ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Energy Science Center

Frontiers in Energy Systems Modelling

Experiences in energy markets, integration of renewables and combining modelling approaches.

Organized by the Energy Science Center (ESC)
19th of November 2015, 10:10 am to 4:50 pm

LEE E 101, LEE Building, ETH Zürich
Leonhardstrasse 21, 8092 Zürich

Morning session *(10:15 am - 12:30 pm)*

SwissMod: A model of the Swiss Electricity Market

University of Basel FoNEW

Prof. Dr. Hannes Weigt and Ingmar Schlecht
Forschungsstelle Nachhaltige Energie- und Wasserversorgung, University of Basel.

We present a bottom-up electricity market model for Switzerland called Swissmod. It includes a detailed electricity network and hydropower representation. Swissmod captures the features and restrictions of run-of-river, yearly storage and pumped-storage power plants and combines this with a network model of the river and water stream system to take the interdependence of hydraulically coupled hydropower plants into account. In addition, the Swiss electricity network is represented using the DC load flow approach, allowing for spatial market evaluations. The model is developed as a deterministic optimization problem in GAMS. It provides an hourly resolution over a one-year horizon with an approximated representation of the surrounding European electricity markets.

Swissmod covers the Swiss high voltage transmission network (220 and 380kV). Although the regional focus of Swissmod is Switzerland, surrounding countries are included to capture the impact of European market developments on the Swiss electricity system. In total Swissmod covers about 200 nodes within Central Europe, about 150 of which are within Switzerland, and about 400 transmission lines. This talk focuses on latest SwissMod developments and a 2050-scenario.

Reference: Schlecht, I. and Weigt, H. (2014): Swissmod: A Model of the Swiss Electricity Market. FoNEW Discussion Paper 2014/01. Further references: https://fonew.unibas.ch/en/about-the-fonew/

Examples of Applications in Hybrid Economy-Energy-Electricity Modelling

Prof. Dr. Sebastian Rausch and Dr. Jan Abrell
Center for Energy Policy and Economics, ETH Zürich.

Highly aggregated economic models are typically plagued by the lack of detail and consistency with which they represent the technological foundations that shape energy supply and demand. At the same time, incorporating economic decision-making, market interactions, and the role of energy in broader economic activities enables moving beyond a pure technology-based assessment. This talk (1) motivates the need for and explains the rationale of hybrid energy-economy modeling and (2) provides examples of applications showcasing the usefulness of hybrid energy-economy models for assessing energy and climate policies.

Reference: S. Rausch and M. Mowers (2014). Distributional and Efficiency Impacts of Clean and Renewable Energy Standards for Electricity, *Resource and Energy Economics*, 36(3), 556-585. Further references available at: http://www.enec.ethz.ch/

How to model decision making in Electricity Markets? Bi-level games and stochastic programming

Dr. Martin Densing[1] and Prof. Dr. Karl Schmedders[2]
[1]Energy Economics Group, Paul Scherrer Institute. [2]University of Zurich.

We consider two decision problems of power producers. In the first problem, the oligopolistic investment and subsequent production decision of several power producers is considered. The producers can invest in different technologies and can exert market power, that is, they can influence prices by withholding investments or capacity in certain load periods. Because investments are still (partially) driven on a country level in Europe, we consider countries as aggregated: Switzerland and the surrounding countries, with transmission constraints between players (in the 1st project phase of this BFE supported work). The investment-production decision of the players form a Bi-level Nash-Cournot game, which is a non-convex complementarity problem of type EPEC (equilibrium problem with equilibrium constraints). We show preliminary numerical results.

In a second decision problem, we reduce the scope by boiling-down to the dispatch-problem of a single pumped-storage hydropower plant against exogenous random electricity prices. For this stochastic programming problem, an analytical dispatch solution can be given in some cases.

Reference: Densing M. (2015). Dispatch under uncertainty: Ancillary service, pumped-storage with two reservoirs, with discontinuous price distribution, and in continuous time (preprint). https://www.psi.ch/eem/

The role of short-term trading in electricity markets

Aymen Salah-Abou-El-Enien and Davide Orifici
EPEX Spot.

The issue of integrating intermittent renewables is often considered in isolation, when the network as a whole should be treated. The key challenge in managing a power system is that the amount of electricity going out must exactly match the amount coming in, and vice versa. Before wind farms became common, the variability of wind energy was virtually indistinguishable from natural

fluctuations in power demand. In addition to fluctuating demand and intermittent generating sources, variability in the power system arises from transmission line and power plant outages, as well as dispatch errors. The experience tells us that (1) large, dynamic power markets with robust connections to neighbouring markets help system operators cope with varying demand and supply, (2) the flexibility that has been built into modern power systems can handle tremendous amounts of variability, and (3) Other problems such as forecasting wind energy are steadily being resolved.

Our presentation will focus on how EPEX Spot markets, mechanisms, and products, help to keep the lights on.

Reference: Further details about EPEX available at***:*** https://www.epexspot.com/en

Afternoon session *(1:15pm - 3:35pm)*

Enerpol: An integrated, high resolution, system-wide, electricity & gas networks model

Prof. Dr. Reza Abhari and Dr. Ndaona Chokani
Laboratory of Energy Conversion, ETH Zürich.

Enerpol is an integrated, high resolution, system-wide, electricity and gas networks model. The geographic coverage of EnerPol includes most of Europe, substantial portions of USA and Canada, and parts of Africa and Asia. For central Europe, the modelled transmission grid has 3000 individual transmission lines (220, 380 and 400 kV) with a total length of 70000 km; 5000 individual conventional and renewable power plants are geo-referenced in EnerPol's framework. The European gas network model is comprised of 76000 km of pipelines, as well as all compressors, gas storages, and LNG stations.

For the electricity and gas markets, hourly chronological simulations are undertaken. In the electricity market model, generation, transmission and demand are modelled at the level of substations with dispatch that is optimized on the basis of physical constraints and economic considerations. In the gas market model, fixed contract or available gas supply is modelled, all flows in pipelines, at nodes & in storage are physically simulated, and the gas demand distributed either to the coupled electricity generation or to other end-users. This holistic, comprehensive framework allows for the data-driven analysis of a broad range of scenarios related to power & energy mixes, market performance, investments, and impact of policy.

Reference: A. Singh, D. Willi, N. Chokani, and R.S. Abhari, "Optimal Power Flow Analysis of Switzerland's Transmission System for Long-Term Capacity Planning," *Renewable Energy and Sustainability Reviews*, vol. 34, pp. 596-607, 2013. Further details available: http://www.lec.ethz.ch/research

Swiss TIMES Energy systems Model (STEM): Application for long term energy transition scenarios

Ramachandran Kannan,
Energy Economics Group, Laboratory for Energy Systems Analysis, Paul Scherrer Institute.

Structural change in the energy system is generally a long-term, uncertain and systemic process, affected by patterns of demand and technology choices across the entire energy system. Thus, understanding how structural changes in energy supply may occur requires analytical approaches that are able to account for system-wide effects. A comprehensive Swiss TIMES Energy system Model (STEM) has been developed. STEM is a bottom-up, technology-rich model built in the Integrated MARKAL EFOM System (TIMES) framework. In STEM, the full energy system of Switzerland is depicted from primarily resource supply to end-use energy service demands (ESDs), such as space heating, and personal/freight transport. It represents a broad suite of energy and emission commodities, technologies and infrastructure. The model is used to identify the least-cost combination of technologies and fuels for the energy transition. It combines a long time horizon (2010-2100) with an hourly representation. Analysis shows that achieving an ambitious low carbon targets such as a 60% requires substantial changes to the energy system. Key technology options on the demand side include further electrification of heating and mobility, and an aggressive adoption of building conservation measures. Policy support will be critical in realising many of these developments, despite uncertainty regarding the exact nature of future domestic climate change policies, and international developments. We present the capabilities of STEM with a set of scenarios exploring long-term energy transition pathway.

Reference: R. Kannan, H. Turton (2014) Switzerland energy transition scenarios – Development and application of the Swiss TIMES Energy system Model (STEM), Final Report to Swiss Federal Office of Energy, Bern.

Green-X: RES policy and investment model

Dr. Gustav Resch and Dr. Claus Huber
TU Wien and Axpo Holding AG.

Green-X covers the EU-28 and selected other EU neighbours. It allows the investigation of the future deployment of RES as well as the accompanying cost (including capital expenditures, additional generation cost of RES compared to conventional options, consumer expenditures due to applied supporting policies) and benefits (for instance, avoidance of fossil fuels and corresponding carbon emission savings). Results are calculated at both a country- and technology-level on a yearly basis. The time-horizon allows for in-depth assessments up to 2050. The Green-X model develops nationally specific dynamic cost-resource curves for all key RES technologies, including for renewable electricity, biogas, biomass, wind on- and offshore, hydropower large- and small-scale, solar thermal electricity, photovoltaic, tidal stream and wave power, geothermal electricity; for renewable heat, biomass, sub-divided into log wood, wood chips, pellets, grid-connected heat, geothermal grid-connected heat, heat pumps and solar thermal heat; and, for renewable transport fuels, first generation biofuels (biodiesel and bioethanol), second generation biofuels (lignocellulosic bioethanol, biomass to liquid), as well as the impact of biofuel imports.

Through its in-depth energy policy representation, the Green-X model allows an assessment of the impact of applying (combinations of) different energy policy instruments (for instance, quota obligations based on tradable green certificates / guarantees of origin, (premium) feed-in tariffs, tax incentives, investment incentives, impact of emission trading on reference energy prices) at both country or European level in a dynamic framework. In a nutshell, Green-X model allows performing a

detailed quantitative assessment of the RES deployment until 2050 in a real-world policy context at national and European level. It has been successfully applied for the European Commission within several tenders and research projects to assess the feasibility of "20% RES by 2020" and for assessments of RES developments beyond that time horizon (up to 2050).

Reference: Ric Hoefnagels, Gustav Resch, Martin Junginger, André Faaij, International and domestic uses of solid biofuels under different renewable energy support scenarios in the European Union, Applied Energy, Volume 131, 15 October 2014, Pages 139-157**.** Further details available: http://www.green-x.at/.

Engineering the Resilience of Interdependent Energy Infrastructures

Prof. Dr. Giovanni Sansavini
Laboratory of Reliability & Risk Engineering, ETH Zürich.

Resilience engineering aims to build system resistance, adaptability and ability to recover quickly in the face of adverse events. Early integration of resilience into the design of systems and the regulatory structures of systems management is needed to address the emerging issues associated with complexity and uncertainty. To this aim, an urgent need exists to develop models enabling system-wide and network-wide resilience analysis, engineering and management. This talk presents ongoing research efforts aimed at developing methods for the resilience-based planning and operation of interdependent energy networks, namely, (I) the capability of models to capture the failure and recovery dynamics of CI, and (II) the quantification of system resilience. Consequence assessment is strongly impacted by operations management, technical equipment, control functions and automated regulations which react to adverse events in CI. Neglecting them may undermine the quantification of system resilience. The electric power supply system is selected as a test case for developing models to support resilience quantification, which account for the interdependencies in the CI and for the intervention of the human operator. Simulation results show effective strategies and interdependency design which can increase system resilience.

Reference: Nan, C and Sansavini, G., 2015. Multilayer hybrid modelling framework for the performance assessment of interdependent critical infrastructures, International Journal of Critical Infrastructure Protection, Volume 10, September 2015, Pages 18–33. Further info: http://www.rre.ethz.ch/about/index

Coffee break 3:30pm - 4:50pm

Ideas for a future market design - modelling needs

Dr. Christian Zeyer, *Swisscleantech.*

Up until recently it was the common belief that RES would - once prices are reduced do to learning curves - become the dominant and cheapest power source of the future. Decreasing prices on the power market demonstrate however, that the refinancing of power plants will become more and more difficult due to close to zero marginal cost of RES. It is very likely that this holds true especially for RES but also for other power plants. Swisscleantech, economic association fostering sustainability has come up with a Greenfield approach that might correct for this short come of the actual merit order market.

Reference Further details available at***:*** http://www.swisscleantech.ch/

Combining Modelling approaches:
AFEM – Assessing Future Energy Markets,
Nexus –'Integrated Energy Systems Modelling platform'

Dr. Christian Schaffner and Dr. Pedro Crespo Del Granado
Energy Science Center, ETH Zürich.

Modelling and analysing energy systems is becoming increasingly challenging due to the growing need of representing the complexity of the system as whole instead of merely considering its separate components. The Energy Science Center of ETH Zurich has recently started two research projects focused on combining modelling approaches to link technology-rich engineering perspective with economic analysis of energy markets and the macro economy. The talk will cover the initial development and vision of the AFEM and Nexus research projects.

Assessing Future Energy Markets (AFEM) objective is to identify and evaluate the performance of alternative designs for future electricity markets, including a continuation of the current market setting, in terms of their ability to meet the challenges created by the targets set in the Energy Strategy 2050. AFEM focuses on 3 main research questions: 1) How will the Swiss and European electricity market evolve if the existing market mechanism (energy only market, reserve market) be perpetuated as is? 2) How will the market evolve if additional market components such as capacity markets are introduced? 3) How do future market models need to be designed in order to give the "right" investment incentive (e.g. flexibility markets) for an efficient yet carbon-free electricity supply system?

Nexus –'Integrated Energy Systems Modelling platform' aims to be an interdisciplinary modelling framework that integrates various modelling approaches and hence harmonize research viewpoints, data and modelling assumptions. *Nexus* will develop interfaces and define coupling points between models to create synergies and new capabilities so as to analyse the interdependencies within the energy system. The project proposes a flexible modular structure that captures individual features of the energy-economic system.

Reference: Further details available at*:* http://www.esc.ethz.ch/research/research-projects.html

Panel session *(4:20pm - 4:50pm)*

Frontiers in Energy Systems Modelling

Dr. Arthur Janssen, *Head of Market Development and Design at Swissgrid AG.*

Prof. Dr. Göran Andersson, *Head of Power Systems Lab, Full Professor, ETH Zürich.*

Dr. Martin Everts, *Head of Energy Economics at Axpo Holding AG.*

Dr. Christian Schaffner, *Executive Director at the Energy Science Center, ETH Zürich.*