Generation Planning under Uncertainty with Variable Resources

A Case Study of Sao Miguel

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Background

- A global trend towards more renewable energy
- Renewable resources like wind and solar are variable and uncertain
- Need to re-visit generation expansion planning to include renewables
- Key challenge: *proper representation of the renewable resource uncertainty*
- Traditional sources of uncertainty (e.g. load and generator outages) are still there

Generation Expansion Model

- A stochastic dynamic programming model for optimal generation expansion under uncertainty
- Objective function: Expected social surplus
- The model finds the optimal first-stage expansion decision considering
  - Long-term uncertainty in load
  - Short-term uncertainty in wind power and load

Original model*: A. Botterud, M.D. Ilic, I. Wangensteen, “Optimal Investments in Power Generation under Centralized and Decentralized Decision Making,” *IEEE Transactions on Power Systems*, Vol. 20, No. 1, pp. 254-263, Feb. 2005.

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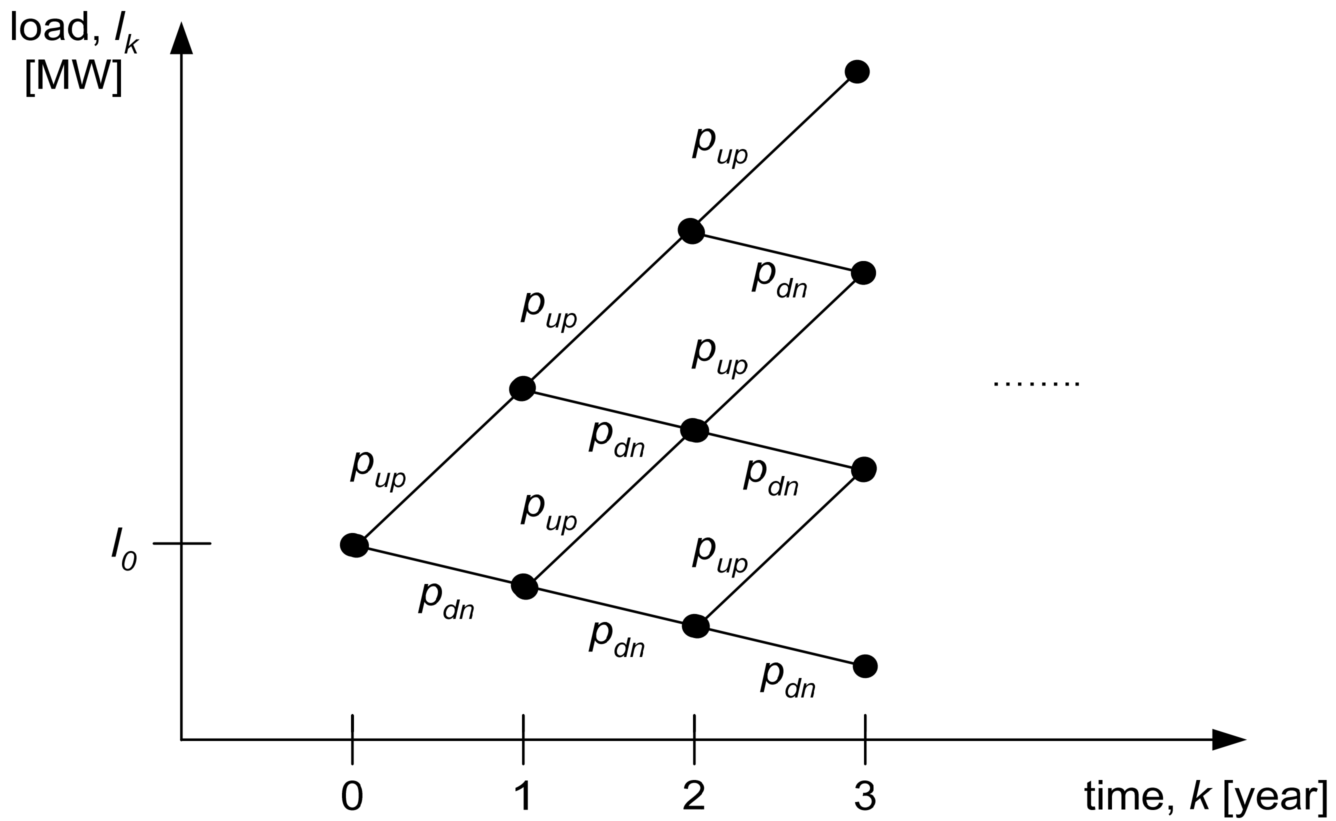
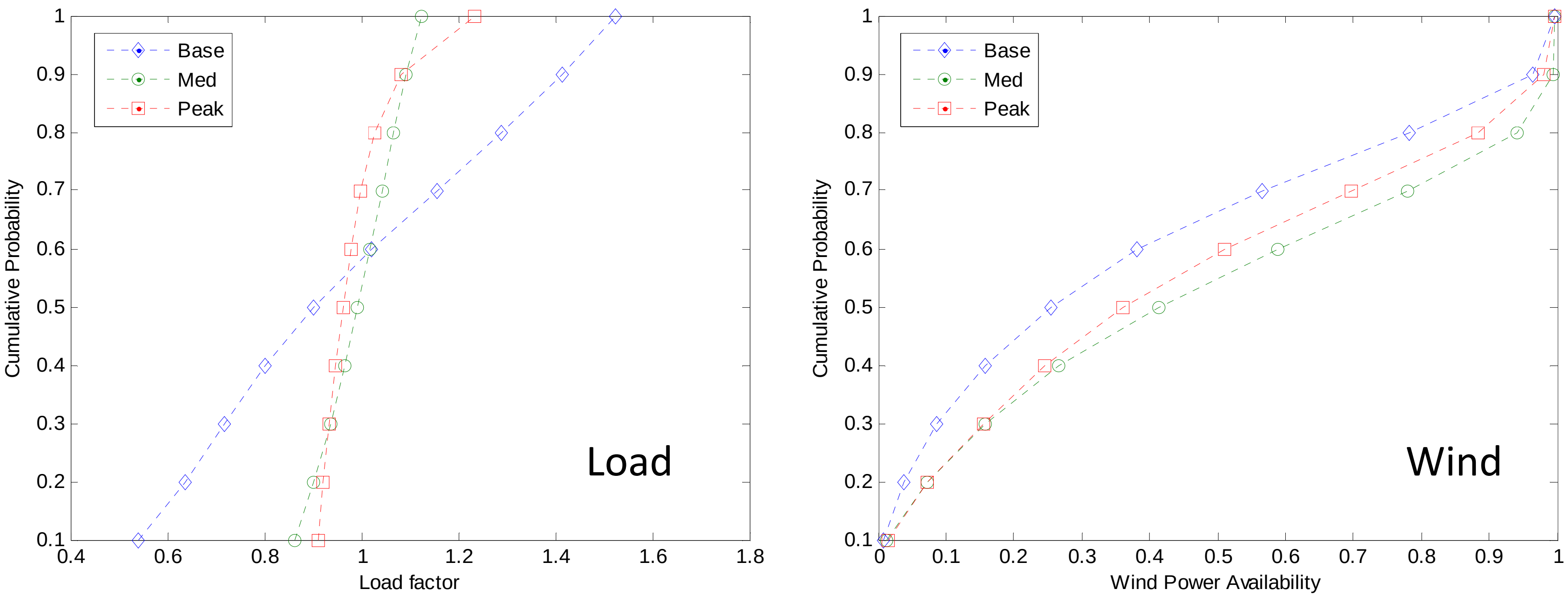
Long-term Uncertainty in Annual Load



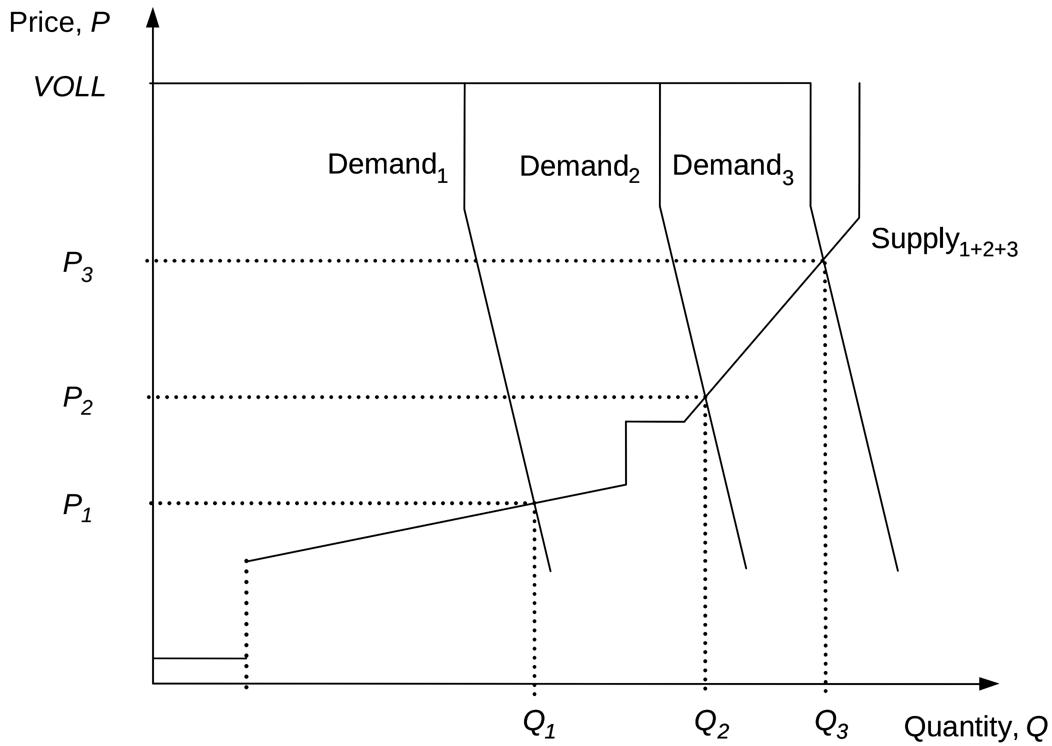
- Markov chain representation of average load captures the option value of waiting for information to unfold

Short-term Uncertainties

- Seasonal distributions for load and wind power
  - Discrete distributions
  - Assumed to be independent
- Estimated distributions for Sao Miguel:



Supply and Demand



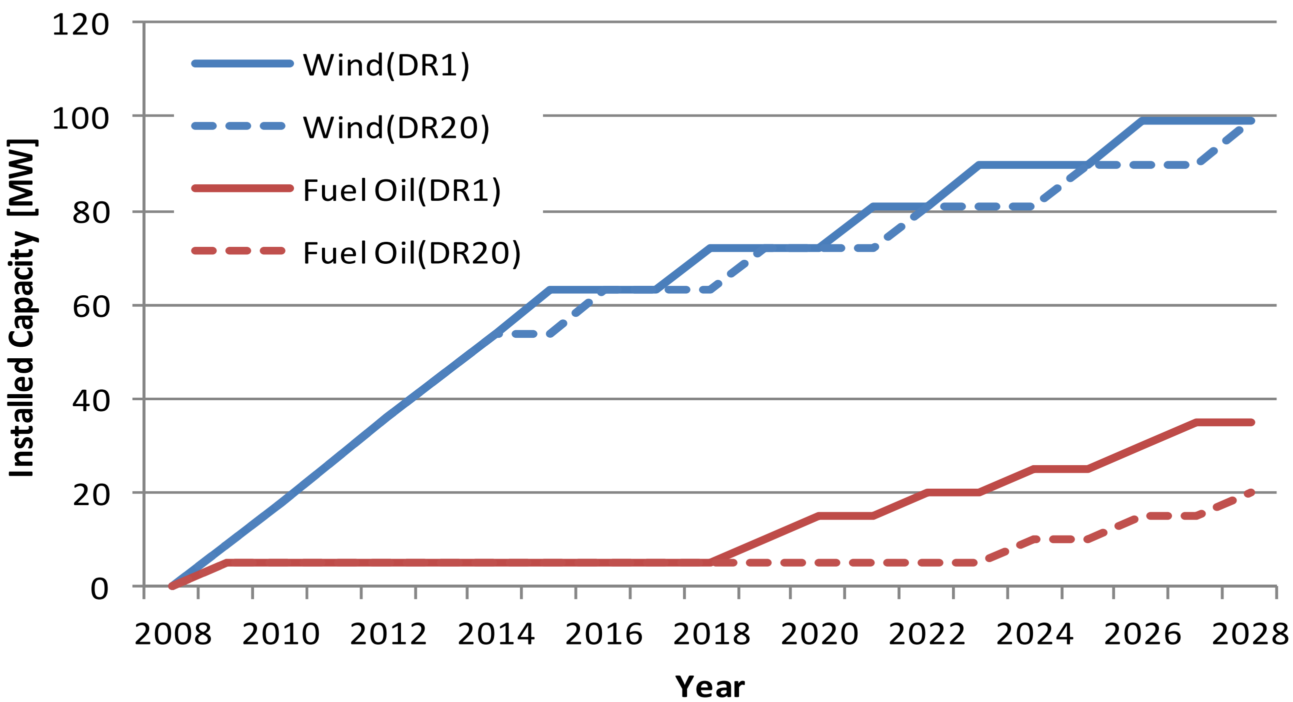
- Dispatch heuristic for each season and each realization of short-term uncertainties (load and wind) within each year
- Expected costs and social surplus calculated accordingly
- Calculations done for each combination of state variables before SDP loop finds optimal expansion strategy

Case Study of Sao Miguel

- Generation expansion decisions
  - First-stage decision with 10 year planning horizon
  - Simulate 20 years of expansion decisions
- Supply and demand parameters estimated based on existing system and historical load growth
  - Hydro and geothermal subtracted from load
- Two new generation alternatives, wind and fuel oil:

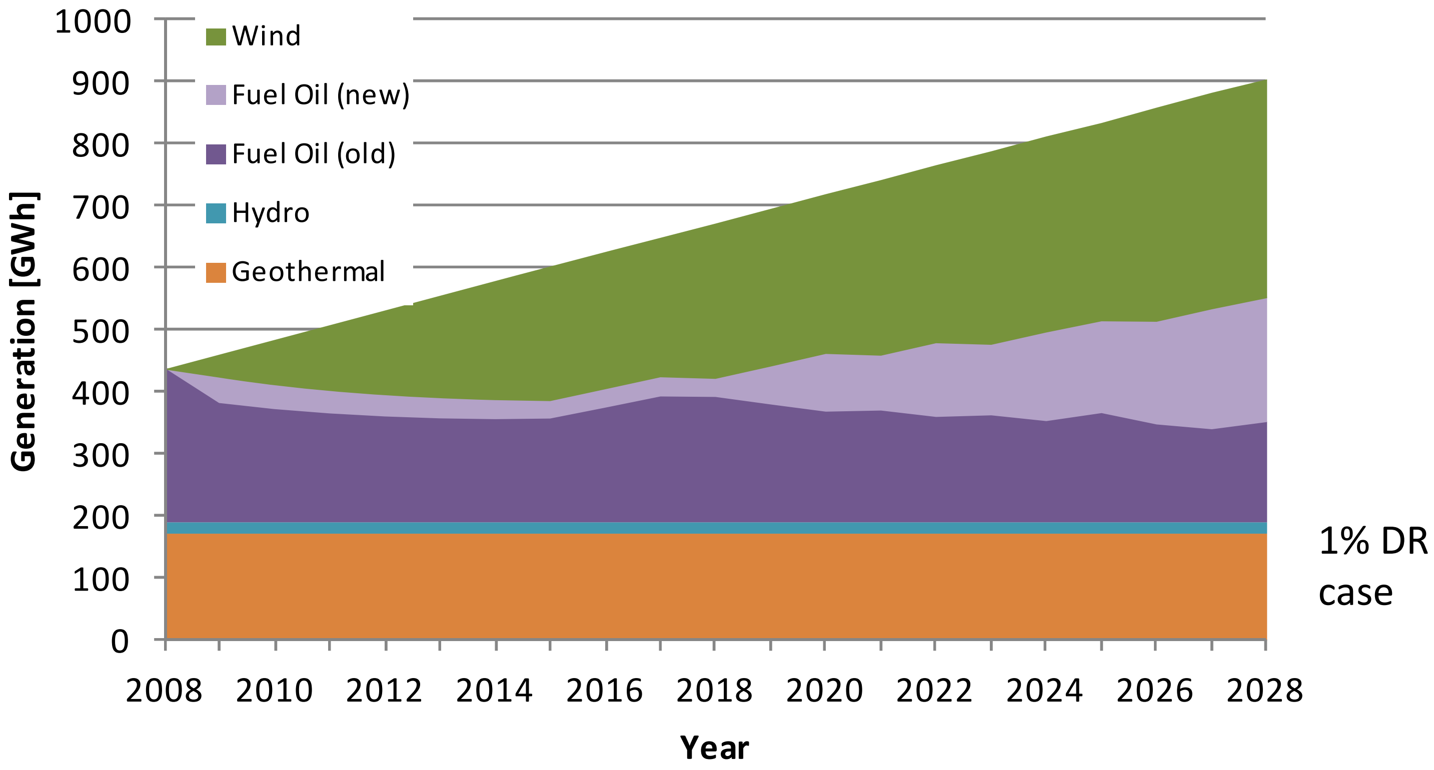
	Wind Power	Fuel Oil			Unit
Capacity Factor	46	20	50	80	**%**
Investment Cost	55.0	50.4	20.2	12.6	**$/MWh**
Operating Cost	0.0	180.0	180.0	180.0	**$/MWh**
Total Cost	**55.0**	**230.4**	**202.2**	**192.6**	**$/MWh**

Results – Generation Expansion



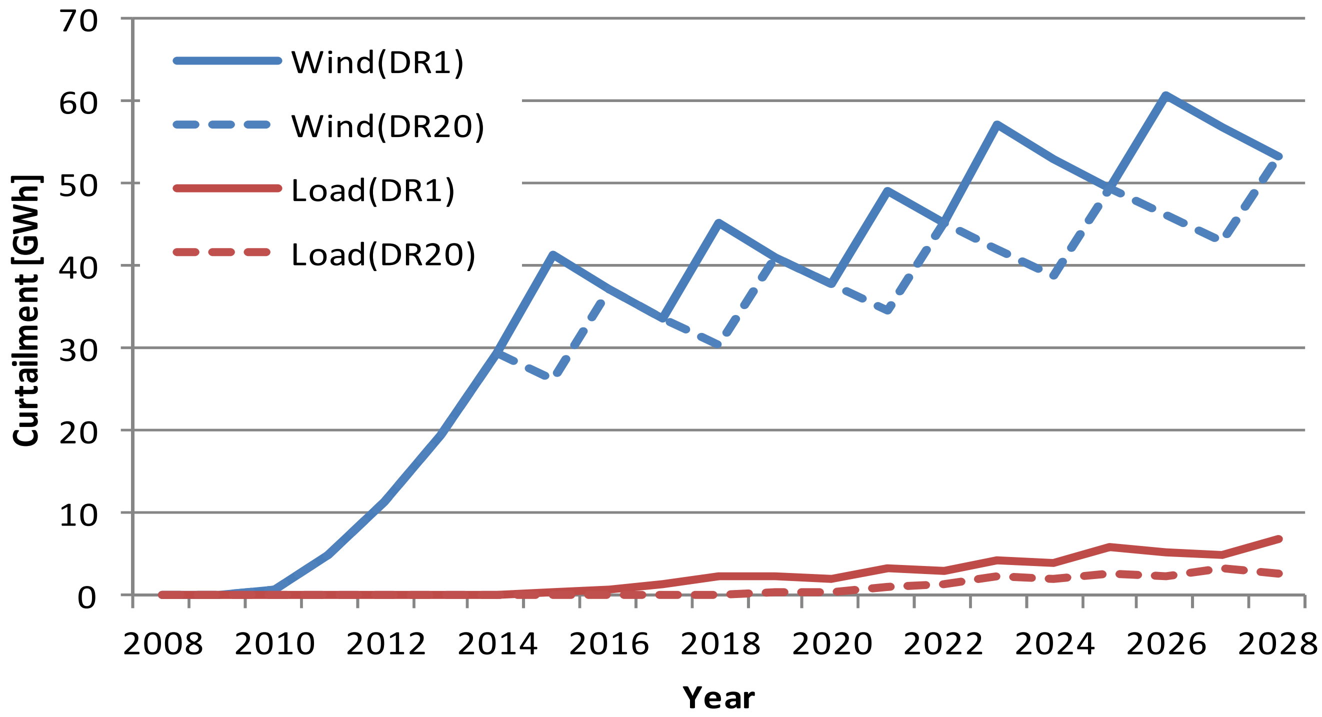
- Majority of new generation capacity is wind power
- Demand response reduces the need for capacity, and particularly for dispatchable fuel oil generation

Results – Dispatch



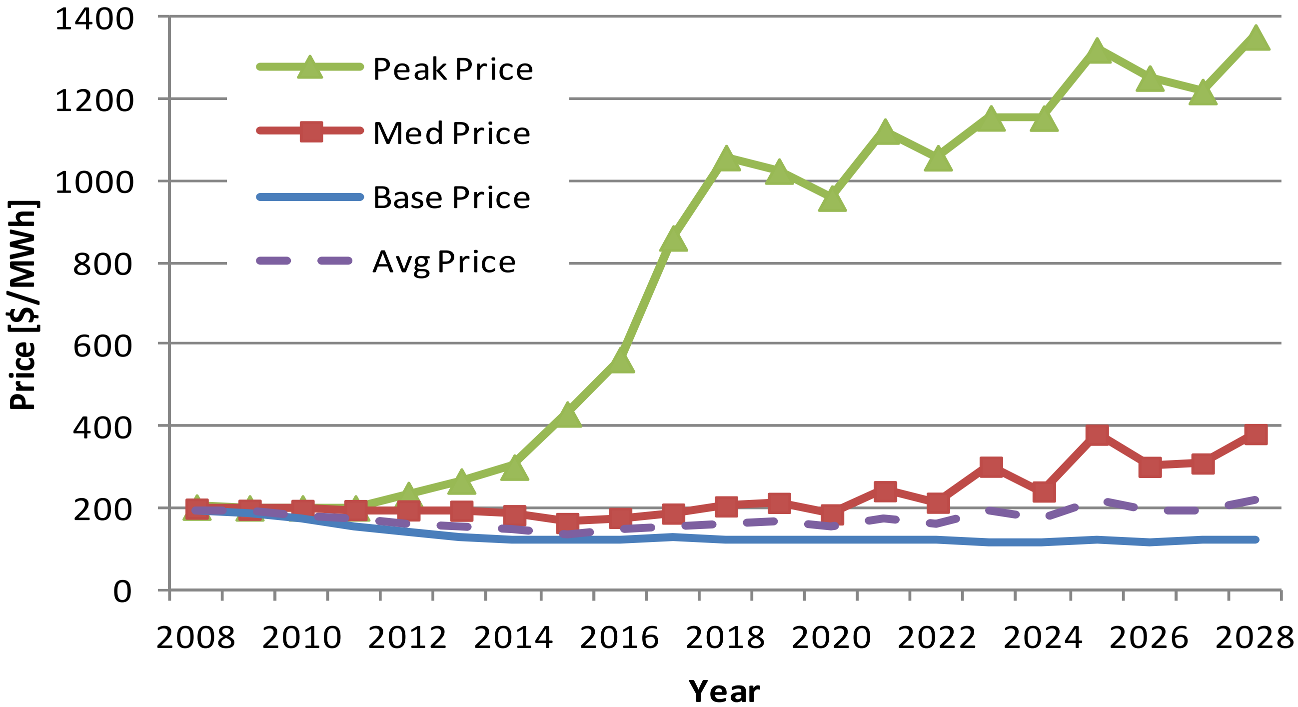
- Wind power reaches 35-40% of total demand
- Some dispatchable fuel oil capacity also needed

Results - Curtailment of Load and Wind



- Some curtailment of both wind power and load
  - Reaches 16-17 % of available wind power
  - Reaches 0.5-1 % of fixed load
- Demand response reduces curtailments of both
- Energy storage not considered

Results – Prices/Marginal Costs



1% DR case

- Average price equal to expected marginal costs in each season
- Average price remains relatively constant
- Lower base price and much higher peak prices emerges as more wind power is integrated
- Could be used for dynamic or real-time pricing

Conclusions

- Stochastic dynamic expansion framework considers short- and long-term uncertainties in supply an demand
- Wind power very attractive on Sao Miguel due to high fuel prices
- Some dispatchable thermal resources still needed to balance the system
- Demand response leads to less need for thermal expansion and less curtailment of wind and load
- Dynamic or real-time prices needed to incentivize consumers to respond to prices