Modeling the Value of Existing Pumped Storage Hydro in a High Renewable Future

DE-EE0008783 - Predicting Unique Market Pumped Storage Significance (PUMPSS)

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Key Objectives and Project Setup

<u>Project objectives</u>

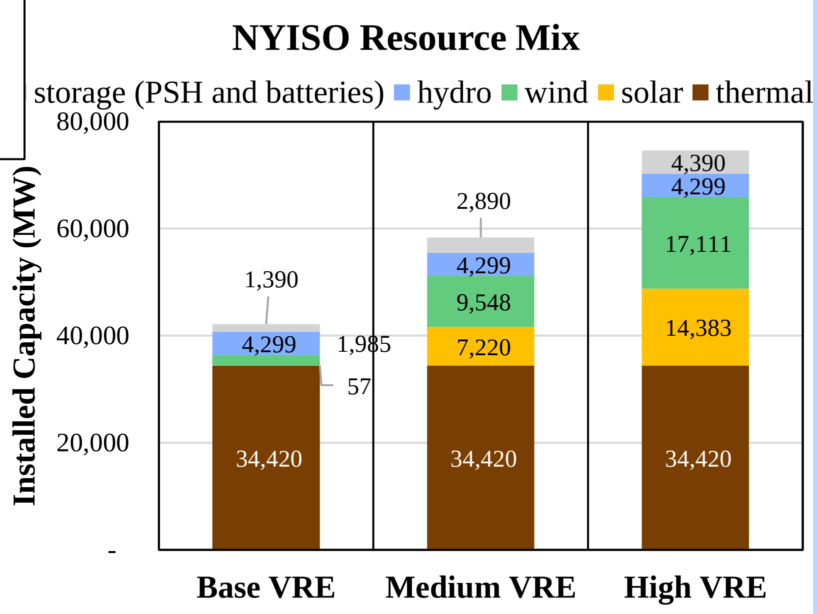
- Identify and demonstrate the current state of the art in modeling of PSH operation in high VRE resource mix scenarios.
- Improve state-of-the-art modeling approaches to better capture value of provision of certain essential reliability services (e.g., ramping, regulation, etc.)
- Examine the value of different PSH technologies/configurations to better understand which technologies and storage durations may provide the most value.
- Study across two different regions (ISO market and vertically integrated) with different resource mixes to see how value may change under different circumstances

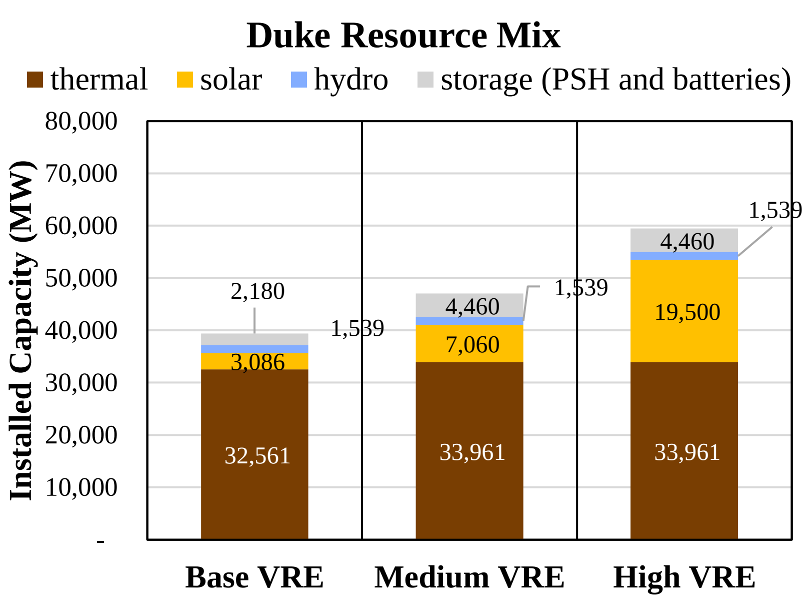
PSO/Enelytix software tool:

- Mixed integer program that co-optimizes energy and ancillary services in nested time intervals
- Allows for advanced treatment of uncertainty and variability, flexible technologies, and ancillary services

Pumped storage characteristics	Duke	NYISO
Capacity (MW)	2,180	1,160
Reservoir size (MWh)	45,000	14,000
Efficiency	80%	71%

Note: The NYISO PSH plant is more constrained than the Duke ones, including modeling of capacity market obligations, assigned turbine and pump on/off periods, and hurdle rate costs.

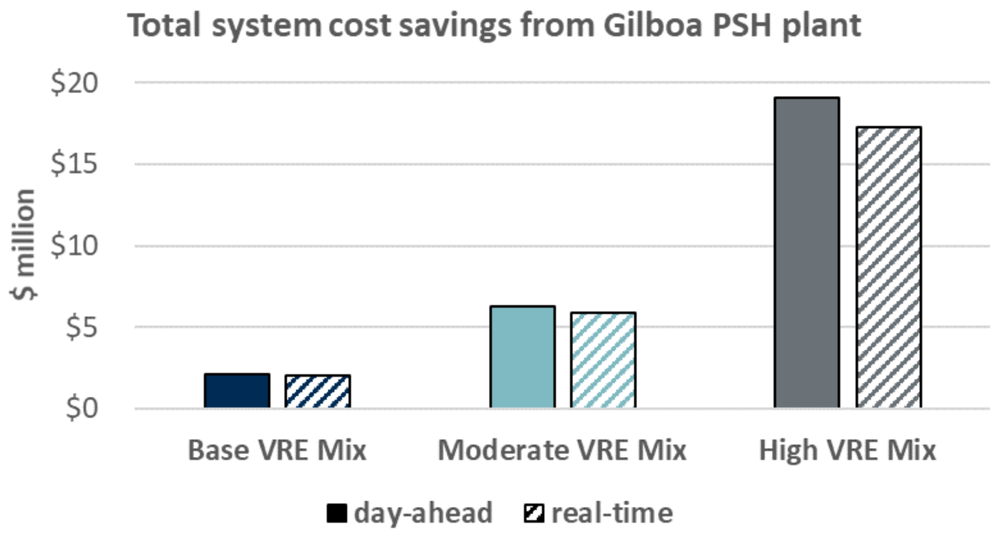


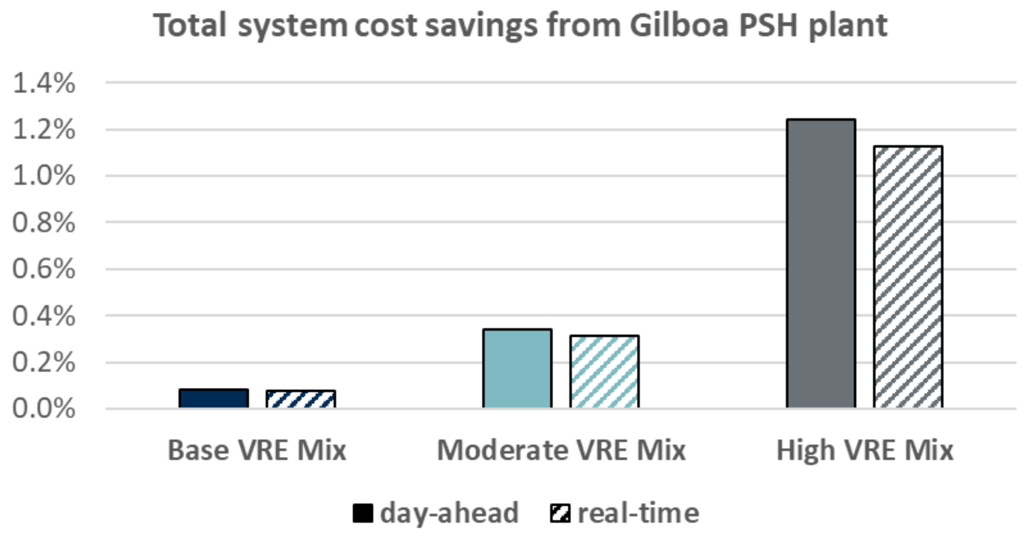


Renewable penetration scenarios (NYISO)

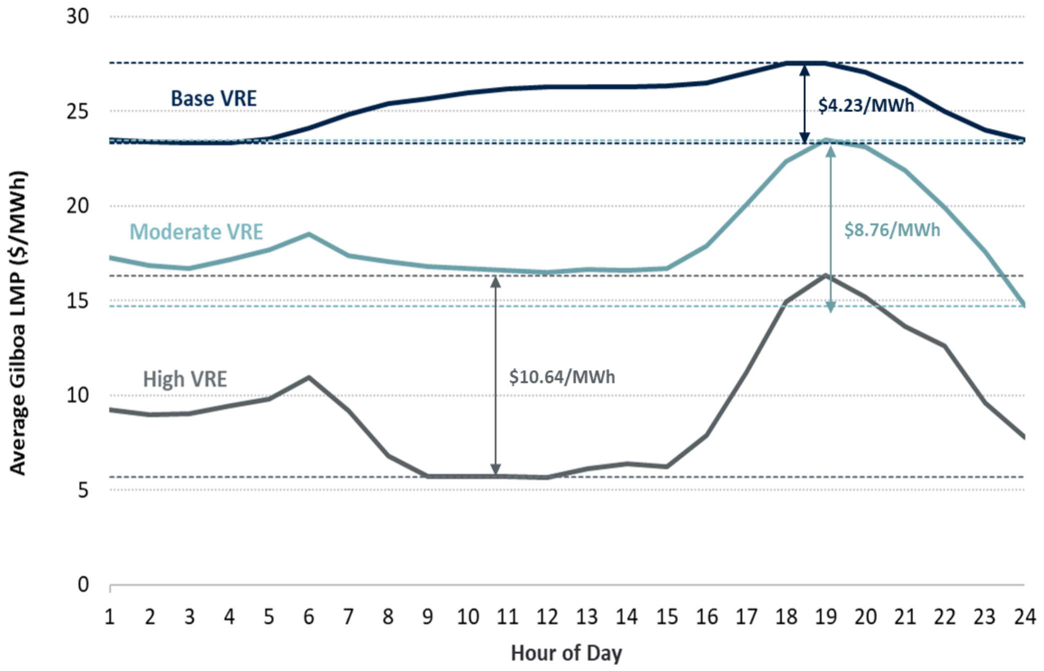
The benefit in the DA cycle is slightly larger than in the RT cycle, because Gilboa dispatch is optimized in the DA cycle, and its schedule fixed in the RT cycle.

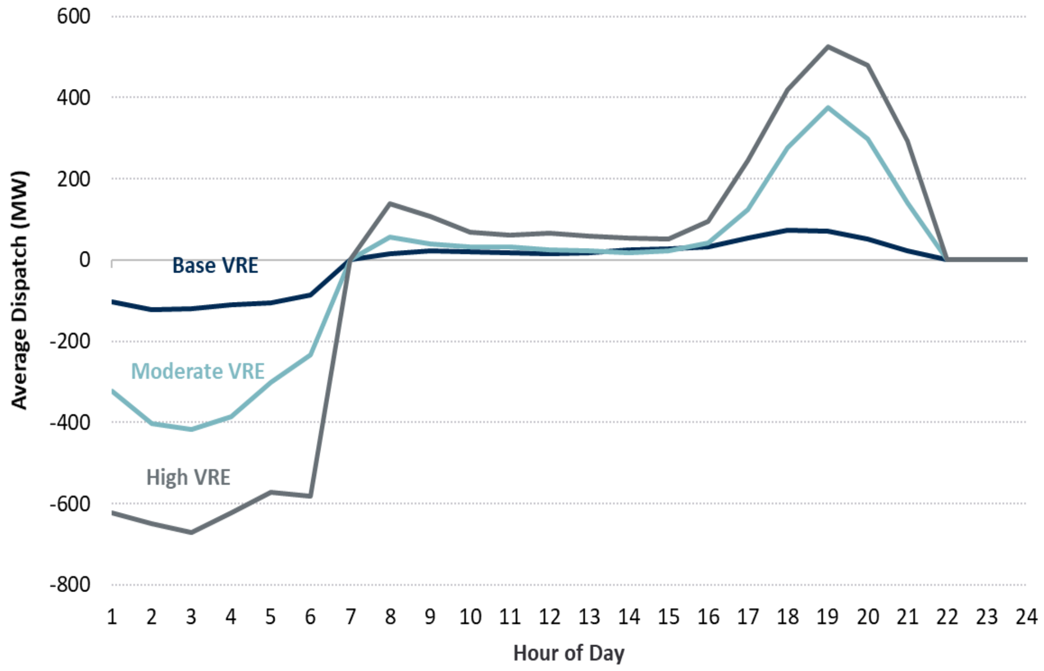
	DA Benefit of Gilboa Plant ($million)	RT Benefit of Gilboa Plant ($million)	DA Benefit of Gilboa Plant (%)	RT Benefit of Gilboa Plant (%)
Base VRE Mix	$2.12	$2.02	0.08%	0.08%
Moderate VRE Mix	$6.25	$5.92	0.34%	0.31%
High VRE Mix	$19.05	$17.27	1.24%	1.13%





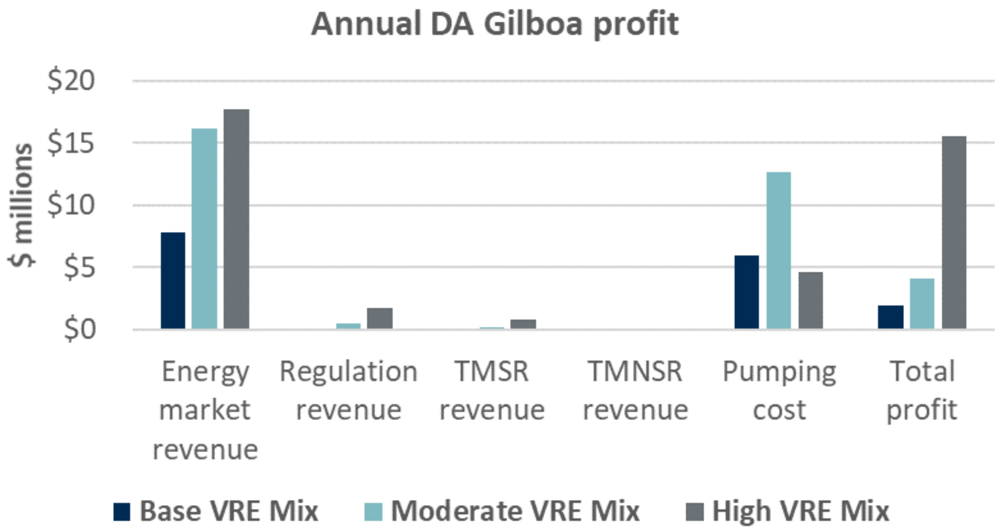
Renewable penetration scenarios (NYISO)





As renewable penetration increases, the price separation between on-peak and off-peak spot prices increases, which leads to increased cycling of the Gilboa PSH units, and thus increased system benefit.

Renewable penetration scenarios (NYISO) – Gilboa profit



Both energy and ancillary service revenues increase with the increased penetration of VERs.

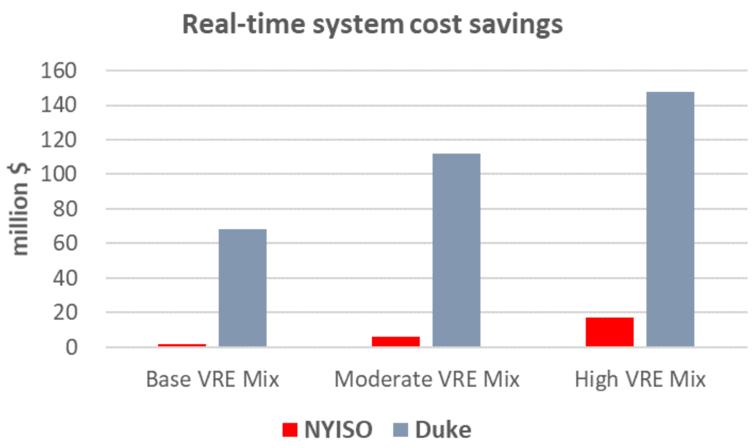
Revenues from the provision of energy service are much larger than those obtained from the provision of ancillary services. This is because of the relatively much lower requirement for ancillary services compared to energy in the system.

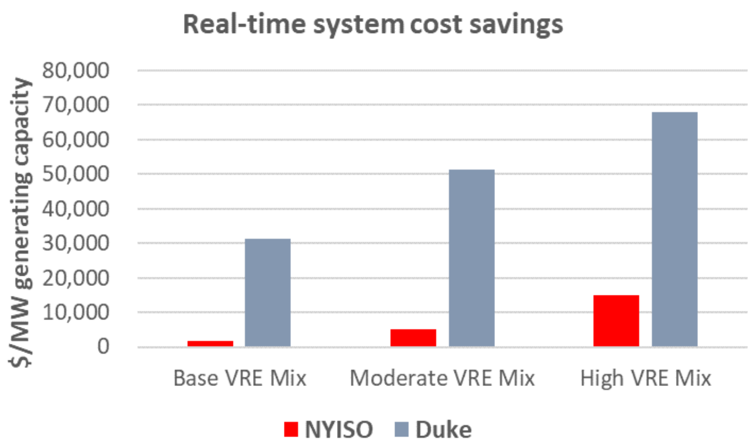
$$PSH\ Value\left(\frac{\$}{MWh}\right) = \frac{total\ system\ operating\ cost\ savings}{annual\ Gilboa\ generation}$$

PSH Value	Base VRE Mix	Moderate VRE Mix	High VRE Mix
Day-ahead	12.3 $/MWh	11.4 $/MWh	19.6 $/MWh
Real-time	11.8 $/MWh	10.8 $/MWh	17.7 $/MWh

The average PSH value to the system operator is lower in the moderate VRE mix case than in the base VRE mix case. This is because although the total system operating cost savings are larger than in the base VRE mix case, the annual Gilboa generation is significantly larger.

Comparison between systems

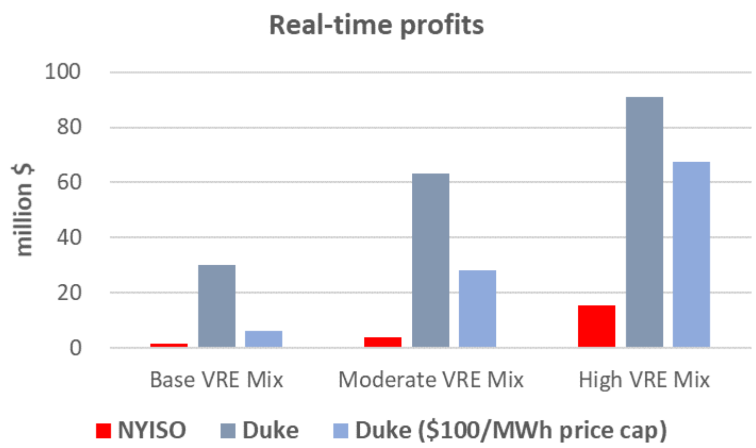




The PSH plants in the Duke system show much larger system cost savings than the Gilboa plant. This is due to a variety of factors, including differences in regional capacity buildout, storage assumptions/constraints and system modeling assumptions.

When benefits are calculated on a per $/MW PSH generating capacity basis, the difference in impact between the two systems is reduced somewhat, due to the difference in PSH capacities between the two systems.

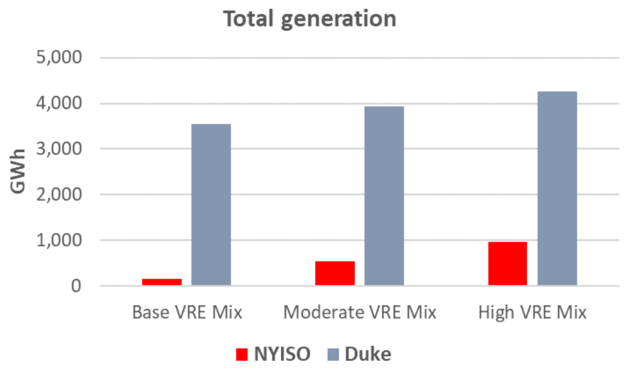
	Duke	Gilboa
Capacity (MW)	2,180	1,160
Reservoir size (MWh)	45,000	14,000
Efficiency	80%	71%

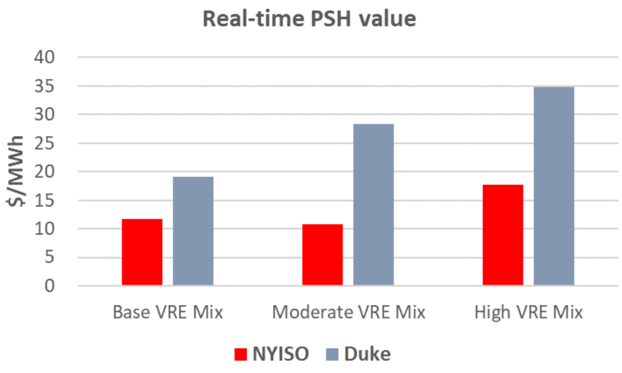


Duke PSH plant profits are significantly larger than Gilboa profits. A handful of very high-priced hours have an outsized impact on plant profit levels in the Duke system.

Comparison between systems

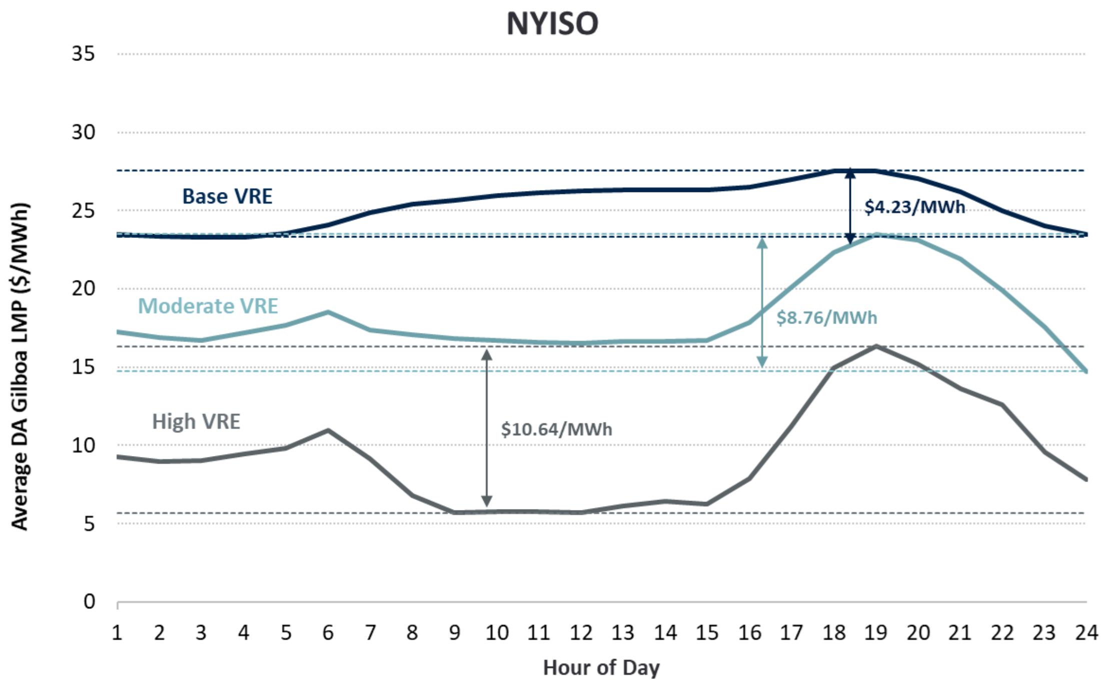
$$PSH\ Value\left(\frac{\$}{MWh}\right) = \frac{total\ system\ cost\ savings}{annual\ generation}$$

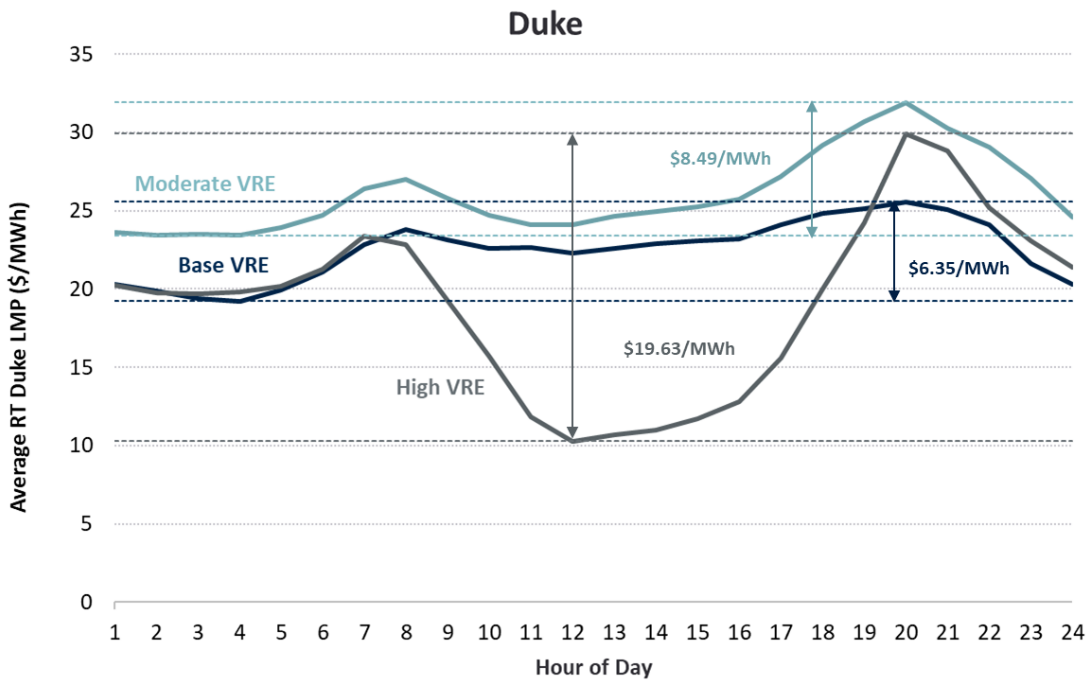




The Duke PSH plants are dispatched much more frequently than the Gilboa plant. This is due to several factors:

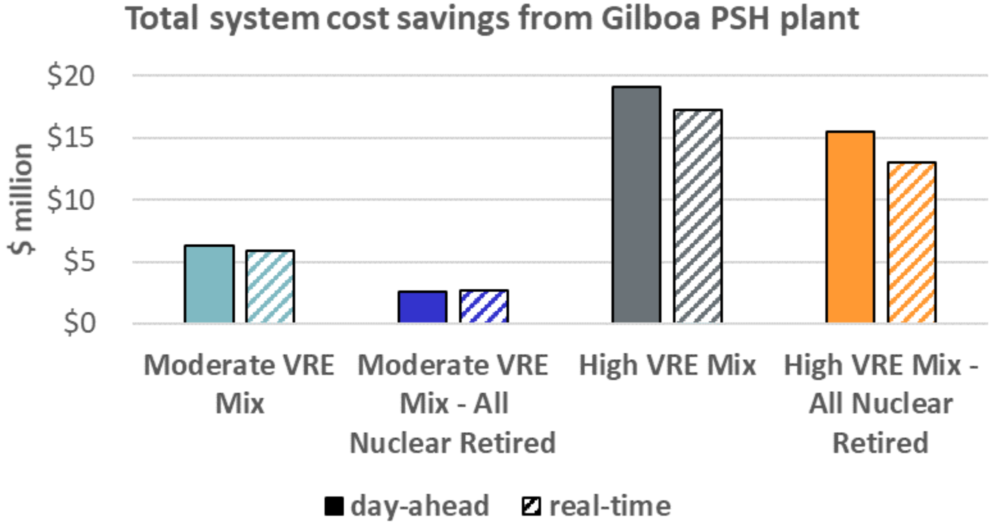
- On average, the daily price separation is larger in the Duke system than it is in the NYISO system
- The Duke plants have an 80% efficiency, whereas the Gilboa plant has a 71% efficiency
- The Duke plants are modeled without any hurdle rates, whereas the Gilboa plant is modeled with a $1/MWh hurdle rate.

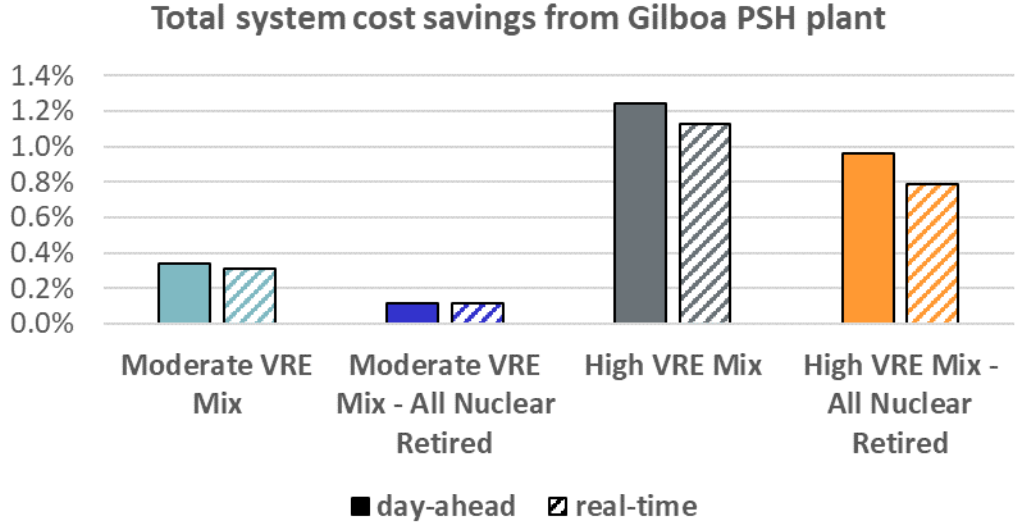




Nuclear buildout sensitivities (NYISO)

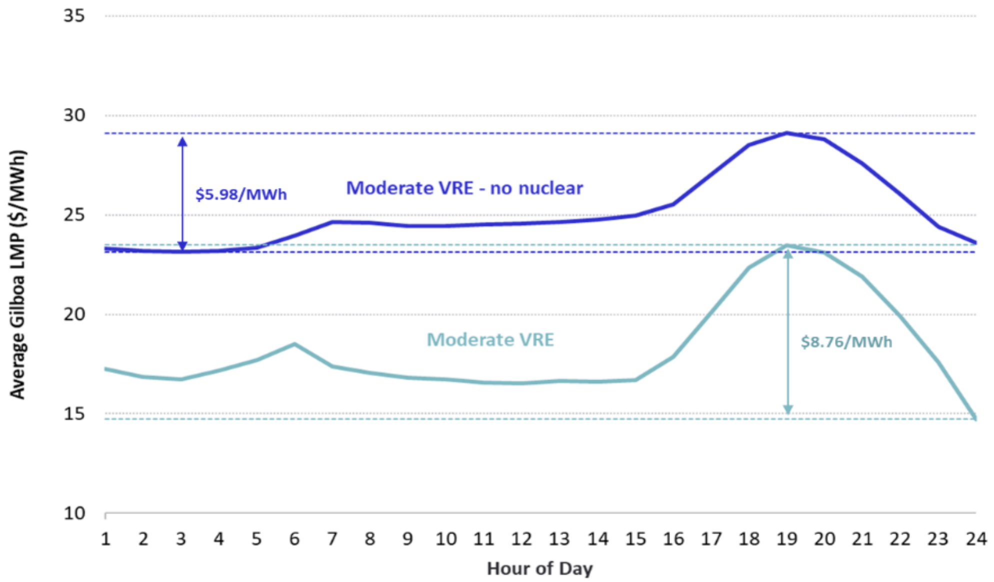
	DA Benefit of Gilboa Plant ($million)	RT Benefit of Gilboa Plant ($million)	DA Benefit of Gilboa Plant (%)	RT Benefit of Gilboa Plant (%)
Moderate VRE Mix	$6.25	$5.92	0.34%	0.31%
High VRE Mix	$19.05	$17.27	1.24%	1.13%
Moderate VRE Mix - All Nuclear Retired	$2.60	$2.67	0.12%	0.12%
High VRE Mix - All Nuclear Retired	$15.49	$13.06	0.96%	0.79%

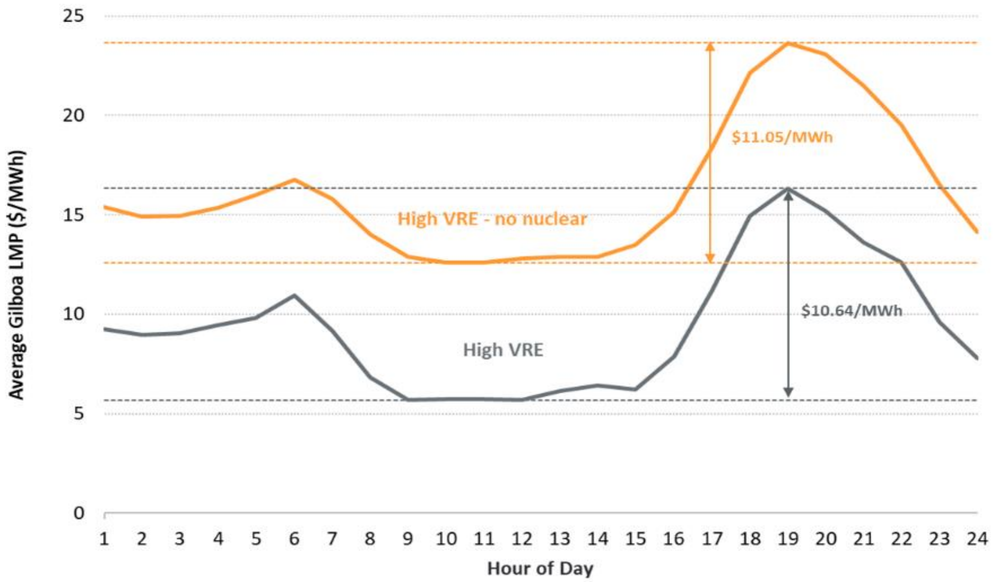


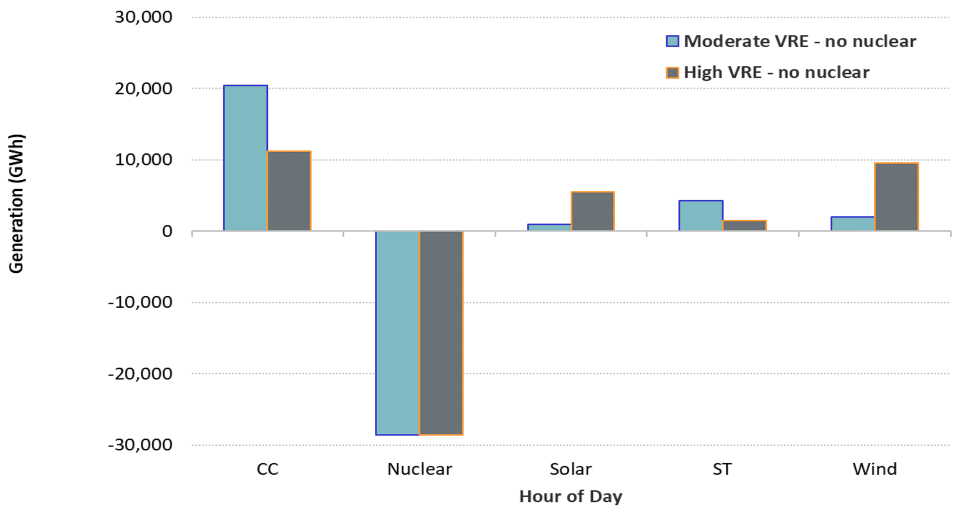


Retiring all nuclear capacity in the system decreases the benefits from the Gilboa plant. This effect is more pronounced in the moderate VRE sensitivity than in the high VRE sensitivity. This is because Gilboa dispatch is greatly reduced when nuclear is retired in the moderate VRE sensitivity, but only slightly reduced in the high VRE sensitivity. The daily price separation is greatly reduced when nuclear is removed in the moderate VRE sensitivity but is largely unaffected in the high VRE sensitivity.

Nuclear buildout sensitivities (NYISO)







In the moderate VRE case, combined cycle generation primarily replaces nuclear generation, while in the high VRE case, previously curtailed renewable generation replaces approximately half of the nuclear generation, with combined cycle generation replacing the other half. This difference leads to a decrease in price separation in the moderate VRE case, and a slight increase in the high VRE case.

Technology sensitivities (NYISO)

	Increased DA Benefit from High VRE Mix ($)	Increased RT Benefit from High VRE Mix ($)
Modified C Rate	$4,319,734	$3,535,271
Variable Speed PSH - Original Pmin (48%)	$1,068,156	$493,819
Variable Speed PSH - 25% Pmin	$1,626,985	$882,973

The 'Modified C Rate' sensitivity shows the impact of increasing the PSH capacity, while keeping the tank storage size the same.

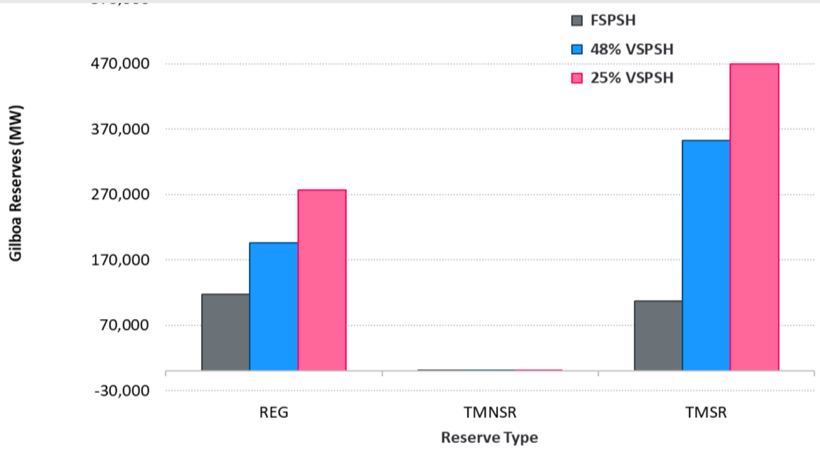
The increased unit capacity allows turbines to generate more during high-priced hours and pumps to pump more during low-priced hours, which increases the benefit of the Gilboa PSH plant by **23%** in the DA cycle and **20%** in the RT cycle.

This offsets the shorter duration showing that, at least for the system under study, capacity is a key value proposition.

Case	Generator Max (MW)	Pump Max (MW)	Reservoir Cap (MWh)	Gen Duration (h)	Pump Duration (h)
Main Case	290	310	14,000	12.1	11.3
Higher Capacity/Shorter Duration Case)	437.5	467.7	14,000	8	7.5

In the 'variable speed PSH' sensitivities, the pumping units can operate across a range of outputs, allowing them to provide reserves even when pumping. Two options are considered: Pmin = 48% of Pmax and Pmin = 25% of Pmax.

Dispatch in the energy market does not change significantly, but reserve provision increases substantially, increasing the benefit of the Gilboa PSH plant by **6-9%** in the DA cycle and **3-5%** in the RT cycle.

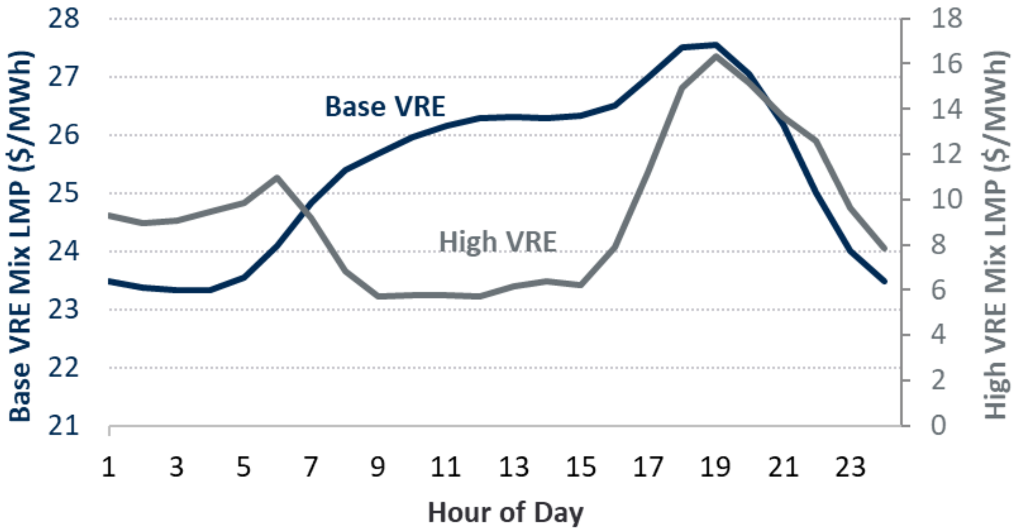


PSH operations sensitivities (NYISO)

	Increased DA Benefit from High VRE Mix ($)	Increased RT Benefit from High VRE Mix ($)
Allow for Real-Time Re-Dispatching	$0	$683,175
No Pumping or Generating Schedule Restrictions	$18,587,061	$12,972,705

In the sensitivity allowing for real-time re-dispatching, real-time Gilboa dispatch can deviate from the day-ahead schedule when the opportunity cost is large enough.

This allows Gilboa the flexibility to respond to changes in real-time system conditions. The system benefit of the Gilboa PSH is **unchanged** in the DA cycle but increases by **4%** in the RT cycle.



The 'no pumping or generating schedule restrictions' sensitivity allows generators and pumps to be fully optimized by the solver, and to operate at any hour of the day, where previously turbine operation was restricted from 7am to 9pm, and pump operation from midnight to 6am.

Without restrictions, the Gilboa charging times change dramatically, with pumping units operating during the middle of the day to take advantage of the LMP 'duck curve' brought about by the high renewable penetration level.

The system benefit of the Gilboa PSH plant increases by **98%** in the DA cycle and **75%** in the RT cycle.

Key Insights

1 Accurately modeling PSH behavior presents several challenges

- Increased computational complexity
- Determining the appropriate storage parameters

2 The benefits of PSH were larger in the Duke system than the NYISO system

- Due to regional capability buildout differences, differing storage assumptions/constraints and varying system modeling assumptions

3 Economic impacts of PSH increase with variable renewable penetration

- Cost savings increased x4 (Duke) or x9 (NYISO) in the high VRE case compared to the base case
- Factor of 18 in NY if no pumping or generating schedule was imposed

4 Resource mix, technology assumptions and operations all impact value

- Adding batteries, removing nuclear reduce value
- Higher PSH capacity with same duration (lower C-rate) improved value in NY
- Variable speed pumping increased value, particularly for reserves
- Removing restrictions on when PSH operates nearly doubled the value (NY)

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