



**UNIVERSITY
OF ALBERTA**

ECON 366: Energy Economics

Topic 3.4: Electricity Generation

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Electricity Generation Basics

- 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

- 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

- 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

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

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

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

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](#).



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APRIL 2023



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 transmission 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*



Levelized Costs of New Generation Resources in the Annual Energy Outlook 2023



EIA Energy Information Administration
April 2023
www.eia.gov/aio

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Introduction

- The paper presents average values of levelized costs for new generation resources as represented in the National Energy Modeling System (NEMS) for the Annual Energy Outlook (AEO) 2023. The AEO 2023 includes:
- Levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) represent the minimum cost required to build and operate generation and storage resources, respectively, over a specified asset lifetime period.
- Levelized avoided cost of electricity (LACOE) is an estimate of the maximum value of new generation during the same period.
- Although LCOE, LCOS, and LACOE do not fully capture all the factors contributing to the capacity expansion decisions, they provide a useful comparison of the relative economic competitiveness among a wider variety of technologies than is possible using LCOE, LCOS, or LACOE exclusively.
- Both a capacity-weighted average reflecting fuel input-output variations and a capacity-weighted average of the regional values across the U.S. are reported for the AEO 2023. Capacity-weighted values are reported for the AEO 2023.

See EIA's report, *Annual Energy Outlook 2023*, for more information on methodology, data, and results.

Link to the report: <https://www.eia.gov/aio/levelizedcosts/>

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AEO2023 representation of tax incentives

The AEO2023 representation of tax incentives is based on the AEO2023 assumptions for the AEO2023. The AEO2023 includes the AEO2023 representation of tax incentives for the AEO2023.

Where applicable, we show LCOE with and without tax credits for a resource available in the year in which the plant is first operated.

The Production Tax Credit (PTC) is a production-based tax credit for electricity generated by wind, solar, and geothermal. The PTC is available for the first 10 years of operation. The PTC is available for the first 10 years of operation. The PTC is available for the first 10 years of operation.

Link to the report: <https://www.eia.gov/aio/levelizedcosts/>

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Technology-specific implementation of tax incentives

The provisions of the AEO2023 for tax incentives are based on the AEO2023 assumptions for the AEO2023. The AEO2023 includes the AEO2023 representation of tax incentives for the AEO2023.

We consider the implementation of the PTC for the AEO2023. The AEO2023 includes the AEO2023 representation of tax incentives for the AEO2023.

Because of high capital costs, we assume that the AEO2023 includes the AEO2023 representation of tax incentives for the AEO2023.

Link to the report: <https://www.eia.gov/aio/levelizedcosts/>

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General assumption

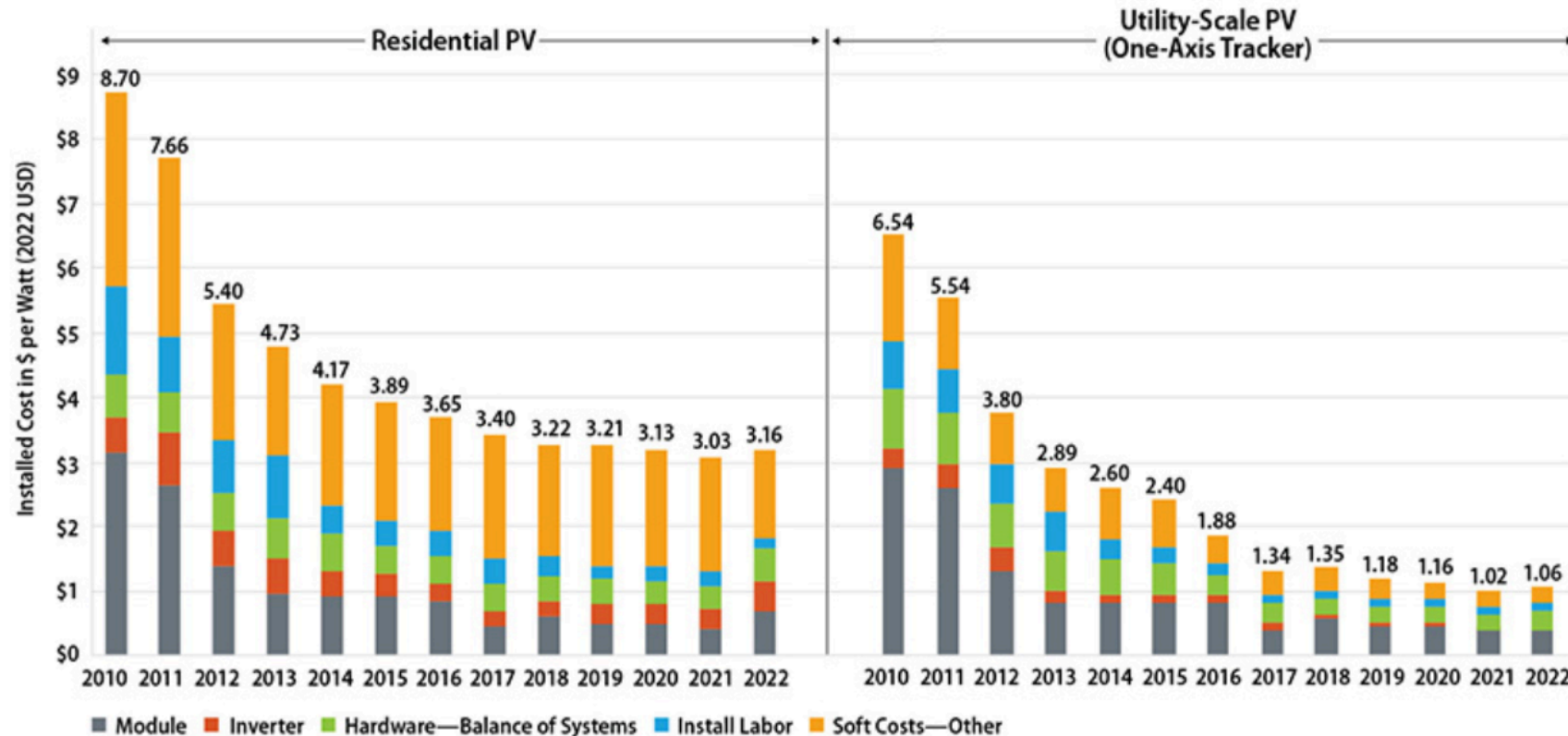
The AEO2023 includes the AEO2023 representation of tax incentives for the AEO2023. The AEO2023 includes the AEO2023 representation of tax incentives for the AEO2023.

Levelized Costs of New Generation in the Annual Energy Outlook 2023



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.



What determines LCOE

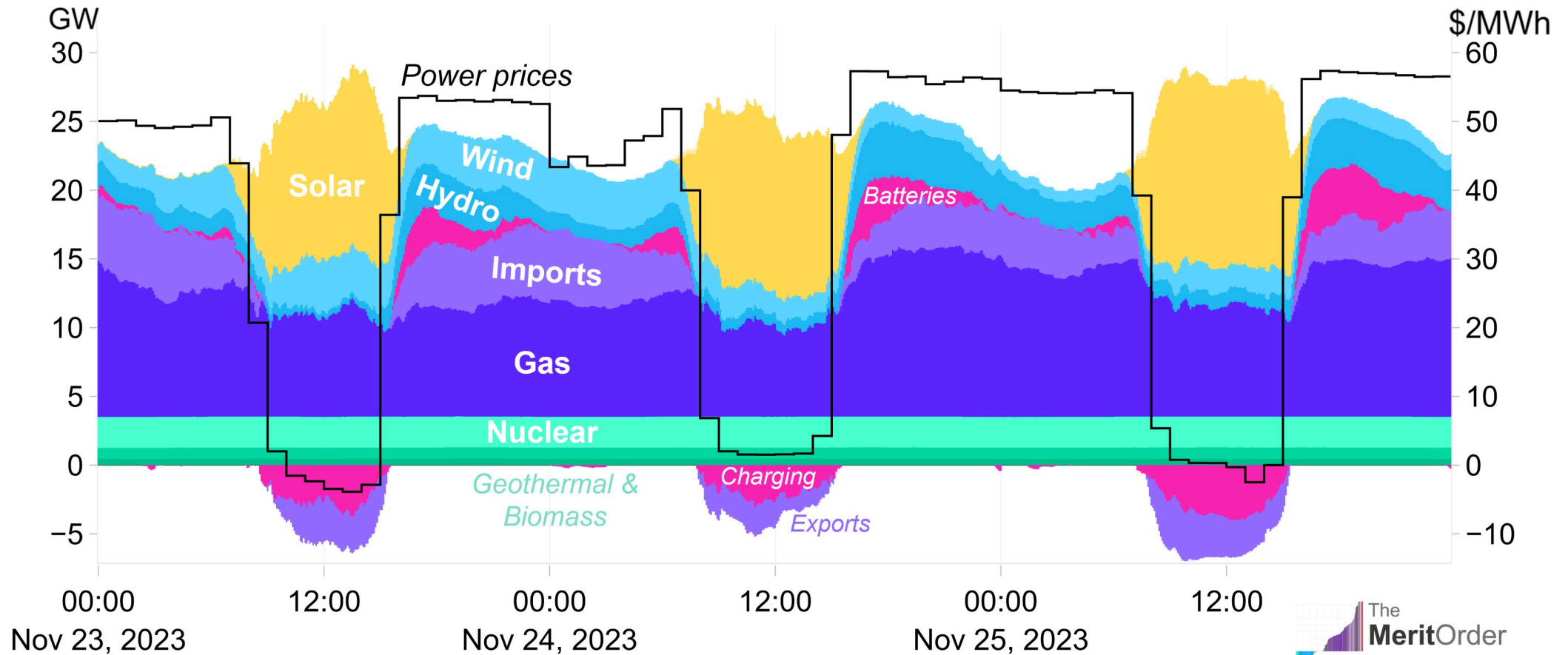
- capital cost
- capacity factor
- operating costs
- taxes and subsidies incl. carbon prices
- fuel costs
- transmission costs (in some locations, not Alberta)
- debt and equity costs (WACC)
- non-electricity revenue (e.g. RECs or offsets)

What about revenue?

- 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

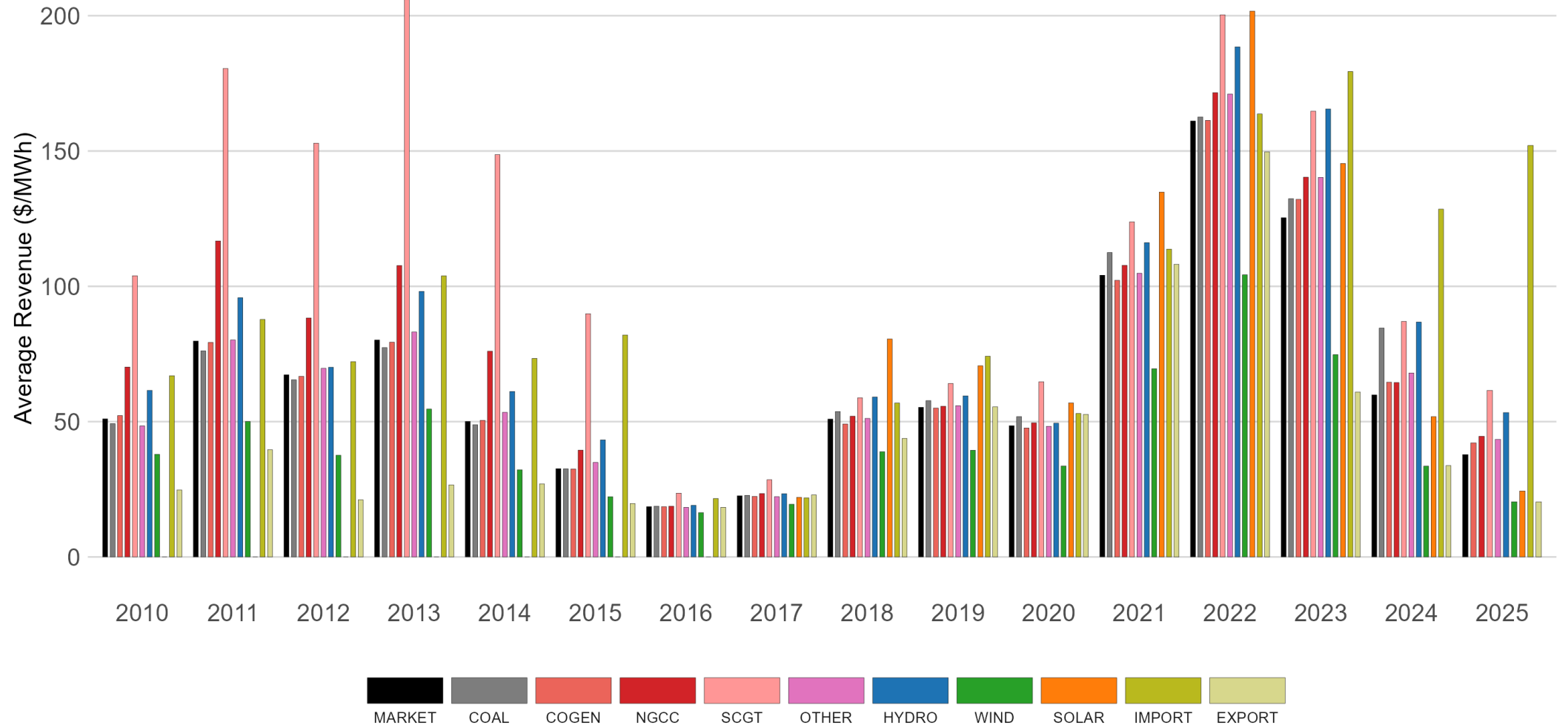
CAISO Daily Patterns of Prices and Loads

CAISO generation and day-ahead power prices



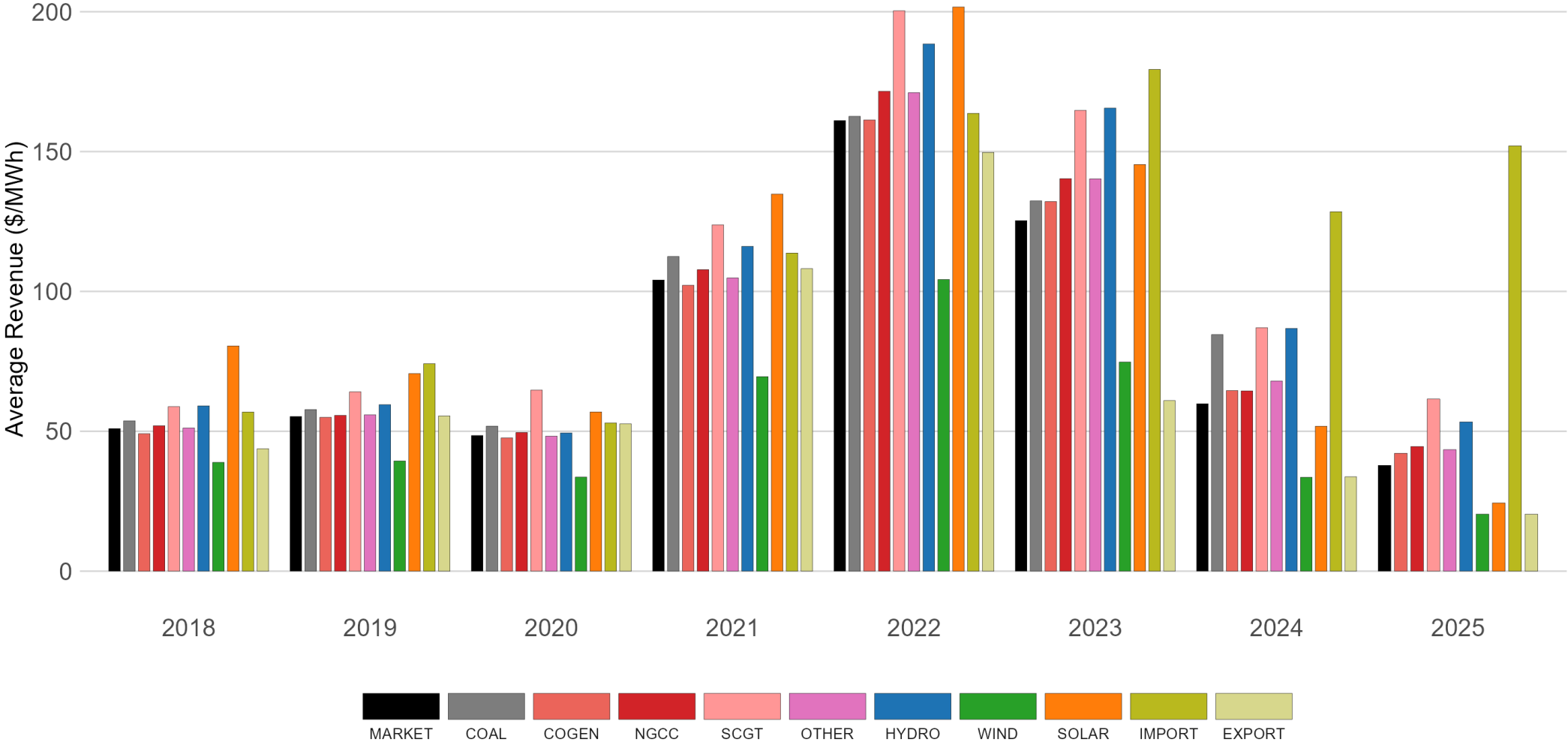
Data: CAISO, GridStatus | Chart: @BPBartholomew | Note: Utility-scale only, SP15 hub prices

Dispatch and correlation lead to different average revenues



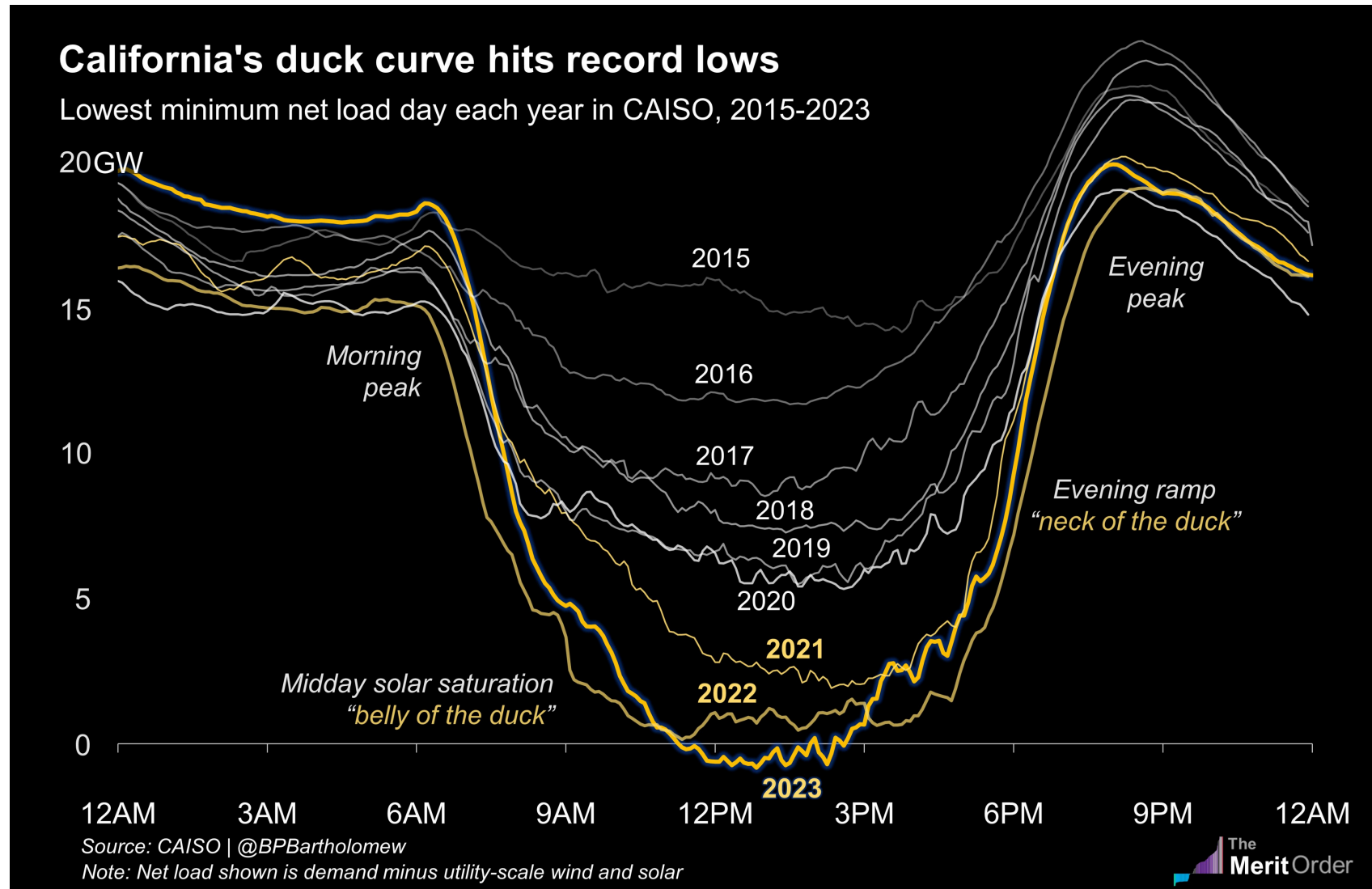
Source: AESO data accessed via NRGStream, graph by @andrew_leach

Dispatch and correlation lead to different average revenues



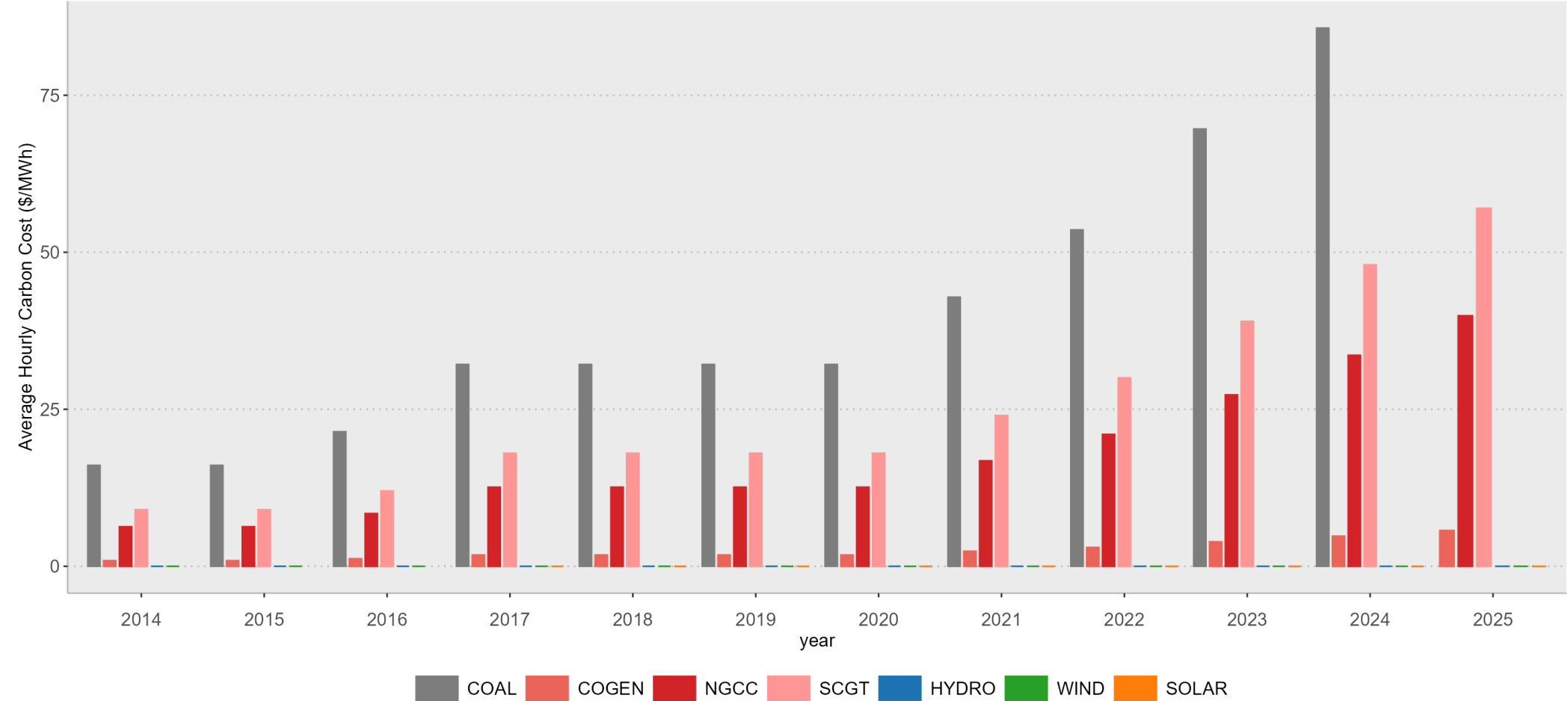
Source: AESO data accessed via NRGStream, graph by @andrew_leach

The *duck* curve



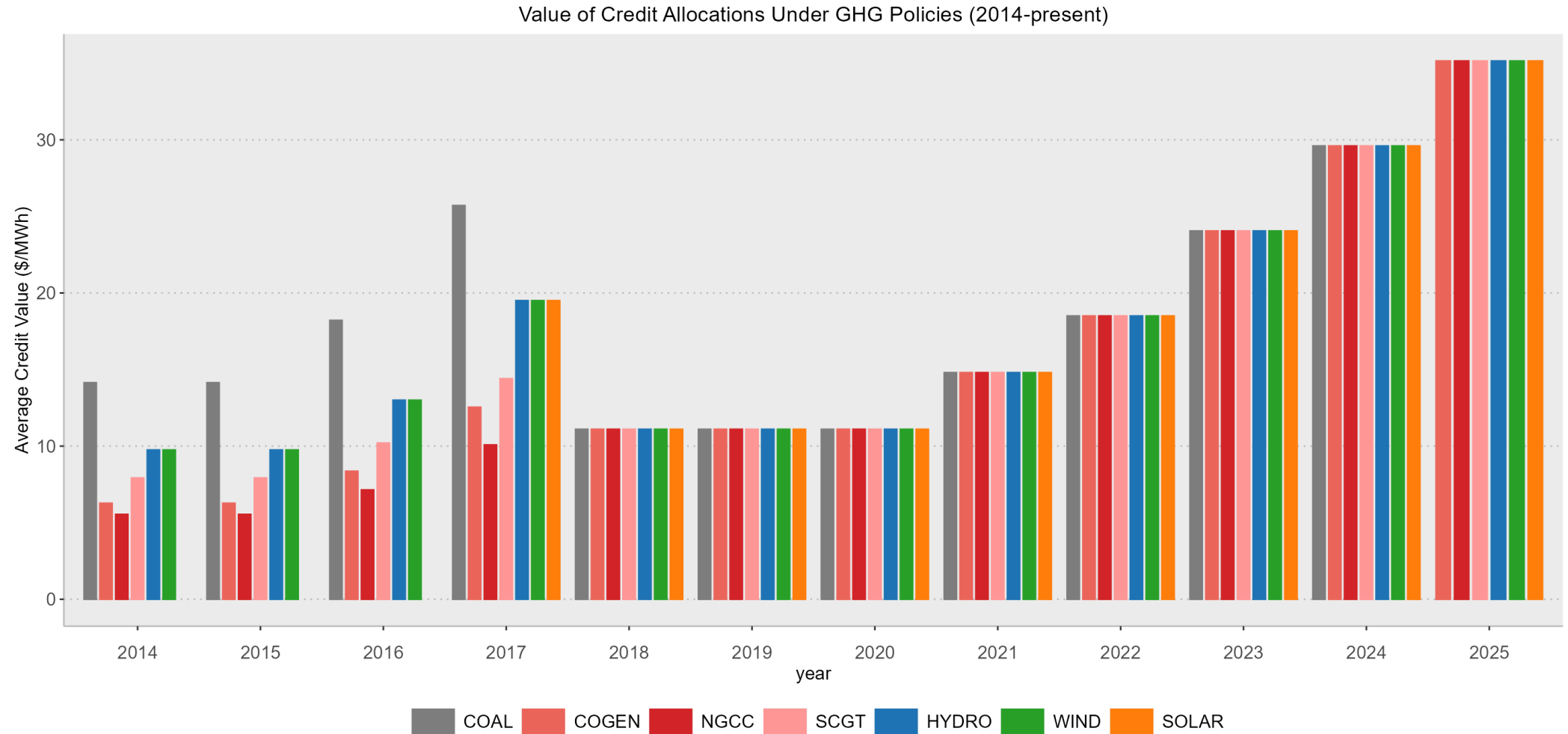
Carbon tax costs matter

Raw Cost of GHG Policies (2014-present)



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

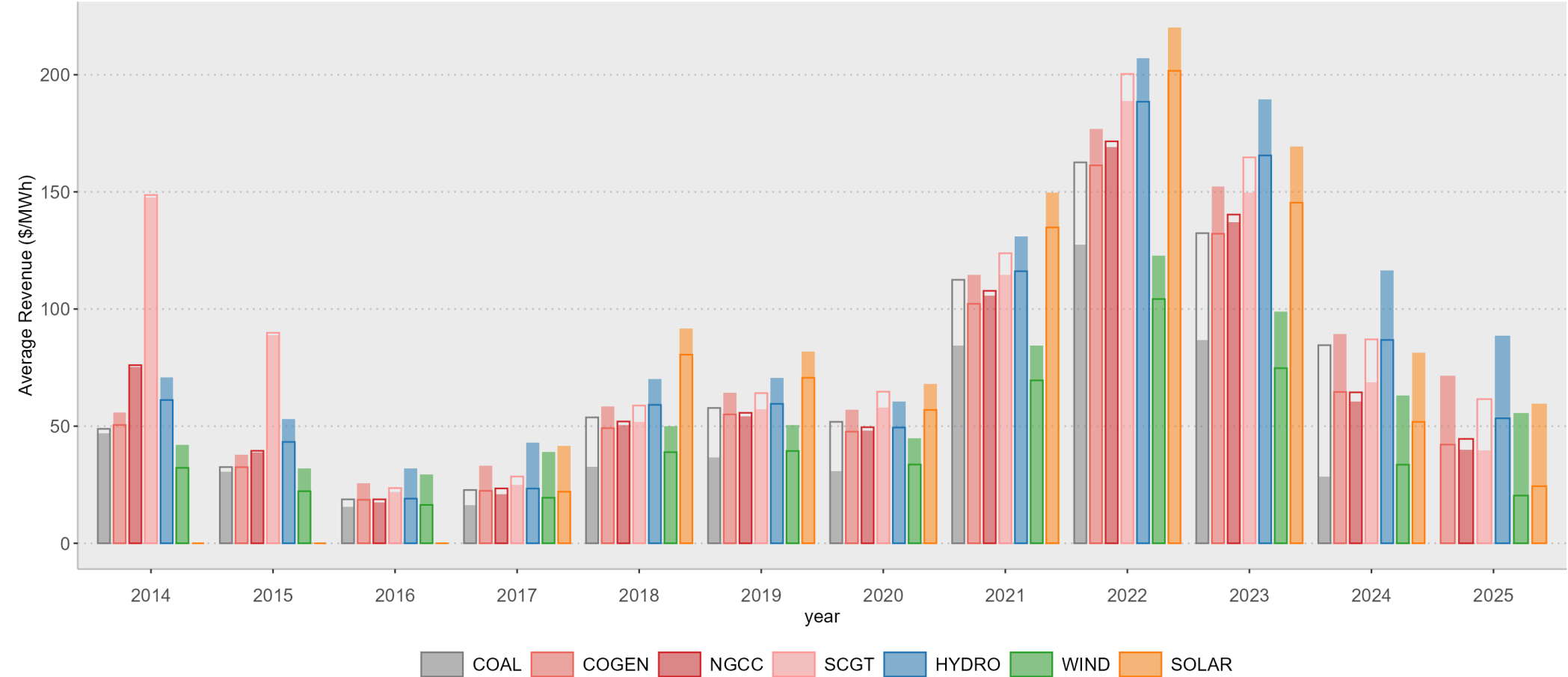
But, so does the value of *output-based allocations*



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

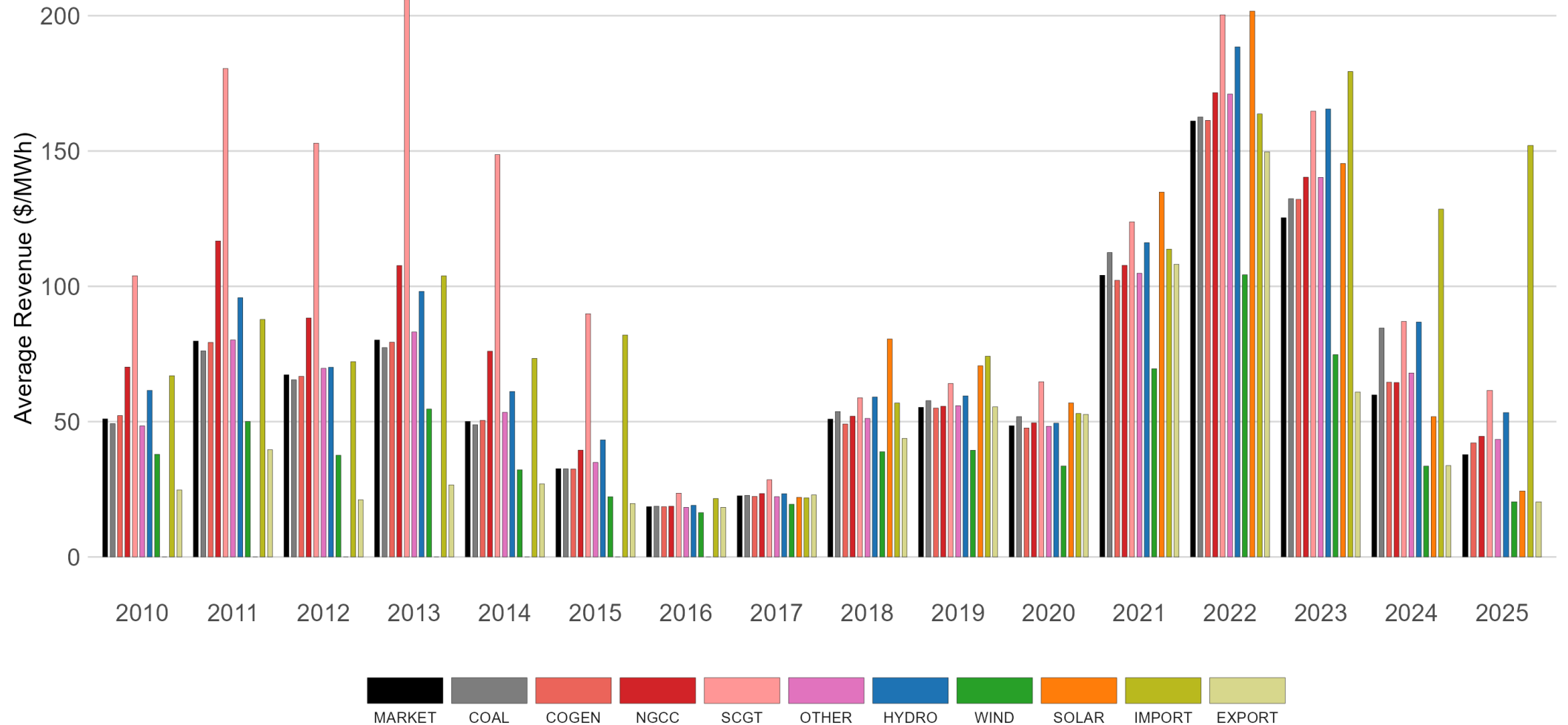
Combined impacts on revenues

Change in Energy Price Capture Due to GHG Policies (2014-present)
Outline shows market revenues, fill shows market revenue plus OBA values less carbon pricing costs



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



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

Market Power And Economic Withholding

- 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

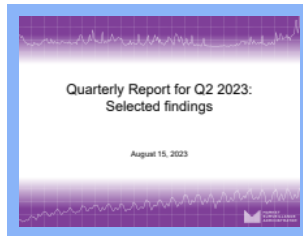
- Is economic withholding a bad thing?

Market Power And Economic Withholding

PowerPoint Presentation

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72%



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Presentation outline

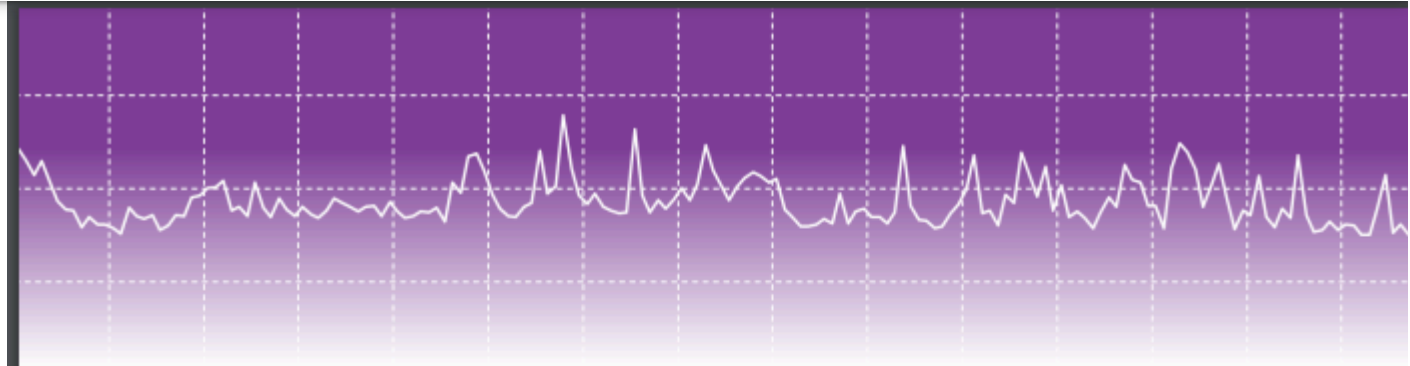
- Scope of this presentation
- Energy market
 - Market power and offer behaviour
 - Carbon emissions
 - Long lead time
- Power system
 - Transmission congestion and post price formation
 - Wind and solar constrained down generation
- Operating reserve markets
- Forward market
- Retail market
- Micro-generation update

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Scope of this presentation

- This presentation provides a selection of findings contained in the MGA's Quarterly Report for Q2 2023
 - Only selected figures are included here
 - Readers are referred to the Quarterly Report itself for discussion of the figures
- All content in this presentation was copied directly from the Quarterly Report and no additional information, including by exclusion of any material, is provided here.

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Quarterly Report for Q2 2023: Selected findings

August 15, 2023