

Challenges and Opportunities for Solar Deployment and Integration

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Aims and Messages

- 1 Solar can be an energy *and* capacity resource (if it is managed correctly and market designs are 'right')
- 2 Solar has a significant role to play in decarbonizing electricity
- 3 Gaps *vis-à-vis* seasonal energy storage remain

Energy and Capacity Value of Solar

Capacity/Peaking Value of Energy Storage

Limited Potential: Widening Peaks

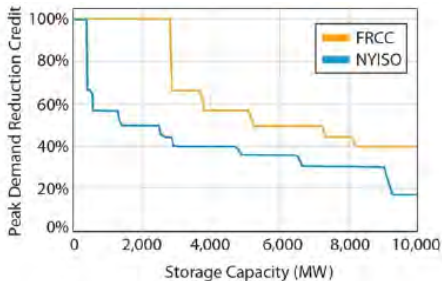
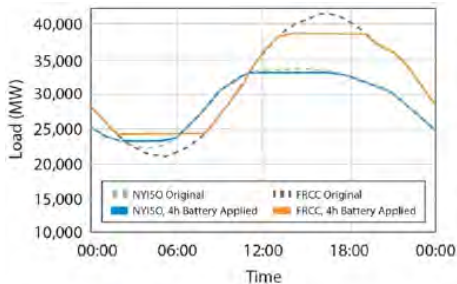


Figure : <https://www.nrel.gov/docs/fy19osti/74184.pdf>

Capacity/Peaking Value of Solar

Limited Potential: Net-Load Peak Shifts

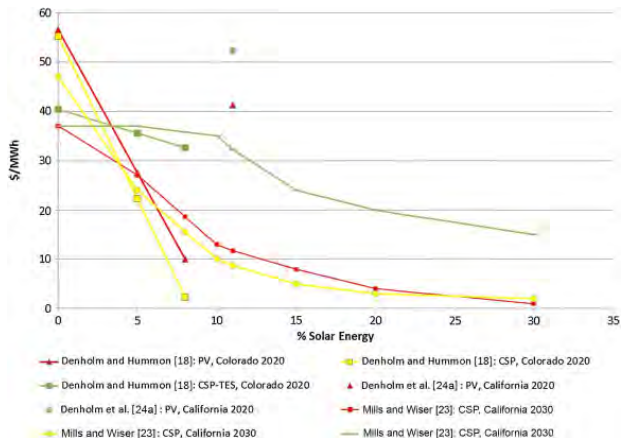


Figure : <https://doi.org/10.1016/B978-0-12-809592-8.00026-3>

Capacity/Peaking Value of Energy Storage and Solar

Synergy: Solar Shifts and Narrows the Peak!

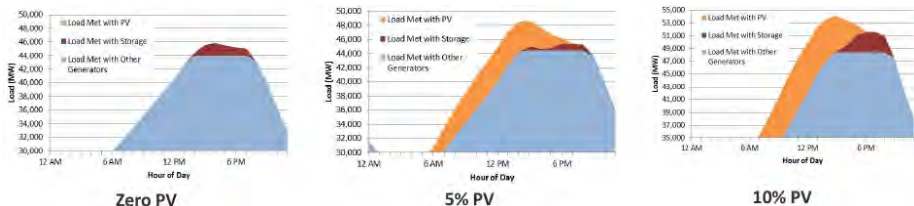


Figure : <https://www.nrel.gov/docs/fy19osti/74184.pdf>

Illustrative Example

NYISO

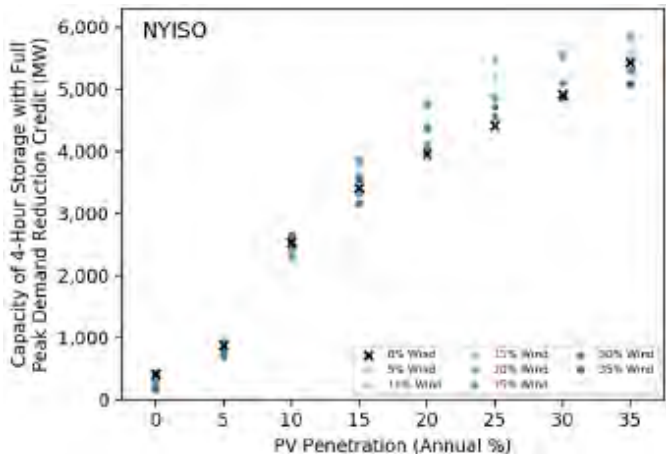


Figure : <https://www.nrel.gov/docs/fy19osti/74184.pdf>

Some Notes

- Wind and energy storage do not have this synergy
- Market design is critical: capacity mechanisms in the 'Eastern' RTOs would likely ascribe most of this capacity value (and remuneration) to the energy storage

Solar's Role in Decarbonization

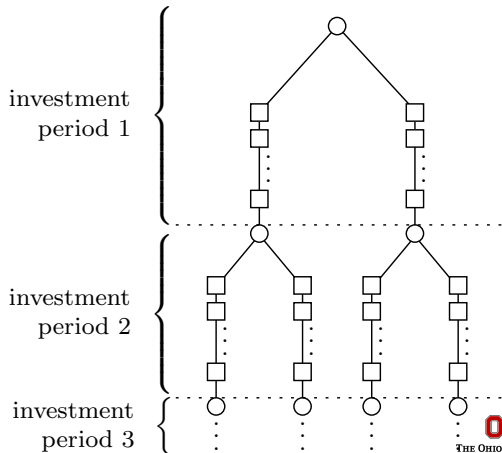
Capacity-Expansion Modeling

<http://dx.doi.org/10.1109/TPWRS.2017.2694612>

<http://dx.doi.org/10.1016/j.eneco.2019.07.017>

Uncertainties

- **Small-scale/operational:** play out over short time periods with short-lived effects (e.g., solar availability on a given day)
 - ➔ captured using a variety of representative operating periods
- **Large-scale/strategic:** play out over long time periods with long-lived effects (e.g., technology development, policy choices)
 - ➔ captured explicitly in scenario tree



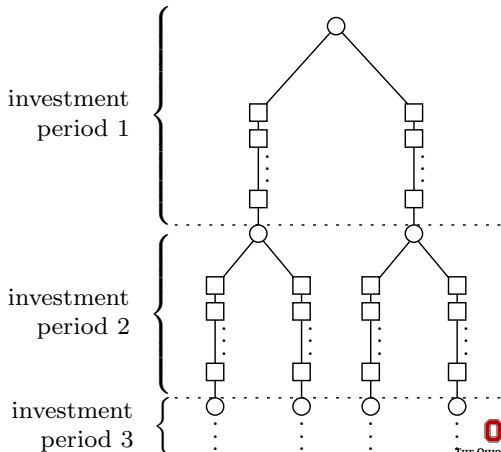
Capacity-Expansion Modeling

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Decisions

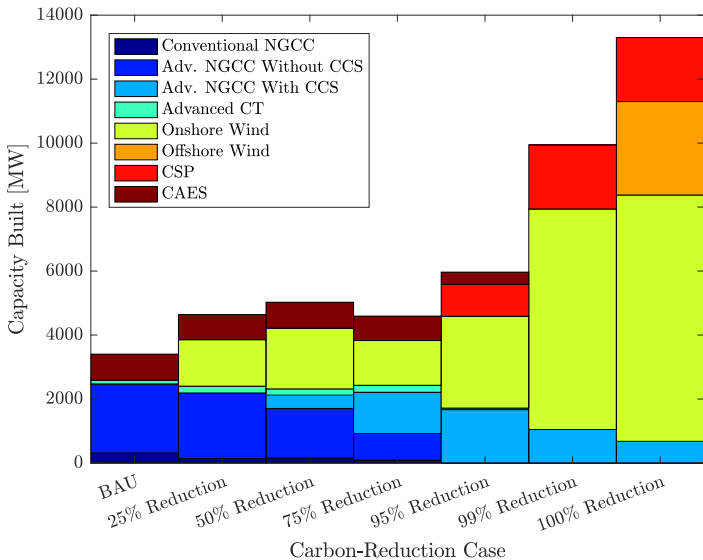
- **Operational:** captured at fine time scales (*e.g.*, hourly over many representative days or weeks)
- **Strategic/investment:** captured at coarse time scales (*e.g.*, decadal over a fifty-year planning horizon)



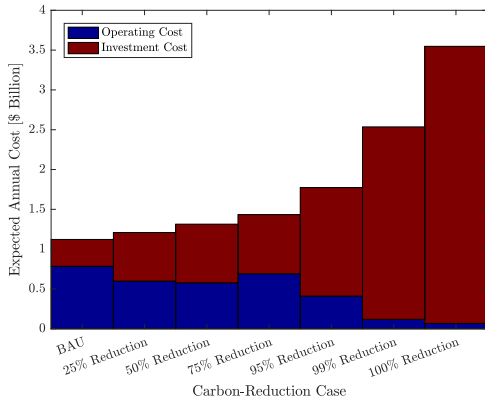
Case Study

- 'Greenfield' study based on Texas
 - Existing transmission is long-lived but generation must be rebuilt in the future
 - Electric island
 - Large load with extreme summer peaks
 - Relatively good wind resource, marginal solar
 - Geologic formations allow for compressed-air energy storage (CAES)
 - Pumped hydroelectric storage has limited viability
- Technology options:
 - Wind
 - Solar thermal with thermal energy storage
 - CAES
 - Fossil-fueled generation with and without CCS
 - Nuclear

Illustrative Build Out



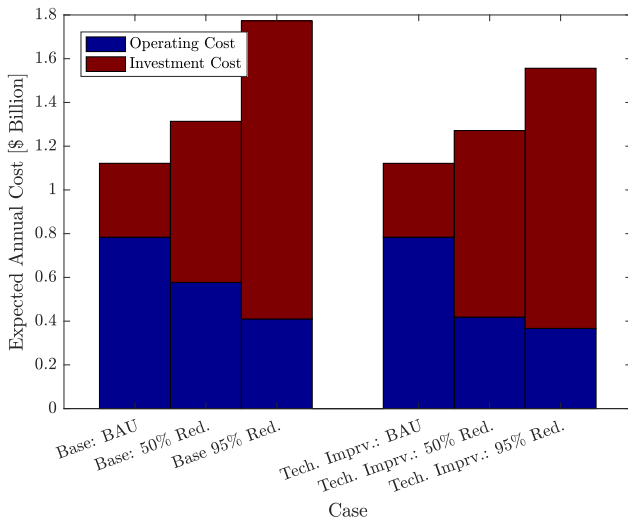
Illustrative Cost



- Social-cost-of-carbon estimates from Obama-era EPA¹ suggest carbon reductions of 25%–85% are socially optimal with technologies that are available today

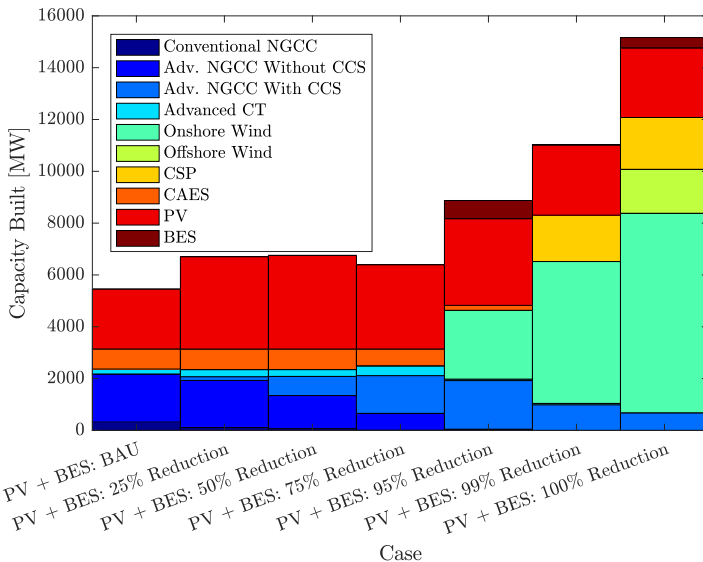
¹https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

Impacts of Technology Improvements



- 95% carbon reductions are now within the socially optimal range

Photovoltaic Solar and Battery Energy Storage



Seasonal Energy Storage

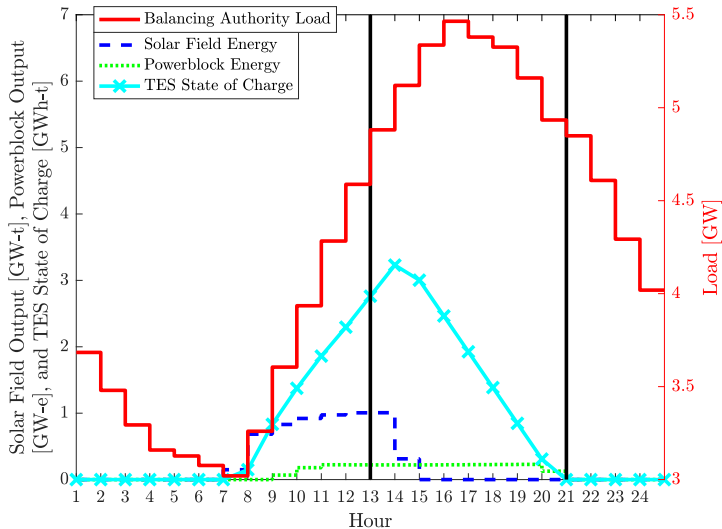
or

*why the last 10% of decarbonization is so #@!\$
expensive*

`http://dx.doi.org/10.1016/j.solener.2019.08.008`

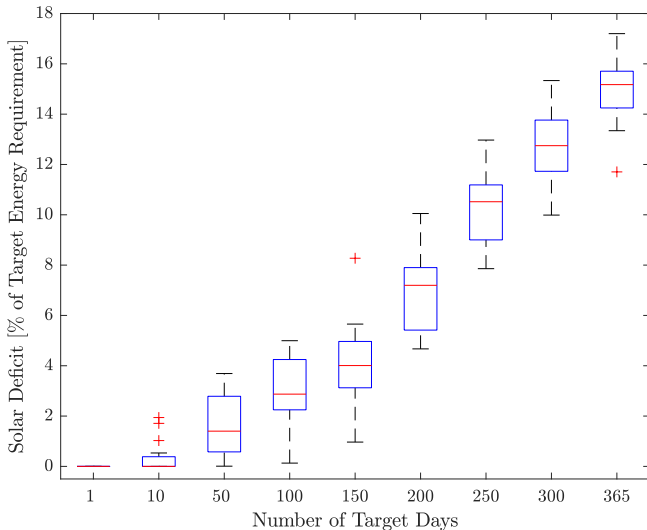
Could Solar Thermal Cover An Eight-Hour Peak?

Solar Multiple 2.0, Six Hours of Thermal Energy Storage



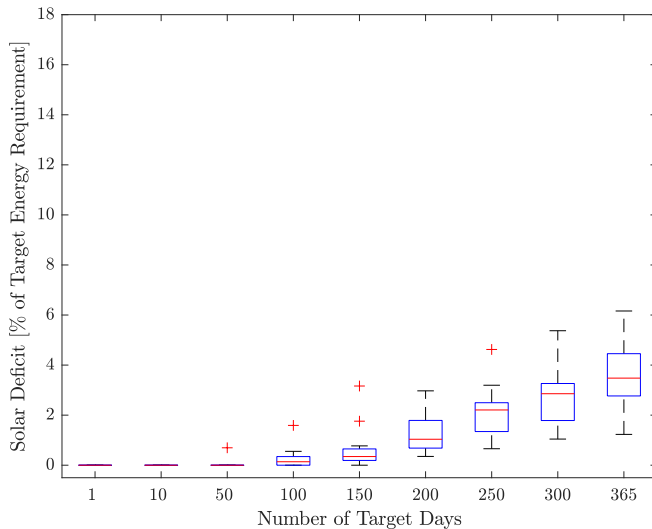
Could Solar Thermal Cover *All* Eight-Hour Peaks?

Solar Multiple 2.0, Six Hours of Thermal Energy Storage

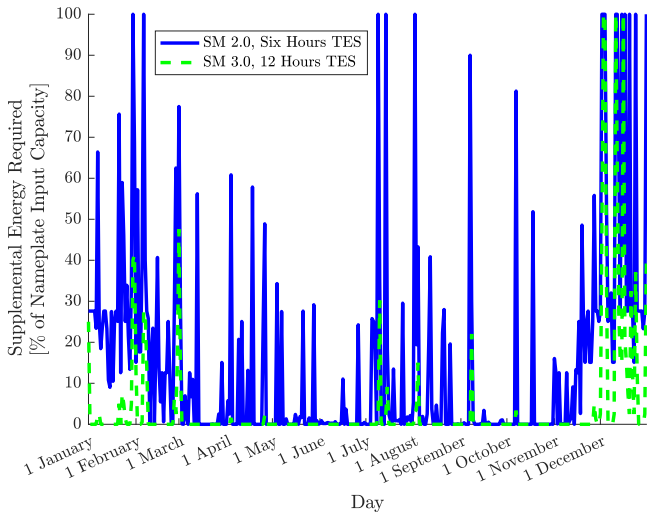


And If It's Bigger?

Solar Multiple 3.0, 12 Hours of Thermal Energy Storage



Needed: Moving Energy From Summer to Winter



To Summarize

- Solar has amazing deployment potential for two main reasons:
 - 1 Low cost of solar itself
 - 2 Low cost of enabling technologies (*e.g.*, energy storage)
- Market-design reforms are likely necessary to remunerate solar for value that it provides
- Seasonal energy storage is a grand challenge to get to complete decarbonization (we have time, even if we shouldn't)

- 1 Capacity versus energy value of solar and use of energy storage and forecasting issues in assessing capacity value
- 2 The economics of solar + energy storage
- 3 The role of solar in deep decarbonization of electricity production

Thank you