Strategies for Mitigating the Reduction in Economic Value of Variable Generation with Increasing Penetration Levels

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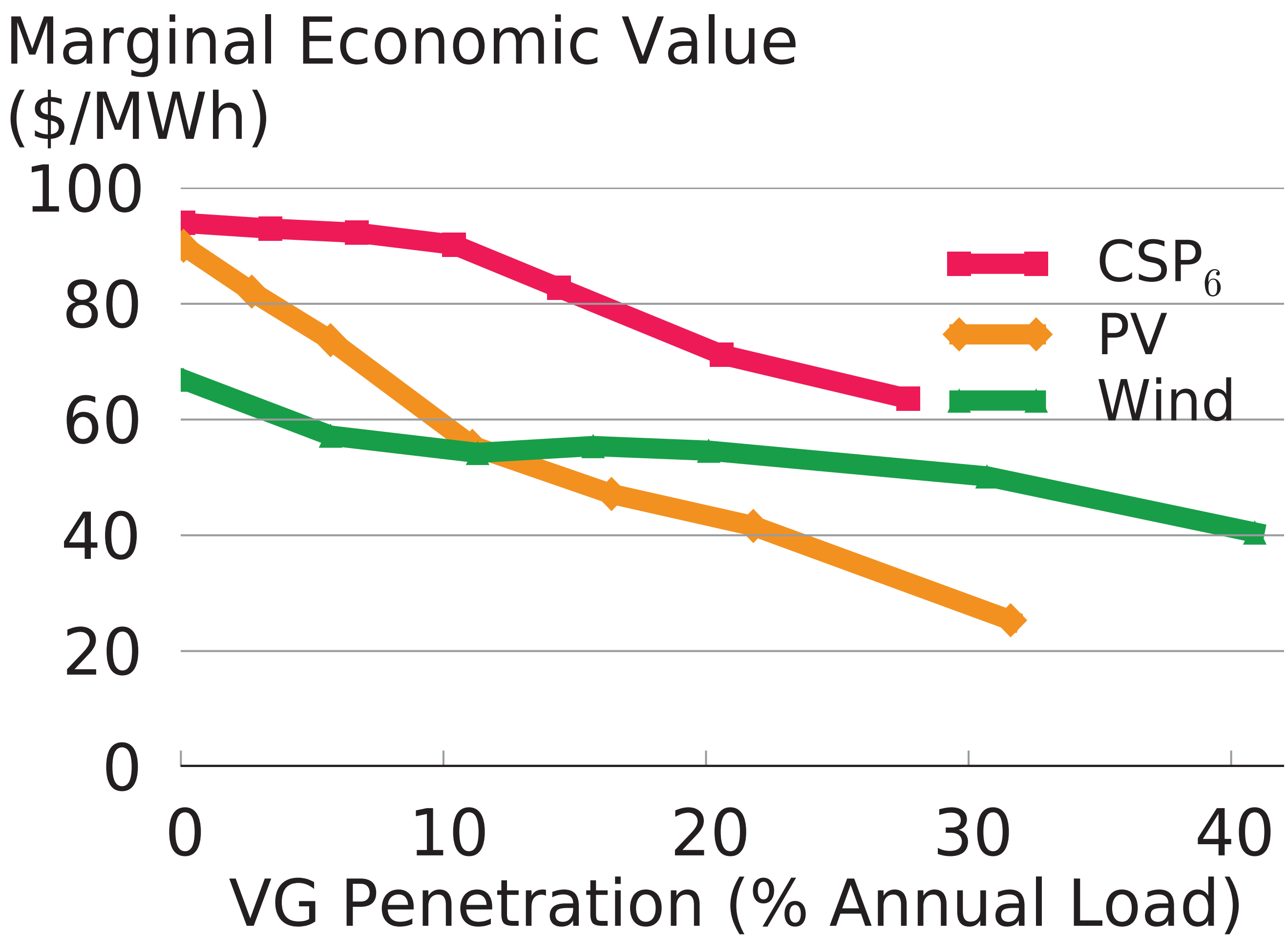
Changes in Value of Variable Generation (VG)

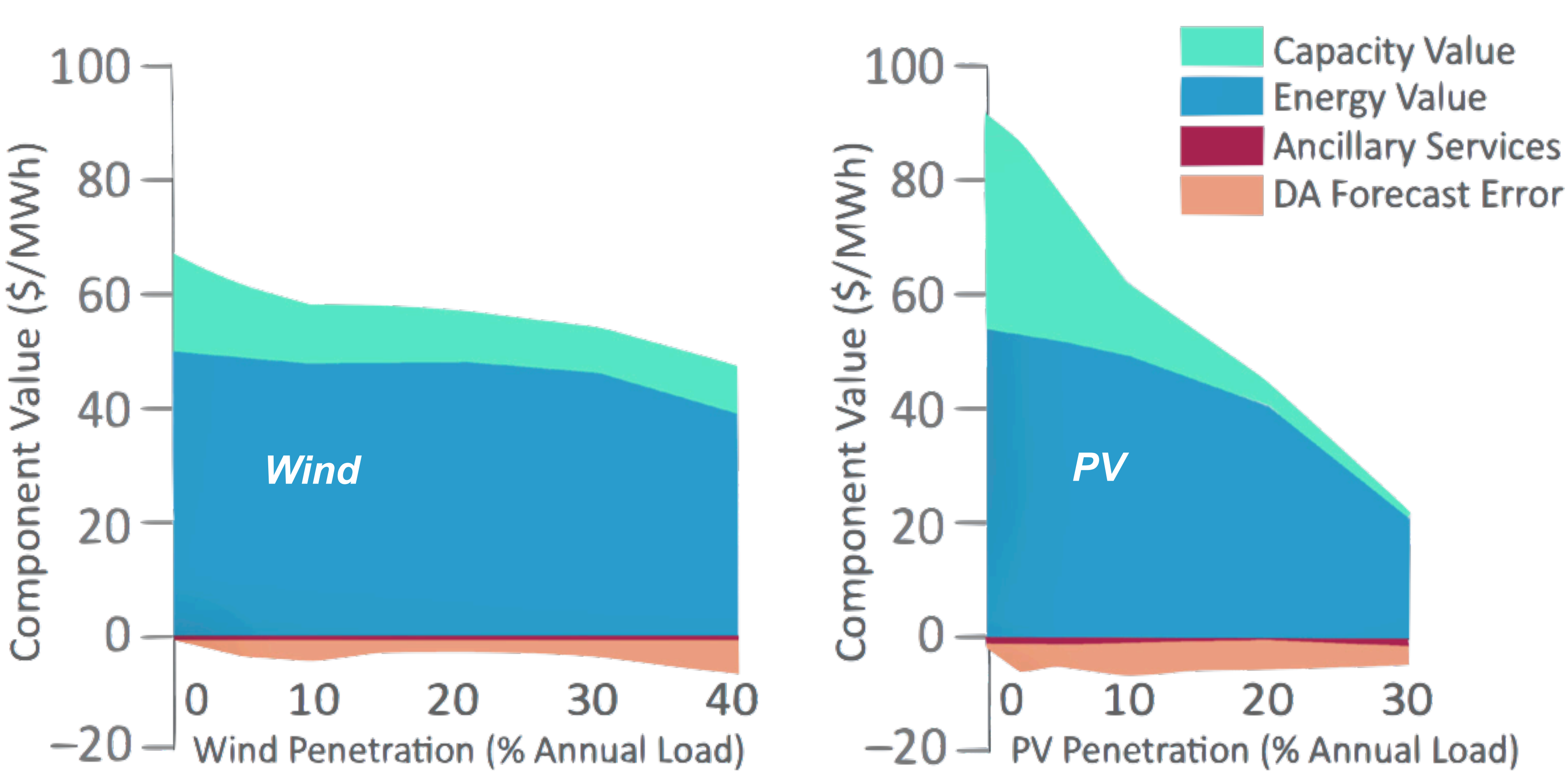


Previous research by the authors* investigated the change in the marginal economic value of wind, PV, and CSP with increasing penetration levels in California.

Marginal economic value was based on avoiding costs from other non-renewable generation including capital investment cost, variable fuel, and variable operations and maintenance (O&M).

*Mills and Wiser 2012

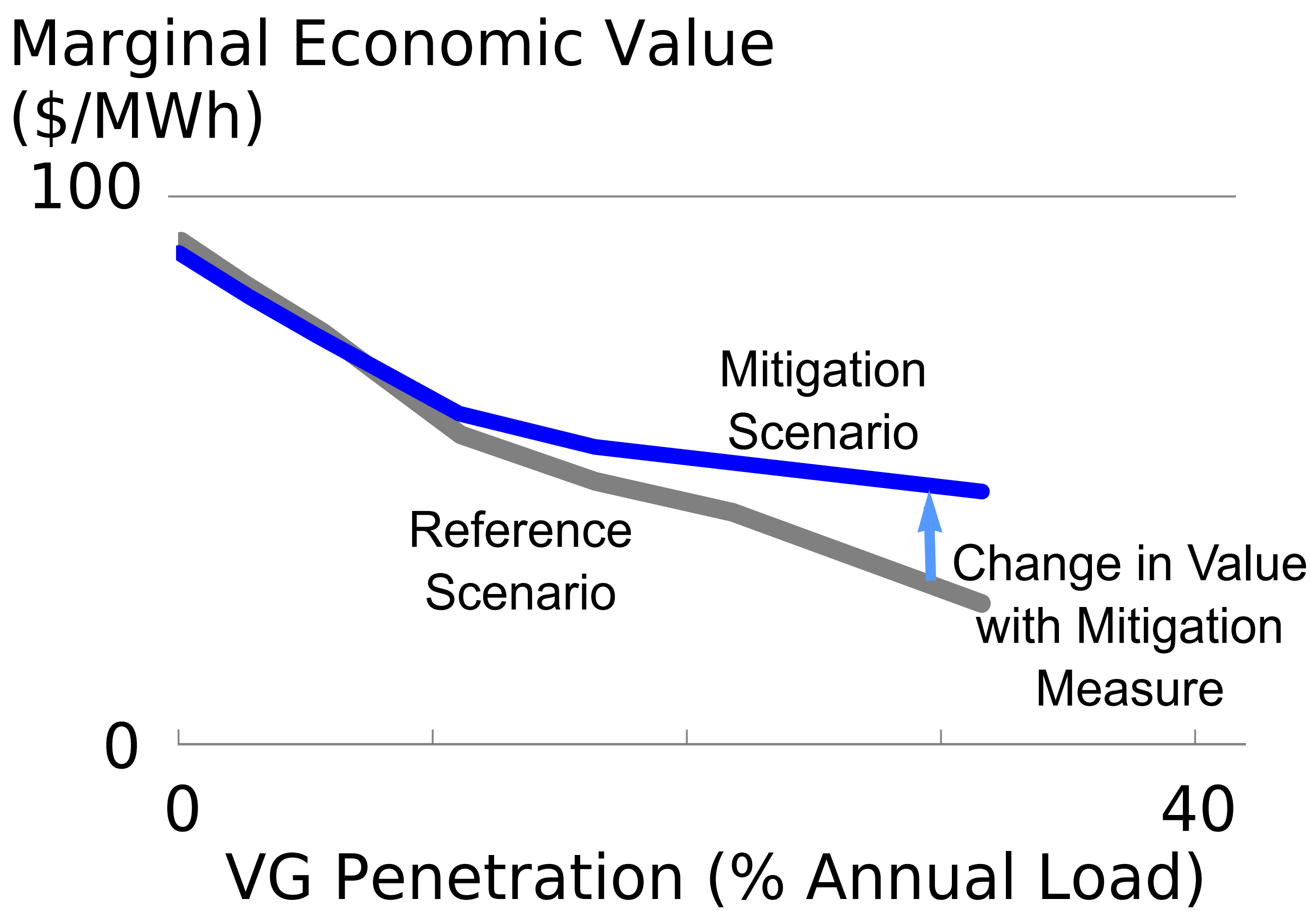
Decline in Economic Value Primarily Driven by Decreases in Capacity and Energy Value



In the previous report we examined causes in the decline in the marginal economic value. The primary factors were decreases in energy value (which fuels were displaced) and capacity value (how much conventional capacity was avoided).
Costs due to operational factors (day-ahead forecast errors and ancillary services) did not increase as much with penetration.

How Much Would the Value of VG Change if Mitigation Measures Were Implemented?

We use the same model and data from the previous report to estimate the degree to which different mitigation measures can stem the decline in the marginal economic value of variable generation.



The mitigation measures considered include:

- increased geographic diversity
- technological diversity
- more-flexible new conventional generation
- lower-cost bulk power storage
- price elastic demand subject to real-time pricing (RTP)

Data and Assumptions for Case Study of California in 2030

- Focus on California, 2030 hourly loads (2004 load shapes)
- Solar PV and wind hourly actual and day-ahead forecast from WWSIS (2004 VG generation / forecast shapes)
- Incumbent generation: retirement after technical life of 30 yr for CT/ CCGT, 50 yr steam, 60 yr nuclear
- Simplified commitment and dispatch based on 19 thermal plant vintages: linear on-line constraints rather than integer commitment.; forecasts are deterministic (not stochastic)
- Hourly energy prices for day-ahead (DA) based on forecasts, real-time (RT) based on actual
- Hourly ancillary services prices for regulation, spinning and non-spinning reserves
- Reserve quantities based on rules-of-thumb developed in the WWSIS
- "Energy only" market, meaning that capacity costs are covered through scarcity prices in energy market rather than side capacity payment
- Revenues based on DA schedule at DA prices, deviations at RT prices, and ancillary services costs/revenues

Primary Caveats

- Narrow definition of economic value:
  - Avoided capital investment cost and variable fuel and O&M costs from other power plants in CA
- Focus on California without evaluation of transmission:
  - Renewable electricity only used to meet CA demand
  - Incumbent generation only includes generation in the CA NERC sub-region
- Marginal economic value instead of average value:
  - Only indicates value of next increment of VG
- Simplified commitment and dispatch decisions:
  - Vintages rather than individual unit commitment
- We do not consider full costs of implementing mitigation measures:
  - Only evaluate impact on VG if mitigation measures were to be implemented
  - In reality, these mitigation measures may have costs or may be driven by factors not directly related to increases in wind and PV
  - A full comparison among mitigation measures would also account for their relative cost

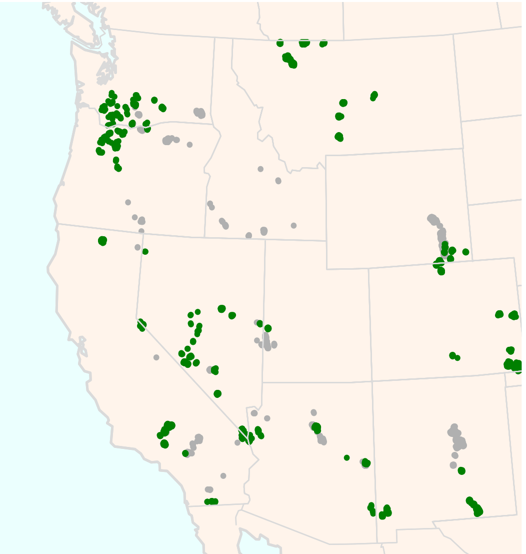
Overview of Results: Change in Value of VG with Implementation of Mitigation Measures

Mitigation Measure	Wind penetration		
($/MWh)	20%	30%	40%
Geographic Diversity	2.5	4.9	10.6
RTP	3.7	5.0	7.9
Low-cost Storage	-0.1	0.4	4.4
Quick-start CCGT	0.3	0.3	-0.6
10% PV	1.1	-1.1	-5.2
10% CSP_6	-0.2	-0.6	-4.4

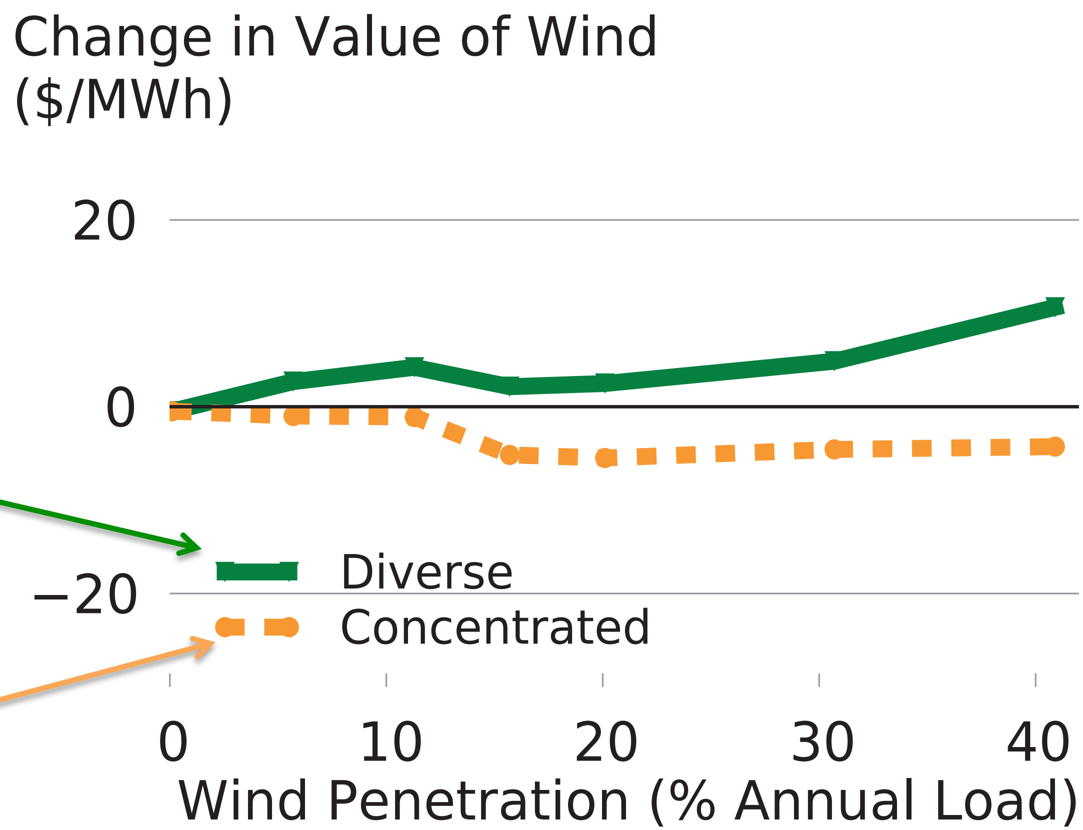
Mitigation Measure	PV penetration		
($/MWh)	10%	20%	30%
Low-cost Storage	3.3	8.4	19.7
RTP	10.4	7.5	7.4
Quick-start CCGT	-1.8	-1.0	-0.2
10% Wind	7.4	-1.1	-6.4

Tables show the change in the value of wind or PV with the implementation of the mitigation measure relative to the value in the Reference Scenario without the mitigation measure. Additional caveats and description of the results are available in the full report.

Geographic Diversity Increases the Value of Wind By Reducing Frequency of Extremes

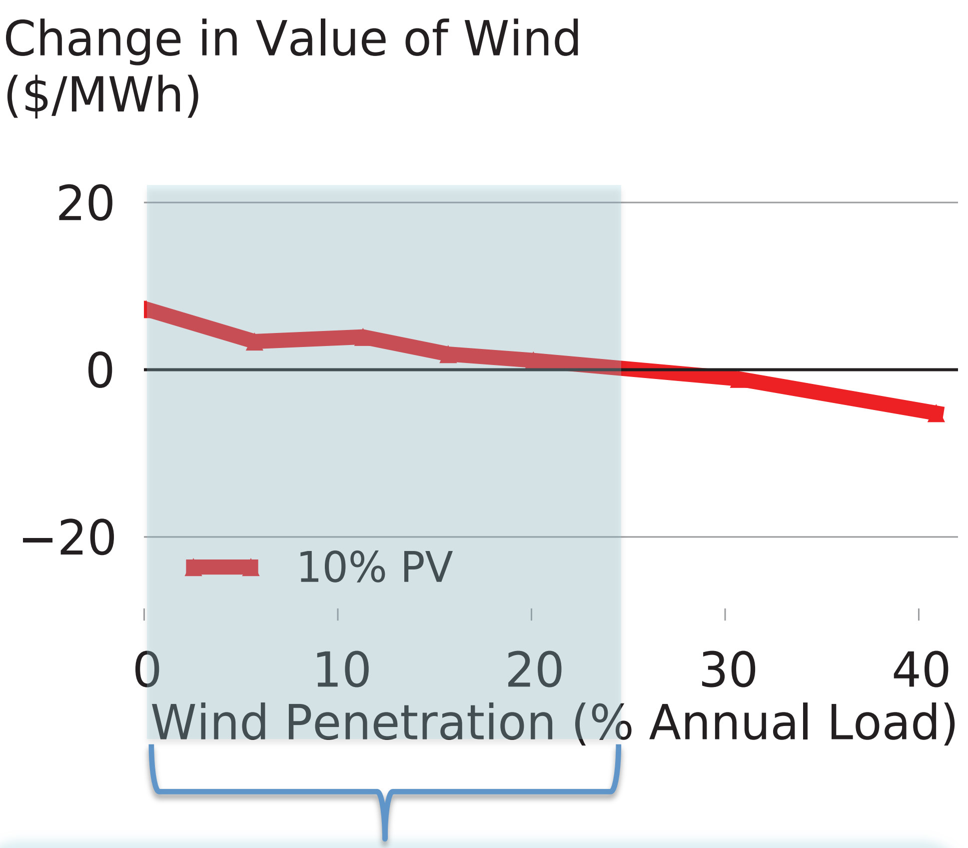


Gray dots represent wind sites used in Reference Case with 40% Wind



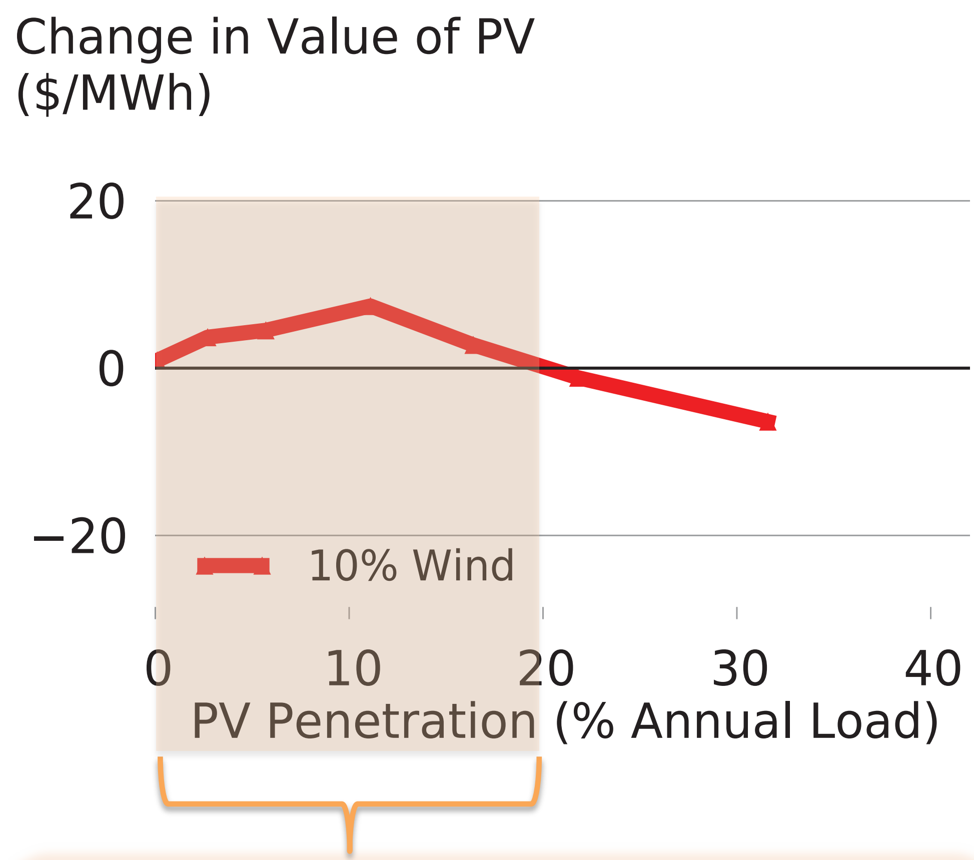
Geographic diversity of wind locations was increased by siting wind to minimize the variance of the aggregated wind output. Higher diversity reduces time when wind is generating during low prices and wind curtailment, thereby increasing the energy value of wind.

Technological Diversity Allows Higher Total VG Penetrations While Maintaining Value



Value of wind at moderate penetrations is greater with 10% PV than value of wind at the same penetration without PV

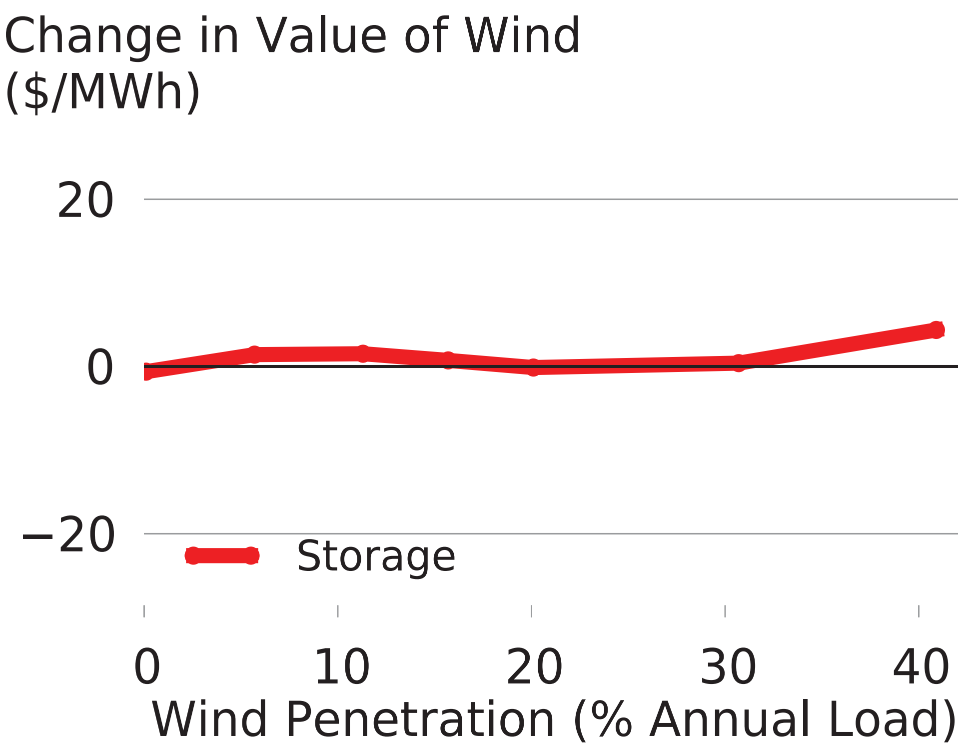
Total VG penetration in this range is 10->30%

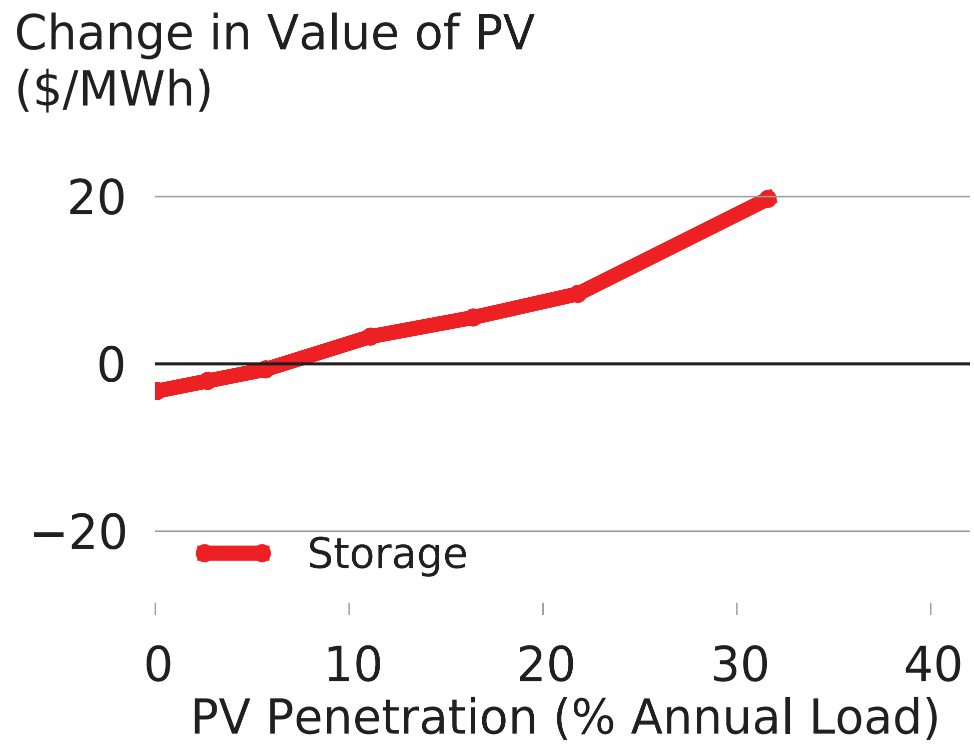


Value of PV at moderate penetrations is greater with 10% Wind than value of PV at the same penetration without Wind

Total VG penetration in this range is 10-30%

Availability of Low-Cost Storage Increases Value of VG at High Penetrations, Particularly for PV

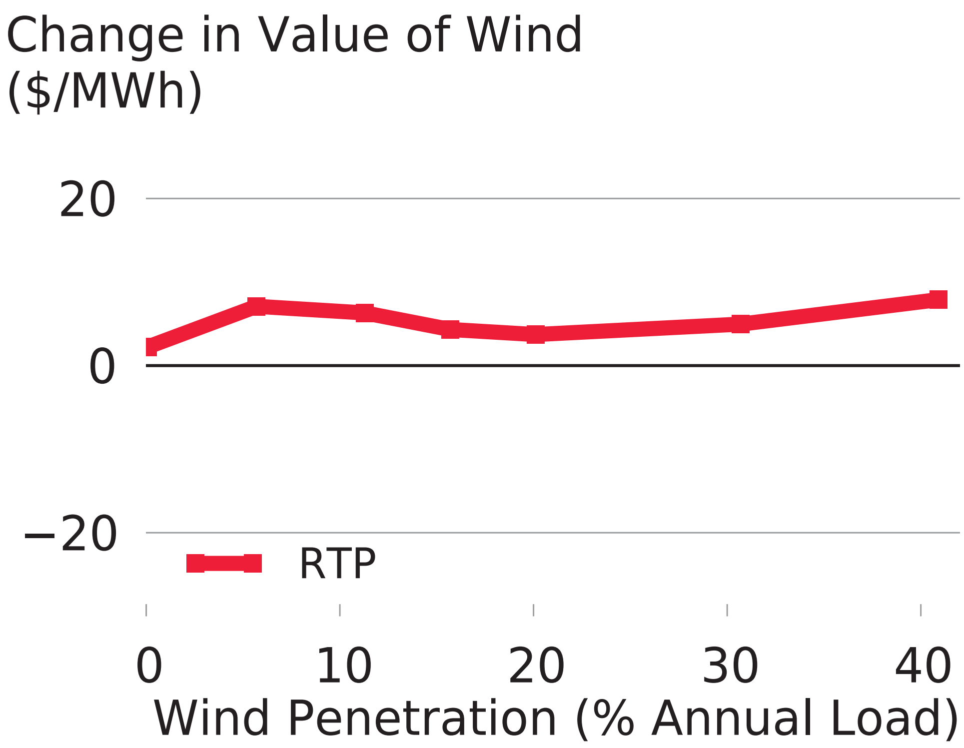


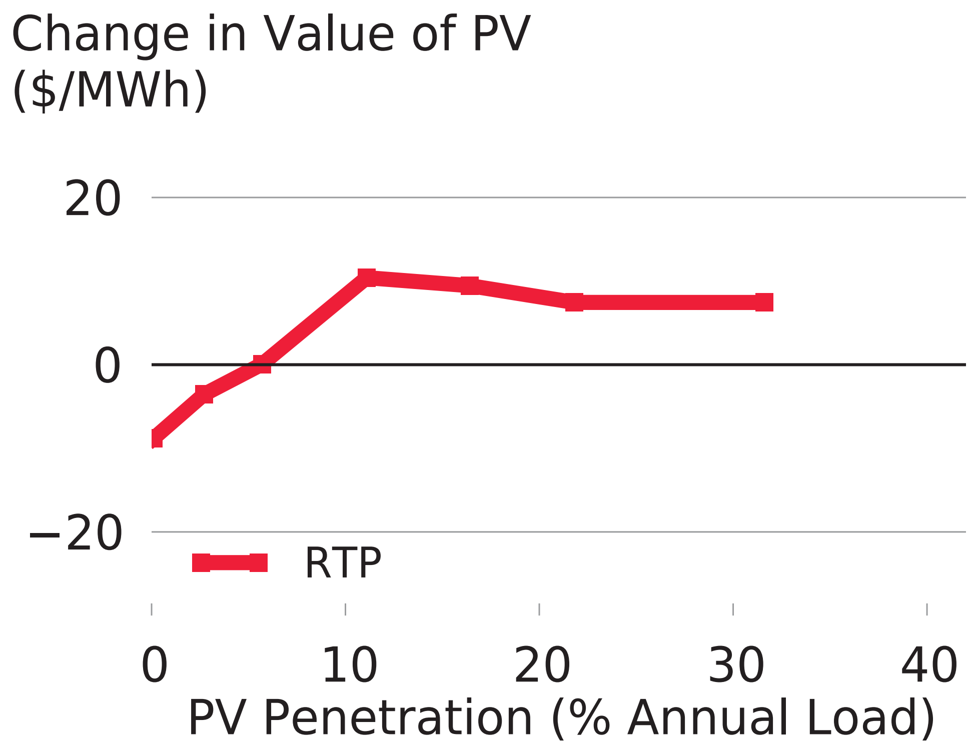


Assuming a low cost of storage leads to a slight decrease in the capacity value of wind and an increase in the energy value of wind. The increase in the energy value is most apparent at high wind penetration levels, in part due to a reduction in wind curtailment.

With high PV penetrations, storage dispatch shifts to absorb power in the morning when PV is generating and to provide power after the sun goes down. The availability of storage increases the energy value of PV and reduces PV curtailment.

RTP Increases Value of VG By Allowing Demand to Change In Response to Availability of VG

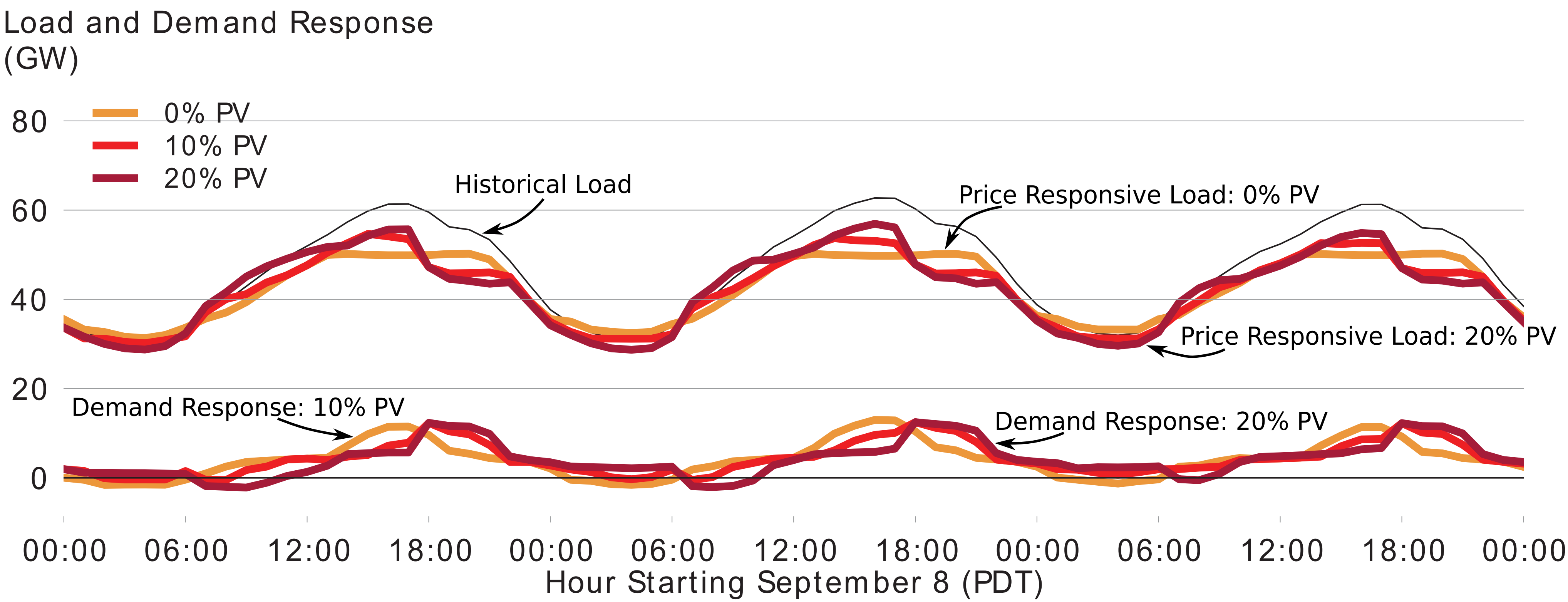




RTP leads to more frequent, but less severe, high prices which increases the capacity value of wind.
Energy value is increased since RTP increases demand during periods of high wind and decreases demand in periods of low wind.

At PV low penetration, RTP lowers demand in the summer afternoon and decreases the value of PV.
At high PV penetration, energy value of PV is increased as RTP shifts demand to times with PV generation.

Character of Demand Response Provided by RTP with High PV is Different than Without PV



RTP without PV leads to demand response that is greatest in the late afternoon and effectively levels the peak demand.

Increasing PV penetration shifts the demand response provided by RTP from late afternoon into early evening on peak load days.

Marginal Values of Mitigation Measures Increase with VG Penetration

- Finding an increase in value of VG with mitigation measures does not answer related question of whether it makes economic sense to pursue these mitigation measures
- We did not consider full cost/benefit analysis of these measures (and many will be driven by factors other than VG deployment), so we cannot directly address this question
- But we did examine whether the economic value of the measures increases with increasing penetration of VG
- In all cases the mitigation measures look more attractive with VG than without. For example, with increased VG:
  - Storage revenues are higher
  - Demand response is more valuable
  - Revenues for flexible generators increase

Conclusions

- Several mitigation measures both increase in attractiveness with increasing penetration of wind and PV and increase the marginal value of wind and PV
- Largest increase in value of wind at 40% penetration is from increased geographic diversity
- Largest increase in value of PV at 20-30% PV penetration occurs with availability of low-cost storage
- Other attractive options include RTP and technology diversity

Recommendations for Future Research

- Benefits of mitigation measures should be compared to their costs
- Interactions of mitigation measures: Impact of combinations of mitigation measures (e.g., storage and RTP) will be different than sum of individual impacts
- Ratio of capacity to energy of storage: wind may require larger storage reservoirs (>10 hours) relative to PV (<10 hours)
- Impact of mitigation measures will be different for different power systems

For More Information…

Download the full report:

http://emp.lbl.gov/sites/all/files/lbnl-6590e.pdf

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