Enhancing the Value of Solar Electricity at High Penetrations

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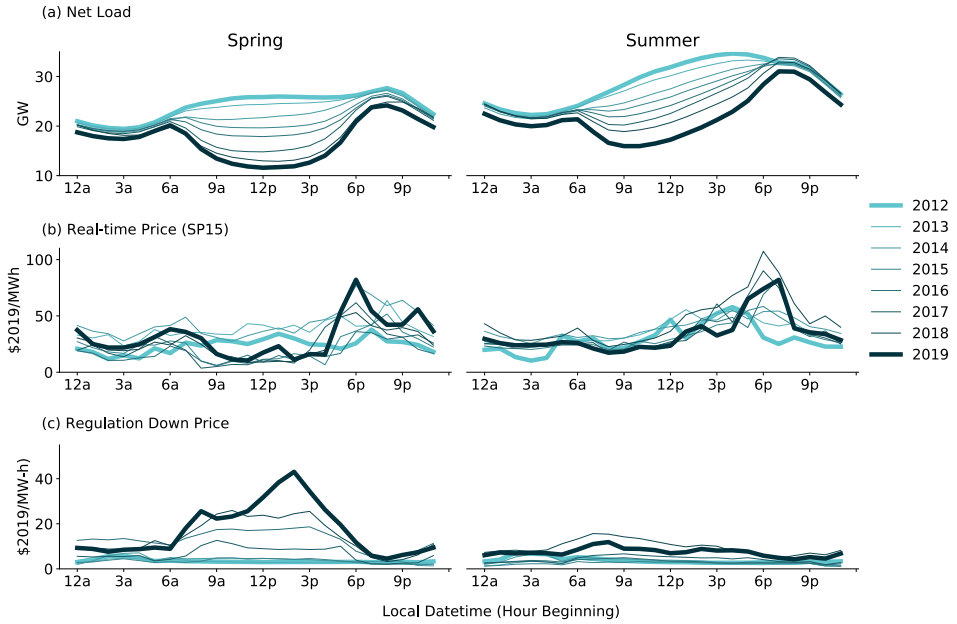
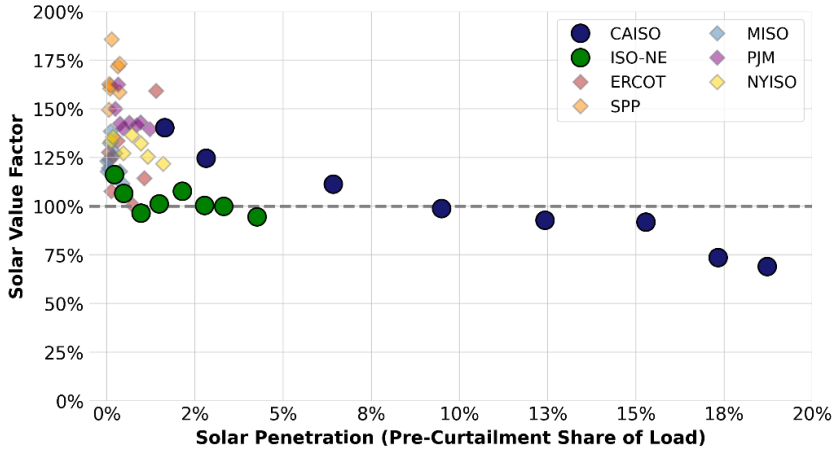
Increasing Solar Penetration Can Decrease the Marginal Value of Additional Solar

Obvious Impacts of Solar on the California ISO



Declining Marginal Value of Solar Relative to Average Prices



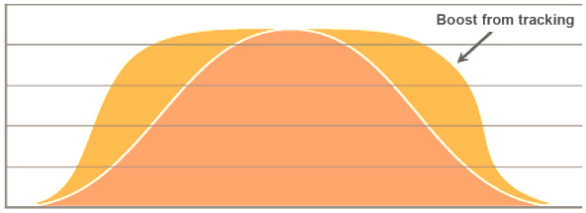
Solar Value Factor = Value of Solar/ Value of a Flat Block of Power

Source: Solar-to-Grid Report with Data Through 2019
https://emp.lbl.gov/renewable-grid-insights

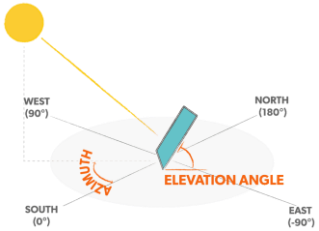
Solar Plant Developers (and Purchasers) Have Many Options to Boost Value at the Plant Level

South-facing, Fixed Tilt

- Single-Axis Tracking

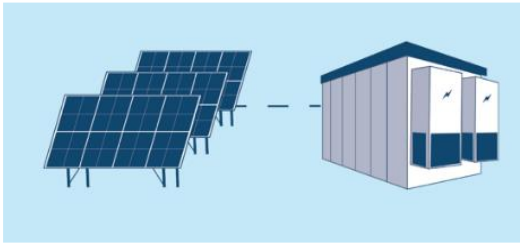


- Westward Orientation



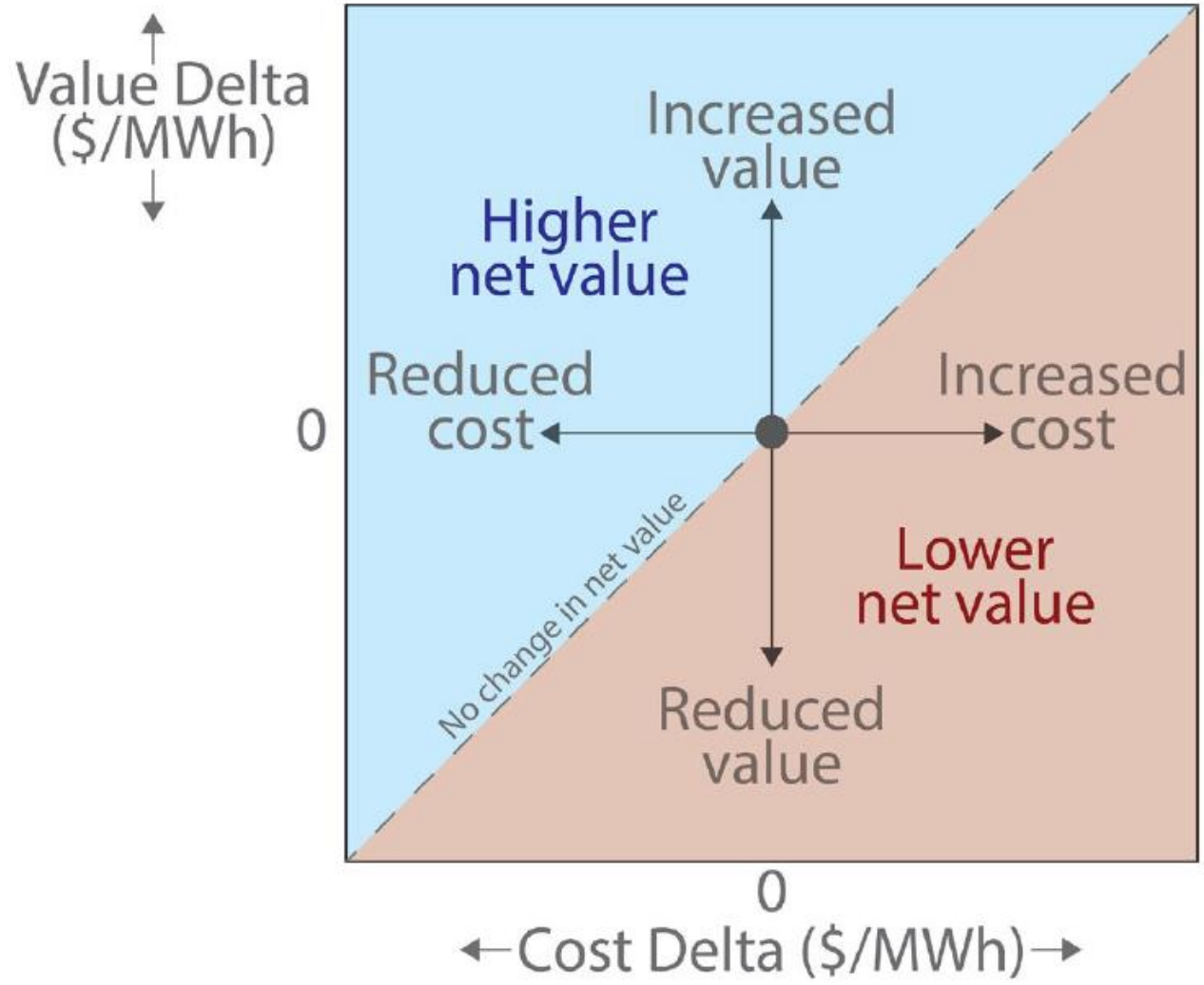
- Vertical Bifacial Modules

- Hybrid



…and many more

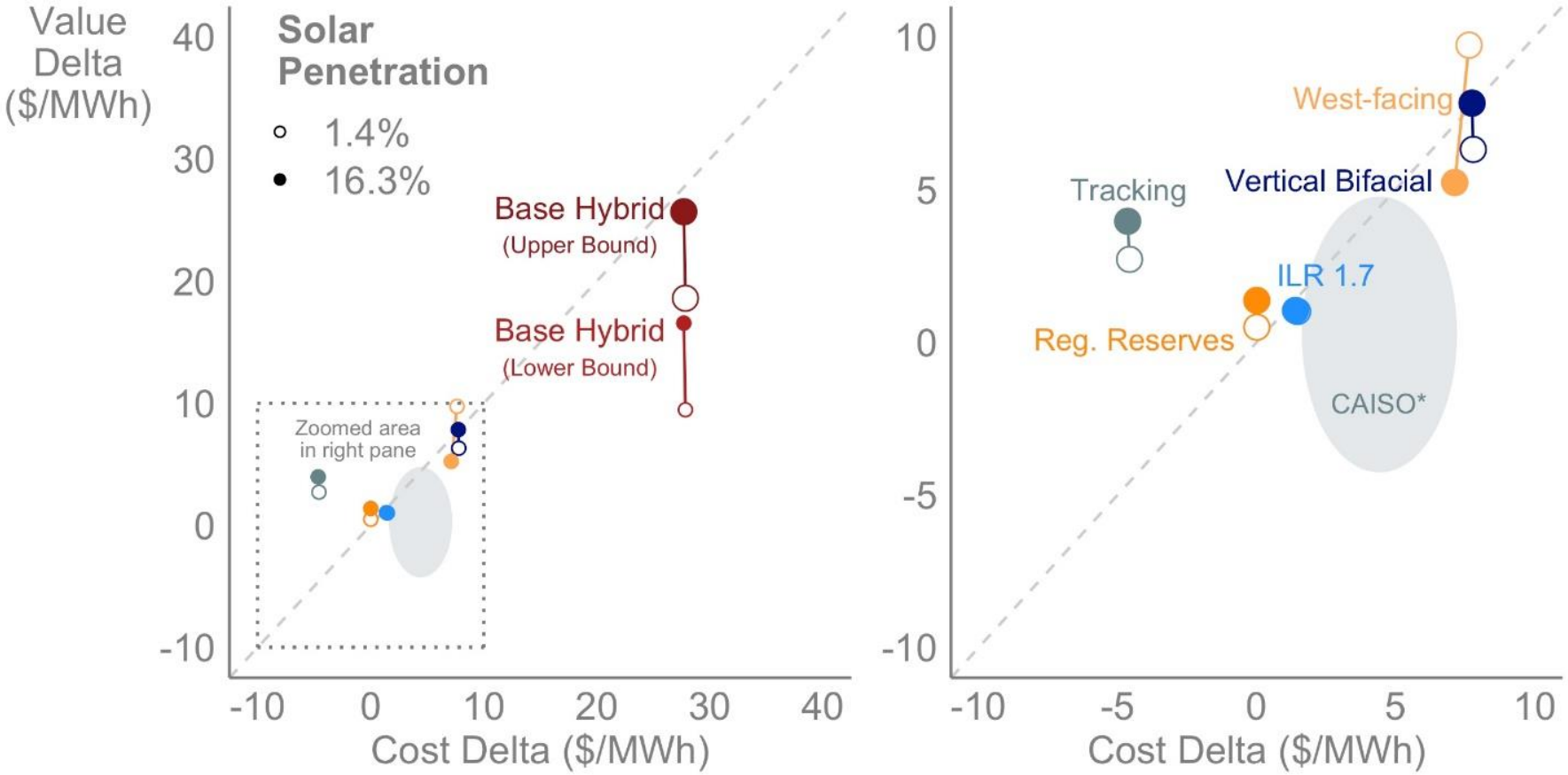
Decision Framework Compares Grid-friendly PV Options to a Base PV Plant Under the Same Conditions



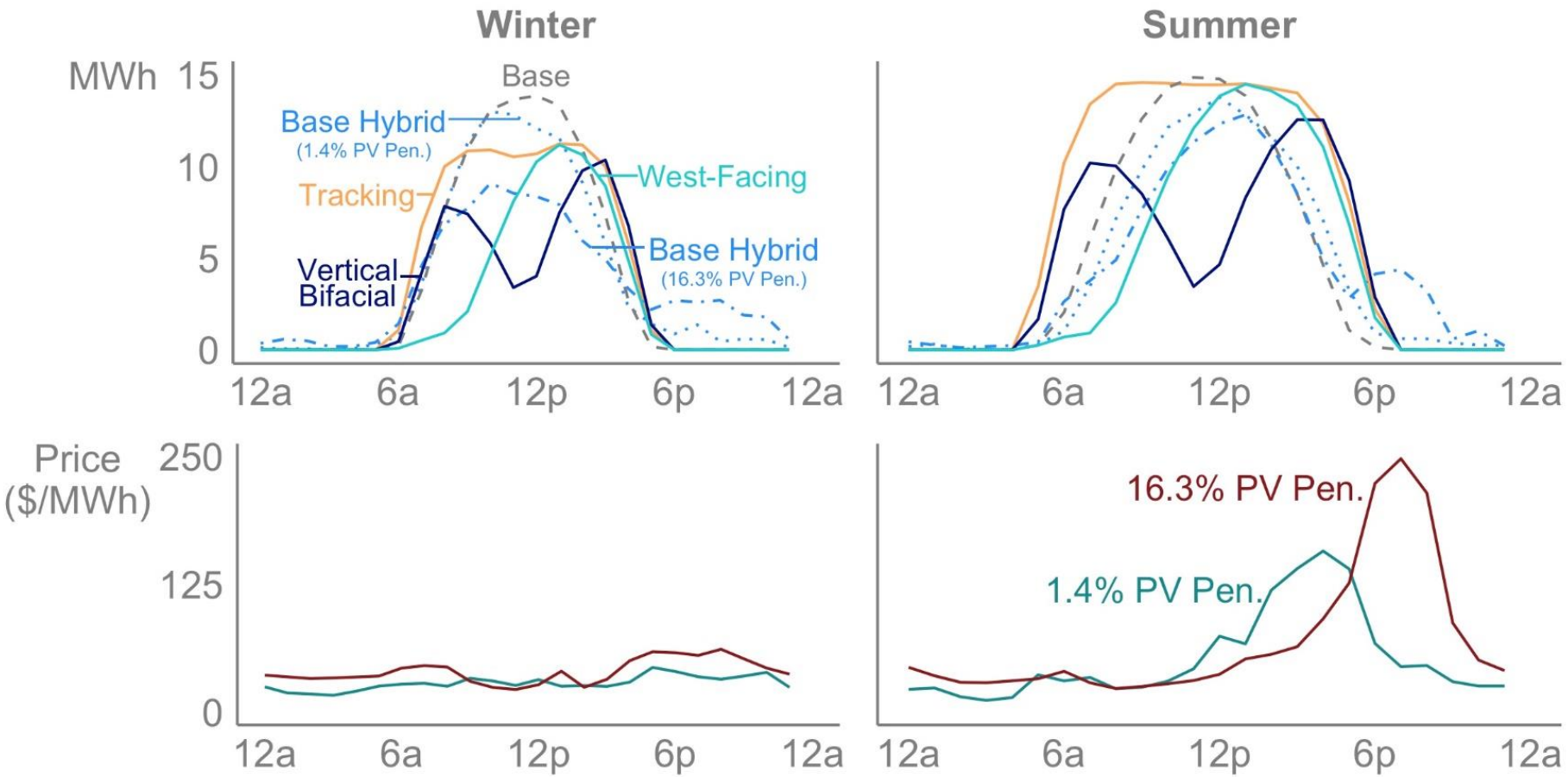
Key Assumptions and Methods

Configurations	Base PV plant: 1.3 inverter loading ratio (ILR), Fixed-tilt, South-facing, Sited near existing plants
	Alternative options: Single-axis tracking, Westward orientation, 1.7 ILR, Vertical bifacial, Provide regulation reserves, Adjust location, Hybrid
	Solar production modeled in NREL's System Advisor Model using historical insolation data from NSRDB
Market Setting	California ISO with 1.4% solar (market prices from 2012) or 16.3% solar (from 2018)
	Base plant uses prices from CAISO's SP15 Hub
Value Calculations	Marginal system value estimated from wholesale market revenue with real-time prices
	Capacity price adder allocated to top 100 net load hours, assuming $50/kW-yr capacity price
Cost	Base plant costs consistent with NREL's Annual Technology Baseline, inclusive of ITC
	Additional capital costs for alternatives estimated from SAM or the broader literature
Hybrid Configuration and Dispatch	Battery sized to 50% of nameplate capacity, 4-hour duration, AC-coupled (except where noted)
	Interconnection capacity limited to the solar plant capacity; storage can only charge from solar
	Hybrid dispatch uses perfect foresight of prices (upper bound) or is set using day-ahead prices and paid real-time prices (lower bound)
	Many alternative hybrids are created by adding storage to different PV subsystems, including a DC-coupled configuration

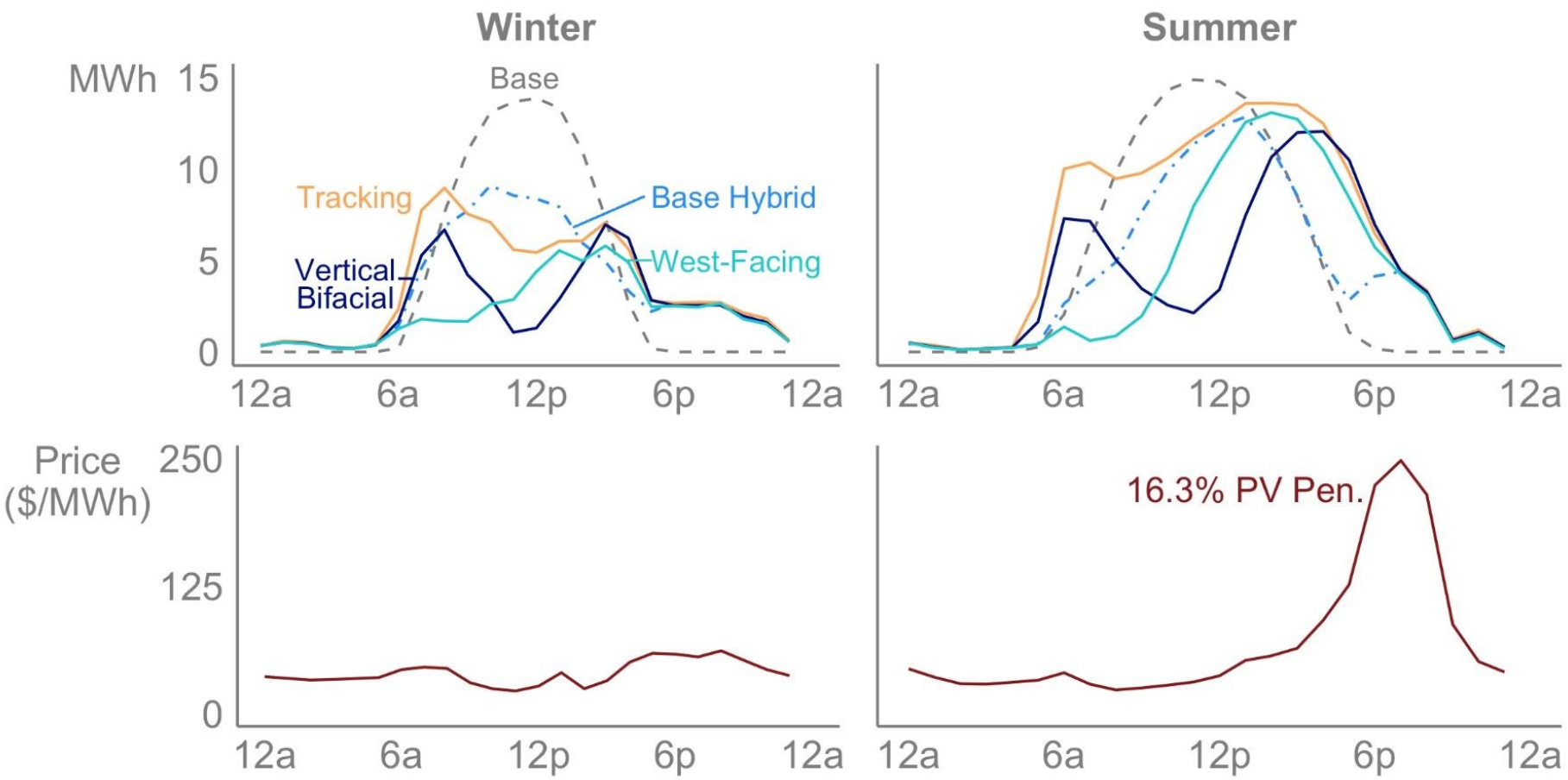
Better Alignment of Production with Peak Prices Increases Value; Hybrid Increases the Value the Most



Impact of Higher Solar Penetration on Value Depends on the Way Production is Shifted by the Option

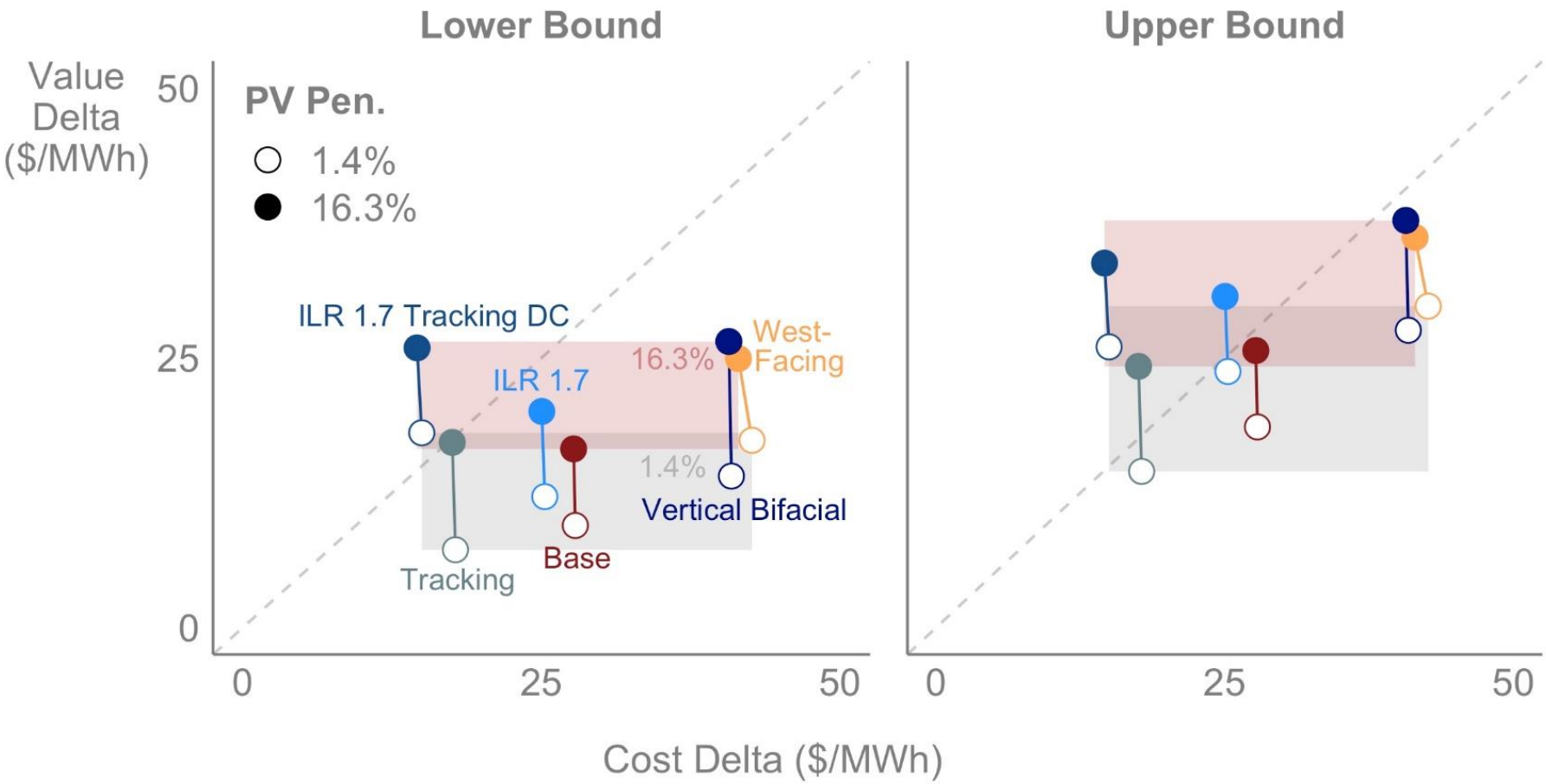


Irrespective of the PV Subsystem Profile, the Output of Hybrid Plants During the Higher Priced Hours is Similar



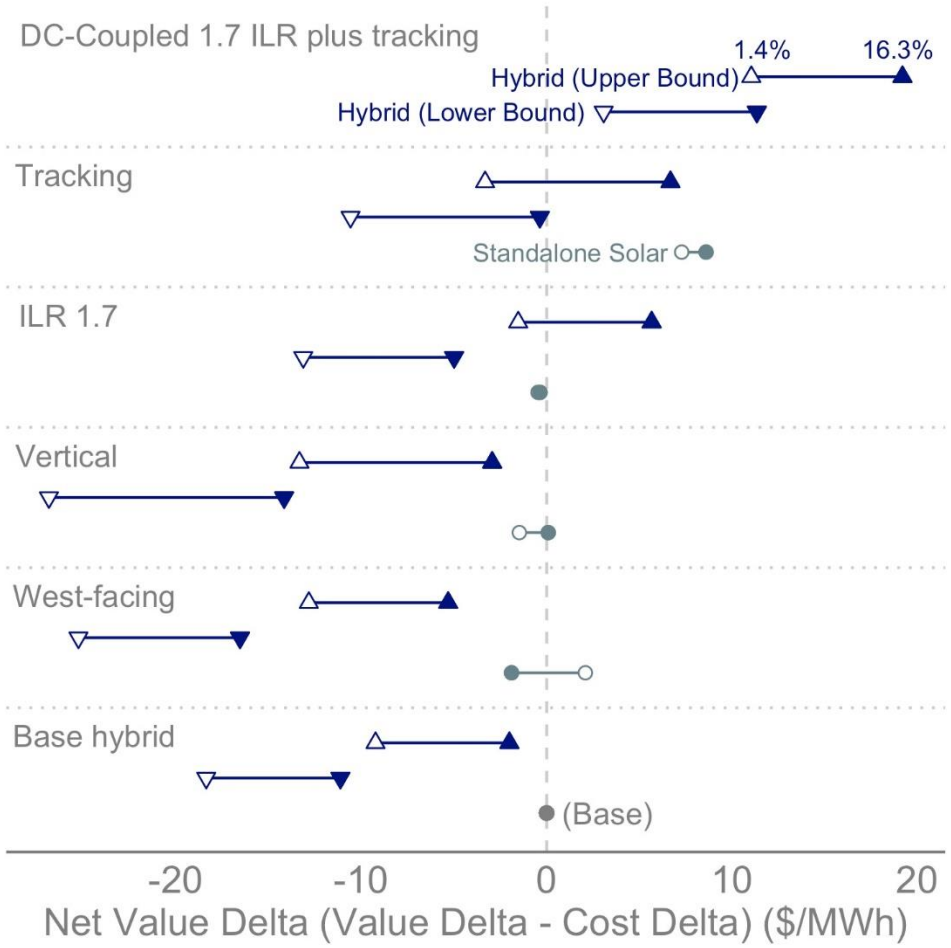
Note: Storage is now added to all different PV subsystems (not just Base)

…But Additional Storage Costs are Allocated Over Varying Annual Production Levels, Impacting $/MWh Costs



The shaded rectangular boxes represent ranges of value and cost changes across all hybrid configurations relative to the base PV plant

Generation-maximizing Strategies with Energy-Shifting Capabilities of Hybrids Result in Highest Net-Value at Higher Solar Penetration

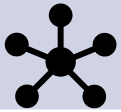


Conclusions

- Standalone PV design options can help maintain PV's grid value, but the net value (grid value–system cost) is marginal and varies with solar penetration
- Adding storage to the PV configurations alters the cost and value dramatically
  - Strategies that shift the timing of PV generation at the expense of total generation results in net value penalties with storage
  - These strategies become redundant when the energy-shifting capabilities of storage are added
- Strategies that maximize PV generation provide the largest net-value gains when combined with storage, especially at high PV penetrations
- These findings may aid stakeholders who are seeking to achieve (or understand the implications of) high solar penetration

Ongoing Future Work

Geospatial



How does the value of coupled systems vary with location?

Configurations

How does the net value of coupled systems change with different configurations?

Ancillary Services

What is the ancillary service value for standalone and coupled systems?

Participation Models

How do different participation models affect the economic and reliability impacts of hybrids?

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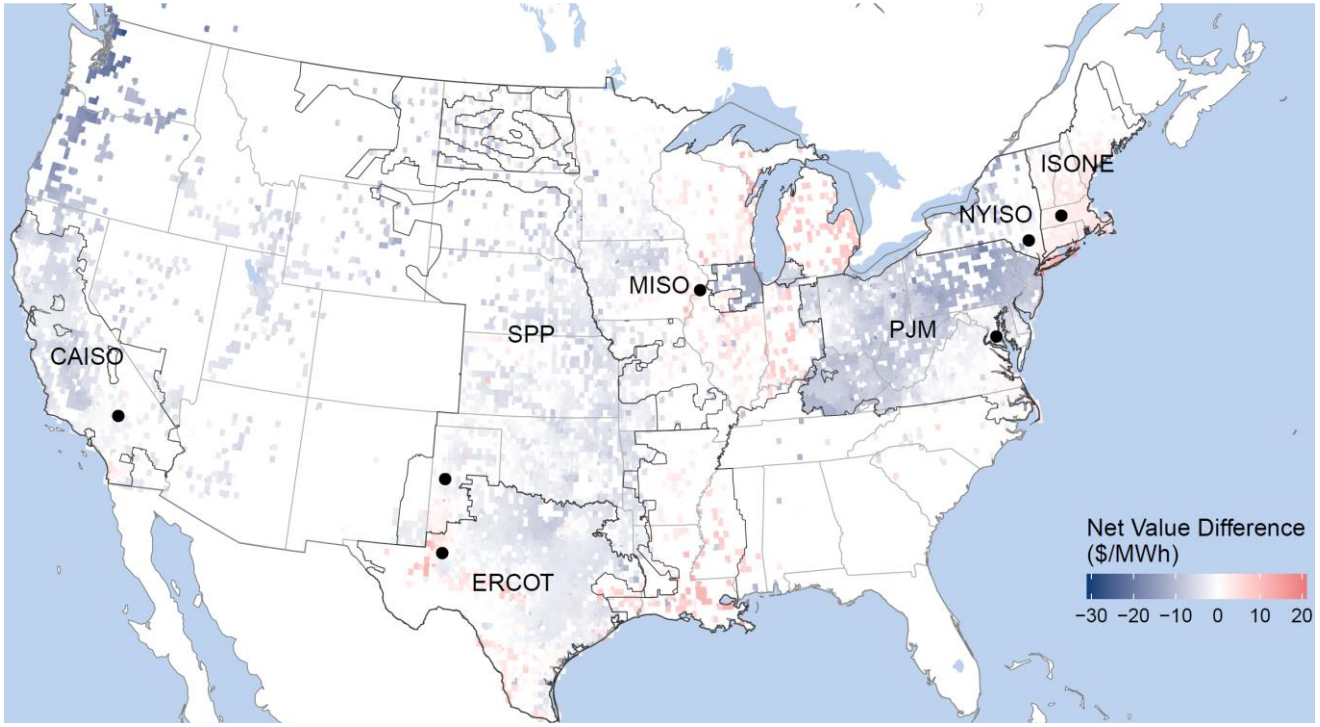
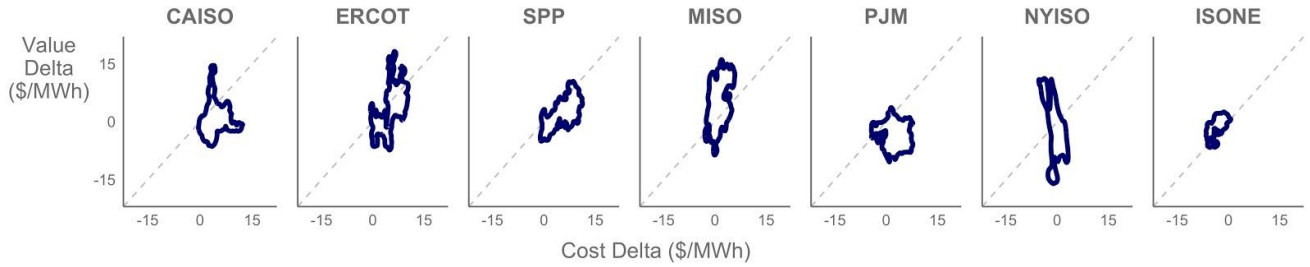
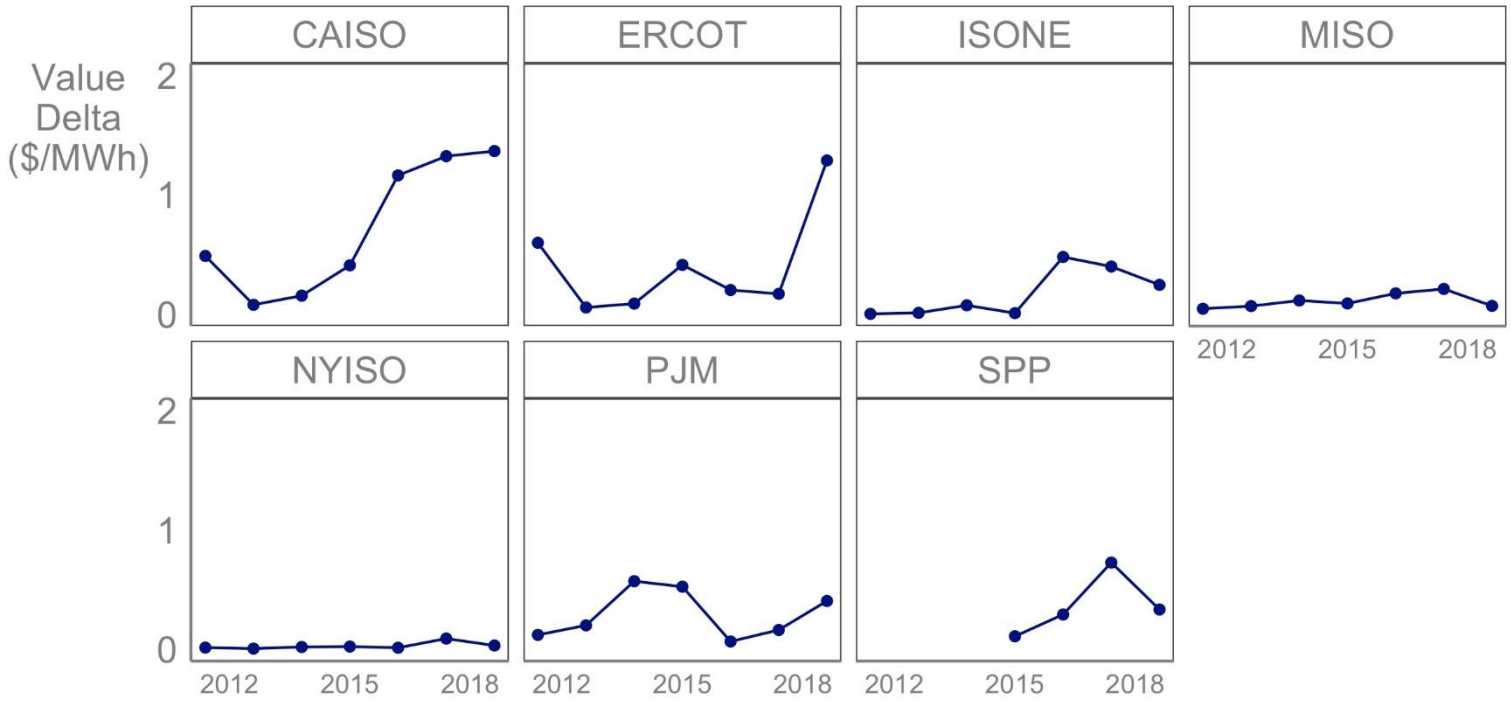
Value of the Base PV Configuration at Other Locations





Black dots: Location of base PV plant at the centroid of currently installed PV
Contour line: 95th percentile of alternative locations

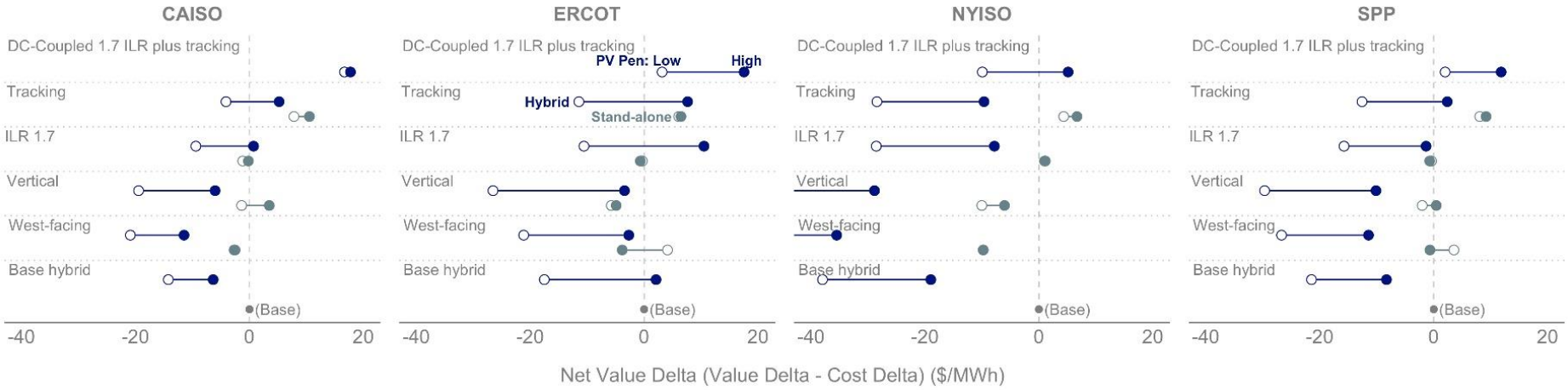
Providing Regulation Reserves from Standalone PV Modestly Increases Net Value



Optimistic assumptions: PV plant has the option of providing regulation and is capable of scheduling the regulation reserves with perfect foresight of market conditions including regulation reserve prices, energy prices, and solar production

Assume solar can offer at most 10% of its nameplate capacity as regulation reserves.
Of the awarded capacity, 30% of solar that provides regulation down is curtailed and 70% of regulation up.

Primary Findings are Not Unique to California



Wholesale prices from 2030 simulations of markets with 2016 levels of VRE ("Low") and 30% Solar/10% Wind ("High")

Prices are further described in Seel et al. 2018