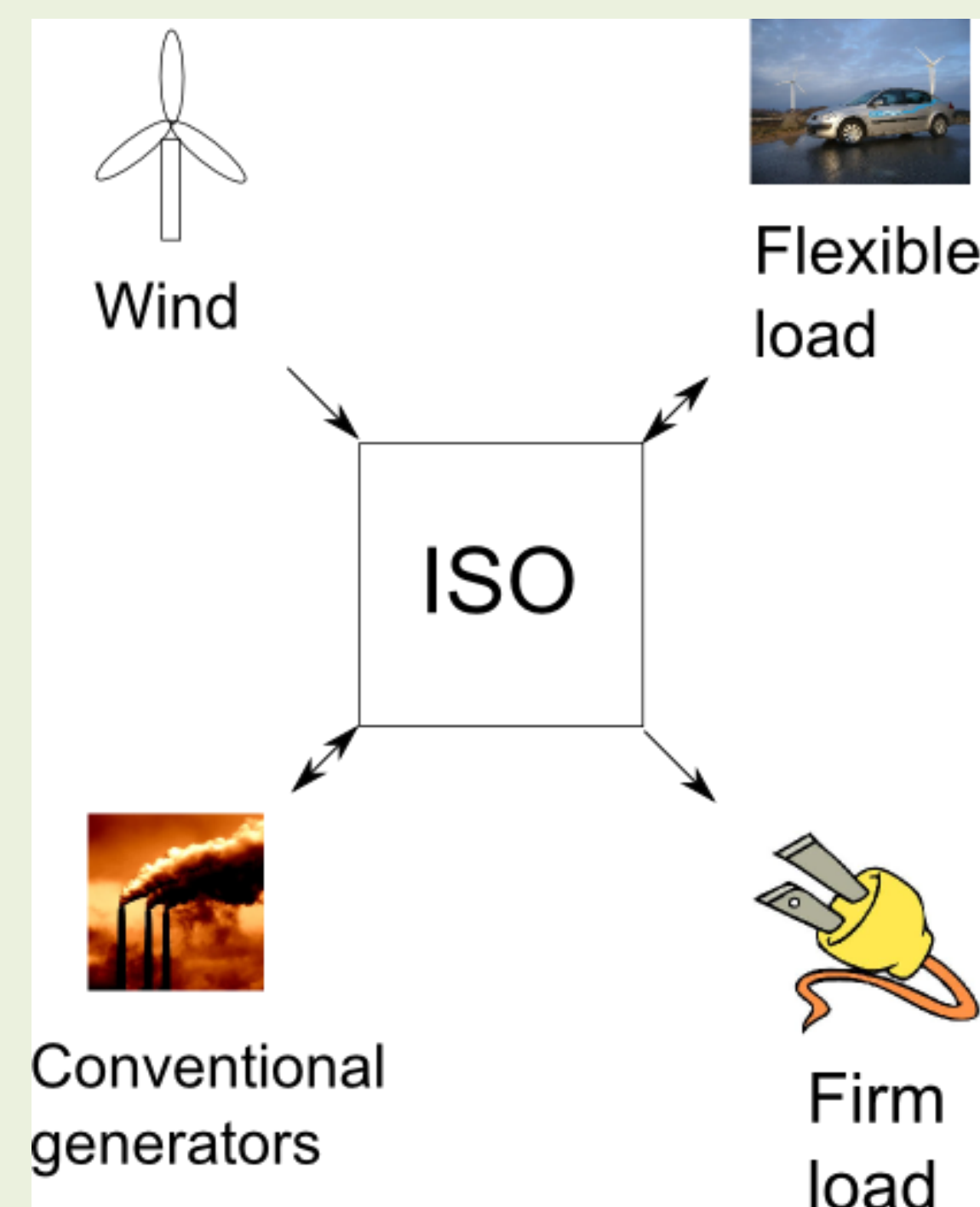# Coupling Renewable Energy Supply with Deferrable Demand

Anthony Papavasiliou, Shmuel S. Oren, Department of Industrial Engineering and Operations Research, U.C. Berkeley
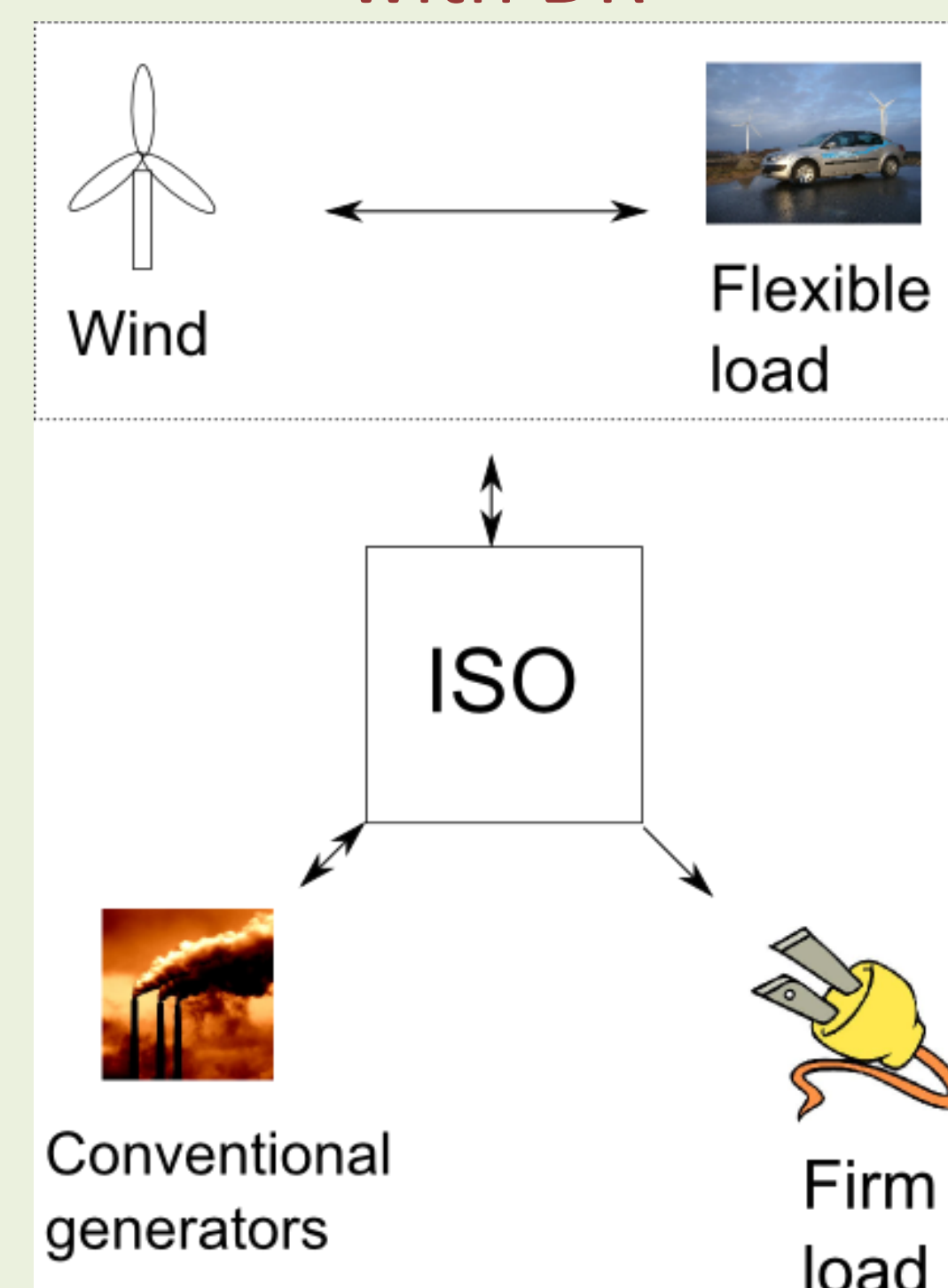
PSERC
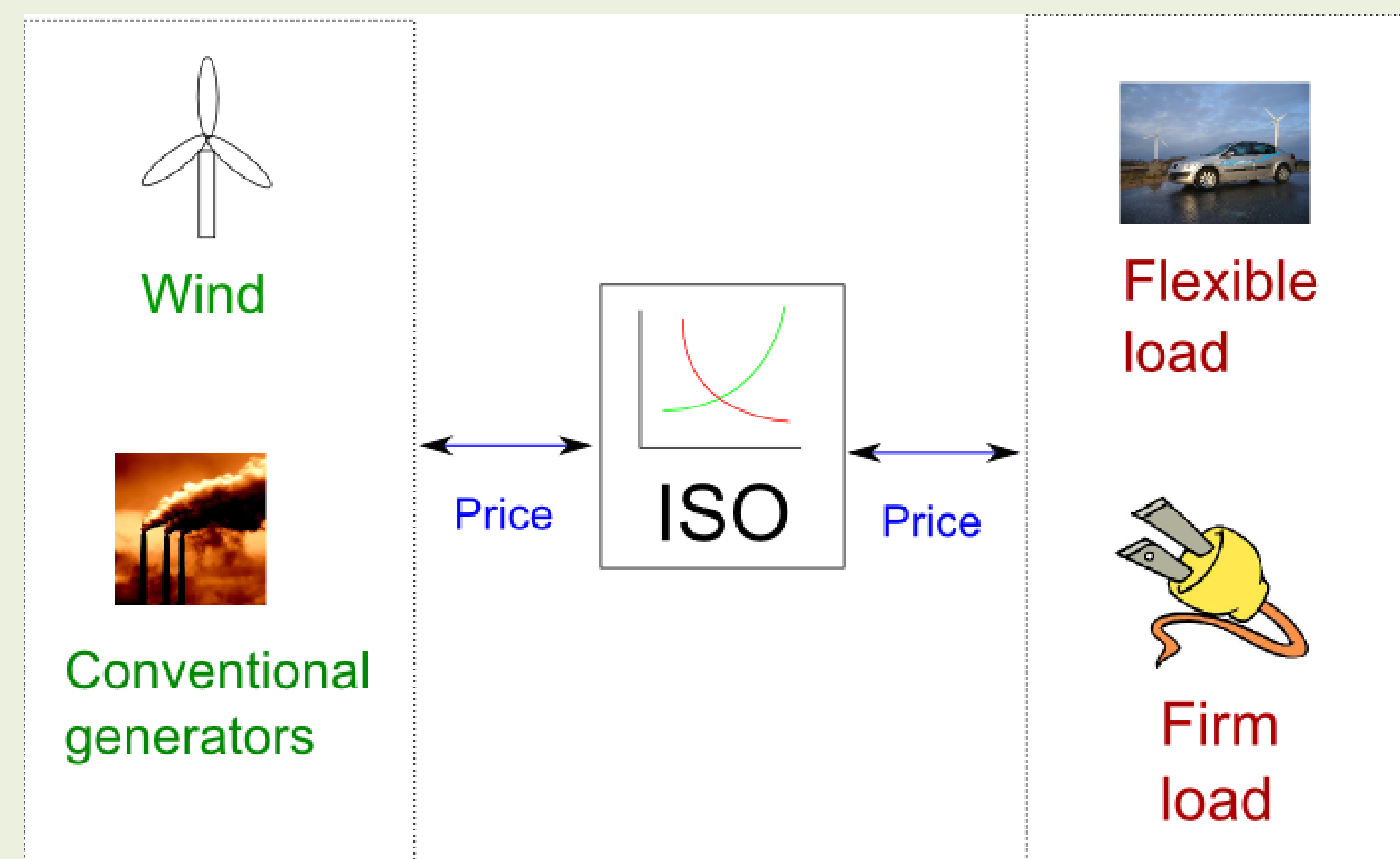
How Should We Structure the Future Grid?

Centralized Control

Wind — Flexible load — ISO — Conventional generators — Firm load

Coupling Renewables with DR

Wind — Flexible load — ISO — Conventional generators — Firm load

Price-Based Control

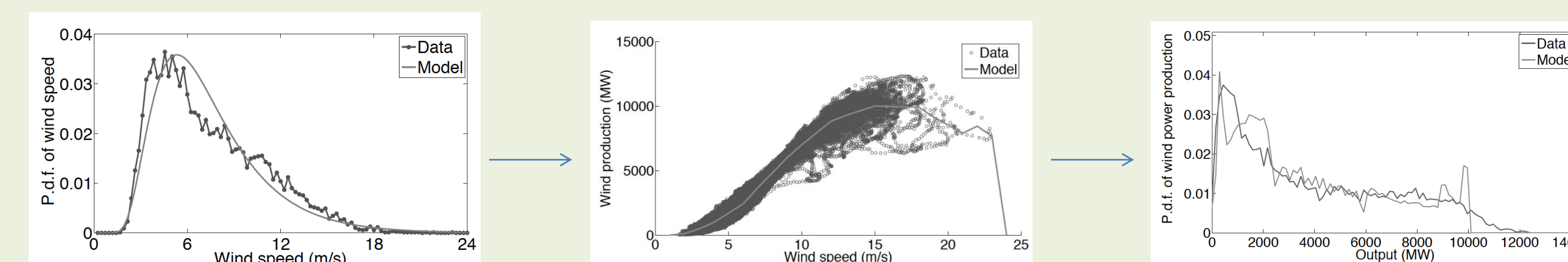Wind — Price — ISO — Price — Flexible load — Conventional generators — Firm load

Research Objectives

Quantify the impact of large-scale renewable supply and demand response on
- Reserve requirements
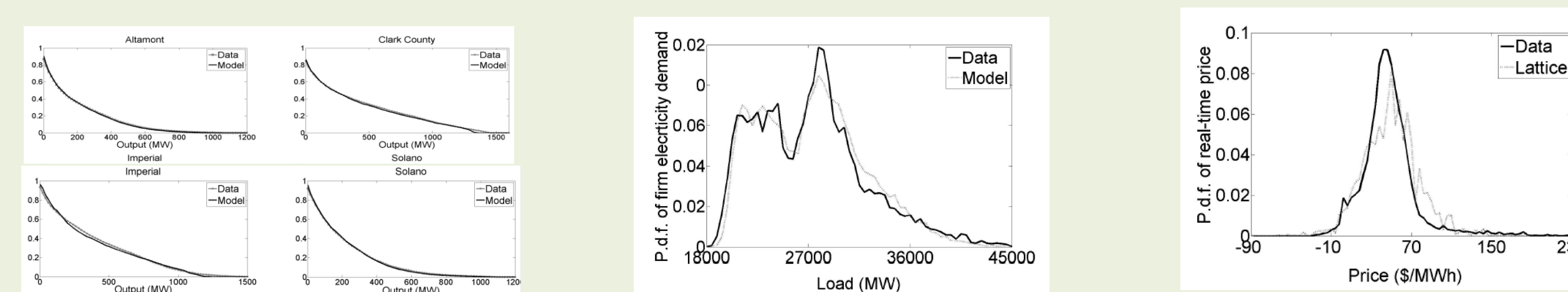- Operating costs
- Renewable supply utilization

Research Approach
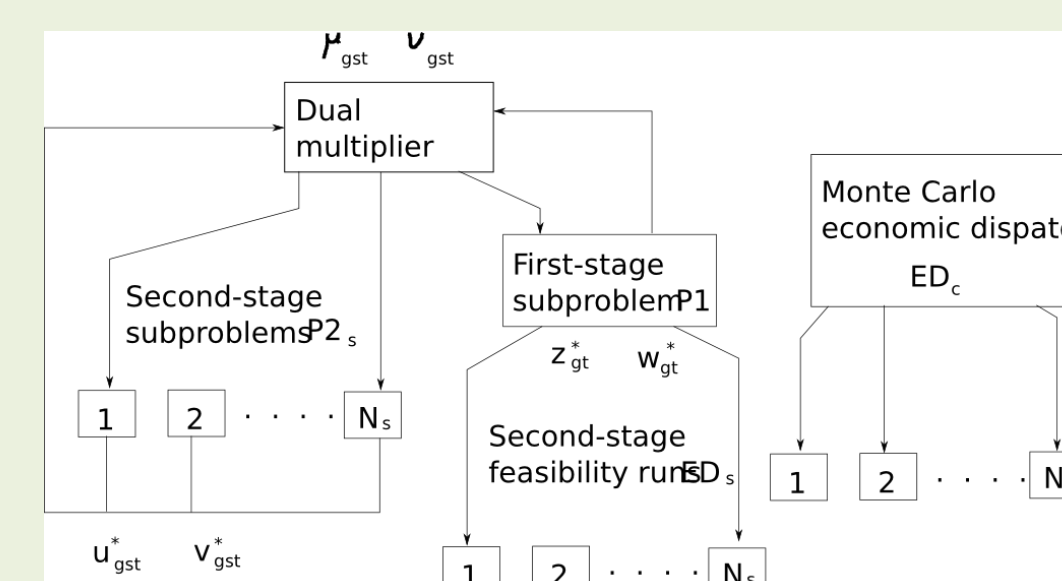
Statistical Models

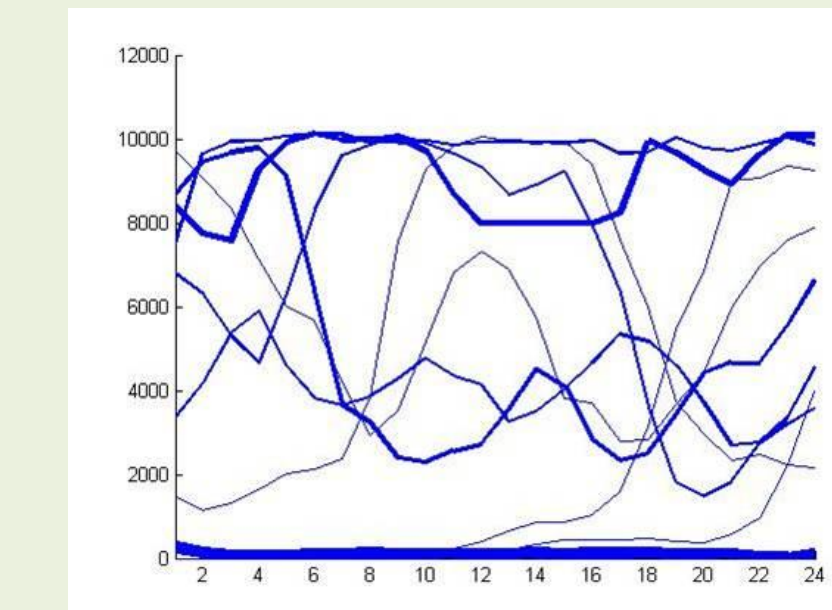

Wind speed — Wind power

Multi-Area wind power — Firm load — Real-time prices

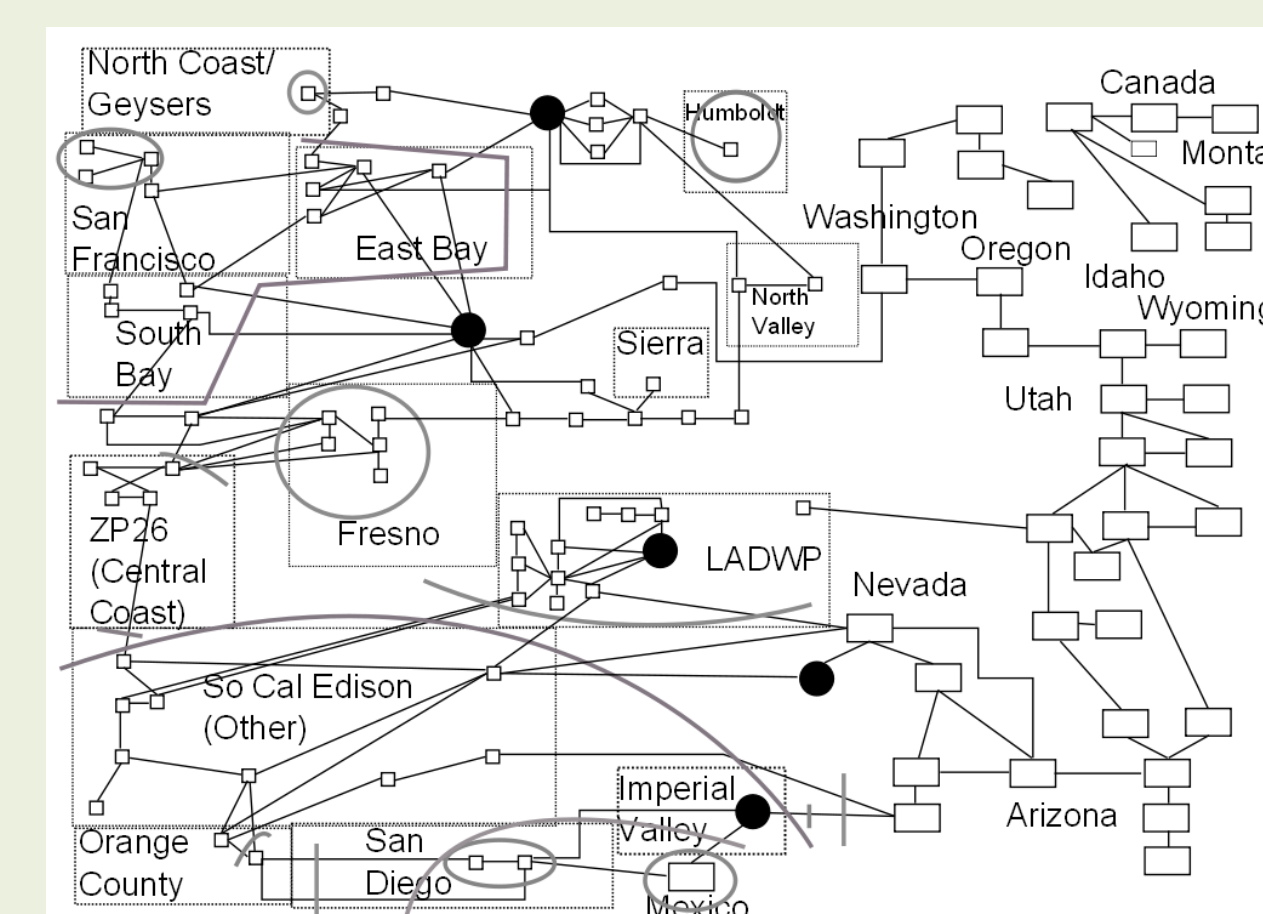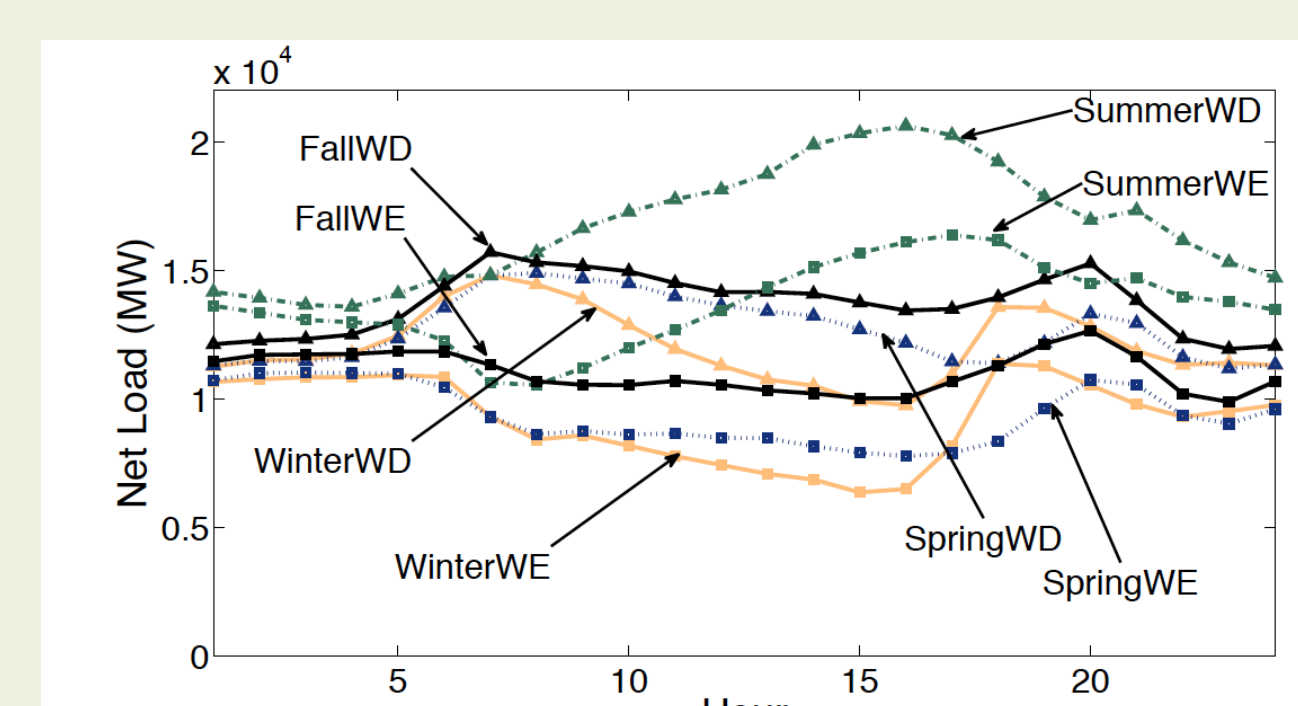### Stochastic Unit Commitment

Decomposition Algorithm — Scenario selection algorithm

Case Study

- California ISO
- 225 Buses
- 371 lines
- 124 generators
- 42 scenarios
- 5 wind sites
- Transmission / generator failures

Type	No. of units	Capacity (MW)
Nuclear	2	4,499
Gas	86	18,745.6
Coal	6	285.9
Oil	5	252
Dual fuel	23	4,599
Import	22	12,691
Hydro	6	10,842
Biomass	3	558
Geothermal	2	1,193
Wind (7.1% pen.)	5	6,688
Wind (14% pen.)	10	14,143
Fast thermal	82	9,156.1
Slow thermal	40	19,225.4

Results

Single-area study

A Jensen-inequality effect

Multi-area study

	Deep-Simple	No Wind	Moderate	Deep
RE daily waste (MWh)	100	0	890	2,186
Cost ($M)	5.012	11.508	9.363	7.481
Capacity (MW)	20,744	26,377	26,068	26,068
Daily savings ($)	38,628	104,321	198,199	188,735
Forecast gains (%)	32.4	35.4	41.9	46.7

Demand response study

	Min load	Fuel	Startup	Total
No wind	1,382,156	7,549,491	80,384	9,098,537
Centralized Moderate	1,246,552	7,364,815	66,489	8,677,857
Bids Moderate	1,317,383	7,471,363	100,123	8,888,866
Coupled Moderate	1,330,130	7,532,898	79,958	8,942,958
Centralized Deep	1,194,606	7,174,611	50,105	8,419,322
Bids Deep	1,360,543	7,494,472	143,217	8,998,232
Coupled Deep	1,432,948	7,592,595	99,276	9,124,819

	Capacity (MW)	Spillage (MWh)
No wind	26,123	N/A
Moderate	26,254	0
Deep	26,789	2

Publications

[1] A. Papavasiliou, S. S. Oren, R. P. O'Neill, *Reserve Requirements for Wind Power Integration: A Scenario-Based Stochastic Programming Framework*, accepted for publication in IEEE Transactions on Power Systems.

[2] A. Papavasiliou, S. S. Oren, *Multi-Area Stochastic Unit Commitment for High Wind Penetration in a Transmission Constrained Network*, submitted to Operations Research, **runner-up 2011 ENRE INFORMS student travel scholarship**.

[3] A. Papavasiliou, S. S. Oren, *Large-Scale Integration of Deferrable Electricity and Renewable Energy Sources in Power Systems*, submitted to IEEE Transactions on Power Systems special section on Electricity Market Operations.

Potential Uses of this Research

- Stochastic unit commitment software
  - Operation
  - Asset valuation
  - Market analysis / forecasting
  - Policy analysis
  - Renewable integration / demand response research
- Smart charging algorithms for deferrable loads
  - Operation
  - Fleet valuation
  - Contract design