Using Storage to Increase the Market Value of Wind Generation

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Background and Motivation

- High renewable targets around the world
  - Texas: ≈6 GW by 2015
  - California: 33% by 2020
  - EU: 20% by 2020
  - The list goes on
- Much of this will likely be wind, due to its low relative cost
- Wind will suppress energy prices, reducing its value (Ragwitz and Sensfuss, 2008; Green and Vasilakos, 2009; and Twomey and Neuhoff 2009)
  - Wind and energy prices slightly negatively correlated due to diurnal and seasonal patterns
  - More noticeable with higher wind penetration due to high-cost generators being displaced
  - Market power can exacerbate this due to hockey-stick shape of supply curve
- Energy storage can increase wind's value by shifting generation from periods with low prices or high price-suppression effect to other periods

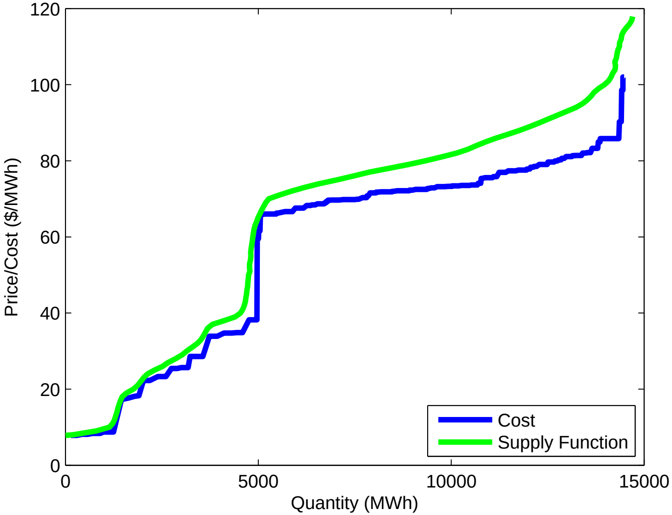
- Model the value of wind and storage in the state of Texas
- Market modeled using supply function equilibrium to derive a ‘market price function,’ which gives energy price as function of net sales from wind/storage operator
- Hourly wind data drawn from NREL’s WWSIS data set, wind sites selected based on planned location of farms through 2013
- Energy storage modeled as a stock and flow system with efficiency losses (assume pure storage and not CAES)
    - Without storage, all available wind is sold unless price drops below −\$19/MWh (PTC)
    - With storage, profits maximized based on market price function, wind availability, and storage capabilities

- Model based on Green, 2008; and Green and Vasilakos, 2009
- Assume market has symmetric firms submitting hourly supply functions to the market, and a competitive fringe
    - SFE is given by solution to the differential equation:

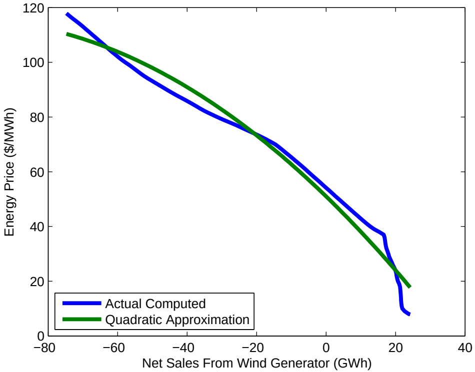
      $$q(p) = (p - c'(q(p))) \left(-\frac{\partial}{\partial p} D(p,t) + (\hat{n} - 1) \frac{d}{dp} q(p) \right),$$

      where $c(q)$ is firms' cost functions, $D(p,t)$ is demand, and $\hat{n}$ is inverse of HHI
    - Nuclear generators are assumed to be non-strategic
    - Assume a duopoly consisting of TXU and Texas Genco
- Generator costs based on fuel price, heat rate, and emissions permit price data from Ventyx and Platts

Methodology
Sample SFE



- Equilibrium supply functions are combined with competitive fringe's supply and actual load to compute market price function
- Because this function is used in storage optimization, it is approximated as a quadratic function to reduce complexity



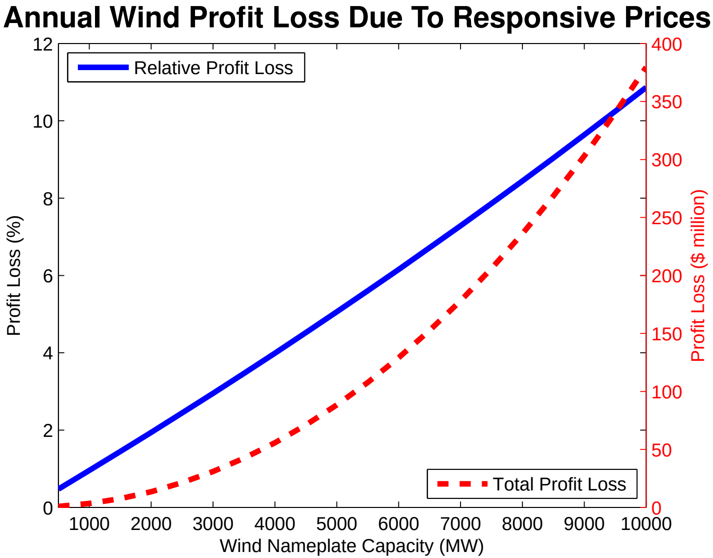
- Based on market price function, storage model determines storage use to maximize profits
- Examine cases with up to 10 GW of wind, and between 1 and 20 hours of up to 10 GW of 80%-efficient storage
- Examine a no-arbitrage case, to determine value of storage purely for wind-related use
- Sensitivity analysis done to determine storage value with arbitrage opportunities and a more competitive market

- Negative correlation between wind and load mean that even with fixed prices, wind's price is below average
- Adding wind suppresses prices overall, but affects wind disproportionately
  - Adding 10 GW of wind reduces overall prices by 6% but price of wind by 13%

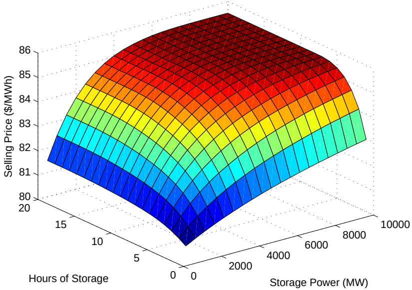
	Average Energy Price ($/MWh)	
Wind (MW)	Wind	Overall
1000	91.41	98.44
2000	90.31	97.92
3000	89.19	97.39
4000	88.03	96.85
5000	86.84	96.30
6000	85.62	95.74
7000	84.36	95.16
8000	83.06	94.57
9000	81.73	93.96
10000	80.37	93.34
Fixed Prices	92.48	98.94

Wind Without Storage

Effect on Wind Profits



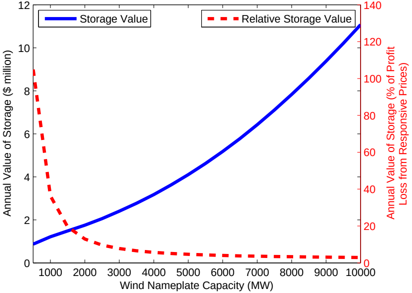
Average Selling Price of Wind (10 GW)



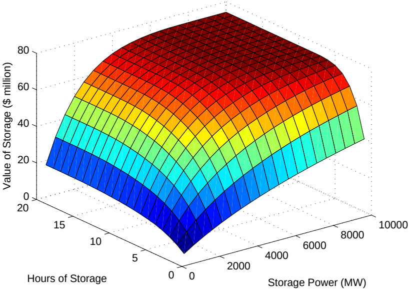
- Storage increases price of wind by between \$0.22 and \$5.16 per MWh
- Translates into annual profit increases of between \$3.8m and \$74.4m
- Value of storage plateaus around 20-hour 5 GW or 6-hour 10 GW device
  - Depending on technology and location, these sizes are all feasible

- Even for a small device, storage value is increasing in wind farm size since ability to influence prices by storing energy becomes more valuable with more wind
- For a small wind generator (< 1 GW), storage value is greater than profits lost from wind suppressing prices

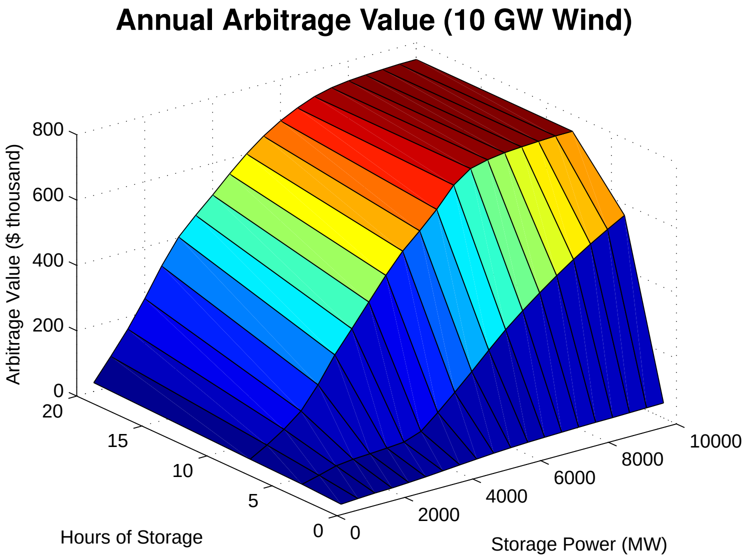
Annual Value of Storage (8-hour 500 MW)



Annual Value of Storage (10 GW Wind)



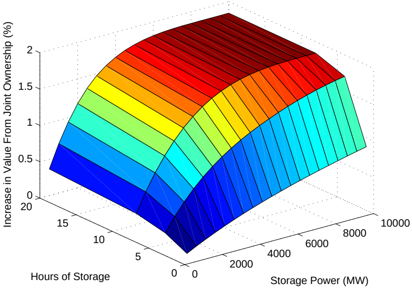
- Storage is valuable to a wind operator, but has high capital cost
- Assuming 11% capital charge rate, the highest cost that can be justified is $317/kW
- CAES cost estimates are $750–1000/kW, PHS $1500–2500/kW, batteries (are you kidding?)



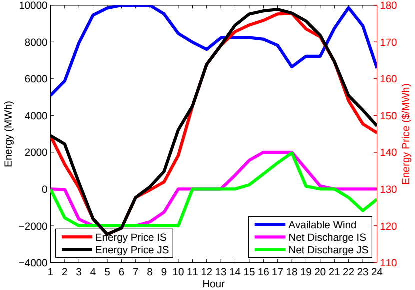
Annual Arbitrage Value (10 GW Wind)
Arbitrage Value ($ thousand)
800
600
400
200
0
20
15
10
5
0
Hours of Storage
0
2000
4000
6000
8000
10000
Storage Power (MW)

- Joint ownership gives small increase in value, so benefits would accrue if someone else owns the storage

Added Value From Joint Ownership (10 GW Wind)



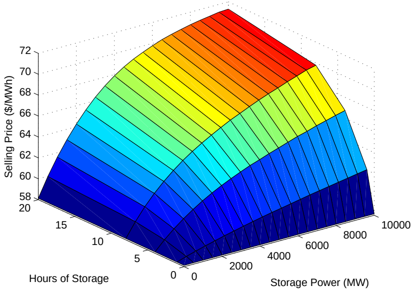
Storage Use (8-Hour 2 GW Storage, 10 GW Wind)

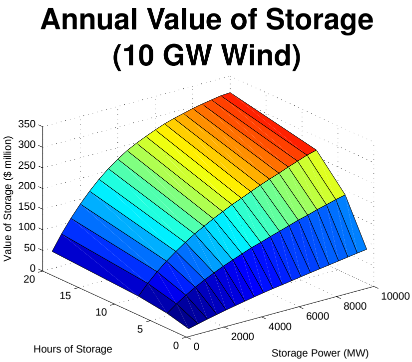


- Difference is that joint storage better manages energy prices during high-wind periods

- Examine case with six strategic firms, i.e. $\hat{n} = 6$
- With six firms prices will be lower on average
- Prices only spike in very high-load periods
- Storage is much more useful here—able to raise wind price by between \$0.29 and \$13.18 per MWh (maximum \$5.16/MWh increase with 2 firms)

Average Selling Price of Wind (10 GW)





- Close to five-fold increase in annual storage value in some cases
- Highest breakeven cost increases to $757/kW (500 MW 20-hour device), which is above lower range of cost estimate of CAES

Conclusions and Future Work

- Storage has another potential value with wind. Other uses include:
  - Handling uncertainty and variability
  - Reducing transmission capacity requirements
  - Using wind during low-load periods
- High capital cost of storage means only small-scale storage viable with current technologies
- May be better rationalized if storage leverages all of these value streams
  - Future work: quantify the total value of storage considering all of these uses and how they interact with one another
- Since most of the value of storage is captured when it is not owned by the wind operator, this may be a second-best alternative since merchant storage operator may better justify investment

Questions?