Webinar
IEA PVPS Task 16: Firm PV Power

Long duration storage modeling in California and Western North America

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Tuesday, August 16th, 2022

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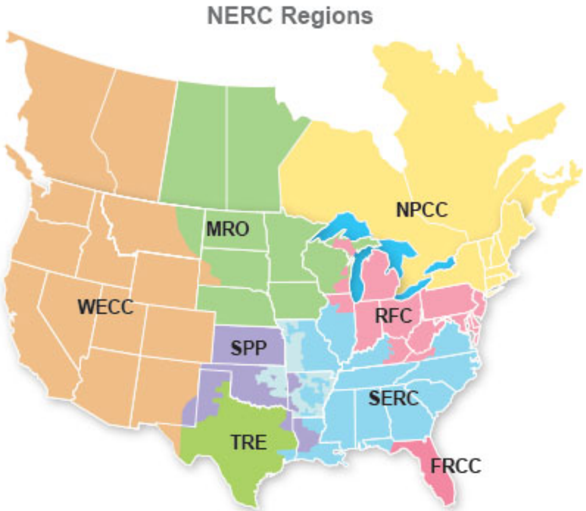
Agenda

The role of long duration energy (LDES) storage in California and Western North America

- Methodology: SWITCH WECC model
- Wind or solar dominant grids
- Varying LDES energy capacity costs
- Electricity pricing benefits of LDES
- Questions

Methodology: SWITCH WECC model[1]



- Capacity expansion deterministic linear program

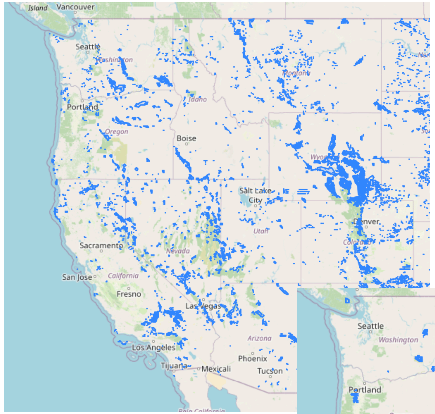
- Minimizes total cost of the power system:
  - Generation investment and operation
  - Transmission investment and operation
- Geographic:
  - Western Electricity Coordinating Council
  - 50 load areas
- Temporal:
  - Investment periods: 2026-2035 ("2030"); 2036-2045 ("2040"); 2046-2055 ("2050");
  - Time resolution: sampling every 4 hours, for a subset of days or every day in a year
  - Dispatch simulated simultaneously with investment decisions

[1] https://github.com/REAM-lab/switch/

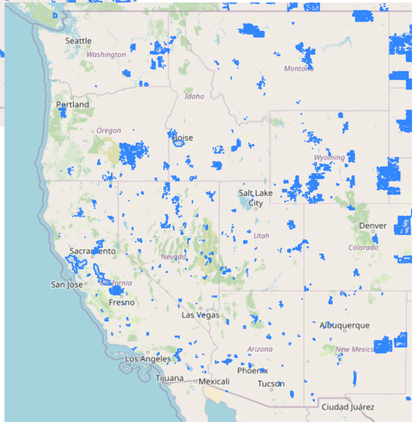
SWITCH WECC model input data and outputs

INPUTS

- Existing generators in the WECC (3,000+, 2020 EIA Form 860)
- 7,000+ potential new generators
- Aggregated existing transmission capacity
- Hourly loads by zone
- Hourly capacity factors for wind and solar supply
- Fuel and overnight yearly costs projections (NREL ATB 2020)



Wind candidates



Solar candidates

OUTPUTS

- Optimal investment of new generators by decade until 2050
- Optimal hourly dispatch for each generator
- Optimal transmission capacity expansion by decade until 2050
- Hourly CO2 emissions by generator
- Investment and operational costs

Preliminary results

M. Staadecker, P. A. Sánchez-Pérez , J. Szinai, S. Kurtz, and P. Hidalgo-Gonzalez, "The value of long-duration energy storage and its interaction with a zero-emissions electricity grid" (submitted)

Motivation

- The U.S. future requirement of energy in storage or its duration for a growing demand in a reliable zero emissions grid is still unclear[1,2]
- Some report 100% renewable energy grids with[3] and without storage[4],
- others rely on "clean firm power"[5] or even biomass to achieve negative emissions[6],
- others consider intraday storage[7], and in some cases seasonal[8].

[1]J. D. Hunt, E. Byers, Y. Wada, S. Parkinson, D. E. H. J. Gernaat,S. Langan, D. P. van Vuuren and K. Riahi, "Global Resource Potential of Seasonal Pumped Hydropower Storage for Energy and Water Storage" Nature Communications, 2020,11, 947.

[2]O. J. Guerra, J. Zhang, J. Eichman, P. Denholm, J. Kurtzand B.-M. Hodge, "The Value of Seasonal Energy Storage Technologies for the Integration of Wind and Solar Power" Energy & Environmental Science, 2020,13,1909–1922.

[3]C. Clack et al., "Evaluation of 100% wind, water, and solar power" Proceedings of the National Academy of Sciences Jun 2017, 114 (26) 6722-6727; DOI: 10.1073/pnas.1610381114

[4]Mark Z. Jacobson, Mark A. Delucchi, Mary A. Cameron, Bethany A. Frew "Stabilizing grid with 100% renewables 2050" Proceedings of the National Academy of Sciences Dec 2015, 112 (49) 15060 15065; DOI: 10.1073/pnas.1510028112

[5]Nestor A. Sepulveda, Jesse D. Jenkins, Fernando J. de Sisternes, Richard K. Lester, "The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation" Joule, Volume 2, Issue 11, 2018, Pages 2403-2420, ISSN 2542-4351

[6]Sanchez, D., Nelson, J., Johnston, J. *et al.* Biomass enables the transition to a carbon-negative power system across western North America. *Nature Clim Change* **5,** 230–234 (2015).

[7]Fernando J. de Sisternes, Jesse D. Jenkins, Audun Botterud, The value of energy storage in decarbonizing the electricity sector, Applied Energy, Volume 175, 2016, Pages 368-379, ISSN 0306-2619

[8]O. J. Guerra, J. Zhang, J. Eichman, P. Denholm, J. Kurtz, B. Hodge, "The value of seasonal energy storage technologies for the integration of wind and solar power" Energy & Environmental Science, 2020, Pages 1909-1922

Staadecker, M. et al. "The Value of Long-Duration Energy Storage and Its Interaction with the Western North America Electricity Grid" (in prep.)

Contributions

- Quantification of the benefits in electricity pricing of federal/state mandates for LDES deployment.
- How does the deployment of LDES change depending on:
    1. the ratio of solar/wind deployed
    2. if transmission expansion is restricted?
    3. The costs of long-duration storage (NREL ATB 2020, DOE storage shot, and ultra low)
    4. Hydropower availability

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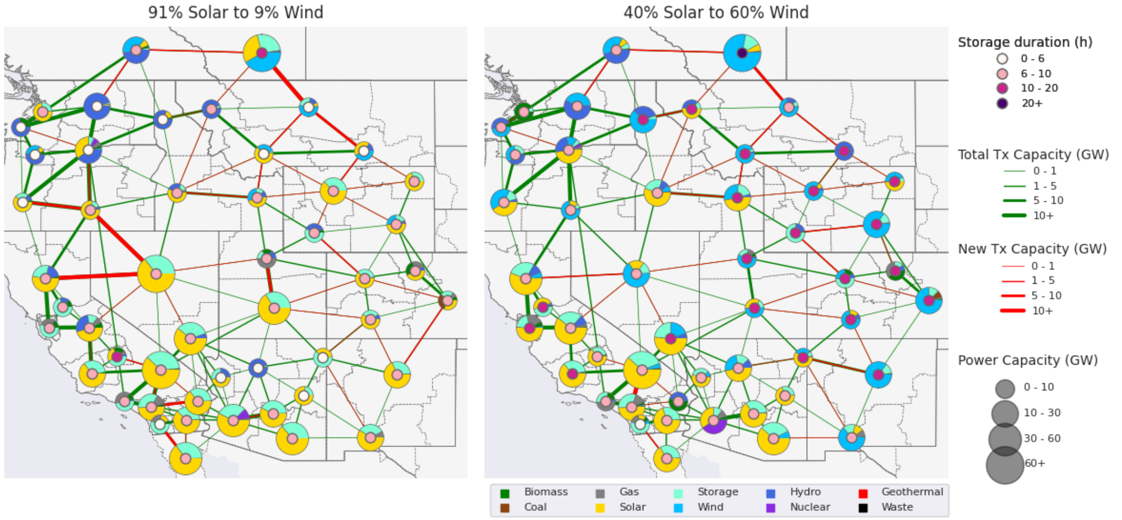
Problem formulation

- 6 hours sampled/day x 365 days/year in 2050
- Zero emissions WECC-wide in 2050

Results: Wind or solar dominant grids

- Nearly all **solar-dominant** load zones have a light pink dot representing **6-to-10-hour storage**
- Nearly all **wind-dominant** load zones have a dark pink dot representing **10-to-20-hour**



Results: Varying LDES energy capacity costs by 2050

- Energy capacity ranges from 1.5 TWh to 36 TWh
- Largest duration ranges from 9h to 825h
- Transmission deployment decreases by 75% for the cheapest LDES case

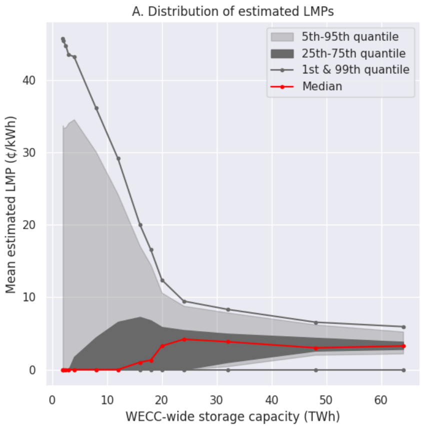
Table 2: Storage, wind, and transmission characteristics under varying energy storage costs

Energy Storage Cost	WECC-wide energy storage capacity (TWh)	WECC mean storage duration (h)	Largest storage duration (h)	Wind Capacity (GW)	New Transmission Capacity (million MW-km)
102 $/kWh	1.5 (-22%)	7.0	8.9	113 (+14%)	27 (+31%)
22 $/kWh (Baseline)	1.9	8.2	18	99	21
10 $/kWh	2.4 (+21%)	9.9	29	98 (-1%)	17 (-18%)
5 $/kWh	6.6 (+239%)	28	378 (16 days)	94 (-5%)	13 (-40%)
1 $/kWh	22 (+1042%)	96 (4 days)	620 (26 days)	82 (-17%)	4.9 (-76%)
0.5 $/kWh	36 (+1747%)	151 (6.3 days)	825 (34 days)	69 (-30%)	5.3 (-75%)

Percentages in parentheses represent the change compared to the baseline.

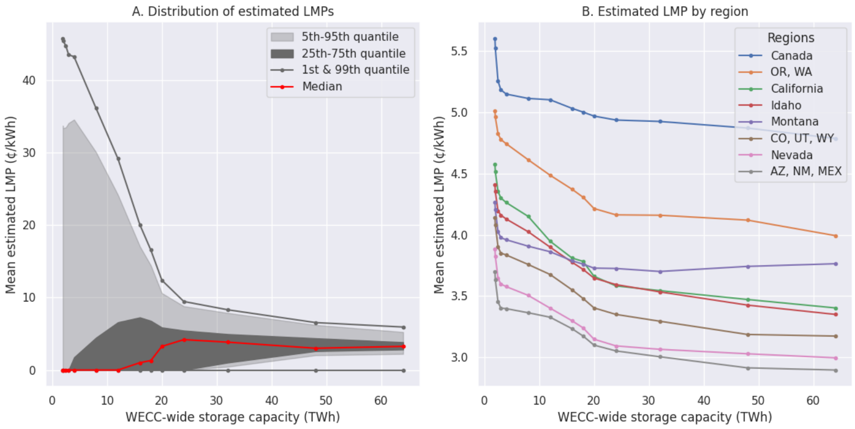
Results: LDES energy capacity mandates

- A: LMPs variability drastically reduced beyond 20 TWh of energy storage



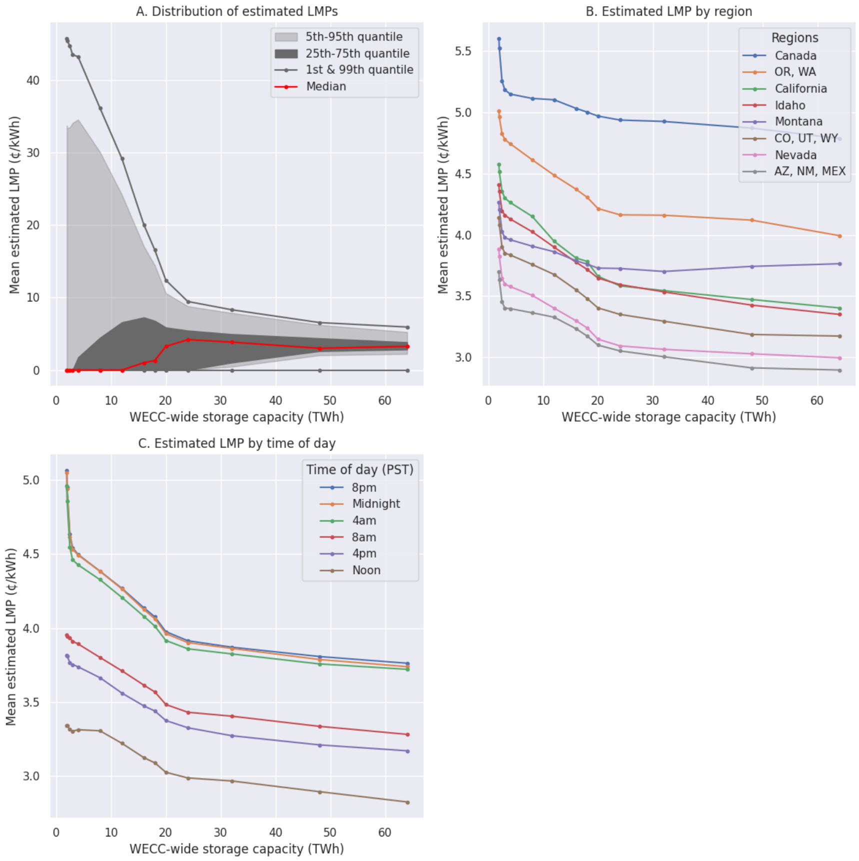
Results: LDES energy capacity mandates

- A: LMPs variability drastically reduced beyond 20 TWh of energy storage
- B: LMP variability across states



Results: LDES energy capacity mandates

- A: LMPs variability drastically reduced beyond 20 TWh of energy storage
- B: LMP variability across states
- C: 8am – 4pm lowest LMPs due to solar generation
- C: 20 TWh reduce LMPs the most
- C: sharpest drop between 1.94 TWh and 3 TWh: every additional 100 GWh of energy storage decrease night-time LMPs by 1.04%



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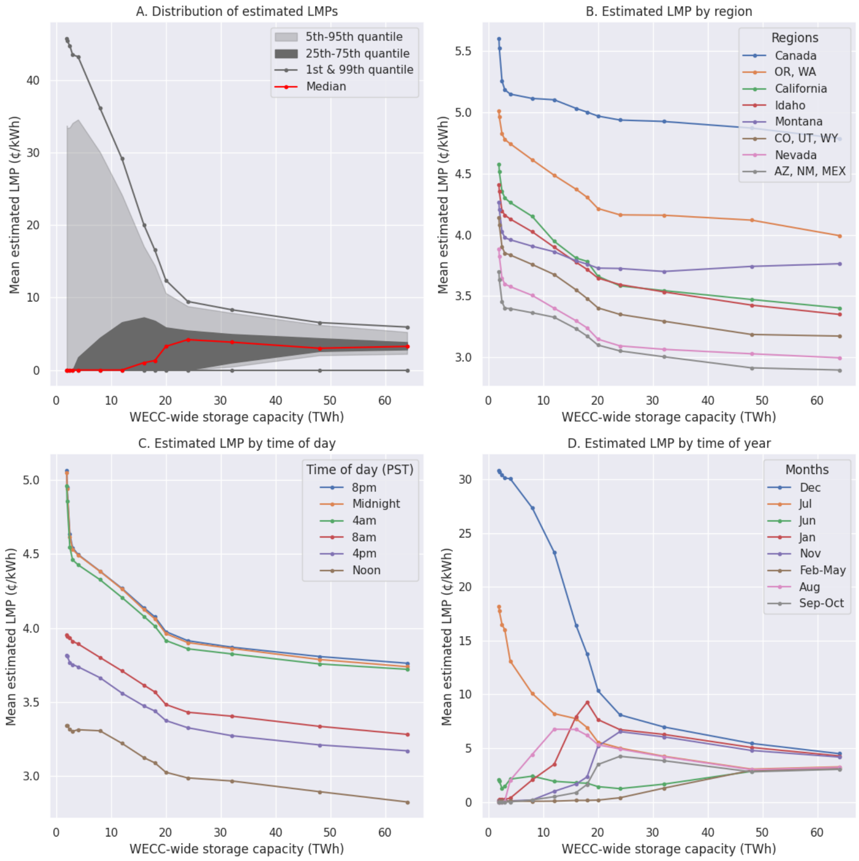
- C: sharpest drop between 1.94 TWh and 3 TWh: every additional 100 GWh of energy storage decrease night-time LMPs by 1.04%
- D: LMPs are highest in July and December (highest demands) while near zero in other months due to excess renewable energy



Conclusions

- Depending on the grid composition, solar or wind dominant, 6-to-10 hours or 10-to-20 hours LDES duration will optimally support its operation
- R&D can play a key role in the optimal deployment of LDES. Achieving an energy capacity capital costs of $5/kWh can enable 28 hours of mean duration, and a maximum of ~400 hours
- Storage mandates can mitigate electricity prices variability and seasonality in a zero emissions grid

Questions?

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Wednesday, June 1st, 2022

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Architecture of the SWITCH WECC model[1]

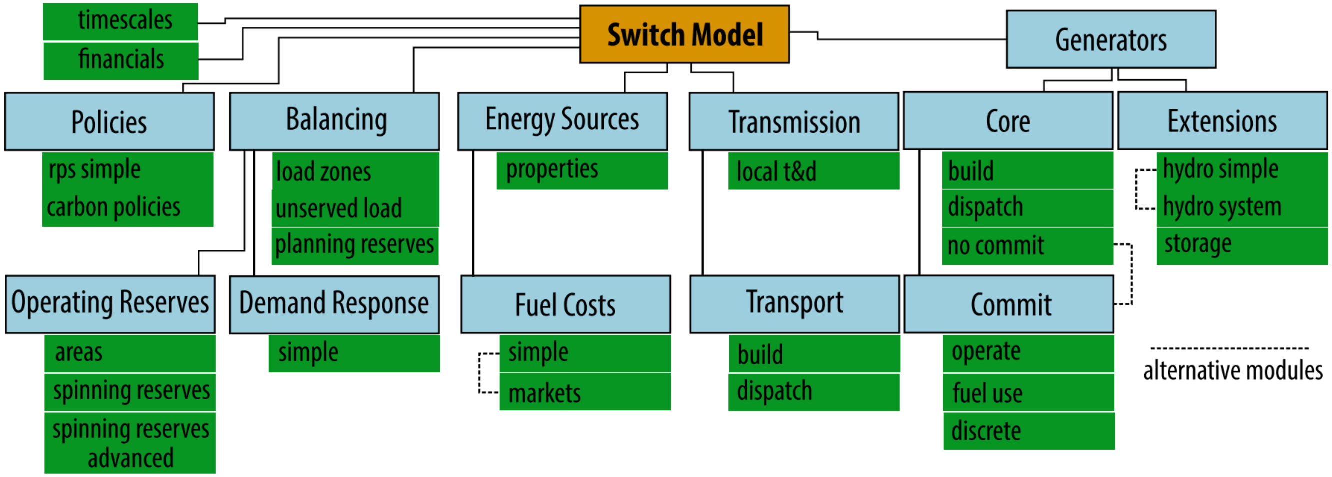

Image source: J. Johnson et al., Switch 2.0: A modern platform for planning high-renewable power systems, 2019

[1] https://github.com/REAM-lab/switch/