Price Formation Efforts Considering High Renewable Penetration Levels and System Resource Adequacy Targets

EPRI/NREL Study

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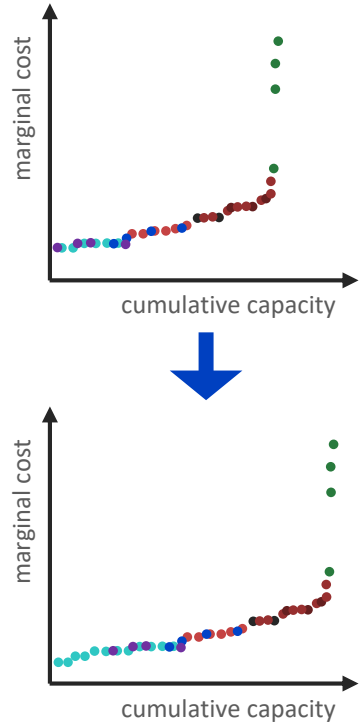
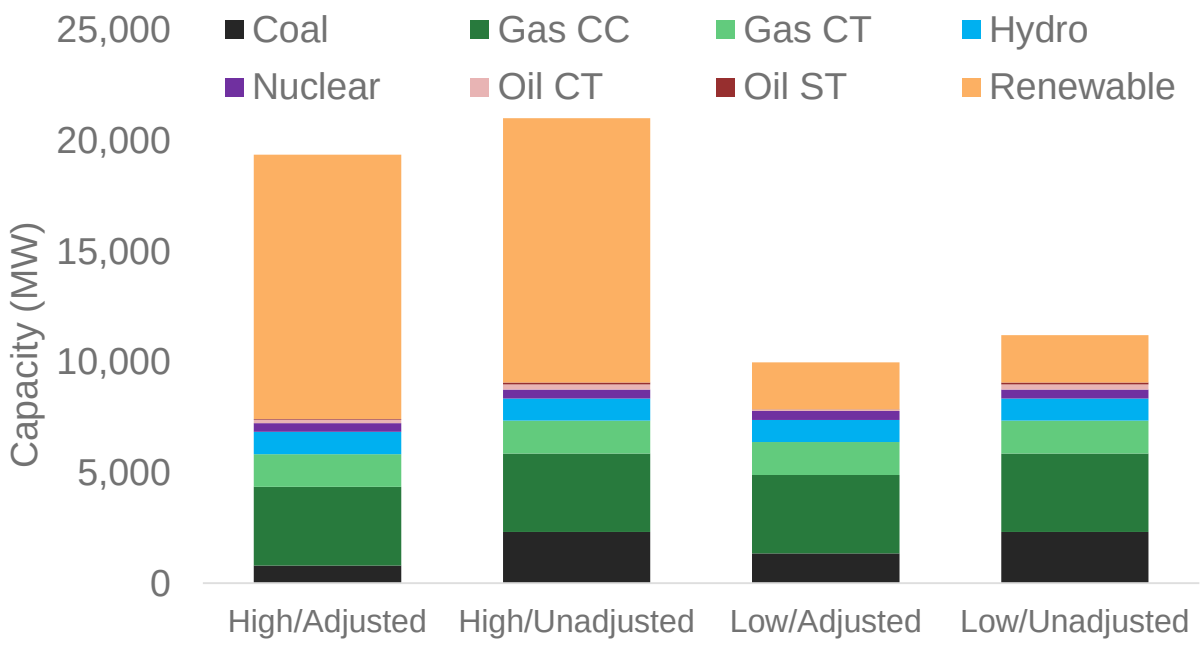
Electric Power Research Institute and National Renewable Energy Lab Study

- Funded by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Wind Energy Technologies Office
  - Results shown are draft results
- Motivation
  - Increasing levels of renewable penetration (zero cost resources) pushes the supply curve to the right, which can decrease spot market prices
  - Operators must ensure adequate resources given a reliability need
    - With lower prices, revenues for existing resources might decrease
  - Alternative pricing methods can incorporate costs that currently are not captured, thereby increasing transparency and reducing the need for uplift or make-whole payments
- Objective
  - Examine different pricing methods and assess prices, revenues, and profits under different renewable penetrations and resource mix assumptions



Test System Characteristics

- Reliability Test System-GMLC
- "Adjusted" study systems had a goal of 2.4 h/year LOLE target, approximately 1 day in 10 years LOLE industry standard
  - Iterations between a capacity expansion model and resource adequacy assessment model



Github.com/GridMod/RTS-GMLC

- 8 scenarios using two pricing methods

Traditional Pricing

$$Marginal\ Cost$$

Alternative pricing

$$Marginal\ Cost + \frac{No\ Load}{Pmax}$$

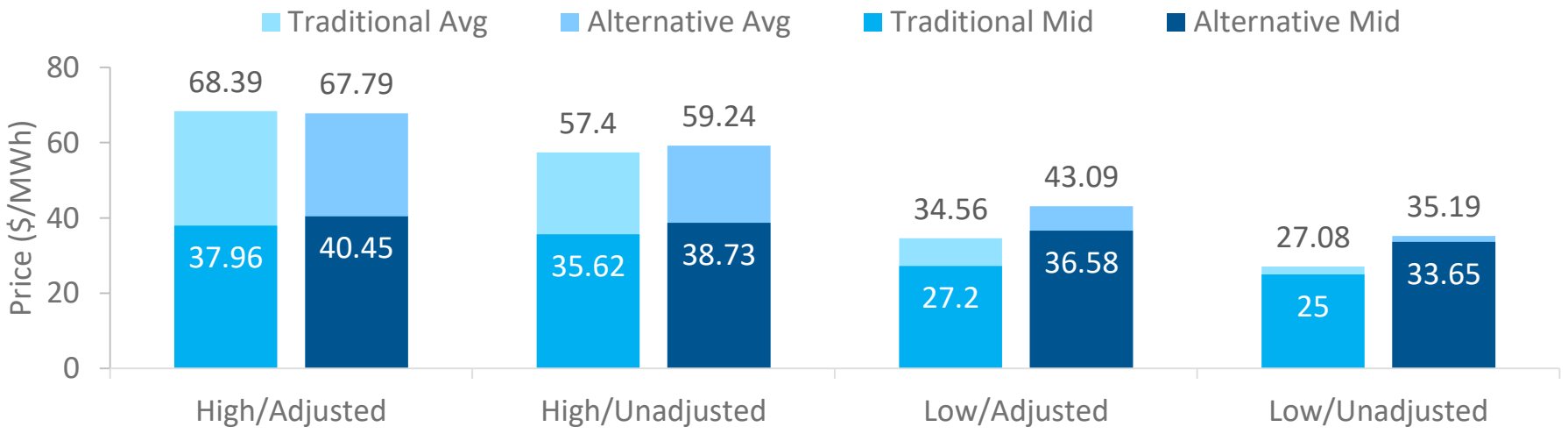
Pricing Type	Resource Mix	Renewable level
Traditional Pricing	Adjusted	High
Traditional Pricing	Adjusted	Low
Traditional Pricing	Unadjusted	High
Traditional Pricing	Unadjusted	Low
Alternative Pricing	Adjusted	High
Alternative Pricing	Adjusted	Low
Alternative Pricing	Unadjusted	High
Alternative Pricing	Unadjusted	Low

Assumptions / Model Simplifications

- No virtual bidders or players that do DA/RT arbitrage
- Renewables bid in at $0/MWh (no negative prices)
- Assume truthful bidding
- Revenue is a subset of all revenue collected from energy markets
- No large storage devices
- No operator action or out of market corrections

Results: Price Statistics

		Mean ($/MWh)	Standard Deviation	Quantity of Price Spikes	Quantity of Zero Prices
High Adjusted	Traditional	68.39	215.58	4.9%	44.4%
	Alternative	67.79	192.80	4.0%	25.8%
High Unadjusted	Traditional	57.40	193.85	3.9%	45.1%
	Alternative	59.24	174.30	3.2%	25.8%
Low Adjusted	Traditional	34.56	87.08	0.8%	0.4%
	Alternative	43.09	80.98	0.7%	0%
Low Unadjusted	Traditional	27.08	46.59	0.2%	0.3%
	Alternative	35.19	39.34	0.2%	0%



Price Duration Curves

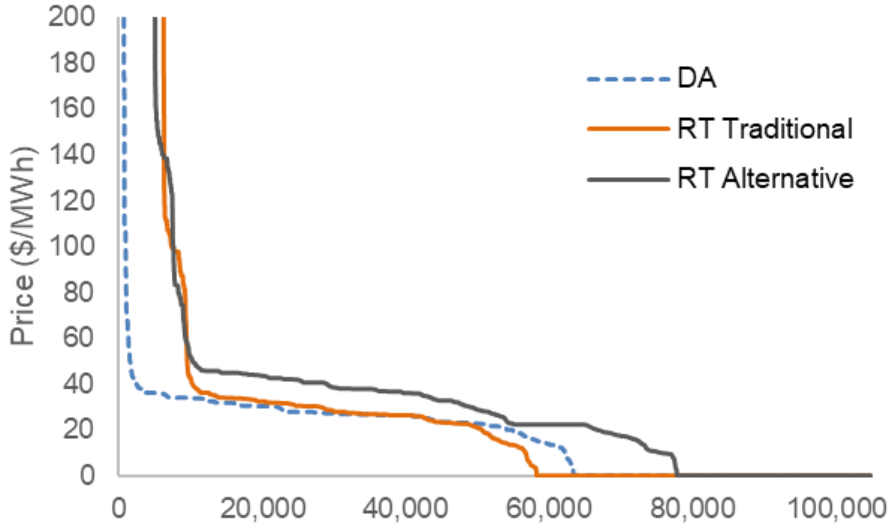
DRAFT RESULTS

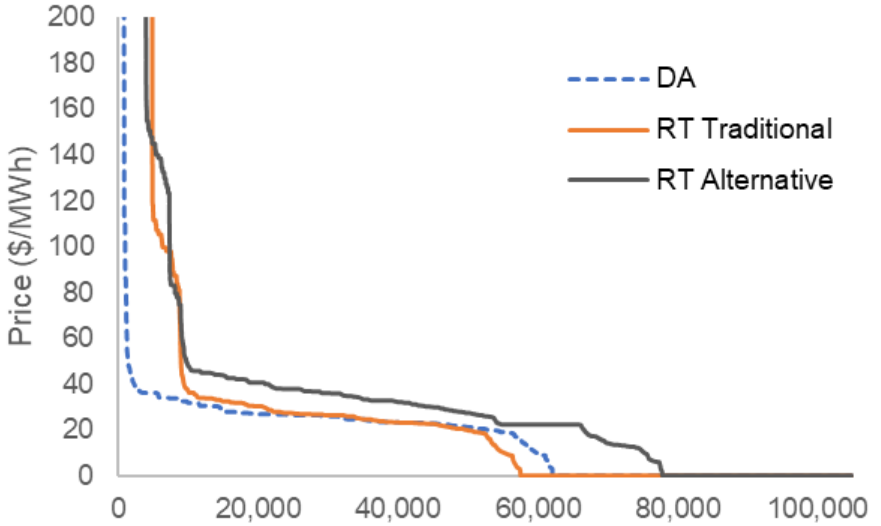
Adjusted System

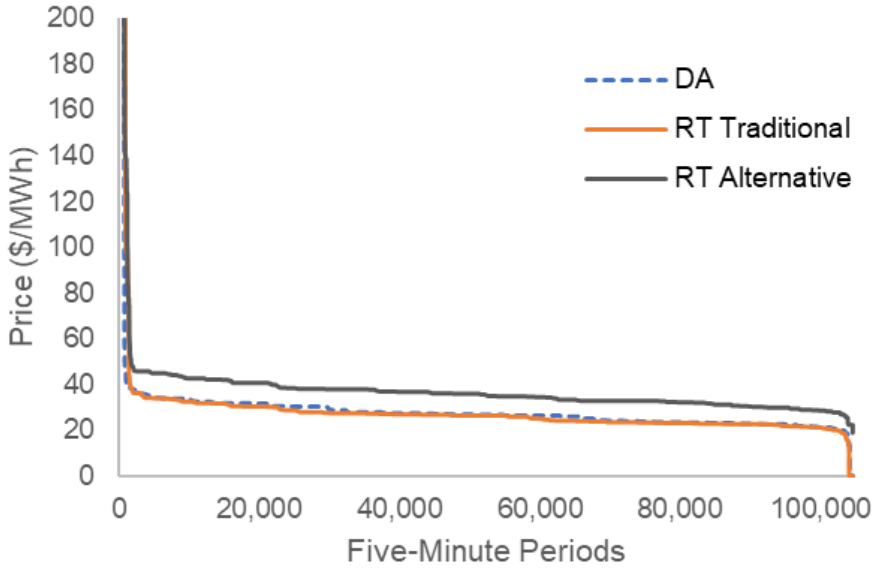
Unadjusted System

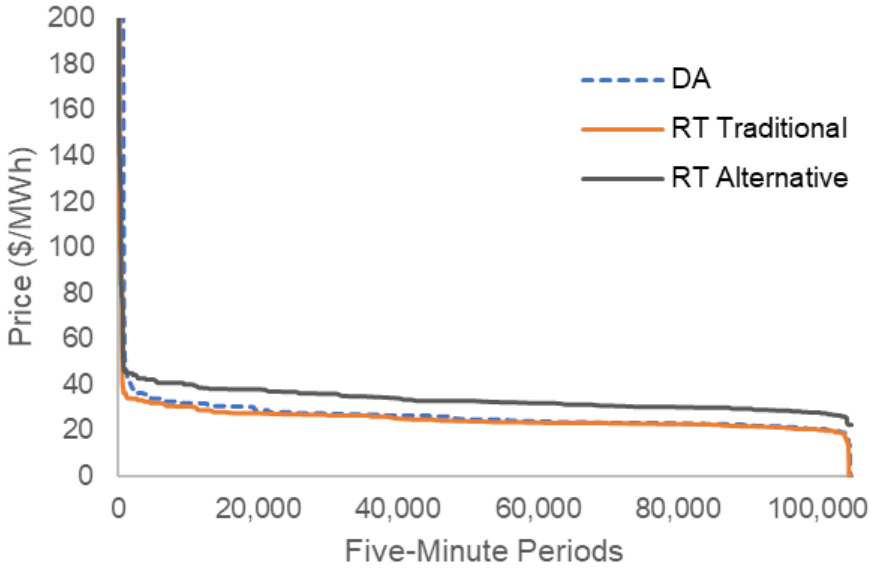
High Renewable

Low Renewable









Heat Maps

- Average real-time prices for the high renewable penetration and adjusted resource mix scenario ($/MWhs) by month and hour

Traditional Pricing

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	38	25	57	41	56	108	468	58	0	0	0	0	0	0	0	0	26	164	56	45	39	26	103	44
Feb	39	51	44	25	97	297	548	31	0	0	0	0	0	3	3	4	12	148	141	32	78	30	92	58
Mar	63	86	54	29	150	528	181	7	0	0	0	0	0	2	2	25	3	136	185	39	27	48	95	89
Apr	105	185	88	151	296	494	13	1	1	1	1	1	0	0	0	0	2	122	220	162	62	63	85	88
May	77	64	62	91	496	69	7	2	0	0	0	0	0	1	23	2	3	29	152	139	32	28	25	96
Jun	51	29	65	83	573	20	5	3	2	1	2	3	18	48	34	10	12	20	196	64	58	54	32	126
Jul	88	100	88	120	481	69	20	6	0	0	2	5	9	11	12	15	17	126	484	106	79	35	67	116
Aug	54	37	71	58	257	355	18	5	1	0	0	1	4	7	10	11	14	100	378	132	48	41	76	50
Sep	35	39	23	41	78	678	21	1	0	0	0	0	0	2	4	7	11	189	68	56	28	27	77	53
Oct	25	39	34	42	77	562	43	2	0	0	0	0	0	0	0	0	18	45	60	33	41	35	33	54
Nov	63	101	38	24	153	362	227	2	0	0	0	0	0	0	0	0	181	107	28	50	22	39	56	114
Dec	32	56	49	69	93	191	608	89	0	0	0	0	1	15	3	4	185	202	33	44	56	65	60	52

Alternative Pricing

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	55	43	71	60	68	97	376	65	2	0	0	0	0	0	0	1	205	236	65	54	50	36	87	50
Feb	51	64	42	39	100	245	385	36	4	0	0	0	0	3	5	4	48	216	145	45	73	42	53	54
Mar	68	73	65	43	145	413	137	16	3	2	1	1	1	3	5	28	13	240	193	50	37	36	56	76
Apr	116	149	102	137	194	425	25	4	3	2	2	2	1	1	2	3	12	227	259	169	74	70	86	87
May	80	63	74	79	383	66	18	7	1	0	1	2	3	6	28	9	15	60	174	145	43	37	34	58
Jun	62	37	57	76	426	32	19	11	7	7	9	11	28	57	44	21	24	33	199	77	63	43	38	79
Jul	68	86	90	93	278	43	31	19	13	13	14	17	19	20	21	26	30	121	479	117	84	47	53	44
Aug	63	39	76	43	141	229	34	18	12	11	11	13	16	18	20	21	27	89	381	137	53	42	61	40
Sep	41	50	35	50	74	585	27	10	4	3	4	5	7	10	12	16	24	190	77	68	42	37	45	42
Oct	33	49	45	50	76	481	43	8	1	0	0	1	2	3	4	10	110	76	70	42	44	33	37	54
Nov	66	103	50	35	138	294	163	7	0	0	0	0	0	0	0	2	286	116	40	60	36	44	54	87
Dec	38	57	44	80	96	160	498	73	5	2	2	2	2	16	5	4	227	195	46	53	64	65	53	47

DRAFT RESULTS

Heat Maps

- Average real-time prices for the low renewable penetration and adjusted resource mix scenario ($/MWhs) by month and hour

Traditional Pricing

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	25	24	24	24	25	27	40	27	24	23	22	22	22	22	22	22	25	38	37	40	29	32	33	26
Feb	25	24	24	24	24	26	28	25	23	23	23	22	22	22	22	23	24	28	36	31	37	35	26	26
Mar	24	24	23	24	24	26	32	24	22	22	22	22	21	21	21	22	23	26	55	33	29	28	26	25
Apr	25	25	25	30	47	25	23	22	22	22	20	20	21	21	22	23	24	25	62	142	29	27	50	26
May	25	24	24	23	24	23	22	22	23	24	24	25	25	26	26	27	27	28	30	31	29	27	27	26
Jun	26	25	24	24	24	23	23	25	26	27	27	28	28	29	76	56	59	31	40	31	31	85	48	28
Jul	27	26	25	25	24	24	24	25	26	28	29	88	90	237	230	159	127	51	66	78	37	31	30	29
Aug	27	26	26	25	26	26	25	25	26	27	28	50	81	201	130	204	81	41	71	53	33	31	29	28
Sep	25	24	24	24	25	26	25	25	25	26	26	27	28	88	123	125	43	48	42	32	52	30	29	27
Oct	25	24	24	24	25	26	25	24	23	23	24	23	24	24	24	25	27	30	37	29	49	27	27	26
Nov	24	23	23	23	24	48	43	23	22	21	22	21	22	22	22	24	27	35	30	29	28	27	26	25
Dec	37	26	30	27	49	51	66	26	23	22	22	21	19	19	21	22	46	60	34	33	30	29	33	26

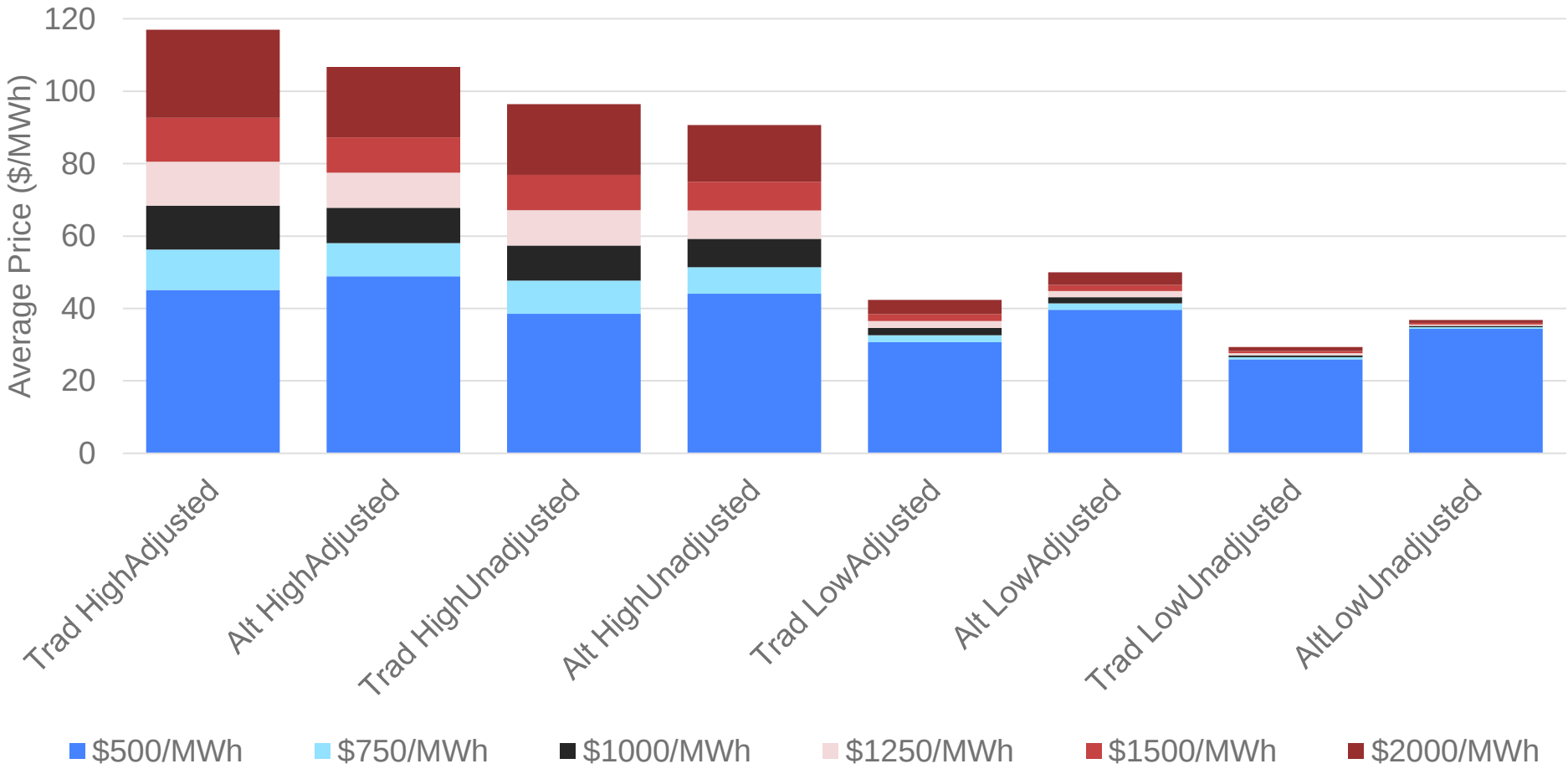
Alternative Pricing

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	34	33	33	33	34	36	49	36	33	31	31	30	30	30	30	31	35	45	47	46	39	39	38	35
Feb	34	33	32	32	33	35	38	34	32	31	31	31	30	30	30	31	33	38	41	40	42	37	36	35
Mar	33	32	32	32	33	35	41	32	31	31	30	30	30	30	30	31	32	36	60	41	39	38	35	34
Apr	34	34	34	36	55	34	32	31	30	30	30	30	31	31	31	32	32	34	72	146	38	36	54	35
May	34	33	33	32	32	34	31	31	32	33	33	34	34	35	36	36	37	38	40	41	39	37	36	36
Jun	36	35	33	33	33	32	32	34	35	37	37	38	39	40	84	67	68	42	48	42	41	51	53	39
Jul	37	36	35	34	34	33	34	35	36	38	39	95	95	236	238	160	127	63	73	84	44	42	41	39
Aug	37	36	35	35	35	35	35	35	36	37	39	61	87	206	139	204	94	50	82	63	43	41	40	38
Sep	35	34	33	33	34	36	34	34	35	36	36	37	38	90	128	128	51	58	46	42	41	39	38	37
Oct	34	33	32	33	34	36	35	33	32	33	33	33	33	33	33	34	36	40	47	39	38	37	36	35
Nov	33	32	32	32	32	57	53	32	31	30	31	31	31	31	31	32	37	45	40	39	38	37	36	34
Dec	39	37	40	38	55	56	73	36	32	30	30	29	28	28	29	30	56	65	46	43	40	39	41	36

DRAFT RESULTS

Sensitivity to scarcity price

- Scarcity price in results shown in prior statistics is $1000/MWh



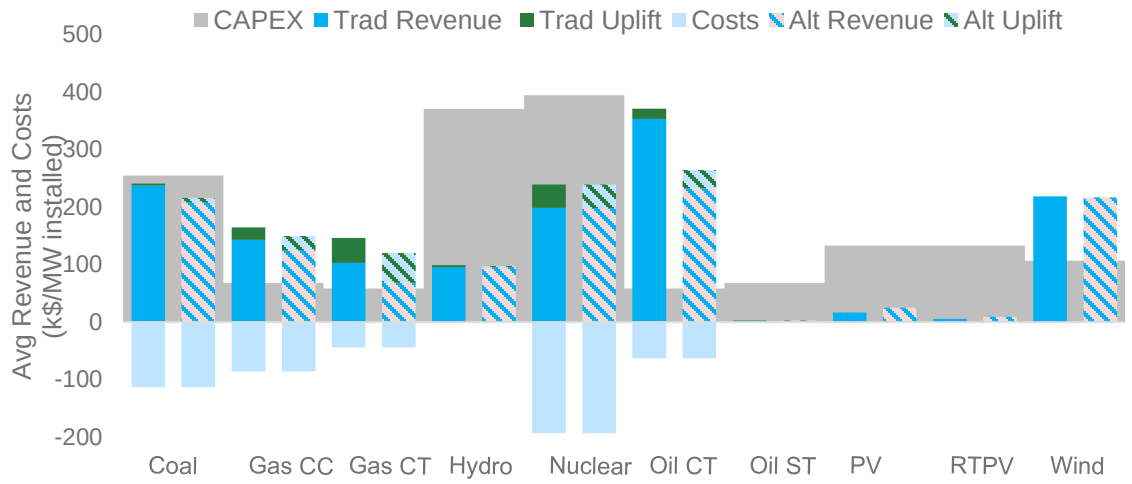
Revenue and Uplift for Renewables

- Revenue is the sum of day-ahead (DA) and real-time (RT)
  - DA Rev = (DA LMP)*(DA Dispatch)
  - RT Rev = (RT LMP)*(RT Dispatch – DA Dispatch)
    - RT based on the deviation, generators might need to buy back their position
- Renewable revenue is calculated from the real-time dispatch
  - Deviation between DA and RT forecast can occur due to forecast error or being dispatched down by the operator
  - Renewable generators do not buy back day-ahead position
- Profit is DA Revenue + RT Revenue + Uplift – RT Operating Costs
  - Figures show annual profits per MW of installed capacity

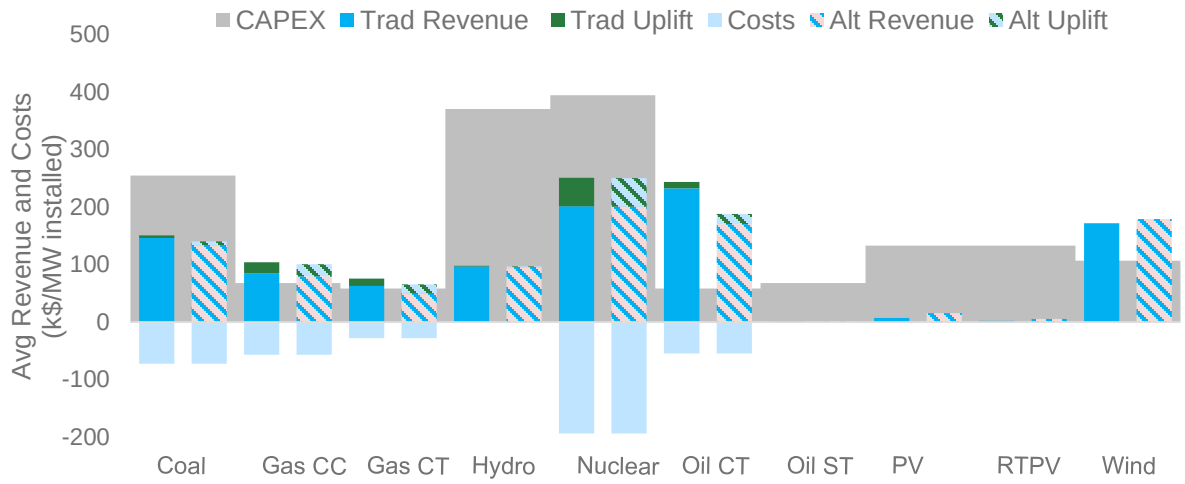
Results: Revenue & Cost Comparison

High Renewable

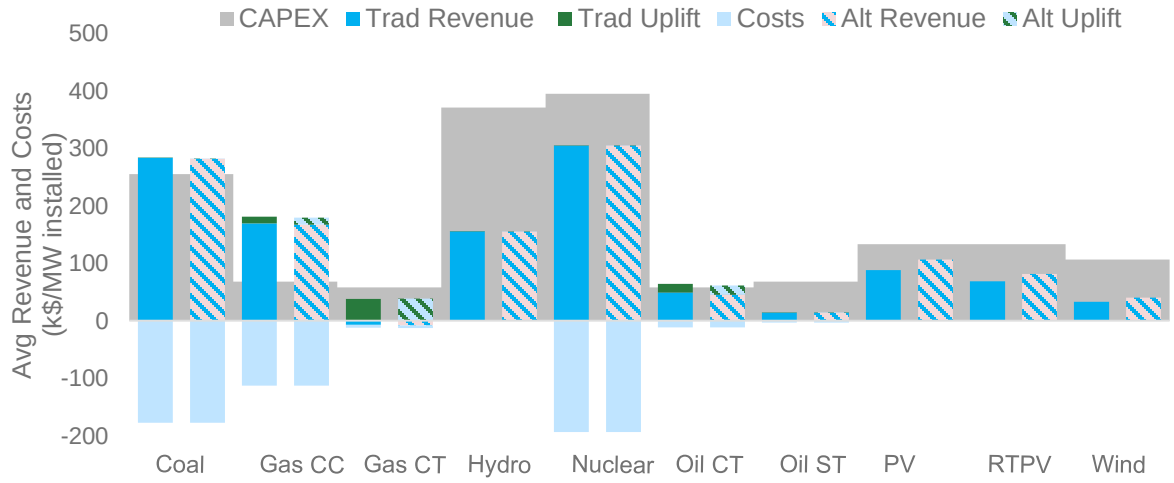
Adjusted System

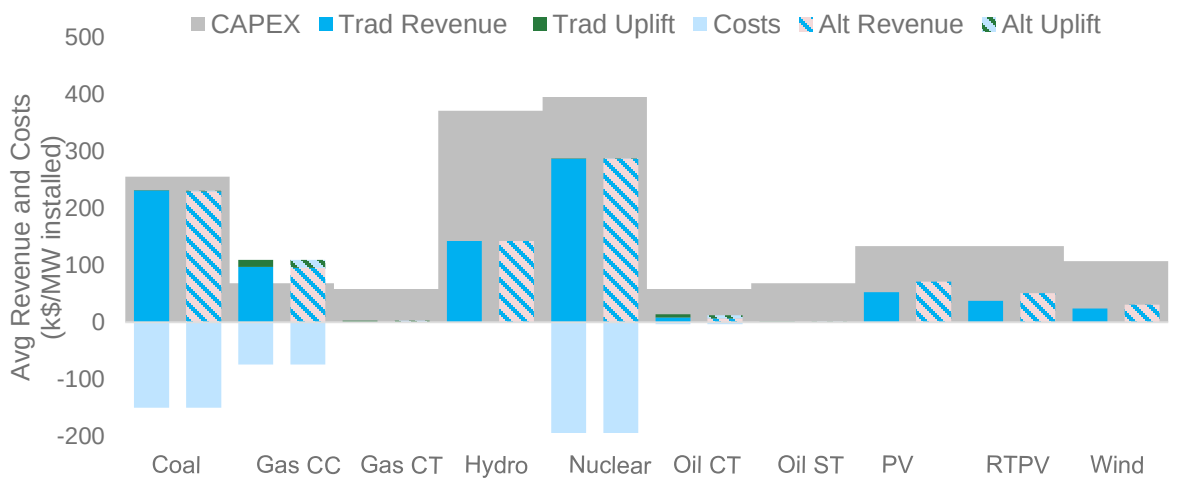


Unadjusted System



Low Renewable



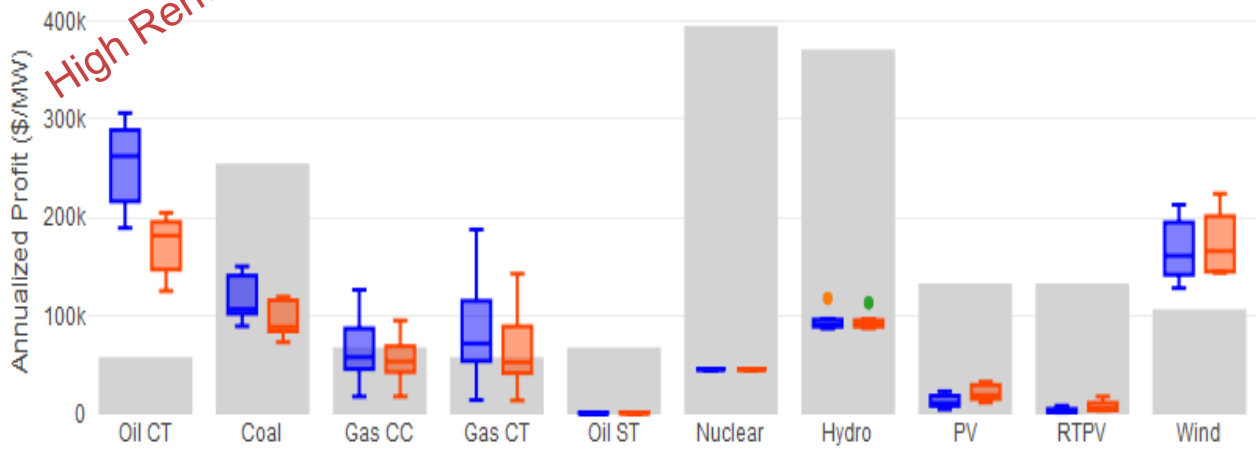


Annual Profits per MW

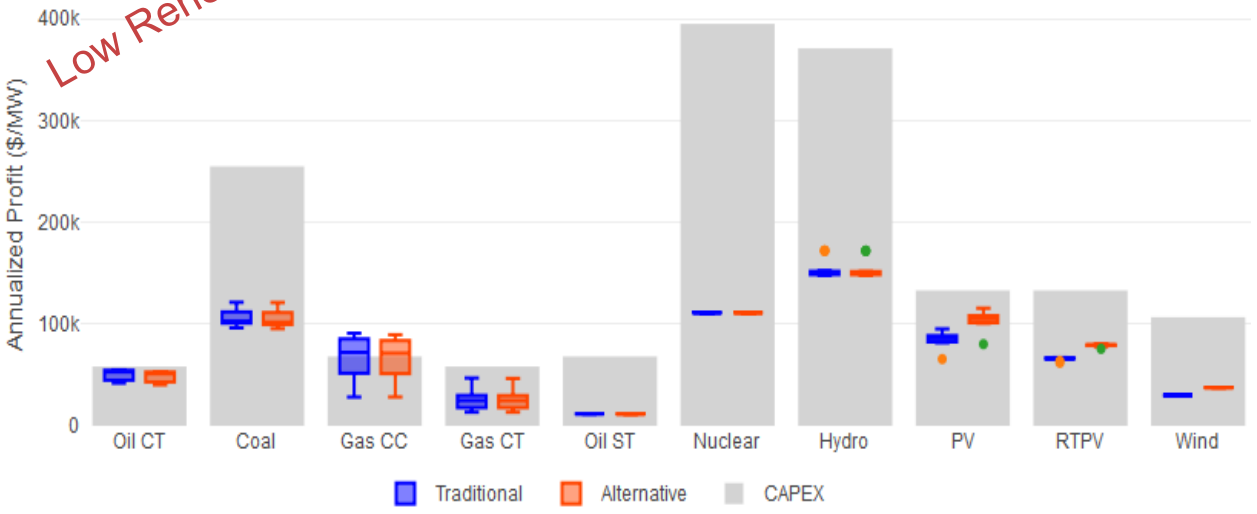
DRAFT RESULTS

System Meeting RA Target

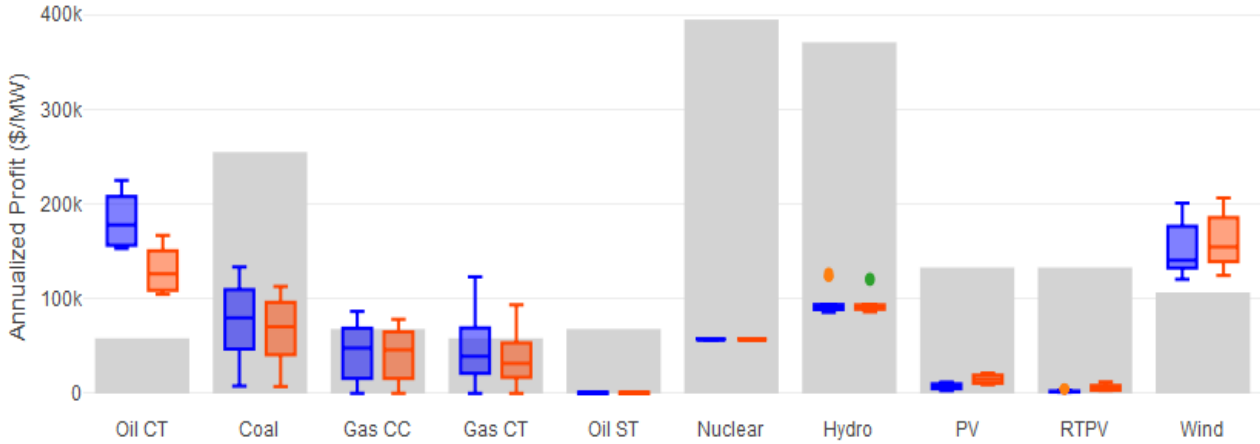
High Renewable

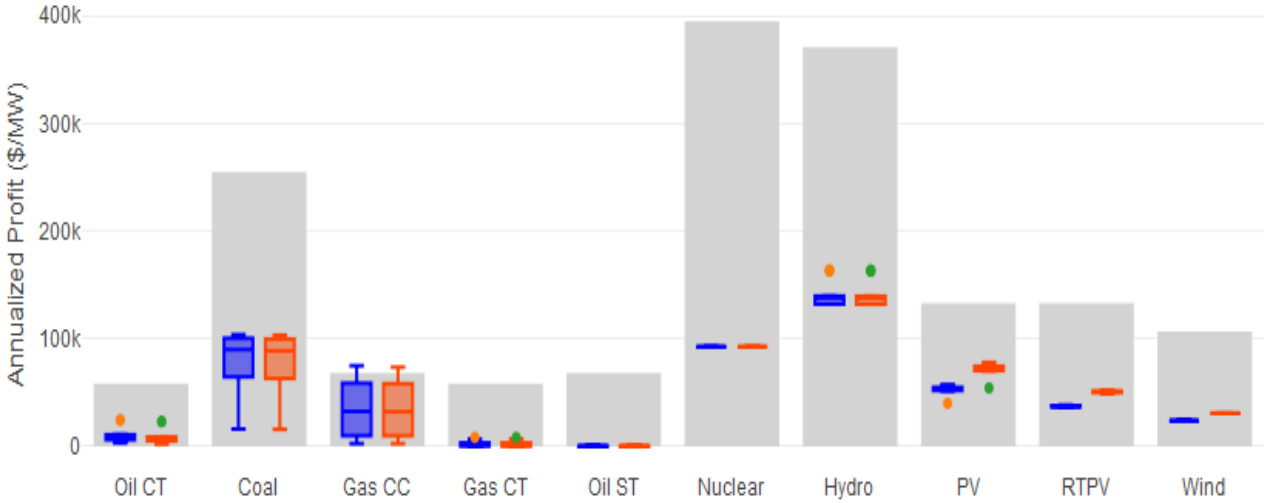


Low Renewable



Overbuilt System





Discussion

- For the simulated system, **renewable penetration** has a greater impact on pricing than the adjusted resource mix

- **Profits did not change significantly** between the two pricing methods
  - Change in profits per MW of installed capacity between the pricing methods ranges between +$2.2k/MW to -$3.6k/MW, representing 0.6% to 2.1% of average expenditure values
  - Under high penetration, wind was able to surpass their capital expenditure
  - Profits in these examples are highly dependent on choice of administratively set shortage/scarcity pricing levels, and operating strategies
- Prices in the higher renewable penetration were higher than the low renewable penetration for many cases
  - Renewables can add uncertainty to markets
  - Many periods of low to no cost prices are countered with very high peaks in the shoulder hours
  - **Choice of scarcity price plays an important role in modeling**

Future Work

- Results are not direct predictions for future outcomes
  - Beginnings of further research on pricing
- Assess other pricing methods
  - Average Incremental Cost Pricing
  - Dual Pricing Algorithm
  - Simulations for multi-period pricing proposals (look-ahead settlement)
- Simulations for multiple build outs (resource mixes)

Together...Shaping the Future of Electricity

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