Karlsruhe Institute of Technology

Institute for Industrial Production

Annual Report 2024

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 2024. The four research groups "Energy and Behavior", "Energy Demand and Mobility", "Sustainable Energy Markets and Future Energy Commodities", and "Sustainable Infrastructures for Renewable Energy Systems" 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 23 research and four administrative staff, divided across these four groups.

During 2024, we worked on around 15 ongoing national and international research projects and started two new projects. We published around 14 peer-reviewed journal articles, six conference papers and five 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

Energy and Behavior Group

Head of research group: Dr. Daniel Sloot



Members of the research group (fltr): Dr. Daniel Sloot, Stephanie Stumpf, Leonie Wagner

The *Energy and Behavior Group* investigates the acceptance and adoption of innovations in the context of the energy transition, as well as other topics related to sustainability transformations, from a social and behavioral perspective. Using theories of decision-making and behavior change, as well as empirical research methods, the group primarily researches the individual drivers and barriers affecting energy technology acceptance and adoption. Among other things, the research includes experimental methods (randomized controlled trials), correlational panel studies, and field studies. Current topics include the diffusion of electric heat pumps, acceptance of bidirectional charging of electric vehicles, and the acceptance of negative emissions technologies.

Energy Demand and Mobility Group

Head of research group: Dr.-Ing Max Kleinebrahm

Members of the research group (fltr): Anthony Britto, Max Kleinebrahm, Jonathan Vogl, Leandra Scharnhorst, Tim Signer, Thomas Dengiz, Moritz Raab

Achieving greenhouse-gas-neutral economies requires deep decarbonization across all sectors. In the past, the transformation processes of individual sectors were often analyzed in isolation. The integration of large shares of renewable energy requires integrated approaches to incentivize flexibility provision and emission reductions effectively. The optimal allocation of climate protection measures opens up a variety of complex socio-techno-economic research questions, particularly given the broad diversity of stakeholders and the multitude of novel technology options.

Within this context, the research group "Energy Demand & Mobility" conducts research on coordinated emission reduction strategies across the energy, mobility, household, and industry sectors. To better understand the future uptake of low-carbon technologies and efficiency measures within and interdependencies between sectors, we apply highly interdisciplinary approaches from economics, engineering, computer science, and sociology. Our primary methodological approach spans a diverse range, including energy system optimization, agent-based simulation, machine learning, econometric analysis, and socio-economic empirical techniques. We have a comprehensive exchange with international partners from academia and industry. National and federal German ministries, the European Commission, and industry provide funding for the research projects in the group.

Sustainable Infrastructures for Renewable Energy Systems Group

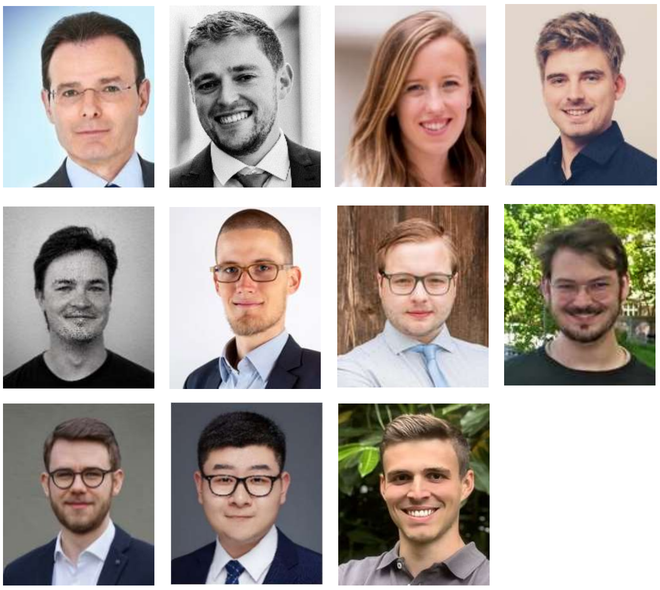
Head of research group: M.Sc. Thorben Sandmeier

Members of the research group (fltr): Thorben Sandmeier, Kira Layer, Kennedi Briggs (University of North Carolina at Charlotte), Christian Perau

The research group aims at developing tools, methods and datasets for scenario-based techno-economic analyses for electricity, gas and hydrogen transport networks in the context of European decarbonisation goals. Research covers for instance the integrated planning and operation of transport networks for electricity, gas and hydrogen, the techno-economic analysis of new components for electricity grids, the interdependencies between market design and grids, the effects of sector coupling technologies on infrastructures and empirical behaviour studies in the living lab Energy Smart Home Lab.

Sustainable Energy Markets and Future Energy Commodities Group

Head of research group: Dr. rer. pol. Armin Ardone and Dr. rer. pol. Victor Slednev



Members of the research group (fltr): Armin Ardone, Victor Slednev, Julia Schuler, Eric Jahnke, Uwe Langenmayr, Thorsten Weiskopf, Julius Beranek, Alexander Plarre, Johannes Schuhmacher, Wenxuan Hu, Jonathan Stelzer

This group focuses on two main research areas. One being the analysis of market design alternatives as well as market price forecast. Main tools are agent-based models of electricity markets with a particular focus on capacity mechanisms in systems with high shares of renewables including impacts from flexibility (e.g., storages) and cross-border effects. The other one focusses on model-based energy systems analysis from regional to global scale with high temporal and spatial resolution including optimized adaptation of infrastructures. The conversion, transportation and storage of future energy commodities include hydrogen and derivates as well as reactive metals.

Outlook: The new Group Structure

At the end of the year, the group "Sustainable Energy Markets and Future Energy Commodities" was restructured into two new groups: "Sustainable Energy Markets" and "Future Energy Commodities", which are briefly described below.

Sustainable Energy Markets Group

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

Members of the research group (fltr): Armin Ardone, Jonathan Stelzer, Julia Schuler, Thorsten Weiskopf, Julius Beranek, Johannes Schuhmacher, Eric Jahnke

The Sustainable Energy Markets (SEM) research group analyses the development of energy markets - in particular the electricity markets in Europe - with the expected high shares of volatile renewable energies. Energy markets are influenced both by market design and by structures on the energy demand and supply side. On the demand side, players can influence the level, temporal structure and flexibility by selecting suitable technologies (heat pumps, electricity storage, electric vehicles, etc.). On the supply side, the market development is determined not only by photovoltaics and wind energy but also by storage technologies. Different technologies play a role in different time horizons. In the short term, the focus is on batteries, in the medium term, storage power plants and possibly Carnot batteries are relevant and in the long term, in addition to hydrogen and its derivatives, reactive metals are also a climate-friendly option. Building on this, analyses of the security of supply with electricity and balancing power are performed. Furthermore, the interaction of these technologies in a market economy context is examined through the development and application of optimising and agent-based system/market models.

Future Energy Commodities Group

Head of research group: Dr. rer. pol. Victor Slednev

Members of the research group (fltr): Uwe Langenmayr, Alexander Plarre, Viktor Slednev

The research group's aim is the model-based techno-economic analysis of the global conversion, storage, and transport of energy carriers along the entire process chain – from primary to final energy conversion. The focus is on existing and potential infrastructures considered in high spatial and temporal resolution. In the context of the desired transformation of the energy system towards a climate-neutral energy supply with net-zero greenhouse gas emissions, the analysis mainly concentrates on the transformation path from fossil to renewable and low-carbon energy carriers. A central component is the investigation of the future hydrogen economy, starting with the global potential analysis of renewable energies for electricity-based hydrogen production and ending with its use by the end consumer. In between lies the conversion and storage of hydrogen and derived energy carriers (e.g., ammonia, methanol, reactive metals) and their transport via pipeline, ship, rail, and truck, which are investigated using mathematical optimization. In particular, for the reduction of emissions in sectors that are difficult to decarbonize, such as industry or the transport sector (e.g. shipping and aviation), the provision of synthetic fuels as well as the capture and storage or use of CO_2 – whether from the air or in the conversion process – can play a decisive role and is therefore included in the optimization. The (cross-sectoral) analysis of energy-related greenhouse gas emissions is always considered in the modeling. It plays a central role, particularly in modeling emissions trading, which is a further research focus. Our primary methods include modeling energy systems using linear and mixed-integer optimization. In addition, heuristic optimization approaches, stochastic and robust optimizations, and mathematical decomposition methods are used.

Research Projects

AsimutE: Intelligent self-consumption and storage for better use of energy

Thomas Dengiz, Max Kleinebrahm, Daniel Sloot, Stephanie Stumpf, Jonathan Vogl

Partner: Université de Haute-Alsace, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Hochschule Offenburg, Hochschule Furtwangen, Centre National de la Recherche Scientifique, Hochschule Kehl, Albert-Ludwigs-Universität Freiburg, Fachhochschule Nordwestschweiz FHNW

Funding: Interreg Oberrhein

Duration: 10/2023 to 01/2027

The ASIMUTE project investigates solutions for optimized and safe energy use and storage by involving end users throughout the project. The aim is to achieve a balance between energy demand and the production capacity of renewable energies, taking into account the available storage options. The project partners will use artificial intelligence methods and conduct surveys among consumers, energy suppliers and stakeholders in the Upper Rhine region. The project is multidisciplinary as it will cover aspects from both a techno-economic and a social science perspective. The legal feasibility in the trinational context as well as the acceptance by end consumers in the different cultural contexts of the three countries will be investigated. This will be based on findings from sociological, legal and technical studies that have emerged from the Interreg projects "*Vehicle*" and "*Advanced Control Algorithms for the Management of Decentralised Energy Systems*".

The DFIU is involved in several parts of the project. Together with the Université de Haute Alsace, the effectiveness of calls to save energy in private households is being investigated, taking into account psychological compensation mechanisms. In addition, the expectations of private households with regard to technologies for self-consumption of energy are being investigated with the help of qualitative and quantitative empirical studies.

The DFIU is also involved in the development of methods for the multi-objective optimization of heating systems in representative residential areas of the respective countries. In addition to energy costs, greenhouse gas emissions, thermal comfort and electrical load peaks are optimized in simulations. As the objectives in a residential area are often contradictory, multi-objective optimization methods in combination with machine learning methods are particularly suitable.

In 2024, a project meeting at INTERREG and a first online meeting took place. In a follow-up meeting in Mulhouse in December 2024, the project partners exchanged the results of the first year. In order to investigate the acceptance of households, various interviews were conducted in Germany and France. In addition, a first quantitative survey was conducted among 500 French and German consumers with PV systems to understand factors that explain household satisfaction with PV. For the part of the DFIU considering multi-objective optimization of heating systems in the residential area, a model for residential demand response was presented. Moreover, a new multi-objective optimization algorithm was developed to obtain different trade-off with respect to the conflicting optimization objectives. A paper presenting the results is currently under review.

BDL –Next

Tim Signer, Max Kleinebrahm

Partners: KIT-IIP, BMW, Bayernwerk Netz, TenneT, E.ON, KEO, Compleo, University of Passau and EBZ

Funding: Federal Ministry for Economic Affairs and Climate Action

Duration: 11/2023 to 11/2026

BDL-next aspires to bring bidirectional charging to mass market readiness, overcoming technical, legal, and procedural hurdles. The initiative builds on the BDL project, which highlighted the multifaceted capabilities of electric vehicles for energy markets, grid support, system services, and user benefits. Essential to this is the smart management of power as seen in self-consumption optimization for solar setups and grid frequency regulation. Currently, technological, legal-regulatory, and procedural gaps still prevent the seamless transition to mass real-world operation of bidirectional charging strategies.

This is precisely where BDL Next begins: The project aims at simplifying and enhancing the technology of bidirectional charging to fit seamlessly into the current energy market and service systems. Work is also being done on the grid-oriented and market-oriented operation of bidirectional vehicles, so that they may become an integral part of our robust and intelligent power grid. A multi-stage field trial will use real-world experiences to identify weaknesses in the concept and technical development, further increase the economic and ecological benefits of bidirectional charging, and simplify the integration of the technology from a customer perspective.

The main tasks of our chair include:

- Analysis of Vehicle-2-Grid cross-border effects.
- Analysis of Vehicle-2-Grid related wholesale market price effects.
- Development of MobiFlex model to estimate V2G flexibility based on new mobility data

The following tasks were carried out in 2024:

- Use-case definition
- Development of V2G module in agent-based-electricity market model
- Survey analyzing V2G willingness to participate
- Publishing of analysis regarding V2G electricity market participation under various tax regimes

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

Analysis of bidding strategies and their influence on the electricity price in the EU domestic market - BETS

Dr. Armin Ardone, Thorsten Weiskopf

Partners: KIT-IIP, IZES gGMBH, Technical University of Denmark

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

Duration: 11/2023 to 10/2026

The short-term value of electrical energy is largely determined by trade in the market areas. The hourly day-ahead market is a reference for future products and end-customer prices. The electricity producers offer a generation price per megawatt-hour (MWh) on the electricity exchange, reflecting the variable power plant operation costs. This marginal cost indicates the cost of the next unit of electricity to be produced. However, it must be questioned whether bidding based on marginal costs will continue to exist in a much more heterogeneous power plant portfolio that is traded on the stock exchange in the future. The continued increase in electricity generation from renewable energy systems will significantly change the characteristics of the merit order. At the same time, market consolidation into an oligopolistic structure is possible due to cost advantages, as is currently being observed with offshore wind energy. This market organization continues to allow strategic behaviour in the electricity market, especially in shortage situations. From the perspective of all market participants, strategic imperatives may appear necessary in the new market environment. A paradigm shift from a marginal cost-based merit order towards an opportunity cost-based or marginal costs plus markup-based merit order is expected. Essentially, these considerations lead to the hypothesis that such bidding strategies can occur more frequently:

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on the basis of a decision by the German Bundestag

a) the more significant the differences in technology-induced marginal costs
b) the more different the generation park is in market areas
c) the less flexibility is available within a market area
d) the more significant the available transmission capacities between market areas.

As part of the project, the bid data available at EPEX SPOT in the price curves of individual market areas will now be analyzed for strategic patterns. The price curves represent the aggregated behaviour of all market participants. In a second step, the strategies found will be tested in the future and their influence on the electricity prices and investments in flexible generation technologies in Germany will be examined, taking into account the very different national electricity generation systems in Europe in the future. The goals of the system analysis project are, therefore, the following:

1. Identify bidding strategies from existing bidding curves that lead to electricity market price increases compared to marginal cost-based bids.
2. Develop a learning agent that depicts the relevant bidding strategies in European electricity market models.
3. Determine the influence of the bidding strategies on electricity prices and investments in a future electricity system with high shares of renewable energies and storage.

CARE-o-SENE - Catalyst Research for Sustainable Kerosene

Paul Heinzmann, Uwe Langenmayr, Andreas Rudi, Viktor Slednev

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 Education and Research

Duration: 10/2022 – 12/2026

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

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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.

C2C Bridge – Country to City Bridge

Moritz Raab, Max Kleinebrahm

Partner: Karlsruhe Institute of Technology (KIT) with the institutes AIFB, ECON, FAST, IEB, IFL, IFV, IOR, IPEK, ITAS, ITI, ITIV, KASTEL, LTI and IIP, The Fraunhofer Society for the Advancement of Applied Research e.V. with the institutes ICT, ISI, IOSB, FZI Research Center for Information Technology, Karlsruhe University of Applied Sciences (HKA), Baden-Württemberg Institute for Sustainable Mobility (BWIM), Pforzheim University – Faculty of Design (HSPF), City of Karlsruhe, TechnologyRegion Karlsruhe

Funding: Federal Ministry of Transport and Digital Infrastructure

Duration: 01/2024 – 07/2027

The Country to City Bridge (C2CBridge) project addresses the transportation gap between rural and urban areas, where private cars dominate commuting, causing high energy consumption, congestion, and CO_2 emissions. On average, a car used for daily commuting carries just 1.1 people, according to the "Mobility in Germany" study. C2CBridge aims to reduce reliance on private vehicles by developing a new, autonomous, ride-pooling mobility service that connects rural areas with cities, supplementing existing public transportation.

C2CBridge

The project envisions using autonomous, battery-electric vehicles that can carry up to four passengers, including space for wheelchairs, strollers, and luggage. These vehicles will provide flexible, cost-effective, and demand-responsive transport, offering a practical alternative to private cars. At city outskirts, passengers can switch to other transport modes—like public transit or bike-sharing—at specially designed mobility hubs. Autonomous vehicles will operate in convoys to maximize space and safety on roads, improving efficiency while reducing traffic.

C2CBridge seeks to provide a seamless, integrated, and sustainable mobility service that benefits both rural and urban areas by reducing CO_2 emissions, lowering costs, and enhancing accessibility.

The project is divided into two phases. In C2CBridge 1 (January 2024 - December 2026), the focus is on analyzing existing transport systems and designing the new mobility concept, including autonomous vehicles and mobility hubs. This phase will lay the foundation for the service by assessing mobility behavior and requirements. The second phase, C2CBridge 2, will involve implementing these concepts, focusing on vehicle automation and the development of mobility hubs. This phase also includes validating the system through real-world testing.

We are responsible for evaluating the impact of C2CBridge on the local energy system. Therefore, we will focus on how the project can contribute to the decarbonization of the energy sector by reducing the demand for electricity from private electric vehicles and public transport through optimized mobility patterns.

IIP's role includes developing a detailed, geographically resolved model of the local energy system to assess the project's economic and ecological effects. This model will examine how the deployment of autonomous vehicles can provide flexibility to the energy system, especially by integrating renewable energy sources. By analyzing charging patterns and mobility demand, IIP will provide insights into how C2CBridge can help alleviate stress on the local grid, support renewable energy integration, and reduce overall emissions.

Supported by: Federal Ministry for Digital and Transport on the basis of a decision by the German Bundestag

This research will contribute to designing a more sustainable and efficient transportation network that benefits both energy systems and mobility solutions.

SPP 2403: Carnot Batteries: Inverse Design from Markets to Molecules

Jonathan Stelzer, Armin Ardone

Partners: Karlsruher Institut für Technologie; Universität Duisburg-Essen; Universität Bayreuth; Technische Universität Dortmund; Technische Universität Ilmenau; Technische Universität Berlin; Ruhr-Universität Bochum; Gottfried Wilhelm Leibniz Universität Hannover; E.ON Energy Research Center; Rheinisch-Westfälische Technische Hochschule Aachen; Technische Universität Braunschweig; Technische Universität Darmstadt; Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR); Technische Universität Dresden; Technische Universität Berlin

Funding: German Research Foundation (DFG)

Duration: 2023 –2026

This project aims at investigating promising CB (Carnot Batteries) configurations, the potential role of CBs in future energy systems, as well as economic incentives and barriers for a successful market entry. As technical CB development is still in progress, energy economics can provide an orientation towards promising directions. This motivates a novel inverse approach to investigate the role of CBs in future energy markets. Such an inverse approach is new to energy market modellers and brings challenges with it. Hence, we aim at depicting CBs in an agent-based market model depicting Germany and its neighbours to identify economically attractive technical configurations and their use in the system, to derive potential profit-risk structures for CBs as an investment option, and to assess inevitable techno-economic trade-offs from a market perspective.

The major challenge consists of the adequate depiction of the market functioning through individual economic decisions. A working programme consisting of six working packages addresses this challenge and thereby deploys an agent-based electricity market simulation. Whereas optimisation approaches usually identify desirable investment and dispatch decisions in a normative manner taking a central planner perspective, the agent-based approach is not dependent on generally assuming perfect foresight and perfect coordination. It is able to depict the market structure and market participants' individual decisions.

The key objectives of the project are threefold: On the one hand, the goal is to integrate the inverse engineering character into agent-based energy system modelling by modelling techno-economic characteristics as decision variables of the agents. This requires extensive methodological developments, both in the short- and in the long-term decision-making of agents. On the other hand, the technical representation of the CB's characteristics requires model enhancements. Particularly the differentiation, interplay and potential profit cannibalisation of competing flexibility options led to challenges, as many degrees of freedom complicate convergence, if the techno-economic properties are very similar or agents face immanent uncertainties in their strategic decisions. The third objective is to develop a framework for assessing profit-risk structures of promising technical configurations, based on mean-reverting and path-dependent energy system uncertainties. Path-dependent uncertainties such as the development of new technologies or renewable capacity expansion require endogenous treatment in the simulation model. We propose extension of the existing agent-based model to derive, among others, dispatch curves for different CB configurations under varying market circumstances, as well as profit-risk structures for CBs from an individual market participant's perspective.

Clean Circles

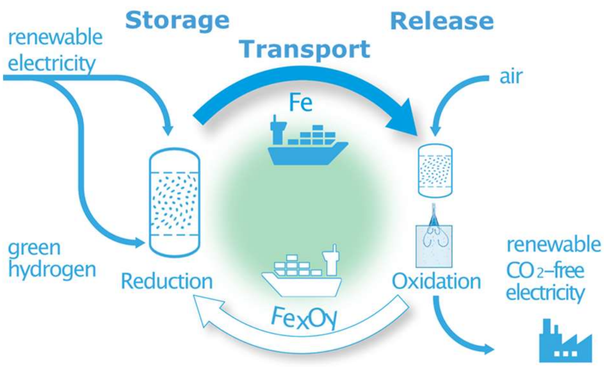
Julia Schuler, Armin Ardone

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

Funding: Strategy Fund of the KIT Presidium

Duration: 01.06.2022-31.12.2024

The interdisciplinary research project Clean Circles evaluates a future carbon-free circular energy economy based on metal fuels.



Main properties that make metals particularly attractive as energy carriers:

- Availability and price: abundant in the earth crust
- High volumetric energy density
- oxidation flame temperatures and residence times similar to hydrocarbons - re-use of existing power plant fleet
- Low toxicity
- Zero-carbon and sulfur emissions
- Simple storage and transport as bulk material, re-use of transport infrastructure (ships, railways, ports)
- No water exports
- Competitive energy efficiency & LCOE
- Reduction of iron oxides: synergies with steel industry (TRL 6-7)

The unique properties of metal fuels, along with preliminary studies conducted at TU Darmstadt, TU Eindhoven, and McGill University Montreal, provide a strong basis for optimism regarding their potential to enable large-scale storage and transport of renewable energy.

Within the interdisciplinary framework of the Clean Circles project, encompassing over 20 subprojects across engineering, natural sciences, humanities, and social sciences, the Chair of Energy Economics contributes its expertise in energy system analysis. Model-based investigations have been conducted to assess the potential of iron and aluminum as fuels, comparing their performance to alternatives such as liquid hydrogen, ammonia, and methanol. This work has laid the foundation for integrating metal fuels into spatially and temporally resolved energy system models developed at KIT, such as the PERSEUS model family. Energy system modeling can assess the potential of metal fuels in Europe's energy transition, with a particular focus on cost reduction through the utilization of existing infrastructure.

CO2Inno - Real laboratory CO2-neutral innovation region Upper Rhine

Nora Baumgartner, Daniel Sloot, Leonie Wagner

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 is responsible for conducting research with a focus on technology acceptance. In 2023, the research team started off with a systematic literature review on factors affecting the acceptance of hydrogen-based technologies. Furthermore, the team created a database with best practice examples of municipalities that plan on using a hydrogen-fueled CHP unit. The best practices were examined in more detail in 2024. A policy brief transferred the lessons learned to the municipal partners of this project.

Moreover, DFIU conducted research on the acceptance and risk perception of smart meter technology. In the course of a joint French-German teaching format, a survey on the risk perception of smart meters, perceived barriers, and opportunities for the energy transition was conducted in both countries.

Kofinanziert von der Europäischen Union
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Interreg Oberrhein | Rhin Supérieur

DEIMOS: Intelligent self-consumption and storage for better use of energy

Anthony Britto, Leandra Scharnhorst, Max Kleinebrahm

Funding: Stiftung Energieforschung Baden-Württemberg

Duration: 04/2024 to 06/2026

The European Green Deal and the "Fit for 55" package aim to achieve greenhouse gas neutrality by 2050, with some nations setting even more ambitious targets by 2045. This transformation involves transitioning to renewable energy sources, displacing fossil fuels from the energy mix, and reducing emissions across various energy demand sectors. Industry in particular, which is responsible for 20% of CO2 emissions in Europe, faces the challenge of reducing both energy-related and process-related emissions due to its large share of energy-intensive processes. Modelling the development of industrial final energy demand can support the analysis and implementation of decarbonization measures in the respective economic sectors. Detailed data sets are essential for this. Therefore, this project adopts an Open Science approach to model European industrial energy consumption and emissions based on high-resolution scenarios, making datasets and models publicly accessible. The project analyzes historical industry trends and the current status to develop future scenarios, considering numerous decarbonization measures. The implementation of the decarbonization measures is parameterized using different scenarios and modelled in a simulation of final industrial energy demand in order to assess their effectiveness in achieving European and national targets. These scenarios range from moderate to ambitious and aim for greenhouse gas neutrality by 2050, 2045 and 2035, taking into account EU and Member State targets. Through scenario modeling, the project assesses energy mixes, emission impacts and the potential of demand-side management at industrial sites. In addition, the increased need for flexibility on the part of industry due to the increasing share of renewable fluctuating energy sources in the energy mix to ensure security of supply is taken into account. Studies on the flexibility potential of various industrial processes have already been carried out, but so far do not offer an open access database with regard to the technical data used. A comprehensive open access database on the temporally and spatially high-resolution industrial energy demand, as well as emission balances and the model code of the calculated scenarios (open source) will be published at the end of the project.

Stiftung
Energieforschung
Baden-Württemberg

En4U – Pathways of a decentralized energy system considering decisions of private and commercial actors under uncertainty

Daniel Sloot, Stephanie Stumpf

Partners: 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 07/2024

The En4U project investigated uncertainties in the energy market and their impact on the operating and investment decisions of households based on three technologies with different market penetration (PV battery storage systems, electric vehicles and heat pumps).

The precise modeling of uncertainties in energy system analysis is of central importance for future energy systems. However, it is difficult to transfer individual decisions to the system level. Therefore, the project combined the agent-based model AMIRIS with a stochastic optimization and a diffusion model for three technologies that increase flexibility. These three micro-models are aggregated with machine learning (ML) to capture the system level. The aim of the project was to analyze the operation and investment decisions of households with regard to PV, electric cars and heat pumps as well as the operation and investment of portfolios of modern conventional and fluctuating renewable power plants in combination with storage, taking into account the respective influences of uncertainties. This also includes interactions between the actors on the electricity market, which were investigated on the basis of an abstraction of individual decisions using neural networks. Taking these interactions into account, explorative development paths of the energy system were finally analyzed and prepared to support decisions on political instruments and regulatory framework conditions.

In a first step, the project analyzed and quantified the uncertainties to which the actors are exposed. Not only economic, meteorological or political uncertainties were taken into account, as is so often the case in energy market research, but also social and qualitative aspects that are often neglected. Taking these uncertainties and other relevant factors (e.g. funding instruments) into account, the future market penetration of the technologies mentioned was analyzed using diffusion models. The operation of these technologies in households was first modeled at the level of individual households and then abstracted with the help of neural networks (NN) in such a way that the operating decisions and the resulting demand could be efficiently integrated into comprehensive energy system models. By developing and applying suitable methods of stochastic optimization, the initially analyzed uncertainties for operators of conventional and renewable power plant portfolios were mapped and their decisions optimized taking into account the supply side. All partial results and models were then coupled with an agent-based electricity market simulation.

The IIP was involved in several parts of the project and was particularly responsible for diffusion modeling.

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)

Alexander Plarre, Eric Jahnke, Leandra Scharnhorst

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 System Design (ESD)

Armin Ardone, Max Kleinebrahm, Thorben Sandmeier, Leandra Scharnhorst, Wenxuan Hu

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 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. Furthermore, options for the future market design of ancillary services in Europe will be developed in the context of the energy transition, evaluated using various indicators of resource adequacy and tested and validated using extreme weather events as examples.

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 are evaluated. For instance, this year we conducted two residential phases. The experiments assessed consumer acceptance and behavior regarding residential CO_2-budgets and the willingness to keep within a given CO_2-budget in accordance with (non)-economic incentives. Furthermore, we publish selected shares of the collected quantitative data regarding electricity and heating demand.

ENSURE 3 – New Electrical Grid Structures for the Energy Transition

Christian Perau, Julius Beranek, Kira Layer, Rafael Finck, Thorben Sandmeier, Armin Ardone

Partners: AllgäuNetz GmbH & Co. KG, Avacon Netz GmbH, BUW, CAU, DUH, DVGW-EBI, E.ON, eMessage, EWI, FAU, Germanwatch, Hitachi Energy, Hochschule München, KIT, LVN, Maschinen Fabrik Reinhausen GmbH, Öko-Institut, OPAL RT Technologies, PSI Software AG, RWTH, Siemens AG, SWB, swa, SW Kiel, Stadtwerke Meerbusch, TU Dortmund, TU Ilmenau, TenneT TSO GmbH, Westfalen Weser Netz

Funding: Federal Ministry of Education and Research
Duration: 01.08.2023 – 31.07.2026

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. In phase 3, ENSURE addresses the following key challenges to the electrical grids as the backbone of the energy transition:

- The geographic focal points of generation and consumption are shifting. The electrical grid must be adapted for longer distances and increasing capacities.
- The electrical grid must support the coupling with other energy sectors (gas, mobility, buildings) and enable synergies ('sector integration').
- The fluctuating power input of renewable sources must be balanced.
- The necessary system services must still be provided and coordinated even after the decommissioning of large power plants.

At the IIP, we work in three working packages. First, we evaluate the expansion of energy networks in the electricity, natural gas, and hydrogen sectors using an integrated energy system model. This allows to predict infrastructure needs in the different sectors when planned conjunctively. Second, we evaluate battery electricity storage systems by optimizing bidding strategies of battery storages in sequential markets and analyze the impact of flexibility in the industrial sector on grid fees. Third, we perform a regionalization of scenario data for Germany and adjacent countries in order to provide technologically, temporarily, and spatially highly resolved data that are the basis for different simulations and optimizations of different partners in the project.

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

Innofuels platform - networking, further development and framework conditions for the ramp-up of electricity-based fuels and advanced biofuels

Andreas Rudi, Viktor Slednev, Paul Heinzmann, Alexander Schneider, Uwe Langenmayr

Partners: Karlsruhe Institut für Technologie – IIP, IFKM, IKFT, Mineralölraffinerie Oberrhein GmbH & Co. KG, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Infraserv GmbH & Co. Höchst KG, Institut für Verbrennungstechnik der Luft- und Raumfahrt des DLR, CENA, Hessen Trade & Invest GmbH, Deutsche Lufthansa AG, Lufthansa Aviation Center, Universität Rostock, Lehrstuhl für Kolbenmaschinen und Verbrennungsmotoren, Fakultät für Maschinenbau und Schiffstechnik, Rolls-Royce Solutions GmbH, Dr. Ing. h.c. F. Porsche AG, Volkswagen AG, Deutsches Biomasse-forschungszentrum gemeinnützige GmbH, International PtX Hub Berlin, Hochschule RheinMain, Verkehrsministerium Baden-Württemberg, Wirtschaftsministerium Hessen, Stabsstelle Luftverkehr, Frontier Economics Limited

Funding: Ministry of Transport Baden-Württemberg

Duration: 10/2022 to 04/2026

The "Innofuels Platform" is intended to serve as a platform for the exchange of expertise, discussion and networking in order to promote the ramp-up of electricity-based fuels and advanced biofuels. Various fuels and fuel paths and their applicability to different transport modalities will be analysed. In addition, value and logistics chains will be analysed, sustainability calculated and possible market and regulatory issues addressed. The IIP is working across all chairs on the techno-economic analysis with a focus on production.

reFuels-Demo: Research-supported measures for the transformation of plants for climate-neutral fuels (reFuels) to an industrial scale

Andreas Rudi, Viktor Slednev, Paul Heinzmann, Uwe Langenmayr

Partners: Karlsruhe Institut für Technologie – IIP, IFKM, IKFT, ITAS, DLR

Funding: Ministry of Transport Baden-Württemberg

Duration: 05/2023 to 12/2024

The "reFuels - Rethinking Fuels" project researched the production and use of renewable fuels for various modes of transport. The aim is to power existing combustion engines in aircraft, heavy goods vehicles, commercial vehicles and rail vehicles as well as in vehicle fleets. In order to bring the technologies to an appropriate level of maturity, scaling and development towards industrial implementation is required. The next step is therefore the construction of a demonstration plant that produces around 50,000 tonnes/year of these fuels and serves as a platform for technology developers. Scalability and cost efficiency are crucial and require flexible plant configurations. The project aims to integrate this concept into existing refinery environments, taking into account material flows, costs and environmental impact. To be successful, risks in synthesis, product quality, costs and environmental impact must be minimised. The project addresses these aspects in different work packages that form a coherent approach. The plant concept developed forms the basis on which project planners and companies can build. With the successful realisation of the project, Baden-Württemberg is establishing itself as a pioneer for comprehensive mobility solutions to achieve CO_2 and climate targets.

Project website: www.refuels.com

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

Johannes Schuhmacher, Armin Ardone, Viktor Slednev

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, Karlsruhe Institute of Technology (KIT) with institutes IAI, ITC, ITAS

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. This year, we have been looking in detail at the impact of a heat wave in 2026 on electricity prices and security of supply. We have also started developing a server tool for the automated download of energy research data. Together in the project, we analyzed how to connect the individual models to run joint analyses.

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

Armin Ardone, Viktor Slednev, Leandra Scharnhorst

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 2025

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 modelling 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).

In the current project state the final integration of the previously defined of the reference energy system for the power sector into the model frame works is supported while the parametrization of the electricity supply side was finalized in 2024.

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Awards

Congratulations to Max Kleinebrahm – GEE Prize Finalist!

The IIP proudly congratulates Max Kleinebrahm on being one of the three finalists for the prestigious GEE Prize for Best Dissertation, awarded in the Energieforum Berlin. Max's dissertation, "Future Residential Energy System Design," stood out among many submissions from across Germany, impressing a jury of 17 professors. His work contributes significantly to the fields of energy economics and residential energy system analysis, showcasing innovative approaches to shaping sustainable residential energy systems. We applaud Max for his remarkable achievement and wish him continued success in advancing energy research at IIP!

Congratulations to Rafael Finck on His Success at the European Statistics Awards

The IIP is proud to congratulate Rafael Finck on his outstanding achievements at the European Statistics Awards for Nowcasting. Rafael excelled across multiple categories, earning 2nd place in the Gas category, 3rd place in Electricity Availability, and the prestigious Reproducibility Award in the Electricity category. Rafael's innovative work in energy time series forecasting showcased both exceptional accuracy and reproducibility. His success highlights the expertise at KIT-IIP and underscores the importance of data-driven methods in advancing energy research. We commend Rafael for this remarkable accomplishment and wish him continued success in his new role at the Joint Research Centre in Petten.

Recognition for Excellence in Master's Thesis: Hanns-Voith-Stiftung Award for Finn Ohlsen

The IIP warmly congratulates Finn Ohlsen on receiving the prestigious Hanns-Voith-Stiftung Award for his outstanding master's thesis, "Generation of Synthetic Power Price Shapes with Generative Adversarial Networks," in the "Innovation & Technology/Artificial Intelligence" category. Finn's thesis introduces an innovative method for generating synthetic power price curves using generative AI, paving the way for improved evaluation of future investments in renewable energy. The thesis was conducted in close collaboration with EnBW, the Institute of Thermal Turbomachinery (ITS), and IIP. Special thanks and congratulations are extended to Finn's supervisors: Geoffroy Chaussonnet (EnBW), Cihan Ateş (KIT-ITS), and Max Kleinebrahm (KIT-IIP). We also express our gratitude to the Hanns-Voith-Stiftung for recognizing and celebrating outstanding achievements in science and engineering through this meaningful award and for hosting a memorable ceremony.

Congratulations to Andreas Epple on the IIP-Bridge Sustainability Award

The IIP is proud to congratulate Andreas Epple on receiving the IIP-Bridge Sustainability Prize for his outstanding master's thesis, "Generative Adversarial Networks for Monte Carlo Simulations of Renewable Production." Andreas conducted his work at the Institute of Thermal Turbomachinery, where he explored innovative methods to enhance renewable energy production modeling through advanced AI techniques. His research stands as an important contribution to the field of energy economics and sustainability. The thesis was conducted in close collaboration with EnBW, the Institute of Thermal Turbomachinery (ITS), and IIP. Special thanks and congratulations are extended to Finn's supervisors: Geoffroy Chaussonnet (EnBW), Cihan Ateş (KIT-ITS), and Max Kleinebrahm (KIT-IIP). We commend Andreas for his exceptional achievement and wish him continued success in his future endeavors.

Congratulations to Kevin Krasnikov – Winner of the Roland Berger Best Thesis Award

The Institute for Industrial Production (IIP) proudly congratulates Kevin Krasnikov on receiving the prestigious Roland Berger Best Thesis Award for his outstanding bachelor's thesis, "Analysis of the Economic Potential of Vehicle-to-Grid Technology in Electricity Markets – A Meta-Analysis." Kevin's thesis examined the profitability of V2G technology in electricity markets, analysing a wide range of literature and identifying key influencing factors. Special thanks and congratulations go to Kevin's supervisor, Tim Signer (KIT-IIP), for his guidance and support. We also thank Roland Berger for recognizing excellence in science and engineering through this meaningful award and for hosting a memorable ceremony.

Completed PhD Dissertations and Habilitations

PhD dissertation: “Impacts of the increasing diffusion of residential photovoltaic battery storage systems”

Daniel Fett

The introduction of feed-in tariffs by the Renewable Energy Act in the year 2000 led to the installation of a high number of photovoltaic systems in Germany. Due to increasing household electricity prices, falling feed-in remuneration and cost reductions for battery storage systems, the majority of residential photovoltaic systems are currently installed with battery storage systems to increase self-consumption. While these battery storage systems bring various benefits, their effects are also cause for discussion. Depending on the utilized charging strategy, they could either reduce feed-in peaks and thereby support the system integration of renewable energies or cause unpredictable photovoltaic production peaks, leading to additional stress for the electricity system. Furthermore, increasing self-consumption could lead to undesired distributional effects. Given the efficiency losses during operation and greenhouse gas emissions from production, their environmental benefit is also disputed. For this purpose, a methodological framework consisting of different modules is developed. A net present value-based investment model determines the most profitable system configuration for various sample households and is combined with a bass diffusion model to forecast the German-wide installed battery capacity. Several operational strategies for the battery storage system are examined in a simulation model. The emissions from battery operation are combined with a partial life cycle assessment (cradle-to-gate) for a comprehensive environmental assessment. To incorporate the system perspective, the prosumer models are coupled with an electricity market simulation model. The results show that in the short term, the diffusion of photovoltaic battery storage systems, the self-consumption and feed-in levels, and the resulting electricity price increase depend strongly on the regulation. Due to increasing electricity prices, photovoltaic battery storage systems become profitable in the medium- and long-term, even under a more restrictive regulation. The battery operational strategy has a stronger influence on the system impact and the integration of renewable energies than the installed battery capacity. Furthermore, system-friendly operational strategies are also beneficial for the greenhouse gas balance of the battery storage system and, under certain conditions, can even lead to an overcompensation of the emissions from production. Finally, favorable regulation may also lead to significant potential for providing frequency containment reserve from residential battery storage systems, reducing the frequency containment reserve costs and thus the grid charges.

PhD dissertation: "Techno-economic assessment of market coupling regimes in future electricity systems"

Jan Rafael Finck

Flow-based market coupling is the target model for European electricity markets. It enables increased exchange compared to the previously used net transfer capacity approach but might lead to increased congestions during grid operation, when minimum capacities are enforced. Therefore, considering the transmission grid becomes imperative in analysing the (future) European electricity markets. Market coupling and grid curtailment are determining factors for both the economic viability of investments in renewable energy sources and their actual share in the power mix. Given the delay in grid expansion, a comprehensive understanding of the interdependencies between market clearing and congestion management in the European electricity market is essential to foster effective investments and create an efficient market design. In this thesis, an integrated framework is developed to investigate the impact of flow-based market coupling on market prices and the revenue potential of renewables. To this end, detailed transmission grid data is collected and processed for the existing and future grid in central Europe to simulate flow-based market coupling and the subsequent grid operation. The market model covers the coupled wholesale markets of 48 European bidding zones with a detailed representation of over 2000 thermal power plant units and includes (demand) flexibility providers such as demand response, power-to-heat and e-mobility applications. The approach leverages a highly detailed renewables expansion planning model that enables the simulation of (future) feed-in and demand profiles based on state-of-the-art weather reanalysis. Finally, a method is proposed to integrate approximate flow-based exchange limits in traditional market models that allows simulating market coupling more adequately while retaining the benefits of such models, such as a faster runtime and reduced memory requirements. After quantifying the impacts of an expanded flow-based region and the effects of minimum exchange capacities introduced by the Clean Energy Package of the European Commission, the developed framework is applied to analyse the difference between the use of flow-based constraints and net transfer capacities for market coupling in highly flexible future energy systems with respect to prices, market values and curtailment needs. The results show that solar PV is most affected. With market value differences between -26 % and 56 %, the market coupling regime can determine the economic (non)viability of renewable projects. The reduction of CO_2 emissions in the market domain is more than outweighed by the increased activation of fossil power plants through re-dispatch.

PhD dissertation: "Flexibility options in a sustainable power system - Approaches from different power system perspectives "

Alexandra Ilg

Energy systems are undergoing fundamental structural and regulatory change to meet the challenges of climate change. The term "Energiewende" refers to the change in the energy system from conventional electricity generation from fossil fuels to electricity generation from renewable energy sources. With the increasing share of electricity generation from weather-dependent renewable energy sources, fluctuations in the feed-in to the electricity grid are to be expected. This volatility in electricity generation due to the integration of renewable energy sources poses new challenges for the entire electricity system. In order to compensate for fluctuations in electricity feed-in, flexibility options must be integrated into the electricity system to ensure grid stability and security of supply. In the scope of this dissertation, flexibility options in the sustainable electricity system are examined both from a theoretical perspective and with regard to their political implications. Against the background of the integration of an increasing share of renewable energies in the electricity sector, a differentiated view is taken from a holistic power system perspective as well as from a local power system perspective. From a holistic power system perspective, supply-side and demand-side flexibility options as well as flexibility through the use of storage and the expansion of the grid infrastructure are examined. The starting point is a modeling of the complex interaction of regulated levels and competitive processes, taking into account the interests of the different market actors and their mutual relationships. For this purpose, the electricity market is modeled using multi-level mathematical optimization models, which are combined with approaches from game theory. From the perspective of the local power system, electric vehicles are considered as flexible options. After the importance of electric vehicles for the reduction of emissions and thus for the achievement of climate targets has been presented by means of a reduced life cycle analysis, possible influencing factors for an efficient integration of electric vehicles into the local power system are comprehensively analyzed. Statistical analyses and a two-stage cluster approach will be applied, and a simulation tool will be developed and applied. As a key result, it can be noted that the consideration of flexibility options is of crucial importance in the design of a sustainable electricity market. In addition to the interactions of different flexibility options, the individual risk attitude of the central actors in the power system must also be taken into account in particular in order to create targeted market-based incentives for (flexibility) investments. It is shown that investments in electricity storage by private market participants have a decisive influence on the decisions of the state-regulated grid operator regarding the location and amount of grid investments. Furthermore, it is also shown that the different risk attitudes of private and public investors can lead to different investments in flexibility options. With regard to the integration of electric vehicles as flexibility options in the local power system, the analyses highlight the importance of individual charging behavior and the associated simultaneity factors as central key factors for political decisions. The results of the work thus provide policy implications for the electricity market design in order to successfully integrate flexibility options into the German power system and ensure a sustainable energy supply.

PhD dissertation: "Future Residential Energy System Design"

Max Kleinebrahm

The objective of greenhouse gas-neutral economies and associated advancements in low-carbon technologies lead to a transformation of the way electricity and heat are supplied and consumed. Across the residential sector, rising energy procurement costs alongside decreasing capital costs for renewable energy technologies have driven recent trends toward individual and independent energy supply systems. Further, the electrification of mobility and heating will fundamentally change the structure of electricity demand. A comprehensive understanding of the underlying drivers that shape residential energy demand and supply is essential for designing future energy systems. Models representing fundamental connections that shape energy supply and demand and extrapolate techno-economic framework conditions are needed to predict future dissemination and impacts of building energy systems. In this thesis, neural network-based approaches from the field of natural language processing are introduced to the field of behavioral modeling. The proposed methodology enables the generation of synthetic activity and mobility schedules of household occupants, which form the basis for a consistent simulation of residential electricity, heat, and mobility demand. Based on a detailed understanding of residential energy demand, a bottom-up framework for determining the cost-minimal design and operation of residential energy systems is presented for analyzing buildings under diverse techno-economic framework conditions. Finally, a building owner's microeconomic perspective is expanded by a central planner's macroeconomic perspective to comprehensively analyze the transformation of residential building stocks within the transformation of the surrounding municipal and national energy systems. Through the detailed representation of the heterogeneity and temporal inertia of local building stocks, existing shortcomings of a highly aggregated building stock representation are overcome. The bottom-up framework is applied to evaluate the potential of a self-sufficient energy supply for 41 million single-family buildings in the European building stock. Cost-minimal and self-sufficient energy systems are calculated for 4,000 representative buildings on a high-performance computing cluster. Finally, surrogate models transfer the results to the entire building stock. The results show that under current techno-economic conditions, 53% of the 41 million buildings can technically supply themselves by only using local rooftop solar irradiation. If building owners would be willing to pay a premium of up to 50% compared with grid-dependent systems with electrified heat supplies, over two million buildings could leave the grid by 2050. Results for municipal building stock transformations from the perspective of a central planner for the exemplary city of Karlsruhe indicate that an increase of the retrofit rate to 2% per year and substantial electrification of the heat supply in the building sector is economically and ecologically beneficial.

PhD dissertation: "Development of a techno-economic energy system model considering the highly resolved conversion and multimodal transmission of energy carriers on a global scale"

Viktor Slednev

This dissertation develops an energy system model that enables an integrated and high-resolution analysis of the extraction, conversion, storage, use and multi-modal transportation of energy sources in the context of techno-economic deployment and expansion planning. The focus is on the minimum expenditure coverage of European electricity and heat demand by 2050 in a closed linear multi-period optimization of global energy flows, taking into account multi-modal road, rail and ship transport as well as the electrical and gas-based transmission network infrastructure. The aim is to determine transformation paths for the complete decarbonization of the transformation sector and final energy consumption endogenously and taking sector coupling into account. Based on the structure of existing transport networks and the distribution of remote primary energy potentials, a data-driven approach is developed to resolve the tension triangle between the mapping of high-resolution potentials of energy conversion at the local level, the overall energy balancing at the aggregated level and the spatial and temporal balancing in between across multiple transport modes and energy carriers. For this purpose, top-down and bottom-up approaches are combined and, starting from a uniform regionalization with a resolution of 100m, processes for balancing energy demand and energy supply, which are simulated on the same weather basis, are aggregated and defined. The functionality of the approach is validated in the context of optimizing the cross-sectoral decarbonization of the energy system in the extended European region and the neighboring electricity sector in Central Asia and the MENA region, taking into account additional supply potentials in Patagonia. The expansion of the renewable electricity supply in the area under consideration, flanked by electricity grid expansion measures, forms the basis for the expansion of electricity use, for example in the heating sector, as well as in the conversion sector for the production of hydrogen. The results illustrate, that there is a wide range of technologies involved in the transformation of the energy system. Hydrogen is being expanded via various conversion and transportation routes, both from renewable and fossil energy sources, both on land and at sea. This drives the expansion of the electrical transport networks, including meshed DC networks for the endogenous connection of individual offshore wind farms, and reduces it again elsewhere, for example when the electrical connection of wind farms to land is replaced by feeding into rededicated natural gas pipelines.

Staff as of December 2024

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

M. Sc. Thorben Sandmeier – Sustainable Infrastructures for Renewable Energy Systems

Dr.-Ing. Max Kleinebrahm – Energy Demand and Mobility

Dr. rer. pol. Armin Ardone – Sustainable Energy Markets

Dr. rer. pol. Viktor Slednev – Future Energy Commodities

Dr. Daniel Sloot – Energy and Behavior

Postdocs & Doctoral Researchers and their research-topics

Julius Beranek: Assessing the value of battery electricity storage systems in future electricity markets

Anthony Britto: The diffusion of energy-efficiency technology: process and policy.

Eric Jahnke: Assessment of future European ancillary services in interconnected energy systems and markets.

Uwe Langenmayr: Multi-method analysis of the production and transportation of hydrogen and its derivatives.

Kira Layer: Impacts of extreme temperature and wind events on the European electricity market and security of energy supply.

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

Alexander Plarre: Investigation of the European emission trading system under consideration of emission abatement technologies.

Moritz Raab: Impact of Innovative Mobility Concepts on Local Energy Systems.

Thorben Sandmeier: Analysis of the economic and technical benefits of an increased use of flexible network elements in electrical transmission grids.

Leandra Scharnhorst: Integrated Assessment of Energy Supply Security, Demand Response Challenges, and Decarbonization in Residential, Commercial, and Industrial Sectors.

Johannes Schuhmacher: Disruptive Events and the Importance of Flexibility in Energy Systems.

Julia Schuler: Future renewable energy carriers: hydrogen, hydrogen derivatives and metal fuels.

Tim Signer: Analyzing the Market Integration of Vehicle-to-Grid

Jonathan Stelzer: Inverse determination of techno-economic parameters for competitive emerging electricity storage technologies.

Stephanie Stumpf: Investigating household adoption of renewable energy technologies.

Jonathan Vogl: Activity-based bottom-up models for sector-coupled load profiles of residential buildings.

Leonie Wagner: Influence of socioeconomic status, perceived fairness and perceived effectiveness on policy acceptance

Thorsten Weiskopf: Investigation of RES-support schemes in connected European electricity markets.

International Collaboration

Location: Madrid, Spain

Who: Christian Perau

Host: Sara Lumbreras Sancho, Comillas Pontificial University, Institute for Research in Technology

Period: September to December 2024

Short description of stay: During his three-month research stay at the Comillas Pontificial University Mr. Perau worked on the modelling of large-scale integrated energy system models. Together with his supervisor Sara Lumbreras Sancho, Professor at the Institute for Research in Technology (IIT), they worked on integrating different methodologies from the field of design of experiments (DOE) into a Bender's decomposition framework. This approach allows an efficient way of identifying relations between decision variables in the transmission expansion planning (TEP) helping the convergence of the Bender's decomposition. This methodology will be applied to a large-scale case study to find the optimal pathway of network expansion in the electrical, natural gas, and hydrogen system until 2050.

Location: Leeds, England

Who: Tim Signer, Nora Baumgartner

Host: Prof. Zia Wadud, University of Leeds

Period: 19.3.2024-20.3.2024

Short description of stay: In March, two chair members visited the University of Leeds for a two-day stay with Prof. Zia Wadud and the Leeds Energy scientific community. We presented our current V2G research, highlighting key findings and ongoing technological developments. Additionally, we presented the findings from our comparative survey on the willingness to participate in V2G in the UK and Germany and received valuable feedback. The results were published on the EEM conference in June 2024. The visit fostered productive exchanges and laid the groundwork for potential collaborative efforts.

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 ~105 students
Prof. Dr. rer. pol. W. Fichtner
M. Sc. T. Sandmeier
M. Sc. L. Scharnhorst

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 ~110 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 ~35 students
Apl. Prof. Dr. rer. pol. M. Wietschel
M. Sc. Nora Baumgartner
M. Sc. J. Schuhmacher

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 follow. 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 are discussed. The final part deals with implementation strategies of material and energy policy.

Liberalised Power Markets ~60 students
Prof. Dr. rer. pol. W. Fichtner
M. Sc. T. Signer
M. Sc. J. Beranek

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 ~35 students
Dr. rer. pol. E. Kraft

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
M. Sc. A. Britto

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
M. Sc. S. Stumpf

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.

Machine Learning and Optimization in Energy Systems ~20 students
Dr.-Ing. T. Dengiz
Dr. Ing. H. Ü. Yilmaz
M. Sc. C. Perau

This course deals with the role of optimization and machine learning approaches in future energy systems with high shares of renewable energy sources. It covers optimization basics, heuristic methods, and multiobjective optimization, as well as unsupervised, supervised, and reinforcement learning, with applications like power plant dispatch, heat pump control, EV charging strategies, energy data clustering, and demand/renewable forecasting. A voluntary Python-based exercise deepens practical understanding, focusing on applications rather than mathematical theory.

(Smart) Energy Infrastructure ~35 students
Dr. rer. pol. A. Ardone
Prof. Dr. Dr. A. M. Pustisek
M. Sc. J. Schuler

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 ~180 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 ~175 students
Prof. Dr. rer. pol. W. Fichtner
M. Sc. J. Schuler
M. Sc. A. Plarre

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, 5,5 ECTS)
• Energy Trading and Risk Management (SS, 3,5 ECTS)
• Simulation Game in Energy Economics (SS, 3,5 ECTS)
• Quantitative Methods in Energy Economics (WS, 3,5 ECTS)</td><td><u>Master Module „Energy Economics and Technology“</u>

• (Smart) Energy Infrastructure (WS, 5,5 ECTS)
• Efficient Energy Systems and Electric Mobility (SS, 3,5 ECTS)
• Energy and Environment (SS, 3,5 ECTS)
• Heat Economy (SS, 3,5 ECTS)
• Machine Learning and Optimization in Energy Systems (WS, 3,5 ECTS)</td></tr>
<tr><td colspan="2"><u>Industrial Business Administration (WS, 3 ECTS)</u></td></tr>
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Publications

University Publications

Fett, D. (2024). *Impacts of the increasing diffusion of residential photovoltaic battery storage systems* [Dissertation, Karlsruher Institut für Technologie (KIT)].

Finck, J. R. (2024). *Techno-economic assessment of market coupling regimes in future electricity systems* [Dissertation, Karlsruher Institut für Technologie (KIT)]. https://doi.org/10.5445/IR/1000173514

Ilg, A. (2024). *Flexibility options in a sustainable power system - Approaches from different power system perspectives* [Dissertation, Karlsruher Institut für Technologie (KIT)]. https://doi.org/10.5445/IR/1000170476

Kleinebrahm, M. (2024). *Future Residential Energy System Design* [Dissertation, Karlsruher Institut für Technologie (KIT)]. https://doi.org/10.5445/IR/1000170239

Slednev, V. (2024). *Development of a techno-economic energy system model considering the highly resolved conversion and multimodal transmission of energy carriers on a global scale* [Dissertation, Karlsruher Institut für Technologie (KIT)]. https://doi.org/10.5445/IR/1000170863

Peer-Reviewed Journals

Britto, A., Dehler-Holland, J., & Fichtner, W. (2024). Wealth maximisation and residential energy-efficiency retrofits: Insights from a real options model. *Energy Economics*, 140, 108022. https://doi.org/10.1016/j.eneco.2024.108022

Dengiz, T., and Kleinebrahm, M., Imitation learning with artificial neural networks for demand response with a heuristic control approach for heat pumps, *Energy and AI*, vol. 18, 2024, 100441. doi: 10.1016/j.egyai.2024.100441

Hu, W., Scholz, Y., Yeligeti, M., Deng, Y., and Jochem, P., Future electricity demand for Europe: Unraveling the dynamics of the Temperature Response Function, *Applied Energy*, vol. 368, 2024, 123387. doi: 10.1016/j.apenergy.2024.123387

Langner, F., Kovačević, J., Zwickel, P., Dengiz, T., Frahm, M., Waczowicz, S., Çakmak, H. K., Matthes, J., & Hagenmeyer, V. (2024). Coordinated price-based control of modulating heat pumps for practical demand response and peak shaving in building clusters. *Energy and Buildings*, 324, 114940. https://doi.org/10.1016/j.enbuild.2024.114940

Limbach, K., What role for environmental cooperatives in collective agri-environmental schemes? *Journal of Environmental Planning and Management*, vol. 67, no. 7, 2024, pp. 1409–1433. doi: 10.1080/09640568.2023.2174414

Misconel, S., Zimmermann, F., Mikurda, J., Möst, D., Kunze, R., Gnann, T., Kühnbach, M., Speth, D., Pelka, S., and Yu, S., Model coupling and comparison on optimal load shifting of battery electric vehicles and heat pumps focusing on generation adequacy, *Energy*, vol. 305, 2024, 132266. doi: 10.1016/j.energy.2024.132266

Ranaboldo, M., Aragüés-Peñalba, M., Arica, E., Bade, A., Bullich-Massagué, E., Burgio, A., Caccamo, C., Caprara, A., Cimmino, D., Domenech, B., Donoso, I., Fragapane, G., González-Font-de-Rubinat, P., Jahnke, E., Juanpera, M., Manafi, E., Rövekamp, J, and Tani, R., A comprehensive overview of industrial demand response status in Europe, *Renewable and Sustainable Energy Reviews*, vol. 203, 2024, p. 114797. doi: 10.1016/j.rser.2024.114797

Risch, S., Weinand, J. M., Schulze, K., Vartak, S., Kleinebrahm, M., Pflugradt, N., Kullmann, F., Kotzur, L., McKenna, R., and Stolten, D., Scaling energy system optimizations: Techno-economic assessment of energy autonomy in 11,000 German municipalities, *Energy Conversion and Management*, vol. 309, 2024, 118422. doi: 10.1016/j.enconman.2024.118422

Scharnhorst, L., Sloot, D., Lehmann, N., Ardone, A., and Fichtner, W., Barriers to demand response in the commercial and industrial sectors – An empirical investigation, *Renewable and Sustainable Energy Reviews*, vol. 190, part B, 2024, 114067. doi: 10.1016/j.rser.2023.114067

Schuler, J., Ardone, A., and Fichtner, W., A review of shipping cost projections for hydrogen-based energy carriers, *International Journal of Hydrogen Energy*, vol. 49, part B, 2024, pp. 1497–1508. doi: 10.1016/j.ijhydene.2023.10.004

Signer, T., Baumgartner, N., Ruppert, M., Sandmeier, T., and Fichtner, W., Modeling V2G spot market trading: The impact of charging tariffs on economic viability, *Energy Policy*, vol. 189, 2024, p. 114109. doi: 10.1016/j.enpol.2024.114109

Silber, F., Scheubner, S., and Märtz, A., Analysis of the simultaneity factor of fast-charging sites using Monte-Carlo simulation, *International Journal of Electrical Power & Energy Systems*, vol. 155, part B, 2024, 109540. doi: 10.1016/j.ijepes.2023.109540

Sloot, D., and Bostrom, A., The role of framing in public support for direct air capture: A moral hazard survey experiment in the United States, *Energy Research & Social Science*, vol. 116, 2024, p. 103694. doi: 10.1016/j.erss.2024.103694

Will, C., Zimmermann, F., Ensslen, A., Fraunholz, C., Jochem, P., and Keles, D., Can electric vehicle charging be carbon neutral? Uniting smart charging and renewables, *Applied Energy*, vol. 371, 2024, 123549. doi: 10.1016/j.apenergy.2024.123549

Conferences

Baumgartner, N., Klumpp, N., Signer, T., Wadud, Z., and Fichtner, W., Users' Willingness to Participate in V2G – A Comparison Between German and UK Households, 2024 *20th International Conference on the European Energy Market (EEM)*, Istanbul, Turkiye, 2024, pp. 1-8. doi: 10.1109/EEM60825.2024.10609014

Beranek, J., Zietlow, S., Weiskopf, T., Ardone, A., and Fichtner, W., Financial Economic Relief using Grid-Scale Battery Storage Systems in Future Electricity Markets, 2024 20th *International Conference on the European Energy Market (EEM)*, Istanbul, Turkiye, 2024, pp. 1-6. doi: 10.1109/EEM60825.2024.10608943

Glynos, D., Weiskopf, T., Lorenz, L., and de la Fuente Munita, L., Strategic Bidding Zone Configuration for Enhanced Grid Efficiency: A Case Study of Germany's Electricity Market, 2024 20th *International Conference on the European Energy Market (EEM)*, Istanbul, Turkiye, 2024, pp. 1-6. doi: 10.1109/EEM60825.2024.10608844

Goerke, N., Märtz, A., and Baumgart, I., Who Controls Your Power Grid? On the Impact of Misdirected Distributed Energy Resources on Grid Stability, 2024 15th ACM *International Conference on Future and Sustainable Energy Systems (e-Energy '24)*, Singapore, 2024, pp. 46–54. doi: 10.1145/3632775.3661943

Scharnhorst, L., Xie, X., Kleinebrahm, M., and Fichtner, W., Techno-Economic Analysis of Future Process-Specific Demand Response in European Industries, 2024 20th *International Conference on the European Energy Market (EEM)*, Istanbul, Turkiye, 2024, pp. 1-10. doi: 10.1109/EEM60825.2024.10608488

Weiskopf, T., Jahnke, E., Kleinebrahm, M., and Britto, A., Impacts of climate change on the European electricity market, 2024 20th *International Conference on the European Energy Market (EEM)*, Istanbul, Turkiye, 2024, pp. 1-6. doi: 10.1109/EEM60825.2024.10608934

Working Papers and Other Publications

Dengiz, T., Raith, A., Kleinebrahm, M., Vogl, J., and Fichtner, W., Pareto local search for a multi-objective demand response problem in residential areas with heat pumps and electric vehicles, *arXiv preprint* arXiv:2407.11719, 2024

Guetlein, M.-C., Sebi, C., Faure, C., Sloot, D., Rauch, D. I., and Schleich, J., *In France and Germany, politics – not nationality – dictate energy preferences*, The Conversation, 2024. Available at: https://theconversation.com/in-france-and-germany-politics-not-nationality-dictate-energy-preferences-230164

Scharnhorst, L., Schuhmacher, J., Jahnke, E., Signer, T., Kleinebrahm, M., Ardone, A., and Fichtner, W., *Integrating flexible demand in the sectors industry and households into the agent-based electricity market model PowerACE*, Poster presented at Agent-Based Modeling for Energy Economics and Energy Policy (ABM4Energy 2024), Freiburg im Breisgau, Germany, March 21–22, 2024

Scharnhorst, L., and Hollert, F., *Unlocking Tomorrow's Decarbonization Potential: A Techno-Economic Assessment of Carbon Capture Diffusion in the European Industrial Landscape*, Presentation given at eceee Zero Carbon Industry (2024), Antwerp, Belgium, January 30–31, 2024

Schuhmacher, J., Jahnke, E., Weiskopf, T., Signer, T., Scharnhorst, L., Ardone, A., and Fichtner, W., *PowerACE – Agent-based electricity market model*, Poster presented at Agent-Based Modeling for Energy Economics and Energy Policy (ABM4Energy 2024), Freiburg im Breisgau, Germany, March 21–22, 2024

Signer, T., Sandmeier, T., Weiskopf, T., Kleinebrahm, M., and Fichtner, W., *Electric Mobility in PowerACE*, Poster presented at Agent-Based Modeling for Energy Economics and Energy Policy (ABM4Energy 2024), Freiburg im Breisgau, Germany, March 21–22, 2024

Weiskopf, T., Signer, T., Stelzer, J., Ardone, A., and Fichtner, W., *PowerACE from a computational view*, Poster presented at the 10th bwHPC Symposium (2024), Freiburg im Breisgau, Germany, September 25–26, 2024

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