

# Annual Report 2025

## 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 2025. The five research groups “Energy and Behavior”, “Energy Demand and Mobility”, “Sustainable Energy Markets”, “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 24 research and four administrative staff, divided across these five groups.



During 2025, we worked on around 15 ongoing national and international research projects and started three new projects. We published around 12 peer-reviewed journal articles, seven conference papers and one PhD was 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): Stephanie Stumpf, Dr. Daniel Sloot, 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 the acceptance and adoption of energy technologies as well as the public support for energy policies. The group conducts empirical studies using experimental methods (randomized controlled trials), longitudinal panel studies, and field studies, as well as simulation studies using agent-based modeling approaches. Current topics include the diffusion of electric heat pumps, policy support for the sustainable energy transition, and risk perceptions around energy security.

### Energy Demand and Mobility Group

*Head of research group: Dr.-Ing Max Kleinebrahm*



Members of the research group (fltr): Moritz Raab, Anthony Britto, Max Kleinebrahm, Leandra Scharnhorst, Linus Heepmann (HiWi); Jonathan Vogl, Tim Signer

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, Christian Perau, Kira Layer, Stephanie Gutmayer

The research group focuses on developing advanced tools, innovative methods and comprehensive datasets to enable scenario-based techno-economic analyses for electricity, gas and hydrogen transport

networks within the framework of European decarbonization objectives. Our work addresses a wide range of topics, including the integrated planning and coordinated operation of multi-energy transport networks, the techno-economic evaluation of emerging components and technologies for electricity grids, the influence of sector coupling technologies on energy systems, and the complex interdependencies between market design and infrastructure development. Furthermore, the research explores the potential impacts of climate change and extreme weather events on energy systems and security of supply.

## Sustainable Energy Markets Group

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



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

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. Viktor Slednev*



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

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<sub>2</sub> – 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 – 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 2025, a mid-project workshop was held in Kehl with all participating academic partners to exchange the latest findings from the respective work packages. In order to investigate the acceptance of households, a quantitative survey was conducted among French (680) and German (800) homeowners to understand factors that explain household acceptance of residential 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*

**Partner:** 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 – 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 2025:

- Development of V2G module in agent-based-electricity market model
- Analysis of MID2023 data
- Analysis of V2G electricity market participation and corresponding price effects



Federal Ministry  
for Economic Affairs  
and Climate Action

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

*Dr. Armin Ardone, Thorsten Weiskopf*

**Partner:** IZES gGMBH, Technical University of Denmark

**Funding:** Federal Ministry for Economic Affairs and Climate Action (03EI1069B)

**Duration:** 11/2023 – 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:

- 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. Bidding strategies have been identified from the existing bidding curves that lead to electricity market price increases compared to marginal cost-based bids.
2. A learning agent depicts the relevant bidding strategies in European electricity market models.
3. The influence of the bidding strategies on electricity prices and investments in a future electricity system with high shares of renewable energies and storage is determined.



Federal Ministry  
for Economic Affairs  
and Climate Action

### CARE-o-SENE - Catalyst Research for Sustainable Kerosene

*Paul Heinzmann, Uwe Langenmayr, Andreas Rudi, Manuel Ruppert*

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

**Funding:** Federal Ministry of Research, Technology and Space

**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 H<sub>2</sub> and sustainable carbon dioxide. A

decisive success factor for viable long-term SAF PtL projects will be a competitive FT catalyst with high conversion efficiencies and yields to the desired SAF product, for which demand is expected to grow rapidly in future. The goal of CARE-o-SENE is the accelerated and knowledge-based development of Fischer-Tropsch catalysts for the highly efficient and sustainable production of green SAFs in relevant volumes for the transformation of the aviation sector. The IIP will contribute to this project with the techno-economic analysis of the developed processes and technologies.



Federal Ministry  
of Research, Technology  
and Space

## 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<sub>2</sub> 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.



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<sub>2</sub> 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:



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.

This year, we conducted a systematic review of how electric vehicles are represented in energy system

models. In addition, we developed an approach to simulate Germany's population and map it to individual buildings, providing a geographically resolved foundation for modeling electric vehicle adoption and the mobility behavior of individual households and persons.

### 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.

Funded by  
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## Clean Circles

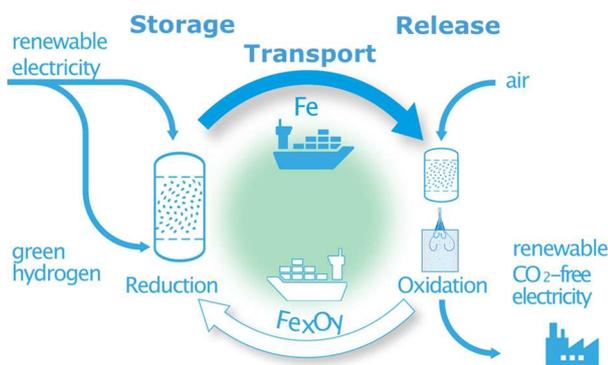
Julia Schuler, Armin Ardone

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

**Funding:** Strategy Fund of the KIT Presidium

**Duration:** 06/2022 – 03/2025

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. To assess the potential of metal fuels in Europe's energy transition, with a particular focus on cost reduction through the utilization of existing infrastructure, energy system models are applied in a successor project (Transformation europäischer Energieinfrastrukturen für die Energieträger von morgen).



## CO<sub>2</sub>Inno - Real laboratory CO<sub>2</sub>-neutral innovation region Upper Rhine

Leonie Wagner, Daniel Sloot, Nora Baumgartner

**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 – 09/2025 (concluded)

The project "CO<sub>2</sub>Inno" was coordinated by the University of Freiburg. Ten other financed partners

from Germany and France were represented in the project consortium. The European Union supported the project with a total of 2,556,522 million Euros from the European Regional Development Fund (ERDF). The objectives of the project were 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 were 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 final project report is available on the project website: <https://co2inno.com/project-results-and-final-report/>

The KIT-IIP/DFIU was 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. A concise, practice-oriented overview of the policy-brief was provided through a flyer. In 2025, research on the acceptance of public EV charging points complemented the systematic literature review and best practices. In a large, binational survey, data on the acceptance of hydrogen-based CHPs and EV charging points and influencing factors was collected. The results of that survey were reported in a poster and formed the basis of the final report, along with the results from two workshops conducted with the public in 2025 and an expert survey conducted in 2025. The final report provides a guideline on the realization of municipal projects for innovative technologies.

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. In 2025, a larger, binationally representative survey built on the results of the earlier survey and examined factors influencing the acceptance of smart meters and their applications, with a focus on perceived cyber-security risks.



### **DEIMOS: Decarbonizing the European Industry – Modelling and Open Science**

*Anthony Britto, Leandra Scharnhorst, Max Kleinebrahm, Wolf Fichtner*

**Funding:** Stiftung Energieforschung Baden-Württemberg **Duration:** 04/2024 – 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 CO<sub>2</sub> 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 future potential

technology diffusion is investigated in a bottom-up, site-specific industrial energy demand model, in order to assess their effectiveness in achieving European and national targets. Through scenario modeling, the project assesses energy mixes, emissions, and the impact of production and investment decisions 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.



### 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 – 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.



Funded by  
**DFG** Deutsche  
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German Research Foundation

## Energy System Design (ESD)

*Armin Ardone, Eric Jahnke, Max Kleinebrahm, Thorben Sandmeier, Leandra Scharnhorst*

**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 – 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<sub>2</sub>-budgets and the willingness to keep within a given CO<sub>2</sub>-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, 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 Research, Technology and Space

**Duration:** 08/2023 – 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 four working packages. First, we participate in the evaluation of the solutions to different challenges in the energy transition that have been developed within the ENSURE project. These solutions will be categorized by the grid level they can be applied to and the benefits they can bring in contexts such as economic, social, or technical. Second, 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. Third, 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. Fourth, 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.



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

*Andreas Rudi, Manuel Ruppert, 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, Infraserb 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 Biomasseforschungszentrum gemeinnützige GmbH, International PtX Hub Berlin, Hochschule RheinMain, Verkehrsministerium Baden-Württemberg, Wirtschaftsministerium Hessen, Stabsstelle Luftverkehr, Frontier Economics Limited

**Duration:** 10/2022 – 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.



Baden-Württemberg  
MINISTERIUM FÜR VERKEHR



**Funding:** Ministry of Transport Baden-Württemberg

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

*Johannes Schuhmacher, Amin Salimi, 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, Brainer 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 – 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, for example, on a power outage caused by a cyberattack.



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

*Viktor Slednev, Armin Ardone, Anthony Britto*

**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 – 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 of the tertiary, residential and other sectors (as long they are not specified in other subprojects).

By providing a dataset that enabled a meaningful aggregation of regionally and technologically highly disaggregated power generation data within a single-node approach, the IIP supported the demonstration of the SEDOS approach through a harmonized setup of the three OS models across different case studies.

Supported by:



on the basis of a decision by the German Bundestag

### **KoRPSA: Kohlenstoffmanagement für Klimaneutralität: Regionale Potentiale und Systemische Analyse**

*Daniel Sloot, Leonie Wagner*

**Partner:** Albert-Ludwigs-Universität Freiburg, Fraunhofer Institut für System- und Innovationsforschung

**Funding:** Innovationscampus Nachhaltigkeit (ICN)

**Duration:** 04/2025 – 12/2026

The goal of reducing carbon dioxide emissions in Germany to net zero by 2045 at the latest, as outlined in the Federal Climate Protection Act, requires a fundamental transformation of carbon flows. The wide range of options and their different effects and sustainability implications raise important questions regarding assessment, strategy and implementation.

The KorPSA project clarifies the significance of regional carbon management strategies including negative emissions using the Upper Rhine region as an example, creates the necessary knowledge from a systemic perspective, identifies options for action, promotes networking between stakeholders and thereby supports the sustainable transformation towards climate neutrality in the Upper Rhine region.

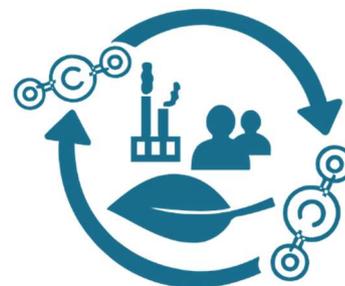
This transdisciplinary research project aims to combine qualitative and quantitative research methods from the participating institutes, integrating perspectives from energy systems modeling, multilevel governance, and behavioral science. At the Institute for Industrial Production, two key areas of focus are planned:

1. Empirical Social Research: The design and implementation of studies to assess public acceptance and perceptions of carbon management.
2. Modeling of Logistical Networks: The development and analysis of essential transport and

infrastructure networks for the implementation of carbon management strategies.

The Chair of Energy Economics focuses on the empirical social research by conducting quantitative survey studies. The aim is to generate a better understanding of how the public perceives carbon management technologies, such as carbon capture and storage or direct air capture. Through quantitative surveys, the project wants to understand which technologies are relatively more supported by the public and what factors determine acceptance. A particular focus is on the question of how carbon management strategies fit into existing mitigation strategies without undermining them.

The project is funded as part of the Innovation Campus Sustainability by the Ministry of Science, Research and the Arts of the State of Baden-Württemberg.



### **SiVEx – Sicherstellung der Versorgungssicherheit im Strom- und Gassektor unter Berücksichtigung von Extremereignissen**

#### **SiVEx – Ensuring security of supply in the electricity and gas sectors, taking into account extreme events**

*Stephanie Gutmayer, Thorben Sandmeier, Armin Ardone*

**Partner:** KIT-IIP, University of Duisburg-Essen

**Funding:** Stiftung Energieforschung Baden-Württemberg

**Duration:** 06/2025 – 05/2028

The SiVEx Project investigates the security of supply of the future European energy system in the context of two developments. First, the transition to greenhouse gas neutrality by 2045 is driving structural changes such as the phase-out of fossil-based power generation, increasing electrification of heating and cooling and the emergence of hydrogen as a substitute for natural gas, leading to stronger interdependencies between electricity and gas systems. Second, climate change introduces increasing uncertainty through a rising probability of extreme weather events, affecting both weather-dependent renewable generation and temperature-sensitive energy demand. These developments motivate the probabilistic and system-integrated analysis pursued in this project, which evaluates security of supply in the current energy system, during the transition phase, and in a climate-neutral target system. Particular attention is paid to the occurrence probabilities and system impacts of extreme weather events.

During the transition phase, natural gas is expected to continue to play a central role in ensuring security

of supply, but is eventually expected to be replaced by hydrogen. However, the availability of hydrogen depends on the development of international markets and is associated with geopolitical risks. Scarcity situations for gas and hydrogen, as seen in the winter of 2021/2022, can lead to price spikes and supply constraints affecting both the electricity and gas systems. Infrastructure challenges arise from the volatility of renewable generation and the gradual coupling and repurposing of gas and hydrogen networks.

Methodologically, the project combines probabilistic analyses with an agent-based market model and an integrated electricity and gas model. Probabilistic time series of electricity and gas demand as well as renewable generation are created based on climate projections. The market model captures operational behaviour and investment decisions of system actors, including generation and storage assets. These investment decisions provide inputs for the network model, which assesses technical feasibility through power and gas flow optimization in transmission networks. The modelling framework accounts for changing infrastructure, including the repurposing of gas infrastructure and the development of hydrogen networks.



### **Transformation europäischer Energieinfrastrukturen für die Energieträger von morgen**

#### **Transformation of European Energy Infrastructures for Tomorrow's Energy Carriers**

*Julia Schuler, Armin Ardone*

**Partner:** none

**Funding:** Stiftung Energieforschung Baden-Württemberg

**Duration:** 09/2025 – 08/2027

Over the past 100 years, Europe has built extensive infrastructure for importing, distributing, storing, and using fossil fuels. Most European countries operate natural gas power plants; in addition, many fossil-fueled steam power plants are in operation,

especially in Eastern and Southeastern Europe as well as Germany. Alongside a dense electricity grid (UCTE<sub>1</sub> network), natural gas pipelines connect European countries with each other and with neighboring states. Furthermore, most countries have underground natural gas storage capacities on the terawatt-hour scale.

This research project aims to investigate how these valuable infrastructures can be transitioned from fossil-based to climate-neutral energy systems, in order to reduce the costs of the energy transition and minimize the occurrence of “stranded assets.” Energy system studies and political decisions in recent years emphasize the central role of hydrogen for decarbonization, as well as its potential for continued use of natural gas infrastructure.

In this project, the conversion of existing natural gas infrastructures - namely European power plants, underground storage facilities, and pipelines - to hydrogen will be analyzed. Strategies for efficiently utilizing Europe’s heterogeneously distributed underground storage capacities through the conversion of existing and development of new caverns, aquifers, and porous reservoirs will be a particular focus.

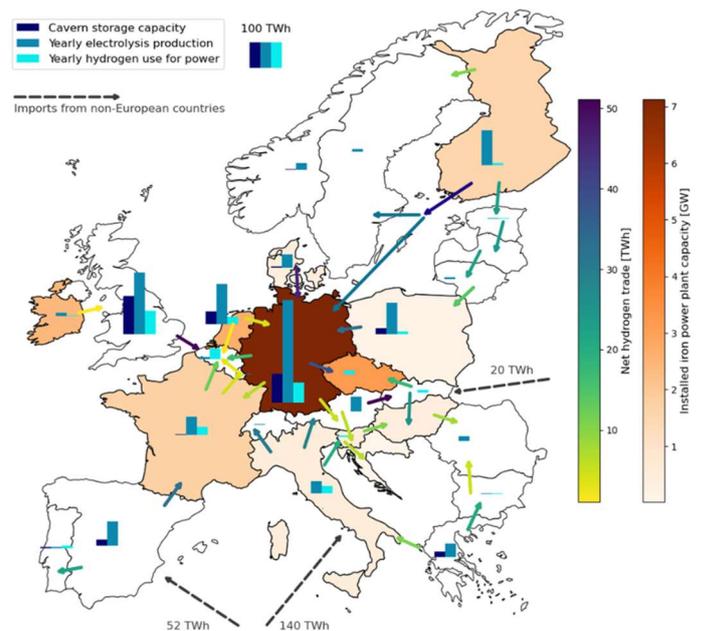
A unique aspect of the project is the inclusion of iron as a metallic energy carrier. Metals are attracting increasing interest worldwide due to their high volumetric energy densities, high availability, and promising characteristics regarding storage, transport, and oxidation behavior. The potential energy use of metals occurs in a cycle between points of use or oxidation and energy-export regions, where energy storage takes place through the reduction of metal oxides. Iron, as a non-toxic and very abundant metal, is a particularly attractive candidate, also because strong synergies exist for the reduction step with the steel industry and its efforts toward hydrogen-based direct reduction of iron ore. Thanks to oxidation characteristics similar to coal, there is also the possibility of continued use of existing steam power plants for electricity generation from iron.

The economic viability of converting European steam power plant sites to iron, compared to electricity generation from hydrogen in new or retrofitted gas turbine power plants, will be examined for the first time in this research project.

To study the development of energy infrastructures for large geographic areas while considering cross-sectoral and temporal aspects (e.g., energy storage), high-resolution energy system modeling is the key tool. In this project, existing resources of KIT/IIP, particularly energy system models of the PERSEUS family, will be used and expanded.

In summary, the goal of the research project is to answer the following questions:

- How can Europe’s existing fossil energy infrastructures and heterogeneous geological storage potentials be efficiently utilized?
- What role can iron fuel play in future energy supply, alongside hydrogen?
- To what extent is the construction of new infrastructure - especially power plants and underground storage - necessary?



### Awards

#### **Congratulations to Uwe Langenmayr – Energie Campus Award for Best Presentation**

The IIP is proud to congratulate Uwe Langenmayr on winning the Stiftung Energie & Klimaschutz – Energie Campus audience award for his presentation on his dissertation titled *Techno-economic and Environmental Assessment of Electricity-based Renewable Hydrogen and Its Derivatives*. Uwe briefly outlined the potential role of hydrogen in the future energy system and the main barriers hindering the upscaling of the hydrogen economy. To address these barriers, he presented the tools he developed for modeling and assessing the production and transport of hydrogen and its derivatives, and explained how these tools support decision-making in investment, operation, and logistics within the future hydrogen economy.



#### **Congratulations to Max Kleinebrahm – Faculty Prize for Interdisciplinary Research**

The IIP is proud to congratulate Max Kleinebrahm on winning the faculty prize in the category Interdisciplinary Research for his dissertation Future Residential Energy System Design. In his dissertation, Max explored how emerging technologies reshape energy demand in the residential building sector. He introduces an AI-based approach to simulate realistic occupant behavior and to model future electricity, heat, and mobility needs. Using a bottom-up optimization framework, he assesses the potential of 41 million single-family homes in Europe for off-grid self-sufficiency. Additionally, he extends a municipal planning model to support cities in transforming their energy systems in line with national climate goals. His work integrates technical, economic, and behavioral perspectives to guide the design of climate-neutral energy systems.

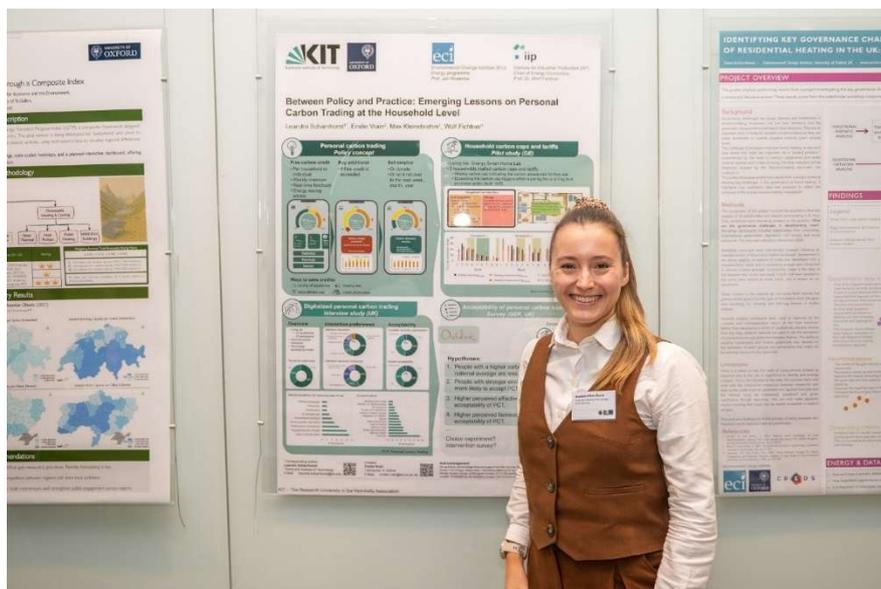
Link to a one-minute presentation of Max's dissertation: <https://www.youtube.com/watch?v=XIK7OLdcLqY>

## Congratulations to Leandra Scharnhorst - First Prize for Visual Design at Oxford Energy Day

The IIP warmly congratulates Leandra Scharnhorst on winning the First Prize for Visual Design at Oxford Energy Day for her poster *"Between Policy and Practice: Emerging Lessons on Personal Carbon Trading at the Household Level"*. The poster presents findings from two living lab studies on personal carbon trading in the residential sector. In Germany, a multi-method intervention in the Energy Smart Home Lab examined how households responded to carbon caps and tariffs, leading emission reductions of 30% to 70% across households. In the UK, the Oxford iDODDLE living lab focused on interviews with 22 households, applying the Technology Acceptance Model to assess willingness to engage with digital personal carbon trading systems.



Together, the studies examine how data-driven and consumer-oriented climate policy instruments may translate into everyday household practice.



### Completed PhD Dissertations and Habilitations

#### **PhD dissertation: “User acceptability of V2G – An empirical investigation”**

*Nora Baumgartner*

Growing climate concerns push policymakers to enact laws to reach national climate goals. In Germany, the “Energiewende” fosters the expansion of renewable energy sources (RES), and simultaneously pursues to reduce the dependency on fossil fuels. In the transport sector, the German Government, among others, aims to shift from internal combustion engine vehicles to electric vehicles (EVs). The widespread adoption of EVs, however, will result in additional electricity demand. Yet, integrating the EV’s battery via a bidirectional power flow into the grid could provide short-term flexibility options for the electricity system. Hence, vehicle-to-grid (V2G) enables a smoother and more efficient integration of large EV numbers and a higher potential of integrating RES into the grid. The adoption of this technology takes place at the local or household level, which, inevitably, assigns the EV owner a key role in the whole V2G system. Achieving system benefits is thus dependent on the user’s acceptance of this technology, highlighting the multilevel and multifaceted character of V2G. This dissertation focuses on the user’s perspective, analyzing different user motivations to adopt V2G technology. To this end, this work first provides a systematic overview of scientific studies in the field of smart charging, assessing how the user is integrated into state-of-the-art research. Secondly, developing three empirical studies, this thesis builds upon several theories, e.g., value belief norm theory, evaluating economic, environmental, technical, and social motives to adopt V2G, using statistical methods, such as mediation analysis and multi-group structural equation modeling. Additionally, the thesis provides comparisons between sub-

groups, i.e., countries (Germany, France, Switzerland, UK), EV experience levels, and between energy initiative members and non-members. Understanding the acceptability of V2G and its underlying motives for different sub-groups is at the core of this thesis. The systematic literature review confirms the existence of typical patterns of how the user is integrated into the different research streams and highlights the need for more in-depth analysis of the user motivations, while calling for integrative research, accounting for the inherent complexity more holistically. The empirical studies analyze user requirements and motivations to adopt a V2G charging tariff, extending current research by using and developing direct rating methods to capture users’ interest in V2G tariff schemes. Results demonstrate, that user requirements about minimum range and monetary compensation are high. Yet, environmental and economic motives positively influence users’ range requirements, and willingness to participate in a V2G charging tariff, raising higher flexibility potentials. Importantly, this especially holds for EV owners. Moreover, battery degradation is perceived as a relevant barrier to V2G, increasing users’ monetary compensation requirements. Next to environmental and economic motives, community factors can act as drivers of adoption interest, too. Specifically, community factors are uniquely related to adoption interest and, furthermore, influence the adoption interest of V2G via personal norms, indirectly. Finally, while motives seem to be similar between the studied countries, EV knowledge levels, and initiative membership have an impact on how V2G is evaluated and which requirements are applied.

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## Staff as of December 2025

### 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

### Doctoral Researchers and their research-topics

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

**Johannes Schuhmacher:** Weather-related disruptive events and their impact on energy markets and systems

**Christian Perau:** Sector coupling and integrated system planning of electricity and gas infrastructure with focus on hydrogen production and energy transmission.

**Thorben Sandmeier:** Enhancing congestion management in electrical transmission grids through the integration of flexible network elements and market-based solutions.

**Thorsten Weiskopf:** Complexity in electricity market and system modelling

**Julia Schuler:** Production, trade and demand of renewable hydrogen, derivatives and metal fuels.

**Eric Jahnke:** Assessment of future European ancillary services and resource adequacy in energy systems.

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

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

**Stephanie Stumpf:** Investigating household adoption of renewable energy technologies

## Staff

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

**Uwe Langenmayr:** Techno-economic and Environmental Assessment of Electricity-based Renewable Hydrogen and its Derivatives

**Leonie Wagner:** Influence of SES, perceived fairness and perceived effectiveness on policy acceptance

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

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

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

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

**Anthony Britto:** Optimal Consumer Adoption of Energy Efficiency.

**Stephanie Gutmayer:** Assessment of security of supply under extreme weather events in a future European energy system

**Amin Salimi:** Energy system reliability and resource adequacy assessment

## International Collaboration

**Location:** Oxford, England

**Who:** Leandra Scharnhorst

**Host:** Prof. Jan Rosenow and Dr. Emilie Vrain, University of Oxford, Environmental Change Institute (ECI)

**Period:** 1<sup>st</sup> June to 30<sup>th</sup> September 2025

**Short description of stay:** Leandra Scharnhorst visited ECI to collaborate with Dr. Emilie Vrain on the iDODDLE living lab project, investigating household acceptability of digital personal carbon trading.

**Location:** Karlsruhe, Germany

**Who:** Dr. Emilie Vrain, University of Oxford (Environmental Change Institute)

**Host:** Daniel Sloot, KIT (IIP)

**Period:** 24<sup>th</sup> November to 18<sup>th</sup> December 2025

**Short description of stay:** Emilie Vrain visited IIP to collaborate on two projects with IIP researchers.

### 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 ten courses in the context of the two master modules "Energy Economics and Energy Markets" and "Energy Economics and Technology". Furthermore, the chair offers several seminars in energy economics where current developments are addressed. The chair supervises on average about 70 bachelor's and master's theses per year.

#### **Introduction to Energy Economics**

~100 students

Prof. Dr. rer. pol. W. Fichtner  
M. Sc. T. Sandmeier  
M. Sc. L. Scharnhorst  
M. Sc. K. Layer  
M. Sc. M. Raab

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**

~90 students

PD Dr. rer. pol. P. Jochem

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

#### **Energy Policy**

~40 students

Apl. Prof. Dr. rer. pol. M. Wietschel  
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**

~80 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** ~50 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** ~10 students  
Dr. rer. pol. M. Genoese  
M. Sc. F. Zimmermann

This course is structured in a theoretical and a practical part. In the theoretical part, the students are taught the basics to carry out simulations themselves in the practical part which comprises amongst others the simulation of the power exchange. The participants of the simulation game take a role as a power trader in the power market. Based on various sources of information (e.g., prognosis of power prices, available power plants, fuel prices), they can launch bids in the power exchange.

**Quantitative Methods in Energy Economics** ~15 students  
Dr. rer. nat. P. Plötz  
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** ~20 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  
Dr.-Ing. M. Kleinebrahm  
M. Sc. E. Jahnke

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** ~65 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**

~20 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**

~40 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**

~100 students

Prof. Dr. rer. pol. W. Fichtner

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.

### **Social Dimensions of Energy**

#### **Transitions**

~10 students

Dr. D. Sloot

This course examines the behavioral and social dimensions of energy transitions in two parts. The first part focuses on the role of energy consumers in the context of household energy use. It explores how energy consumers make decisions regarding their energy use and how these decisions can be influenced by psychological mechanisms and external factors, such as financial incentives. The second part of the course extends this perspective beyond the individual household and examines the social acceptance of energy technologies and policies.

<b><u>Teaching at the Chair of Energy Economics</u></b>	
<b><u>Bachelor Module „Energy Economics“</u></b>	
<ul style="list-style-type: none"> <li>• Introduction to Energy Economics (SS, 5.5-ECTS)</li> <li>• Renewable Energy – Resources, Technologies and Economics (WS, 3.5-ECTS)</li> <li>• Energy Policy (SS, 3.5-ECTS)</li> </ul>	
<b><u>Master Module „Energy Economics and Energy Markets“</u></b> <ul style="list-style-type: none"> <li>• Liberalised Power Markets (WS, 5,5 ECTS)</li> <li>• Energy Trading and Risk Management (SS, 3,5 ECTS)</li> <li>• Simulation Game in Energy Economics (SS, 3,5-ECTS)</li> <li>• Quantitative Methods in Energy Economics (WS, 3,5-ECTS)</li> <li>• Social Dimensions of Energy Transitions (SS, 3,5-ECTS)</li> </ul>	<b><u>Master Module „Energy Economics and Technology“</u></b> <ul style="list-style-type: none"> <li>• (Smart) Energy Infrastructure (WS, 5,5 ECTS)</li> <li>• Efficient Energy Systems and Electric Mobility (SS, 3,5 ECTS)</li> <li>• Energy and Environment (SS, 3,5 ECTS)</li> <li>• Heat Economy (SS, 3,5 ECTS)</li> <li>• Machine Learning and Optimization in Energy Systems (WS, 3,5 ECTS)</li> </ul>
<b><u>Industrial Business Administration (WS, 3-ECTS)</u></b>	

# Publications

### University Publications

Baumgartner, N. (2025). *User acceptability of V2G - An empirical investigation* [Dissertation, Karlsruher Institut für Technologie (KIT)]. <https://doi.org/10.5445/IR/1000183237>

### Peer-Reviewed Journals

Baumgartner, N., Sloot, D., Günther, A., and Hahnel, U., Development and test of a dual-pathway model of personal and community factors driving new energy technology adoption - The case of V2G in three European countries, *Ecological Economics*, 2025, vol. 230, 108514. doi: 10.1016/j.ecolecon.2024.108514

Bertsch, V., Finke, J., Esser, K., Plaga, L., Mersch, M., Stelzer, J., Atakan, B., Fichtner, W., Markides, C., and Sioshansi, R., How can energy-system models inform technology development? Insights for emerging energy-storage technologies, *International Journal of Electrical Power and Energy Systems*, 2025, vol. 173, 111360. doi: 10.1016/j.ijepes.2025.111360

Dehler-Holland, J., From virtuous to vicious cycles – towards a life cycle model of technology deployment policies. *Research Policy*, 2025, 54, 105267. doi: 10.1016/j.respol.2025.105267

Denzig, 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, *Energy*, 2025, 335, 138063. doi: 10.1016/j.energy.2025.138063

Langenmayr, U., Heinzmann, P., Schneider, A., Ruppert, M., Rudi, A., and Fichtner, W., Stand-alone power-to-X production dynamics: A multi-method approach to quantify the emission-cost reduction trade-off, *Journal of Industrial Ecology*, 2025, 29, pp. 1791-1805. doi: 10.1111/jiec.70085

Mishra, S., Silva, T., Hellemo, L., Jaehnert, S., Egner, L., Petersen, S., Signer, T., Zimmermann, F., and Bordin, C., Agent-based modeling: Insights into consumer behavior, urban dynamics, grid management, and market interactions, *Energy Strategy Reviews*, 2025, 57, 101613. doi: 10.1016/j.esr.2024.101613

Miskiwi, K., Kraft, E., and Fleten, S., Coordinated bidding in sequential electricity markets: Effects of price-making, *Energy Economics*, 2025, 144, 108316. doi: 10.1016/j.eneco.2025.108316

Sandmeier, T., Scharnhorst, L., Geis-Schroer, J., Ardone, A., Leibfried, T., and Fichtner, W., Detecting Residential Power Peaks for Innovative Tariff Designs: A Living Lab Experiment, *Energy and Buildings*, 2025, 330, 115350. doi: 10.1016/j.enbuild.2025.115350

Scharnhorst, L., Sandmeier, T., Kleinebrahm, M., and Fichtner, W., Household carbon caps and tariffs: A living lab experiment, *Energy Research & Social Science*, 2025, 127, 104294. doi: 10.1016/j.erss.2025.104294

Schuler, J., Neumann, J., Ardone, A., Dammel, F., Stephan, P., and Fichtner, W., Metals and hydrogen derivatives for long-distance energy supply—A techno-economic comparison, *Energy Conversion and Management*, 2025, 342, 120125. doi: 10.1016/j.enconman.2025.120125

Weinand, J., Kleinebrahm, M., Sanjuan, B., Trutnevyte, E., Treyer, K., Claret, F., Dalla Longa, F., Burgherr, P., van der Zwaan, B., McKenna, R., and Stolten D., The role of geothermal plants in the global energy and materials transition, *Nexus*, 2025, 2, 100099. doi: 10.1016/j.nexs.2025.100099

Weinand, J., Pelser, T., Kleinebrahm, M., and Stolten, D., Countries across the world use more land for golf courses than wind or solar energy, *Environmental Research Communications*, 2025, 7, 021012. doi: 10.1088/2515-7620/adb7bd

## Conferences

Beranek, J., Jochem, P., Ardone, A., Fichtner, W., and Geisert, T., Benefits of Dynamic Electricity Tariffs for Industrial Companies in Germany, 2025 *21st International Conference on the European Energy Market (EEM25)*, Lisbon, Portugal, 2025, pp. 1-5. doi: 10.1109/EEM64765.2025.11050242

Kiefer, V., Kraft, E., Beranek, J., and Signer, T., Optimizing Battery Dispatch Under Consideration of Technical Constraints, 2025 *21st International Conference on the European Energy Market (EEM25)*, Lisbon, Portugal, 2025, pp. 1-7. doi: 10.1109/EEM64765.2025.11050240

Langenmayr, U., Slednev, V., and Heinzmann, P., Power-to-X in Chile, Namibia, and Saudi Arabia: A Systematic Cross-Regional Assessment of Costs, Emissions, and Land Use, 2025 *Hydrogen and syngas - Platform for a sustainable future*, Essen, Germany, 2025, pp. 2–16. ISBN: 978-3-947716-75-3

Layer, K., Perau, C., Fierke, M., Sandmeier, T., and Fichtner, W., A methodology for storage allocation in large-scale integrated energy systems based on nodal prices, 2025 *14. Internationale Energiewirtschaftstagung (IEWT)*, Vienna, Austria, 2025, KITopen-ID: 1000182585

Plarre, A., Slednev, V., and Fichtner, W., Pyseus: Modelling the Mechanisms of the EU ETS in the Decarbonisation of the European Electricity Market, 2025 *21st International Conference on the European Energy Market (EEM25)*, Lisbon, Portugal, 2025, pp. 1-7. doi: 10.1109/EEM64765.2025.11050219

Signer, T., Mack, J., Kleinebrahm, M., Slednev, V., Weiskopf, T., and Fichtner, W., Integration of Block, Linked and Loop Bids in a Market Coupling Algorithm, 2025 *21st International Conference on the European Energy Market (EEM25)*, Lisbon, Portugal, 2025, pp. 1-7. doi: 10.1109/EEM64765.2025.11050140

Stelzer, J., Ardone, A., and Fichtner, W., Modeling the Impact of Mid-Term Storage on Electricity Markets: Insights from Carnot Battery Integration, 2025 *21st International Conference on the European Energy Market (EEM25)*, Lisbon, Portugal, 2025, pp. 1-6. doi: 10.1109/EEM64765.2025.11050107

## Working Papers and Other Publications

Baumgartner, L., Langenmayr, U., Ölmez, J., Schultmann, F., and Hilgers, C., *Wasserstoffwirtschaft - Rohstoffbedarf und Kosten für die Elektrolyse: Eine regionale Analyse für Baden-Württemberg*, preprint, doi: 10.5445/IR/1000179523, 2025

Glöser-Chahoud, S., Heinzmann, P., Langenmayr, U., and Schultmann, F., *Production of Alternative Fuels and Chemicals from Green Hydrogen and Various Carbon Sources*, book chapter, *Eco-Industrial Development as an Industrial Strategy – Contributions from a German-Chilean Research Partnership*, pp. 281-307, doi: 10.1007/978-3-031-73576-9\_15, 2025

Sandmeier, T., Scharnhorst, L., Kleinebrahm, M., and Fichtner, W., *Household heat and electricity consumption data from three living lab interventions in the Energy Smart Home Lab*, research data, doi: 10.35097/txjj7yawp9gr4ts8, 2025

## Publications

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Schuhmacher, J., *Deutsche Strommärkte während und nach einem Blackout - Ein allgemeinverständlicher Überblick der Prozesse und Verantwortlichen*, preprint, doi: 10.5445/IR/1000187823, 2025

Vogl, J., Kleinebrahm, M., Raab, M., McKenna, R., and Fichtner, W., *A Review of Challenges and Opportunities in Occupant Modeling for Future Residential Energy Demand*, preprint, doi: 10.5445/IR/1000185143

