



ORDC Supplemental Information

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Forced Outages Uncertainty

- In addition to load, wind, and solar forecast error uncertainty, the probability that thermal generators experience forced outages also increases the Probability of Reserves Falling Below the Minimum Reserve Requirement (PBMRR)
- While it is true that the MRR is based on the failure of the largest unit in the system, the probability that any of the rest of units experiences a forced outage is small, but non-zero
- Therefore, the PBMRR should account for these non-zero probability of units experiencing a forced outage
 - This represents a change from what PJM presented at last meeting based on feedback received from stakeholders

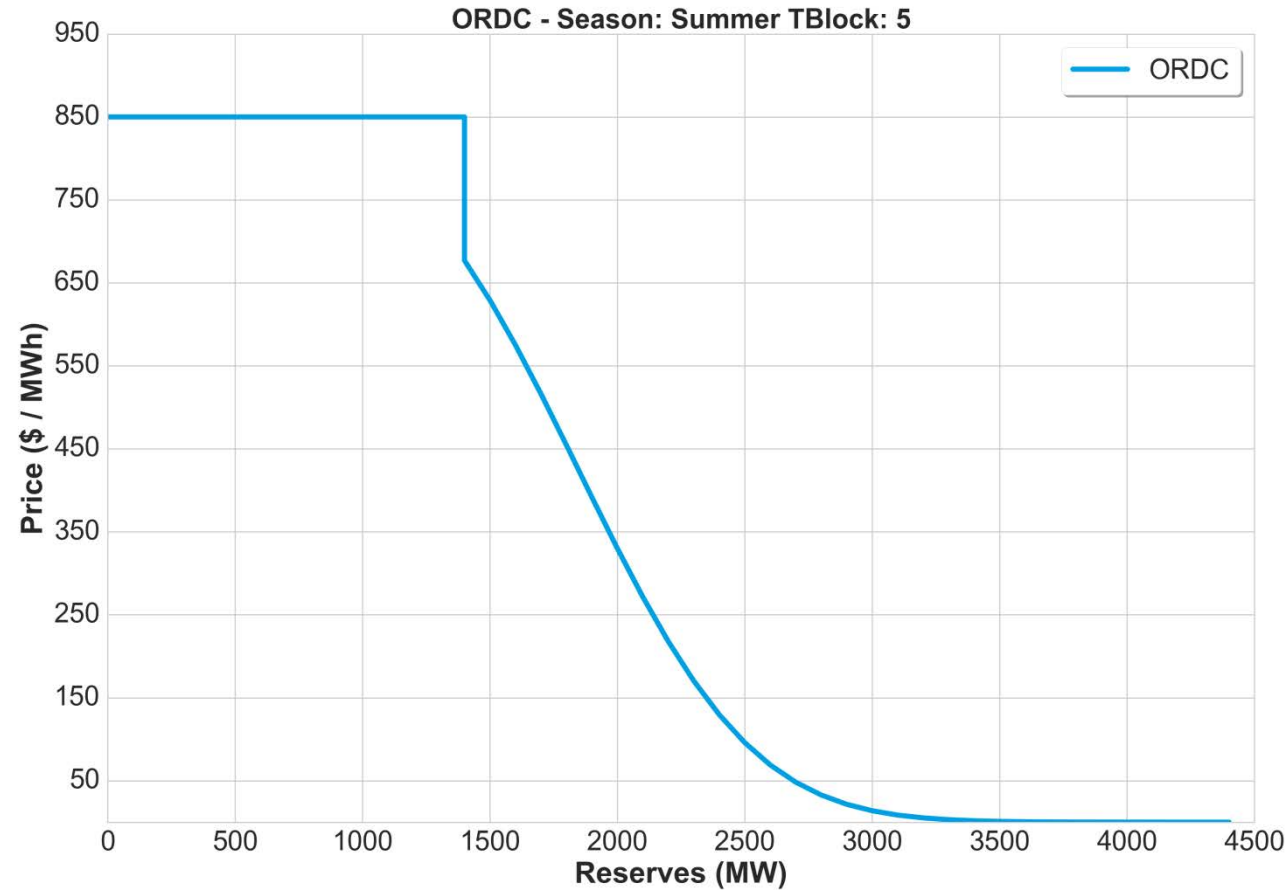
- For each unit in the PJM fleet, the mean time to failure can be computed using GADS data
 - Mean time to failure = Number of service hours / Number of Full Forced Outages
- *Time a unit is in service, not in a forced outage* can be modeled as a random variable with an exponential distribution (standard assumption in reliability models)
 - Exponential distribution has only one parameter, the mean. In our case, that parameter is the mean time to failure

- For instance, if the mean time to failure of a unit is 534 hours, then:
 - $P(X < t) = 1 - e^{-\frac{t}{534}}$
- If we are interested in uncertainty 1 hour ahead, we can calculate
 - $P(X < 1) = 1 - e^{-\frac{1}{534}} = 0.00187$
- The probability can be calculated for uncertainty intervals of less than an hour ahead (30 minutes: 0.5 hours, 15 minutes: 0.25 hours, etc.)

- The individual forced outages probabilities can be added by using convolution to derive an aggregate unavailable capacity distribution.
- The above aggregate unavailable capacity distribution is assumed to be normally distributed and can then be added to the rest of the uncertainties (load, wind, solar) to calculate the Probability of Reserves Falling Below the Minimum Reserve Requirement (PBMRR)

- GADS data for each unit with Capacity Interconnection Rights (CIRs) was used to estimate the parameters of the 30-min RTO-aggregate unavailability distribution
 - Mean and standard deviation are 0.24% and 0.16%, respectively
- To convert the mean and standard deviation percentages to MWs, the mean actual load in each Season-Time-of-Day Block (TBlock) combination is used as a proxy for total generation.
- For instance, the mean actual load for Summer TBlock 5 is 119,730 MW. Therefore,
 - Mean Unavailability: $119,730 \text{ MW} \times 0.24\% = 287 \text{ MW}$
 - StDev Unavailability: $119,730 \text{ MW} \times 0.16\% = 192 \text{ MW}$

ORDC for Summer TBlock 5 including forced outages uncertainty



Impact of Normality Assumption on PBMRR calculation

- To assess the impact of imposing the normality assumption on the load and wind forecast errors, the PBMRR for Summer TBlock 5 was calculated using 3 different methods:
 - **Method 1 (TFE-Normal):** Load Forecast Error (LFE) and Wind Forecast Error (WFE) are assumed to be normally distributed. The Total Forecast Error (TFE) is calculated by adding the two normal distributions, LFE and WFE, and is also normally distributed. The TFE is used to calculate the PBMRR.
 - Method 1 was used to derive the ORDC presented in most recent EPFSTF meeting

- **Method 2 (NLFE-Normal):** The Load Forecast Error data is combined with the Wind Forecast Error data to derive the Net-Load Forecast Error data. The Net-Load Forecast Error (NLFE) is assumed to be normally distributed. The NLFE is used to calculate the PBMRR.
- **Method 3 (NLFE-Empirical):** Similar to Method 2, but the NLFE is not assumed to be normally distributed. Instead, the PBMRR is calculated using an empirical distribution constructed with the Net-Load Forecast Error data.

Impact of Normality Assumption on PBMR calculation

Method 1

Load Forecast Error (MW)	Wind Forecast Error (MW)
150	-50
135	40
-50	-30
-40	-75
...	...
...	...
...	...
...	...
50	25

LFE Normal

WFE Normal

$$TFE = LFE + WFE \text{ (Normal)}$$

Method 2

Net-Load Forecast Error (MW)
200
95
-20
35
...
...
...
...
25

NLFE Normal

Method 3

Net-Load Forecast Error (MW)
-200
-95
20
-35
...
...
...
...
-25

NLFE Empirical

Impact of Normality Assumption on PBMRR calculation

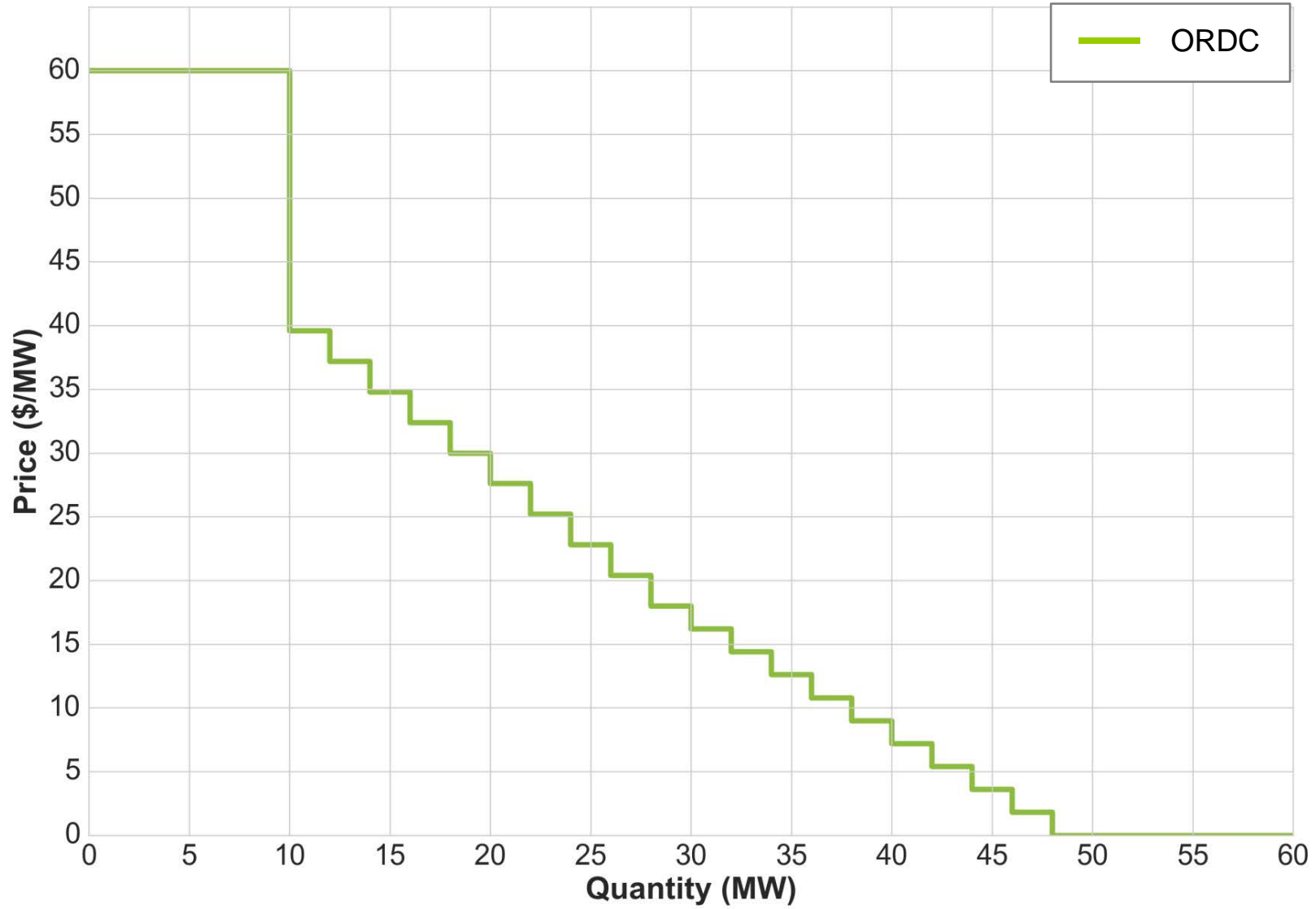
Reserves (MW)	PBMRR		
	Method 1	Method 2	Method 3
1500	0.52	0.52	0.53
1600	0.44	0.44	0.44
1700	0.36	0.37	0.36
1800	0.29	0.30	0.29
1900	0.23	0.23	0.22
2000	0.17	0.18	0.17
2100	0.13	0.13	0.12
2200	0.09	0.09	0.09
2300	0.06	0.06	0.06
2400	0.04	0.04	0.04
2500	0.03	0.03	0.03
2600	0.02	0.02	0.02
2700	0.01	0.01	0.01
2800	0.01	0.01	0.01
2900	0.00	0.00	0.00

Assuming MRR for Synchronized Reserves is 1,400 MW.

(PBMRR values for Reserves less than or equal to 1,400 MW are equal to 1 under the 3 methods)

PBMRR values are practically identical under the 3 methods. Therefore, assuming normality for each of the forecast error distributions has a negligible impact on PBMRR calculations.

Energy and Reserves Co-Optimization Examples



Example #1: Capacity Constrained

■ Available MW

Demand 141 MW

Energy Offer:
\$100/MWh

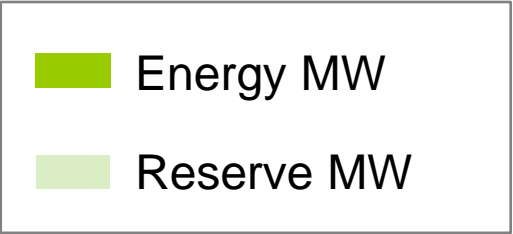
120

Energy Offer:
\$50/MWh

50

Resource
1

Resource
2

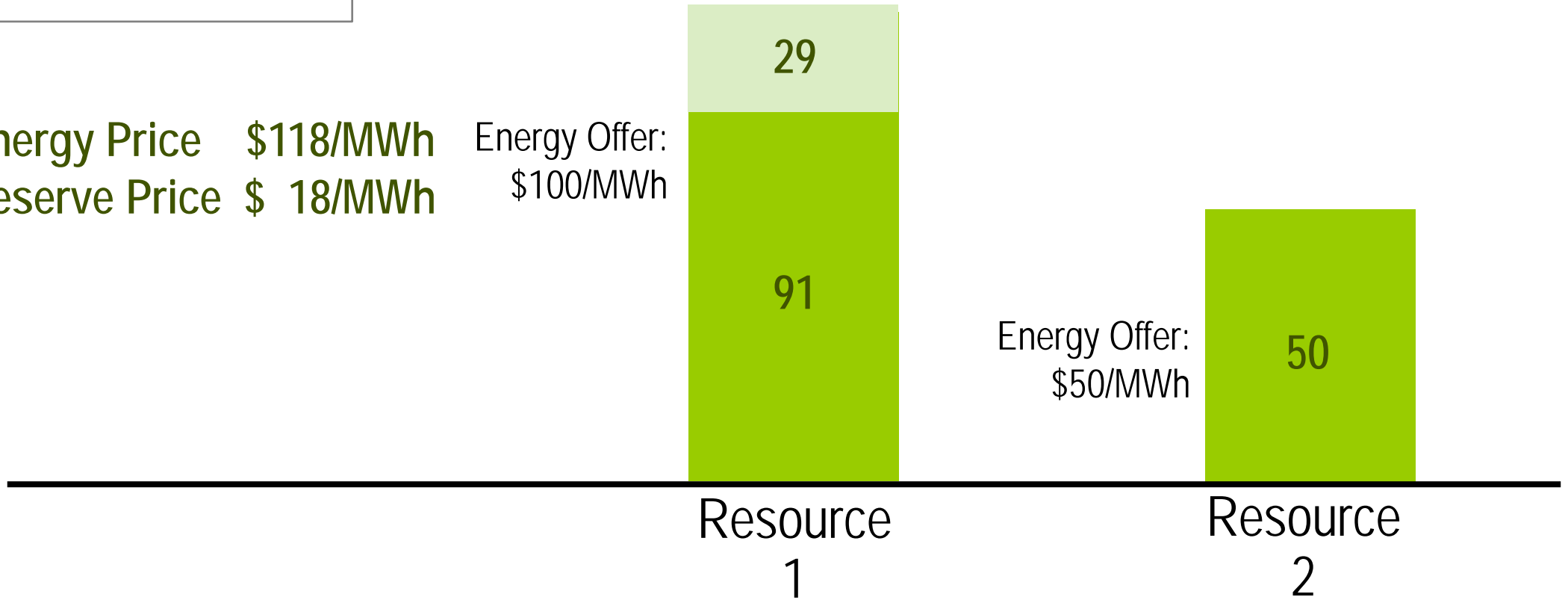


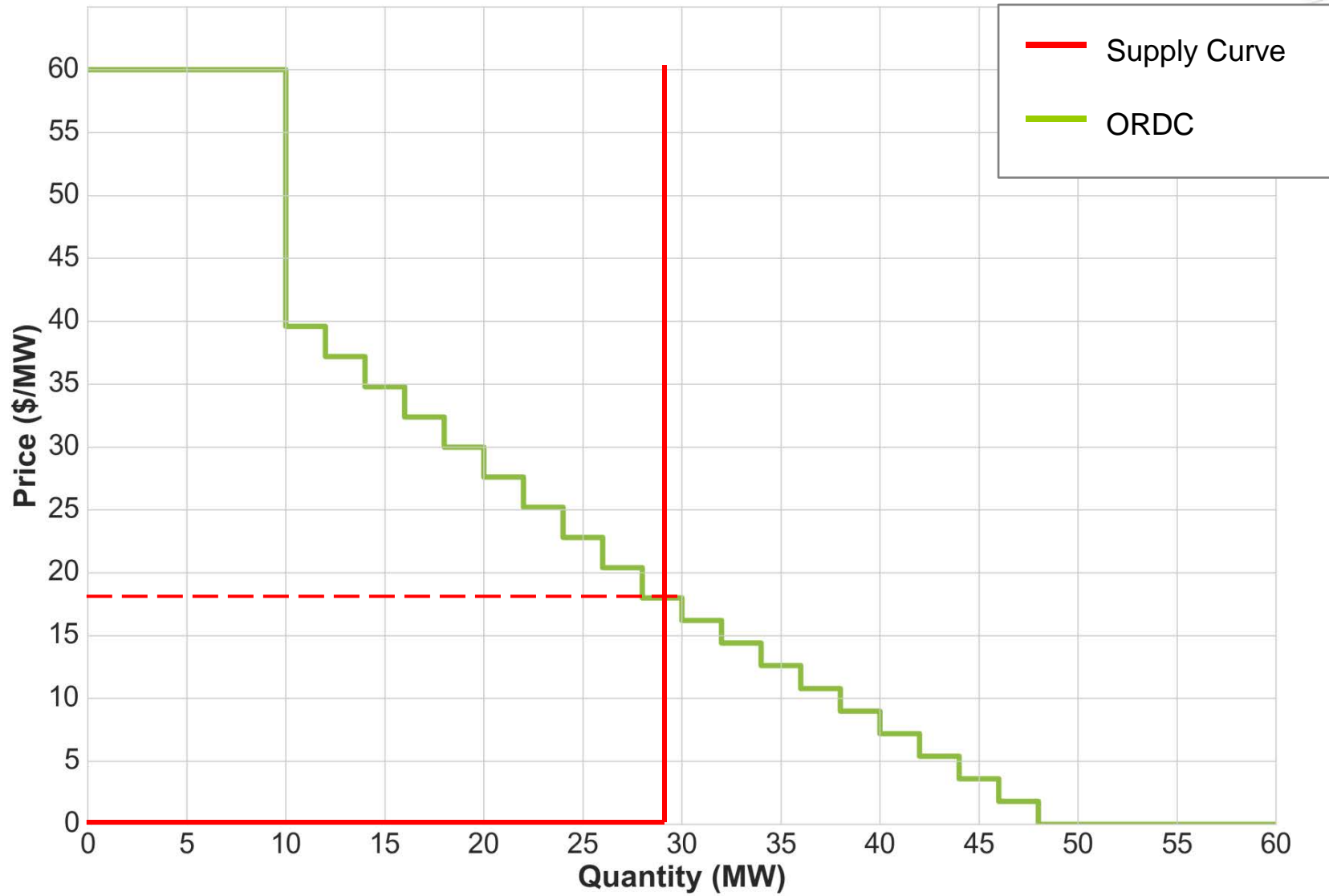
Demand 141 MW

Energy Price \$118/MWh
Reserve Price \$ 18/MWh

Energy Offer:
\$100/MWh

Energy Offer:
\$50/MWh





Example #2: Capacity Constrained with Reserve Offer

■ Available MW

Demand 141 MW

Energy Offer:
\$100/MWh
Reserve Offer:
\$5/MWh

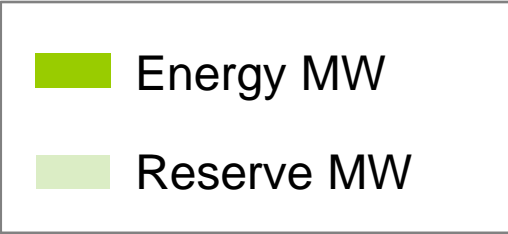


Resource
1

Energy Offer:
\$50/MWh



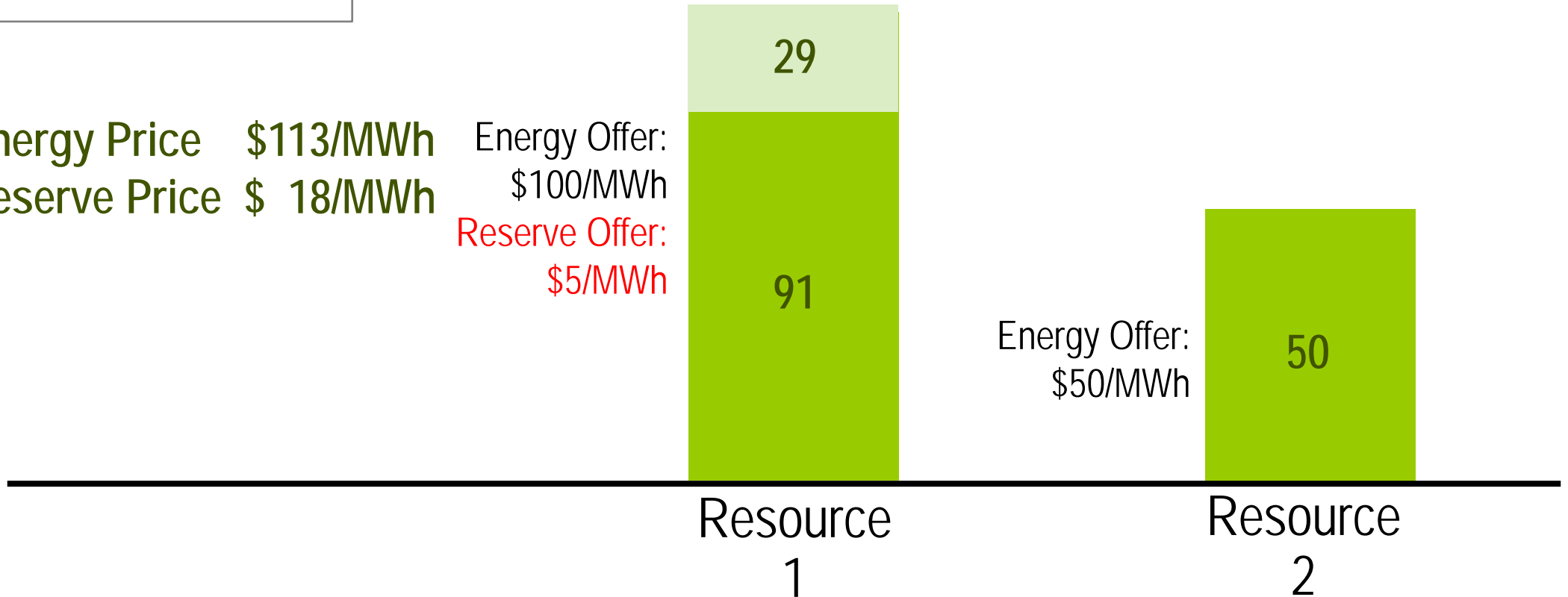
Resource
2

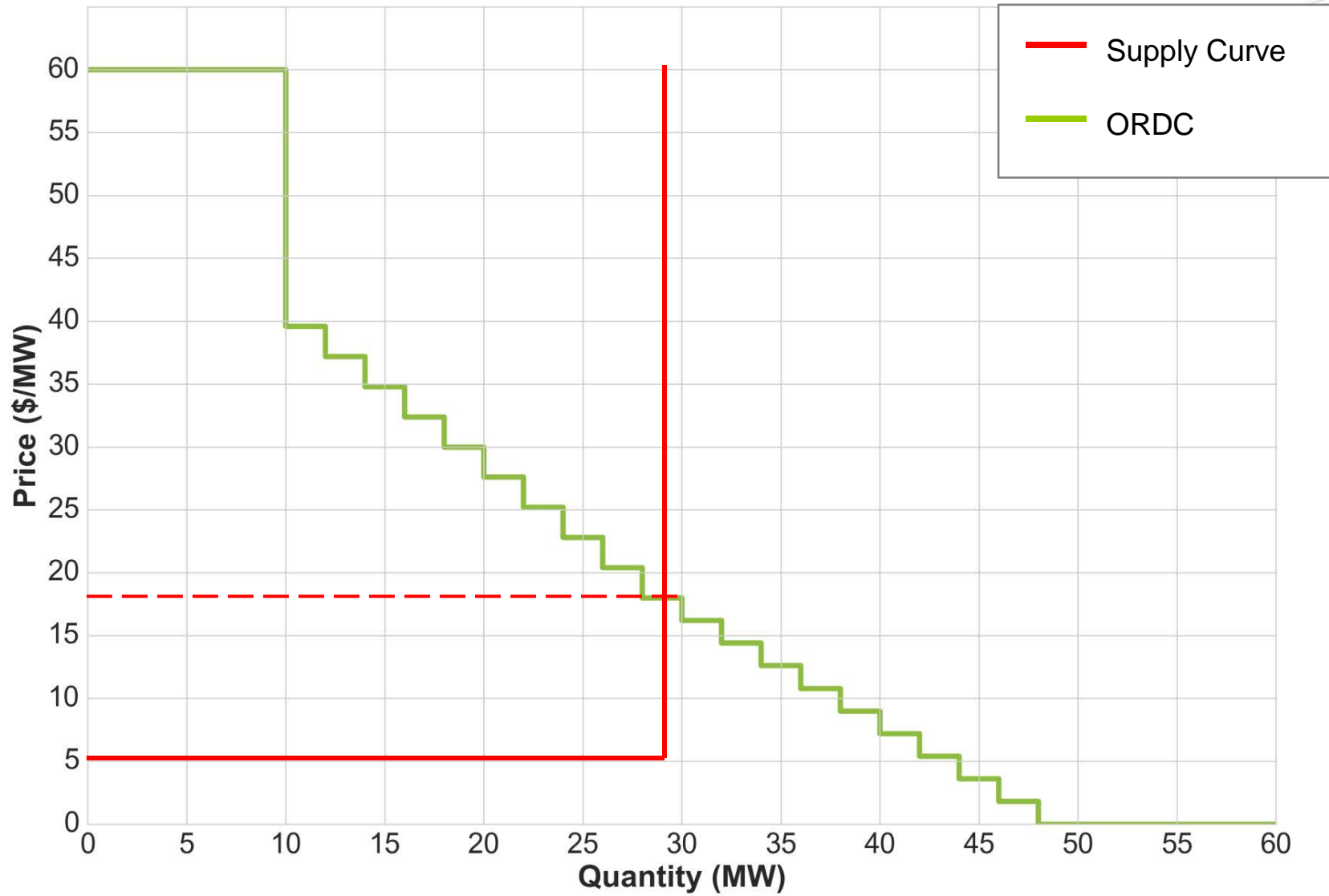


Demand 141 MW

Energy Price \$113/MWh
 Reserve Price \$ 18/MWh

Energy Offer: \$100/MWh
 Reserve Offer: \$5/MWh





Example #3: Ramp Constrained

■ Available MW

Demand 141 MW

Energy Offer:
\$100/MWh
Reserve Limit:
10 MW



Resource
1

Energy Offer:
\$50/MWh



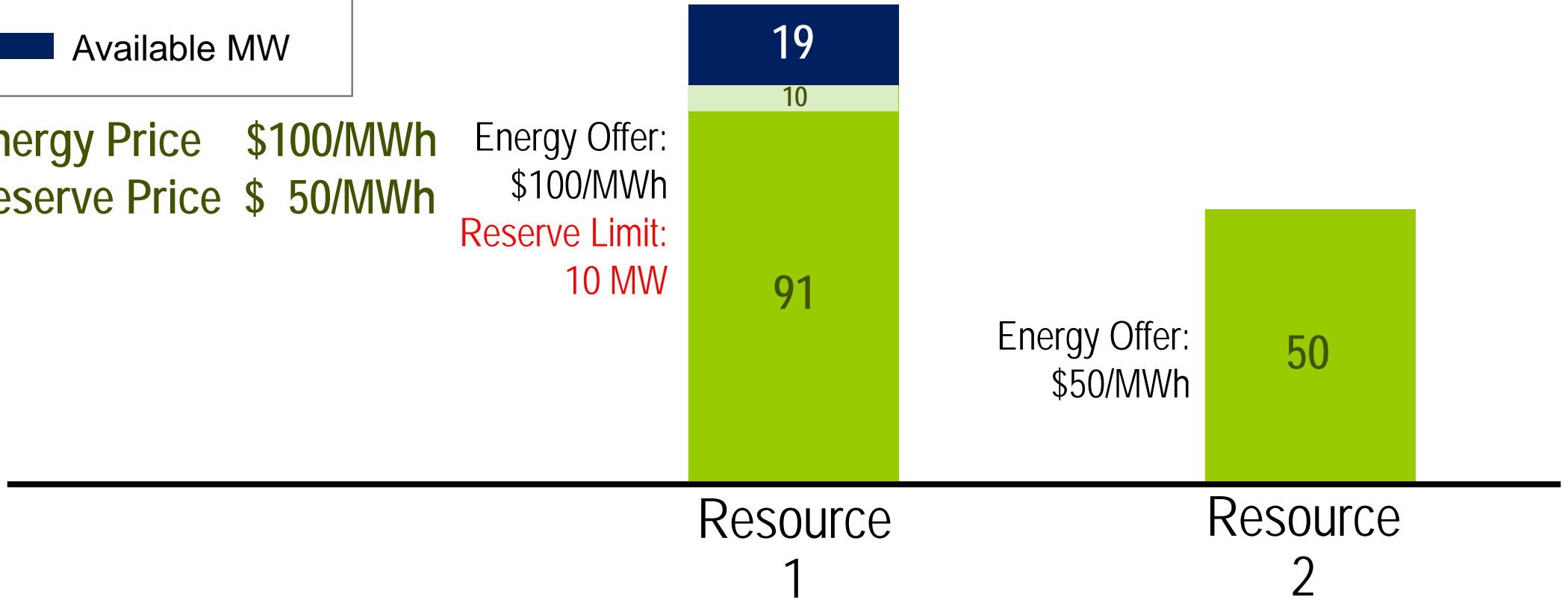
Resource
2



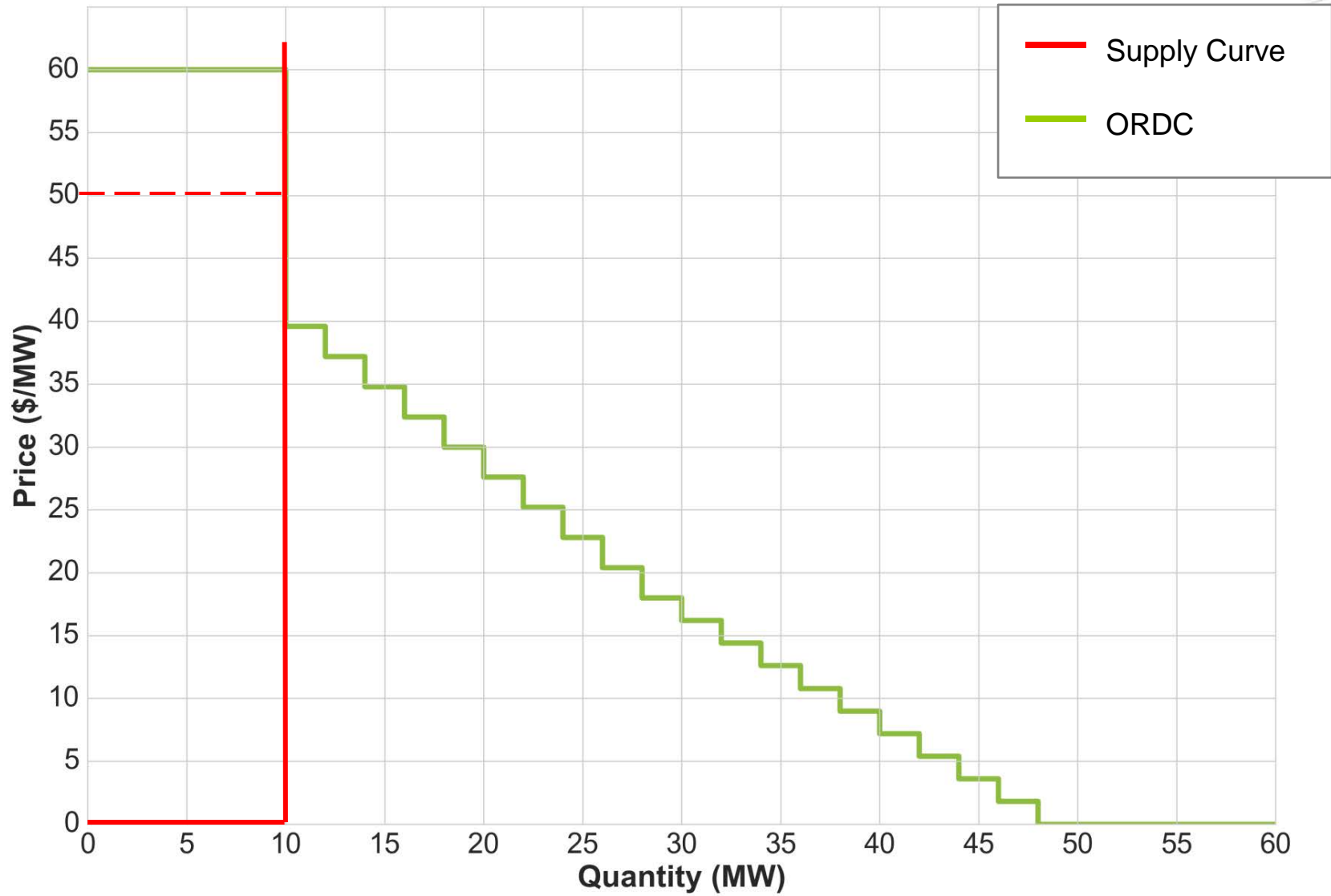
Demand 141 MW

Energy Price \$100/MWh
Reserve Price \$ 50/MWh

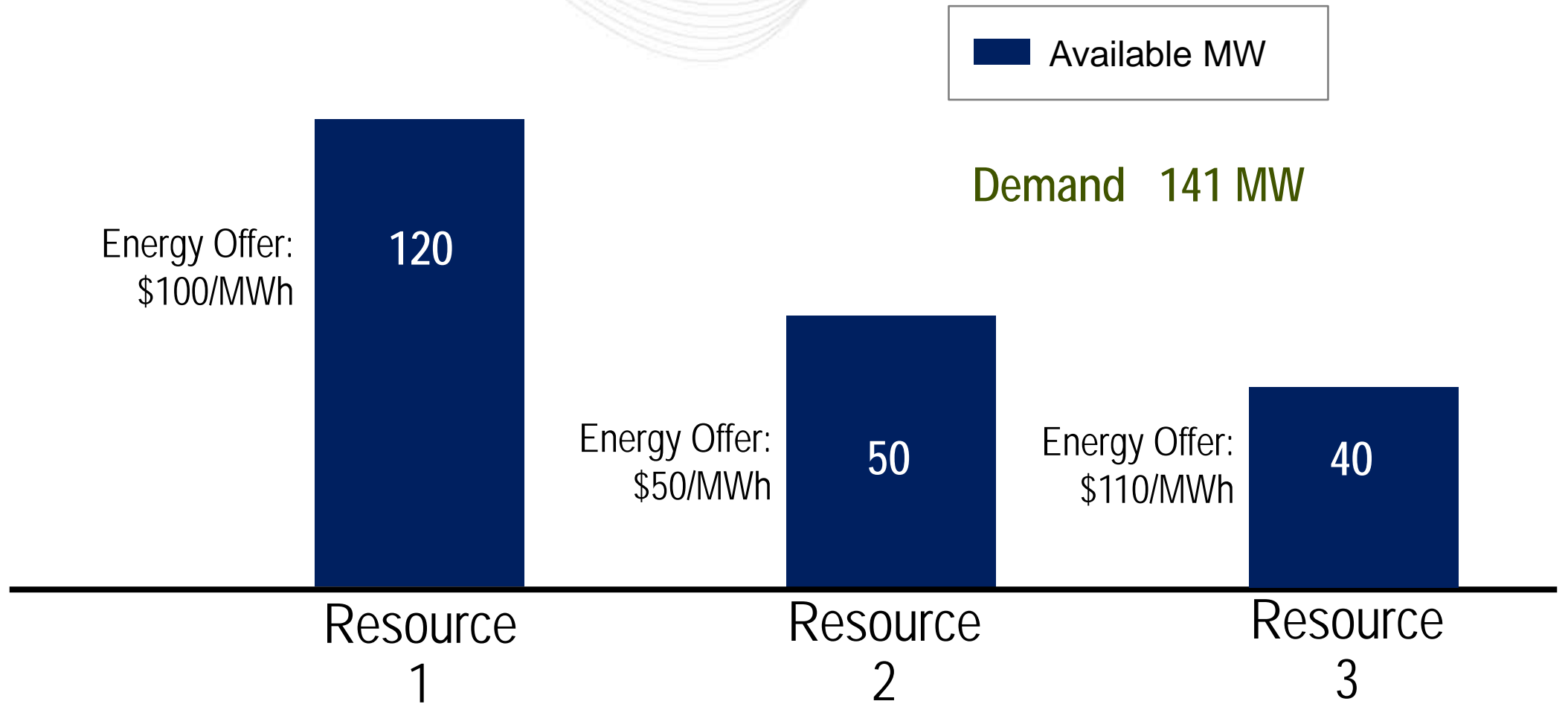
Energy Offer: \$100/MWh
Reserve Limit: 10 MW

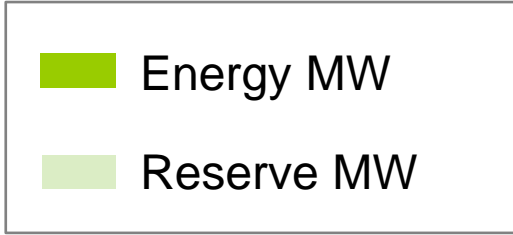


Energy Offer: \$50/MWh



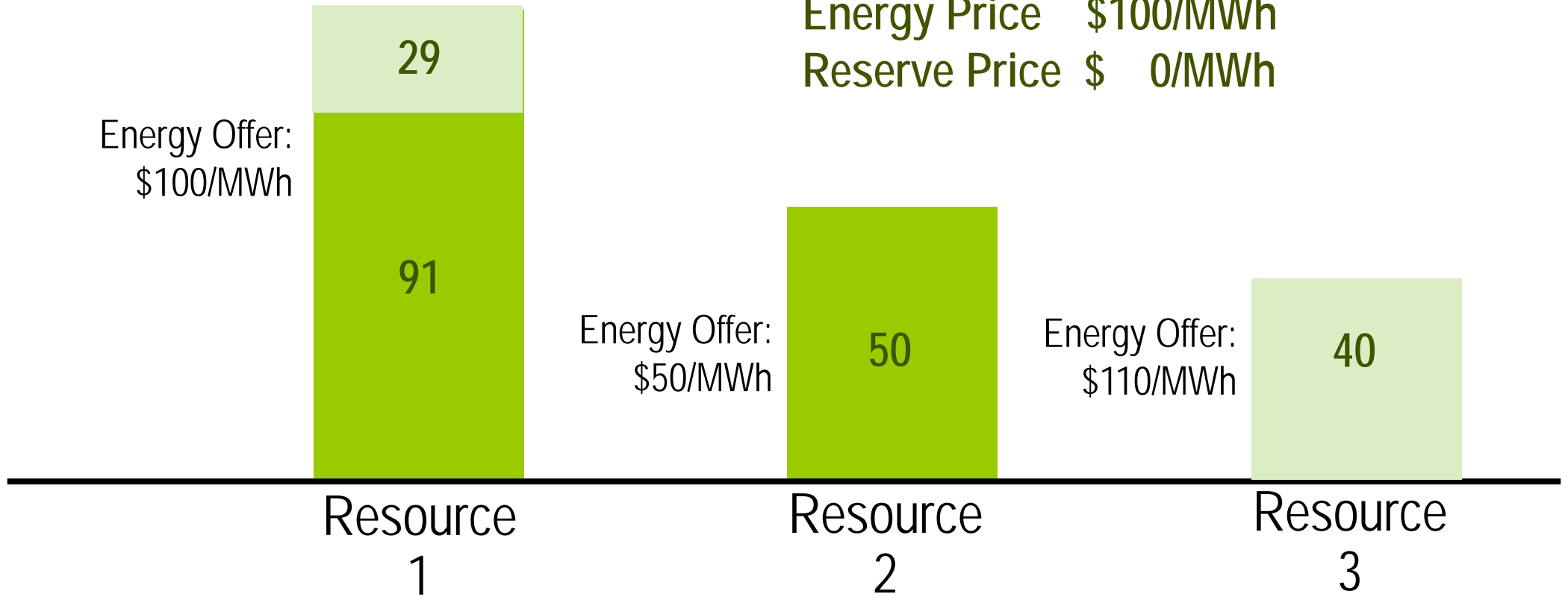
Example #4: Reserves Surplus

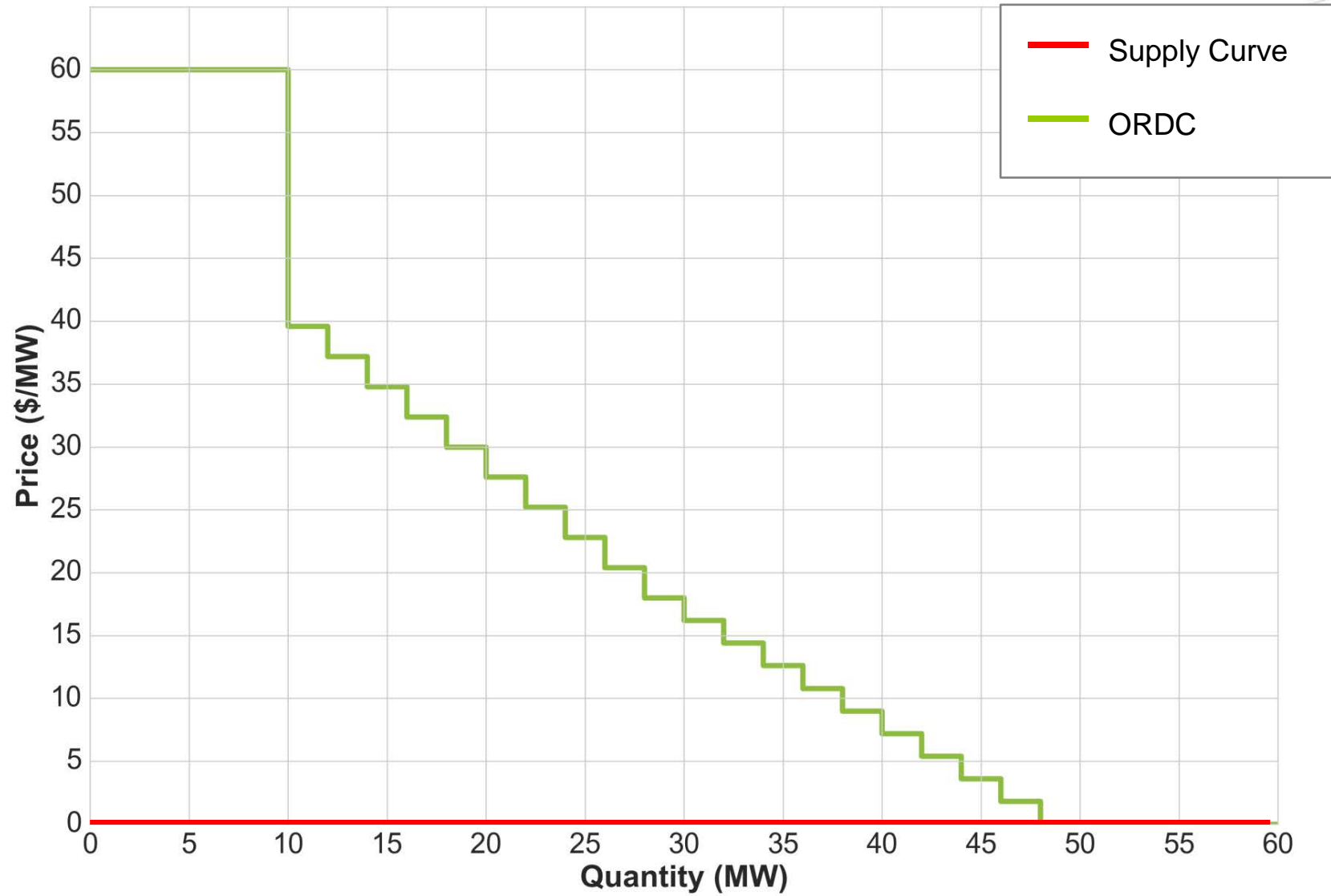




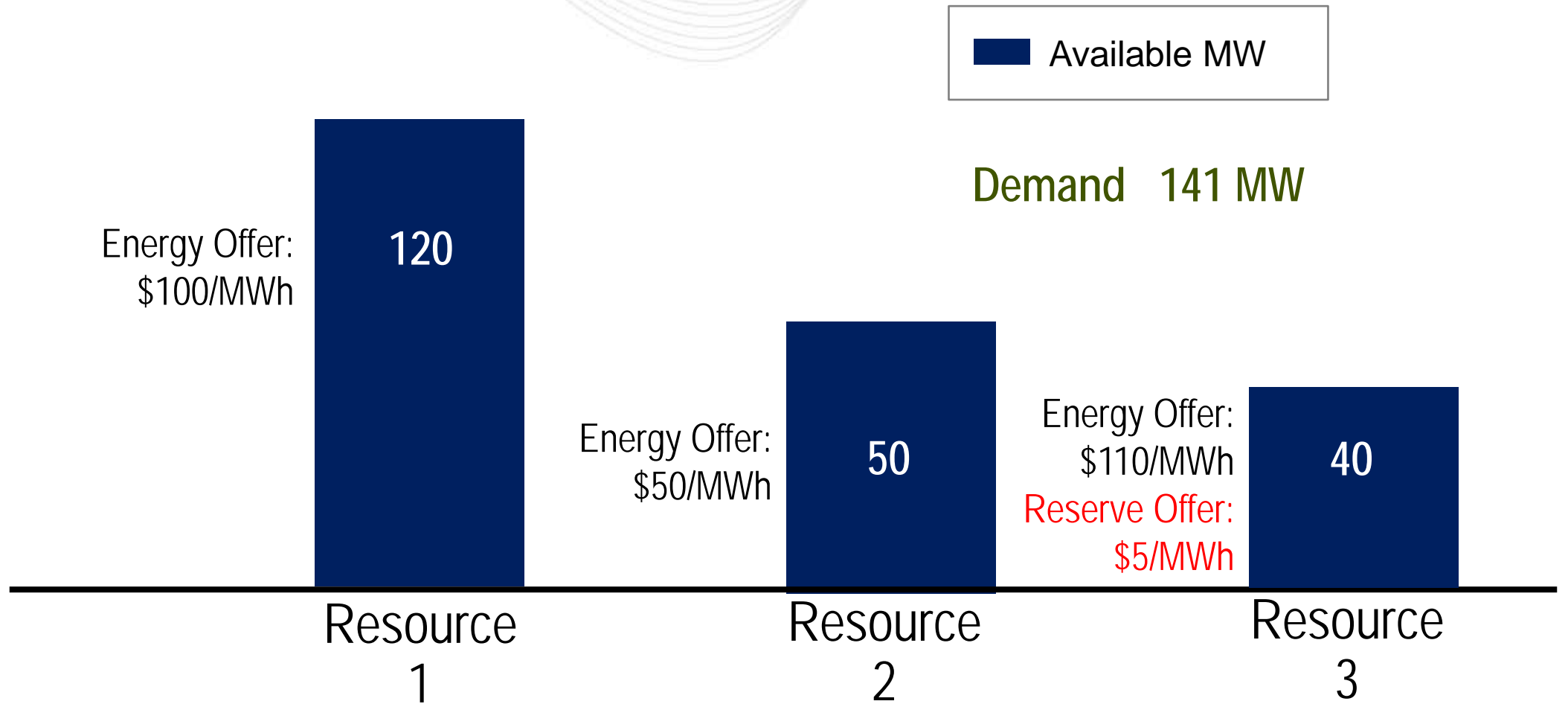
Demand 141 MW

Energy Price \$100/MWh
 Reserve Price \$ 0/MWh





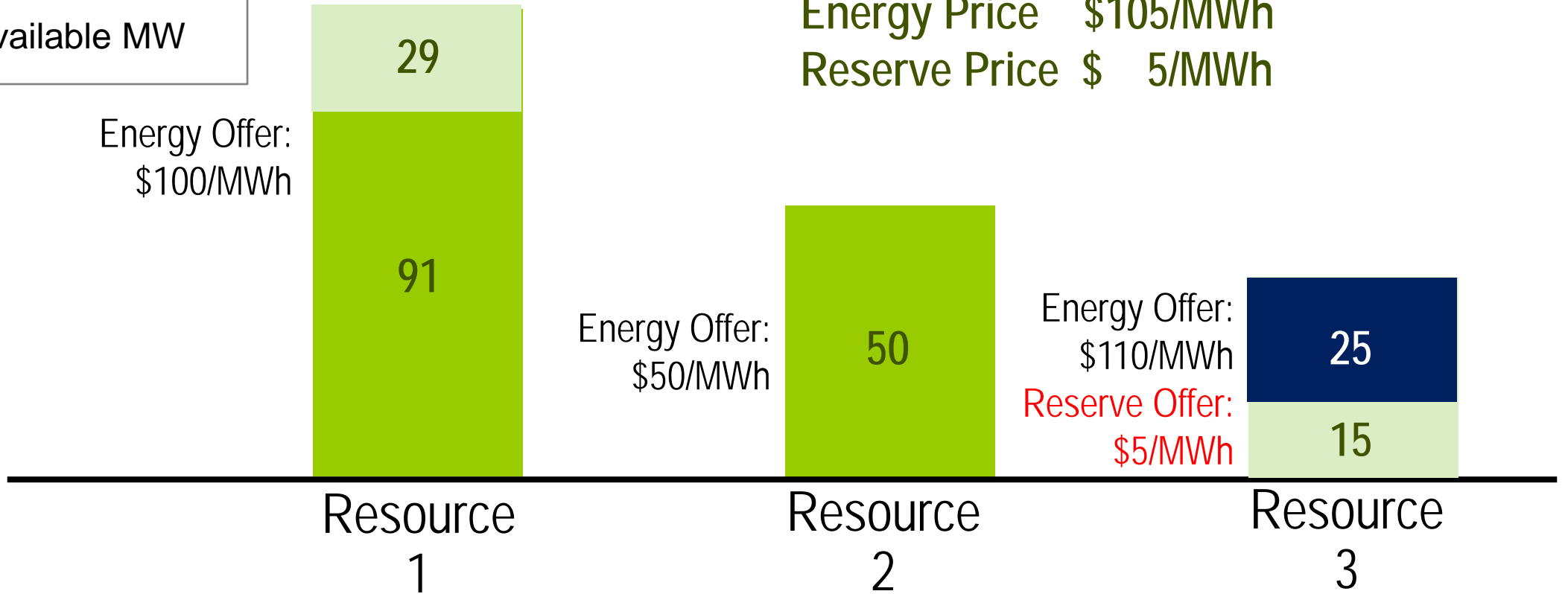
Example #5: Reserves Surplus with Reserve Offer

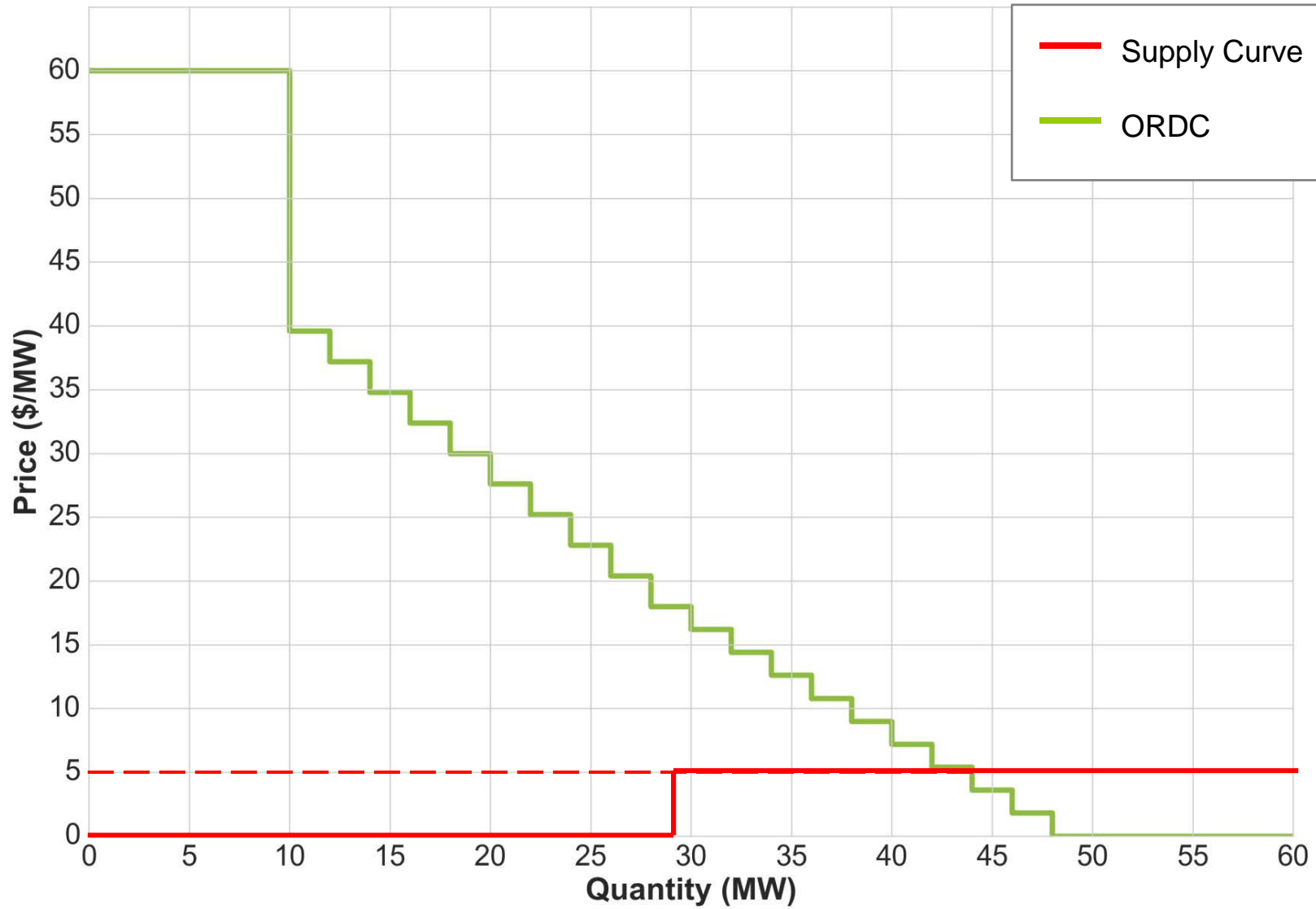




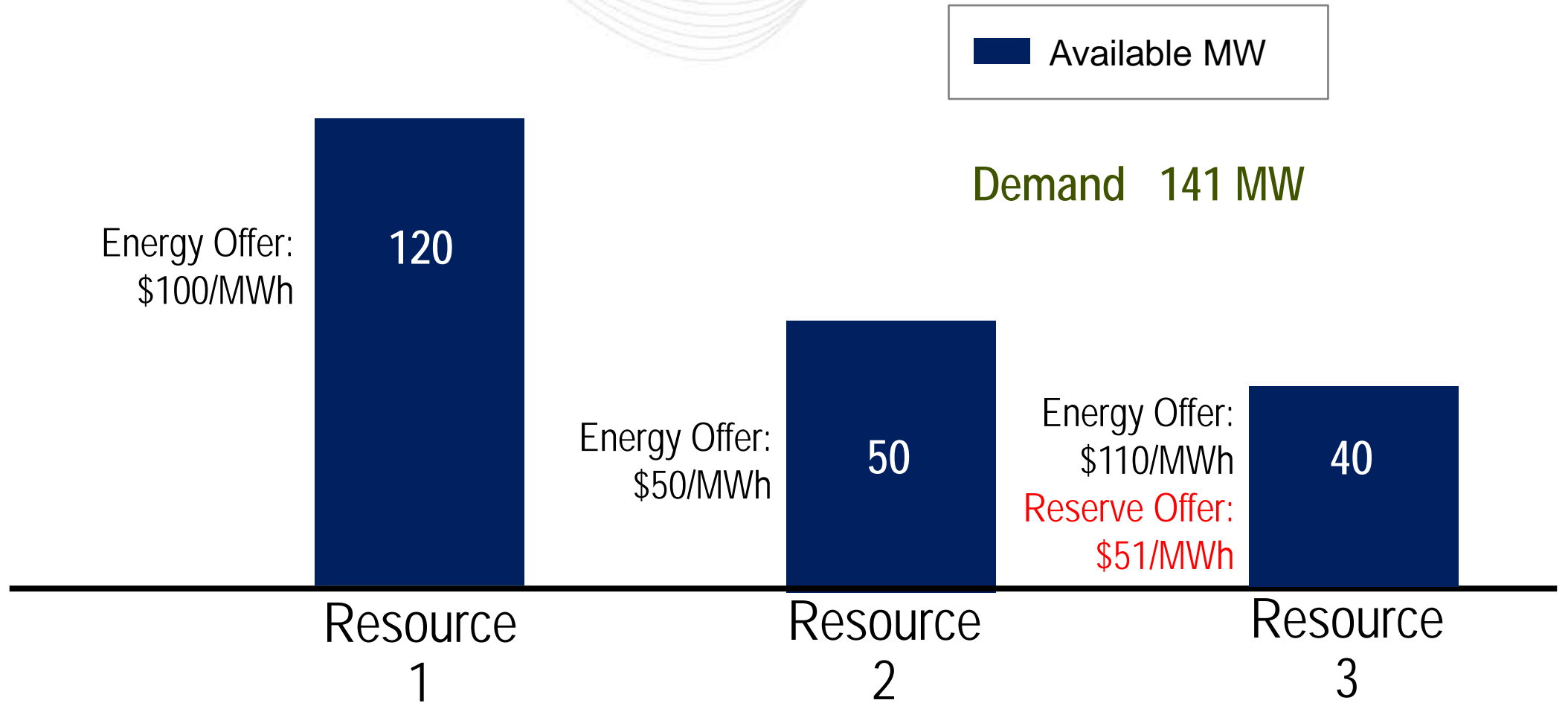
Demand 141 MW

Energy Price \$105/MWh
Reserve Price \$ 5/MWh





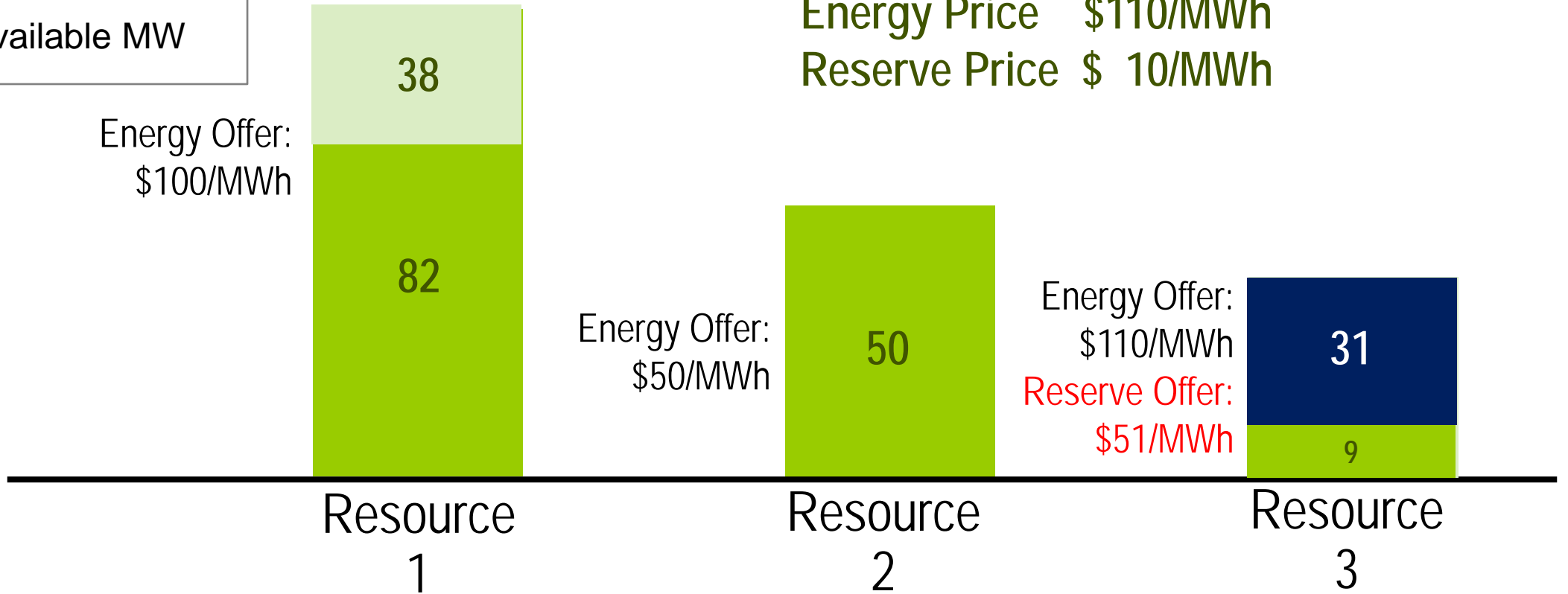
Example #6: Reserves Economic Shortage

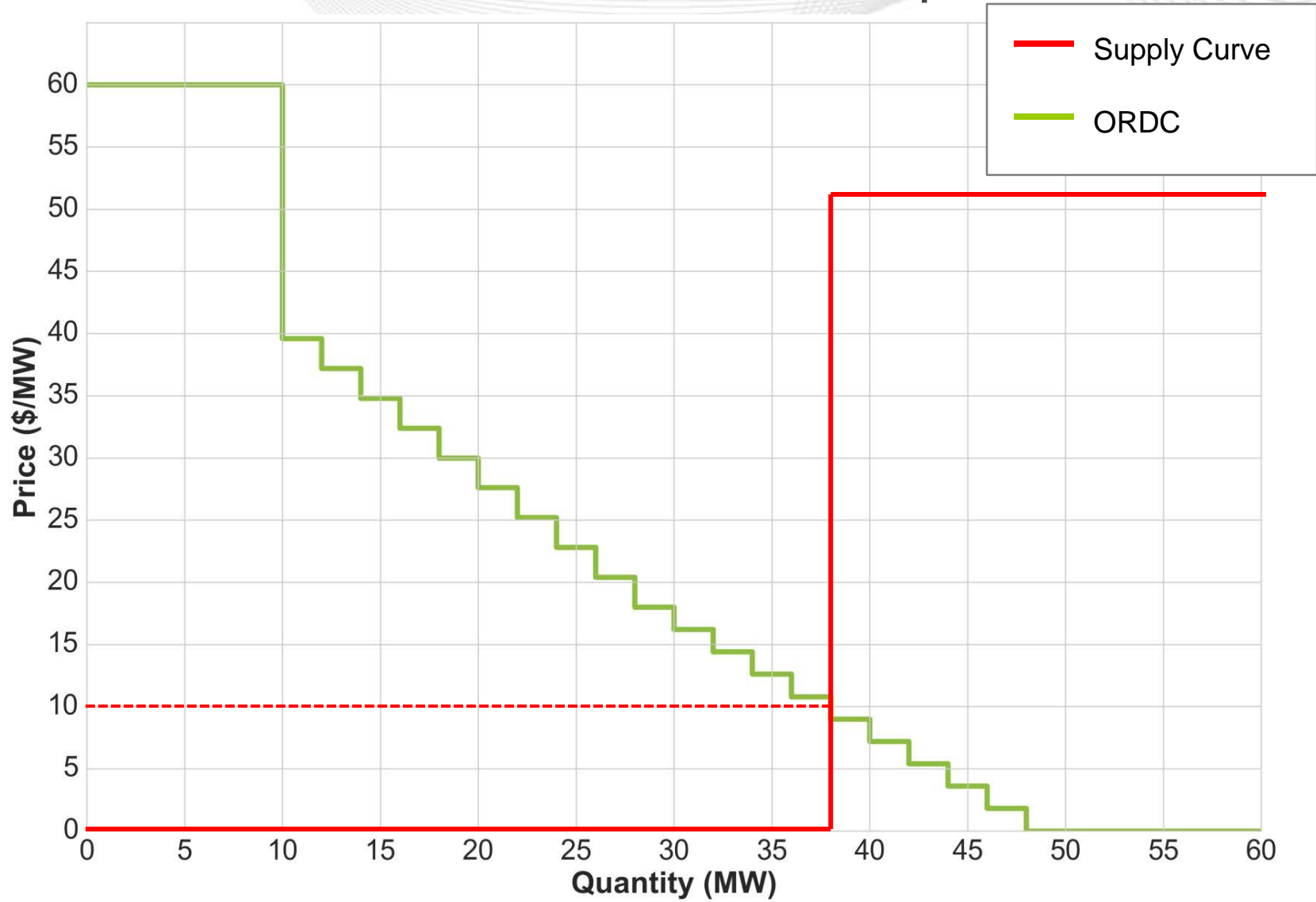




Demand 141 MW

Energy Price \$110/MWh
Reserve Price \$ 10/MWh





Appendix: ORDCs for all Season – Time-of-Day Blocks combinations (including Forced Outages Uncertainty)

