



Future Value of PV+Battery Hybrid Systems

Anna Schleifer, Caitlin Murphy, Wesley Cole, and Paul Denholm

October 14, 2021

Contents

1 Research Objectives and Methodology

2 Results: PV+Battery Architecture

3 Results: PV+Battery Component Sizing

4 Questions

Research Objectives

How does the highest-value PV+battery hybrid system vary by location and over time?

- How does the **coupling type** affect how the energy and capacity values of select PV+battery hybrid systems evolve over time in Texas, New York, and California?
- How do the **inverter loading ratio** and **battery size** affect how the energy and capacity values of PV+battery hybrid systems evolve over time in the same locations?

Methodology

BPS Optimization: Planning

- Optimize evolution of electric power sector technologies through 2050

Regional Energy Deployment System (ReEDS) Model

BPS Optimization: Operations

- Optimize hourly system operation to minimize total production cost

Energy Exemplar's PLEXOS

Data Compilation

- Compile hourly marginal energy and capacity prices
- Compile hourly PV generation profiles

Cambium

Annual Technology Baseline

System Advisor Model

Hybrid System Optimization

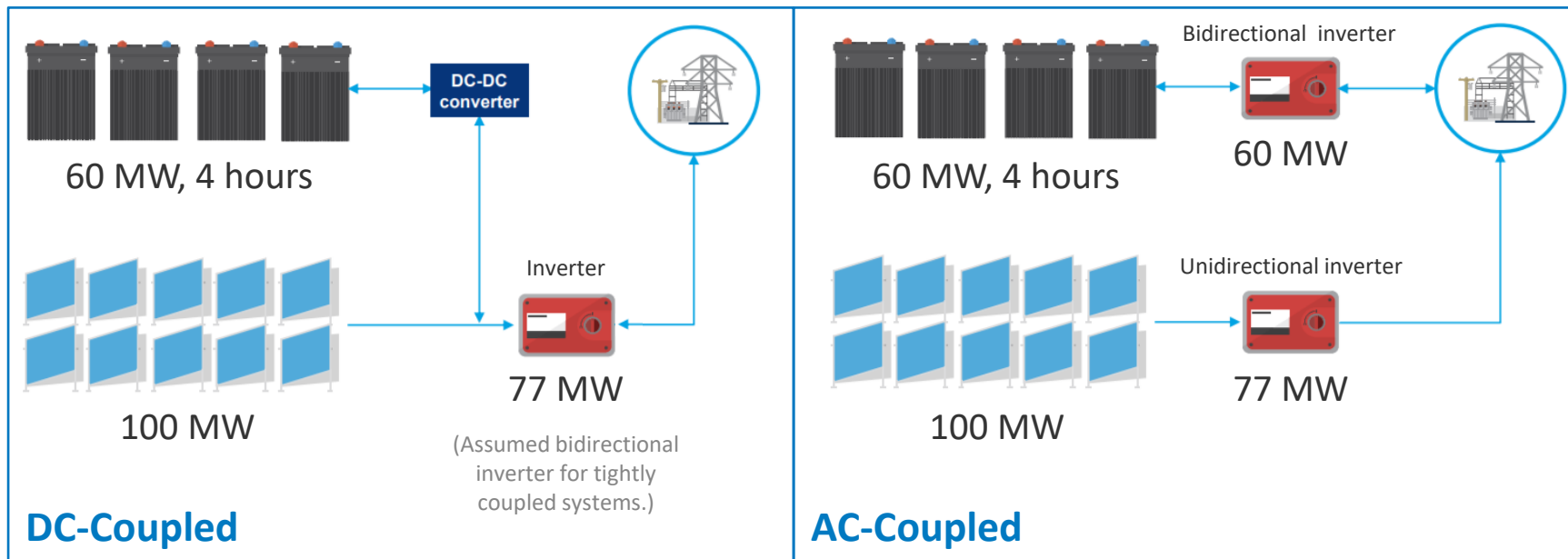
- Dispatch PV+battery systems against hourly prices to maximize value

Revenue, Operation, and Device Optimization (RODeO) Model

Results

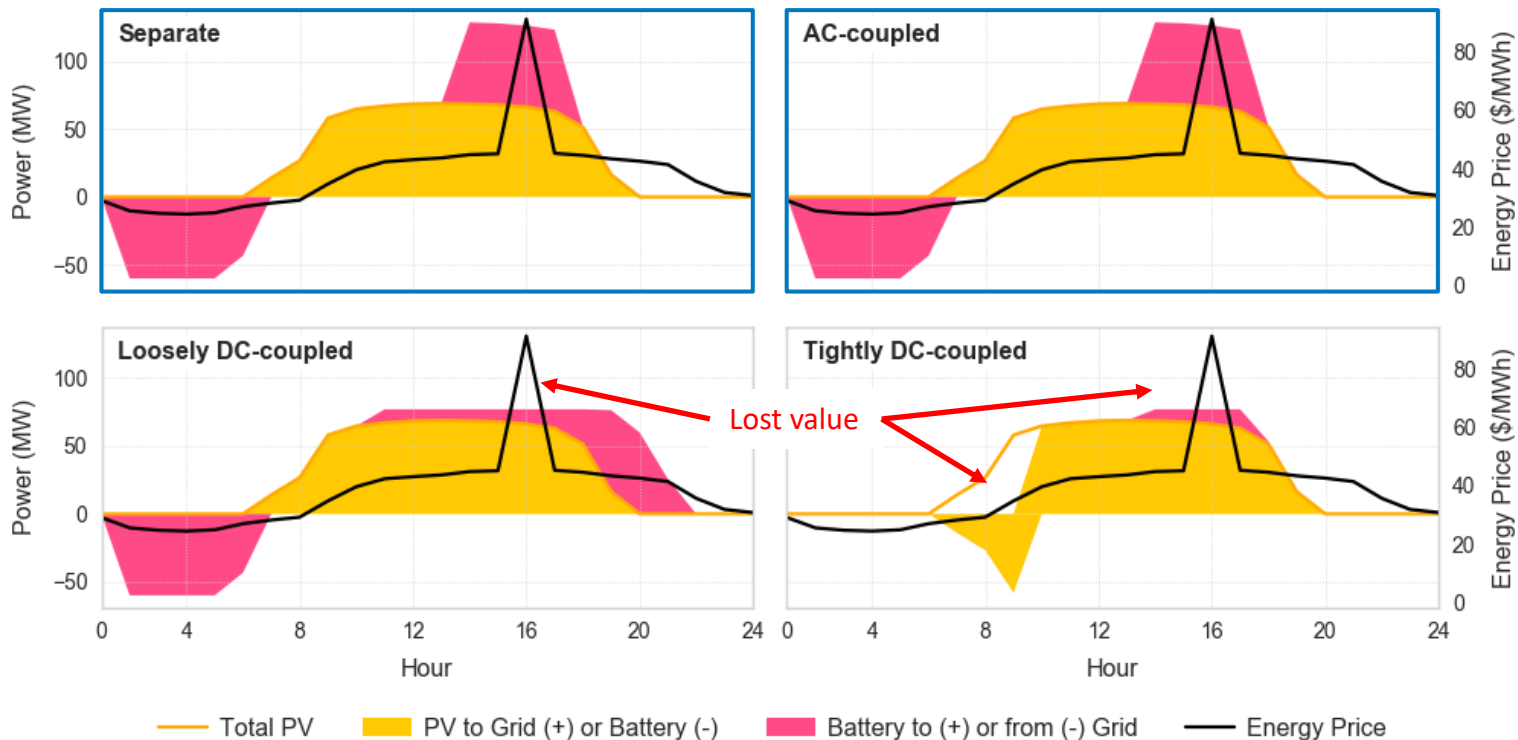
Part 1: Architecture

Part 1 Configurations

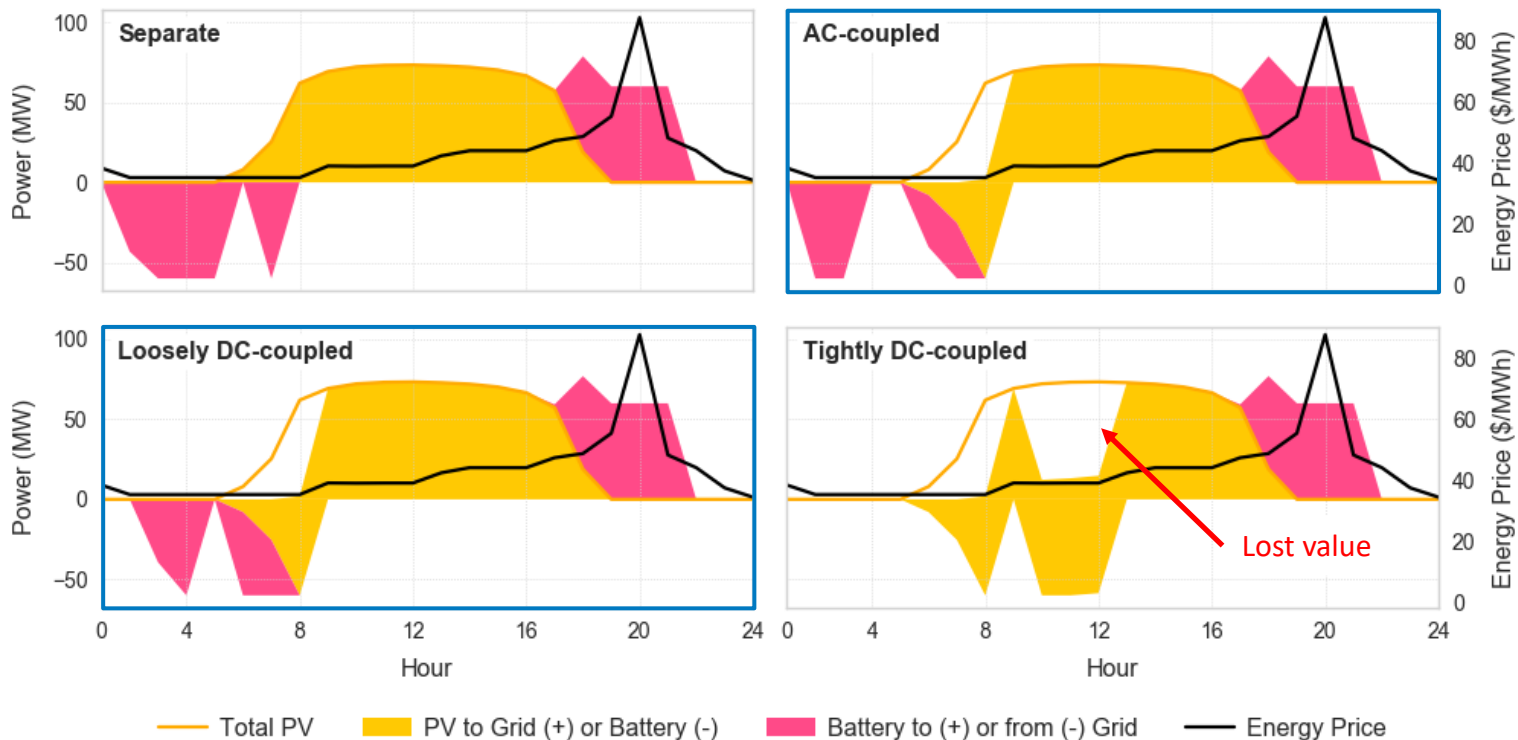


Figures from Wood Mackenzie Power and Renewables

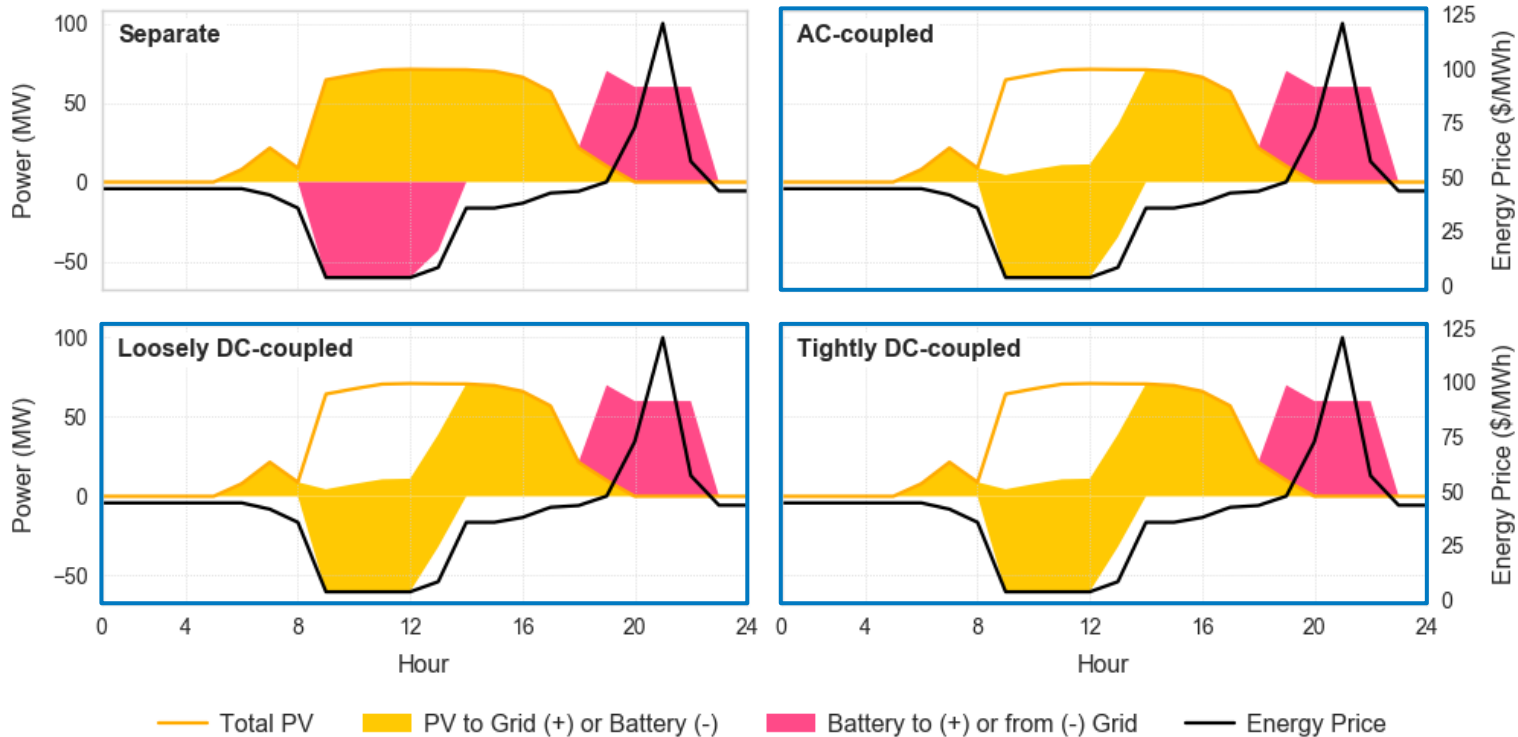
DC-coupled systems can be loosely or tightly coupled; loosely coupled systems can charge from the grid, whereas tightly coupled systems cannot.



The value premium of AC-coupled systems over DC-coupled systems depends on the value of standalone PV systems.



As the value of generation during daylight hours declines, more PV generation is directed to the battery.



When standalone PV provides little or no value, most of the PV generation is directed to the battery.

Capacity Value

The top black, horizontal line represents the capacity value that the DC-coupled systems would have if they had full capacity credit.

The lower line represents the capacity value of the battery alone with full capacity credit.



Capacity Value

When standalone PV has relatively high capacity value, the shared inverter of the DC-coupled systems limits their value.

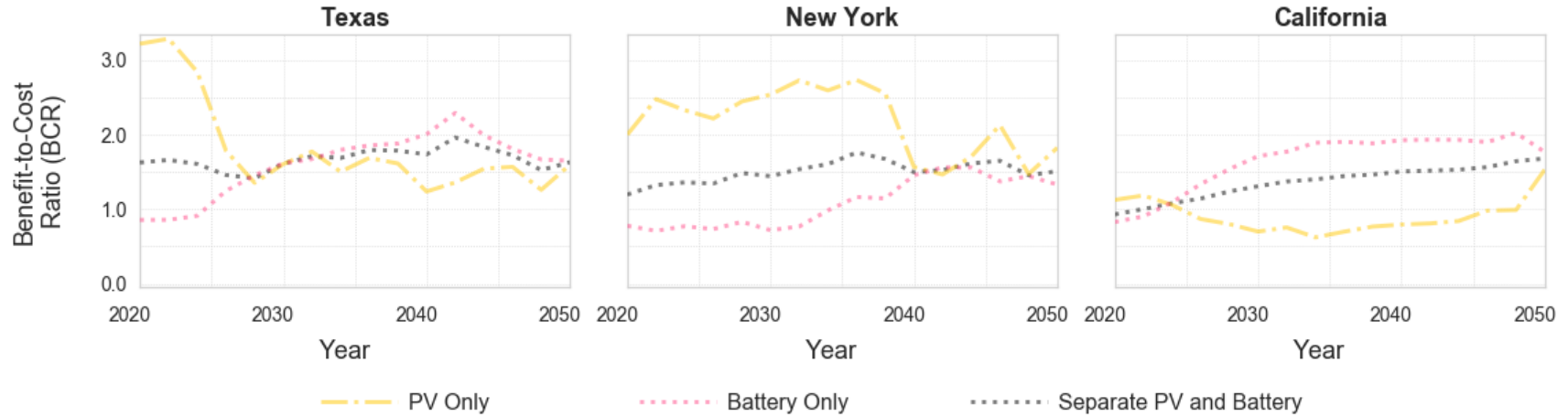


Capacity Value

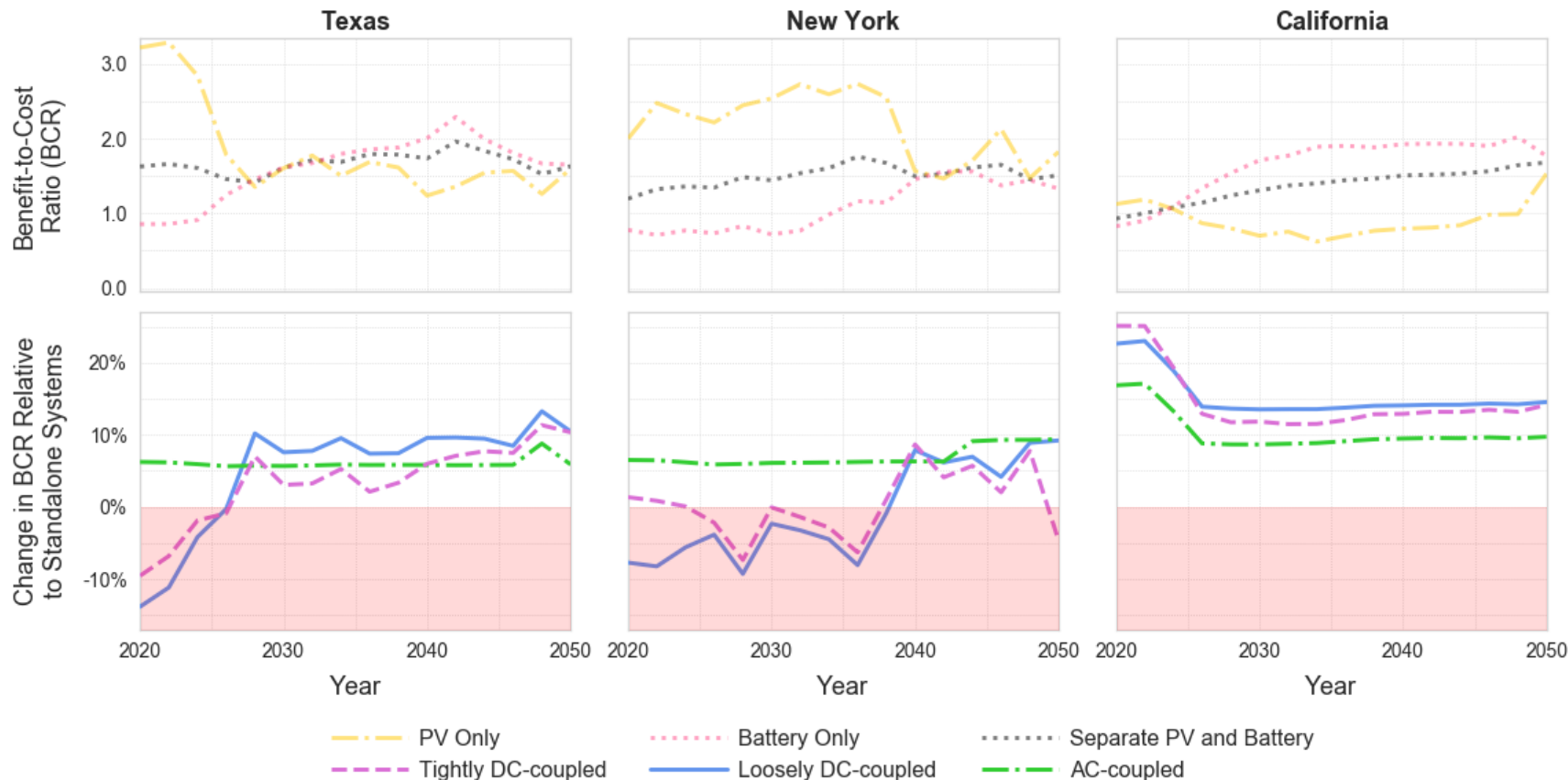
When standalone PV has negligible capacity value, the hybrid systems' capacity values are limited to that of the battery.



Benefit-Cost Ratio



Benefit-Cost Ratio



Part 1 Conclusions

Among the configurations we modeled:

- We did not find an optimal coupling type across the three areas, especially in the near term.
- We did not find synergies in the **energy or capacity values** of hybrid systems compared to separate systems.
 - In other words, none of the hybrid systems has a higher value than the combined values of separate systems.
- Over time, with increasing PV share, the coupling types converge toward similar operation and value.

Results

Part 2: Component Sizing

Part 2 Configurations

DC-Coupled

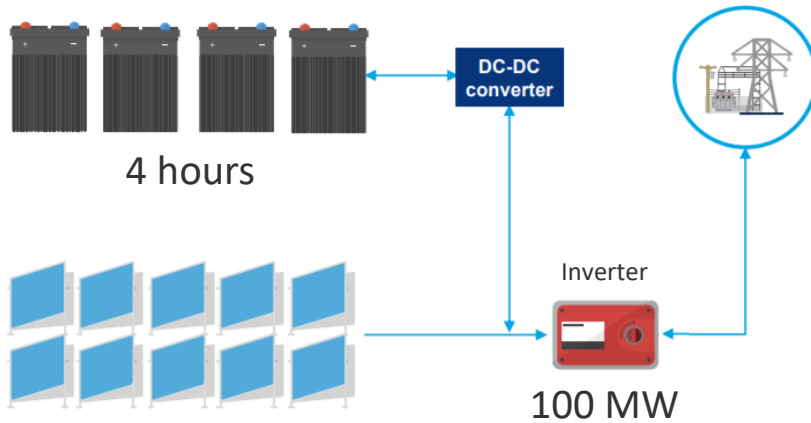
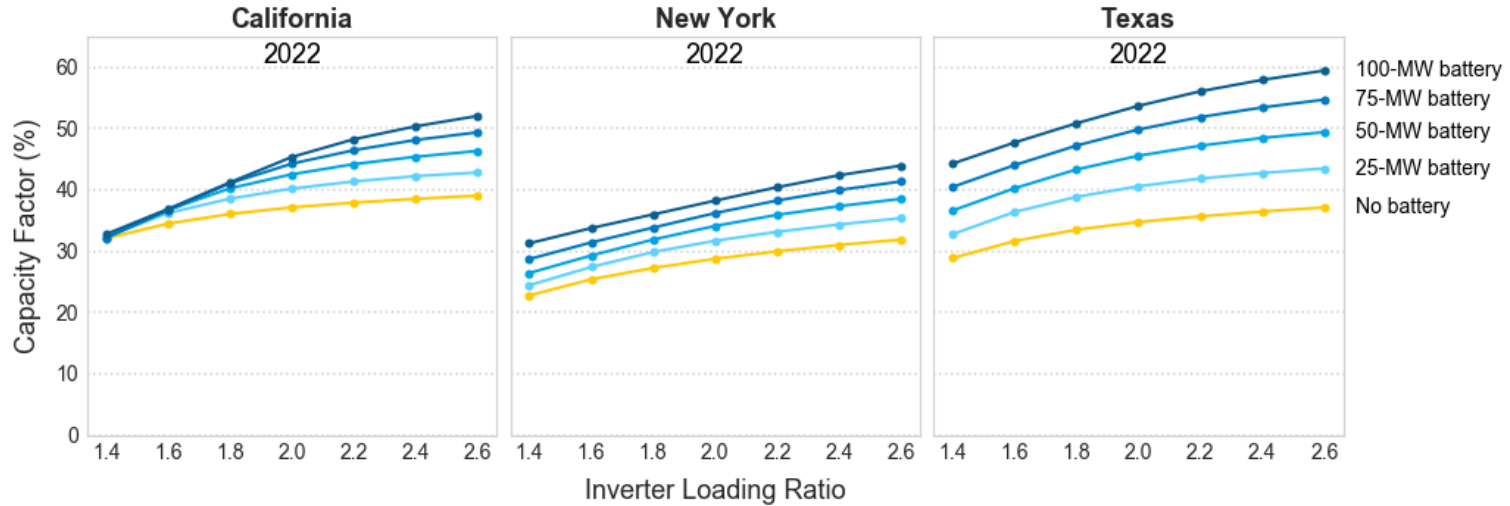


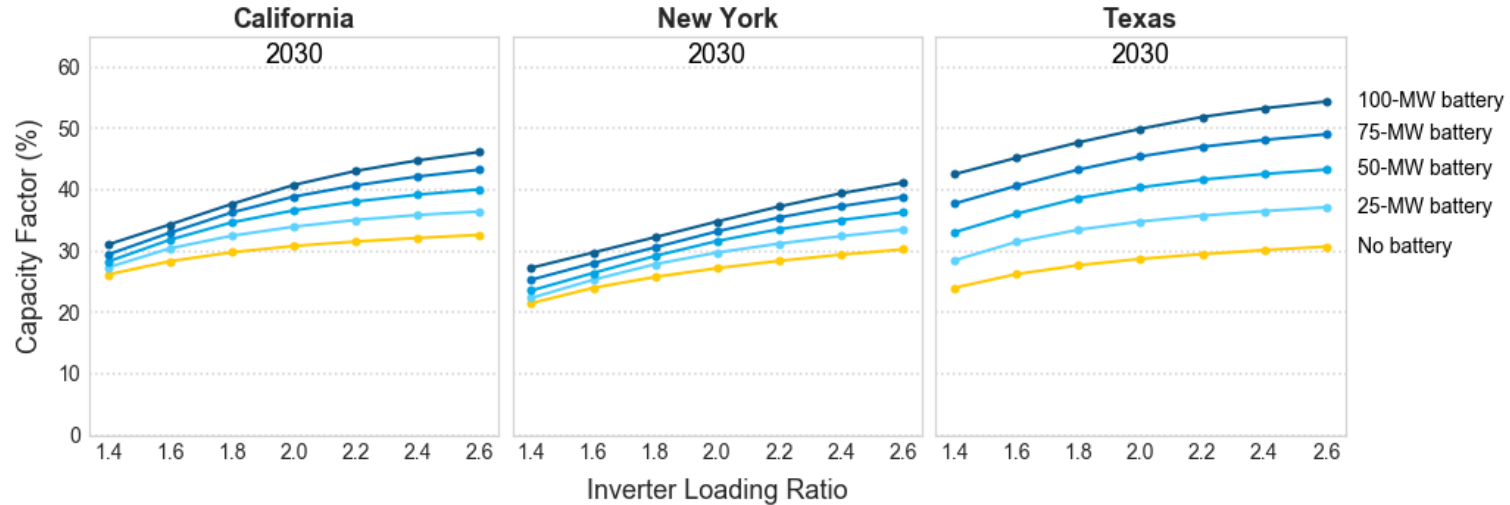
Figure from Wood Mackenzie Power and Renewables

Inverter Loading Ratios	1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6
Battery-Inverter Ratios	0.25 0.5 0.75 1.0
Grid Charging	Yes (loosely coupled)

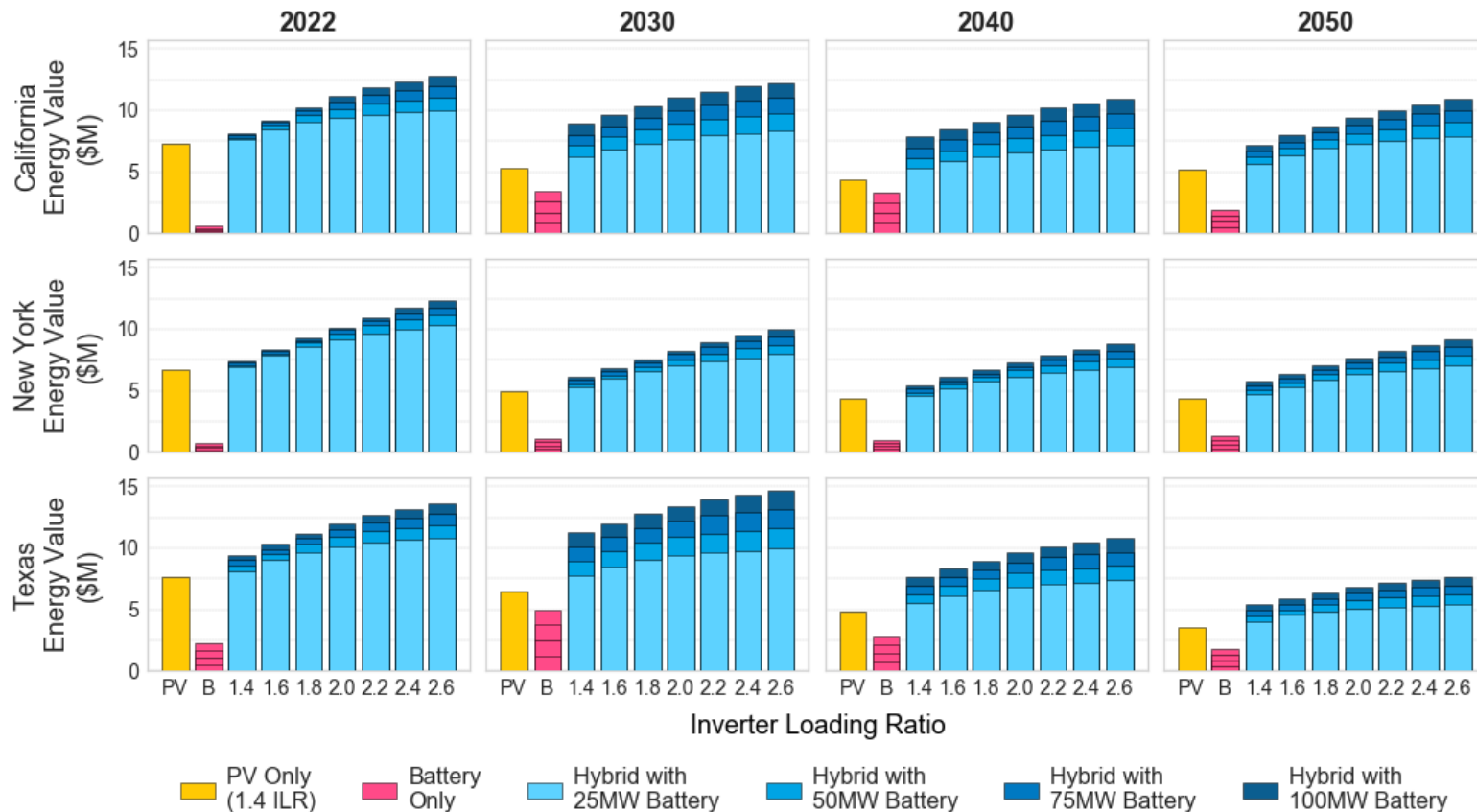
Capacity Factor



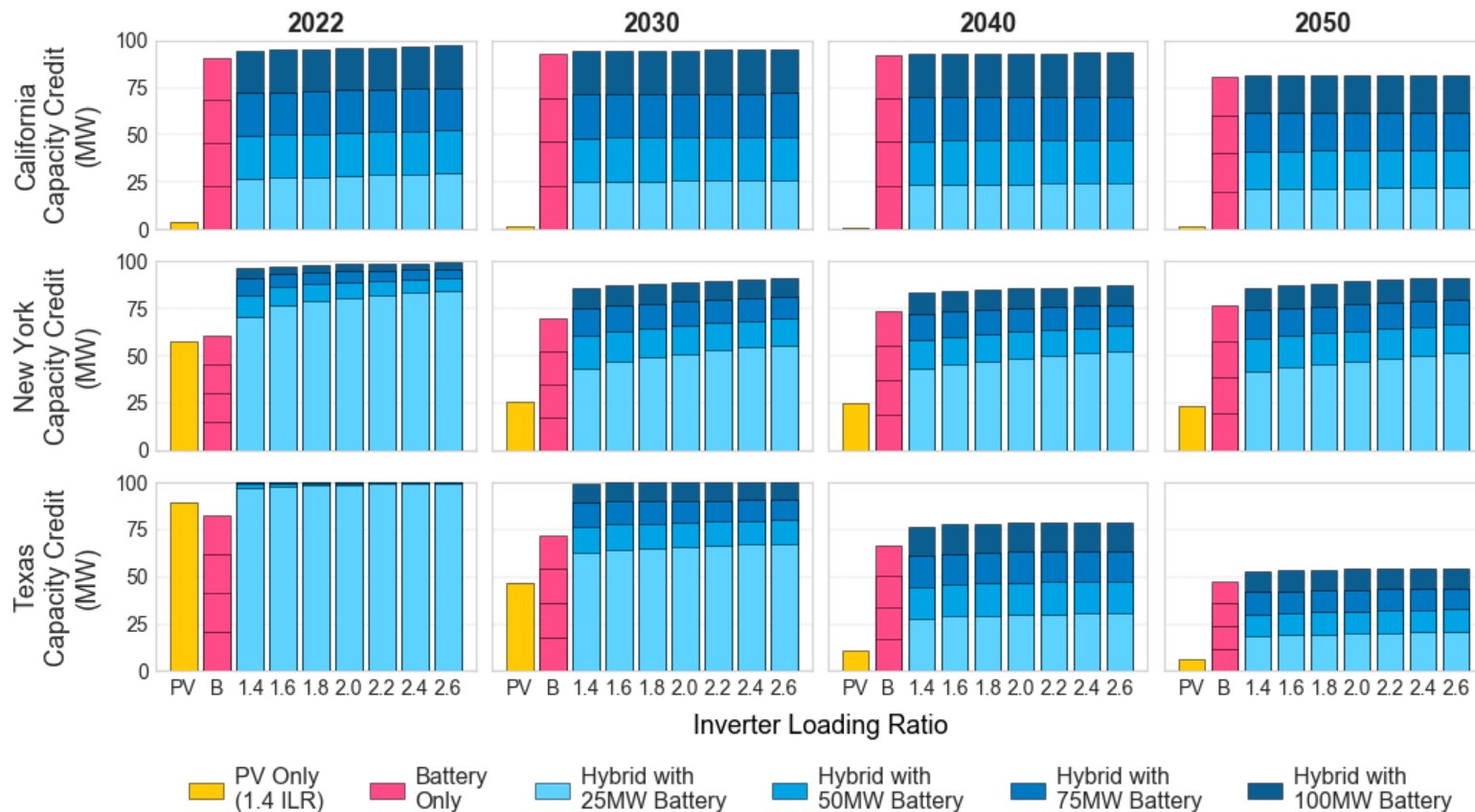
Capacity Factor



Energy Value



Capacity Credit



Part 2 Conclusions

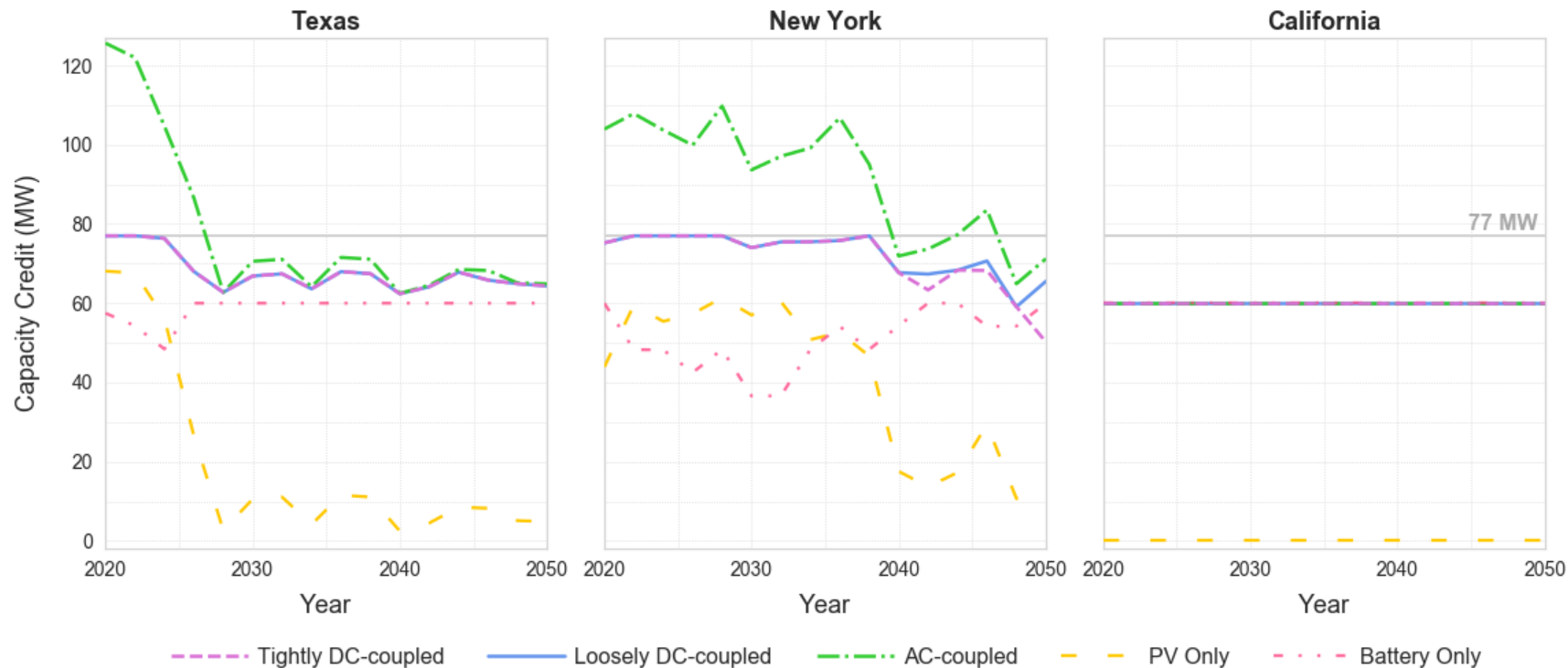
- A likely evolution of the design of PV+battery systems in the medium- and long-term will be:
 - Increasingly higher battery power capacities that will provide a growing share of the coupled system's capacity value as PV capacity credit declines
 - Increasingly higher ILRs, enabled by the presence of larger batteries, that will further increase the coupled system's energy value
 - Depends on how PV module costs decline in the future

Questions

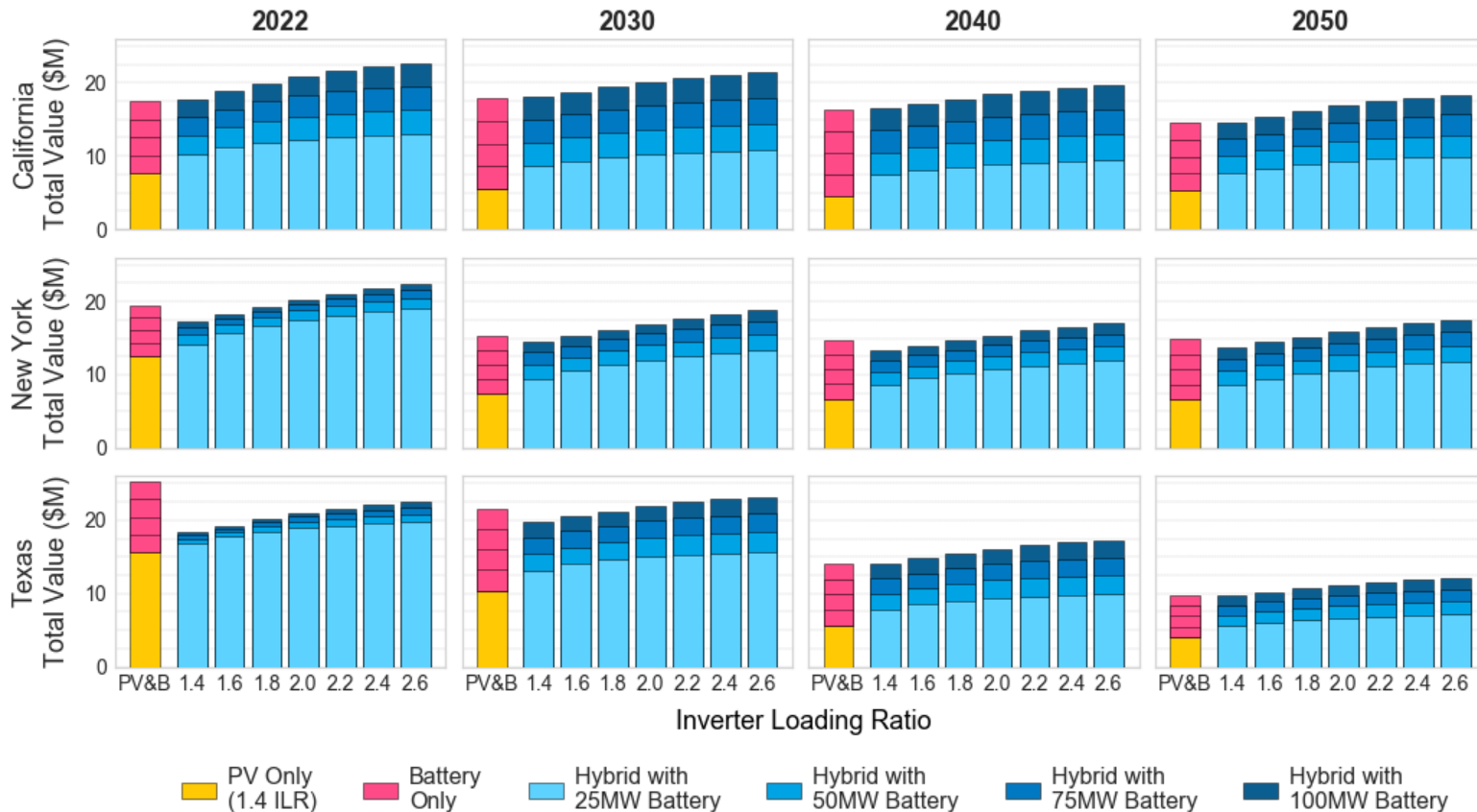
www.nrel.gov



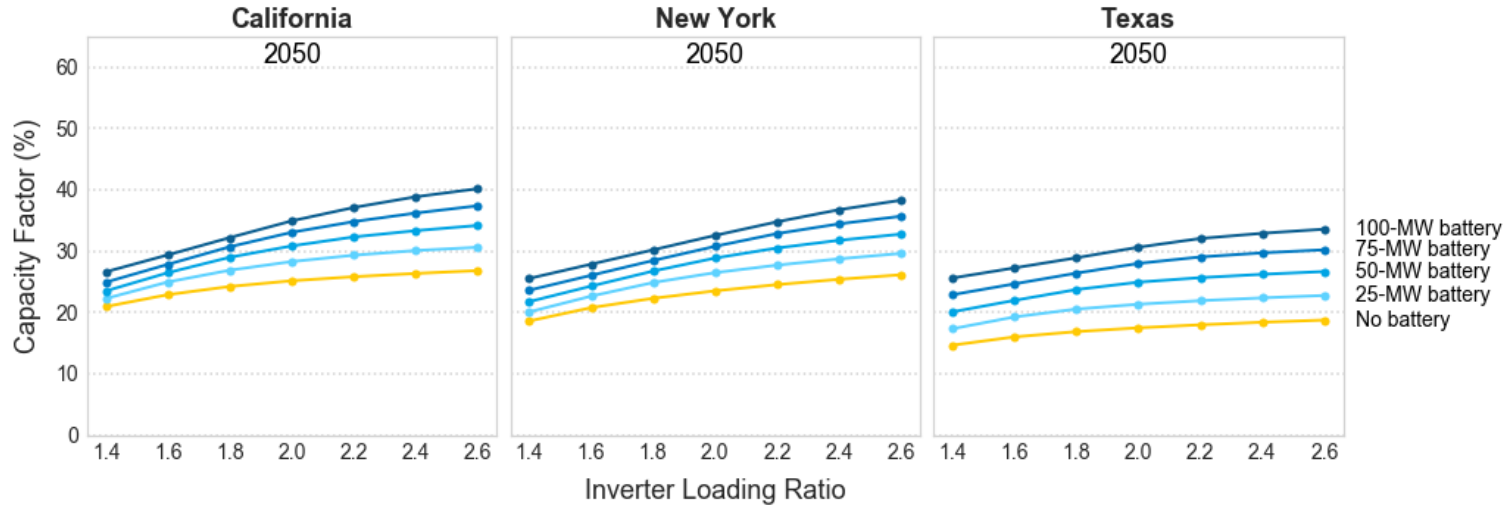
Part 1: Capacity Credit



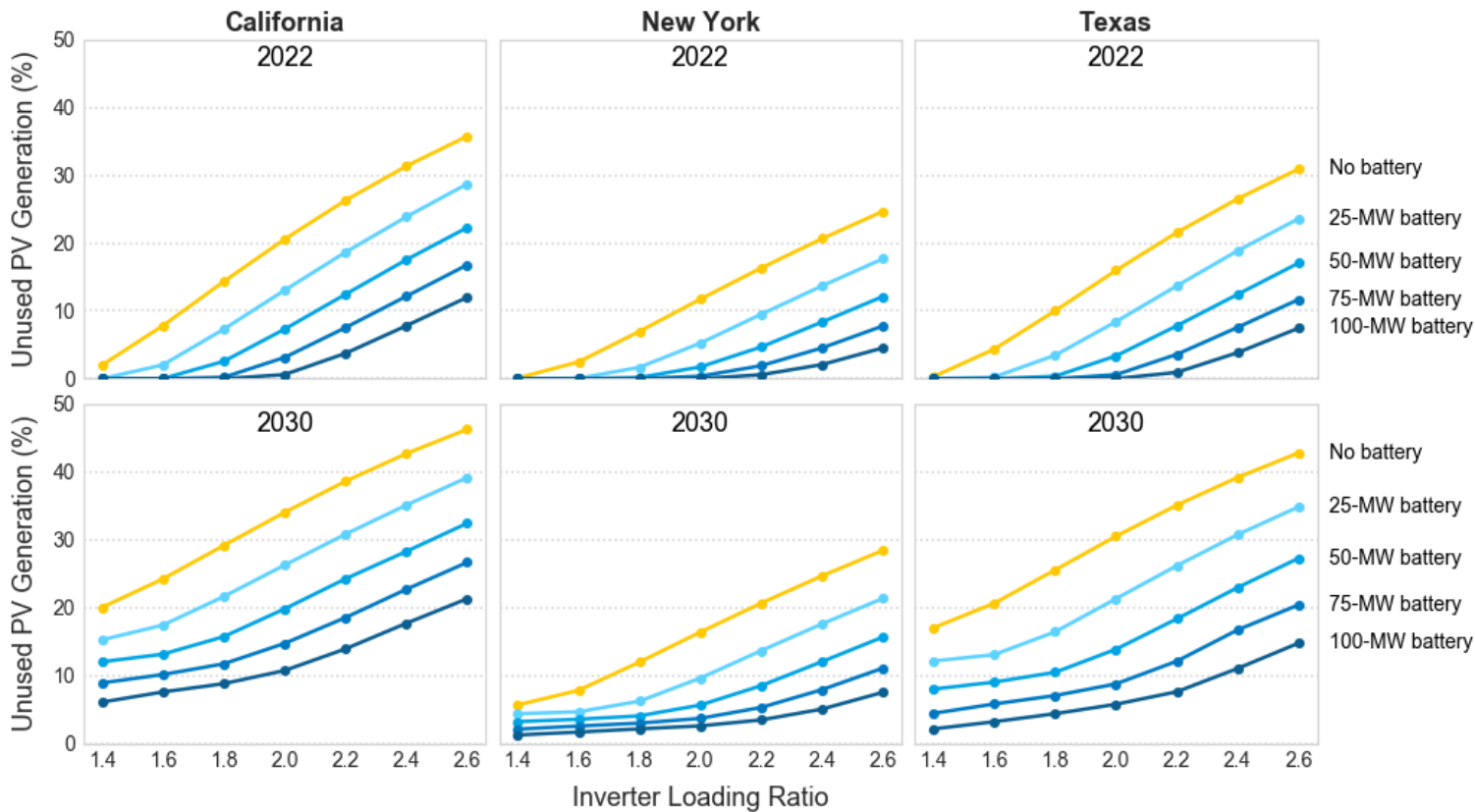
Part 2: Total Value



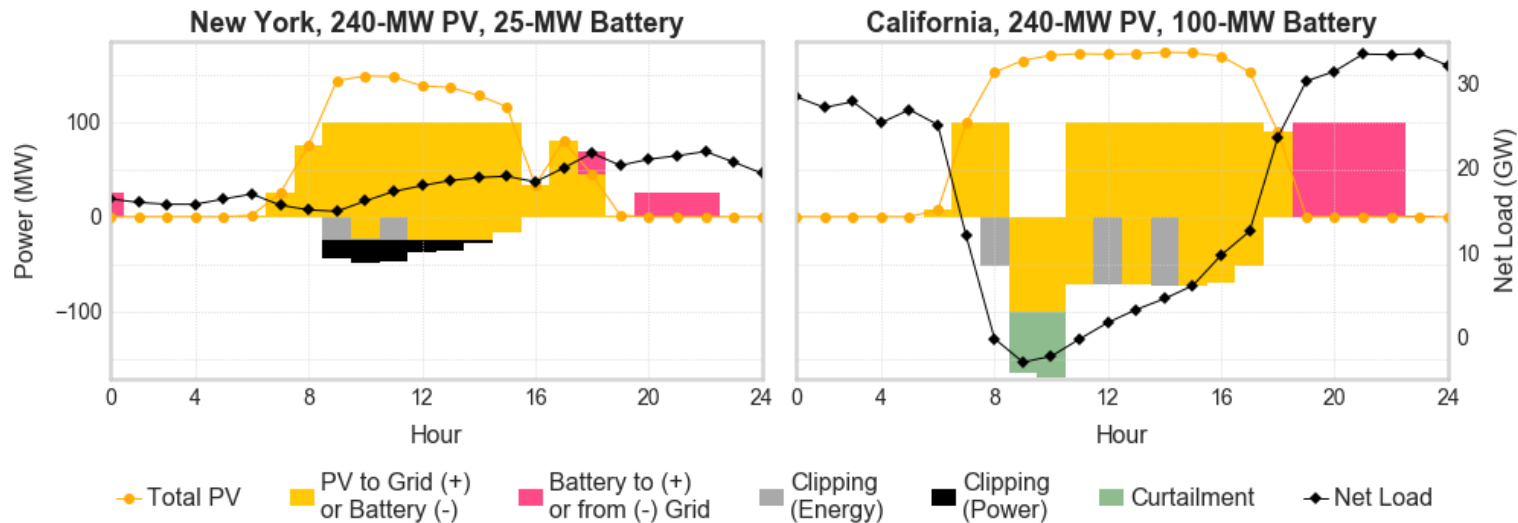
Part 2: Capacity Factor



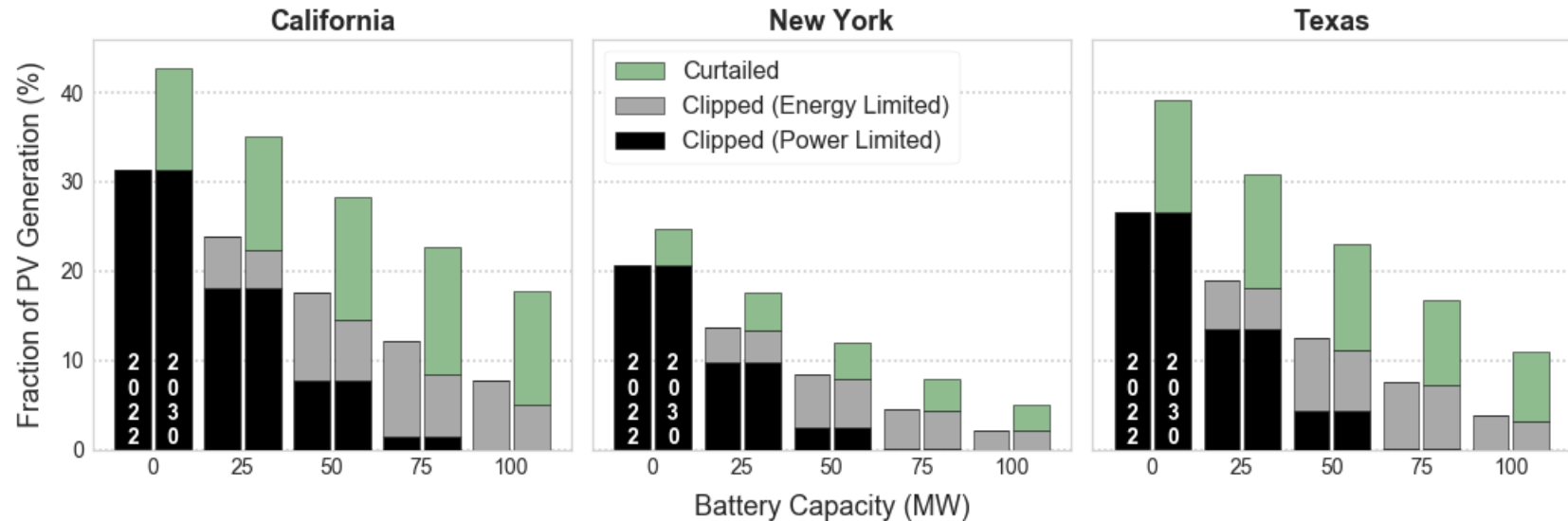
Part 2: Unused PV Generation



Part 2: Unused PV Generation



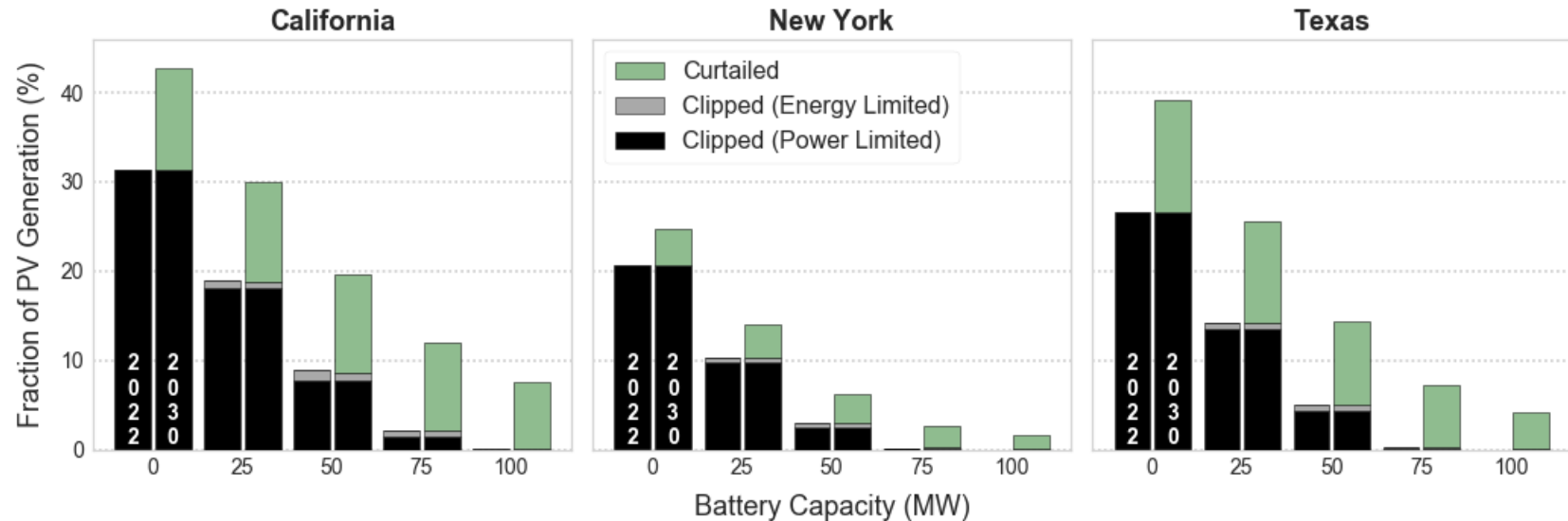
Part 2: Unused PV Generation



2.4 ILR

4-hour battery

Part 2: Unused PV Generation



2.4 ILR

8-hour battery