Enhanced Long-Duration Energy Storage Modeling

Brady Cowiestoll, Sourabh Dalvi, Omar Jose Guerra Fernandez

NREL Webinar

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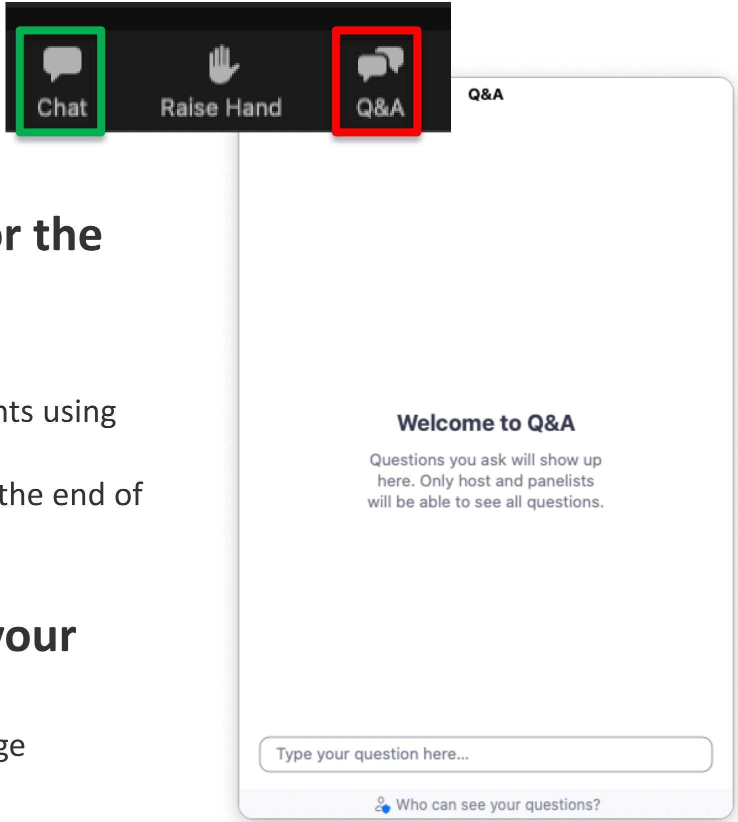

Project Team

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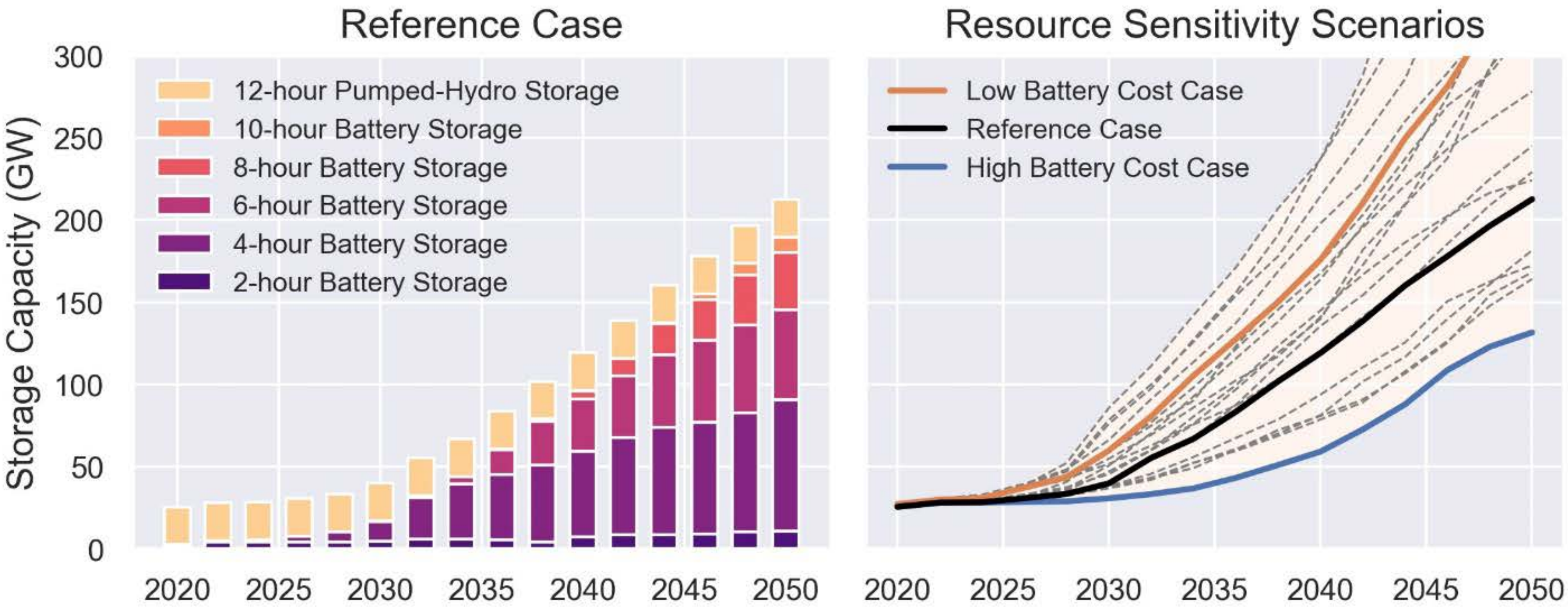
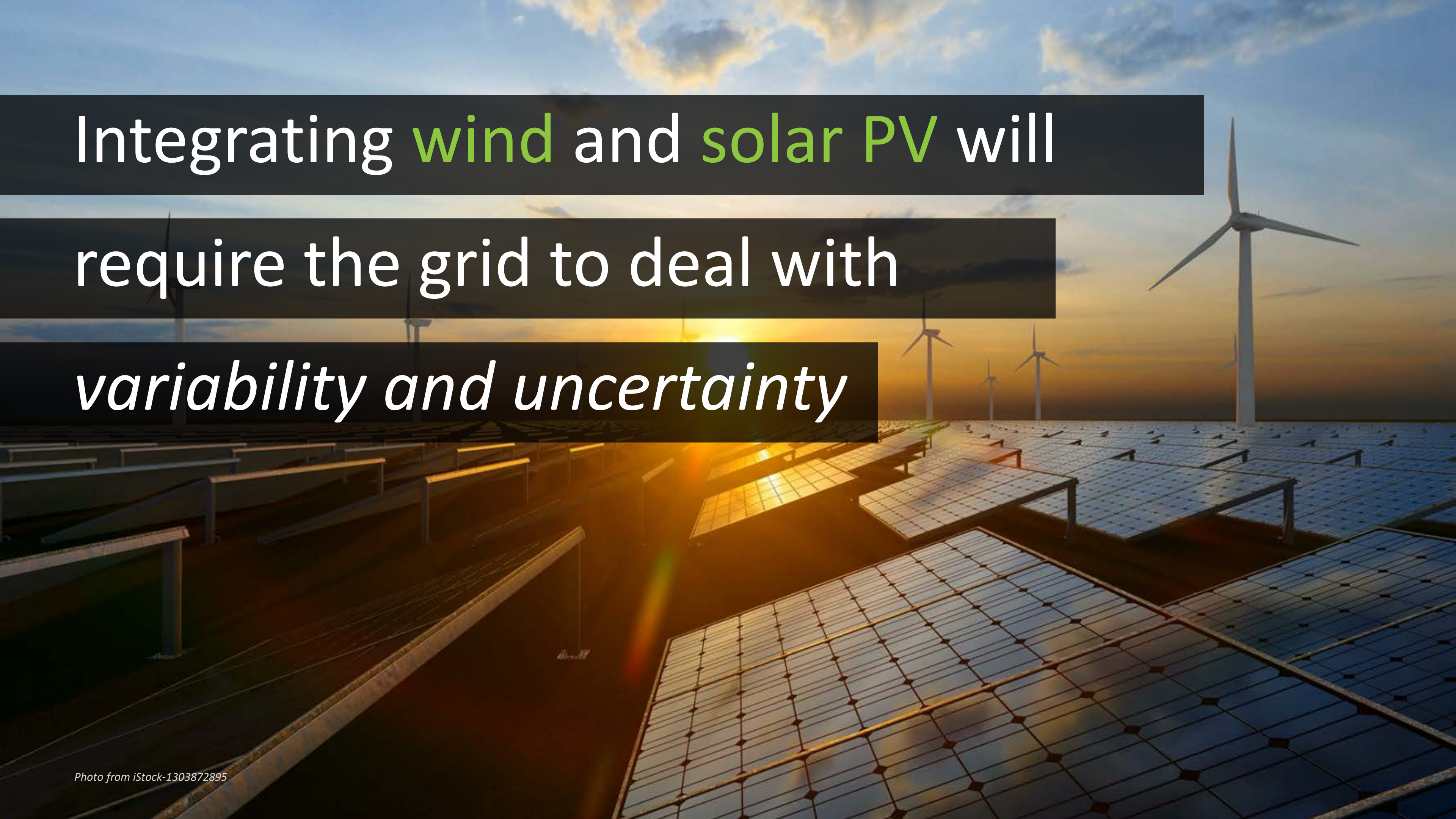
Introduction to Storage

- Increasing solar PV and wind are complementary to storage
- Storage is important to help with grid flexibility
- Currently, we typically have diurnal storage, but in the future, longer-duration storage will become more valuable
- We don't fully understand this value due to limitations in modeling

Storage Futures Study: Possible Deployment of Energy Storage in United States



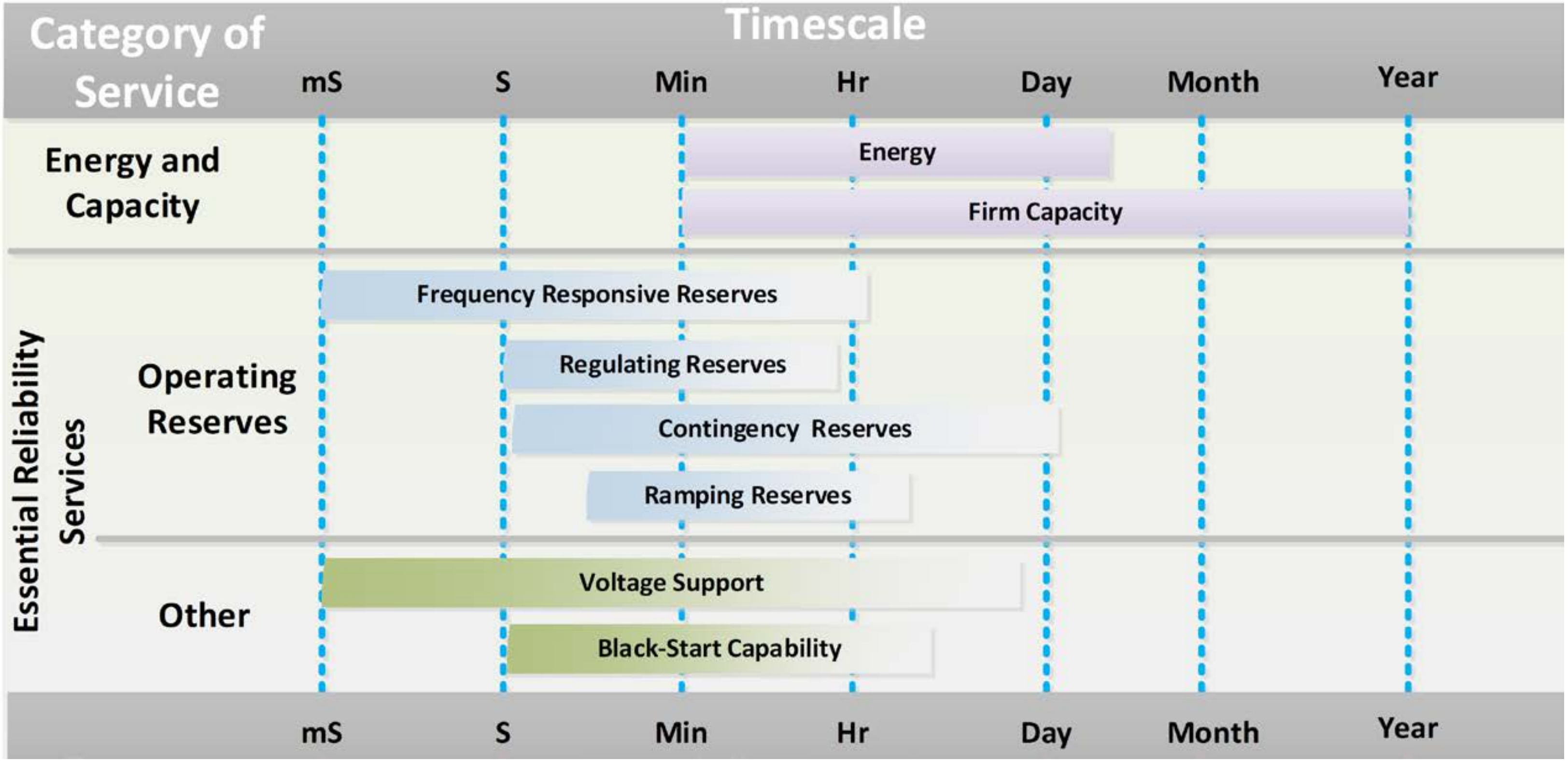
Ref: Frazier, A. Will, Cole, Wesley, Denholm, Paul, Machen, Scott, Gates, Nathaniel, and Blair, Nate. **Storage Futures Study: Economic Potential of Diurnal Storage in the U.S. Power Sector.** United States: N. p., 2021. Web. doi:10.2172/1785688.



Integrating wind and solar PV will require the grid to deal with *variability and uncertainty*

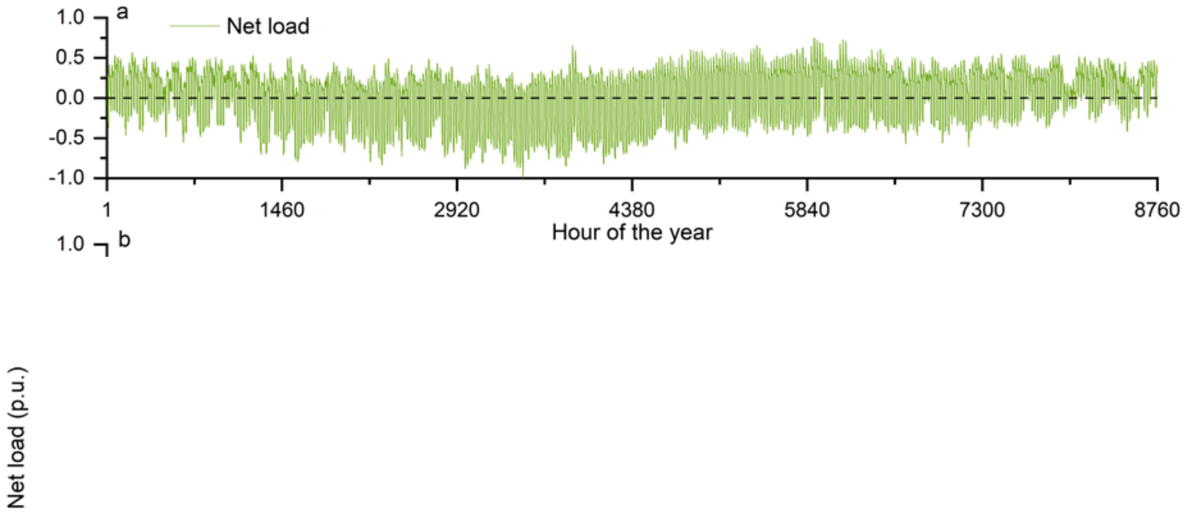
Photo from iStock-1303872895

Main Storage Services Procured in the U.S. Power System.



Denholm, Paul L., Sun, Yinong, and Mai, Trieu T. An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind. United States: N. p., 2019. Web. doi:10.2172/1493402.

The Role of Energy Storage Across Multiple Timescales



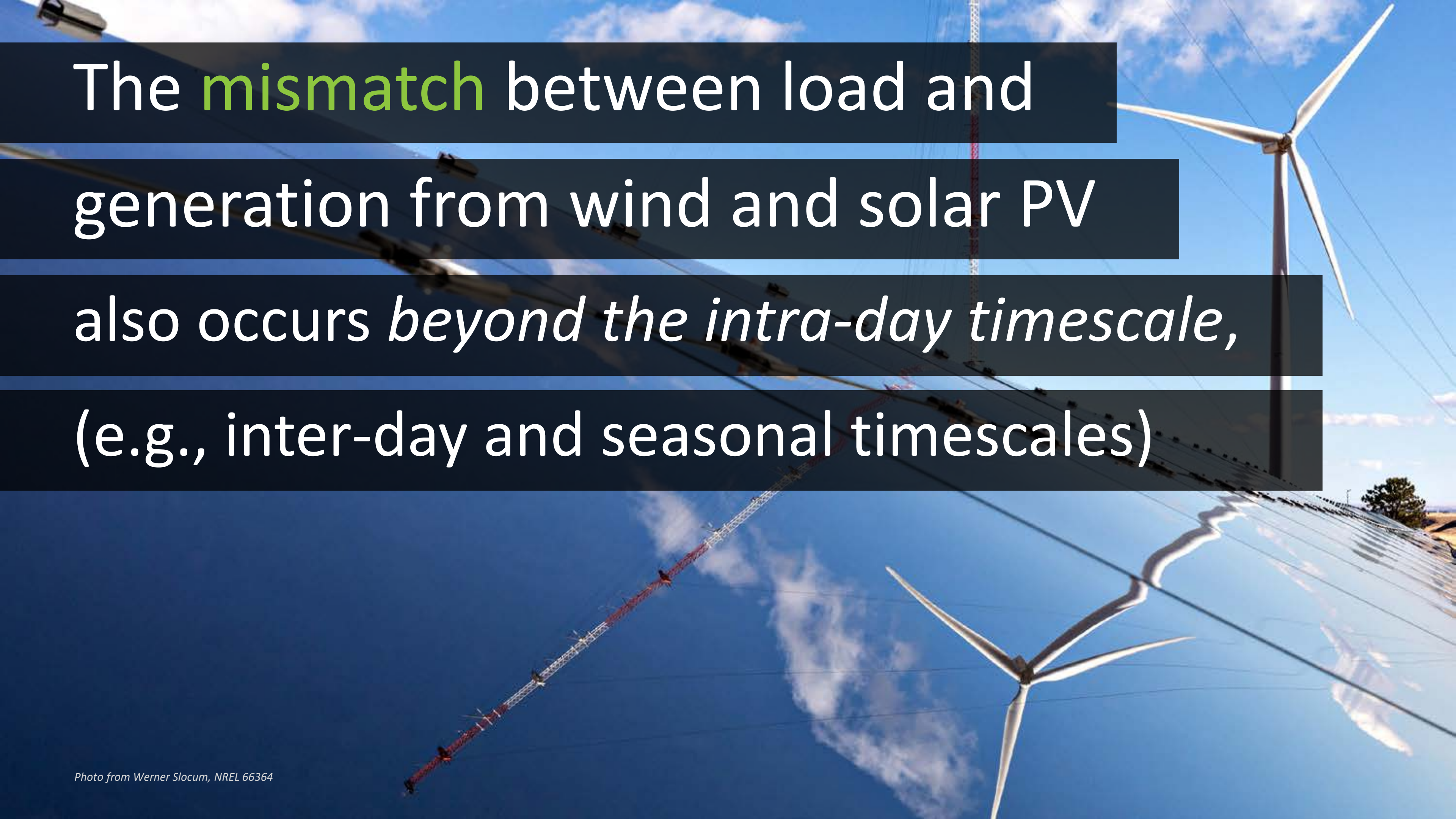
- **Net load**: electricity demand minus total variable renewable energy (wind and solar)
- **Short-duration storage**: up to 10 hours of discharge duration at rated power before the energy capacity is depleted.
- **Long-duration energy storage**: discharge duration >10 hours and <100 hours
- **Seasonal energy storage**: discharge duration >100 hours

Multi-scale energy storage needs for 95% carbon-free CAISO power system
(28.4% wind and 51.5% solar PV energy share)
Ref : Guerra, O. J. [Beyond short-duration energy storage]. Nature Energy 6, 460–461 (2021).

Our grid models *do not adequately* represent the value that long-duration storage may provide

Photo from Dennis Schroeder, NREL 58009

The mismatch between load and generation from wind and solar PV also occurs *beyond the intra-day timescale,* (e.g., inter-day and seasonal timescales)



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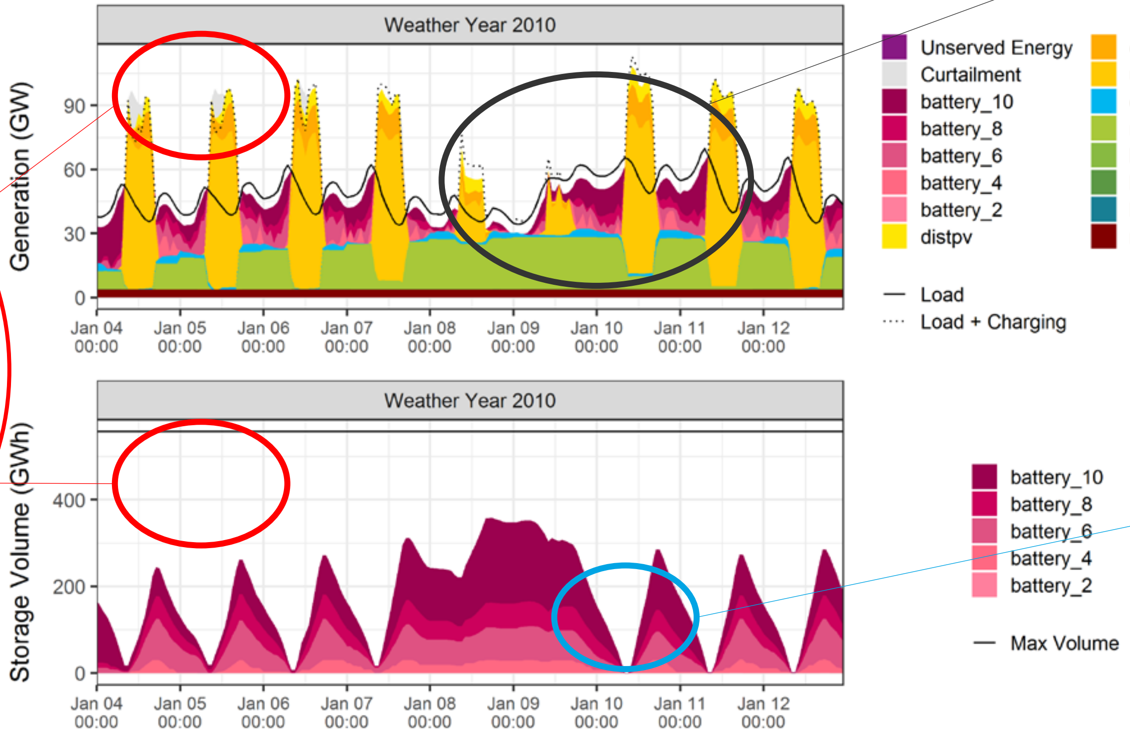
Example of Mismatch



Curtailment of solar earlier in the week instead of storing energy

Low solar days followed by peak system load due to cold snap

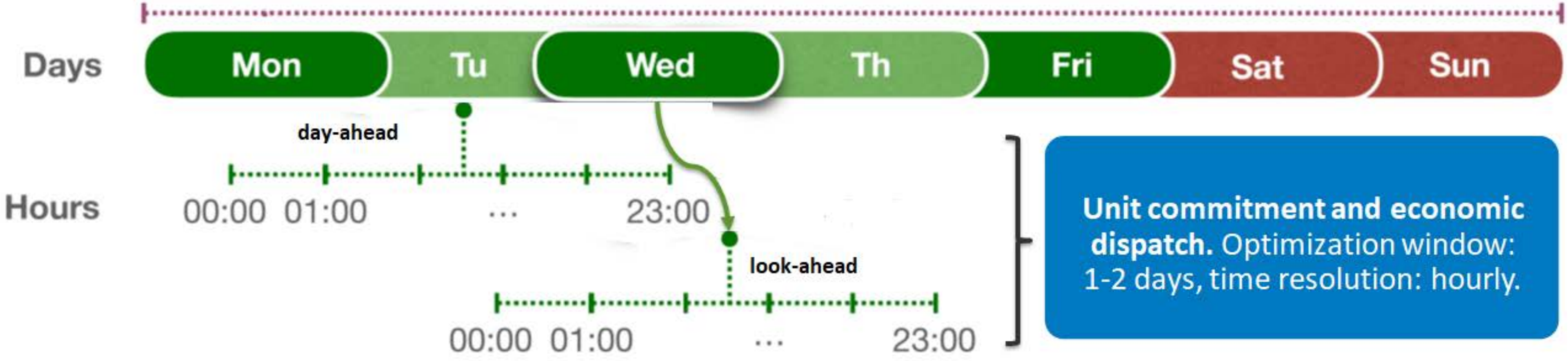
Preference to completely empty storage indicates poor representation of future uncertainty

Figures from NREL

Modeling Methodologies

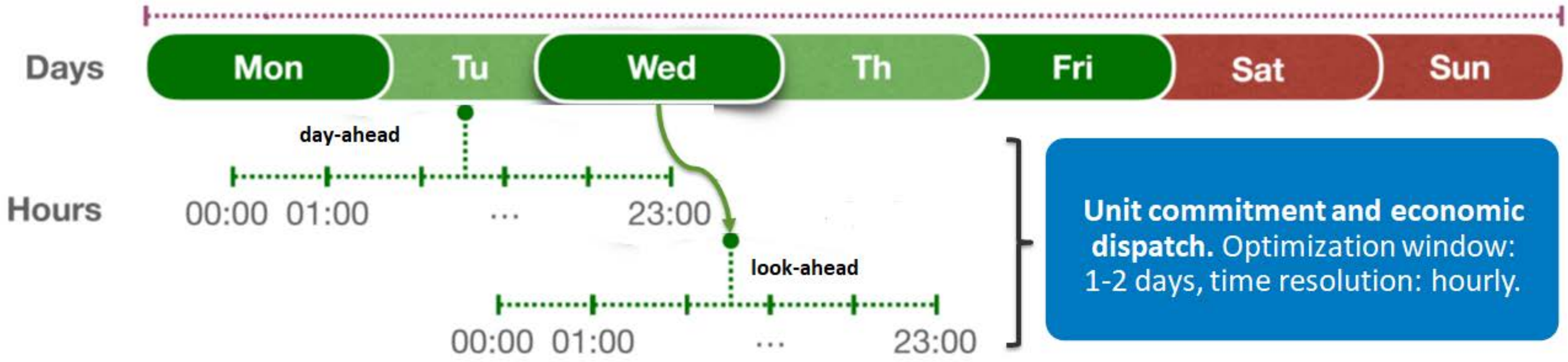
Traditional Modeling Approach for Long-Duration Energy Storage

Optimization window and temporal resolution for unit commitment and economic dispatch models



Traditional (1 day-ahead with hourly resolution): No foresight of conditions past the end of the simulated time frame or optimization horizon, with no value of storing energy for usage outside that timeframe.

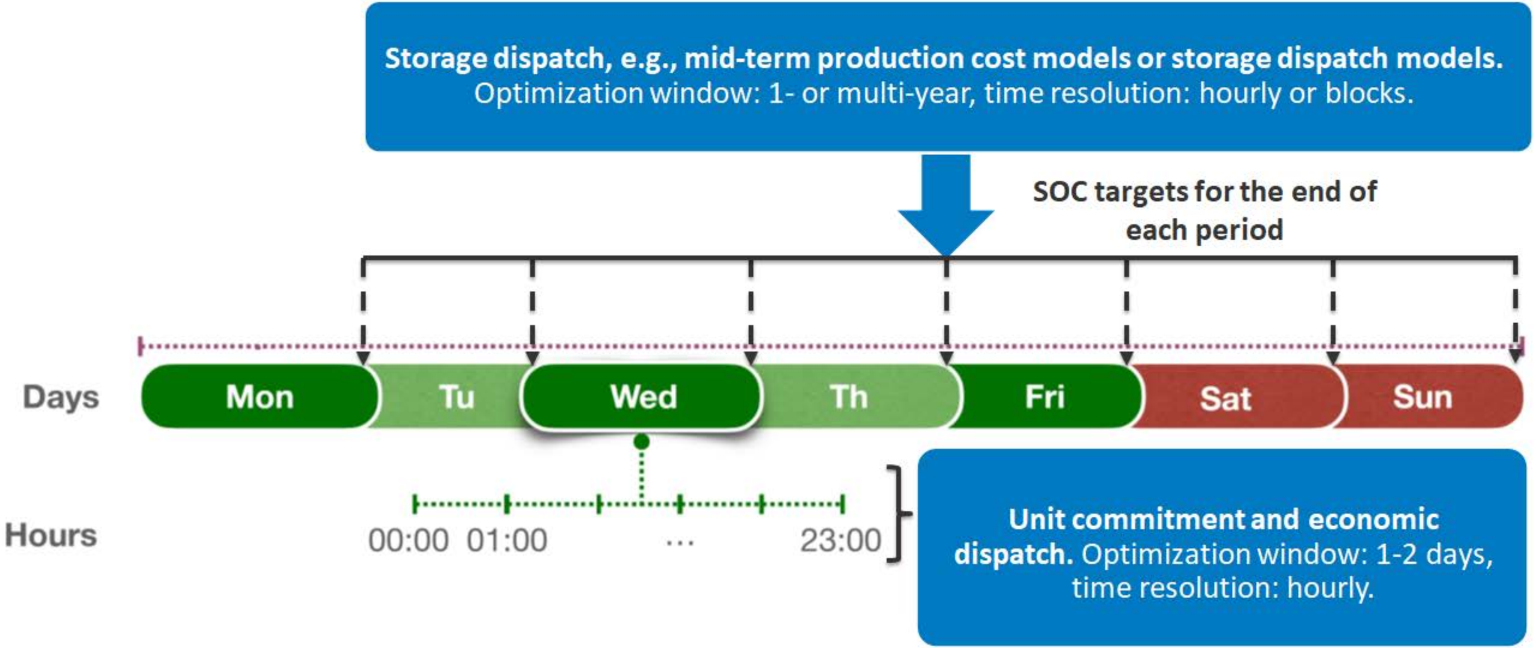
Alternative Approach: Extended Optimization Horizon



Option 1: extend the optimization horizon to consider more than one day at time. For long-duration storage, this might be several days, e.g., 2 days-ahead, or even a week, 1 week-ahead.

Option 2: add some foresight, i.e., look-ahead window. The look-ahead window may be less detailed than the optimization horizon itself to maintain computational tractability and may be optimized at a less resolved time resolution or include fewer constraints.

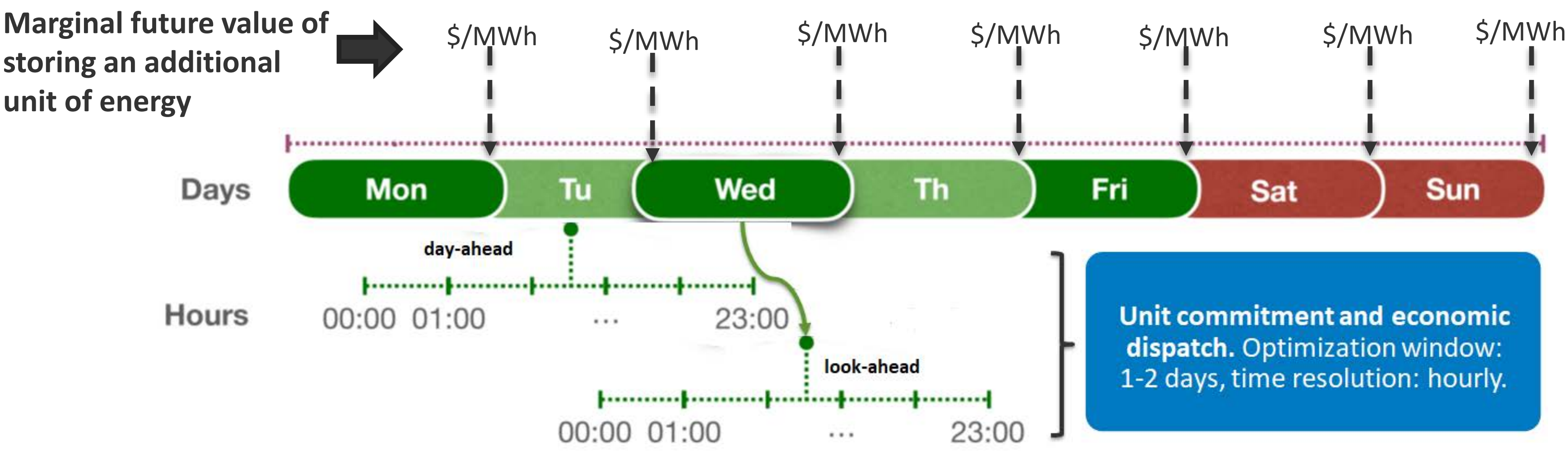
Alternative Approaches: End Volume Targets



Use an exogenous storage dispatch model to optimize the operation of storage technologies. Then, the storage dispatch from the external model is used to input state-of-charge targets for the standard production cost model run.

Preliminary Results: Do not Cite

Alternative Approaches: Stored Energy Value

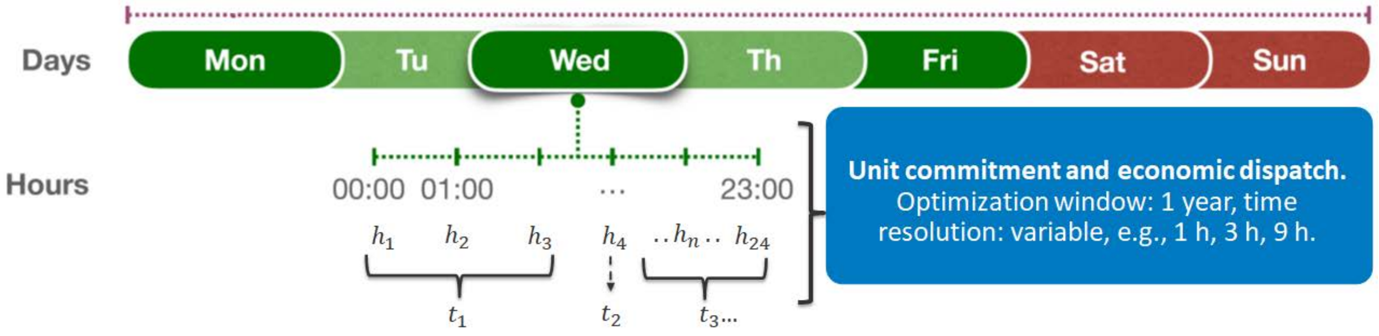


Apply a value X in $/MWh to the stored energy

marginal price of energy < X (accounting for efficiency losses)→ "charge up" to store the cheaper energy

marginal price of energy > X (again accounting for any losses)→ the device would discharge

Alternative Approaches: Variable Time-Step

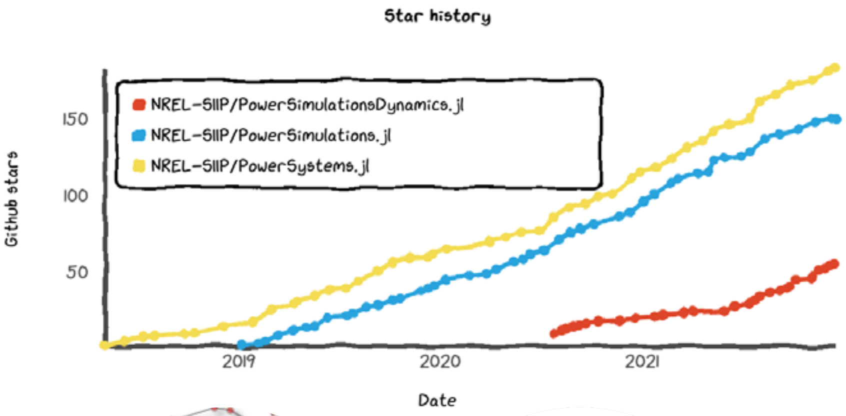


Use a variable time step to reduce the complexity of the unit commitment and economic dispatch problems by aggregating some consecutive hours, while keeping the associated chronology between time steps such that time steps remain in the same sequential order.

To this end, critical periods—periods in which hourly temporal resolution is required, e.g., peak-net-load hour, 4-hour peak period without the peak net load, etc.—are identified a priori and the remaining hours are aggregated based on a given daily sub-sampling strategy.

Selected critical periods could depend on the load, wind generation, and solar PV generation time series or input data, which could vary across scenarios used in production cost modeling studies.

Long Duration Energy Storage Simulations

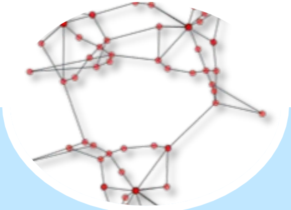


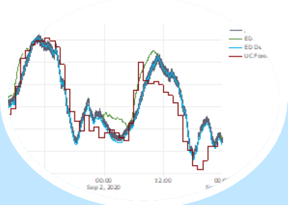
Scalable Integrated Infrastructure Planning for Power Systems

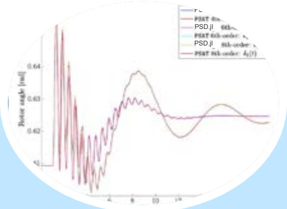
SIIP::Power

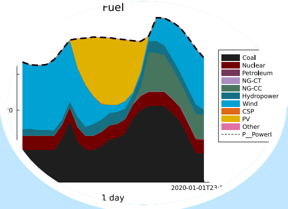
PowerSystems.jl
PowerSimulations.jl
PowerSimulationsDynamics.jl

NREL-SIIP









PowerSystems.jl

Rigorous power system data model:

- Parsers
- Time series
- Quasi-static model data
- Dynamic model data
- Basic power-flow calculations

PowerSimulations.jl

Mathematical formulations and simulation assemblies:

- Quasi-static problems and simulations
- PCM, UC/ED, OPF
- Reserve co-optimization
- AGC/ACE simulation
- Integrated with PowerModels.jl

PowerSimulations Dyanmics.jl

Scalable stability modeling:

- Advanced AD
- Small signal stability
- Full dynamic simulations
- Low inertia simulation capabilities
- Modular separation between device model and numerical integrator

PowerGraphics.jl

Lightweight interactive visualizations:

- Extensible and configurable graphics
- Interactive visualizations with PlotlyJS
- Supports results generated with PowerSimualtions.jl

Extensions

SIIPExamples.jl

PowerModelsInterfaces.jl

HydroPowerSimulations.jl

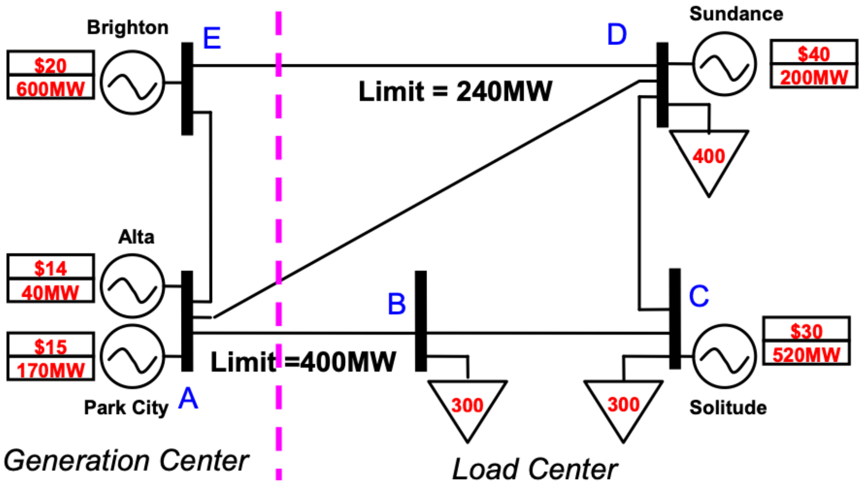
PowerSimulationsDemand Response.jl

ReliablePowerSimulations.jl

PowerSystemCaseBuilder.jl

5-bus Test System

- This is a modified version of the PJM 5-bus test case published in 1999.
- The changes to resource mix to create our base system are listed below.
- The systems include contingency reserves (spinning reserves) and ramping reserves (flexibility reserves)



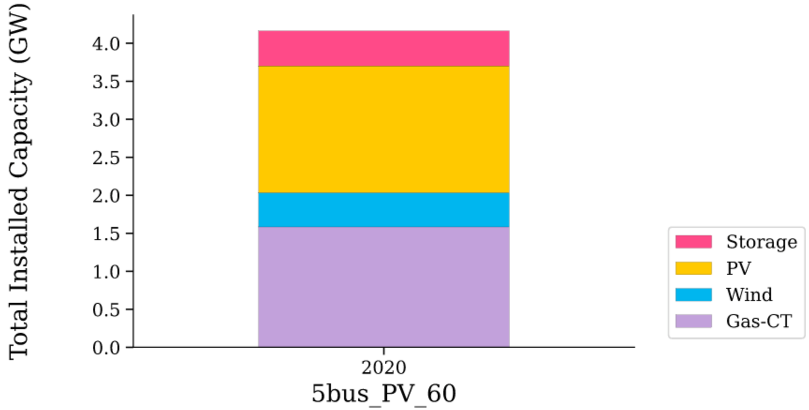
5 bus test systems: 5 buses, 3 load centers, 6 transmission lines

Device Type	Prime Mover	Fuel	Capacity (MW)
Thermal	CT	NATURAL_GAS	1583.9
PVe	PVe		768
Wind	WT		451
Storage	BA		200
Load			1000

5-bus Test System

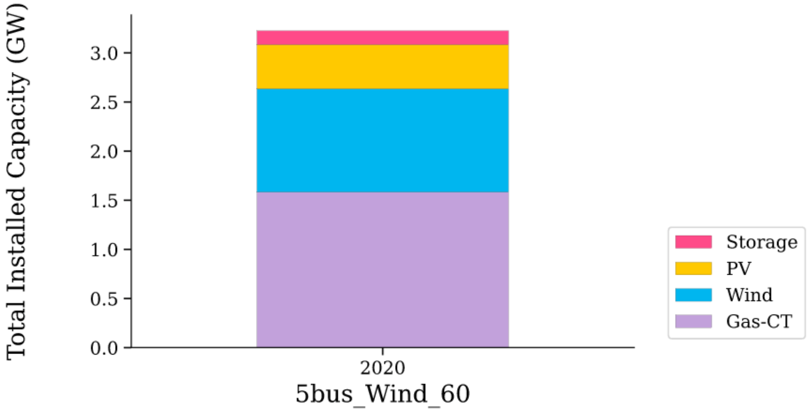
Case: PV dominant 5-bus System

- PV : 1668 MW
- Wind :451 MW
- Long duration Storage
  - Energy Capacity : 3600 MW
  - Power Capacity: 300 MW
- Short duration Storage:
  - Energy Capacity : 600 MW
  - Power Capacity: 160 MW



Case: Wind dominant 5-bus System

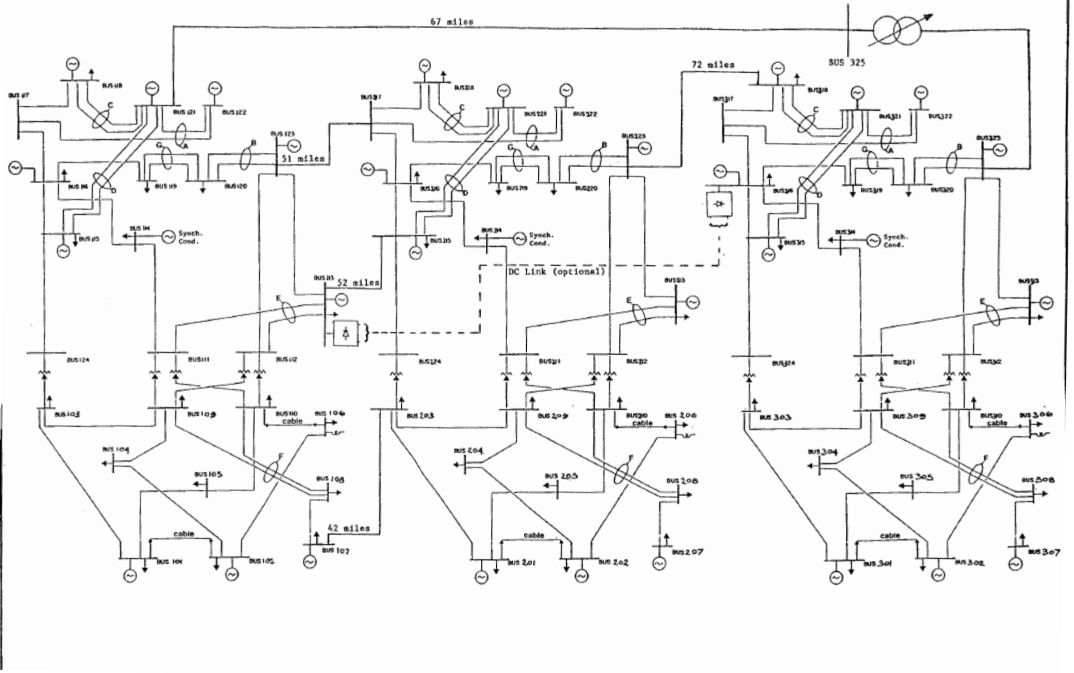
- PV : 570 MW
- Wind : 1058 MW
- Long duration Storage
  - Energy Capacity : 900 MW
  - Power Capacity: 80 MW
- Short duration Storage:
  - Energy Capacity : 120 MW
  - Power Capacity: 60 MW



Reliability Test System (RTS-GMLC)

- The RTS-GMLC is based upon the 1979 and 1996 IEEE Reliability Test Systems.
- We made the following changes to the base RTS system

Device Type	Prime Mover	Fuel	Capacity
Hydro	HY		52.50
Thermal	CT	NATURAL_GAS	1,594.32
Thermal	CC	NATURAL_GAS	3,853.89
Thermal	ST	COAL	2,554.52
Thermal	ST	NUCLEAR	447.21
Solar	PVe		2,507.90
Wind	WT		3,109.00
Storage	BA		0.0
PowerLoad			52.50



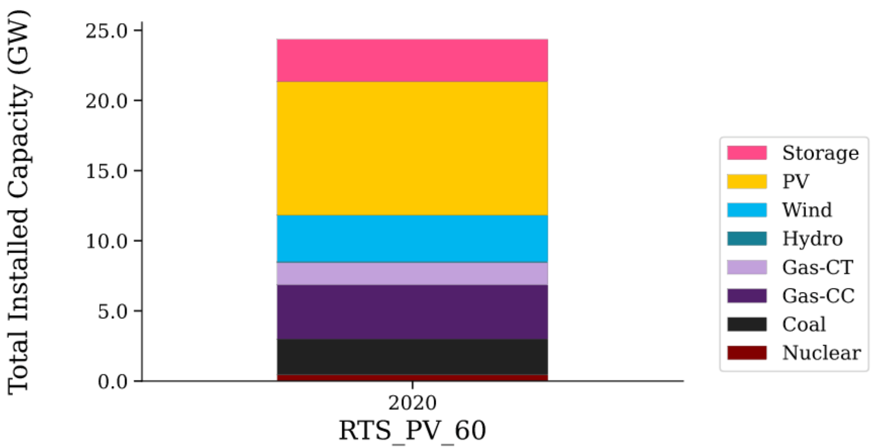
Reliability Test System (RTS-GMLC)

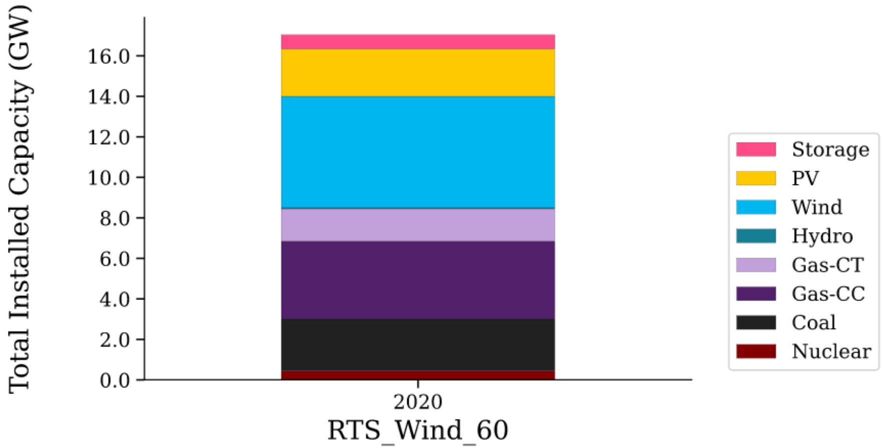
Case: PV dominant RTS

- PV : 9500 MW
- Wind : 3300 MW
- Long duration Storage
    - Energy Capacity : 20000 MW
    - Power Capacity: 2000 MW
- Short duration Storage:
    - Energy Capacity : 4000 MW
    - Power Capacity:1000 MW

Case: Wind dominant RTS

- PV : 2330 MW
- Wind : 5500 MW
- Long duration Storage
    - Energy Capacity : 5000 MW
    - Power Capacity: 400 MW
- Short duration Storage:
    - Energy Capacity : 600 MW
    - Power Capacity: 300 MW





Scenarios

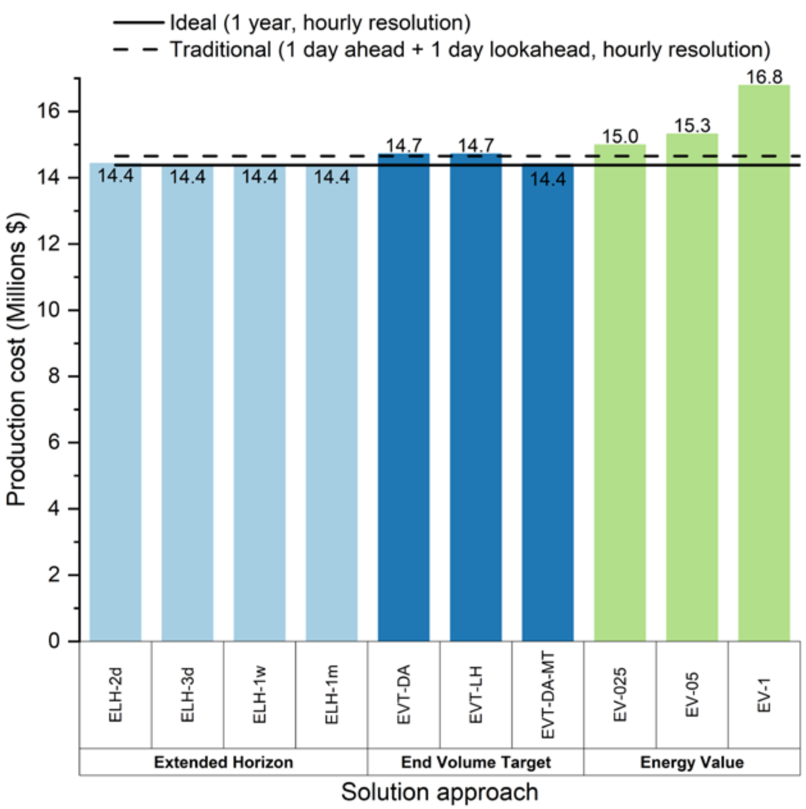
- (VRE60PV) ~60% solar PV-driven VRE mix
- (VRE60W) ~60 wind-driven VRE mix
- Assumptions:
  - Copper Plate transmission model.
  - Perfect foresight for forecasted Load, PVe and Wind.
  - Single Storage device to avoid computational complexity.

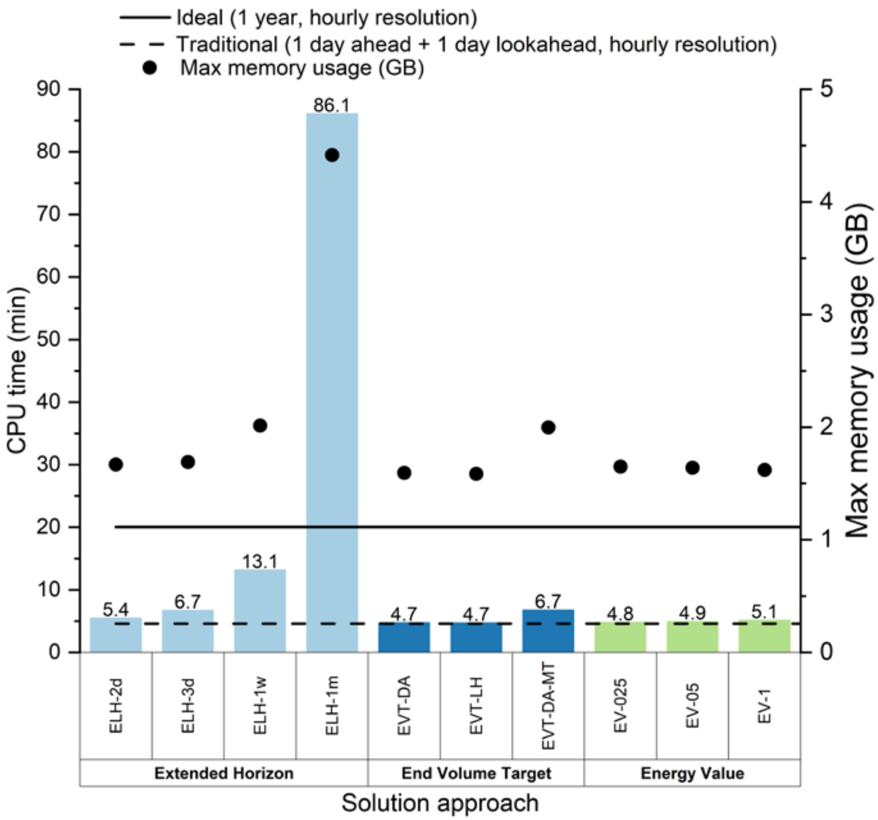
- Metrics to be evaluated: (i) total production cost, (ii) computational time, (iii) memory usage, (iv) VRE curtailment, (v) storage dispatch.

Modeling Long-Duration Energy Storage: Methods and Scenarios

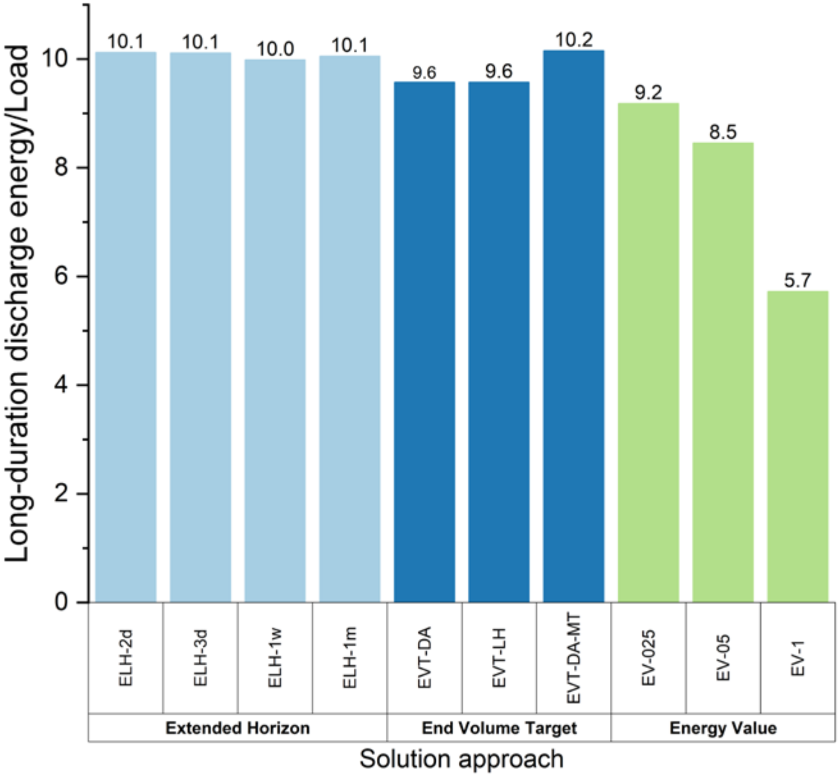
Method	Notation	Optimization horizon	Look-ahead horizon	Parameter/Detail
Ideal	ID	8760 h	-	-
Traditional	TR	24 h	24 h	-
Extended look-ahead	ELH-2d	24 h	48 h (2 days)	-
Extended look-ahead	ELH-3d	24 h	72 h (3 days)	-
Extended look-ahead	ELH-1w	24 h	168 h (1 week)	-
Extended look-ahead	ELH-1m	24 h	720 h (1 month)	-
End volume targets	EVT-DA	24 h	24 h	50% SOC @ hour 24
End volume targets	EVT-LA	24 h	24 h	50% SOC @ hour 48
End volume targets	EVT-DA-MT	24 h	24 h	MT SOC @ hour 24
Energy Value	EV-025	24 h	24 h	$0.25/MWh
Energy Value	EV-05	24 h	24 h	$0. 5/MWh
Energy Value	EV-1	24 h	24 h	$1.0/MWh

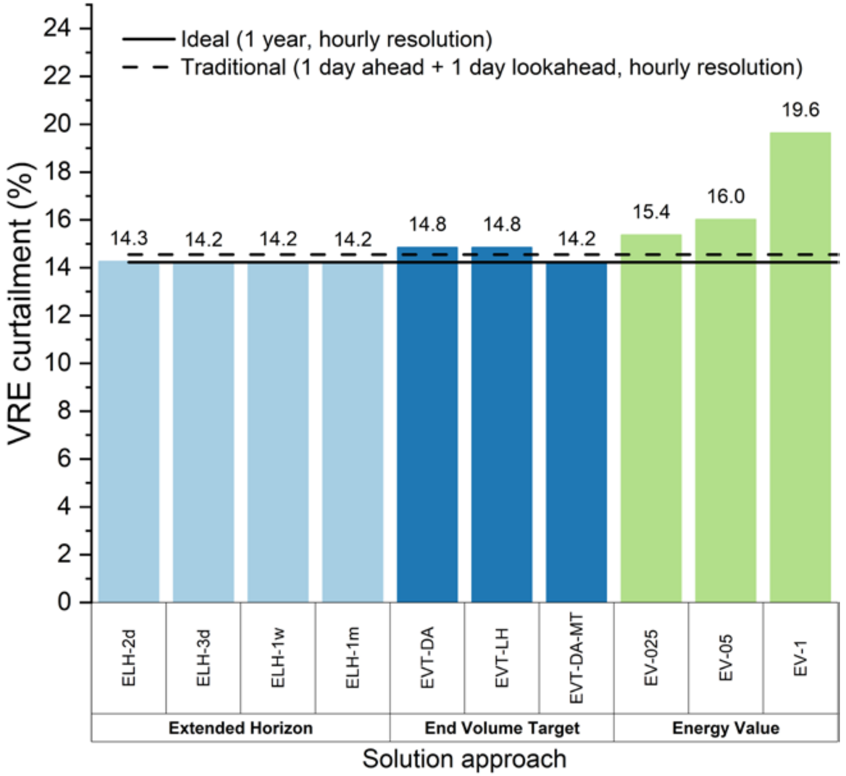
Results: VRE60PV, 5-bus



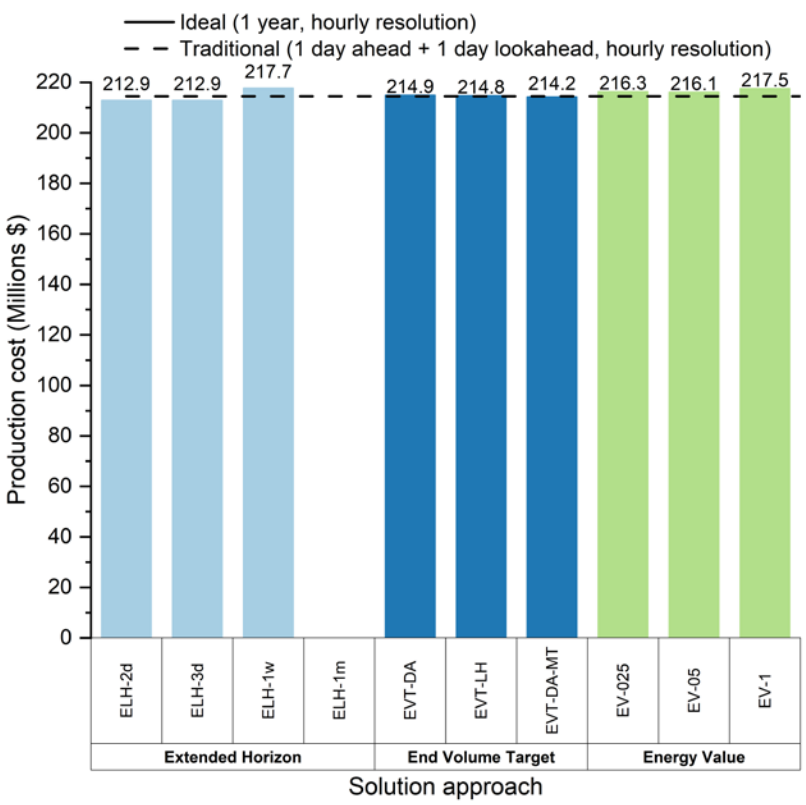


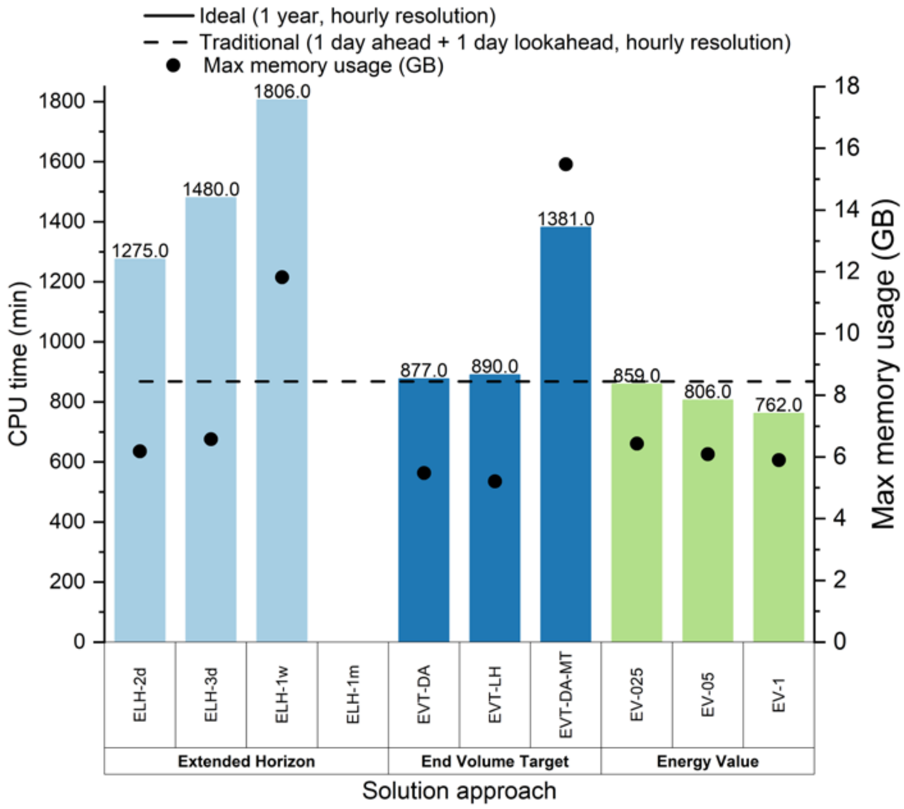
Results: VRE60PV, 5-bus



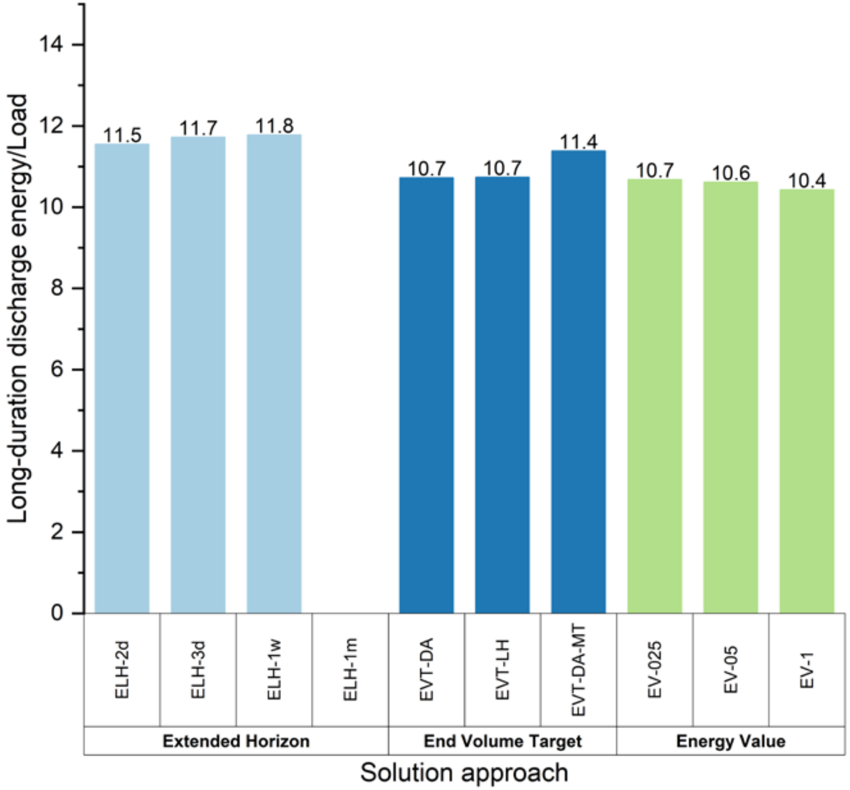


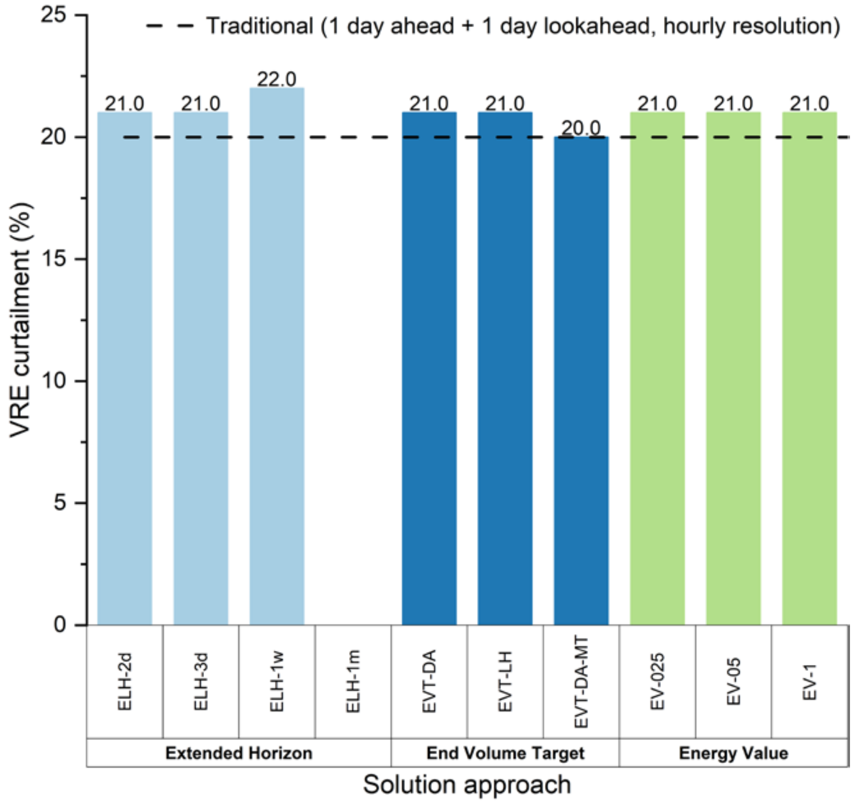
Results: VRE60PV, RTS



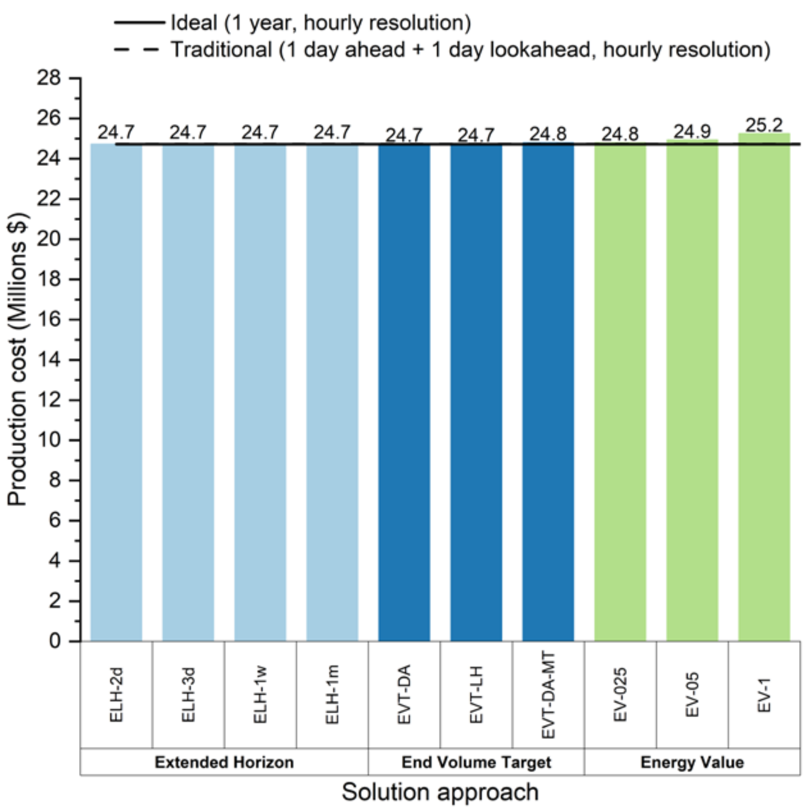


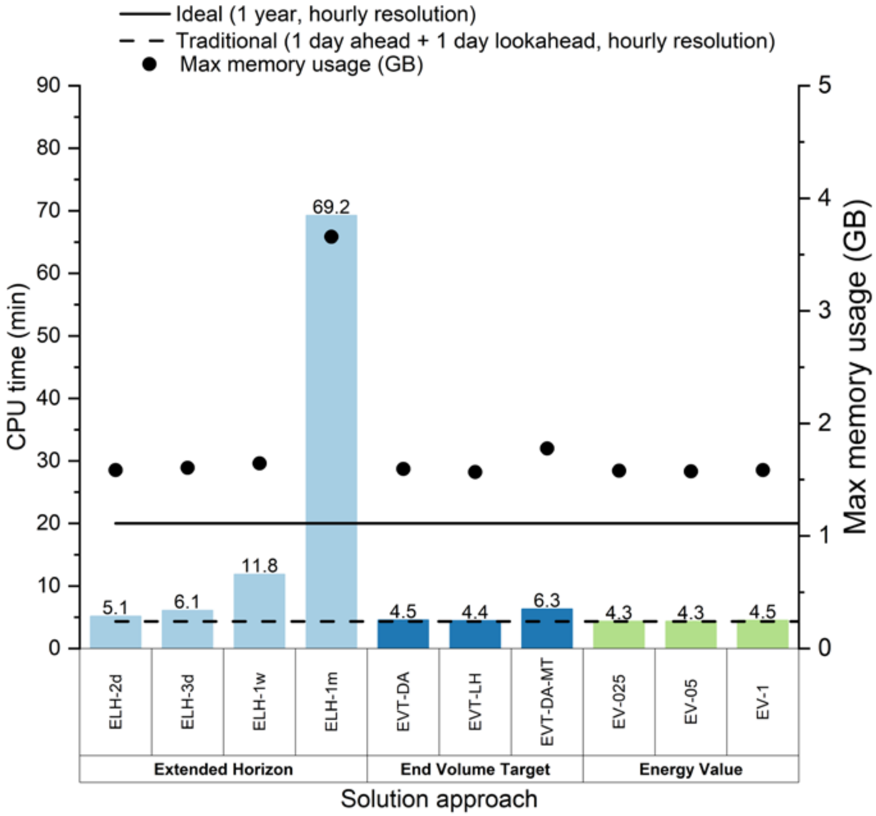
Results: VRE60PV, RTS



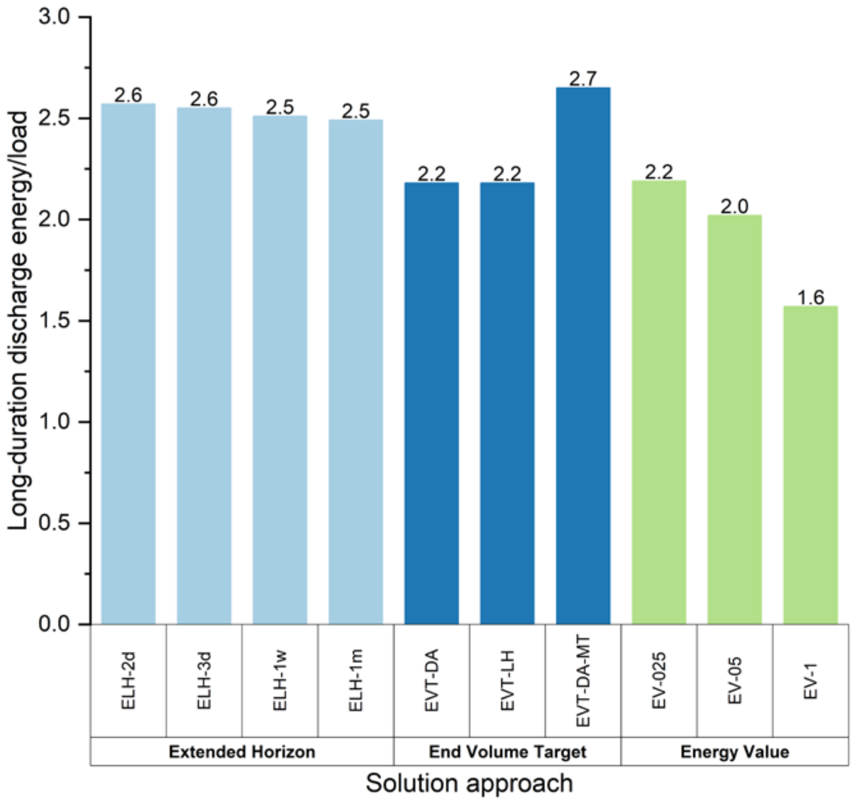


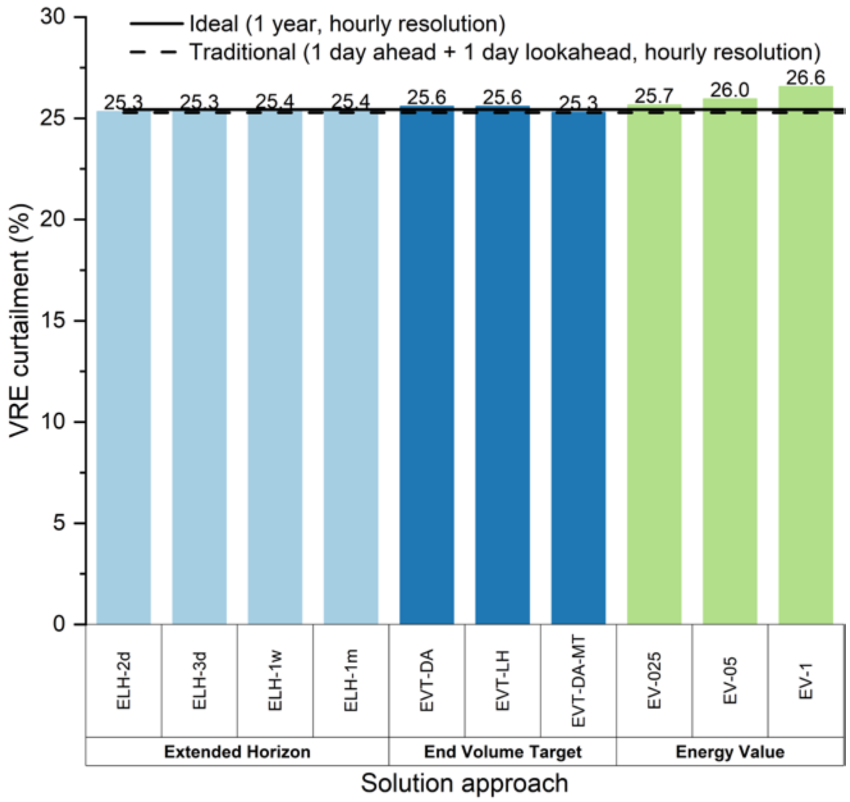
Results: VRE60W, 5-bus



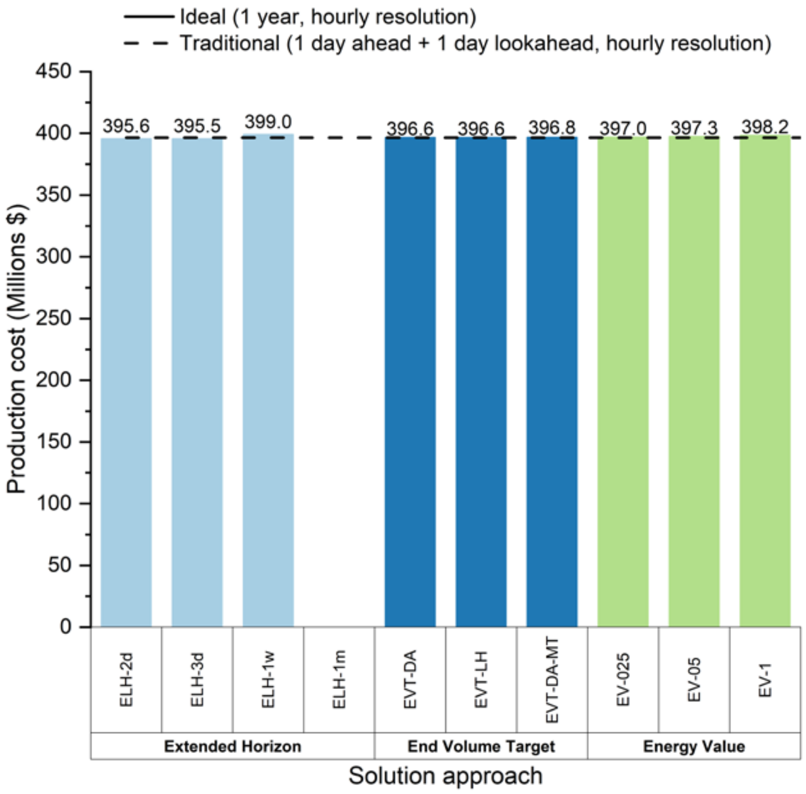


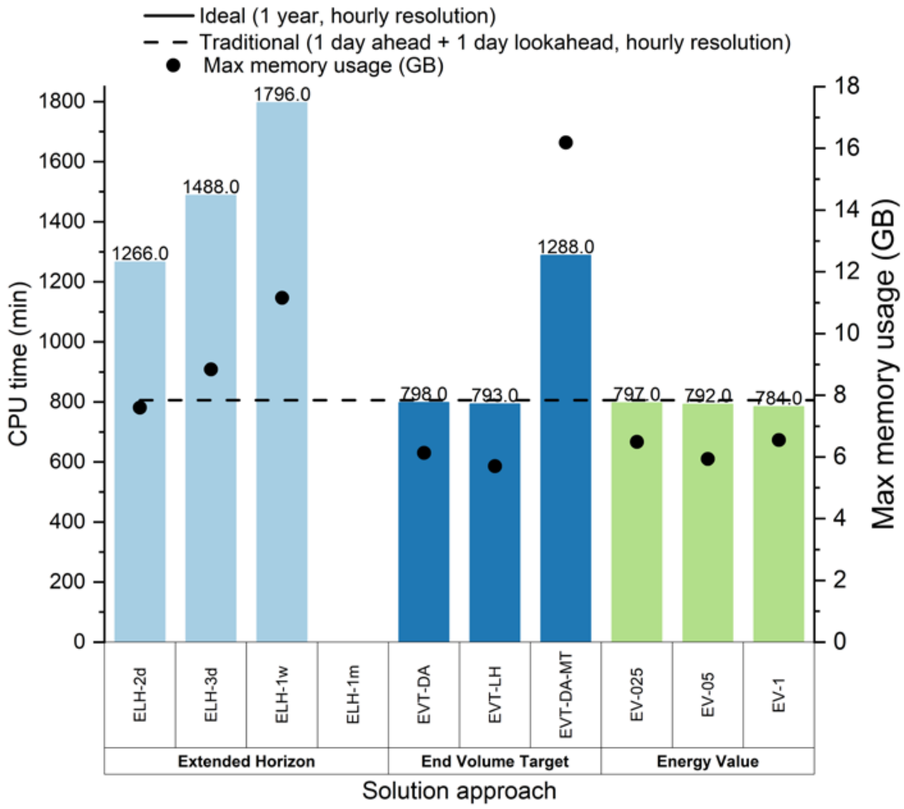
Results: VRE60W, 5-bus



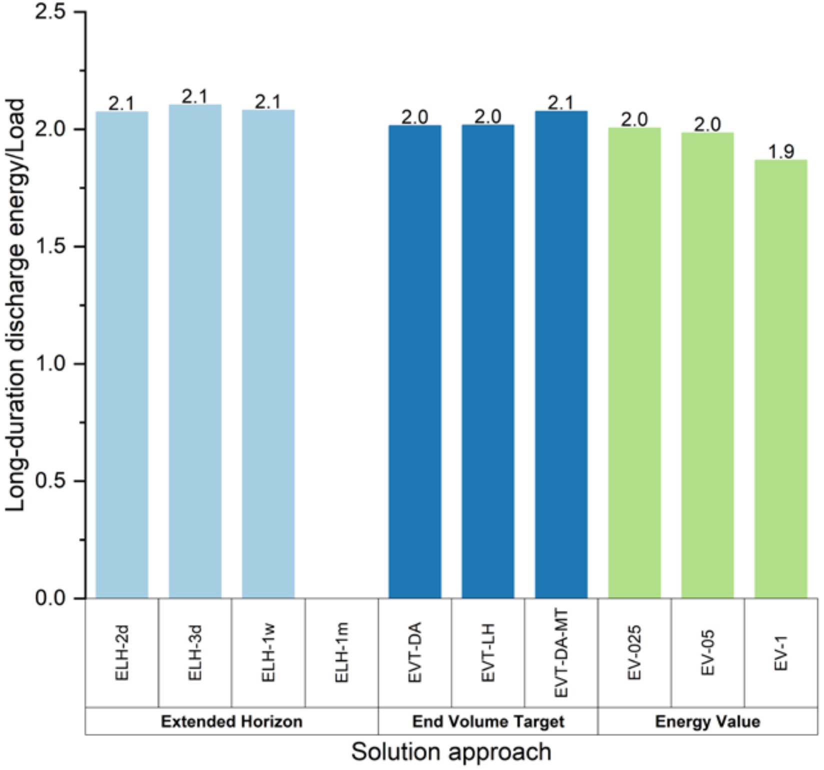


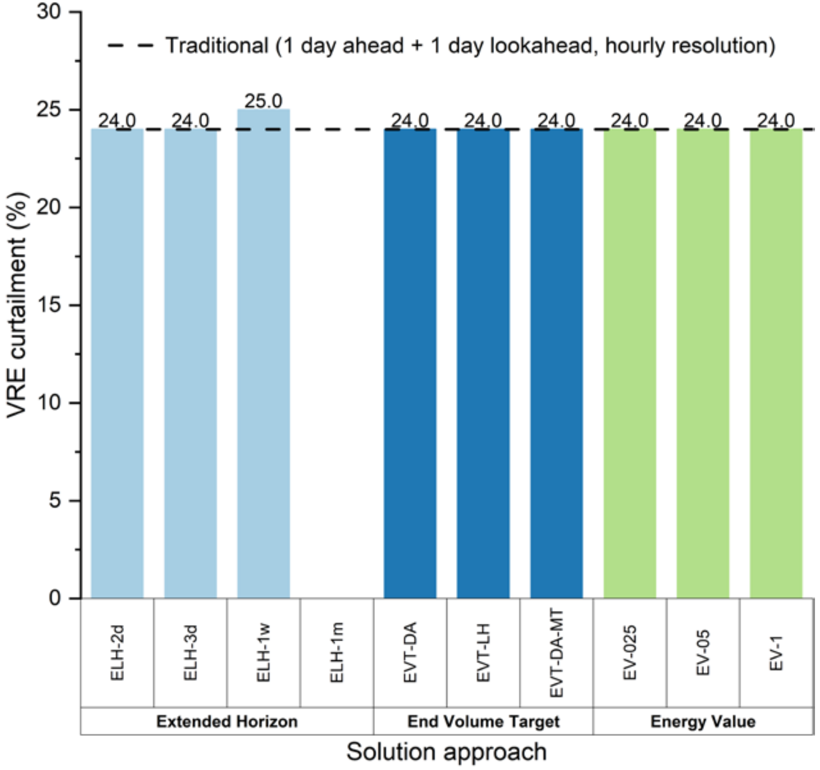
Results: VRE60W, RTS





Results: VRE60W, RTS





Key Takeaways

- Long Duration Energy Storage can provide important flexibility to the power grid as shares of variable renewable energy increase
- Representing these storage devices accurately in modeling tools will be critical for modeling large-scale power systems with significant deployment of long-duration energy storage.
- There frequently is a trade-off between improved representation and computational complexity in modeling methodologies

Next Steps

- Simulate larger and more diverse power systems to further compare methods on more complex models
- Integrate uncertainty and imperfect foresight to better represent real-world conditions
- Analyze reliability metrics for each method and system, identifying how long duration storage modeling methods can impact perceived reliability and improve outcomes during unexpected events.

Questions?

Photo from Dennis Schroeder, NREL 58009

Thank you!

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