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ECON 366: Energy Economics

Topic 3.4: Electricity Generation

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Electricity Generation Basics

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- plant characteristics
- plant costs
- plant revenues
- levelized cost of electricity (equiv. supply costs)
- generation mix here and elsewhere in Canada (data assignment)
- challenges of renewable integration
- forward markets and hedging

Key plant characteristics

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- capacity: peak generation, in MW
- capacity factor: average share of peak (%)
- dispatch: can I turn it on or off?
- seasonal constraints

Cost of New Generation

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- we tend to express the costs of new generation as the levelized cost of electricity (LCOE)
- this is, like the supply cost for oil sands, a value that represents the electricity market revenue you need to earn to make a reasonable rate of return on capital and/or equity
- you can think of it as an gross or a net measure, and I'll show you what I mean in both cases

Simplified LCOE

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You can simplify an LCOE using an annual amortization method (see NREL) to calculate a project's levelized cost of energy (LCOE), using the following inputs:

```
Capital cost, $ (TCC)
Fixed annual operating cost, $ (FOC)
Variable operating cost, $/kWh (VOC)
**Fixed charge rate (FCR)**
Annual electricity production, kWh (AEP)
```

NREL's LCOE calculator uses the following equation to calculate the LCOE:

$$LCOE = \frac{(FCR \times TCC + FOC)}{AEP} + VOC$$

The fixed charge rate, or FCR, is an annualized share of capital costs recovered each year, based on project financial parameters

True LCOE

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The LCOE is no different from a supply cost that we did for oil sands projects:

```
Capital cost, $ (K)
Fixed annual operating cost (FC)
Variable operating cost (VC), $/MWh
Discount rate (r), %
Annual electricity production (Q), MWh
```

$$LCOE = \sum_{t=0}^{T} \frac{1}{1+r} \frac{(K_t + FC_t + VC_t \times Q_t)}{Q_t}$$

It's a production-weighted average of the net present value costs per unit of generation, generally calculated at a rate of return of 5-10%

LCOE vs supply cost

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The LCOE is no different from a supply cost that we did for oil sands projects:

$$LCOE = \sum_{t=0}^{T} \frac{1}{1+r} \frac{(K_t + FC_t + VC_t \times Q_t)}{Q_t}$$

Think of it this way: if prices are such that:

$$\sum_{t=0}^{T} \frac{1}{1+r} P_t = \sum_{t=0}^{T} \frac{1}{1+r} \frac{(K_t + FC_t + VC_t \times Q_t)}{Q_t}$$

The project makes it's *break even* rate of return on capital

True LCOE

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Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Capacity (MW)	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175
Generation (MWh)	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540	582540
Electricity Revenue ($/MWh)	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81	34.81
Electricity Revenue ($millions)	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28
Carbon credits (t)	211229	207004	202864	198807	194831	190934	187116	183373	179706	176112	172589	169138	165755	162440	159191	156007	152887	149829	146833	143896
Carbon price	51.00	52.02	53.06	54.12	55.20	56.31	57.43	58.58	59.75	60.95	62.17	63.41	64.68	65.97	67.29	68.64	70.01	71.41	72.84	74.30
GHG policy revenue	10.77	10.77	10.76	10.76	10.76	10.75	10.75	10.74	10.74	10.73	10.73	10.73	10.72	10.72	10.71	10.71	10.70	10.70	10.70	10.69
Gross Revenue ($ millions)	31.05	31.05	31.04	31.04	31.03	31.03	31.02	31.02	31.02	31.01	31.01	31.00	31.00	30.99	30.99	30.99	30.98	30.98	30.97	30.97
Fixed Costs ($millions)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Variable Costs ($/MWh)	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Total Costs ($ Millions)	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58
EBITDA ($ Millions)	24.47	24.46	24.46	24.45	24.45	24.45	24.44	24.44	24.43	24.43	24.42	24.42	24.42	24.41	24.41	24.40	24.40	24.39	24.39	24.39
Capital costs ($ Millions)	238	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Debt open ($ Millions)	142.80	139.68	136.31	132.67	128.74	124.49	119.91	114.96	109.61	103.83	97.59	90.86	83.58	75.72	67.24	58.07	48.17	37.48	25.94	13.47
Interest ($ Millions)	11.42	11.17	10.90	10.61	10.30	9.96	9.59	9.20	8.77	8.31	7.81	7.27	6.69	6.06	5.38	4.65	3.85	3.00	2.07	1.08
Payment ($ Millions)	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54	14.54
Close ($ Millions)	139.68	136.31	132.67	128.74	124.49	119.91	114.96	109.61	103.83	97.59	90.86	83.58	75.72	67.24	58.07	48.17	37.48	25.94	13.47	0.00
Principle pmt ($ Millions)	3.12	3.37	3.64	3.93	4.25	4.59	4.95	5.35	5.78	6.24	6.74	7.28	7.86	8.49	9.17	9.90	10.69	11.55	12.47	13.47
Depreciation Expense ($ Millions)	23.80	47.60	47.60	47.60	47.60	23.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Taxable income ($ Millions)	-10.76	-34.31	-34.05	-33.76	-33.45	-9.31	14.85	15.24	15.66	16.12	16.62	17.15	17.73	18.35	19.03	19.76	20.54	21.40	22.32	23.31
Taxes (net, $ millions)	-2.47	-7.89	-7.83	-7.76	-7.69	-2.14	3.42	3.51	3.60	3.71	3.82	3.94	4.08	4.22	4.38	4.54	4.73	4.92	5.13	5.36
After tax cash flow ($ millions)	-82.80	17.81	17.74	17.67	17.60	12.04	6.48	6.39	6.29	6.18	6.06	5.93	5.79	5.65	5.49	5.31	5.13	4.93	4.71	4.48
IRR	12%																			

Excel model available here.

Lazard LCOE

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EIA AEO LCOE

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Table 1b. Estimated unweighted levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2027 (2021 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[a]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[b]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	85%	$52.11	$5.71	$23.67	$1.12	$82.61	*NA*	$82.61
Combined cycle	87%	$9.36	$1.68	$27.77	$1.14	$39.94	*NA*	$39.94
Advanced nuclear	90%	$60.71	$16.15	$10.30	$1.08	$88.24	-$6.52	$81.71
Geothermal	90%	$22.04	$15.18	$1.21	$1.40	$39.82	-$2.20	$37.62
Biomass	83%	$40.80	$18.10	$30.07	$1.19	$90.17	*NA*	$90.17
Resource-constrained technologies								
Wind, onshore	41%	$29.90	$7.70	$0.00	$2.63	$40.23	*NA*	$40.23
Wind, offshore	44%	$103.77	$30.17	$0.00	$2.57	$136.51	-$31.13	$105.38
Solar, standalone[c]	29%	$26.60	$6.38	$0.00	$3.52	$36.49	-$2.66	$33.83
Solar, hybrid[c,d]	28%	$34.98	$13.92	$0.00	$3.63	$52.53	-$3.50	$49.03
Hydroelectric[d]	54%	$46.58	$11.48	$4.13	$2.08	$64.27	*NA*	$64.27
Capacity resource technologies								
Combustion turbine	10%	$53.78	$8.37	$45.83	$9.89	$117.86	*NA*	$117.86
Battery storage	10%	$64.03	$29.64	$24.83	$10.05	$128.55	*NA*	$128.55

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

EIA AEO LCOE

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NREL Solar LCOE

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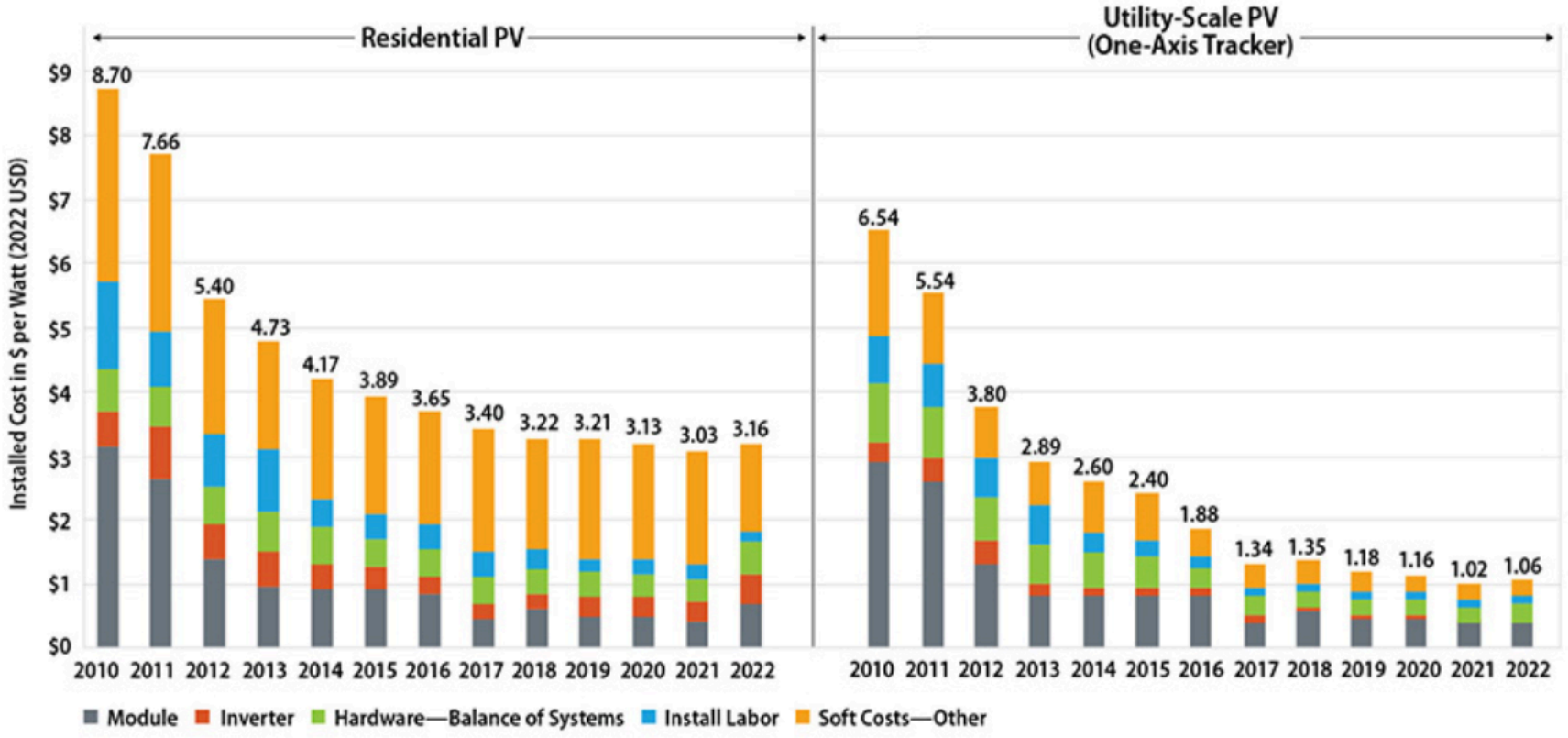
Solar Installed System Cost Analysis

NREL analyzes the total costs associated with installing photovoltaic (PV) systems for residential rooftop, commercial rooftop, and utility-scale ground-mount systems. This work has grown to include cost models for solar-plus-storage systems.



NREL Solar LCOE Report

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What determines LCOE

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- capital cost
- capacity factor
- operating costs
- taxes and subsidies incl. carbon prices
- fuel costs
- transmission costs (in some locations, not Alberta)
- debt and equity costs (WACC)
- non-electricity revenue (e.g. RECs or offsets)

What about revenue?

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- dispatchable plants can avoid low cost periods and take advantage of high cost periods
- storage assets can arbitrage high and low prices
- some non-dispatchable assets may generate at peak price periods (e.g. solar)
- renewable generation tends to be correlated and thus associated with lower prices
- renewable generation can erode value of *base-load* plants

CAISO Daily Patterns of Prices and Loads

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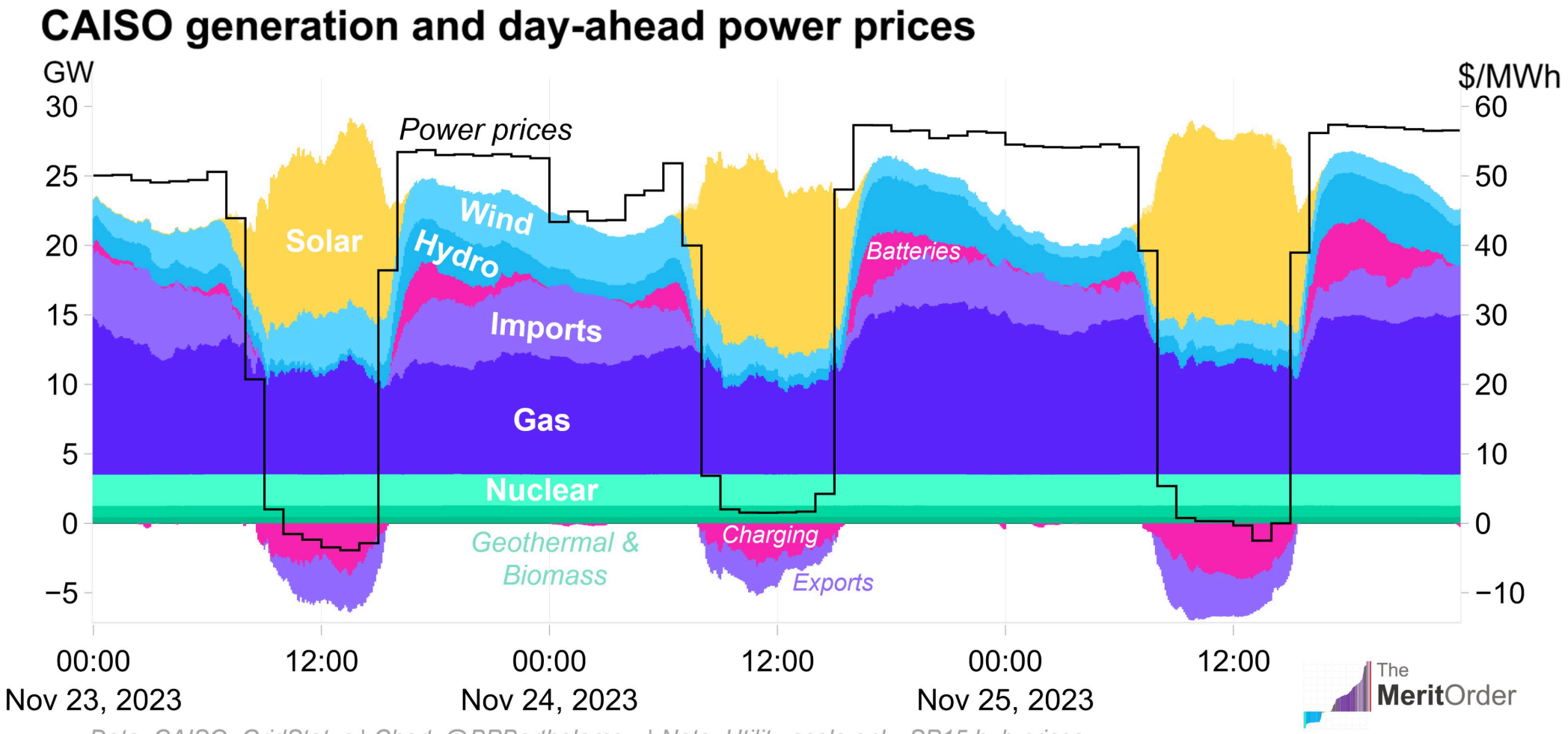

Data: CAISO, GridStatus | Chart: @BPBartholomew | Note: Utility-scale only, SP15 hub prices

Dispatch and correlation lead to different average revenues

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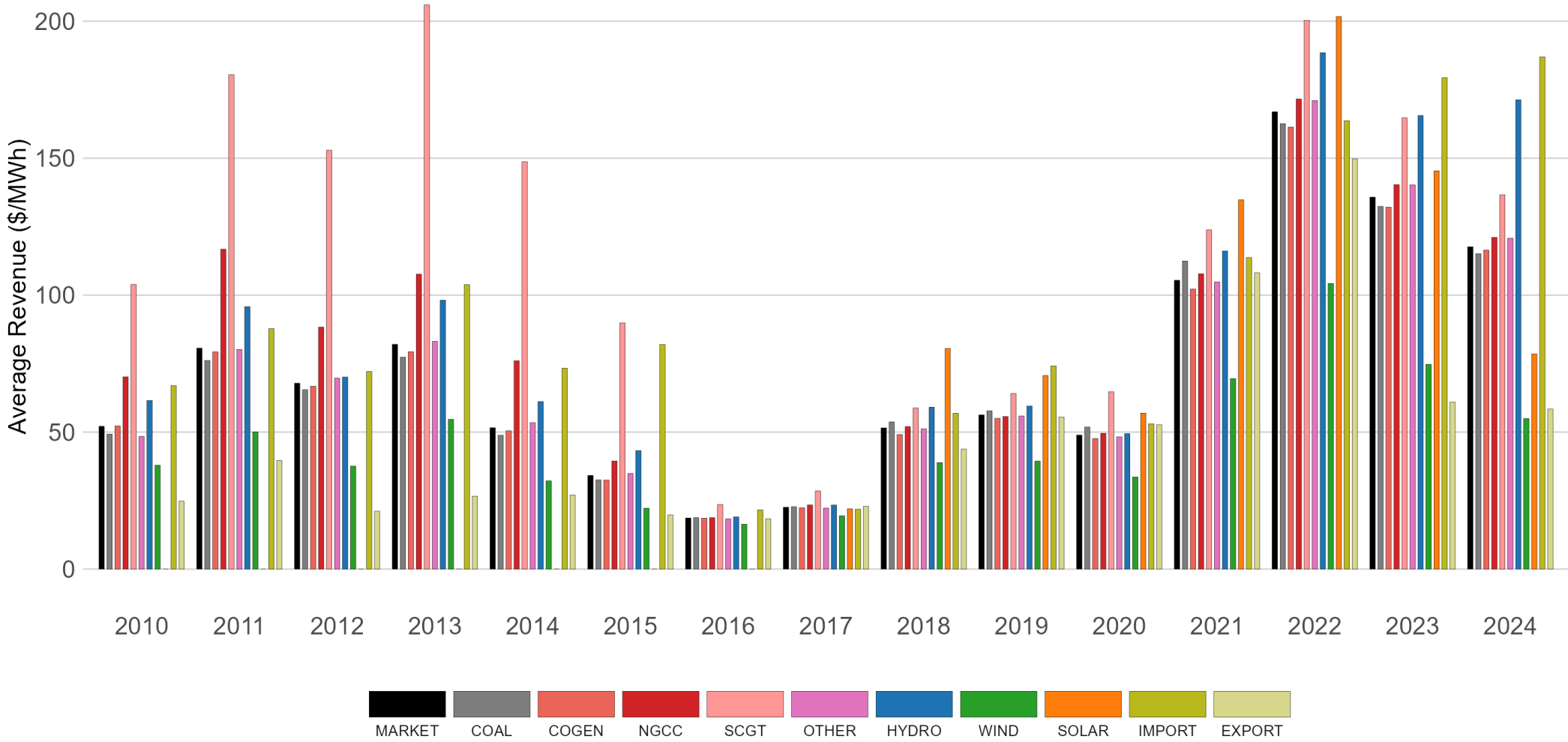

Source: AESO data accessed via NRGStream, graph by @andrew_leach

Dispatch and correlation lead to different average revenues

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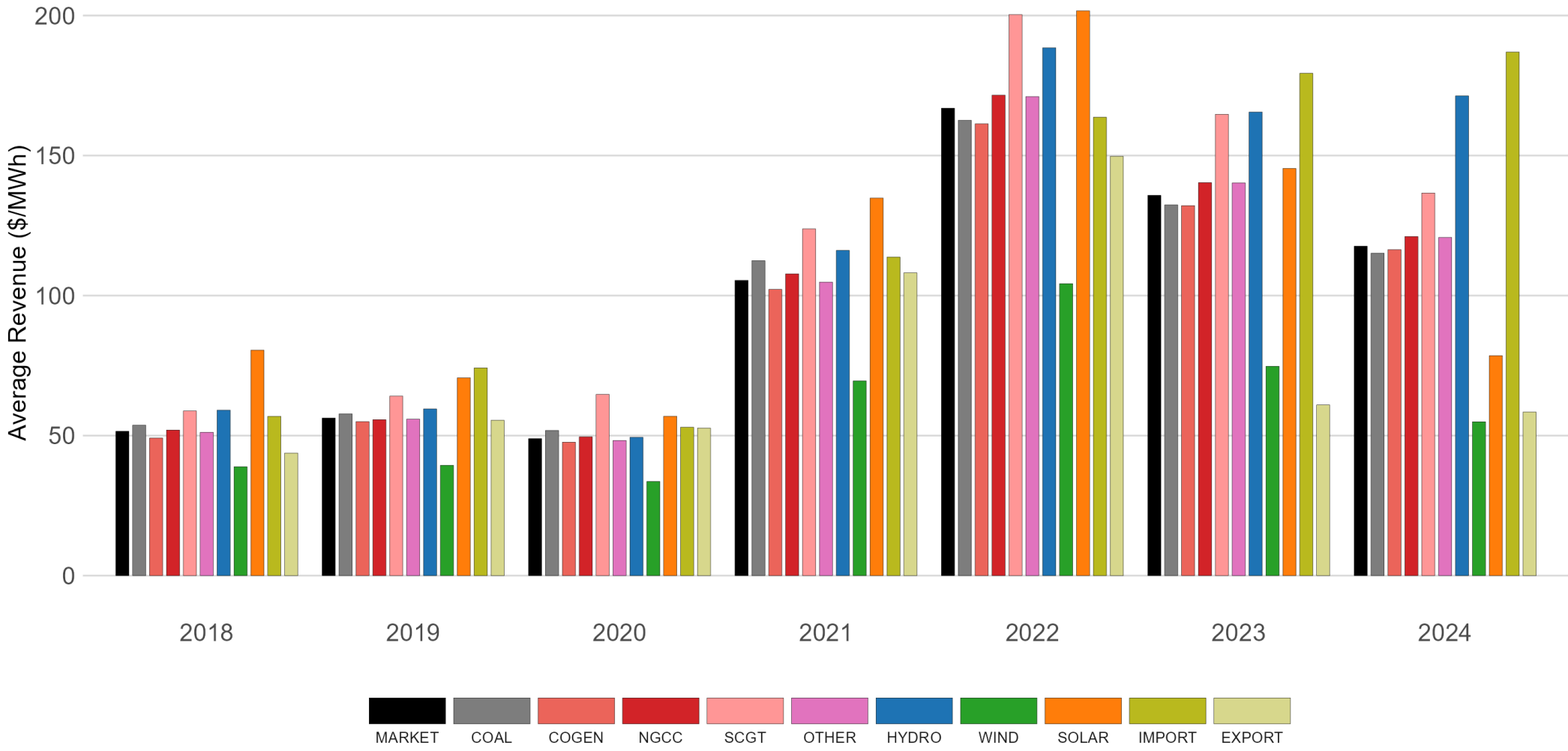

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The *duck* curve

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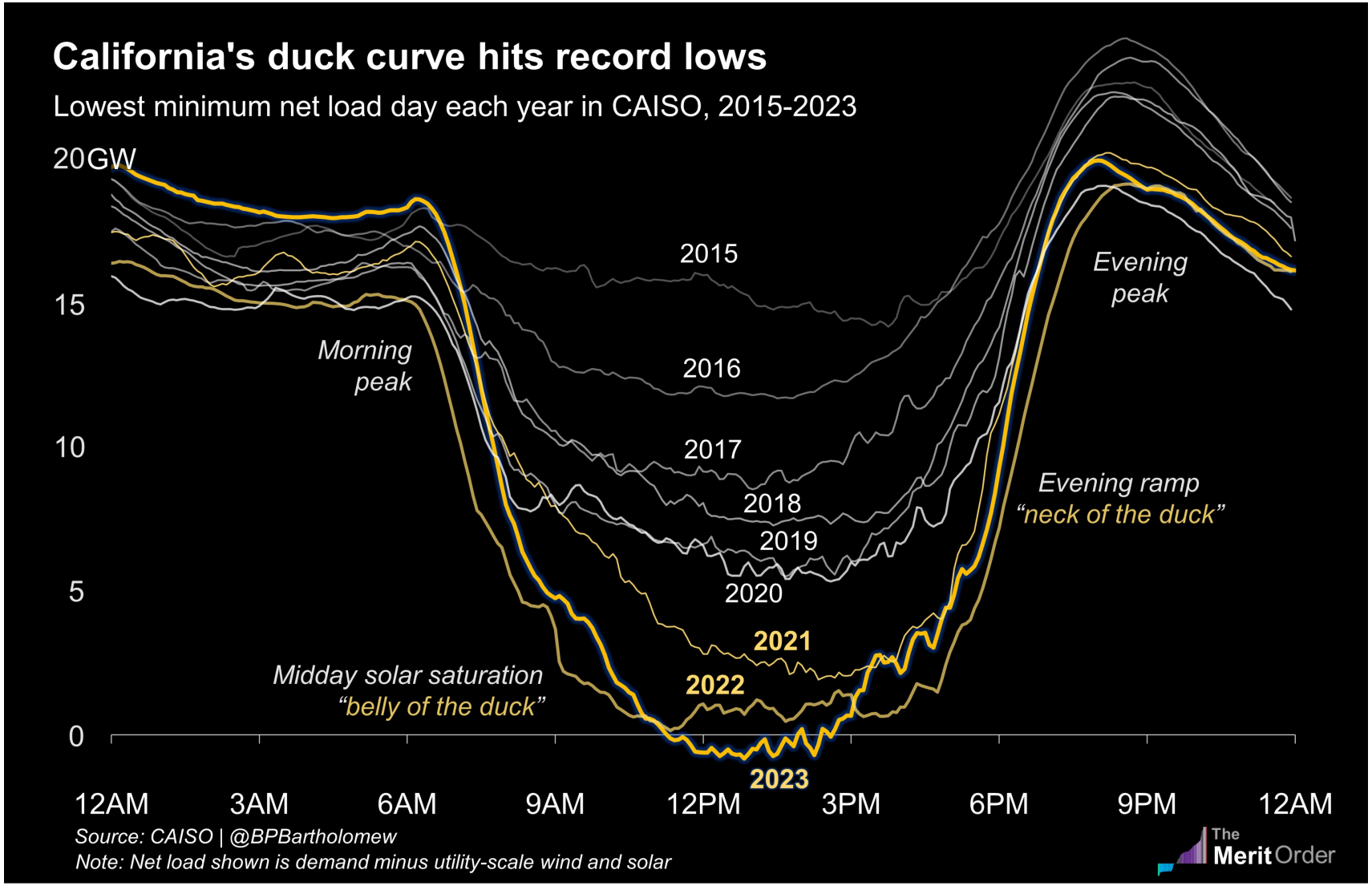

Carbon tax costs matter

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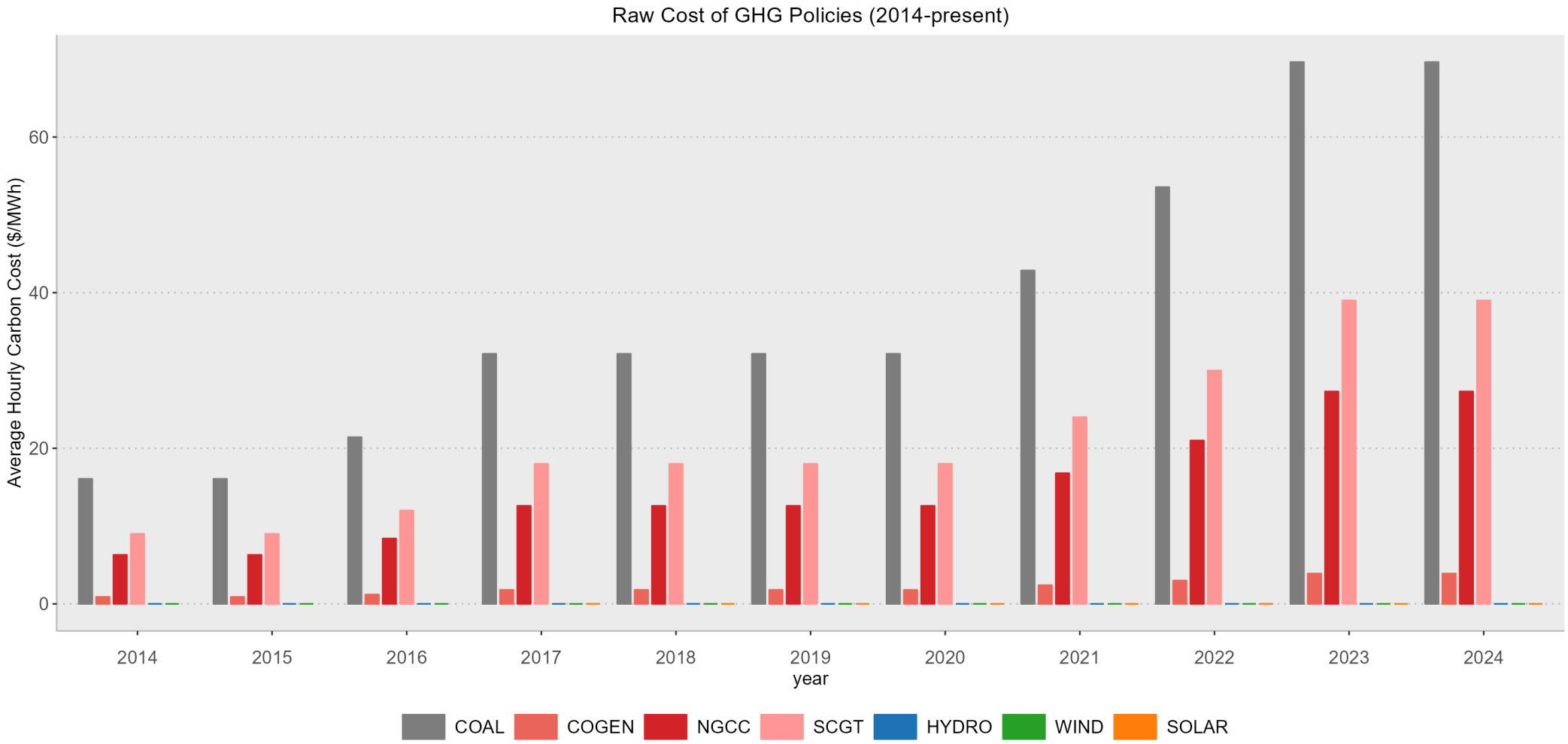

Source: AESO and SGER Data, with assumption that renewables capture full offset value pre-2018.
AESO data accessed via NRGStream, graph by @andrew_leach

But, so does the value of *output-based allocations*

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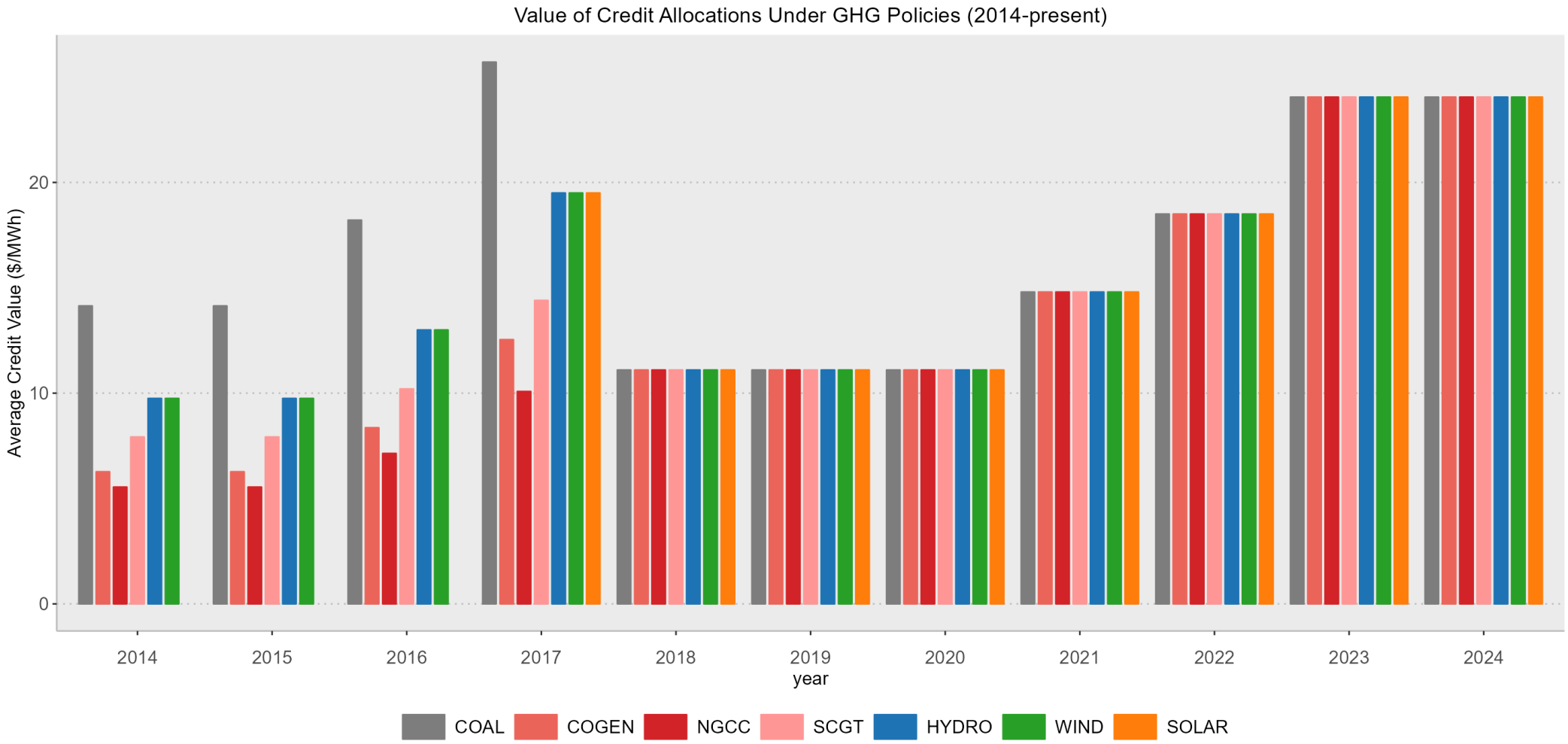

Source: AESO and SGER Data, with assumption that renewables capture full offset value pre-2018.
AESO data accessed via NRGStream, graph by @andrew_leach

Combined impacts on revenues

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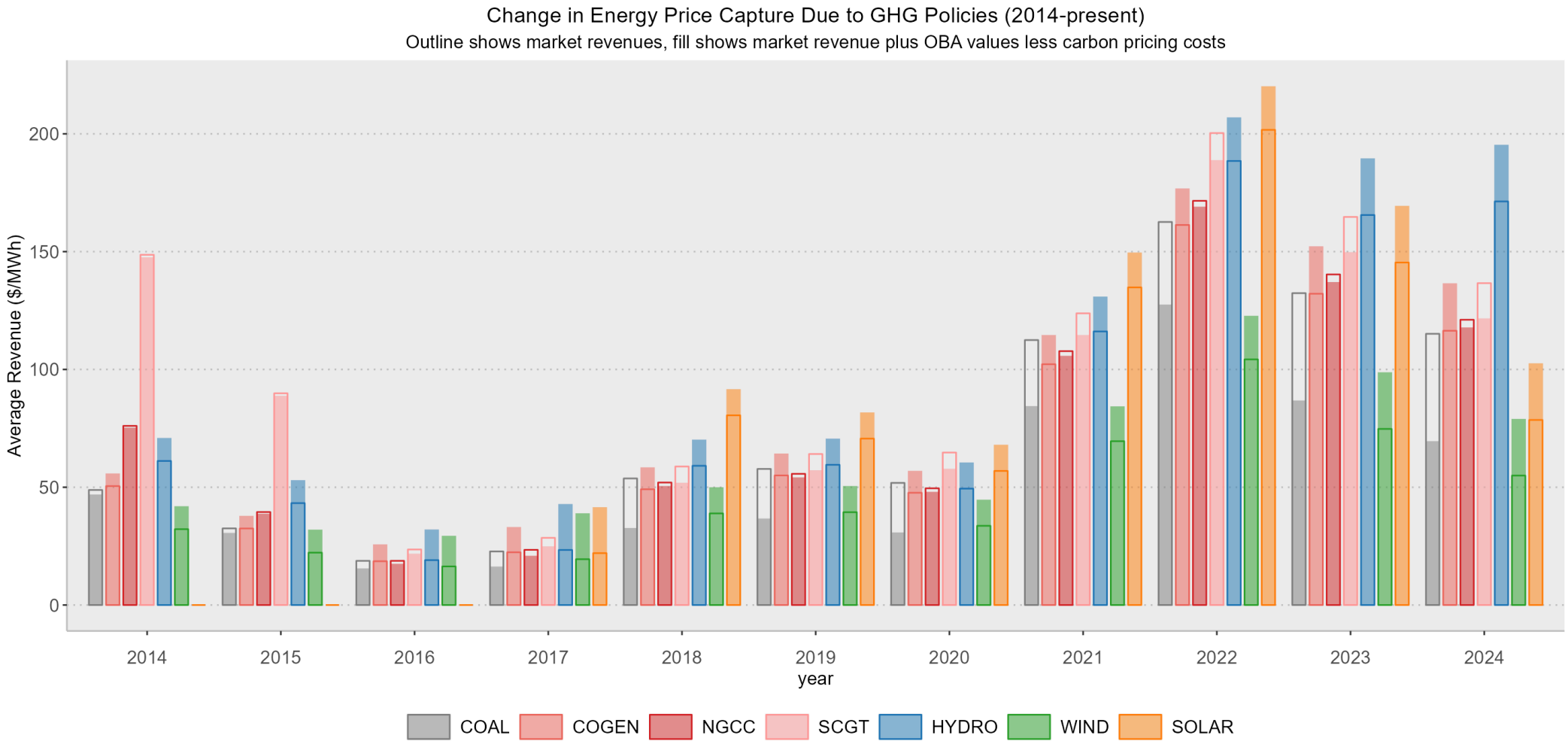

Source: AESO and SGER Data, with assumption that renewables capture full offset value pre-2018.
AESO data accessed via NRGStream.

Dispatch and correlation lead to different average revenues

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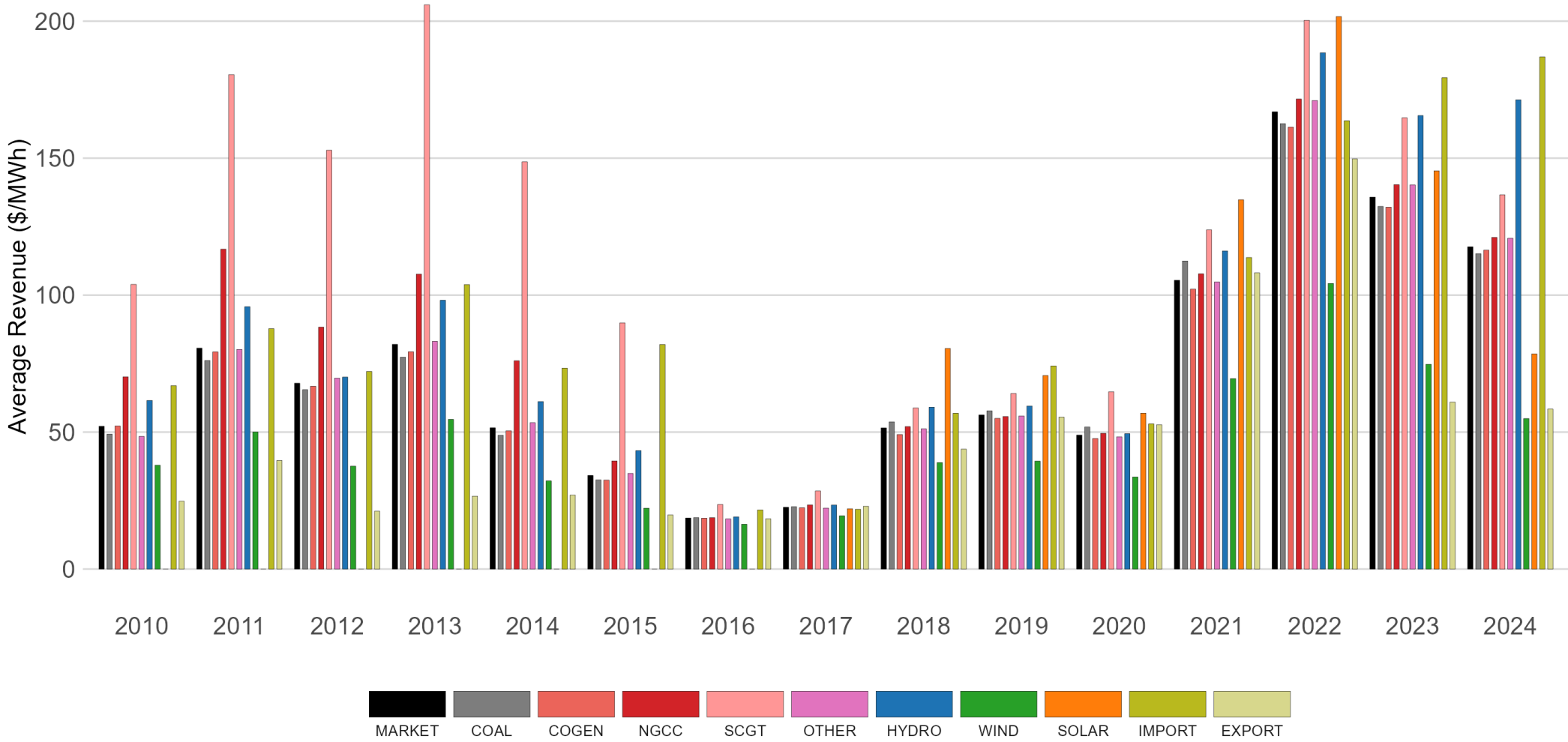

Source: AESO data accessed via NRGStream, graph by @andrew_leach

Market Power And Economic Withholding

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- Lerner index (% markup of price over marginal cost)
- Market concentration metrics (3-firm, 4-firm concentration ratios, Herfindahl Hirschman Index (HHI))
  - $$HHI = \sum_{i=1}^{n} S_i^2$$

    , where

    $$S_i$$

    is the market share of each firm i in the market
- Is economic withholding a bad thing?

Market Power And Economic Withholding

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