Projects

Multilevel mixed-integer nonlinear optimization for gas markets (B08) (2022-2026)

(Third Party Funds Group – Sub project)

Overall project: TRR 154: Mathematical modelling, simulation and optimization using the example of gas networks
Funding source: DFG / Sonderforschungsbereich / Transregio (SFB / TRR)
URL: https://www.trr154.fau.de/subprojects-phase-3/
Abstract: The goal of this subproject is to develop mathematical methods to solve mixed-integer and nonlinear multilevel optimization problems for gas markets coupled with markets of other energy sectors such as electricity. Motivated by the two cases of cooperating or non-cooperating network operators of the different sectors, we investigate on the one hand bilevel problems with potentially multiple solutions on the lower level, for which we establish methods to assess pessimistic solutions. On the other hand, we study multi-leader-follower games and develop problem-tailored solution approaches. Finally, based on our mathematical and algorithmic developments, we characterize equilibria in coupled energy systems for different combinations of market designs in the considered sectors.
More information

Multi-sector coupled energy system modeling on a regional level

(Third Party Funds Group – Overall project)

Funding source: Bundesministerium für Wirtschaft und Technologie (BMWi)
URL: https://www.esm-regio.de
Abstract: Reducing primary energy use and greenhouse gases are central goals of the energy transition. However, switching from fossil to regenerative energy sources is not enough to achieve them. An overarching view and optimization of the different sectors of the energy system - electricity, gas, heat and transport - can significantly advance the further development of the energy system in Germany. Potential exists above all on a regional level.
The goal of the ESM-Regio project - short for "Multisectoral Coupled Energy System Modeling on a regional level" - is to create a temporally high-resolution energy system model on a county level that takes into account the four sectors of electricity, gas, heat and transport as well as the required interface technologies. A key feature of the project is a cross-sector model logic. Suitable simulation

methods enable a holistic analysis and optimization of the system operation under consideration of the four relevant sectors of the energy system.
More information

Process optimization for hospital logistics

(Third Party Funds Single)

Funding source: Industrie
URL: https://en.www.math.fau.de/edom/projects-edom/logistics-and-production/process-optimization-for-hospital-logistics/
Abstract: This project aims at developing solution methods for problems arising in the logistics management of the public health care sector. More specifically, transport orders in hospitals or other medical facilities should be allocated to employees in order to generate a plan of transport, that also incorporates the routes and execution times of all orders. In this plan, the routing of the transport orders shall be computed considering the infectiousness of the patients, the properties of the means of transportation and, among other requirements, the location of the responsible employee. Moreover the scheduled plan shall minimize order delays, transport distances and the burden of executing employees or other configurable criteria specified by the customers of OrgaCard.
Thus, the overall goal of this project is to organize transport logistics of medical facilities in an integrated mathematical framework in real time, using techniques of machine learning and combinatorial respectively discrete optimization.
More information

MIP techniques for equilibrium models with integer constraints (B07) (2018 -2022)

(Third Party Funds Group – Sub project)

Overall project: TRR 154: Mathematische Modellierung, Simulation und Optimierung am Beispiel von Gasnetzwerken
Funding source: DFG / Sonderforschungsbereich / Transregio (SFB / TRR)
Abstract: In this subproject we will develop techniques to solve equilibrium problems with integer constraints using MIP techniques. To this end, we will consider first mixed-integer linear, then mixed-integer nonlinear problems as subproblems. To solve the resulting problems we will study both complete descriptions as also generalized KKT theorems for mixed-integer nonlinear optimization problems.
More information

Decomposition methods for mixed-integer optimal control (A05) (2018 - 2022)

(Third Party Funds Group – Sub project)

Overall project: TRR 154: Mathematische Modellierung, Simulation und Optimierung am Beispiel von Gasnetzwerken
Funding source: DFG / Sonderforschungsbereich / Transregio (SFB / TRR)
Abstract: The focus lies on the development of mathematical decomposition methods for mixed-integer nonlinear optimal control problems on networks. On the top level (master) mixed-integer linear problems are in place, whereas in the sub-problem only continuous variables are considered. The exchange between the levels is performed not only via cutting planes, but also via the modelling of disjunctions to deal with non-convex optimal control problems as well. The overall emphasis is the mathematical analysis of structured mixed nonlinear optimization problems based on hierarchical models.
More Information

Optimierung der Netzeingriffe

(Third Party Funds Group – Sub project)

Overall project: Flächenbezogene Modellierung, Simulation und Optimierung von Solar-Einspeisung, Lastfluss und Steuerung für Stromverteilnetze, unter Berücksichtigung von Einspeisungsunsicherheiten
Funding source: Bundesministerium für Bildung und Forschung (BMBF)
URL: https://en.www.math.fau.de/edom/projects-edom/analytics/optimal-control-of-electrical-distribution-networks-with-uncertain-solar
Abstract: The steady expansion of renewable energies increases the need of efficient mathematical models for the prediction of renewable feed-in and for the corresponding control of electrical distribution networks.One challenging issue is the feed-in by photovoltaics. Innovative methods are needed to improve the conventional aggregation of point-based predictions. In combination with methods for the approximately representation of network levels it is possible to calculate and optimize power flows.We develop a space continuous stochastic model for local solar irradiations to determine probabilities of critical feed situations. To optimize network interventions we have to solve a large-scale nonlinear mixed-integer program (MINLP). We approximate the nonlinearities with piecewise-linear functions to construct linear relaxations. Another new approach is to immunize the model against uncertainty, which leads to a combination of stochastic and robust optimization.
More information

Reduced Order Modelling, Simulation and Optimization of Coupled systems

(Third Party Funds Group – Sub project)

Funding source: EU - 8. Rahmenprogramm - Horizon 2020
URL: https://www.romsoc.eu/
Abstract: Product development today is increasingly based on simulation and optimization of virtual products and processes. Mathematical models serve as digital twins of the real products and processes and are the basis for optimization and control of design and functionality. The models have to meet very different requirements: Deeply refined mathematical models are required to understand and simulate the true physical processes, while less refined models are the prerequisites to handle the complexity of control and optimization. To achieve the best performance of mathematical modeling, simulation, and optimization techniques (MSO), in particular in the industrial environment, it would be ideal to create a complete model hierarchy.
More information

Energiemarktdesign

(Third Party Funds Group – Sub project)

Overall project: Energie Campus Nürnberg (EnCN2)
Funding source: Bayerisches Staatsministerium für Bildung und Kultus, Wissenschaft und Kunst (ab 10/2013)
URL: http://www.encn.de/en/forschungsthemen/energiemarktdesign/
Abstract: In the project "Energy Markt Design" within EnCN2 a team of researchers from economics, mathematics, and law analyses the economic and regulatory environment for the transformation of the energy system. The main objectives are to enhance the methods in energy market modeling and to contribute with well-grounded analyses to the policy discourse in Germany and Europe. For the electricity market, the focus is on the steering effect of market designs on regulated transmission expansion and private investments, as well as on the identification of frameworks at the distribution level that provide regional stakeholders with business models for the provision of flexibility measures. In order to address these complex issues, mathematical techniques are developed within the project that allow for solving the respective models. Another key research topic results from the advancing sector coupling in energy markets. Within EMD, gas market models, that are developed within DFG Transregio 154 (Simulation and Optimization of Gas Networks) in cooperation with project partners, are applied to evaluate the European gas market design. The long-term objective of the research group is an integrated assessment of the electricity and gas market design and their combined effects on investment decisions.
More information

Combined Optimization, Simulation and Grid Analysis of the German Electrical Power System in an European Context

(Third Party Funds Group – Overall project)

Funding source: Bundesministerium für Wirtschaft und Technologie (BMWi)

Abstract: Germany decided to reorganize its energy supply system in a sustainable way by initiating the energy transition (Energiewende). One of its main targets is to be one of the most environmentally friendly and energy-conserving economies worldwide with competitive energy prices at the same time. This requires the support of all-embarrassing analytical systems, which take into account the technical, market and regulatory framework at once. Existing energy system analysis models often neglect or simplify the modeling of the electrical grid, which motivated the preliminary multidisciplinary work of the chairs of the FAU Erlangen-Nürnberg in the recent years.
A holistic system-oriented modeling approach for the electrical power supply system in Germany was initially developed with a focus on Bavaria. The model of the German electrical power supply system includes the transmission grid, conventional power plants and feed-in from renewables concerning the current market mechanisms in Germany. With the developed model it is possible to derive statements about grid and storage expansion or the development of CO2 emissions for the federal state Bavaria. The overall model includes sub-models for optimization (determination of cost-optimal expansion scenarios), for simulation (stochastic simulation of different scenarios with high temporal resolution and technical detail) and grid analysis (quasi-stationary AC load flow calculations) for checking the required grid planning criteria and stable system operation.
Within the research project KOSiNeK funded by the Federal Ministry for Economic Affairs and Energy (BMWi) we now extend the existing holistic system-oriented modeling approach for the German electric energy system to derive statements about the future development of the system within the European context. This includes both the evaluation of net expansion scenarios and the simulation and analysis of regulatory frameworks. In order to cope with the increasing complexity of the problem, new approaches from the fields of mathematics, computer sciences and net analysis are necessary, which includes aggregation and decomposition techniques, hierarchical multipoint model approaches as well as probabilistic methods to determine the probability of occurrence of certain conditions. This leads to models of high complexity. To take this into account, the approaches from mathematics, computer science and grid analysis will also be coupled iteratively. This enables displaying technical and economic aspects with regard to the control of power plants in a very detailed manner as well as considering grid-regulations in order to guarantee a safe electrical power supply. In addition, it is possible to examine energy markets in an European context including their regulatory framework. The flexible and component-based model construction allows the influence of new market mechanisms such as dividing Germany into price zones or changing market conditions or funding mechanisms with a detailed, agent-based market model. For the integrated power grid analysis, the continental European transmission grid is integrated by network equivalents. A novel probabilistic approach will also be developed to evaluate the grid expansion scenarios.

The project KOSiNeK (project number 03ET4035) is funded by the 6th energy research program of the German Federal Ministry for Economic Affairs and Energy (BMWi).
More information

Adaptive MIP-Relaxations for MINLPs (B07) (2014 - 2018)

(Third Party Funds Group – Sub project)

Overall project: TRR 154: Mathematical Modelling, Simulation and Optimisation Using the Example of Gas Networks
Funding source: DFG / Sonderforschungsbereich / Transregio (SFB / TRR)
Abstract: Goal of the project is the analysis and solution of large-scale MINLPs, especially from the application of instationary gas network optimization, using adaptive MIP models. We approximate the nonlinearities with piecewise-linear functions to construct MIP relaxiations of the underlying MINLP. In addition, theoretical results linking the complexity of the relaxiations to structural properties of the nonlinear functions and the linearization error shall be derived.
More information

TRR 154: Mathematical Modelling, Simulation and Optimisation Using the Example of Gas Networks

(Third Party Funds Group – Overall project)

Funding source: DFG / Sonderforschungsbereich / Transregio (SFB / TRR)
URL: http://trr154.fau.de/
Abstract: The "turnaround in energy policy" is currently in the main focus of public opinion. It concerns social, political and scientific aspects as the dependence on a reliable, efficient and affordable energy supply becomes increasingly dominant. On the other side, the desire for a clean, environmentally consistent and climate-friendly energy production is stronger than ever. To balance these tendencies while making a transition to nuclear-free energy supply, gas becomes more and more important in the decades to come. Natural gas is and will be sufficiently available, is storable and can be traded.
On the other side, focussing on an efficient handling of gas transportation induces a number of technical and regulatory problems, also in the context of coupling to other energy carriers. As an example, energy transporters are required by law to provide evidence that within the given capacities all contracts defining the market are physically and technically feasible. Given the amount of data and the potential of stochastic effects, this is a formidable task all by itself, regardless from the actual process of distributing the proper amount of gas with the required quality to the customer. It is the goal of the Transregional Collaborative Research Centre to provide certified novel answers to these grand challenges, based on mathematical modelling, simulation and optimisation. In order to achieve this goal new paradigms in the integration of these disciplines and in particular in the interplay between integer and nonlinear programming in the context of stochastic data have to be

established and brought to bear. Clearly, without a specified underlying structure of the problems to face, such a breakthrough is rather unlikely.
Thus, the particular network structure, the given hierarchical hybrid modelling in terms of switching algebraic, ordinary and partial differential-algebraic equations of hyperbolic type that is present in gas network transportation systems gives rise to the confidence that the challenges can be met by the team of the Transregional Collaborative Research Centre. Moreover, the fundamental research conducted here will also be applicable in the context of other energy networks such as fresh-and waste-water networks.
In this respect, the research goes beyond the exemplary problem chosen and will provide, besides a cutting edge in enabling technologies, new mathematics in the emerging area of discrete, respectively, integer and continuous problems.
The following Sub projects are located at FAU: More information

Decomposition methods for mixed-integer optimal control (A05) (2014 - 2018)

(Third Party Funds Group – Sub project)

Overall project: TRR 154: Mathematical Modelling, Simulation and Optimisation Using the Example of Gas Networks
Funding source: DFG / Sonderforschungsbereich / Transregio (SFB / TRR)
Abstract: The focus lies on the development of mathematical decomposition methods for mixed-integer nonlinear optimal control problems on networks. On the top level (master) mixed-integer linear problems are in place, whereas in the sub-problem only continuous variables are considered. The exchange between the levels is performed not only via cutting planes, but also via the modelling of disjunctions to deal with non-convex optimal control problems as well. The overall emphasis is the mathematical analysis of structured mixed nonlinear optimization problems based on hierarchical models.
More information

Sustainable Business Models in Energy Markets: Perspectives for the Implementation of Smart Energy Systems

(FAU Funds)

Abstract: Die Liberalisierung des Energiemarktes sowie der zunehmende Ausbau erneuerbarer Energien stellen neue Anforderungen an unser Energiesystem im Hinblick auf den Ausbau von Netzen, die Produktion, Verteilung sowie zukunftsweisende Stromspeichertechnologien. Eine erfolgreiche Transformation hin zu einem „Smart Energy System" hängt dabei wesentlich von adäquaten Investitionsanreizen und der Attraktivität der Geschäftsmodelle der beteiligten Stakeholder ab. Im Rahmen des Forschungsprojekts „Sustainable Business Models in Energy Markets: Perspectives for the Implementation of Smart Energy Systems" sollen daher das

Energiesystem und die Geschäftsmodelle der Beteiligten interdisziplinär analysiert werden. Ziele des Forschungsprojekts sind die Generierung von neuen und dringend erforderlichen Erkenntnissen zur Interaktion zwischen Geschäftsmodellen und Regulierung unter Berücksichtigung der technischen Referenzmodelle sowie die Ableitung von Empfehlungen für politische und regulatorische Rahmenbedingungen zur Sicherstellung einer erfolgreichen Transformation des Energiesystems.
More information

Development of new Linear and Integer Programming Techniques to solve Supply Chain Management Problems

(Third Party Funds Single)

Funding source: Industrie
Abstract: Supply Chain Management (SCM) deals with the combination of procurement, production, storage, transport and delivery of commodities. Problems of this kind occur in all kinds of industry branches. Since the integrated planning of these processes contains a high potential for optimization it is of great importance for the companies' efficiency.
The method of choice to find optimal solutions in SCM is linear and integer programming. Nevertheless, there are big challenges to overcome – concerning both hardware and algorithms – due to very detailed and therefore large models. Additionally there may occur numerical difficulties that standard techniques cannot deal with.
As a consequence, the problem's mathematical formulation has to be done carefully and new methods need to be implemented to improve the performance of MIP algorithms.
More information