# Optimization and Equilibrium in Energy Economics: Challenges for the research communities

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(summarizing comments from workshop participants)

A workshop related to Optimization and Equilibrium in Energy Economics was held at IPAM on January 11-15, 2016. It was based on the premise that design and decision problems in electrical power systems and markets can only be addressed effectively when tools from several disciplines are brought to bear. Successful design and operation of the electrical power grid and the market for electrical power can lead to billions of dollars in savings, but they require expertise from optimization, data analysis, economics and computational mathematics, as well as close interaction with power systems engineers and energy economists. The workshop brought together experts in each of these domains, as well as key researchers who work at the intersection of these disciplines.

The meeting focussed on mathematical topics related to optimization and equilibrium in energy economics. There was strong consensus that these topics are significant for the industry and that mathematical approaches could have impact provided the research was carried out in collaboration with power system engineers and economists.

The broad consensus of the meeting was that there are a number of potential technical breakthroughs in mathematical programming within three focus areas that would result in being able to answer very challenging questions.

A) Modelling Paradigm Improvements

The mathematical community must consider relevant problems, and facilitate formulations and supporting algorithms that enhance our ability to provide solutions to these problems.

Key model features that need to be developed include:

i) The modeling and inclusion of uncertainties (stochasticity) into the basic models, including load (long or short term, interaction with neighboring transmission systems) and supply (in particular renewables). Technical contingencies play such a fundamental role and good modeling of these uncertainties would stabilize prices.
ii) Equilibrium, and specifically participant behavior. It only makes sense to talk of an equilibrium within the context of optimizing behavior by participants and there is a need to better describe such behavior, so that our models have relevance to reality. This needs to encompass both demand and generation sides; it needs to include financial trading where relevant; and in part it should be supported by empirical work.

Solution enhancements must include treatment of nonlinearities and non-convexities, coupled to faster/larger/structured algorithms at scale. Neglected nonlinearities adversely affect many of the analyses in at least two different ways: first, the difference between a DCOPF and ACOPF (direct/alternating current optimal power flow) creates a mismatch in models that result in either operational or market inefficiencies. Second, it forces the use of imperfect proxies to represent limits in the nonlinear models that cannot be represented in the linear models. (An example is voltage limits in a DCOPF, modeled poorly by a power flow limit.)

Decomposition methods for structured equilibrium problems are needed to deal with networks with AC flows and losses, 0-1 variables and renewables

Progress should be made on making connections between mathematicians and different domain experts: programmers, market designers, operations, and policy experts. Facilitating these relationships could result in rapidly implementable model improvements (i.e., nearly-optimal solutions).

B) Market Design

The meeting participants favored an overall redesign of markets due to changes that have occurred in power generation and data availability. This redesign may need to start from a blank slate; practical limitations to a "blank slate" approach may be mitigated if market operators offer guidance from the beginning. The markets are designed for conventional generators, not flexible loads, not renewables, not storage. We need to reconsider market designs for services provided by these other resources.

At present, it's often being suggested that "technicians/scientists" consider the existing system (market mechanism) and make marginal improvements on various components of that system. Serious thought is needed about what would be an overall desirable system without worries about its solvability. The research community will then find ways to determine the appropriate approximations and acceptable simplifications that can be introduced.

Key areas where existing mechanisms are lacking include:

i) Re-evaluation of what physical aspects can be represented by simple mechanisms and their effect on market inefficiencies
ii) Designing short-run prices to reflect scarcity and to compensate for market failures,
    a. How to set real-time prices that reflect value of scarcity?
    b. How often to update those prices?
    c. How short should time intervals be? Should regulation be based on 4 second prices?
    d. Technology for communicating real-time prices, and incenting all parties to act on them.
iii) Fixed price recovery (and related issues in capacity markets),
    a. How to incent honest disclosure of nonconvex costs?
    b. How to ensure that make-whole payments or other mechanisms avoid distorting investment decisions?
    c. In markets with capacity mechanisms, what's the capacity value of new technologies, and how can we correctly reward it?
iv) Timescale interactions (i.e., control-level (seconds-minutes) and policy-level (years)). We typically exploit timescale separation to partition our problems into manageable sub-problems, often at a single timescale. This ignores the interactions across timescales, and we do not know what we lose in this process.

v) Distribution level management and markets, along with treatment of storage, demand-response and behind-the-meter effects.
vi) Disruptive technological and social change with respect to energy. Will these influences lead us to a local social optimum, and if so, can we provide incentives to move towards a global (social) optimum?

With the exception of the electricity sector, optimization has a muted impact on the operations of other energy markets. Researchers should glean experience from electricity modeling and suggest data collection improvements for other natural applications.

C) Sustainable and Secure Energy Provision

How can we plan and incentivize energy systems to address long term sustainable concerns and secure our energy supply. Specific issues include:

i) How to optimize with increasing renewable resources and inherent uncertainty in electricity demand, climate, and technological change?
ii) Optimal pricing for CO2 reductions
   a. How can we design carbon markets so that they yield efficient carbon reductions, and don't mess up power markets?
   b. How do we prevent inefficiencies arising from rate-based regulation or trading of CO2, and its incompatibility with mass-based trading?
iii) How to reduce or enable the transition to a carbon-free power sector (e.g., how can carbon markets be designed to not interfere with operational stability criteria?)

Challenges in research for mathematicians who work in energy modeling fall into two types, which are linked together.

(1) What questions should we be asking?
(2) What tools should we be developing to help answer these questions?

Here (1) evolves as circumstances evolve, and new questions emerge. These questions can come from policy issues that deal with incentives (industrial organization challenges), or from an operational need to dispatch and control equipment efficiently (technical challenges).

The challenges are linked, as one should refrain from asking questions that are ill-posed or impossible to answer in a suitable time frame. Similarly, technical research on tools and models in this area should continually ask the "who cares?" question.