Karlsruhe Institute of Technology

Institute for Industrial Production

Annual Report 2022

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 2022. 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 22 research and four administrative staff, roughly divided equally between these four groups.

During 2022, we worked on around 13 ongoing national and international research projects and started three new projects. We published around 36 peer-reviewed journal articles, and three PhDs were completed.

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

Prof. Dr. Wolf Fichtner, Chair of Energy Economics

Distributed Energy Systems and Networks Group

Head of research group: Dr. rer. pol. Armin Ardone

Members of the research group (fltr): Armin Ardone, Daniel Sloot, Thorben Sandmeier, Viktor Slednev; Nico Lehmann, Leandra Scharnhorst, Rafael Finck, Julia Schuler.

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

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

Energy Markets and Energy System Analysis Group

Head of research group: Dr. rer. pol. Emil Kraft

Members of the research group (fltr): Thorsten Weiskopf, Florian Zimmermann, Anthony Britto, Stephanie Stumpf, Julius Beranek, Emil Kraft.

The design of sustainable 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 turbulent

year 2022 has once more shown the significance of energy markets and the supply with energy on all facets of modern societies and particularly the economies. The goal of the research group Energy Markets and Energy System Analysis (EMESA) is the formulation and application of various types of quantitative models to analyse the implications of political and economic framework conditions as well as technological trends onto the future development of energy systems.

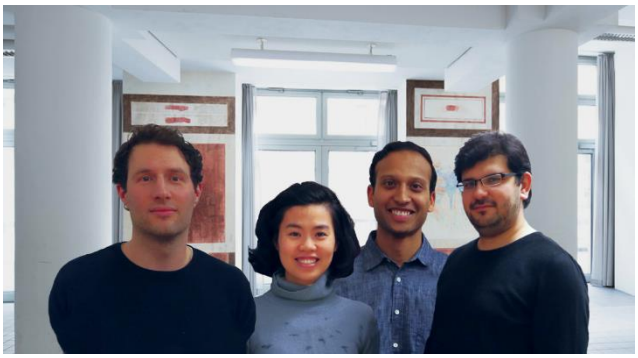
The main research topics include

- security of supply,
- electricity market design,
- investments in flexibility options and decarbonisation technologies,
- economics of energy storage on different time scales,
- system integration of renewable energy, and
- decisions under uncertainty in energy markets.

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 studies of the research group EMESA are decision-makers from politics, business and industry.

Energy Policy Group

Head of research group: Joris Dehler-Holland



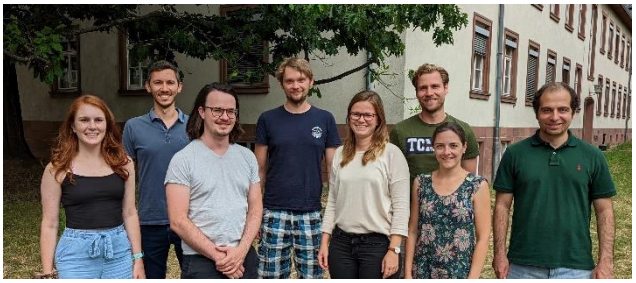
Members of the group (fltr): Joris Dehler-Holland, Phuong Minh Khuong (left the chair), Anthony Britto, Hasan Ümitcan Yilmaz (left the chair). Missing in the picture: Stephanie Stumpf.

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): Savanna Fraleigh (left the group in August), Manuel Ruppert, Uwe Langenmayr, Christian Perau, Alexandra Märtz, Tim Signer, Nora Baumgartner, Thomas Dengiz.

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, also considering interdependencies and interaction with electricity and gas infrastructure. Third, mobility patterns, user behaviour and user acceptance analyses of (technological) innovations in the transportation sector are performed. For answering these 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. We have a comprehensive exchange with international partners from academia and industry. Funding of the research projects in the group is provided by national and federal German ministries, the European Commission, and industry.

Research Projects

BDL – Bidirectional Charging Management

Tim Signer, Nora Baumgartner, Manuel Ruppert

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

Funding: Federal Ministry for Economic Affairs and Climate Action (BMWK)

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. 20 households are involved in testing the use cases intraday trading and vehicle-to-home. The pilot phase started in August 2021 and lasts until the end of 2022. Besides private households, eight companies participate in the testing of a total of eight use cases. For example, the objective is to raise the pooled potential of company EVs to reduce the peak load of the facility. Most use cases are tested in the field, while some use cases are tested using a simulation model. Further use cases are tested in a laboratory environment. All tests are conducted using a V2G-enabled BMW i3.

Apart from the technical development and implementation of the use cases, three research partners were involved in the accompanying research of this project. In this regard, the KIT had a special focus on the question, how to optimally integrate the flexibility and storage capacity of electric vehicles (EVs) 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. The existing electricity market model PowerACE has been extended to include the effects of bidirectional chargeable EVs in the analysis. Different simulations to determine electricity market effects of V2G have been conducted. Some of the findings of the pilot phase, where 50 EVs have been tested in different use cases, have been included in the PowerACE simulations.

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, in 2022 several surveys with pilot customers were conducted by the University of Passau and the KIT to gain more insights into the feasibility and acceptance of the bidirectional charging technology.

The final project year was again affected by the COVID-19 pandemic. The project meeting in April 2022 thus took place in a digital format. However, the second project meeting in September 2022 took place in Munich. Here obtained results of the pilot phase were presented and discussed. In view of the approaching end of the project, ways of communicating the results were discussed. Finally, the last project meeting took place in November 2022. Here, the most relevant findings were presented to the partners. All project partners and pilot customers participated at the final event.

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

CARE-o-SENE - Catalyst Research for Sustainable Kerosene

Paul Heinzmann, Uwe Langenmayr, Andreas Rudi, Manuel Ruppert

Partners: Sasol Ltd; Sasol Germany GmbH; Helmholtz-Zentrum Berlin für Materialien und Energie (HZB); Karlsruher Institut für Technologie (KIT): IKFT, IIP; University of Cape Town, Department of Chemical Engineering (UCT); Fraunhofer Institute for Ceramic Technologies and Systems (IKTS); Ineratec GmbH

Funding: Federal Ministry of Eduction and Research

Duration: 10/2022 – 10/2025

The Power-to-Liquids (PtL) strategy is the future key to a sustainable decarbonization of hard to abate sectors, such as the aviation sector. The PtL approach can produce sustainable aviation fuels (SAF) by utilising Fischer-Tropsch (FT) processes to convert green H2 and sustainable carbon dioxide. A decisive success factor for viable long-term SAF PtL projects will be a competitive FT catalyst with high conversion efficiencies and yields to the desired SAF product, for which demand is expected to grow rapidly in future. The goal of CARE-o-SENE is the accelerated and knowledge-based development of Fischer-Tropsch catalysts for the highly efficient and sustainable production of green SAFs in relevant volumes for the transformation of the aviation sector. The IIP will contribute to this project with the techno-economic analysis of the developed processes and technologies.

Supported by:
Federal Ministry of Education and Research
on the basis of a decision by the German Bundestag

Clean Circles

Julia Schuler, Viktor Slednev, Armin Ardone

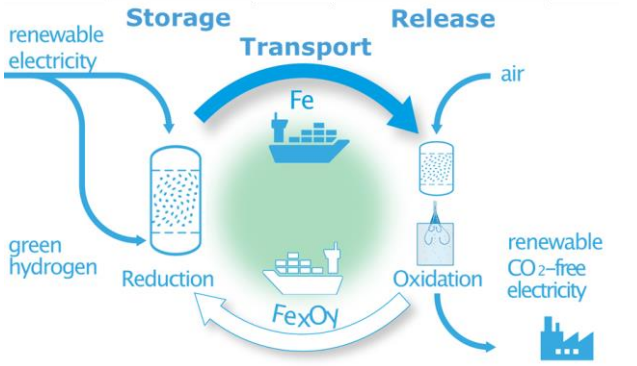
Partners: TU Darmstadt, JGU Mainz, DLR, Max-Planck-Institut für Eisenforschung

Funding: Strategy Fund of the KIT Presidium

Duration: 01.06.2022-31.03.2025

The interdisciplinary research project Clean Circles evaluates a future carbon-free circular energy economy based on iron and its oxides as a renewable energy carrier.

The technical concept is illustrated below:



Renewable energy (e.g., hydrogen) is used to chemically reduce iron oxide to store energy in iron powder. $Fe_2O_3 + 3\,H_2 \longrightarrow 2\,Fe + 3\,H_2O$

After being shipped to the demand destination, the iron powder is combusted to release the stored energy for example for electricity production, ideally using existing infrastructure such as retrofitted coal-fired power plants. $2\,Fe + 3/2\,O_2 \longrightarrow Fe_2O_3$

The main properties that make iron particularly attractive as a storage medium are:

- Availability and price: fourth most abundant element in the earth crust
- non-toxicity
- high volumetric energy density (16,5 kWh/l compared to 2,4 kWh/l for liquid hydrogen)
- oxidation flame temperatures and residence times similar to hydrocarbons

Those properties as well as preliminary studies at TU Darmstadt, TU Eindhoven and McGill University Montreal give reason to be optimistic that iron can enable large-scale storage and transport of renewable energy as well as the reuse and retrofit of existing infrastructure, namely power plants and proven transport routes for bulk material such as ships, railway and ports.

Within the interdisciplinary framework of Clean Circles with over 20 subprojects in engineering, natural, humanities and social sciences, the Chair of Energy Economics will bring in its competence in energy system analysis. Model-based investigations on the potential of iron as fuel in power and heat sector, industry, GHD and transport will be carried out, as well as a comparison of iron to alternatives (e.g., liquid H_2, NH_3, synfuels) and the evaluation of regions worldwide regarding their suitability for the reduction process. Answers will be provided regarding the role of iron within Europe's energy transition, with focus on the contribution to reduce costs by building on existing infrastructures. The application of spatially and temporally highly resolved energy system models existent at KIT, such as PERSEUS-gECT (global Energy Conversion and Transmission), allows to reach a level of detail which will provide valuable political decision support.

CO2Inno - Real laboratory CO2-neutral innovation region Upper Rhine

Nora Baumgartner, Daniel Sloot, Manuel Ruppert

Partners: University of Freiburg, University Haute-Alsace, TRION-climate e.V., University of Applied Science Karlsruhe, City of Offenburg, Collectivité européenne d'Alsace, University of Strasbourg, University of Applied Science Kehl, Klimapartner Oberrhein e.V., Badenova AG & Co. KG

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

Duration: 10/2022 to 09/2025

The project "CO2Inno" is coordinated by the University of Freiburg. Ten other financed partners from Germany and France are represented in the project consortium. The European Union is supporting the project with a total of 2.556.522 million Euros from the European Regional Development Fund (ERDF). The objectives of the project are the following:

1. To promote the technical development and societal anchoring of selected technologies and approaches in the field of sustainable energy and mobility systems (cogeneration unit, e-mobility, smart grid, smart meter and cyber security) in cooperation with the operators of two selected public institutions in the region (DE/FR).

2. A comparative analysis (Germany/France) of the legal-administrative feasibility and social acceptance of the tested technologies and approaches and derivation of recommendations.

3. An assessment of the overall environmental impact of reusing a former nuclear site for the development/implementation of low-carbon energy solutions.

4. The participatory involvement of key regional stakeholders from Germany and France in the design, implementation and dissemination of the project.

5. To raise awareness among politicians and the general public by presenting, discussing and further developing the climate-friendly solution approaches for sustainable energy and mobility within public events and involving economic actors in finding solutions.

The key findings will be incorporated into a guidebook that provides policy recommendations for the acceptance of cross-border use of decarbonizing technologies across multiple

dimensions: technological, legal-administrative, and societal.

The KIT-IIP/DFIU will be responsible for conducting the accompanying research with a focus on technology acceptance. The aim will be to identify factors influencing acceptance of the studied technologies and to create acceptance of key-stakeholders by providing input to the co-creation processes.

A kick-off meeting was carried out in November 2022. The project partners met in Freiburg for a get-together and to present the planned research plans of each partner.

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

Anthony Britto, Joris Dehler-Holland

Partners: Karlsruhe Institute of Technology: IPD, IIP, ITI, ITEP, IAI, KASTEL, ZAR, IPE, IISM

Funding: German Research Foundation (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.

Within the scope of this graduate college, Anthony Britto focuses on investment in energy technology using tools from decision theory and operations research. The goal of this research is to first understand the investment behaviour of agents in different sectors of the energy economy, and consequently, to map out patterns of investment (i.e. technology diffusion) that emerge at a macro level.

ENERGY STATUS DATA
COLLECT • ANALYSE • UTILISE

Energy System Design (ESD)

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

Partners: 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 redemonstrating 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 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. For instance, this year we confronted users with temporary, planned power shutdowns in order to investigate and quantify their willingness to pay (to avert a shutdown) and willingness to accept (a shutdown) associated to the security of supply. Furthermore, we will provide the collected quantitative data to our partners.

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

ENSURE 2 – New Electrical Grid Structures for the energy transition

Kim Miskiw, Julius Beranek, Christian Perau, Rafael Finck, Emil Kraft, Christoph Fraunholz, Manuel Ruppert,

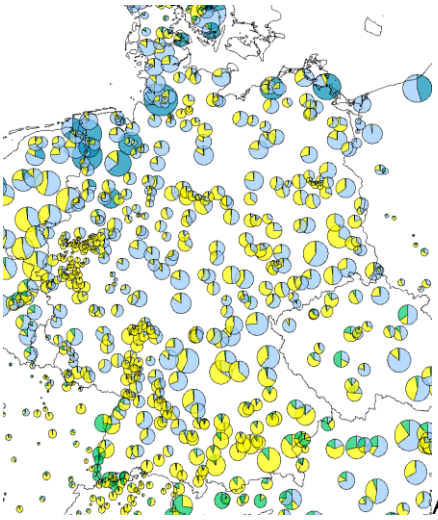
Partners: ABB Power Grids Germany AG, Bergische Universität Wuppertal, CAU, DUH, DVGW-EBI, EWI, FAU, FGH, FH Westküste, Germanwatch, KIT, Maschinenfabrik Reinhausen, OFFIS, Öko-Institut, RWTH Aachen, SH Netz, Siemens AG, SWKiel Netz GmbH, TenneT, TU Dortmund, TU Ilmenau

Funding: Federal Ministry of Education and Research

Duration: 02/2020 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.

Installed renewable capacities in one of the ENSURE-storylines

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.

Supported by:

Federal Ministry of Education and Research

on the basis of a decision by the German Bundestag

FlexKälte

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 Climate Action (BMWK)

Duration: 01/2020 to 03/2023

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.

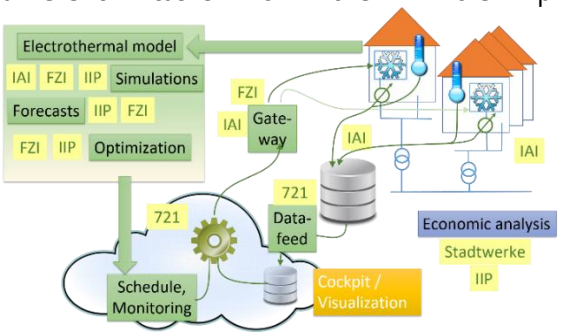


Figure taken from the Institute for Automation and Applied Informatics (IAI), Karlsruhe Institute of Technology

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 2022:

- Forecasting of the cooling loads and the (inflexible) electricity loads for the relevant buildings
- Analysis of measured electricity load data from the cooling devices
- Design of a model-free optimization algorithm for demand side management of buildings with multiple-zones

Supported by:

Federal Ministry for Economic Affairs and Climate Action

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

Daniel Sloot, Nico Lehmann, Armin Ardone

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 Climate Action (BMWK)

Duration: 2019 to 2023

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 two representative studies 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, focus group studies, and quantitative studies. Repeated surveys are also being conducted among participants of the project's field test. The aim is to achieve reliable and valid results. By doing so, conclusions can be drawn on optimal market design options.

Supported by:

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and Climate Action

on the basis of a decision
by the German Bundestag

reFuels – rethinking fuels

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

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 06/2022

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 project ended in September with a final meeting of all project partners, research groups and members of the ministry of transportation of the state of Baden-Württemberg at the MiRO refinery in Karlsruhe. Project results and the final report will be published on https://www.refuels.de/

RESUR - Design of Robust Energy Systems and Resource Procurement (Helmholtz Platform)

Anthony Britto, Emil Kraft, Armin Ardone

Partners: Forschungszentrum Jülich (FZJ), Deutsches Zentrum für Luft- und Raumfahrt (DLR), TransnetBW GmbH, Siemens AG, EnBW - Energie Baden-Württemberg AG, VDA - Verband der Automobilindustrie e.V., DVGW e.V., gwi - Gas- und Wärme-Institut Essen e.V., Uniper Global Commodities SE, Westenergie AG, Stadtwerke Karlsruhe Netzservice GmbH, Brainery Park Jülich GmbH, Thyssengas GmbH, E.ON SE, Amprion GmbH, BASF SE

Funding: Helmholtz Gemeinschaft

Duration: 2022 to 2025

The transformation of our energy system and the achievement of climate neutrality in 2045 are the central social challenges of our time, and are our responsibility. The increasing pace of integration of renewables into the energy system, as well as recent disruptive events such as the war in Ukraine and its impact on the energy system and the economy, have demonstrated the need for a rapid proactive analysis of the fundamental aspects of the energy system and resource procurement for decision-makers in Germany in politics, business, science and society on the basis of highly-detailed, model-supported, and sector-coupled basis. The goal is to support strategic decision-making for supply, and to accelerate the implementation of the energy turnaround in Germany in the European context, as well as including global central imports. Geostrategic aspects, criticality and risk diversification are given special consideration.

Within the scope of this project, the IIP contributes to the modules "Energy and resource markets, energy market design, and economic evaluation" and "Disruptive scenarios and robustness of the energy system." In the first module, the IIP will develop extended energy market models, which can be used to investigate the robustness of energy systems with regard to the effects of disruptive events. In the second module, using PERSEUS, the geographic focus of diversified multimodal imports of renewables into Europe will be extended to global coverage. The influences of disruptive scenarios on the energy system as well as the security of supply of materials and energy carriers relevant for the energy system will be investigated with the help of an impact analysis, and spatially and temporally quantified.

SEDOS – The Importance of Sector Integration within the Energy Transition in Germany - Modeling with a National Open Source Reference Energy System

Viktor Slednev, Leandra Scharnhorst, Anthony Britto, Armin Ardone

Partners: Institut für Energiewirtschaft und Rationelle Energieanwendung (IER) Stuttgart, Reiner Lemoine Institut (RLI) Berlin, Technische Universität München (TUM), Deutsches Zentrum für Luft- und Raumfahrt (DLR-VE) Stuttgart, Forschungszentrum Jülich (FZJ-IEK-3), Karlsruher Institut für Technologie (KIT)

Funding: Federal Ministry for Economic Affairs and Climate Action (BMWK)

Duration: 2022 to 2024

The terms sector integration or sector coupling have become indispensable in discussions of energy and climate policy. The goal of the research project SEDOS, 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 is structured along the four major sub-areas of energy system analysis: (i) data management, (ii) model or system structure (in the form of the so-called reference energy system (RES)), (iii) mathematics and associated solution algorithms in the model frameworks oemof, TIMES and FINE, and (iv) user interface. 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 the electricity demand oft the tertiary, residential and other sectors (as long they are not specified in other subprojects).

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag

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 Climate Action (BMWK)

Duration: 07/2020 – 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. For this, it is crucial to simultaneously address the available technologies, the players in the distribution grid and the further analysis of regulation.

To this end, a field test with 28 selected prosumer households has been conducted since the beginning of 2022. In the field test in Walldorf, we are piloting how decentralized power supply from renewable energies and consumers such as electric cars and heat pumps can be optimally coordinated.

The energy systems of the pilot households were initially equipped with smart metering and control infrastructure: a newly developed control box that intelligently networks energy components on site, an intelligent electricity metering system including a smart meter gateway for secure communication of metering data, a web portal that displays all energy flows in the house, and a charging app for charging one's own electric vehicle at particularly low cost.

This allows generation and consumption to be optimally matched. In the pilot households, flexible electricity consumers are matched with the availability of their own electricity and the situation in the power grid. This improves the economic efficiency of the decentralized energy systems - both for the individual participants and for the community.

The KIT-IIP is particularly aims to support 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, the focus is particularly on the simultaneity as well as the flexibility potential of the charging processes.

In order to also take the regional aspect into account, within the scope of the project, a model is also being developed to identify spatial areas in which an above-average penetration of electric vehciles can be expected in the future. In particular, OSM data will be used to estimate the regions.

In summary, 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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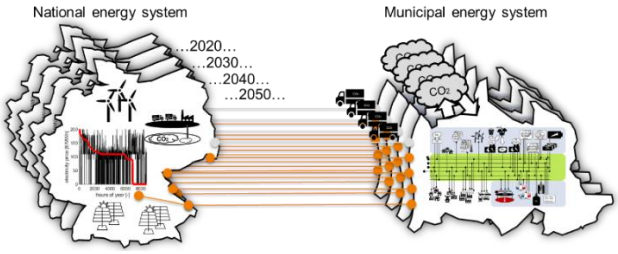
TrafoKommunE – Transformation process for the municipal energy transition – sector coupled infrastructure and strategies to integrate local actors

Max Kleinebrahm, Nico Lehmann, Viktor Slednev, 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 Climate Action (BMWK)

Duration: 2020 to 2023



Kleinebrahm, M.;Weinand, J.M.;Naber, E.; McKenna, R.;Ardone, A. „Analysing municipal energy system transformations in line with national greenhouse gas reduction strategies, 2023, Applied Energy, Volume 332

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 (especially municipal utilities) in shaping the energy transition will be identified. The cross-sectoral approach of this project is intended to 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, inter alia, the analysis of the current building stock (including 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

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and Energy Efficiency Analysis and System OptimizatioN) model developed at the IIP for the analysis and optimisation of municipal energy systems.

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

Rafael Finck, Viktor Slednev, Leandra Scharnhorst, Armin Ardone

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

Funding: Federal Ministry for Economic Affairs and Climate Action (BMWK)

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 the ERA-5 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 based on highly resolved generation capacities depicted in Fig.1.

Determination of potential flexibility induced by cross border trade for the German electricity system under consideration of dynamic trading capacities for the coupled markets. The dynamic nature of line capacities is exemplary shown in Fig. 2.

Evaluation of the European internal market during extreme weather events for a future year according to the "TYNDP 2022 Decentralized Energy Scenario" and estimation of the remaining gap between supply and demand in Germany.

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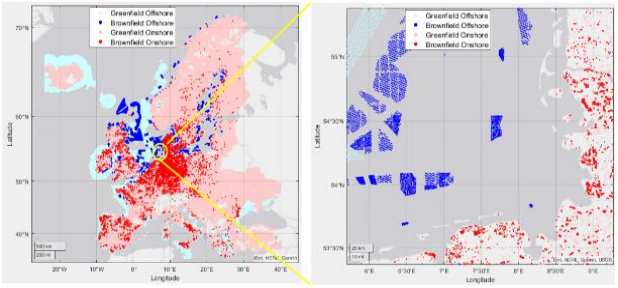
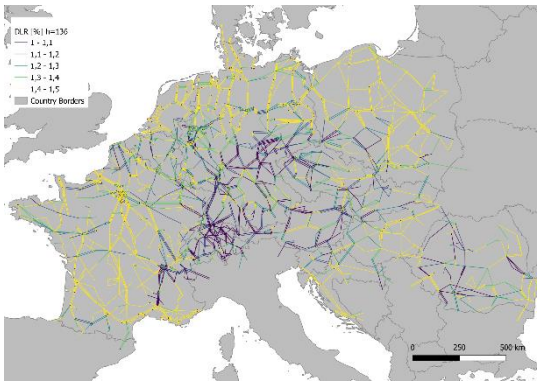


Expansion potentials for wind onshore and wind offshore.



Relative transmission capacity compared to static line limits in one hour.

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

Florian Zimmermann, Thorsten Weiskopf, Christoph Fraunholz, Emil Kraft

Partner: TU Dresden, Fraunhofer ISI, ESA² GmbH

Funding: Federal Ministry for Economic Affairs and Climate Action (BMWK)

Duration: 07/2020 to 06/2023

VerSEAS

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.

VerSEAS workshop in Stuttgart

Panel discussion at the VerSEAS workshop in Stuttgart; f.l.t.r.: Prof. Peter Saling und Dr. Matthias Stark, Dr. Ninghong Sun, Prof. Dominik Möst, Dr. Clemens Cremer, Prof. Wolf Fichtner.

As part of VerSEAS, a public workshop on supply security was planned and held in Stuttgart on September 26, 2022. Compelling presentations from politics, industry and science, which provided insights into the stakeholder-specific positions and served as a starting point for the discussions, were followed by about 80 participants. The following people were on hand for a presentation: Dr. Christoph Maurer (Consentec GmbH), Martin Eggstein (Ministry for the Environment, Climate Protection and the Energy Sector Baden-Württemberg), Dr. Matthias Stark (Bundesverband Erneuerbare Energie e.V. (BEE)), Dr. Philip Schnaars (Energy Economics Institute at the University of Cologne

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(EWI)), Dr. Emil Kraft (Karlsruhe Institute of Technology (KIT)), Dr. Holger Krawinkel (MVV Energie AG), Dr. Ninghong Sun (TransnetBW GmbH), Philipp Hauser (VNG AG), Dr. Clemens Cremer (EnBW Energie Baden-Württemberg AG), Prof. Peter Saling (BASF SE). Finally, a panel discussion moderated by Prof. Wolf Fichtner took place.

Awards

- Dr. Christoph Fraunholz was awarded the price for interdisciplinary research by the KIT-Department of Economics and Management for his dissertation "Market Design for the Transition to Renewable Electricity Systems".
- The Operations Research Society of New Zealand (ORSNZ) rewarded Uwe Langenmayr the second price of the Young Practitioner Prize for his presentation on the topic Calculation of Synthetic Energy Carrier Costs with high Temporal and Geographical Resolution, presented at the annual ORSNZ conference in Auckland, New Zealand.

Completed PhD Dissertations and Habilitations

PhD dissertation: "Decision-making under uncertainty in short-term electricity markets"

Emil Kraft

In the course of the energy transition, the share of electricity generation from renewable energy sources in Germany has increased significantly in recent years and will continue to rise. Particularly fluctuating renewables like wind and solar bring more uncertainty and volatility to the electricity system. As markets determine the unit commitment in systems with self-dispatch, many changes have been made to the design of electricity markets to meet the new challenges. Thereby, a trend towards real-time can be observed. Short-term electricity markets are becoming more important and are seen as suitable for efficient resource allocation. Therefore, it is inevitable for market participants to develop strategies for trading electricity and flexibility in these segments.

The research conducted in this thesis aims to enable better decisions in short-term electricity markets. To achieve this, a multitude of quantitative methods is developed and applied: (a) forecasting methods based on econometrics and machine learning, (b) methods for stochastic modeling of time series, (c) scenario generation and reduction methods, as well as (d) stochastic programming methods. Most significantly, two- and three-stage stochastic optimization problems are formulated to derive optimal trading decisions and unit commitment in the context of short-term electricity markets. The problem formulations adequately account for the sequential structure, the characteristics and the technical requirements of the different market segments, as well as the available information regarding uncertain generation volumes and prices. The thesis contains three case studies focusing on the German electricity markets.

Results confirm that, based on appropriate representations of the uncertainty of market prices and renewable generation, the optimization approaches allow to derive sound trading strategies across multiple revenue streams, with which market participants can effectively balance the inevitable trade-off between expected profit and associated risk. By considering coherent risk metrics and flexibly adaptable risk attitudes, the trading strategies allow to substantially reduce risk with only moderate expected profit losses. These results are significant, as improving trading decisions that determine the allocation of resources in the electricity system plays a key role in coping with the uncertainty from renewables and hence contributes to the ultimate success of the energy transition.

PhD dissertation: "Optimization methods for developing electric vehicle charging strategies"

Zongfei Wang

This cumulative thesis makes methodological contributions to the fundamental and universal challenges in developing charging strategies for integrating electric vehicles into energy systems. The electrification of the road transport sector is a major technical pathway for decarbonization. If charged in an uncontrolled manner, electric vehicles may lead to several negative impacts, such as the peak demand increase and the grid bottleneck. Therefore, novel controlled charging strategies should be developed to help integrate electric vehicles into energy systems.

Against this background, the thesis analyzes the development of electric vehicle charging strategies from two research perspectives. From the micro perspective focusing on the operational stage of electric vehicle integration, the thesis proposes a new stochastic optimization model and provides solutions for the common problems in developing an electric vehicle charging scheduling model. The model minimizes the variance between the ideal charging curve and the actual one. In addition, it effectively alleviates the impact of the uncertain availability and charging demand from future electric vehicles on the current solutions. The model performance is demonstrated in various applications, including peak shaving and load leveling. The model is further applied in a case study to explore the correlation between the volatile generation of a wind turbine and the charging demand of an electric vehicle fleet.

From the macro perspective focusing on the planning stage, the thesis first examines the impact of different charging strategies on greenhouse gas emissions in Europe in 2050 and encourages the adoption of bidirectional charging strategies (vehicle-to-grid). A follow-up study summarizes three types of modeling methods to integrate huge fleets of electric vehicles into energy system models (two developed by the thesis and one from literature). The three methods are applied in a simplified energy system model for comparing and analyzing their performances from multiple aspects, including solution accuracy, computational complexity, parameter requirement, and their impact on greenhouse gas emissions. The work unveils the mechanisms behind the differences, makes specific recommendations for further improvements and provides guidance for model users on method selection.

The thesis discusses the crucial but often ignored concerns in designing electric vehicle charging strategies and highlights the importance of method demonstration. Hence, the thesis would inspire future research in electric vehicle integration.

PhD dissertation: "Optimization methods for developing electric vehicle charging strategies"

Verena Weiler

The importance of climate protection and sustainability as well as the demand for concrete implementation measures has been steadily increasing in Germany in recent years. However, the responsible municipalities and districts often lack suitable tools for calculating and evaluating individually adapted scenarios for converting the heat supply of buildings. Many analyses are carried out top-down on a national level or look at individual buildings bottom-up. The intermediate level of neighbourhoods, which is relevant for decision-making and implementation, is rarely addressed.

Therefore, a process was developed in the context of the present work, which makes it possible to calculate, evaluate and compare energy balances as well as different scenarios for a sustainable heat supply of the buildings for a neighbourhood or a whole municipality. It is based on tools for modelling and simulation that, independently of this work, already include the determination of local renewable potentials as well as certain demand-side analyses and has been developed at HFT Stuttgart since 2013. Building on this, various methods from the fields of geoinformatics, heuristic decision-making, object-oriented modelling with UML and mathematical modelling in the form of physical modelling with Python, Java and INSEL are used in this thesis. The focus is on linking the individual methods to enable automated calculation of centralised and decentralised heat supply systems.

The application of the developed methods is demonstrated using various case studies. The simple applicability and the transferability of the method are demonstrated. The comparison of the simulation results with measured data shows only a small deviation of 6 % in the annual mean.

Overall, the extensions of this work provide a tool that covers the entire field of urban building energy simulation. With only a few, widely available information and a descriptive user interface, scenarios for renewable heat supply can be mapped and compared. These can be used for decision-making in municipalities vii and districts to accelerate the implementation of concrete measures to reduce greenhouse gas emissions.

Staff as of December 2022

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. rer. pol. Armin Ardone – Distributed Energy Systems and Networks

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

Dr. rer. pol. Emil Kraft – Energy Markets and Energy System Analysis

M.Sc. Manuel Ruppert – Transport and Energy

Postdocs & Doctoral Researchers and their research-topics

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

Julius Beranek: Analysis of security of supply in European electricity markets.

Anthony Britto: Wealth, Uncertainty, and Energy Technology Investments.

Joris Dehler-Holland: The socio-technical dynamics of renewable energy policies 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.

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

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 of 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.

Julia Schuler: Techno-economic assessment of an iron-based energy circular economy.

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.

Thorsten Weiskopf: to be defined, started in December 2022.

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

International Collaboration

Location: Auckland, New Zealand

Who: Uwe Langenmayr

Host: Dr. Anthony Downward, University of Auckland, Department of Engineering Science

Period: September to December 2022

Short description of stay: Financed via the Karlsruhe House of Young Scientists (KHYS) Research Travel Grant, Uwe Langenmayr spent 3 months at the Department of Engineering Science at the University of Auckland. Together with his supervisor, Anthony Downward, he worked on robust optimization of stand-alone power-to-x facilities. This approach will allow the consideration of long-term and short-term uncertainties from renewable generation when planning large-scale synthetic energy carrier production facilities.

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 ~100 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 ~80 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 ~45 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 ~40 students

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

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 ~20 students

Dr. rer. pol. C. Fraunholz
Dr. rer. pol. 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 ~10 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 ~25 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 ~30 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 ~40 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 ~35 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 ~145 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. L. Scharnhorst

M. Sc. J. Schuler

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.

Teaching at the Chair of Energy Economics

Bachelor Module „Energy Economics"

- Introduction to Energy Economics (SS, 5.5 ECTS)
- Renewable Energy – Resources, Technologies and Economics (WS, 3.5 ECTS)
- Energy Policy (SS, 3.5 ECTS)

Master Module „Energy Economics and Energy Markets"

- 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)

Master Module „Energy Economics and Technology"

- Efficient Energy Systems and Electric Mobility (SS, 3.5 ECTS)
- Energy and Environment (SS, 4.5 ECTS)
- Energy Systems Analysis (WS, 3 ECTS)
- Heat Economy (SS, 3 ECTS)
- (Smart) Energy Infrastructure (WS, 3 ECTS)

Industrial Business Administration (WS, 3 ECTS)

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Wang, Z. (2022). Optimization methods for developing electric vehicle charging strategies. PhD Dissertation. KIT Karlsruhe. DOI: 10.5445/IR/1000144202

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