The value of energy storage in decarbonizing the electricity sector

Fernando J. DE SISTERNES (ANL/MIT*),[1,2,3] Jesse JENKINS (MIT) [4], Audun BOTTERUD (ANL/MIT) [1,2]

[1] Energy Systems Engineer, Center for Energy, Environmental, and Economic Systems Analysis (CEEESA)
Energy Systems Division (ES), ARGONNE NATIONAL LABORATORY*

[2] Research Affiliate, MIT Energy Initiative, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

[3] Associate, Harvard Kennedy School of Government , HARVARD UNIVERSITY

[4] Research assistant, MIT Energy Initiative, PhD candidate, Institute for Data, Systems, and Society, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

sisternes@gmail.com - jessedj@mit.edu - abotterud@anl.gov

* Now at the World Bank

Past, Present, and Future of Battery Storage
Argonne National Laboratory – August 31, 2016

Motivation

- Is energy storage critical for meeting stringent carbon emissions limits?
- How does storage change the optimal capacity mix for meeting carbon emissions limits?
- Can storage enable a renewables-only pathway to deep decarbonization?
- What is the value of energy storage (in avoided system costs) under different emissions limits?

Methodology: IMRES

Single Node Planning Model with Operational Constraints

INVESTMENT MODEL FOR RENEWABLE ELECTRICITY SYSTEMS (IMRES)

Long-Term/Investment

Optimal Generation Capacity Expansion

↔

Short-Term/Operation

Unit Commitment with Reserves

Capacity Expansion with Unit Commitment Constraints (MILP)

Objective: minimize total generation cost over one year (*annualized* investment costs + operating costs)

Subject to: DETAILED OPERATING CONSTRAINTS

(Reserves, ramp rates, min up/down time etc.)

See: F. de Sisternes (2014)

Key Inputs: ERCOT (Texas)-like System in 2035

- Load projection for ERCOT system 2035
  - Hourly loads for 2013 scaled up based on EIA projected load growth
  - Peak load 97.1 GW
- Five generation technologies (investment alternatives)
  - Nuclear, Coal, Gas CC, Gas CT, Wind, Solar
  - Cost and performance assumptions from EIA AEO 2014, DOE Wind and Sunshot Vision reports
  - Nuclear assumed flexible (i.e. with load following capabilities)
  - Greenfield expansion (no existing generation)
- Energy storage
  - Exogenous input
  - Provides load leveling and reserves

de Sisternes, Jenkins, Botterud (2016)

Experimental Design

Storage			CO_2 Emissions Limit				
Power [GW]	Energy [GWh]	Technologies	No Limit	200 t/GWh	150 t/GWh	100 t/GWh	50 t/GWh
0	0	W, S, N	X	X	X	X	X
10	100	W, S, N	X	X	X	X	X
20	200	W, S, N	X	X	X	X	X
30	300	W, S, N	X	X	X	X	X
10	20	W, S, N	X	X	X	X	X
20	40	W, S, N	X	X	X	X	X
30	60	W, S, N	X	X	X	X	X

→ Baseline Case: No Storage

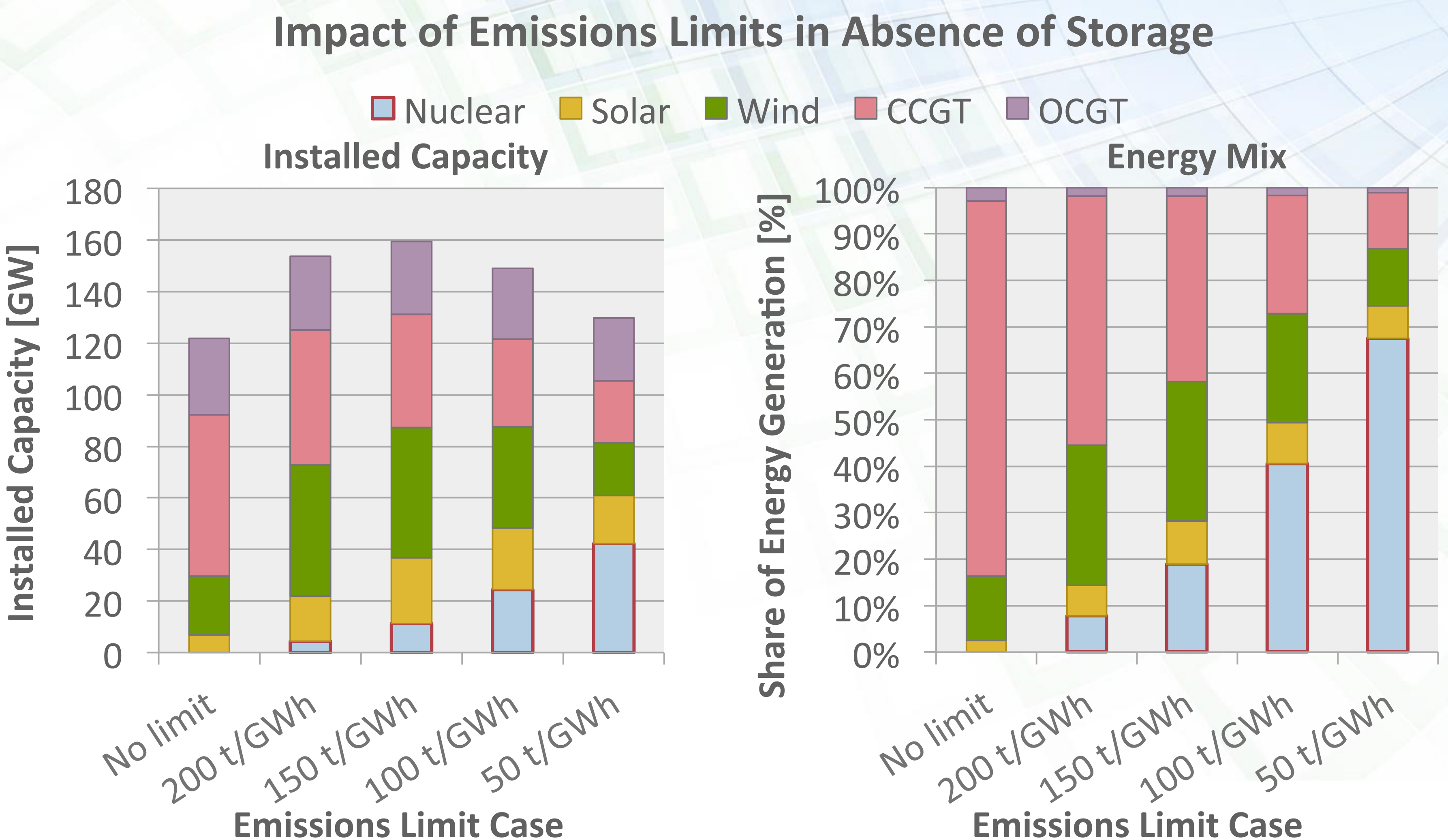
→ 10/1 Energy-Power Ratio (CAES, PSH)

→ 2/1 Energy-Power Ratio (Li-ion, Pb-Acid, Flow, other)

de Sisternes, Jenkins, Botterud (2016)

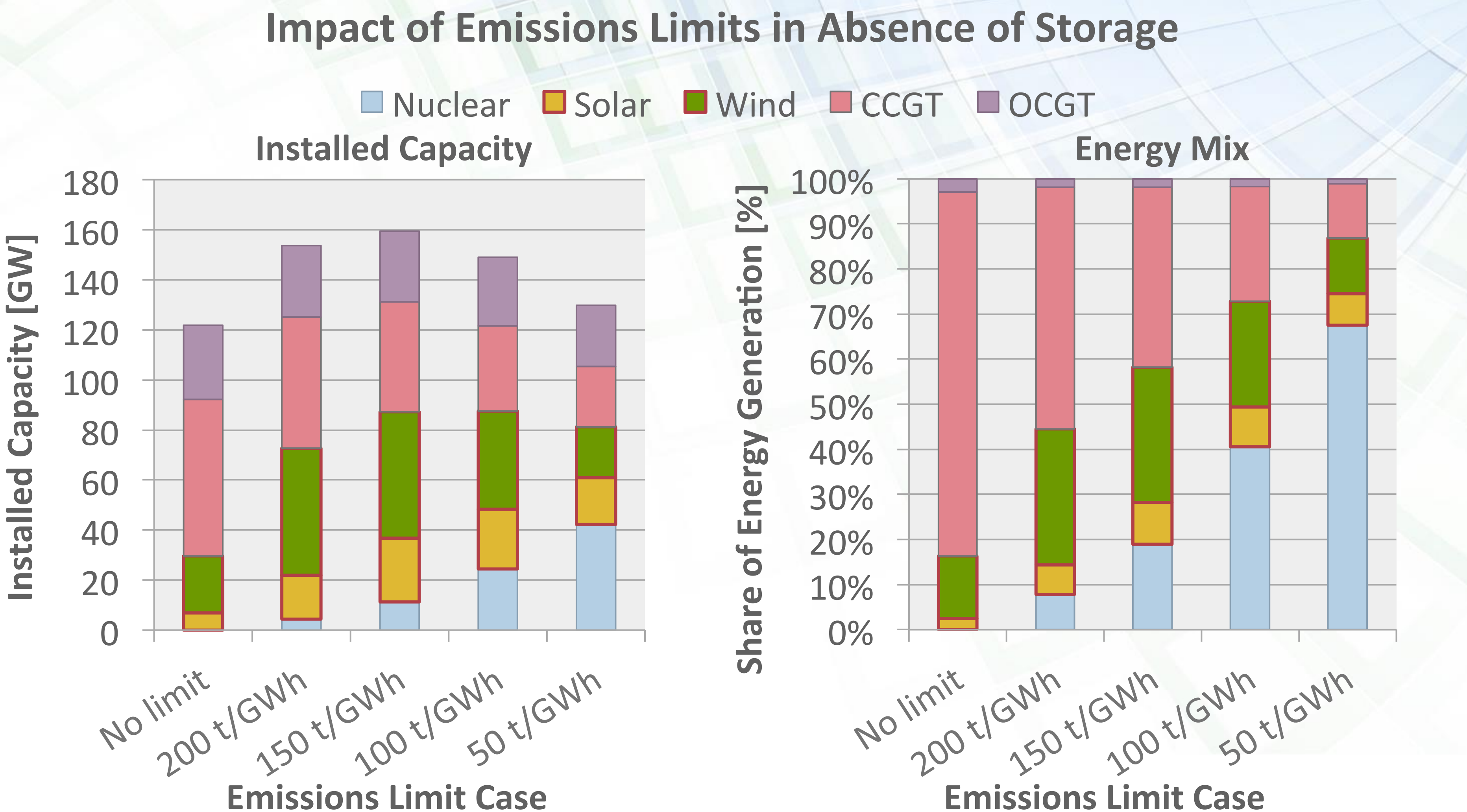
Is energy storage critical for meeting stringent carbon emissions limits?

Insight: tight emissions limits can be met without storage, if low-carbon dispatchable or "flexible base" resources are available



de Sisternes, Jenkins, Botterud (2016)

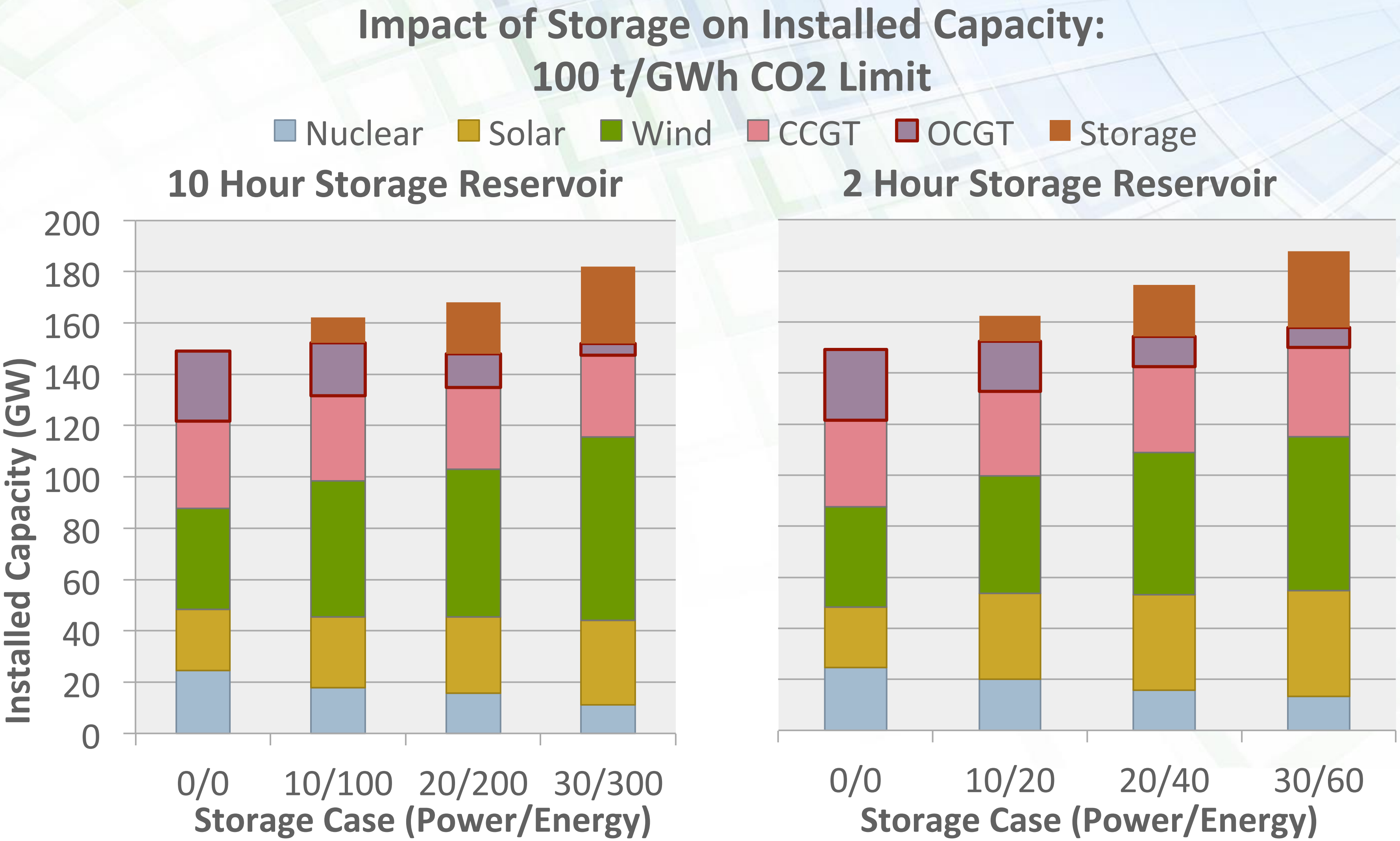
Insight: without storage, share of variable renewable sources (wind & solar) is limited and is largest in moderate emissions limits



de Sisternes, Jenkins, Botterud (2016)

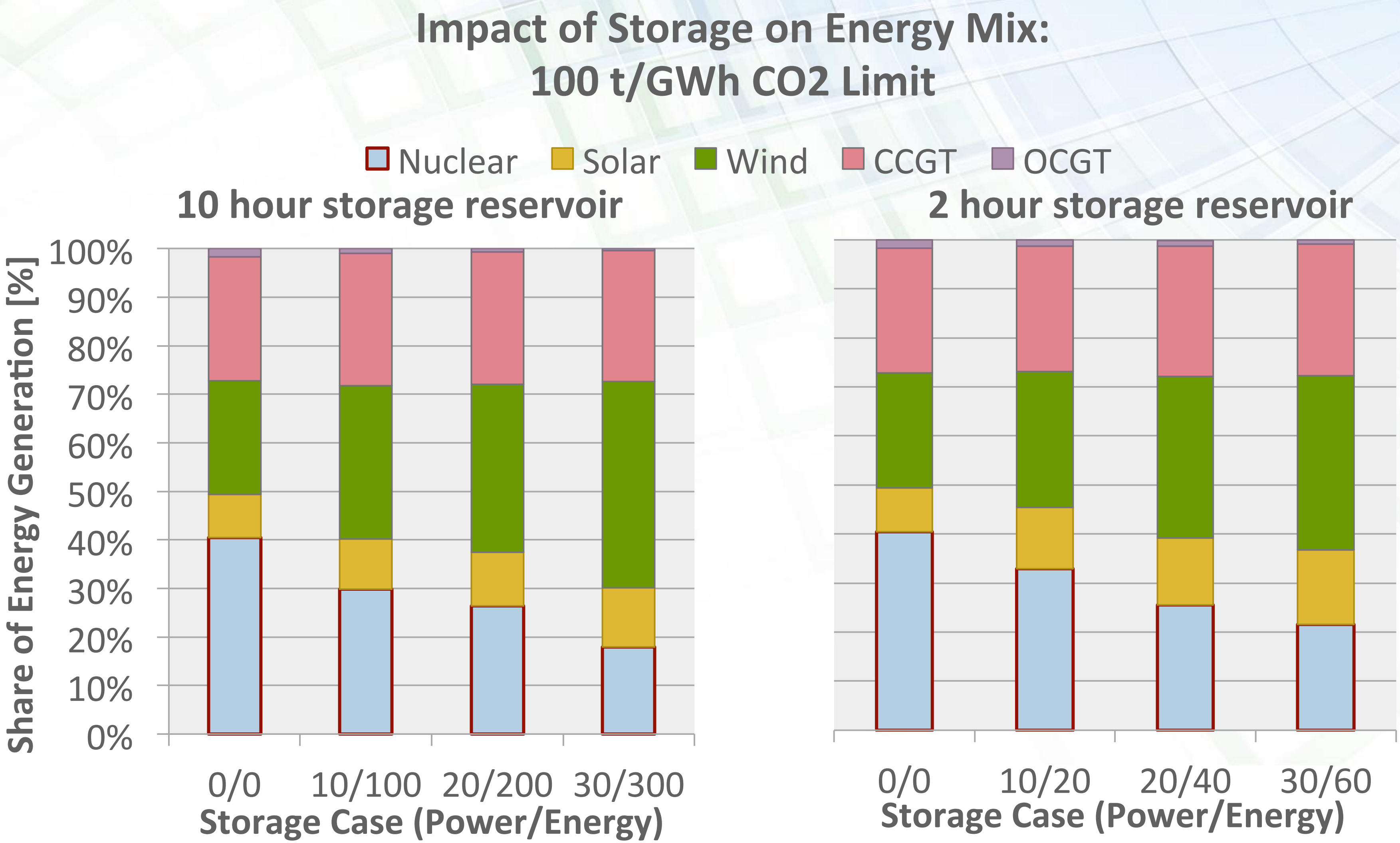
How does storage change the optimal capacity mix for meeting carbon emissions limits?

Insight: storage is a strong substitute for "peaking" power plants.



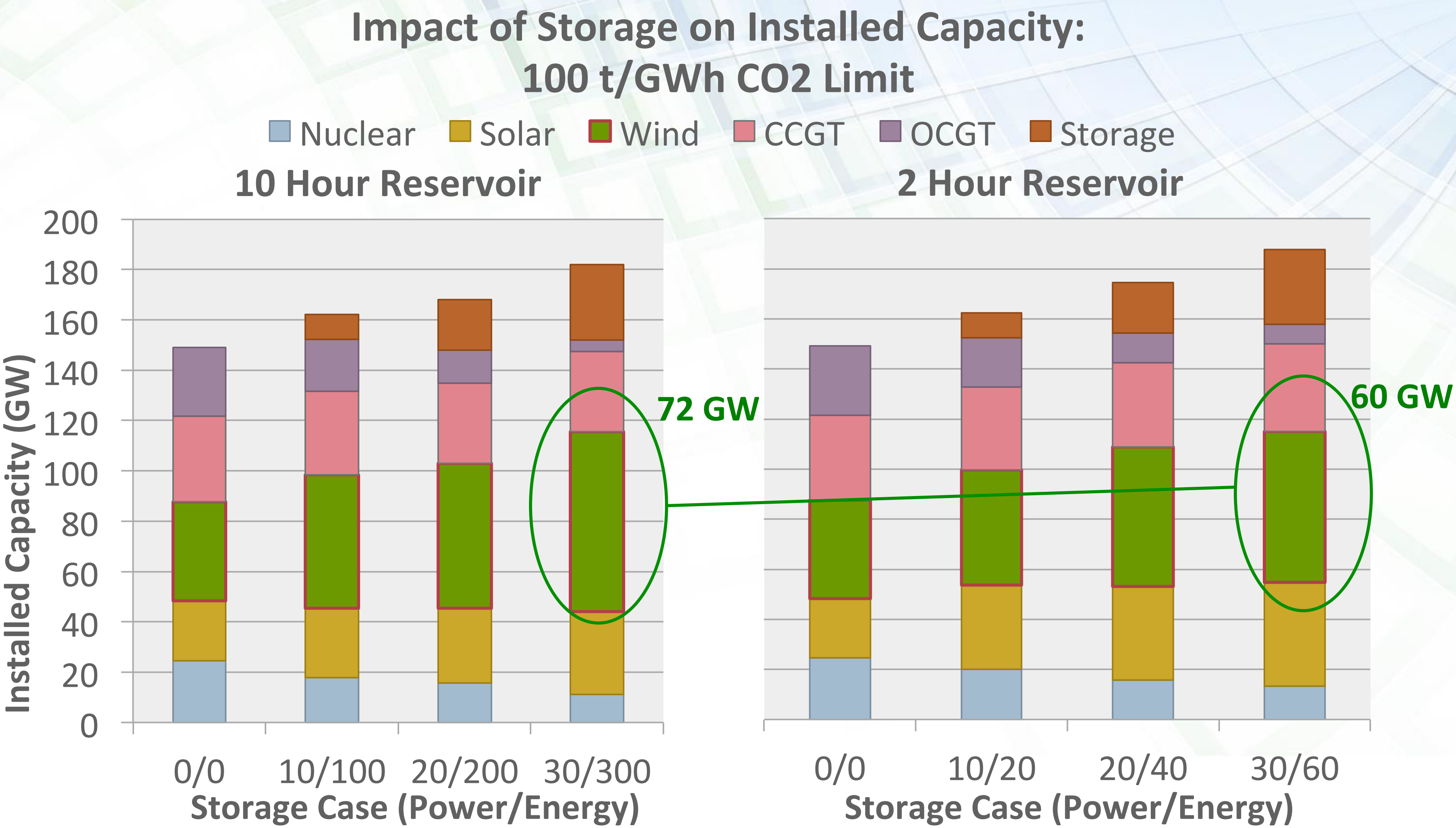
de Sisternes, Jenkins, Botterud (2016)

Insight: storage expands wind & solar share. Variable renewables + storage are a weak substitute for flexible base resources.



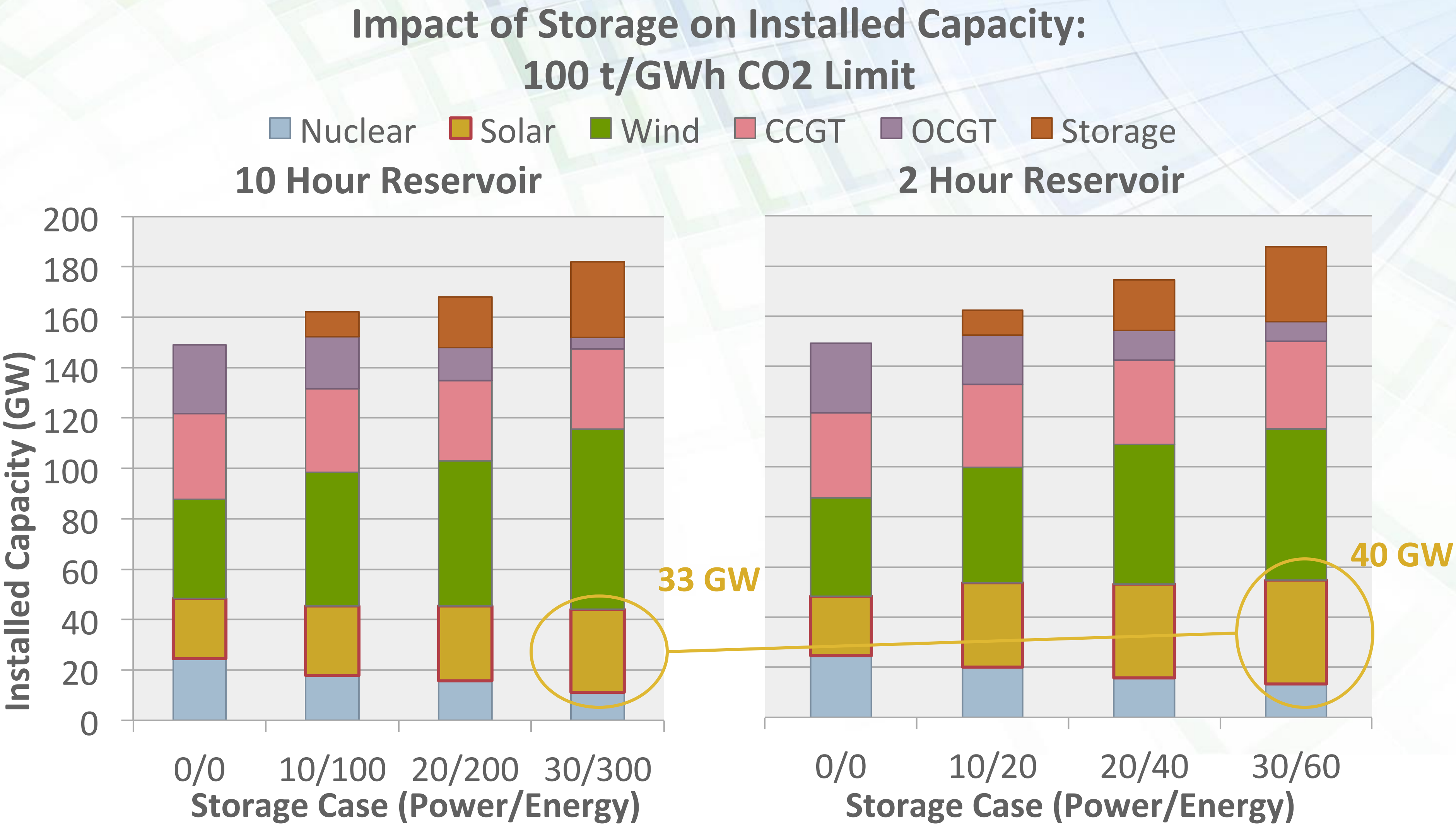
de Sisternes, Jenkins, Botterud (2016)

Insight: longer duration (high energy capacity) storage increases wind share more than solar.



de Sisternes, Jenkins, Botterud (2016)

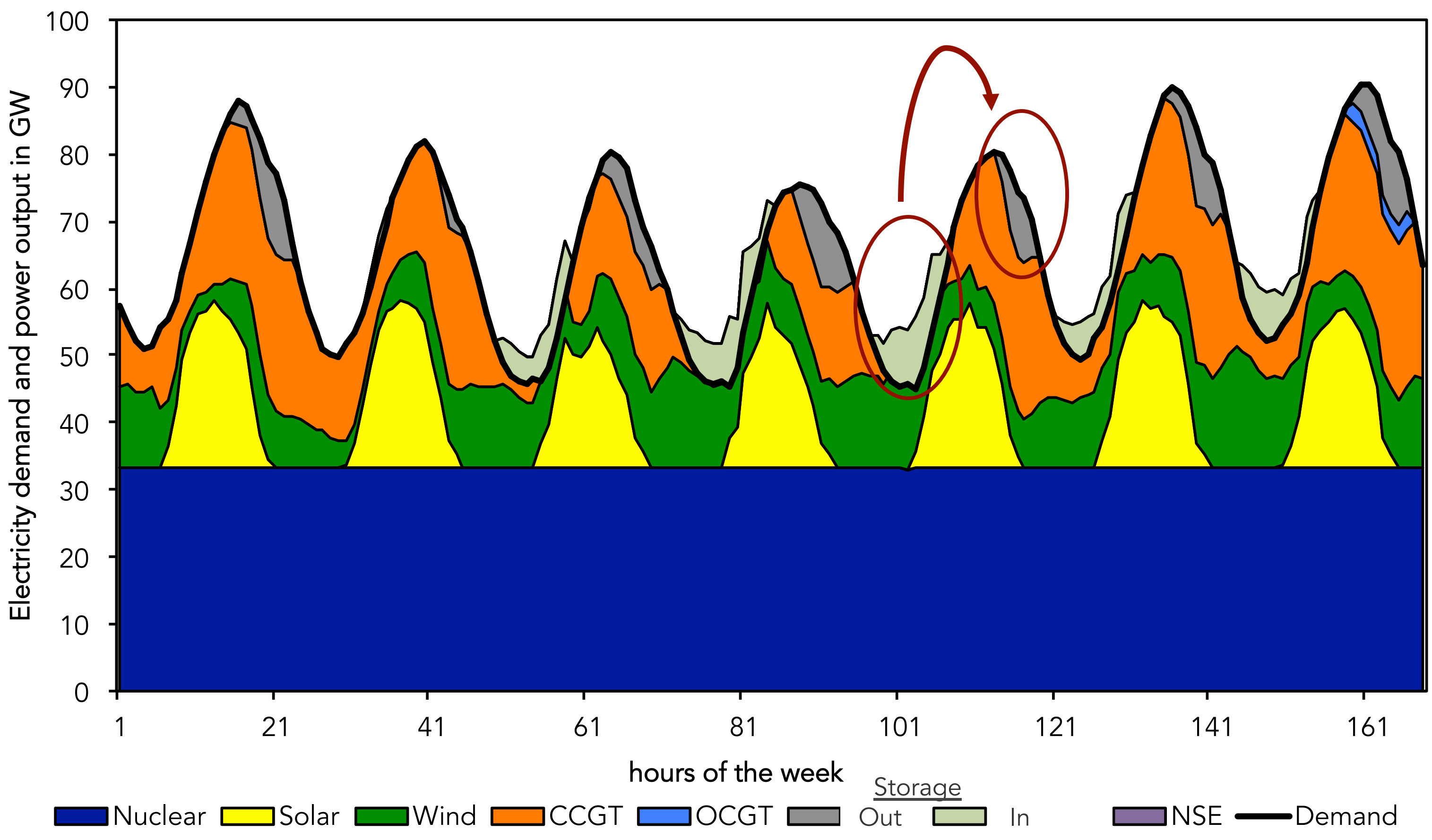
Insight: longer duration (high energy capacity) storage increases wind share more than solar.



de Sisternes, Jenkins, Botterud (2016)

Insight: longer duration (high energy capacity) storage increases wind share more than solar.

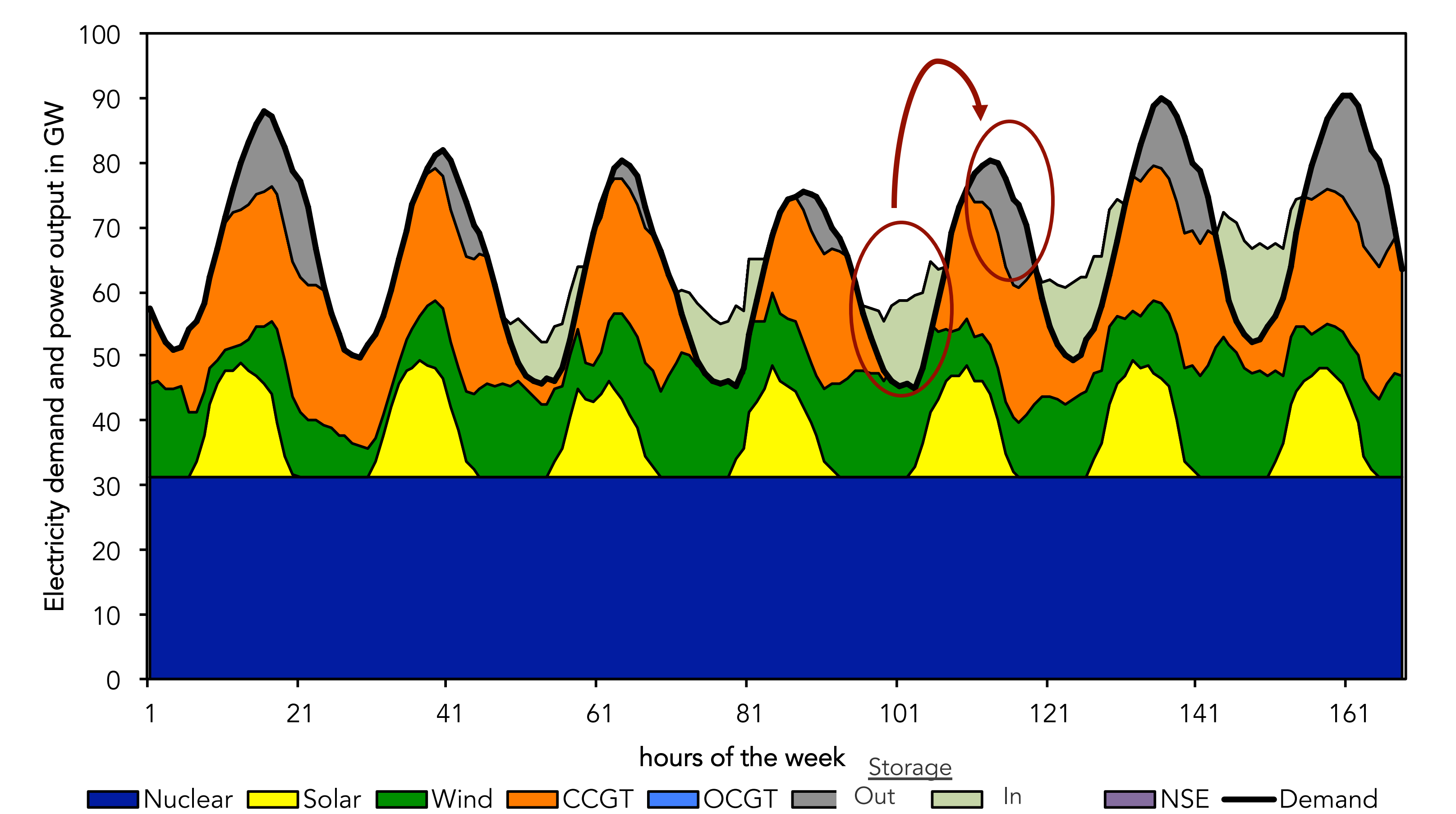
One week economic dispatch with 30 GW 2-hour energy storage and a carbon limit of 50 tons/GWh:



de Sisternes, Jenkins, Botterud (2016)

Insight: longer duration (high energy capacity) storage increases wind share more than solar.

One week economic dispatch with 30 GW 10-hour energy storage and a carbon limit of 50 tons/GWh:



de Sisternes, Jenkins, Botterud (2016)

Can storage enable a renewables-only pathway to deep decarbonization?

Insight: energy storage essential to meet strict emissions reductions without a zero-carbon flexible base resource, but doing so raises costs vs more diverse mix

Storage				CO$_2$ Emissions Limit			
Power [GW]	Energy [GWh]	Technologies				100 t/GWh	
0	0	W, S, ~~N~~				**INFEASIBLE**	
10	100	W, S, ~~N~~				**8.6 % (*)**	
20	200	W, S, ~~N~~				**2.6 % (*)**	
30	300	W, S, ~~N~~				**1.1 % (*)**	
10	20	W, S, ~~N~~				**6.0 % (*)**	
20	40	W, S, ~~N~~				**4.1 % (*)**	
30	60	W, S, ~~N~~				**4.5 % (*)**	

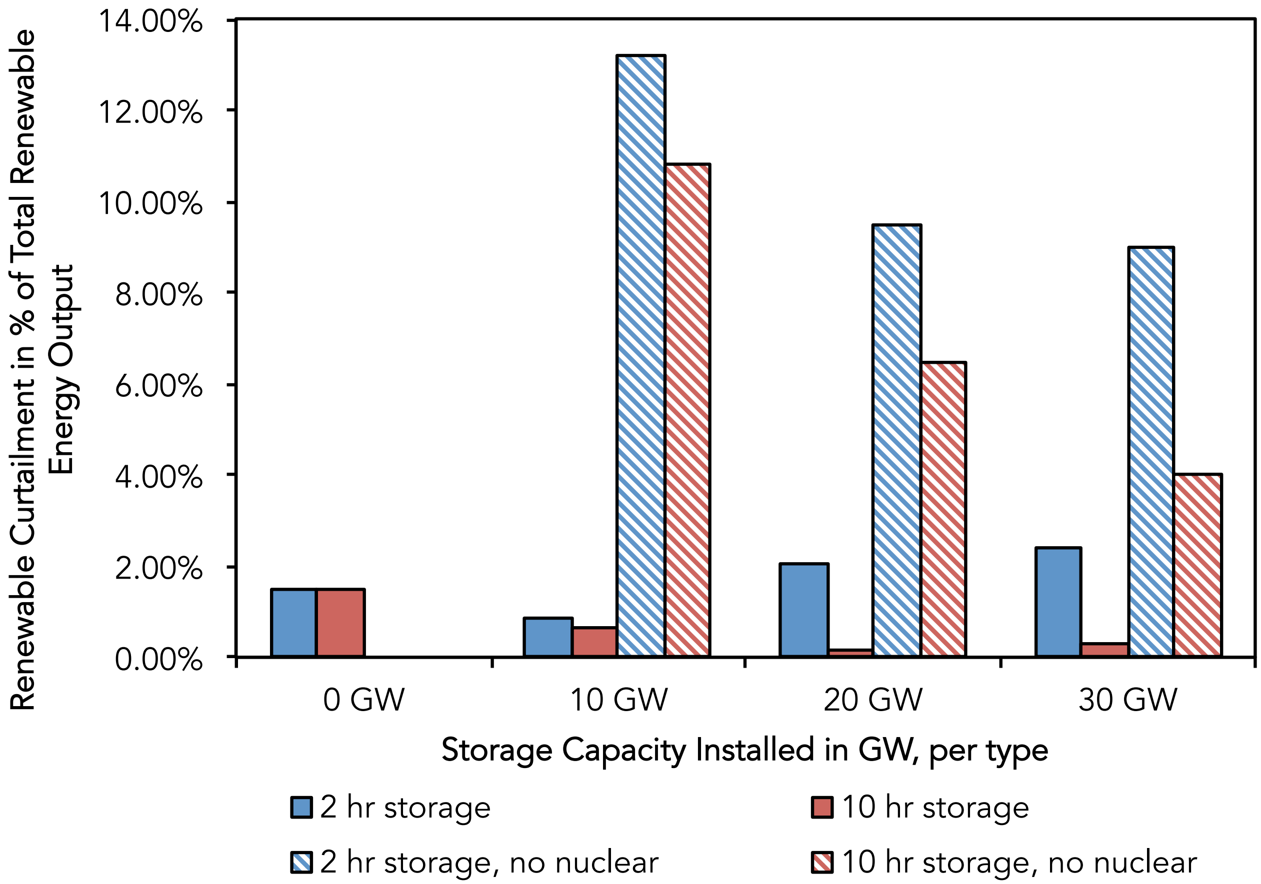
(*) extra cost compared to the full mix (including nuclear)

- The problem becomes **infeasible without storage** because the only technologies that can provide spinning reserves are gas-fired power plants, exceeding the 100t/GWh limit if they run at their minimum output level.

de Sisternes, Jenkins, Botterud (2016)

Insight: renewables-only pathway entails significant curtailment, even with high storage capacities

Impact of energy storage on renewable curtailment under a carbon emissions constraint of 100tns/GWh

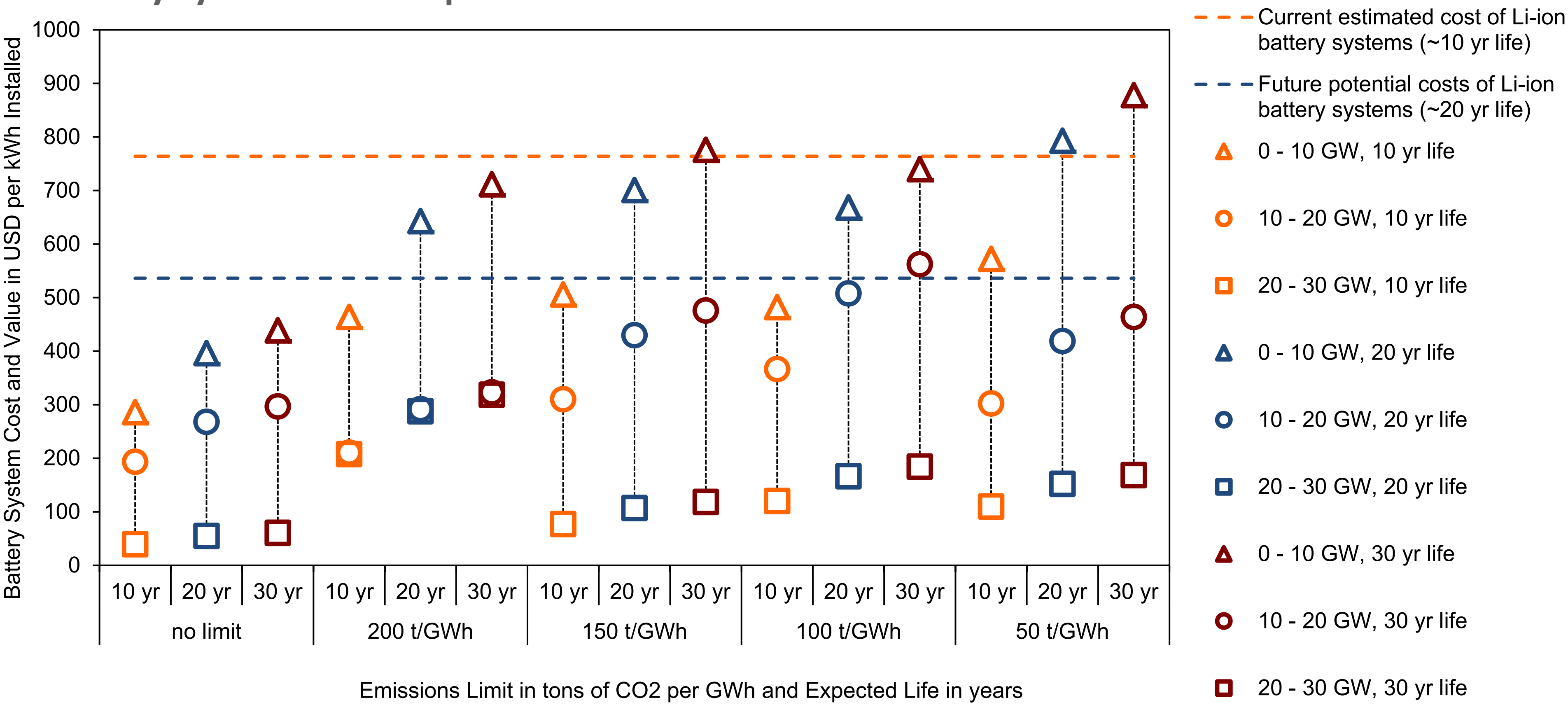


de Sisternes, Jenkins, Botterud (2016)

What is the value of energy storage (in avoided system costs) under different emissions limits?

Insight: storage has value under emissions limits, but costs need to fall further to combat declining marginal value and justify widespread adoption

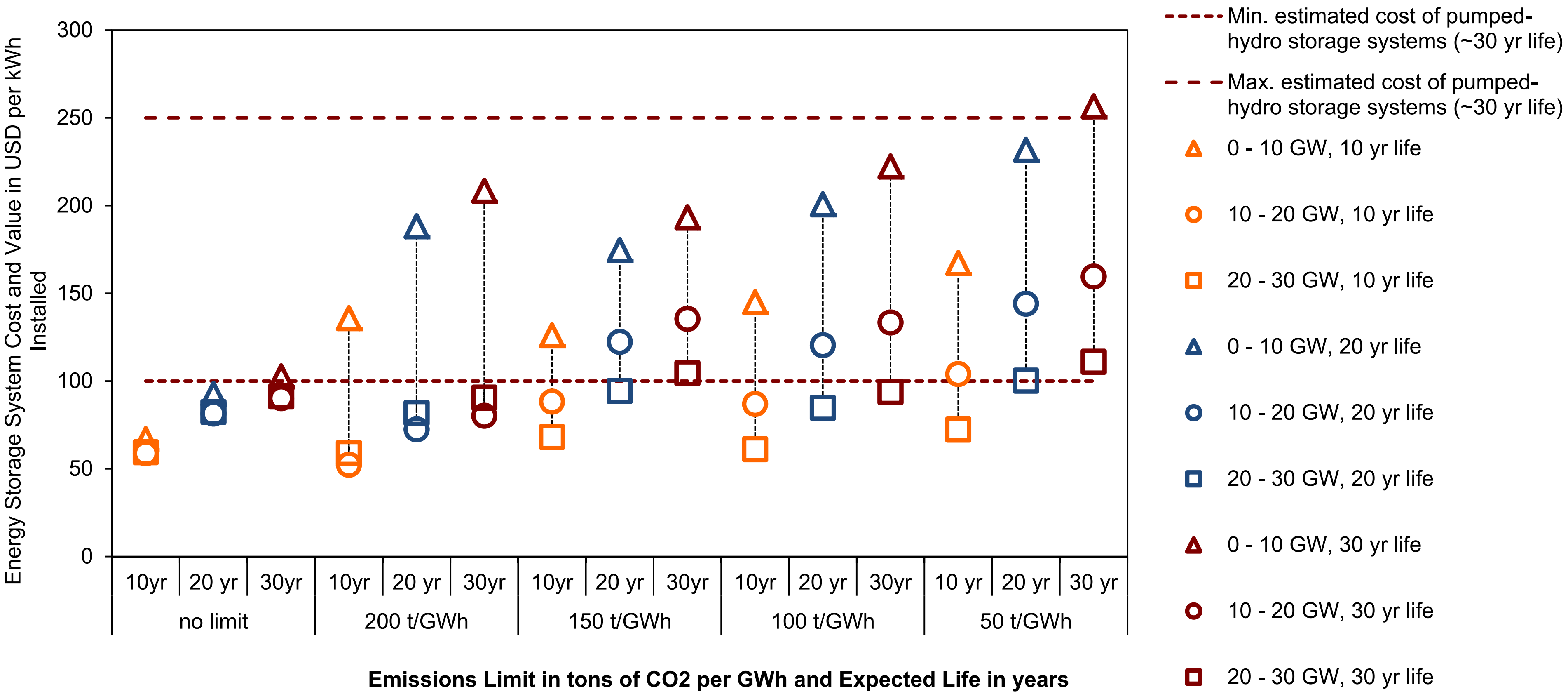
Cost-benefit of energy storage: system value of 2-hour energy storage capacity for different carbon emissions goals and current and potential future cost for Li-ion battery systems for comparison.



de Sisternes, Jenkins, Botterud (2016)

Insight: pumped-hydro may be economical under emissions limits but faces its own constraints.

Cost-benefit of energy storage: system value of 10-h energy storage capacity for different carbon emissions goals and minimum and maximum current estimated cost of pumped-hydro storage systems for comparison.



de Sisternes, Jenkins, Botterud (2016)

Summary

Is energy storage critical for meeting stringent carbon emissions limits?

No, if low-carbon "flexible base" resources are available. However, storage can reduce total generation costs and might justify deployment.

How does storage change the optimal capacity mix for meeting emissions limits?

Energy storage displaces peaking power plants, helps expand renewables and reduce importance of nuclear power. Long-term storage (10hrs) favors wind over solar, and short-term storage (2hrs) favors solar over wind.

Can storage enable a renewables-only pathway to deep decarbonization?

Cost-effective and scalable storage is essential to reach strict emissions goals without a zero-carbon flexible base resource. Costs of reaching equivalent goal is higher than in a more diverse resource mix. Curtailment remains significant.

What is the value of energy storage under different emissions limits?

The marginal value with an emissions limit of less than 200 t/GWh justifies initial deployment of Li-ion at current cost. Marginal value of storage falls as penetration rises, so <u>further cost reductions would be necessary for deeper deployment.</u>

Pumped hydro can be economical. Will other long-duration techs come to market?

References

Value of energy storage paper:

1. de Sisternes, F., Jenkins, J., Botterud, A. (2016). The value of energy storage in decarbonizing the electricity sector. *Applied Energy,* 175 (August, 2016): 368-379.

IMRES capacity expansion model references:

1. de Sisternes, F., Webster, M., Perez-Arriaga, J.I. (2015). The Impact of Bidding Rules on Electricity Markets with Intermittent Renewables. *IEEE Transactions on Power Systems*, special section on "Wind & Solar Energy: Uncovering and Accommodating Their Impacts on Electricity Markets", Vol. 30, Issue 3:1603 – 1613. May 2015
2. de Sisternes, F. (2014) Risk Implications of the Deployment of Renewables for Investments in Electricity Generation , PhD Thesis, Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA
3. de Sisternes, F. (2013). Investment Model for Renewable Electricity Systems (IMRES): an Electricity Generation Capacity Expansion Formulation with Unit Commitment Constraints. MIT Center for Energy and Environmental Policy Research, CEEPR WP 2013-16, Cambridge, MA
4. de Sisternes, F., Webster, M. (2013). Optimal Selection of Sample Weeks for Approximating the Net Load in Generation Planning Problems. ESD Working Paper Series, ESD WP 2013-03, Cambridge, MA

Thank you

Jesse D. JENKINS
Researcher and PhD Candidate
MIT Energy Initiative and Institute for Data, Systems, and Society
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
77 Massachusetts Avenue, E19-307
Cambridge, MA 02139
jessedj@mit.edu