CITIES/FutureGas Joint Seminar:
Modeling and Optimization of Integrated Energy Systems

15 December 2017
DTU Elektro, Lyngby Campus, Building 329, Room 329A-120

Organizers: Jalal Kazempour (DTU Elektro) and Marie Münster (DTU Management Engineering)

Link for Registration: http://www.conferencemanager.dk/CITIES-FutureGas

The event is free of charge, but registration is required.

Agenda:

9:00 - 9:30 **Pierre Pinson (DTU Elektro, head of ELMA Group)**
ELMA Group Introduction

9:30 - 10:00 **Marie Münster (DTU Management Engineering, Senior Researcher)**
Group and Project Introduction

10:00 - 10:30 **Stefanie Buchholz (DTU Management Engineering, PhD Student)**
Advanced Mathematical Modeling Related to Comprehensive Energy System Models

Abstract: The main purpose is to analyze the complex mathematical problems connected to modelling of large integrated systems and to develop solutions to handle the large numbers of variables and equations imposed in large energy system models. The work will act as a support function to the rest of the FutureGas project. Besides from possible complexities that may arise with the integration of gas into the energy models, already known complexities will be attacked. As examples, it is expected to look into different solvers used to solve the Danish Energy System models in order to study if a modification of the models or tuning of the solvers can improve the solution times. Also the problematic of including binary decision variables in the models will be addressed as well as finding alternative solution techniques to stochastic programming enabling uncertainty handling without increasing complexity too much. Another way to overcome the high level of complexity is to use a restriction technique on the time dimension based on selecting representative time slices that simultaneously reflect the annual variability of the original time series. The goal is to analyze what a good balance between model performance and solution times of different aggregations might be. Existing aggregation techniques struggle to handle the increased variability resulting in too many time slices being selected or the flexibility needs being underestimated. We propose a new simple cluster strategy and compare the performance of this to other aggregation techniques in the literature. We put a special focus on analyzing if more gain can be achieved by making more complex aggregation techniques and we address whether the validation guidelines used up until today actually provide good validation of aggregation techniques.

10:30 - 10:45 **Break**

10:45 - 11:15 **Rasmus Bramstoft (DTU Management Engineering, PhD Student)**

Modelling of the Gas System as an Integrated Part of the Future Energy System

Abstract: Denmark has set the ambitious goal of achieving an energy system, which is independent of fossil fuels by 2050. This implies that the Danish energy system will experience a remarkable transformation in the future, heading towards energy production based on renewable energy sources (RES), and stronger couplings and interactions between energy subsystems.

Today, Denmark self-sufficient with natural gas, and gas is a key energy carrier in the Danish energy system, accounting for 17% of the total energy consumption. However, given the Danish long-term energy policy targets, combined with declining gas consumption, and limited natural gas resources in the North Sea; answers to the crucial question of the role of gas and the gas infrastructure in a future Danish energy system is urgently demanded by the Danish gas sector. This project seeks to answer the emerging question and to contribute to the research field by developing energy system models, which can facilitate modelling of the integrated energy system including the power, district heating, transport, and gas system. In this way, modelling of future effective, cost-efficient, and sustainable pathways towards future energy systems with high shares of RES can be facilitated. Specifically, the model of the future gas system includes renewable gas production, conditioning, transmission, storage, trade and use.

In particular, in this study, the role of renewable gas (RE-gas) i.e. biomethane, bioSNG, hydrogen and power-to-gas, and renewable fuels for transportation in a future renewable based Danish energy system is investigated utilizing integrated energy systems assessments. To facilitate the modelling of renewable gas production, model developments in the generalized spatiotemporal network optimization model, OptiFlow, is undertaken. Furthermore, OptiFlow is hard-linked to the open source energy system optimization model Balmorel, allowing an integrated energy assessment of RE-gas production, storage and demand.

Both Balmorel and OptiFlow relies on a bottom-up modelling approach and is, furthermore, deterministic, partial equilibrium models which assumes perfect competition. The objective is to maximize social surplus and thereby provide the least-cost solution of the system, which includes operational costs and annualized investment costs of the power and district heating system. The Balmorel model entails a comprehensive representation of technical components in the current energy system e.g. electricity and heat generation technologies and transmission capacities. Balmorel computes the conversion of primary energy to electricity and heat, while OptiFlow computes the production of renewable gas and renewable fuels. The temporal resolution is user-defined and allow either hourly or time-aggregated simulations. Geographically, North West Europe is modelled, however, Denmark is modelled with higher spatial resolution, i.e. district heating 35 areas and two power regions.

This framework enables detailed modelling of the chain from transportation of primary resources to renewable gas production plants, through storage facilities and to end consumers, while taking into account the spatial and temporal energy system integration. The co-simulation of OptiFlow and Balmorel leads to the socio-economic optimal system, where investments and operations optimization is facilitated for the integrated energy system.

11:15 - 11:45 **Christos Ordoudis (DTU Elektro, PhD Student)**

Coordination of Electricity and Natural Gas Systems via Market-based Mechanisms under High Shares of Stochastic Power Production

Abstract: Gas-fired power plants (GFPPs) are expected to have a prominent role in the future energy system where power production will be dominated by renewable sources of energy. The electric power sector will be the main driver of natural gas consumption increase in the upcoming years, thus a tighter coordination between electricity and natural gas networks is

foreseen. For this reason, the current operation practices and market designs need to be revised as operational flexibility will be essential in energy systems. In this talk, we examine the coordination of electricity and natural gas systems under the uncertainty introduced by renewables. First, a two-stage stochastic program in which day-ahead and real-time dispatch of both energy systems is optimized aiming to minimize total expected system cost is presented. We provide a novel formulation for a dynamic natural gas system that uses an outer approximation to linearize the natural gas flow equation, as well as models linepack flexibility and compressors. That way, the importance of proper natural gas system modeling in short-term operations to reveal valuable flexibility of the natural gas system is highlighted. Moreover, aiming to reduce the efficiency gap of the current market from the stochastic ideal model, we formulate two coordination mechanisms based on the natural gas price and the quantity of natural gas that is available to GFPPs, to exploit flexibility in a market environment and cope with forecast errors of stochastic production. Finally, we present a data-driven method to solve the energy and reserves problem with fuel capacity constraints for GFPPs, where the distribution of random variables that characterize stochastic power production is only available through a limited finite dataset. We formulate a distributionally robust optimization problem and evaluate its performance on an out-of-sample basis where the features of the proposed model are highlighted via a comparison with a deterministic and a two-stage stochastic programming formulation.

11:45 - 12:15 **Lesia Mitridati (DTU Elektro, PhD Student)**

Coordination of Heat and Electricity Systems through Markets Environments

Abstract: The large-scale penetration of renewable energy sources has increased the need for flexibility in the power sector. In systems with a high share of Combined Heat and Power (CHP) plants and heat pumps, exploiting the potential synergies between heat and electricity can help tackle this issue. However, due to the strong linkage between heat and electricity outputs, the participation of CHPs and heat pumps in both markets can have negative impacts on the power sector. Thus, rather than focusing on flexibility in power systems alone, a more holistic approach to renewables integration relies on flexibility from coordinating heat and electricity. First, we compare various frameworks for heat and electricity markets, including a traditional sequential market framework and an ideal combined economic dispatch. And, in order to improve the coordination between heat and electricity markets while respecting their sequential nature, we introduce an improved heat dispatch model. The proposed model is a hierarchical heat dispatch, constrained by electricity market equilibrium.

Furthermore, we introduce a novel model for Combined Heat and Power Dispatch (CHPD), accounting for time delays and energy storage capacity in district heating networks. This approach provides operational flexibility to the energy system by temporally decoupling heat and electricity production. In order to deal with non-convexities introduced by temperature dynamics in district heating networks, we propose a convex relaxation of heat flows based on outer approximation and McCormick envelopes. We assess the operational flexibility provided by the district heating network by comparing the proposed model to a conventional economic dispatch.

Finally, the growth of fuel-shift technologies, such as heat pumps, and heat storage can provide virtual storage capacity and flexibility to the electricity system. We discuss the pricing of such flexibility using financial storage rights in a multi-energy systems framework.

12:30 **Lunch**