (Institute for Automation and Applied Informatics), Forschungszentrum Informatik (FZI), Stadtwerke Karlsruhe GmbH, Seven2one Informationssysteme GmbH

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 01/2020 to 12/2022

The project "FlexKälte" (Joint project: *Investigation of existing cooling systems in order to use flexibilities in a real-world application*; sub-project: *Campus instrumentation for optimal cooling system control*) has the aim to develop a methodology to make use of the flexibility of decentralized, cold producing and cold using plants existing in a property. Besides the identification of the flexibility potential, the "FlexKälte" project focuses on the demonstration of the practical feasibility of an efficient and economic operation of cooling in a real-world application, while at the same time ensuring the identified boundary conditions, such as user comfort.



Within the scope of the project, distributed cooling applications at KIT Campus North will be instrumented, connected, and virtually combined for central control. First, different optimization strategies to be developed are tested with a large number of cooling systems in a simulation and then the practical implementation is realized in an exemplarily. The intended central management should enable the virtual network to serve as cooling capacity/storage in the overall system and thus - beyond operational optimization - to react on changing supply network conditions. The following picture shows an overview of the different tasks of the whole project.

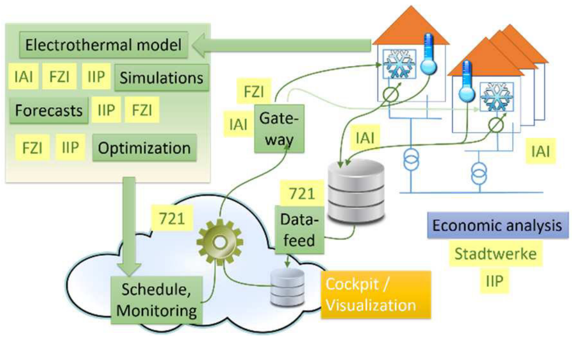


Figure was created by the Institute for Automation and Applied Informatics (IAI) of the Karlsruhe Institute of Technology

The main tasks of our chair include:

- Design of optimization algorithms for multiple cooling units
- Analysing the available flexibility at KIT Campus North
- Forecasting the cooling demand
- Economic analysis of the load flexibility potential

The following tasks were carried out in 2021:

- Survey about existing flexibility options at KIT Campus North
- Selection of the different buildings for the simulations and the analysis
- Setting up an electro-thermal building model
- Forecasting of the cooling loads and the (inflexible) electricity loads for the relevant buildings

Supported by:

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on the basis of a decision by the German Bundestag

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

Armin Ardone, Nico Lehmann, Daniel Sloot

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 aims to make a significant contribution both to the realization of flexibility provision 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 traffic 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 provided in the distribution grid. It is essential that asset operators (e.g., private individuals or industrial companies) 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 generation plants, sector-coupling flexibility options (e.g., heat pumps, electric vehicles) and other flexible consumers are to be integrated. In order to ensure a reliable flexibility provision, 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 traffic light concept is developed.

Within the framework of flexQgrid, the Chair of Energy Economics investigates the incentives necessary for providing flexibility in the low-voltage grid. The first step focused on the development of suitable instruments, e.g. surveys, experiments and expert interviews, which allow investigating the preferences of flexibility providers and thus the quantification of socio-economic constraints. Subsequently, incentives and motivations for flexibility provision among private households were empirically examined through a representative study that included a discrete choice experiment and a randomized control trial. Additionally, the potential for flexibility is being assessed in commercial and industrial sectors by means of expert interviews and focus group studies. The aim is to achieve reliable and valid results and to include these results in the market simulations. This way, market behavior can be observed and conclusions can be drawn on optimal market design options.

Supported by:

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

Alexandra Märtz, Florian Zimmermann, Christoph Fraunholz, Manuel Ruppert, Hasan Ümitcan Yilmaz

Partners: 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 transition, 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 experiment was 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 comparison focused on the areas of e-mobility and heat pumps in residential buildings, for which the consortium applied 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. With regard to the car purchase decisions, individual behavior (preferences) plays a central role. The decision is not completely objective and also reacts to non-cost-related aspects. However, the integration of individual user behavior makes modelling the development of car market evolution challenging. For this purpose, three different market diffusion models (ALADIN (Fraunhofer ISI), ASTRA (M-Five), and TE3 (KIT IIP)) were compared. The modelling approaches were contrasted with regard to the integration of user behavior and the individual model results were compared with respect to new passenger car registrations, passenger car stock and final energy consumption of the passenger car stock up to the year 2030. *Figure 1* shows a comparison of the model-specific results with regard to new passenger car registrations using a harmonized dataset for all three models. The drivetrains considered are gasoline, diesel, compressed natural gas (CNG), liquefied petroleum gas (LPG), hybrid electric vehicles without plug (HEV), battery electric vehicle (BEV), plug-in hybrid electric vehicles (PHEV), and hydrogen fuel cell electric vehicles (FCEV). For further results and a detailed description, please refer to the publication "How to integrate real-world user behavior into models for the market diffusion of alternative fuels in passenger cars - an in-depth comparison of three models for Germany".

As shown in *Figure 1*, all models show large market shares of EV in Germany. However, the ratio between PHEV and BEV differs significantly in the individual models, especially in 2030 depending on the methodological integration of the individual user behavior. To conclude, it was possible to observe, that all models have their specific use case, depending on the purpose of the models. Therefore, for a model comparison, a balance must be found between the best possible calibration of the individual models and a unified dataset for comparability of the results. 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.

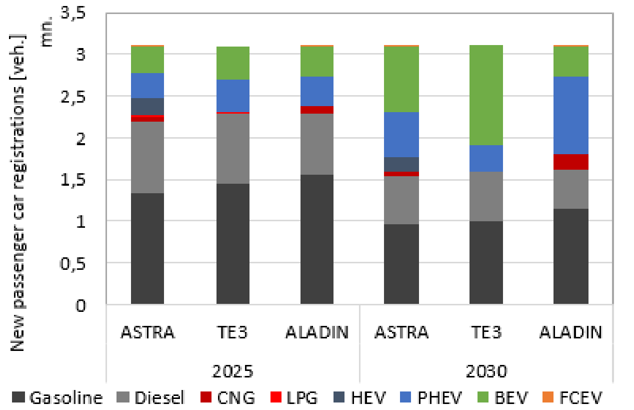

Figure 1: Comparison of installed conventional capacities (incl. reservoir and pumped storage plants) and non-weather-dependent renewable energy sources capacities between the models IDILES, PowerACE and ELTRAMOD for the German electricity market until 2030. [2]

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 were to be coupled with electricity market models.

adequacy. A selection of output parameters, such as investment and dispatch decisions in flexible power plants, storage dispatch, wholesale electricity prices, CO_2 emissions and resource adequacy in hours with critical supply situations, such as cold dunkelflauten in Germany until 2030 were analyzed. Differences in the results were traced back to conceptual differences as the models can be distinguished not only with regard to their mathematical approaches, but also to their level of detail.

Representatively, *Figure 2* shows the development of the fuel-specific installed capacities, which are identical between the models up to 2025. Due to the massive decommissioning, the generation capacities are not sufficient to cover the electricity demand in every hour of the target year 2030, even if the renewable energy sources expansion is continued and the yearly sum of the residual load (inclusive net exports) decreases to its lowest level in 2030 compared to the other years. Consequently, a demand for dispatchable capacity remains, and thus all models cover the deficits in dispatchable capacity

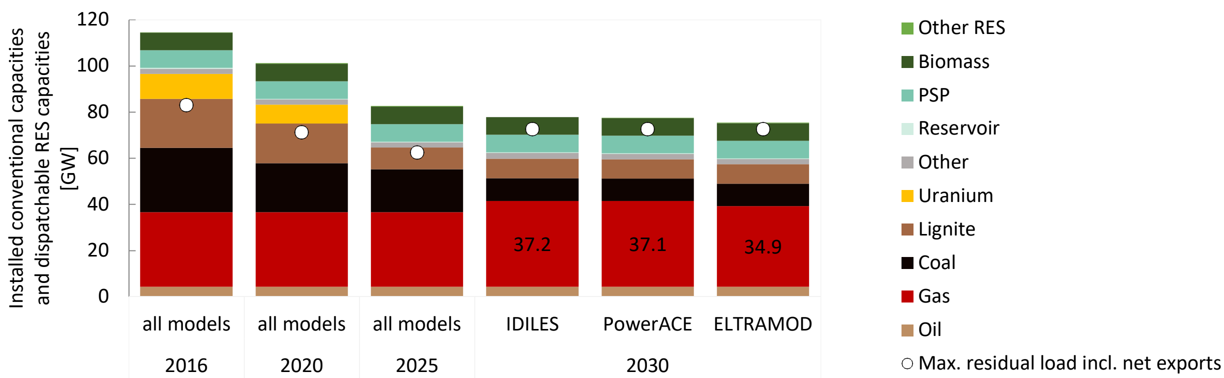

Figure 1: Comparison of installed conventional capacities (incl. reservoir and pumped storage plants) and non-weather-dependent renewable energy sources capacities between the models IDILES, PowerACE and ELTRAMOD for the German electricity market until 2030. Figure taken from "Systematic comparison of high-resolution electricity system modeling approaches focusing on investment, dispatch and generation adequacy", S. Msiconel, R.Leisen, J.Mikurda, F. Zimmermann, C. Fraunholz, W. Fichtner, D. Möst, C. Weber, 2022, Renewable and Sustainable Energy Reviews, 153, https://doi.org/10.1016/j.rser.2021.111785

The latter was used specifically for an analysis of future resource adequacy, i.e., the ability of generation, backup capacities, demand side management, or reserve power plants to deal with periods of high residual load. By comparing the results of three different electricity market models (IDILES, PowerACE and ELTRAMOD), it was possible to determine in particular the impact on resource by endogenous investments in additional combined cycle gas turbines (CCGT). However, differences in the added generation capacity occur between the models. These differences are caused by the different methodological approaches in the models, their system perspectives and optimization horizons. For further results and a detailed description, please refer to the publication "Systematic comparison of

[2] *Figure is based on Fig 7. of "How to integrate real-world user behavior into models of the market diffusion of alternative fuels in passenger cars – An in-depth comparison of three models for Germany", T. Gnann, D. Speth, K. Seddig, M. Stich, W. Schade, J.J. Gómez Vilchez, 2022, Renewable Energy Revies, 158, https://doi.org/10.1016/j.rser.2022.112103.*

high-resolution electricity system modeling approaches focusing on investment, dispatch and generation adequacy”.

In order to consider demand flexibility in the electricity market models, possible load curves for the new electricity applications were derived from the demand models and used as input for the electricity market models. By iterating the models to be coupled, it was possible to trace back influencing factors on the electricity price to account for interdependencies of the market launch with regard to e-mobility and heat pumps.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Modex-NET

Thomas Dengiz, Rafael Finck, Armin Ardone, Viktor Slednev

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

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

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.

The following tasks were carried out in 2021:

- Finished the comparison of the grid simulation results
- Finished the analysis of the different regionalization approaches for the demand and generation data
- Organized a final workshop for a broader audience
- Published the results in a paper

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

OptTech - Analyse des optimalen und technologiespezifischen Speicher-Mixes für Deutschland und Europa bei einer vollständigen Umstellung der Stromversorgung auf erneuerbare Energien bis 2050

Hasan Ümitcan Yilmaz, Daniel Fett, Viktor Slednev, Joris Dehler-Holland

Funding: Stiftung Energieforschung Baden-Württemberg

Duration: 2019 to 2021

The OptTech project investigates how a secure power supply can be achieved through 100 % renewable energies by 2050 if fossil fuels are phased-out. In particular, the project evaluates which storage technologies are required to compensate for fluctuations in renewable energies. The European energy system model PERSEUS-EU is extended to model long and short-term storage technologies and combined with a prosumer simulation to analyze the effects of the diffusion of decentralized PV battery storage systems. Our analyses find that a CO_2 price of 160 €/t (by 2050) alone is not sufficient to decarbonize the power sector unless PtG technologies are available. The combination of a high CO_2 price with PtG technologies, on the other hand, could lead to the decarbonization of the European power system by 2050. Battery storage can contribute in this context by closing short-term generation gaps at lower costs. Although PV home storage systems have a substantial impact on the electricity consumption of individual households, their impact on the overall system is shallow under the analyzed framework conditions.

Profilregion Mobilitätssysteme Karlsruhe

Nora Baumgartner, Manuel Ruppert, Uwe Langenmayr

Partners: 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 to 12/2017; Phase 2: 03/2019 to 06/2021

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.

As part of the Profilregion, the indicator system developed in the SuMo-Rhine project was applied to Karlsruhe Oststadt. Since the indicators are designed for the evaluation of municipalities, they were scaled to the district level and adapted. In the course of the application, the actual state of Karlsruhe Oststadt was evaluated and compared with possible scenarios. Mobility scenarios have been developed for this purpose. The assumptions were validated in expert discussions.

On the 16th of April 2021 the final event of Profilregion took place as an online format due to the COVID-19 pandemic. Besides oral presentations of results by scientists from the different institutes, Profilregion organised an exhibition with each sub-project presenting selected exhibits and the possibility to discuss the results with interested stakeholders.

Baden-Württemberg
MINISTERIUM FÜR WIRTSCHAFT, ARBEIT UND WOHNUNGSBAU

PROFILREGION
MOBILITÄTSSYSTEME
KARLSRUHE

reFuels – rethinking fuels

Simon Glöser-Chahoud, Manuel Ruppert, Paul Heinzmann, Uwe Langenmayr, Florian Zimmermann

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

Funding: Ministry of Transport Baden-Württemberg

Duration: 01/2019 to 12/2022

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 - Concepts for an Integrated, Efficient and Sustainable Energy Supply and Storage in the Upper Rhine Region

Joris Dehler-Holland, Phuong Minh Khuong, Hasan Ümitcan Yilmaz

Partners: University of Freiburg, TRION climate e.V., University of Strasbourg, University of Upper Alsace, badenova AG & Co. KG

Funding: European Regional Development Fund (ERDF) by the INTERREG V programme.

Duration: 01/2019 to 06/2022

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. Due to the multidisciplinary approach of the project, different aspects of social acceptance, regulatory framework, economic feasibility and last but not least data security can be illuminated. The Chair of Energy Economics contributes its many years of experience in energy system analysis. In order to analyze scenarios for the development of the energy system, the Upper Rhine region was integrated as a separate zone into the energy system model PERSEUS developed at DFIU/IIP. The basis for this is an extensive data research of energy data in the Upper Rhine region, such as the generation of electricity from renewable energy sources or existing transmission lines.

The aim of the project work is the analysis of scenarios with high penetration of renewable energies in the Upper Rhine region as well as in the neighboring countries. Through the integration into the European system model PERSEUS, the exchange with neighboring countries can be taken into account as a non-negligible factor in a highly interconnected energy system.

The preliminary results show that the Upper Rhine region is particularly suitable for the installation of systems for solar energy generation, while wind energy is less of an option. This development is mainly due to the fact that windy areas such as coastal regions offer a higher potential for wind energy generation. However, the results could not account for significant factors such as the expansion of national transmission lines. The additional expansion of wind energy in the region would allow energy consumption to be met from the region to a greater extent. Supply shortages due to significant delays in grid expansion projects could thus be mitigated.

RES-TMO

Die Bedeutung der Sektorintegration im Rahmen der Energiewende in Deutschland – Modellierung mit einem nationalen Open Source ReferenzEnergieSystem (SEDOS)

Armin Ardone, Joris Dehler-Holland, Leandra Scharnhorst, Viktor Slednev

Partner: Forschungszentrum Jülich (FZJ-IEK-3), Institut für Energiewirtschaft und Rationelle Energieanwendung (IER) der Universität Stuttgart, Reiner Lemoine Institut Berlin (RLI), Lehrstuhl für Erneuerbare und Nachhaltige Energiesysteme der Technischen Universität München (TUM), Energiesystemanalyse des Instituts für Vernetzte Energiesysteme des Deutschen Zentrum für Luft- und Raumfahrt (DLR-VE, Stuttgart)

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

Duration: Jan 2022 to Dec 2024

The terms sector integration or sector coupling have become indispensable in discussions of energy and climate policy. Sector integration is expected to make a decisive contribution to achieving ambitious climate protection targets. This poses new challenges for system-analytical energy planning, which cannot focus on individual subsystems but must adopt an energy system perspective in order to meet the new requirements and possible solutions. The goal of the research project "SEDOS - The Importance of Sector Integration within the Energy Transition in Germany - Modeling with a National Open Source Reference Energy System", the basic ideas of which were developed within the framework of the BMWi's System Analysis Research Network, is to improve the representation of sector integration in energy system models and to establish greater comparability of the models by means of open data. In addition to the orientation towards Open Science, the project thus has the goals of jointly developing a reference data set including documentation for the consideration of sector integration in energy system models for Germany and a coordinated model or system structure for three OS models (oemof, TIMES, FINE) with a focus on the energy system of Germany, which equally takes into account the criteria of transparency and traceability, detailing and simplification as well as balance between the subsectors and solvability of the models. This should substantially improve the robustness, transparency and quality of quantitative analyses. By developing a reference data set for energy system modeling for Germany, a high acceptance in the model scene can be assumed. The development of an OS model structure (reference energy system, RES) is also expected to provide easier access to energy system modeling for modelers and users.

In order to achieve the formulated objective, the work will be structured along the four major sub-areas of energy system analysis, 1) data management (Open Data), 2) model or system structure (in the form of the so-called reference energy system (RES)), 3) mathematics and associated solution algorithms in the model frameworks oemof, TIMES and FINE, and 4) user interface. These four sub-areas will be implemented as separate work packages (WP) (WP 1 Data Management; WP 2 Model Structure; WP 9 Interfacing to oemof, TIMES & FINE; WP 3 User Interface). In order to be able to adequately capture the specific aspects in the model or system structure and data acquisition in individual parts of the German energy system, separate work packages are defined for these, starting with electricity supply (WP 4), other conversion sectors with a focus on power-to-X (PtX) (WP 5), the heat market (district and local heat supply, residential and non-residential buildings) (WP 6), industry (WP 7), and finally transport (WP 8). The connection and harmonization between these separate work packages is done in joint coordination in WP 2, which provides the "general structure" for the overall modeling. WP 10 on overall coordination is used to coordinate the individual work packages. Here, the IER of the University of Stuttgart exercises the role of project coordinator and also has the lead in WP 6 on the heat market and in WP 7 on industry. For WP 3 on user interfaces and WP 5 on PtX, the IER acts as the project internal reviewer. The IER is also involved in other work packages, in the development of the model structure in WP 2, in the data analyses for transport in WP 8 and in the connection to the TIMES energy system model in WP 9.The focus of the work at KIT is on the parameterization of power-side technologies and structures on the supply side, the model-adequate representation of renewables and demand (not specified in other subprojects).

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SuMo-Rhine - Sustainable mobility in the Upper Rhine region

Manuel Ruppert, Nora Baumgartner

Partners: Institute of Economics (KIT-ECON); Chair of Remote Sensing and Landscape Information Systems (University of Freiburg); Institute of Environmental Sciences (University of Koblenz-Landau), Image, City, Environment Laboratory (University of Strasbourg), Centre National de la Recherche Scientifique; University of Haute-Alsace; 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" 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. The web application can be reached via this link.

During the project duration, the project partners met twice for a two-day "retreat" in Hinterzarten in the Black Forest. The aim was to strengthen cooperation on a professional and a personal level. During the retreats, previously achieved results were reflected and synergies between the individual work packages were identified. In addition, the remaining project duration was planned in detail.

Furthermore, the project partners were able to organise seven participatory workshops in total. The workshops followed the aim to present and discuss interim results with mobility and urban planners and with decision-makers from municipalities. Moreover, the results were evaluated regarding their practical relevance and feasibility. Until March 2019 the workshops took place in person. With the beginning of the COVID-19 pandemic, these workshops were realised online The DFIU took over the organisation in each case. Despite the difficult circumstances, the response was great and the discussions with the participants were valuable and effective.

The project is currently in the cost-neutral prolongation and will be finalised by end of 2021. To celebrate the successful project and to present the results to relevant stakeholders, the DFIU organised a final event that took place on the 17th of November 2021 in Freiburg. Due to COVID-19, the event took place in a hybrid format. The project consortium thus welcomed 34 people on-site and about 60 people attending online. Professor Fichtner welcomed all participants in an opening speech and Nora Baumgartner, project coordinator, moderated through the event.

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

SynergieQuartier Walldorf - Intelligent networking of actors and digitalized technical systems for a cost-efficient and resilient energy system transformation

Alexandra Märtz, Manuel Ruppert

Partners: beegy, FZI Forschungszentrum für Informatik, MVV Energie AG, Stadtwerke Walldorf

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 07/2020 to 07/2023

The project consortium consists of two research institutes and other partners from industry and is funded by the Federal Ministry for Economic Affairs and Energy within the framework of the 7th Energy Research Program of the Federal Government.

The energy transition in Germany has reached a point at which the simple expansion of renewable energies is not sufficient. The system integration of photovoltaic, charging stations for electric vehicles, battery storage and other decentralized loads as well as generators is becoming increasingly important. The digitization of power grids can play the central role in this. To achieve this, it is crucial to focus on the available technologies, the players involved in the distribution grid and the further development of regulation simultaneously.

Based on the smart-meter-gateway architecture and the legal framework for the further development of the regulatory framework for communication between energy industry actors and technical systems, the project will investigate the possibilities of resilient system integration of solar systems, charging stations for electric vehicles, battery storage systems and other decentralized loads. For this purpose, a field test will be carried out with selected pilot households, which is planned for 2022.

By equipping the pilot households with gateways, the power and energy data of individual devices will be recorded, for example, in order to estimate the effects of increasing penetrations of electric vehicles and solar systems on the electricity grid. The KIT-IIP is particularly pursuing the goal of supporting a system-serving and sustainable integration of electric vehicles into the energy system. In order to estimate the impact of electric vehicle charging on the electricity grid, the individual mobility and charging behavior of the pilot households is being studied in detail. Here, information from logbooks filled out by pilot households as well as the measurement data collected are included in the analyses. The simultaneity of the charging processes and the resulting network load as well as the flexibility potential of charging processes are the focus of the analyses.

In particular, the "systemic character" of the project should be emphasised, as only the interconnected consideration of many individual elements makes the turnaround towards a decentralised energy system based entirely on renewable energies possible.

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Technical assistance to assess the potential of renewable liquid and gaseous transport fuels of non-biological origin (RFNBOs) as well as recycled carbon fuels (RCFs), to establish a methodology to determine the share of renewable energy from RFNBOs as well as to develop a framework on additionality in the transport sector[3]

Simon Glöser-Chahoud, Manuel Ruppert, Paul Heinzmann, Uwe Langenmayr

Partners: Guidehouse, Fraunhofer ISI, ESA², TU Wien

Funding: European Union

Duration: July 2020 to December 2021

The general objective of the contract is to obtain detailed information on the potential of renewable fuels of non-biological origins (RFNBOs) and recycled carbon fuels (RCFs) in the EU from 2021 onwards; to provide producers of RFNBOs a framework enabling them to deliver evidence that the renewable electricity used in the production of their fuel is fully renewable; and to develop a general framework to measure the additionally of electricity in the EU transport sector.

The specific objectives of this contract are to assist the Commission in:

- Assess the potential of renewable liquid and gaseous transport fuels of non-biological origin as well as recycled carbon fuels, as defined in REDII, over the period 2020 to 2050 in the transport sector in the EU, including deployment potential, resource competition and decarbonisation potential (task 1).
- Develop detailed rules by which producers of renewable liquid and gaseous transport fuels of non-biological origin can provide evidence that they are using fully renewable electricity in the production of their fuel in order to establish the methodology under Article 27, paragraph 3, subparagraph 7 of REDII (task 2).

Develop a framework on additionality in the transport sector and develop different options with a view to determining the baseline of Member States and measuring additionally, in accordance with Article 27, paragraph 3, subparagraph 3 of REDII.

TrafoKommunE – Transformationsprozess für die kommunale Energiewende - sektorengekoppelte Infrastrukturen und Strategien zur Einbindung von lokalen Akteuren

Max Kleinebrahm, Jann Michael Weinand, Armin Ardone

Partners: DVGW-Forschungsstelle am Engler-Bunte-Institut des KIT, Karlsruhe Institute of Technology (KIT), Gas- und Wärme-Institut Essen e.V., Institut für Ressourceneffizienz und Energiestrategien GmbH, Fraunhofer Institut für System- und Innovationsforschung, MTU Friedrichshafen GmbH, Stadtwerke Karlsruhe GmbH

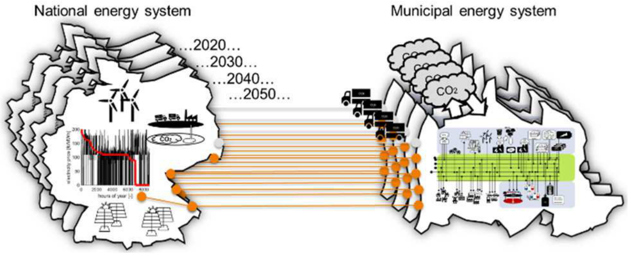
Funding: Federal Ministry for Economic Affairs and Energy (BMWi)

Duration: 2020 to 2023

The cross-sectoral implementation of the energy transition is a major challenge. Municipal suppliers with the involvement of customers as well as local politics and market participants play a central role in this process. The aim of the TrafoKommunE project is, on the one hand, to provide recommendations for action for the cost-effective and timely realisable design of the energy system at the municipal level. On the other hand, possibilities to involve the actors (here especially municipal utilities) in shaping the energy transition will be identified. The cross-sectoral approach of this project is intended to

[3] This project is hosted by the Chair of Business Administration, Production and Operations Management held by Prof. Schultmann.

show a way in which municipal energy suppliers can guarantee their supply responsibilities for electricity, heat and gas, as well as mobility and digitalisation, at reasonable costs. The simultaneous social science investigations take into account the acceptance of citizens and market partners. With this approach, synergy opportunities and limits of the existing infrastructure and the infrastructure measures necessary for a secure supply until 2050 will be identified and monetarily evaluated. A particular focus of the project is the analysis of the city of Karlsruhe. The tasks of the IIP include on the one hand the analysis of the current building stock, together with its age, appliance equipment, heating types and retrofitting. On this basis, current and future electricity and heating demands for Karlsruhe are estimated. Furthermore, the scenarios developed in the project are quantitatively evaluated with the help of the RE³ASON (Renewable Energies and Energy Efficiency Analysis and System OptimizatioN) model developed at the IIP for the analysis and optimisation of municipal energy systems.



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VERMEER – Security of supply in Germany and central Europe during extreme weather situations – The contribution of international power exchange at high shares of renewable energy

Armin Ardone, Rafael Finck, Viktor Slednev, Leandra Scharnhorst, Tim Signer

Partners: Deutsches Zentrum für Luft- und Raumfahrt (DLR), Karlsruher Institut für Technologie (KIT)

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 2019 to 2022

In system with large shares of renewable energies, weather events crucially impact power generation across the system. The project VERMEER aims at investigating the security of supply in Germany and central Europe during extreme weather situations. In a first step, extraordinary weather events are identified on the basis of historic weather reanalysis data. The main focus regards generation from solar PV and wind power generation. In a highly interconnected system, the possibility for cross-border exchange of electricity plays a key role to determine the security of supply. These cross-border capacities depend upon the thermal capacity of the power grid overhead lines, which are impacted by weather conditions such as wind speed and direction, which have a cooling effect or solar radiation, which has a heating effect. These interdependencies between weather and maximum trading capacities are explicitly considered in the project. Expected results of the project are:

- Extensive evaluation of the characteristics of extreme weather events for long-term time scales, including spatial and cross energy carrier correlations.
- Calculation of highly spatially and technologically resolved infeed profiles.
- Determination of potential flexibility induced by cross border trade for the German electricity system under consideration of dynamic trading capacities for the coupled markets.

- Evaluation of the European internal market during extreme weather events including resulting deficits in generation (heat waves, calm periods, cold spells) and estimation of the remaining gap between supply and demand in Germany.

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VerSEAS – Security of supply in a transformed power system with extreme shares of renewable energies and strong sector coupling

Florian Zimmermann, Malin Lange, Christoph Fraunholz

Partners: TU Dresden, Fraunhofer ISI, ESA² GmbH

Funding: Federal Ministry for Economic Affairs and Energy

Duration: 07/2020 to 06/2023

The main objective of the research project "VerSEAS" is to investigate the security of supply in Germany and its neighboring countries in compliance with the Paris climate targets. In order to reduce carbon emissions to a sufficient extent, high shares of renewable energies and, at the same time, a strong sector coupling are required. The focus of the analyses is on the one hand on the interactions and the potential of different flexibility options and on the other hand on possibly needed adjustments of the market design and the regulatory framework to raise this potential. Previous analyses of security of supply in Germany are extended by three main aspects:

- drivers and effects of the diffusion and operation of residential PV battery storage,
- influence of individual decision behavior of investors on the regional diffusion of sector coupling technologies,
- contribution of targeted regional allocation of investments in generation capacity and use of regional flexibilities to security of supply, under consideration of the transmission grid.

The analyses are based on the joint application of the electricity market simulation model PowerACE, the optimal power flow model ELMOD, and the two demand models FORECAST and eLOAD. For this research project, the model portfolio will be extended by a newly developed simulation model for decentralized electricity markets. This model will be integrated into the existing model coupling framework in order to investigate the effects of the nationwide rollout of decentralized markets on the centralized electricity market.

The work at IIP aims to evaluate the effects of individual investment decisions of different actors on the security of supply in an interconnected electricity market with different market designs. For this purpose, the existing agent-based electricity market model PowerACE will be extended with respect to various aspects.

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Awards

- Dr. Kai Mainzer has been rewarded the second price of the NEULAND innovation competition for the development of the model “RE³ASON” (“Renewable Energies and Energy Efficiency Analysis and System OptimizatioN”), which is now used for the planning of sustainable energy systems by greenventory GmbH.

Completed Dissertations and Habilitations

Dissertation: "Optimization approaches for exploiting the load flexibility of electric heating devices in smart grids"

Thomas Dengiz

Energy systems all over the world are undergoing a fundamental transition to tackle climate change and other environmental challenges. The share of electricity generated by renewable energy sources has been steadily increasing. In order to cope with the intermittent nature of renewable energy sources, like photovoltaic systems and wind turbines, the electrical demand has to be adjusted to their power generation. To this end, flexible electrical loads are necessary. Moreover, optimization approaches and advanced information and communication technology can help to transform the traditional electricity grid into a smart grid.

To shift the electricity consumption in time, electric heating devices, such as heat pumps or electric water heaters, provide significant flexibility. In order to exploit this flexibility, optimization approaches for controlling flexible devices are essential. Most studies in the literature use centralized optimization or uncoordinated decentralized optimization. Centralized optimization has crucial drawbacks regarding computational complexity, privacy, and robustness, but uncoordinated decentralized optimization leads to suboptimal results. In this thesis, coordinated decentralized and hybrid optimization approaches with low computational requirements are developed for exploiting the flexibility of electric heating devices. An essential feature of all developed methods is that they preserve the privacy of the residents. This cumulative thesis comprises four papers that introduce different types of optimization approaches.

In Paper A, rule-based heuristic control algorithms for modulating electric heating devices are developed that minimize the heating costs of a residential area. Moreover, control algorithms for minimizing surplus energy that otherwise could be curtailed are introduced. They increase the self-consumption rate of locally generated electricity from photovoltaics. The heuristic control algorithms use a privacy-preserving control and communication architecture that combines centralized and decentralized control approaches. Compared to a conventional control strategy, the results of simulations show cost reductions of between 4.1% and 13.3% and reductions of between 38.3% and 52.6% regarding the surplus energy. Paper B introduces two novel coordinating decentralized optimization approaches for scheduling-based optimization. A comparison with different decentralized optimization approaches from the literature shows that the developed methods, on average, lead to 10% less surplus energy. Further, an optimization procedure is defined that generates a diverse solution pool for the problem of maximizing the self-consumption rate of locally generated renewable energy. This solution pool is needed for the coordination mechanisms of several decentralized optimization approaches. Combining the decentralized optimization approaches with the defined procedure to generate diverse solution pools, on average, leads to 100 kWh (16.5%) less surplus energy per day for a simulated residential area with 90 buildings.

In Paper C, another decentralized optimization approach that aims to minimize surplus energy and reduce the peak load in a local grid is developed. Moreover, two methods that distribute a central wind power profile to the different buildings of a residential area are introduced. Compared to the approaches from the literature, the novel decentralized optimization approach leads to improvements of between 0.8% and 13.3% regarding the surplus energy and the peak load. Paper D introduces uncertainty handling control algorithms for modulating electric heating devices. The algorithms can help centralized and decentralized scheduling-based optimization approaches to react to erroneous predictions of demand and generation. The analysis shows that the developed methods avoid violations of the residents' comfort limits and increase the self-consumption rate of electricity generated by photovoltaic systems. All introduced optimization approaches yield a good trade-off between runtime and the quality of the results. Further, they respect the privacy of residents, lead to better utilization of renewable energy, and stabilize the grid. Hence, the developed optimization approaches can help future energy systems to cope with the high share of intermittent renewable energy sources.

Dissertation: "Market Design for the Transition to Renewable Electricity Systems"

Christoph Fraunholz

The research carried out in this thesis aims to shed light on the role of the European electricity market design in the transition to a target electricity system that combines sustainability, affordability, and reliability. While the ongoing expansion of fluctuating renewable electricity sources challenges the established structures and market mechanisms, governments across Europe have decided to phase-out certain conventional technologies like coal or nuclear power. Since traditional electricity systems rely on flexibility provided by controllable generation capacity, other flexibility options are needed to compensate for the decommissioned conventional power plants and support the system integration of renewables.

Against this background, the dissertation extends an established large-scale agent-based electricity market model in order to account for the developments towards an integrated European electricity market and the characteristics of storage technologies. In particular, the representation of cross-border effects is enhanced by integrating approaches from the fields of operations research, non-cooperative game theory, and artificial intelligence in the simulation framework. The extended model is then applied in three case studies to analyze the diffusion of different flexibility options under varying regulatory settings. These case studies cover some central aspects of the European electricity market, most importantly capacity remuneration mechanisms, the interaction of day-ahead market and congestion management, and the role of regulation for residential self-consumption.

Results of the case studies confirm that by designing the regulatory framework, policymakers and regulators can substantially affect quantity, composition, location, and operation of technologies – both, on the supply side and the demand side. At the same time, changes and amendments to market design are frequent and will continue to be so in the years ahead. Moreover, given the increasing level of market integration in Europe, the role of cross-border effects of national market designs will gain further in importance. In this context, agent-based simulation models are a valuable tool to better understand potential long-term effects of market designs in the interconnected European electricity system and can therefore support the European energy transition.

Dissertation: "Urbanisation and renewable energies in ASEAN: multi-disciplinary approaches to analysing past and future trends"

Phuong Minh Khuong

By using multi-dimensional and comprehensive analyses, this thesis aims at providing harmonized targets, which not only follow the global trend of sustainable development but also serve the rapid economic and demographic growths in the developing countries. This thesis consists of four papers dealing with different challenges faced by Asian Emerging and Developing Countries (EMDCs) in the face of fast-approaching climate change and energy transition. The four papers can be divided into two main streams based on the research method applied. The first two essays employ decomposition and correlation methods to investigate long-term energy service demand and renewable energy developments. The last two essays turn to techno-socio-economic models with much attention to solar PV, a promising renewable energy type in most of Asian EMDCs.

The relationship between urbanisation and renewable energy are explored throughout all articles of the thesis. Paper 1 + 2 conclude that urbanisation causes energy consumption increases drastically in Southeast Asian countries, but at the same time creates momentum for renewable energy development, especially in urban areas. Suggestions for combining urban and energy plans in policy design are provided to use urbanisation as a motivation for renewable energy development. Paper 3 estimates a techno-economic potential for rooftop PV and found evidence of a high-concentration of rooftop solar PV potentials in urban areas in Vietnam. Paper 4 conducts a socio-economic assessment to investigate Social Acceptance (SA) and Willingness To Pay (WTP) toward residential PV products in Vietnam. The results show that PV can be considered as a lifestyle product with much greater attention and intention to purchase from the public in urban areas.

To assist policymakers in energy planning, Papers 1 + 2 provide decision support and innovative multilevel comparison tool, called the Impact Matrix. It is used for visualising factors comparison by placing considered factors in four quadrants of the matrix corresponding to four relative priority levels of policy focus requirements. The complex relationships between impact factors and energy demand and renewable energy changes can be explained by following the instruction in Paper 2.

Paper 3 develops a cost-effective, accessible, transferable and scalable method for cost-potential assessment of decentralised solar rooftop PV in developing countries where limited resource availability. Adjusting the module efficiency corresponding to regional and household conditions has been implemented to improve the output accuracy. The simulation for rooftop PV market is made regarding different input assumptions and estimates of the effect of various policy designs, including changing the Feed-In Tariffs (FiTs), grid tariff, and technology development.

In order to explore future rooftop PV adoption, paper 4 conducts empirical research focusing on discovering the differences between Social Acceptance (SA) and Willingness To Pay (WTP). This paper contributes to the literature of customer behaviour toward renewable energy by providing extended moderated mediation models to differentiate the distinctive roles of each influencing variable of SA and WTP. Policy advice is given to translate environmental interest and PV knowledge to higher SA and adopting action.

Dissertation: "Controlled charging of electric vehicles in distribution grids with high generation from renewables"

Sabrina Ried

Due to the targeted climate neutrality, a continuation of the expansion of renewable energies (RE) and the market ramp-up of electric passenger cars (EVs) is to be expected. This will be accompanied by decentralization and volatility of electricity generation, spatial mismatch of electricity supply and demand, and higher peak loads. Emerging grid bottlenecks will be addressed, among other things, through the curtailment of RE plants. As a result, the full potential of RE plants cannot be utilized, which is why less RE electricity is produced than is possible (so-called surplus electricity). Controlled charging of e-vehicles represents an opportunity to use the flexibility of vehicle batteries, for example, to avoid this RE curtailment.

The goal of this work is to quantify this flexibility potential as well as the associated costs and greenhouse gas emissions of charging energy. For this purpose, a methodology is developed for the first time to investigate the use of curtailed RE generation in distribution grids for controlled (bidirectional) charging (vehicle-to-grid or V2G) of e-vehicles, modeling load shifting potentials in a differentiated manner.

In order to model the interactions between the congestion management of a distribution grid operator and the charging management of an aggregator, three sub-models are coupled. A load flow optimizing congestion management model for the 110 kV grid in Schleswig-Holstein is extended by the electric demand of e-cars and a peak shaving algorithm. The developed mixed-integer optimization model Curtailment-to-Vehicle enables the charging of the e-cars utilizing surplus electricity and electricity purchase via local electricity markets. A cost-minimizing as well as a surplus power-minimizing charging strategy is investigated. Based on representative empirical data, a bottom-up model simulates and aggregates the flexibility potentials on fleet level. Uncertainties regarding future e-car flexibility potentials are analyzed with scenarios for the year 2030.

Model-based analyses for the Schleswig-Holstein case study show that a maximum of 19 % of the RE curtailment is avoided. Nevertheless, at grid nodes with RE regulation and V2G, on average, up to 65 % of the charging energy is covered with surplus electricity, at individual grid nodes even 95 %. Although in the V2G scenarios the costs for electricity purchase are overcompensated by revenues of up to 75 €/year, the total annual charging costs only decrease by an average of 20 - 27 % due to further electricity price components even at the grid nodes with curtailment. V2G can double the average annual battery full cycles. If surplus electricity is available, the greenhouse gas emissions from 69 to around 40 g CO_2/km, at individual grid nodes to as little as 7 g CO_2/km.

Dissertation: "Analyzing decarbonization strategies for Europe with advanced energy system modeling"

Hasan Ümitcan Yilmaz

In order to limit global global warming to an increase of no more than to two degrees Celsius compared to pre-industrial levels, the world's energy systems must be decarbonized. To achieve this decarbonization goal, the already high share of wind power and photovoltaics in European electricity production must be further increased. However, electricity production based on these technologies is weather-dependent and consequently shows high spatial and temporal variability. This development represents a significant challenge to the European energy system. In parallel, several European countries are considering different decarbonization strategies, such as phasing out of coal-fired electricity production. The alternative decarbonization strategies and the necessary flexibility options for integrating renewable energy sources (RES) into the energy system must be analyzed.

Energy system models (ESMs) are useful tools to analyze these challenges. ESMs are primarily used to analyze political, technical, and economic research questions related to the development of an energy system. The main instrument used in the analyses of this dissertation is the European energy system model PERSEUS-EU. However, including RES into ESMs increases the complexity and execution times of the models significantly, as the fluctuant, weather-dependent electricity production from RES requires a modeling approach with a high level of granularity. For this reason, both temporal model decomposition methods and data reduction methods are developed and applied to PERSEUS-EU. Data reduction, however, is the primary method employed in this dissertation. A data reduction pipeline based on a specific type of neural network, known as self-organizing maps, is applied for the input time series of ESMs. This approach enables reduction of the input time series without them losing their key, energy-related characteristics.

The ESM incorporating the reduced time-series is applied to analyze different pathways to reduce carbon emissions caused mainly by coal- and gas-fired electricity production. However, coal-fired power plants have significantly higher emissions than gas-fired power plants, making them the primary focus. The PERSEUS-EU based analyses of coal phase-out strategies find that a country-specific strategy, such as the German coal phase-out, can indeed have a significant impact on domestic emissions, it nevertheless makes a limited contribution to the overall carbon emissions in Europe. A strict and coordinated decarbonization strategy at the European level is more effective in reducing emissions.

In the long term, a gradual reduction in gas-fired electricity production is necessary, which would lead to a further reduction of emissions. Nevertheless, the dispatchable electricity production from gas provides flexibility to the electricity system, compensating for the inflexible electricity production from RES. Demand side-management (DSM) and storage technologies can play an essential role in replacing the flexibility provision of gas-fired electricity production. Storage technologies enable storing of electricity during periods of very high electricity production from RES, and then using this electricity during periods of insufficient electricity production from RES. Similarly, DSM can help to shift demand to those hours when there is a higher level of electricity production from RES.

Sector coupling, such as coupling of electricity sector with heat, transport, or gas sectors, contributes to the decarbonization of these sectors, as well as provides flexibility to the electricity sector. While the findings of some studies agree that sector coupling, DSM and storage technologies have certain advantages in the reduction of emissions, there is no consensus regarding the merits or quantification of the impacts of these technologies, nor on the best practices. The benefits of these technologies are not sufficiently, analyzed on a large scale. Studies at the European level are hardly available.

This dissertation analyzes, short- and long-term storage options and, as a prime example of DSM, flexible operation of power-to-heat technologies and controlled charging strategies for passenger electric vehicles (PEVs), including vehicle-to-grid. The findings show that the use of short-term storage and demand response contributes significantly to the reduction of emissions in Europe. Notwithstanding, insufficient electricity production from RES in certain periods cannot be overcome without the support of gas-fired electricity production, based on the chosen framework assumptions.

Long-term storage options, such as power-to-gas, are necessary in order to avoid the emissions of gas-fired generation and reach net-zero emissions. The model-based analyses show that a high carbon price path in combination with power-to-gas technologies can lead to an economically viable complete decarbonization of the European electricity system by 2050.

Staff as of December 2021

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

Dipl.-Math. Joris Dehler-Holland – Energy Policy

Dr. Christoph Fraunholz – Energy Markets and Energy System Analysis

M.Sc. Manuel Ruppert – Transport and Energy

Doctoral Researchers and their Topics

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

Anthony Britto: Theoretical underpinnings of technology diffusion and the energy-efficiency gap.

Joris Dehler-Holland: The socio-technical dynamics of renewable energy policies and technologies in Germany.

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: Market Design for the Transition to Renewable Electricity Systems.

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

Emil Kraft: Decision-making under uncertainty in short-term electricity markets.

Uwe Langenmayr: Sector coupling 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.

Christian Perau: Sector coupling electricity and gas infrastructure with focus on hydrogen production and transmission.

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

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

Leandra Scharnhorst: Demand response and security of supply in the residential and industrial energy demand sectors of tomorrow.

Tim Signer: Analysis of bidirectional charging with agent-based energy models.

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

Daniel Sloot: Peoples acceptance of and participation in energy systems, specifically consumer participation in demand response programs.

Stephanie Stumpf: Analysis of uncertainties in the energy market and their impact on household energy decisions.

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

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

International Collaboration

Location: Trondheim, Norway

Who: Emil Kraft

Host: Prof. Stein-Erik Fleten, Norwegian University of Science and Technology (NTNU), Department of Industrial Economics and Technology Management (IØT).

Period: September to December 2021

Short description of stay: With travel support funded by the Karlsruhe House of Young Scientists (KHYS) Research Travel Grant, Emil Kraft stayed for three months at NTNU in the Department of Industrial Economics and Technology Management (IØT). During his stay there, he presented and discussed recent publications and project ideas around stochastic optimization in the field of energy economics with Stein-Erik Fleten and his colleagues. He started a collaboration that intends to develop methods to trade battery storage assets under uncertainty in short-term electricity markets.

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 70 bachelor's and master's theses per year.

Introduction to Energy Economics ~110 students

Prof. Dr. rer. pol. W. Fichtner
Dr. rer. pol. A. Ardone
M. Sc. N. Lehmann
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 as well as associated technologies are introduced. 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

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
Dipl.-Math. J. Dehler-Holland

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 this concept into policy decision follows. In the subsequent 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 is discussed. The final part deals with implementation strategies of material and energy policy.

Liberalised Power Markets ~35 students

Prof. Dr. rer. pol. W. Fichtner
M. Sc. E. Kraft

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 Trading and Risk Management ~15 students

Dr. rer. pol. C. Fraunholz
M. Sc. E. Kraft
Prof. Dr. rer. pol. W. Fichtner

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
M. Sc. F. Zimmermann

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. nat. P. Plötz
Dr.-Ing. T. Dengiz
Dr.-Ing. H. Ü. Yilmaz

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

Heat Economy ~15 students
Prof. Dr. rer. pol. W. Fichtner
Dr.-Ing. T. Dengiz

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

Energy Systems Analysis ~20 students
Dr. rer. pol. A. Ardone
Dr.-Ing. T. Dengiz
Dr.-Ing. 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 ~30 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 ~30 students
PD Dr. rer. pol. P. Jochem

This lecture series combines two of the most central topics in the field of energy economics at present, namely energy efficiency and electric mobility. The objective of the lecture is to provide an introduction to and overview of 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 ~130 students
Apl. Prof. Dr. rer. nat. U. Karl
M. Sc. U. Langenmayr

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.

Industrial Business Administration ~200 students
Prof. Dr. rer. pol. W. Fichtner
M. Sc. M. Kleinebrahm

In this lecture, students from various fields of study are given an introduction to industrial business administration. Topics from the areas of legal forms, financing, management, cost accounting, investment accounting, optimization, marketing, project management and technology acceptance are presented.

<table>
<tr><th colspan="2"><u>Teaching at the Chair of Energy Economics</u></th></tr>
<tr><td colspan="2"><u>Bachelor Module „Energy Economics“</u>
Introduction to Energy Economics (SS, 5.5 ECTS)
Renewable Energy – Resources, Technologies and Economics (WS, 3.5 ECTS)
Energy Policy (SS, 3.5 ECTS)</td></tr>
<tr><td><u>Master Module „Energy Economics and Energy Markets“</u>
Liberalised Power Markets (WS, 3 ECTS)
Energy Trading and Risk Management (SS, 3 ECTS)
Simulation Game in Energy Economics (SS, 3 ECTS)
Quantitative Methods in Energy Economics (WS, 3 ECTS)</td><td><u>Master Module „Energy Economics and Technology“</u>
Efficient Energy Systems and Electric Mobility (SS, 3.5 ECTS)
Energy and Environment (SS, 4.5 ECTS)
Energy Systems Analysis (WS, 3 ECTS)
Heat Economy (SS, 3 ECTS)
(Smart) Energy Infrastructure (WS, 3 ECTS)</td></tr>
<tr><td colspan="2"><u>Industrial Business Administration (WS, 3 ECTS)</u></td></tr>
</table>

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