Title

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Grid Value and Cost of Utility-Scale Wind and Solar:

Potential Implications for Consumer Electricity Bills

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Image source: Google Gemini

Contents

Project Objectives

Wind and solar cost declines and wholesale power price fluctuations have once again brought the “hedge value” of renewable energy to front of mind. Meanwhile, recent research has found that cost savings are the most persuasive driver of broad support for renewable energy. Yet whether consumers directly benefit from the price hedge that wind and solar can provide depends on various factors, most notably the contractual and market structures under which these generators operate. Drawing upon a vast amount of plant-level empirical data, we quantify the net market value (“net value”) of wind and solar over time and explore various factors that determine the extent to which consumers can capture and benefit from that value. The focus is on elements that may directly impact consumer electricity bills.

Motivation and Goal

- **Inflection point: Wind and solar power are increasingly economic**
  - Power purchase agreement prices for wind and solar have increased in recent years, partly due to supply chain pressures[1]
  - Nonetheless, levelized generation costs have historically declined, reaching price parity with other forms of generation[2]
  - Wholesale electricity prices continue to fluctuate, again bringing the “hedge value” of solar and wind power to front of mind
- **Consumer electricity bill savings**
  - The societal benefits of wind and solar have historically motivated state (and federal) policy support
  - But for many, potential cost savings is the most persuasive driver of support or opposition for renewable energy[3]
  - Customer electricity bills are impacted by many drivers, of which the cost and value of wind and solar is one
- **Open analysis questions**
  - How has the cost of past utility-scale wind and solar compared to its wholesale market value? What is the net value?
  - What are the drivers for, time profile, and regional details of those net value results?
  - How do contractual and market structures impact the degree to which end-use customers benefit from that value?
- **Analysis scope and methods**
  - Drawing on plant-level empirical data, we quantify the historical “net value” of wind and solar over time
  - We then explore various factors that determine the extent to which consumers can capture and benefit from that value
  - Focus is on several key elements that may directly impact consumer electricity bills, not on broader cost and value element

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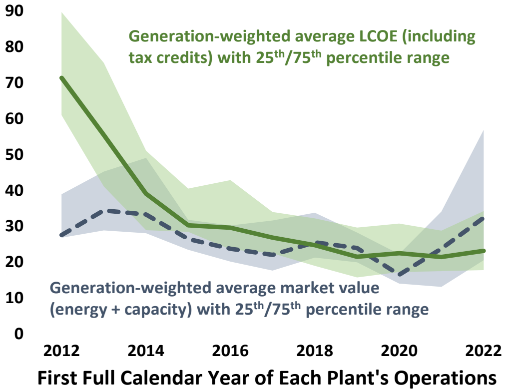
[1] See, for example: https://www.leveltenenergy.com/
[2] See, for example: https://www.sciencedirect.com/science/article/pii/S2589004222006496?via%3Dihub
[3] See, for example: https://www.nature.com/articles/s41560-022-01099-2

High-Level Findings

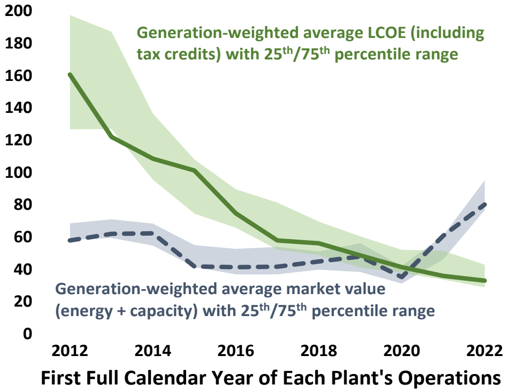
(1) Wind and solar economics have improved over time

- Wind and solar costs (after tax credits) have been roughly in-line with market value since 2018 or 2019, increasingly enabling economic purchases in the absence of state policy
- Improvement in “net value” among more recent plant vintages is primarily due to significant declines in the cost of wind and PV over time, coupled with an uptick in wholesale market value in 2021 and especially 2022

Wind LCOE and Market Value (2022 $/MWh)



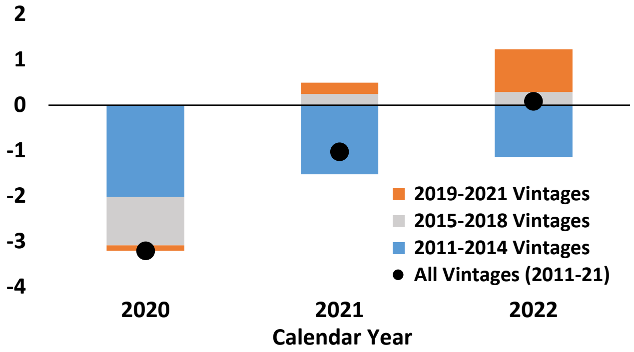
Solar LCOE and Market Value (2022 $/MWh)



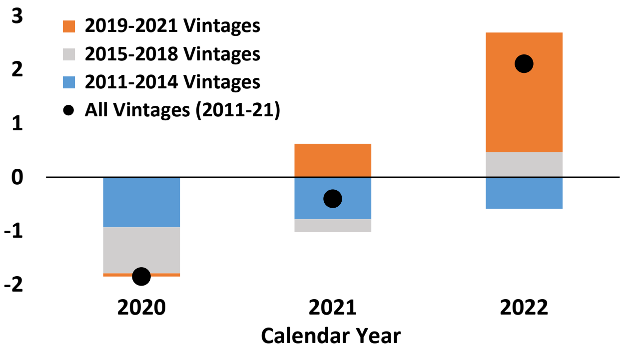
(2) Consumer electric bill savings and hedge value are possible

- Considering all plants within sample, in 2022, solar generated $2.1 billion in net value nationwide, wind generated $100 million
- Net costs in previous years were primarily due to the dominance of early wind and solar projects that had higher costs
- Considerable regional diversity exists in the results
- With solar and wind increasingly competitive as bulk power assets, the question of “who benefits” is becoming more important

National Wind Net Value (Billion $)



National Solar Net Value (Billion $)



(3) Whether end-use customers benefit via lower electricity bills and hedge value is impacted by contractual structures

- In the case of regulated and public utilities, any savings (or costs) from owned or contracted generation tend to pass through to customers; same is true with voluntary demand when PPAs are used; fixed-price unbundled RECs do not offer same potential value
- Improved economics of wind and solar over time are causing, in some cases, purchasers to rethink their contracting practices to ensure that retail customers (especially residential customers) capture more of the hedge value that wind and solar can provide

INTRODUCTION

Can installing new wind and solar power plants reduce electricity bills?

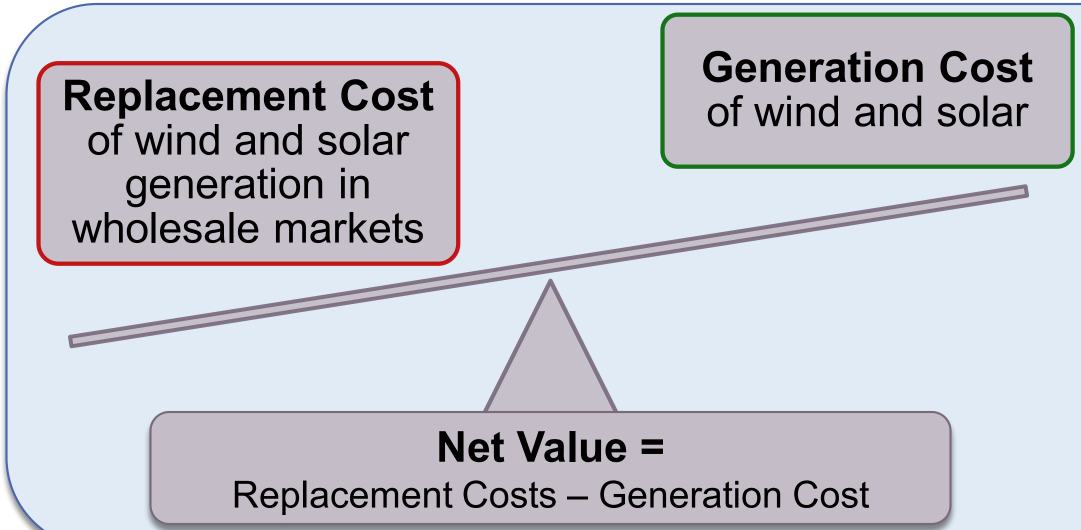
Why research this question now?

Because we are at a key inflection point:

Electricity from wind and solar plants used to be expensive but is now much cheaper

- New technologies in general, and wind and solar in our case, typically follow a declining cost curve – they are expensive at first but become much cheaper as production of the technologies increases over time
  - Cost declines are due to many factors such as economies of scale, technological improvement, and manufacturing optimizations
- 10 to 15 years ago, electricity from wind and solar was often expensive compared to wholesale market prices, and deployment was supported through public policies such as renewables portfolio standards and tax credits
  - State and federal policies, domestically and internationally, helped drive early deployment and resulting cost reductions
  - Wind and solar were, and continue to be, supported through public policy partly because they provide public benefits beyond what is contained in market prices, such as through reducing health and environmental damages from fossil-fuel generation
- Roughly 5 years ago, wind and solar costs (with federal tax incentives) declined to the point that costs were sometimes (or often) lower than wholesale market prices→ increasingly enabling economic purchases absent state mandates
- These cost declines and the alignment between cost and wholesale market value raise the possibility that wind and solar cannot only provide public benefits, but also possibly lower consumer electricity bills
- The analysis that follows assesses the market cost-value balance on a plant-by-plant basis across the United States to determine the potential impact on consumer electricity bills
- Multiple factors impact retail electricity rates and customer bills: wind and solar cost and value affect electricity procurement costs, but their influence is often not the dominant one; many drivers makes causal attribution challenging

Net value: The cost of generating wind and solar electricity *versus* the cost of purchasing replacement electricity in wholesale power markets



Replacement Cost of wind and solar generation in wholesale markets

Generation Cost of wind and solar

Net Value = Replacement Costs – Generation Cost

- Replacement cost is determined by hourly real-time energy prices at the location and times of wind and solar generation plus an adder describing their capacity (resource adequacy) contributions
  - Replacement cost = energy value + capacity value
  - Also described and known as “wholesale market value”
- Generation cost of wind and solar is estimated as project-level levelized cost of electricity (LCOE)

- Net value is positive when the cost to purchase replacement energy in wholesale markets (i.e., wholesale market value) is greater than the cost of wind and solar generation
- A positive net value indicates the possibility for consumer electricity bill savings, a negative net value indicates possible consumer expenses
- A positive net value can occur because wind and solar plants have relatively low costs or when wholesale prices rise high in particular years
- Over the long term (in equilibrium) we expect net value to equal zero – cost and value are balanced because a positive net value leads to additional deployment until the point where net value reaches zero

Net value is different from plant profitability

- **Important to note that net value will often not equate to plant profitability for the developer / plant owner**
  - Actual revenue earned by a plant can diverge from “replacement cost” for several reasons, for example:
    - Long-term power sales agreements that lock-in revenue, even if different from real-time wholesale market prices
    - Revenue from the sale of renewable energy certificates into compliance (RPS) markets or voluntary markets

- **Nevertheless, net value is relevant from a societal perspective**
  - For the purchaser, it captures the economic trade-off in choosing between entering a wind or solar contract or, instead, purchasing electricity directly from the wholesale spot market
  - This tradeoff is one that all purchasers of electricity face, whether a utility, a retailer, or a large end-use customer
  - A positive net value creates the opportunity for power-sector cost savings for purchasers, which can be distributed to retail customers

Why would net value be different from zero?

- **Long-term versus short-term costs**
  - Solar and wind projects generally sign multi-year sales agreements at fixed or known prices
  - If wholesale electricity prices then increase, for example, in 2022 electricity prices spiked with natural gas costs, the net value of wind and solar could be positive (as the earlier wind and solar plants are still selling at the previously established fixed price)
  - The above situation is often described as a ‘hedge’ value of wind and solar – fuel prices, such as natural gas, are historically variable, and wind and solar can provide a value by reducing the impact of fuel price spikes
- **Market friction makes equilibrium hard to reach**
  - Interconnection delays, for example, may limit the rate at which new inexpensive wind and solar plants can be installed, thus leaving a positive net value in place for the wind and solar that can be deployed
- **Regulations and policy**
  - Renewables portfolio standards, for example, may require the purchase of electricity with a negative net value, as the objective of the policy is to drive other social or longer-term outcomes that diverge from what the market alone would deliver (e.g., industry learning, environmental/health benefits)
  - As a result, we anticipate negative net value in the early years of wind and solar deployment, but with net value becoming more favorable over time as wind and solar costs decline → in part driven by policy

Do cost savings in electricity markets flow through to consumers?

- **Even if wind and solar provide electricity at costs lower than the alternatives, market structures and contracts will determine who benefits from those savings**
  - In some structures and contracts, consumers will see reduced electricity bills
  - In other structures and contracts, other entities will benefit with increased profits

  → Results may depend on the sophistication of the purchaser / customer

- **This report not only analyzes the net value of wind and solar but also explores factors that determine the extent to which consumers can capture and benefit from that value**
  - Report presents multiple case studies with varying consumer electricity bill impacts
  - Report also analyzes the amount of wind and solar deployed in various types of markets to gain insight into which actors gain savings from low-cost wind and solar

METHODS

Net value = (Energy Value + Capacity Value) – LCOE (w/ tax credits)

Approach to value and cost is consistent with and detailed in other work e.g.,[1,2,3]

- **Energy Value + Capacity Value** equate to the marginal cost of replacing wind and solar generation, with energy value calculated for each hour
  - **Energy value:** Indicates how much the generation from each wind or solar plant is worth in wholesale energy markets. It is the product of each plant's hourly generation and concurrent hourly locational marginal prices (LMPs) at the nearest wholesale market pricing node to that plant—i.e., it is the wind- or solar-generation-weighted average LMP.
  - **Capacity value:** Indicates how much each plant's contribution towards resource adequacy is worth. It is the product of each plant's capacity credit and local capacity prices. We use the capacity accreditation rules in place within each region and calendar year to determine each plant's historical capacity credit. We then multiply that capacity credit by historical capacity prices applicable to each plant given its location, gleaned either from actual capacity markets or from known bilateral capacity transactions.
- **LCOE (w/ tax credits)** describe the generation costs of wind and solar and serve as a proxy for power purchase agreement (PPA) prices
  - PPAs dictate the price at which wind and solar generation is bought and sold. They serve as the ideal measure of the actual cost of generation for the purpose of calculating net value. However, plant-specific PPA data are scarce.
  - To greatly expand sample size, we instead employ a useful proxy for PPA prices: each project's levelized cost of electricity (LCOE), modified to include the effect of federal tax incentives. Appendix slide shows close alignment between LCOE and available PPAs.
  - We adopt NREL's ATB LCOE formula, adjusted for receipt of tax credits: $\mathrm{LCOE} = \frac{(\mathrm{CapEx} * \mathrm{Capital\ Recovery\ Factor} * \mathrm{Tax\ Factor}) + \mathrm{OpEx}}{\mathrm{Annual\ Energy\ Production\ (AEP)}}$
- We aggregate individual plants into cohorts by vintage and by region and present results on an annual basis from 2012-2022 (though energy value is calculated hourly)

[1] https://emp.lbl.gov/wind-technologies-market-report; [2] https://emp.lbl.gov/utility-scale-solar; [3] https://www.sciencedirect.com/science/article/pii/S2542435121002440

Wind and solar sample: we focus on utility-scale projects that achieved commercial operations from 2011 through 2021 (ignore older plants)

Utility-scale defined to include any plant >5 MW_{AC}; in addition, wind plants must be land based and PV plants must be ground mounted. We further limit the sample to those plants for which we have credible estimates of wholesale market value as well as CapEx and/or capacity factor—two key components of LCOE. We focus on standalone wind and solar, so exclude any value from co-located battery storage. The resulting sample is extensive (see below, and appendix for details).

935 PV plants

44.4 GW_{AC}

87% of all ground-mounted utility-scale PV capacity installed over this 11-year period

502 wind plants

77.4 GW_{AC}

80% of all land-based utility-scale wind capacity installed over this 11-year period

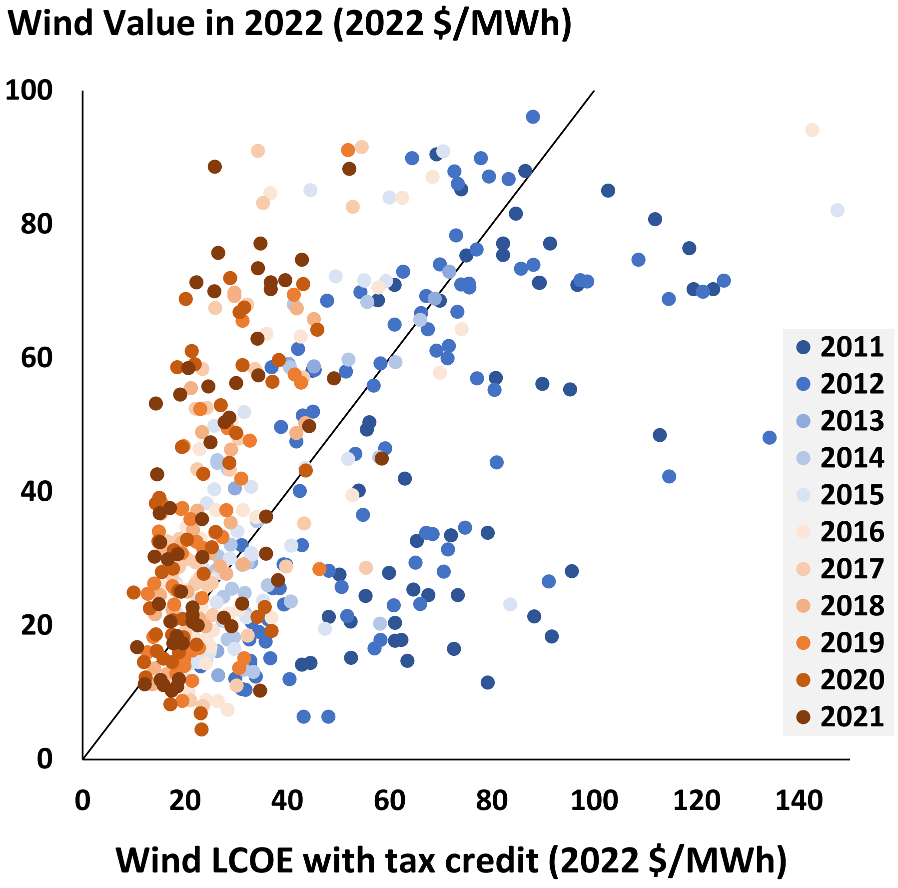
Scope limitations

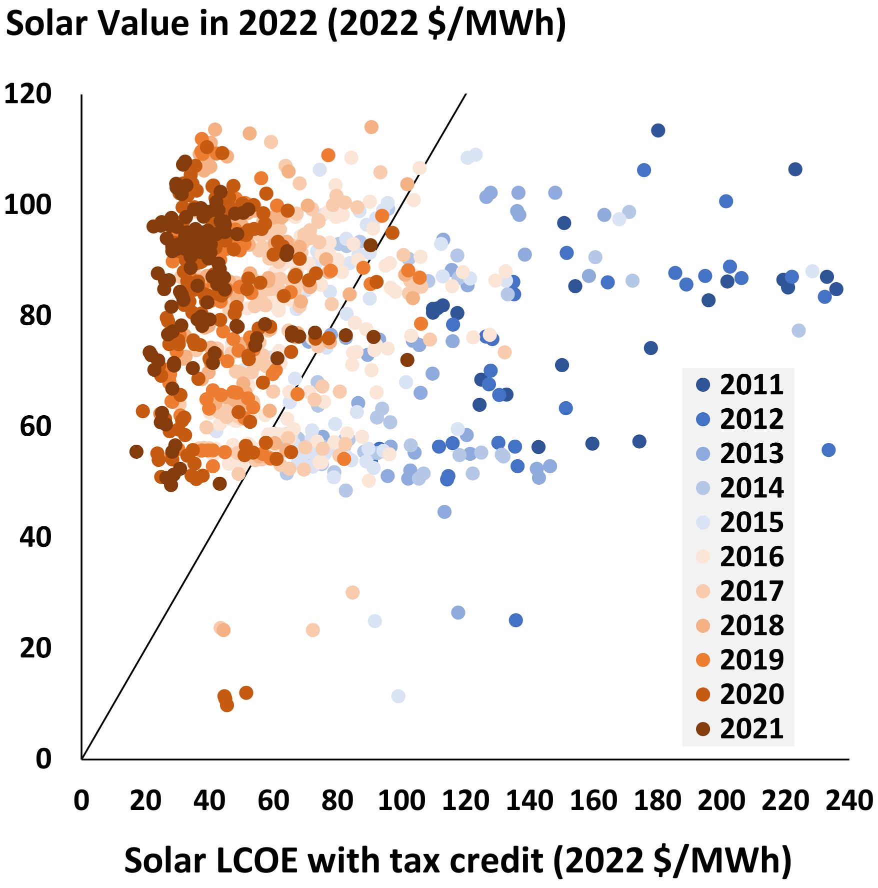
- Analysis **focuses on the primary drivers of direct** power-system costs and benefits and the key ones that determine development and purchase decisions, following industry practice and past research
  - Important to recognize that “wholesale market value” and “LCOE” are credible estimates, but are not precise for each plant
  - Actual revenue earned by a plant will diverge from “market value” (impacted by PPAs, RPS-derived revenue, renewable energy certificate sales, etc.), but market value is equal to the effective cost to replace that generation for the purchaser
- Does **not include all drivers of power-system costs and benefits** that may be experienced by consumers, though past research shows that most of the following have not been large or are temporary
  - Does not include potential value of selling wind and solar into ancillary services markets
  - Includes value in real-time LMP market, but does not fully consider sub-hourly variability and forecast error
  - Includes locational LMPs, which reflect transmission congestion, but may not fully account for transmission costs
  - Does not include broader impacts of merit order effect, whereby wind and solar reduce wholesale prices on the margin
- Analysis **excludes broader societal- and sectoral- impacts** outside core power-sector costs and values
  - Excludes social benefits in the form of reducing climate damages and improving public health
  - Excludes the cost to the Treasury of federal investment- and production- tax credits
  - Excludes effect of wind and solar on reducing natural gas demand and therefore also prices
  - Excludes other costs and benefits to local communities and ecosystems
  - Excludes separate value of renewable energy certificates, focusing instead on LCOE and energy+capacity value
- To contextualize core analysis results, we draw from broader literature to briefly discuss subset of above

ANALYSIS RESULTS

Market value in 2022 of most wind and solar plants built in recent years (red dots) was higher than cost; opposite true for older projects (blue dots)

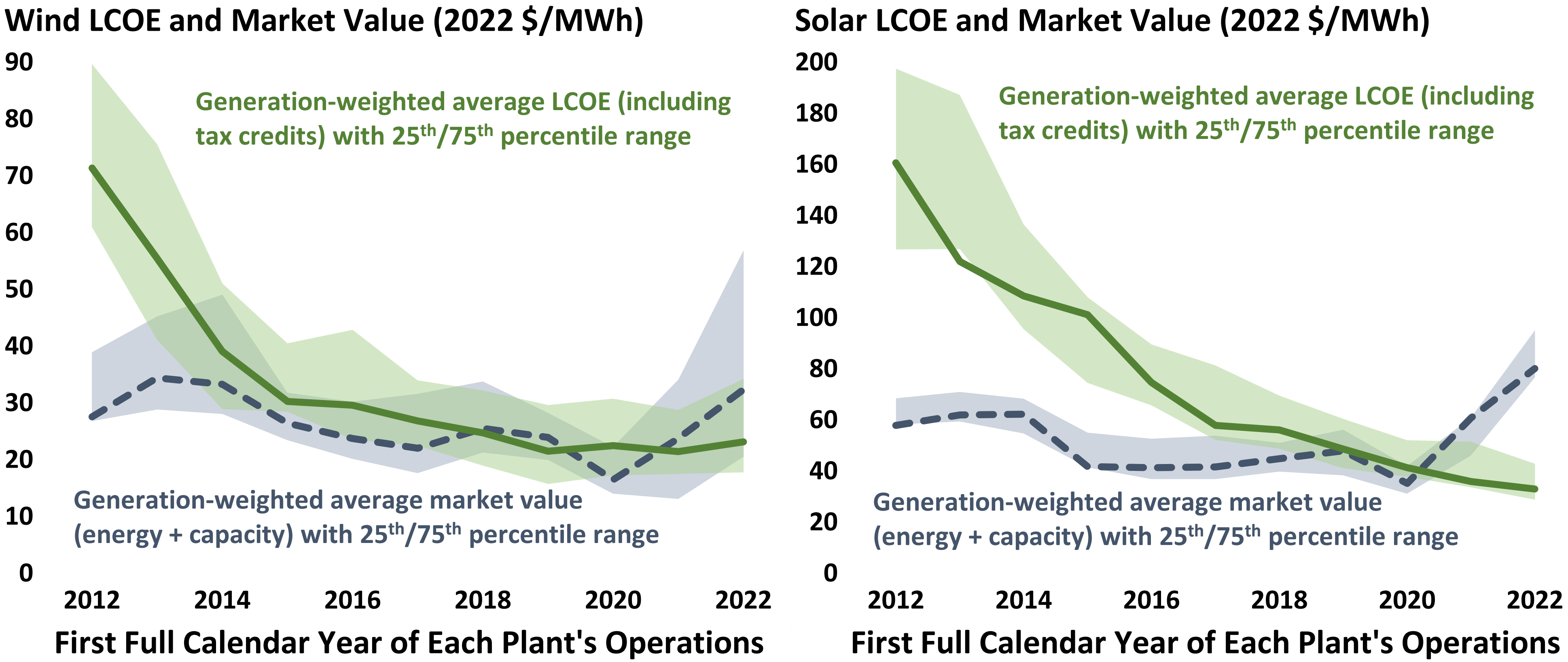
- ☐ Scatterplots focus on wholesale market value (vertical axis) and levelized cost (horizontal axis) in calendar year 2022, for individual wind (left) and solar (right) projects with varying CODs.
- ☐ Underlying analysis also evaluates other years—as shown in following slides.





In 2021-2022, on a national basis, new power purchasers typically paid less for wind or solar than its value in wholesale markets: a positive net value

- Charts show the national average LCOE (green) and market value (aka replacement costs, blue) of wind (left) and solar (right), by plant vintage.
- Value roughly matched costs (i.e., net value = 0) beginning with 2018/2019 plant vintages, primarily due to significant declines in the LCOE of wind and PV plants over time. An uptick in market value (and net value) is observed in 2021 and especially 2022.

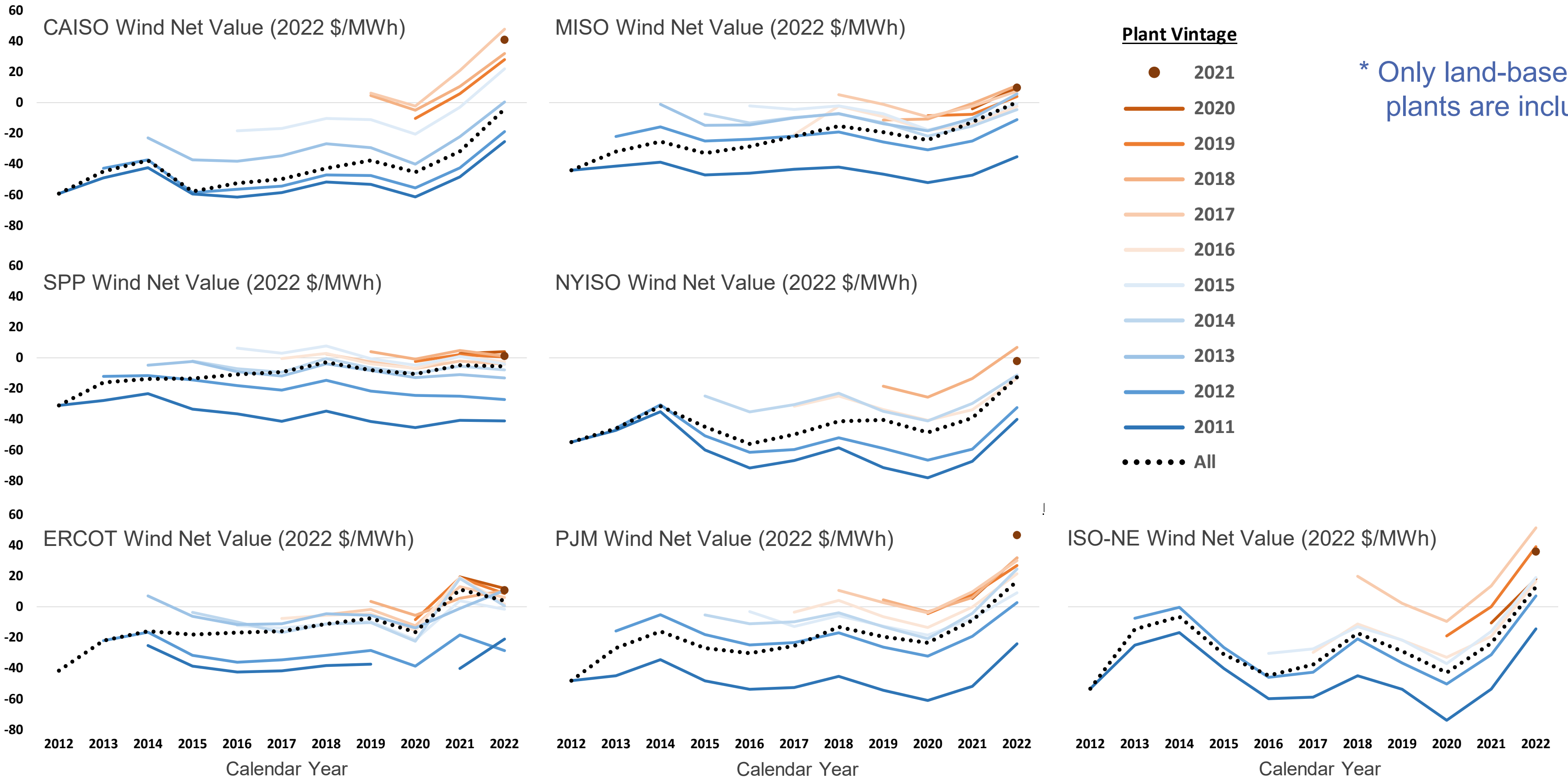


Many recent projects are economic for purchasers based on market value and post-tax credit LCOE.

Older projects mostly received state policy support (e.g., RPS) to augment market value and motivate deployment.

WIND: “Net value” results demonstrate generally improving economic value across all regions of the country with newer plant vintages

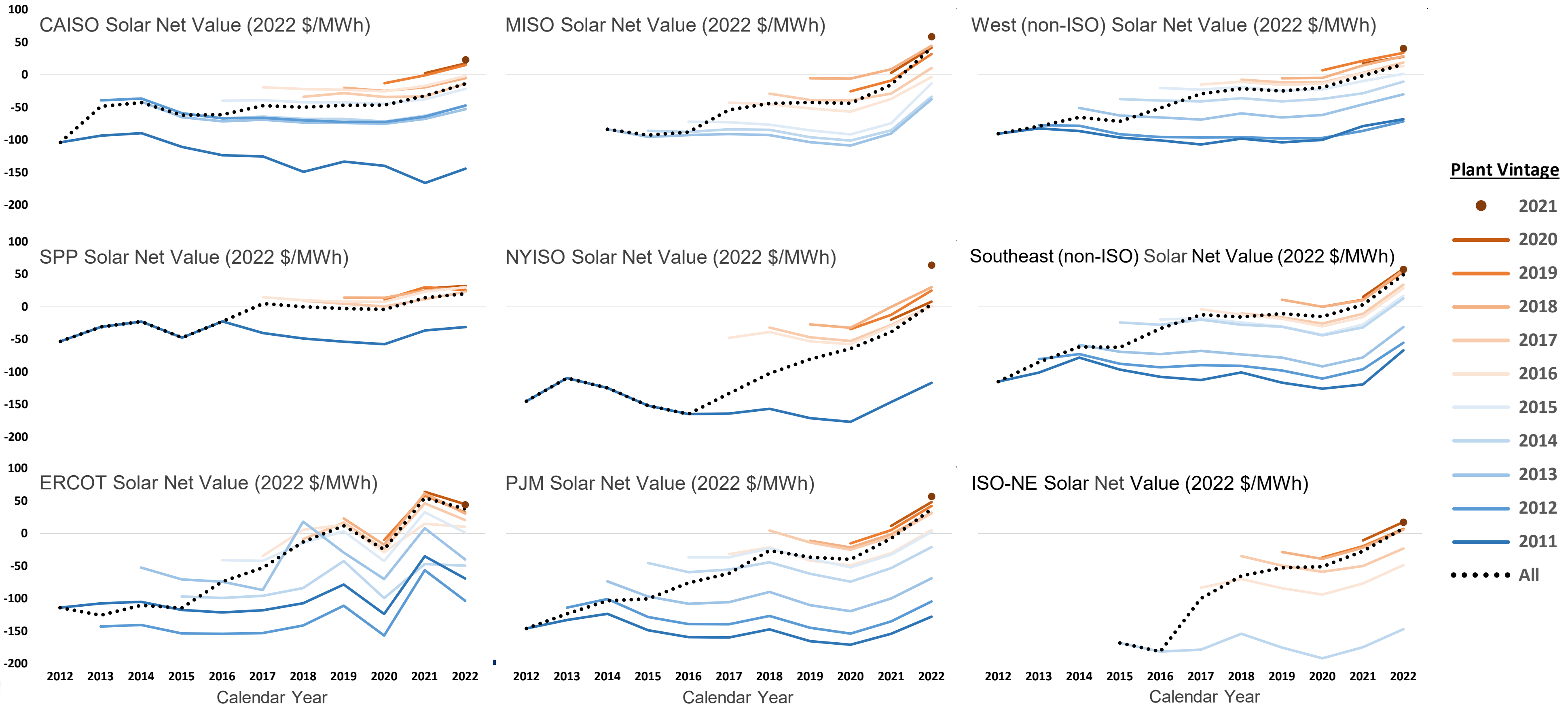
- □ Figures below focus on **WIND**, and show net value (i.e., value - cost), by plant vintage and region.
- □ The regions with the highest net value among recent plant vintages are PJM, CAISO, and ISO-NE.
- □ The regions in which most wind capacity is located—i.e., ERCOT, SPP, and MISO—have also had positive net value but to a lesser degree.



* Only land-based wind plants are included

SOLAR: “Net value” results demonstrate generally improving economic value across all regions of the country with newer plant vintages

- ☐ Figures below focus on **SOLAR**, and show net value (i.e., value - cost), by plant vintage and region.
- ☐ The regions with the highest net value among recent plant vintages include the Southeast, followed closely by MISO, ERCOT, and PJM. Net value in CAISO and the non-ISO West is hurt by solar’s significant market share and resulting erosion of energy and capacity value.


CAISO Solar Net Value (2022 $/MWh)

MISO Solar Net Value (2022 $/MWh)

West (non-ISO) Solar Net Value (2022 $/MWh)

SPP Solar Net Value (2022 $/MWh)

NYISO Solar Net Value (2022 $/MWh)

Southeast (non-ISO) Solar Net Value (2022 $/MWh)

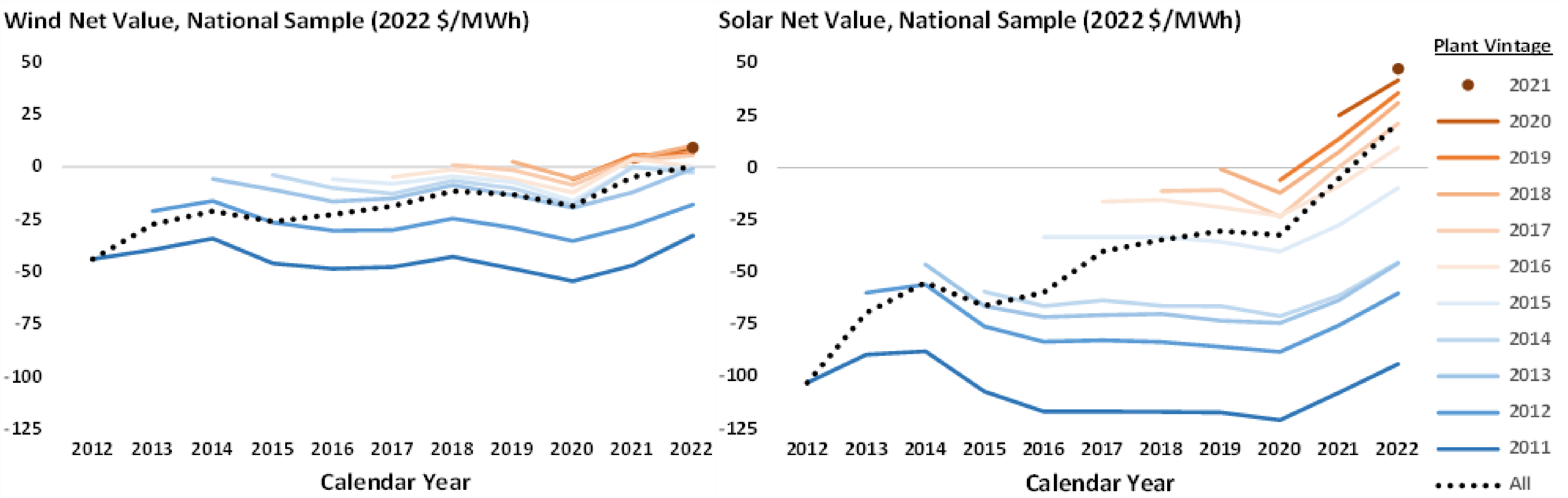
ERCOT Solar Net Value (2022 $/MWh)

PJM Solar Net Value (2022 $/MWh)

ISO-NE Solar Net Value (2022 $/MWh)

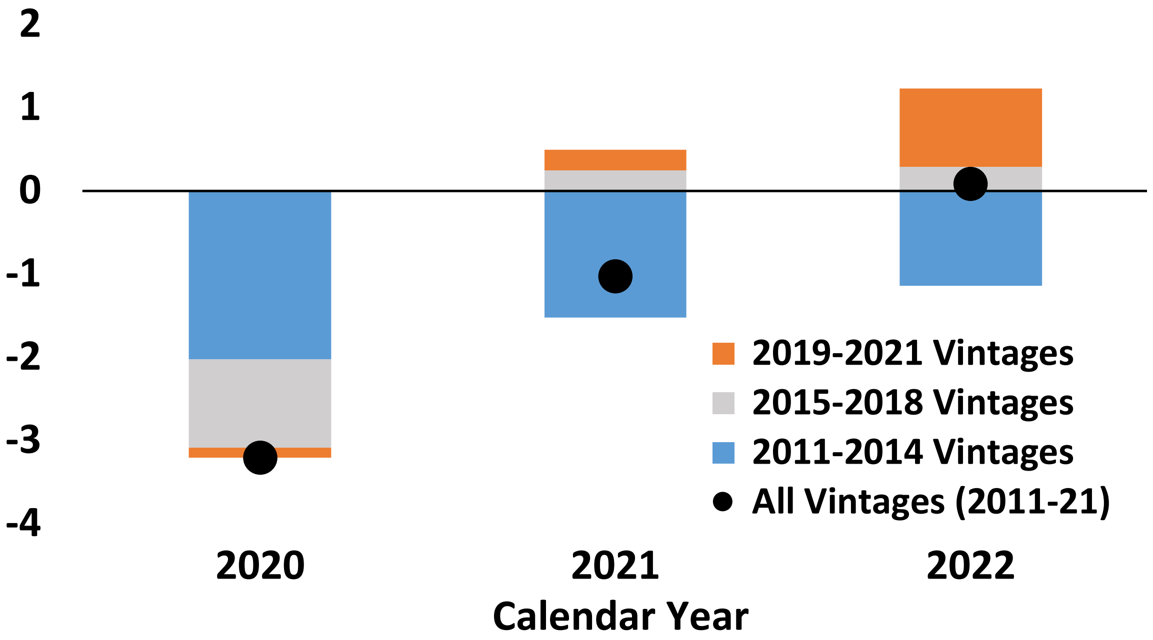
Nationally, solar's net value is significantly worse than wind's among older plant vintages, while the reverse is true for newer plant vintages

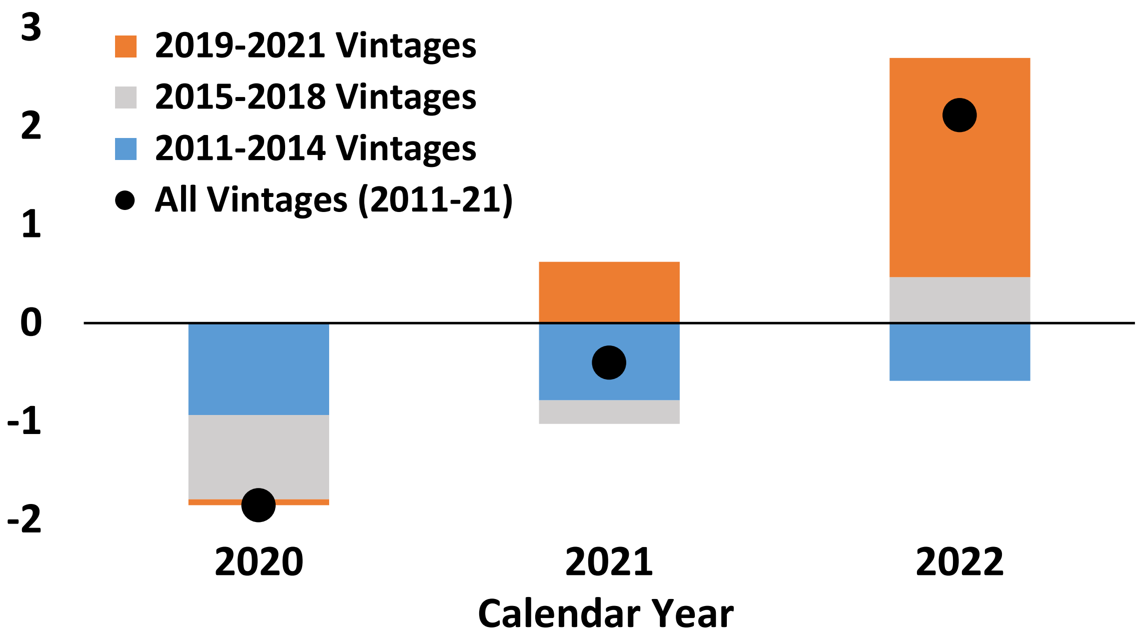
- Figure presents the same net value data in the same format as previous two slides, but this time rolled up to the national level and presented side-by-side on the same scale.
- The results help explain the explosion of recent interest in solar deployment relative to land-based wind.



Considering all plants within sample, net value has generally increased; in 2022, solar generated $2.1 billion in net value nationwide; wind $100 million

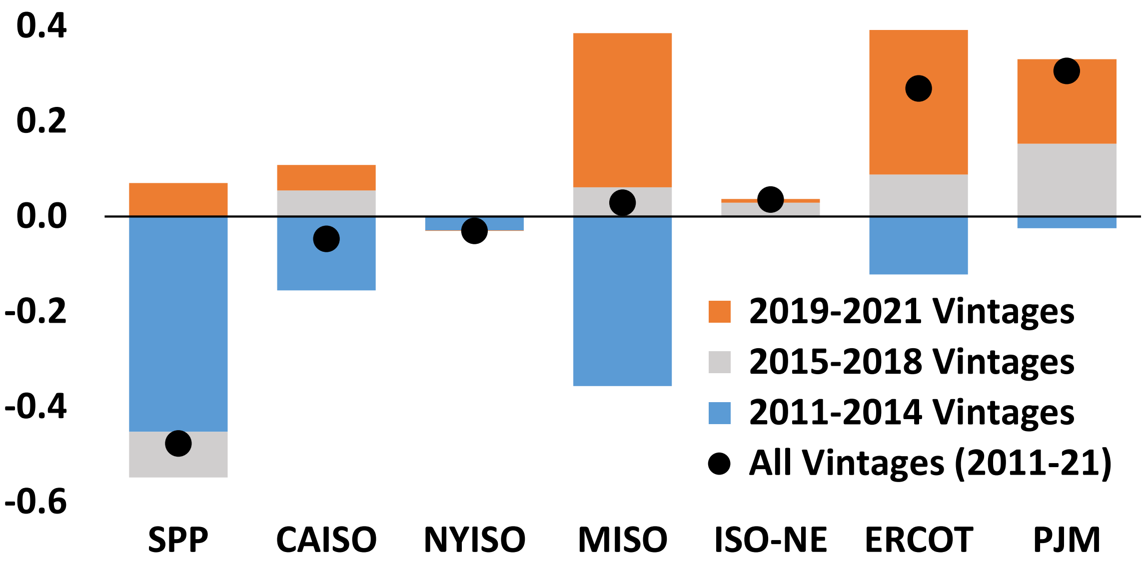
- Figure presents the national net value of wind (left) and solar (right) in dollar terms for calendar years 2020-2022, by plant vintage cohort.
- The cohort consisting of the oldest plants (2011-2014) always experiences negative net value, the cohort consisting of the newest plants (2019-2021) nearly always shows positive net value, and the middle cohort (2015-2018) provides mixed results.


National Wind Net Value (Billion $)

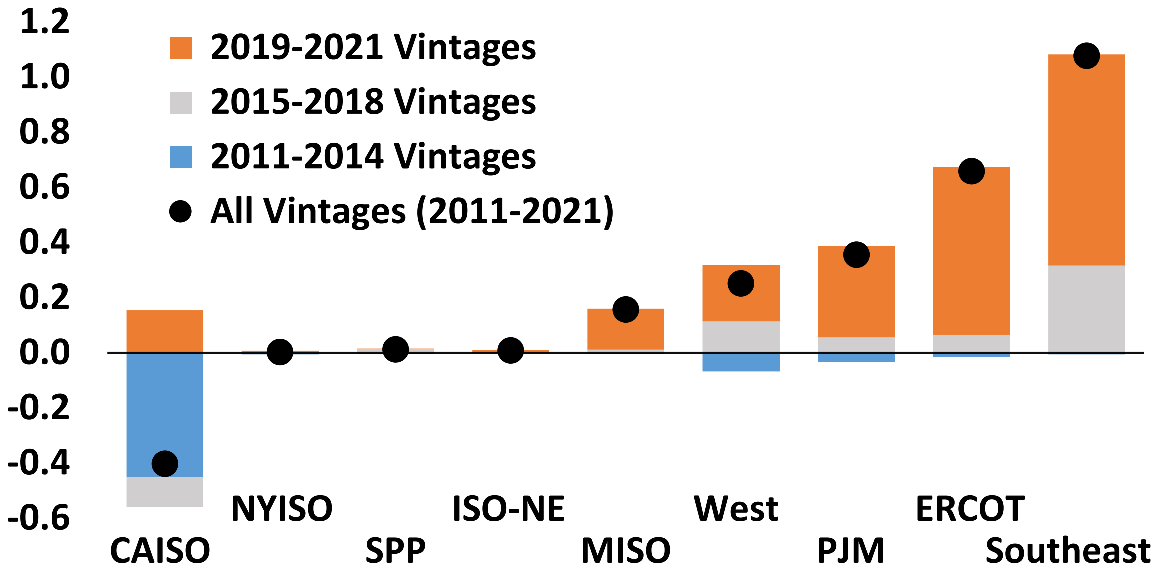

National Solar Net Value (Billion $)

Regionally in 2022, results are mixed; solar had positive net value in most regions, wind is weighed down by higher-cost older plants in some regions

- Figure presents regional net value of wind (left) and solar (right) in dollar terms for just calendar year 2022, by plant vintage cohort.
- In 2022, net value is positive for solar in nearly all regions. CAISO is an exception, weighed down by the relatively high preponderance of older, higher-cost plants (despite the newest cohort of CAISO solar providing positive net value). For wind, ERCOT and PJM contributed high net value in 2022, offset by negative net value (i.e., net cost) from plants in SPP (again, heavily weighed down by the earliest vintage cohort).



Regional Wind Net Value in 2022 (Billion $)



Regional Solar Net Value in 2022 (Billion $)

CONSUMER BILL IMPACTS
WHO BENEFITS FROM HEDGE VALUE

Case studies illustrate diversity of impacts of past wind & solar deployment on consumer electricity bills, and how contracting structures impact whether consumers benefit from potential cost savings and hedge value

- Electric utilities have gone on record describing past and future ratepayer savings from wind and solar, most commonly in areas with strong solar and wind resources and when the utility is either purchasing via long term contract or instead owns the projects directly.

Utility procurement

- States with renewables portfolio standards (RPS) tend to show increased electric bills, especially in regions with higher-cost and early wind and solar purchases, and when load-serving entities contract through unbundled renewable energy certificates (RECs).

State RPS

- Voluntary markets are diverse, but some contractual structures automatically result in net costs for consumers (e.g., fixed-price RECs) whereas others enable consumers to benefit from wind and solar's hedge value if other generation costs rise (e.g., virtual PPAs)

Voluntary demand

Many utilities have made statements about expected savings and/or hedge benefits for their customers from wind and solar project—examples:

Reports 999 MW of new wind and solar to be built in 2024-25 at a positive net value of $1.38/MWh on a levelzed basis over 30-35 years. (Texas SOAH 2023)

Increased its planned investment in renewable generation from 2,400 MW to 3,300 MW, and projects “long-term customer savings of nearly $2 billion” from this investment in renewables. (WEC Energy Group 2022)

Noted that “Our investments to date in wind energy—a power source that carries no fuel cost—have already saved our customers money, lowering costs in the Upper Midwest by nearly $1 billion from 2017 to 2021.” (Xcel Energy 2023)

Updated plan includes adding ~20 GW of new solar, noting “We believe the expansion of cost-effective solar and storage will provide a valuable hedge for our customers against volatile natural gas prices and meet the electricity demand of FPL’s growing customer base with a low-cost generation source.” (NextEra Energy 2023)

Examination of a 300 MW solar PPA: $59.90/MWh nominal levelized cost for the PV, versus $68.02/MWh projected nominal levelized market value (energy + capacity) over 20-year PPA term. (Consumers Energy 2024)

Plans to invest $11 billion in clean energy over the next decade, including 3,600 MW of renewable energy and 780 MW of storage by 2030. Expects $2.5 billion savings as a result, compared to plan for 2019. (DTE 2023)

Estimates of the cost of complying with state RPS' span a wide range, impacted by resource economics, policy design, and contractual structure

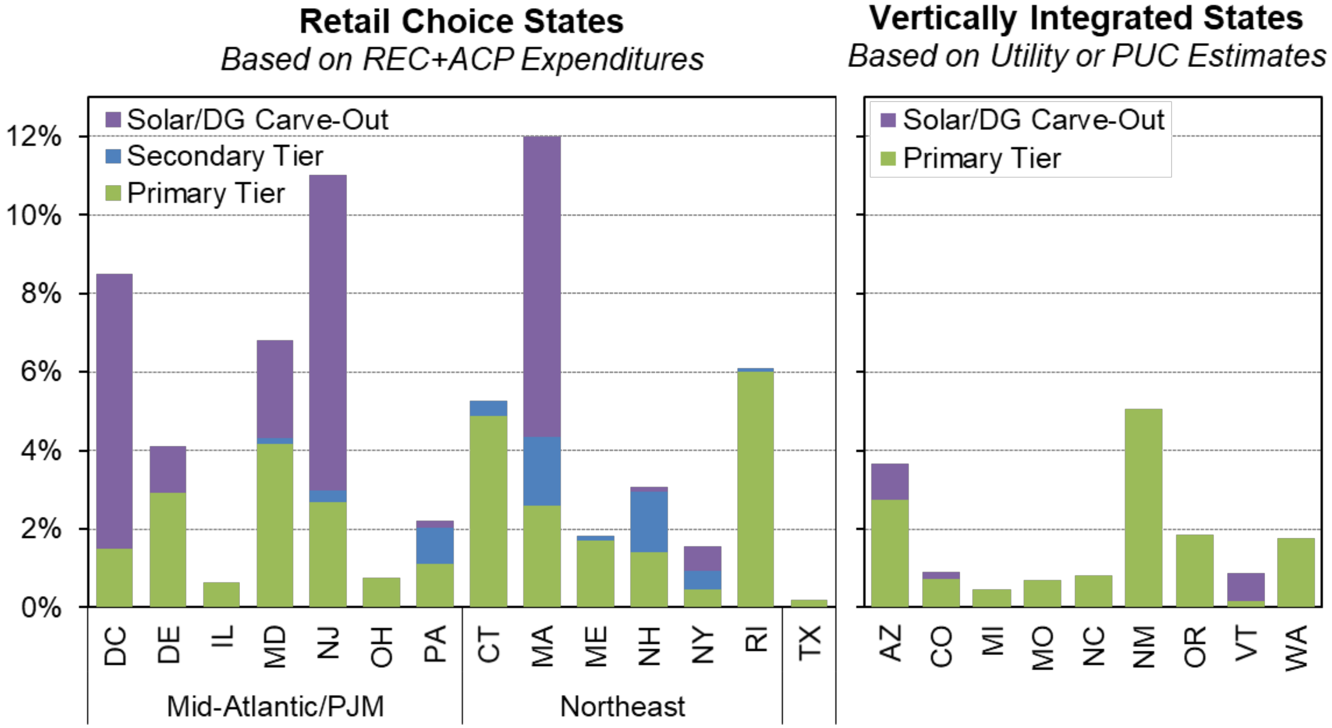
Figure shows estimated net cost to the load-serving entity, above and beyond what would have been incurred in the absence of RPS, presented as a percent of the average retail electricity bill in 2021 or 2022. RPS's have generally increased retail prices, in part due to legacy contracts signed when wind and solar costs were higher and in part due to REC contractual practices.

Retail Choice States

- Compliance primarily via unbundled RECs
- Unbundled RECs typically priced at a positive $/MWh level, inherently resulting in some overall retail price impact
- Little opportunity to benefit from hedge to volatile wholesale electricity prices

Vertically Integrated States

- Compliance primarily via bundled PPAs
- Price of bundled PPA may be higher- or lower- than wholesale prices, meaning that purchaser retains some hedge value

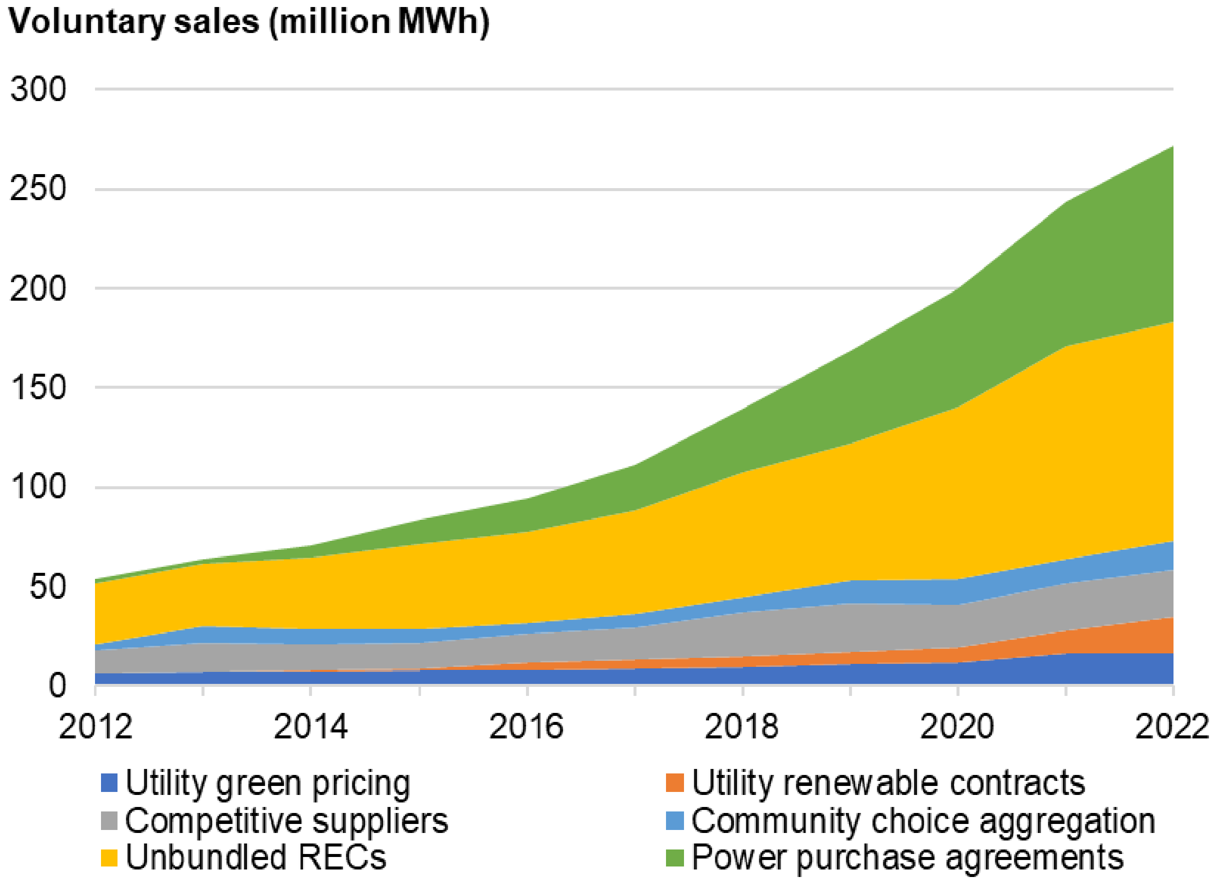


See: https://emp.lbl.gov/publications/us-state-renewables-portfolio-clean

ACP = alternative compliance payment, in cases where RECs are too extensive

Voluntary markets are diverse: pricing is not broadly public, but some contractual structures automatically result in a net costs for consumers whereas others enable consumers to benefit from hedge value

- Unbundled RECs (yellow in the chart) trade at a positive price, such that consumers automatically pay a premium (unless priced based on an index, see later example)
- Power purchase agreements (green) vary in structure, but often have a fixed price giving the consumer a hedge against volatile wholesale prices → these structures are increasingly common for large customers, demonstrating that sophisticated buyers are capturing value
- Other sales types shown in figure are smaller in volume and vary in approach: whether consumers always pay a premium or retain some hedge against the risk of higher wholesale prices varies
- Smaller, less-sophisticated customers may be more likely to be on "premium" green power contracts, less able to benefit from value upside

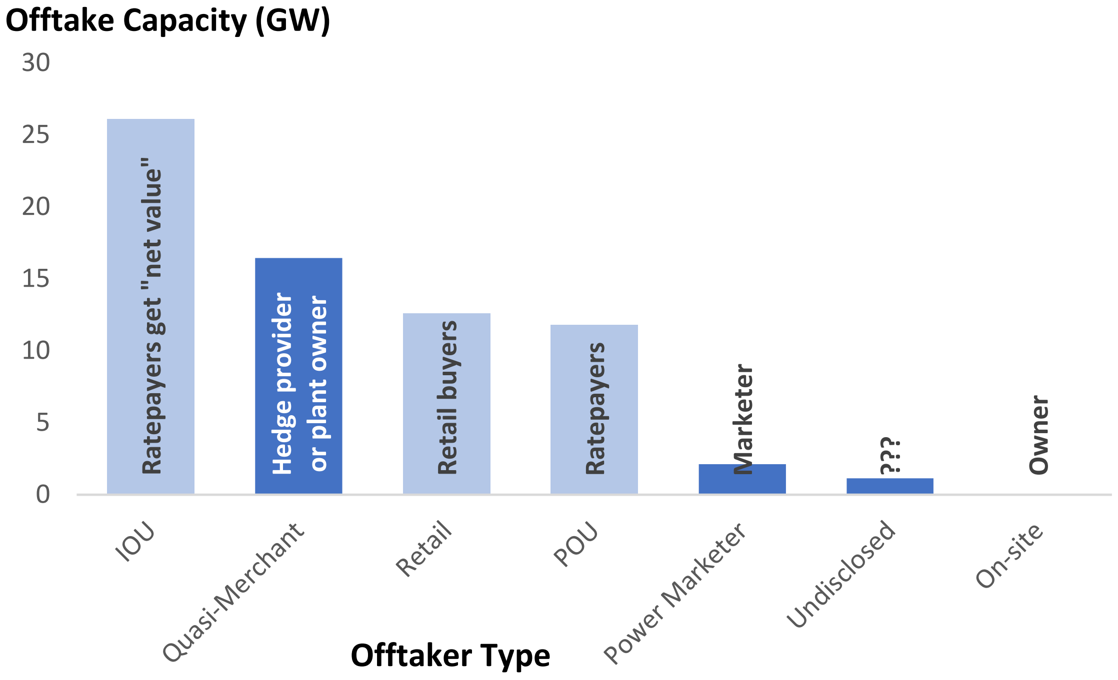


See: https://www.nrel.gov/docs/fy24osti/88219.pdf

Bottom line: whether consumers benefit from potential cost savings and hedge value via lower electricity bills is impacted by contractual structures and the sophistication of the purchaser and customer

- With wind and solar increasingly competitive as bulk power assets, the question of “who benefits” from net and hedge value is becoming more relevant
- As illustrated in the previous slides, whether consumers see these savings is impacted by market and contractual structures, and buyer sophistication
- Examples:
  - **Utility ownership of or long-term fixed-price PPAs:** Will tend to pass on the cost savings (or increases) to end-use customers as a customary part of cost-of-service regulation
  - **Merchant projects:** A merchant solar or wind project that sells directly into wholesale markets takes on price risk, but also retains upside should wholesale prices increase—i.e., end-use customers do not directly capture net value
  - **Unbundled RECs:** Consumers and other purchasers who buy fixed-price RECs will always pay a premium over wholesale prices, but index-priced RECs—whose price varies inversely to wholesale power prices—will receive a hedge benefit

- Figure estimates recipient of net value among our project sample, based on offtake type
- Net value (or cost) and hedge value often accrues to end-use customers, but not always



New York case study illustrates how the changing economics of wind and solar are, in some cases, causing purchasers to rethink their contracts

- Under the New York RPS, the New York State Energy Research and Development Authority (NYSERDA) regularly runs competitive solicitations to support new power projects via long-term contracts
- Initially, NYSERDA's contracts involved the purchase of fixed-price RECs under long-term contract but, over time, NYSERDA has moved toward index-based RECs
- Unlike a fixed-price REC, an index REC is based on the developer's estimated revenue requirement for the project as represented by a strike price (i.e., an all-in price for RECs, energy, and capacity)
- Under this approach, the developer is paid a variable REC price that is calculated by subtracting, from the strike price, index prices for energy and capacity
- The goal was, in part, to increase the likelihood that a developer will satisfy its revenue requirement for a project, thereby reducing financing risks and costs
- Additionally, index-based RECs offer potential hedge benefits to consumers in case wholesale energy and capacity prices increase – resulting in lower REC prices

New York is not alone. Numerous other examples exist domestically, in Europe, and elsewhere.

OTHER COSTS AND BENEFITS:
NOT THE FOCUS OF THIS RESEARCH

Previous analysis focused on the core cost and value elements that impact purchase decisions and customer electric bills. Excluded elements are:

Health and climate benefits	• Wind and solar provide climate and health benefits by reducing climate damages and improving air quality • Benefits do not often directly impact electricity bills, but are a key motivator for federal and state policy support
Cost to Treasury of federal tax credits	• Federal support for wind and solar through tax credits has been a long-standing feature of energy policy • These tax expenditures fall on the Treasury and taxpayers, with some of the benefits flowing through as lower wind and solar costs
Wholesale electricity & natural gas merit order	• Wind and solar reduce demand for other forms of generation, and thereby also reduce demand for natural gas • Reduced demand can in turn reduce marginal prices—of real-time wholesale electricity supply and of natural gas • These impacts largely represent wealth transfers from producers to purchasers, and are transitory, uncertain, and may not in all cases be passed on to end-use customers
Ancillary services, variability, forecast error	• Research shows limited opportunity for wind and solar to earn ancillary services revenue absent hybridization with storage • Also shows low costs associated with standalone wind and solar's sub-hourly generation variability and short-term forecast errors
Transmission needs and related costs	• By using nodal LMPs, our analysis accounted for transmission to a significant degree; transmission costs related to generator interconnection are also partially embedded in project CapEx and thus also in LCOE estimates • Though transmission expenditures specific to wind and solar have occurred outside the two processes noted above, they have been limited since at least ~2015
Community and ecosystem impacts	• New capital projects and those they replace have many impacts on local communities and ecosystems, some positive, some negative • Projects may impact local economic development, property values, dis-amenities associated with visibility and other characteristics, ecosystems, demands for water, and many more

CONCLUSIONS

Conclusions

1 **Wind and solar costs have been roughly in-line with market replacement costs since 2018 or 2019, allowing for consumer savings at times, such as during natural gas prices spikes**

- Looking ahead, the cost of wind and solar can be expected to decline as supply chain pressures ease, the new tax credit provisions in the Inflation Reduction Act take full effect, and technology continues to advance; but at the same time, the cost of replacing standalone wind and solar generation may decline with increased saturation
- Regardless of the push and pull of the above trends, wind and solar can offer a hedge against potential fluctuations and increases in the cost of other generation resources, and are increasingly offering a compelling value proposition to purchasers even in the absence of state policy drivers

2 **With solar and wind increasingly competitive as bulk power assets, and providing a larger share of generation, the question of “who benefits” is becoming more important**

- Utility PPAs and ownership can deliver value to end-use customers, as can voluntary retail purchases via PPAs
- Alternatively, fixed-price unbundled RECs will always remain a premium product and do not offer a hedge value

3 **Electricity purchasers should, in some cases, rethink their contracting practices to capture more of the rising net value of wind and solar power**

- Potential for moving away from fixed-price REC purchases
- A possible preference for physical and virtual PPAs, floating-price REC contracts such as in New York, etc.

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Related Publications

Visit https://emp.lbl.gov/

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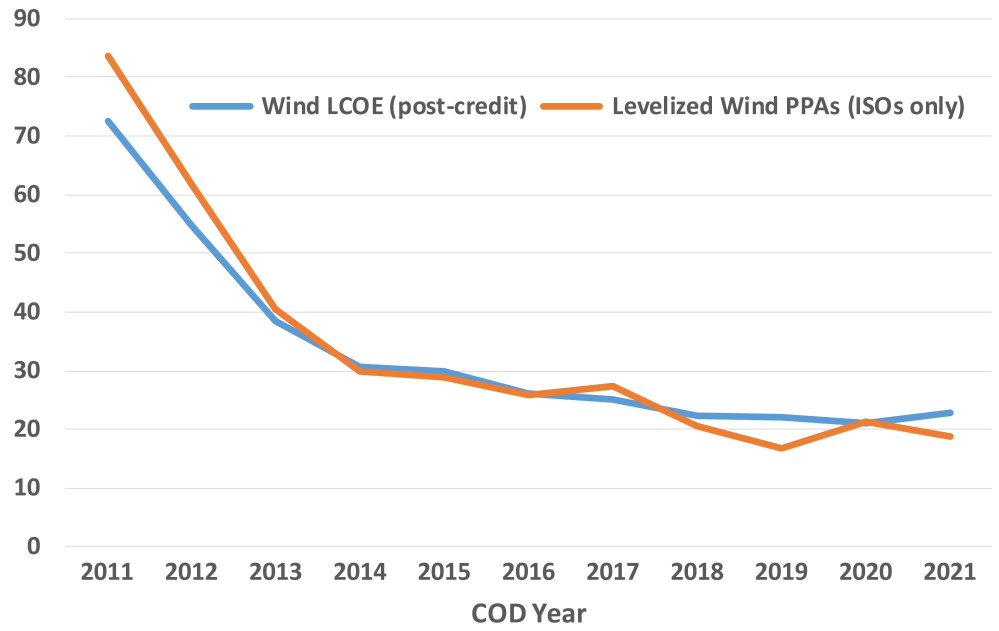
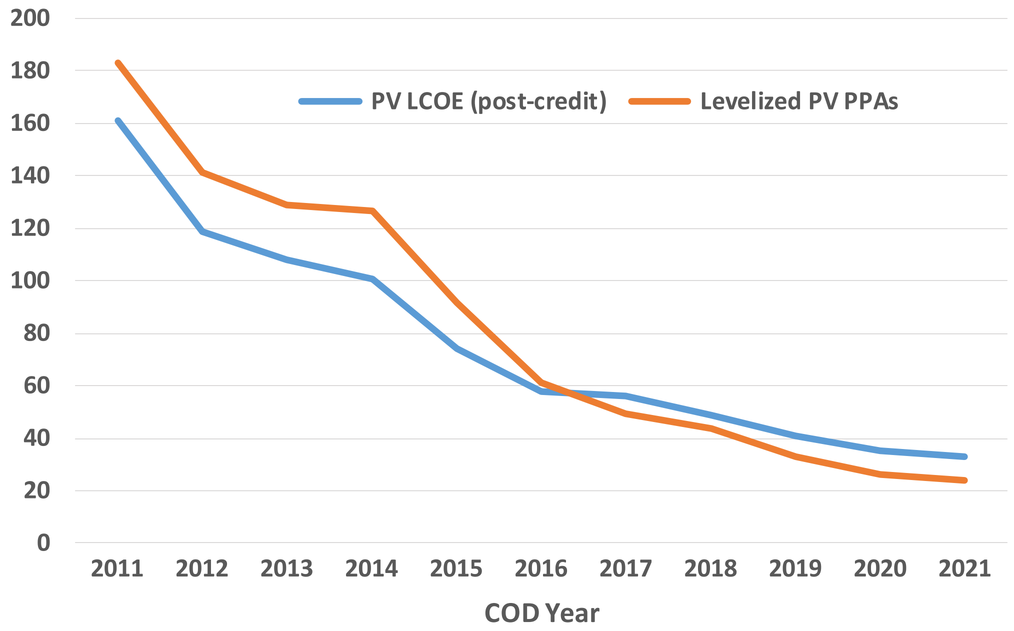
APPENDIX: ADDITIONAL DETAILS

Benchmarking post-tax credit LCOE with wind and solar PPA prices

Figures below compare levelized PPA prices from Wiser et al. (2023)[1] and Bolinger et al. (2023)[2] to our LCOE time series for utility-scale wind and PV, as adjusted for the PTC and ITC, respectively. The match is not perfect—nor would we expect it to be, given the crude means of incorporating tax credits into LCOE, the possibility of other incentives not accounted for, differences in sample size and composition, and the vagaries of working with empirical data. In general, however, the correlation is encouraging and suggests that our measure of LCOE adjusted for federal tax credits provides a good proxy for the price at which wind and solar generation is bought and sold.





[1] See: https://emp.lbl.gov/wind-technologies-market-report

[2] See: https://emp.lbl.gov/utility-scale-solar

Details on wind and solar sample: utility-scale projects that achieved commercial operations from 2011 through 2022

Solar Plants

COD	Total	CAISO	MISO	SPP	ERCOT	PJM	NYISO	ISO-NE	West (non-ISO)	Southeast (non-ISO)
2011	**28**	6	0	5	1	8	1	0	6	1
2012	**31**	9	0	0	3	8	0	0	9	2
2013	**41**	16	4	0	1	4	0	0	11	5
2014	**50**	31	2	0	1	8	0	1	4	3
2015	**78**	33	2	0	3	13	0	0	14	13
2016	**141**	38	13	3	2	21	1	2	35	26
2017	**136**	21	6	2	13	22	2	3	24	43
2018	**83**	6	3	2	9	15	2	3	13	30
2019	**88**	12	3	1	7	18	4	5	17	21
2020	**140**	16	9	1	16	35	1	4	19	39
2021	**119**	7	16	0	17	27	1	10	10	31
Total	**935**	**195**	**58**	**14**	**73**	**179**	**12**	**28**	**162**	**214**

Wind Plants

COD	Total	CAISO	MISO	SPP	ERCOT	PJM	NYISO	ISO-NE	West (non-ISO)	Southeast (non-ISO)
2011	**51**	8	19	10	1	7	1	5	0	0
2012	**93**	15	26	22	10	11	3	6	0	0
2013	**8**	2	3	2	1	0	0	0	0	0
2014	**30**	0	8	11	7	2	2	0	0	0
2015	**50**	4	5	15	20	3	0	3	0	0
2016	**49**	0	8	19	12	4	1	5	0	0
2017	**39**	1	7	13	11	5	0	2	0	0
2018	**32**	2	7	11	7	3	2	0	0	0
2019	**42**	1	14	7	16	3	0	1	0	0
2020	**51**	0	23	13	9	5	0	1	0	0
2021	**57**	8	14	16	14	2	2	1	0	0
	502	**41**	**134**	**139**	**108**	**45**	**11**	**24**	**0**	**0**

Solar MW

COD	Total	CAISO	MISO	SPP	ERCOT	PJM	NYISO	ISO-NE	West (non-ISO)	Southeast (non-ISO)
2011	**386**	95	0	50	30	79	32	0	96	6
2012	**756**	437	0	0	30	76	0	0	193	20
2013	**1,276**	808	39	0	10	45	0	0	280	94
2014	**2,934**	2,659	17	0	40	94	0	6	81	37
2015	**2,733**	1,420	10	0	130	239	0	0	550	384
2016	**6,047**	2,095	192	165	270	298	10	27	1,890	1,101
2017	**3,623**	365	186	14	651	519	15	22	703	1,149
2018	**3,482**	817	105	18	466	361	33	60	230	1,392
2019	**4,120**	997	33	6	488	478	60	90	595	1,372
2020	**8,847**	1,517	416	20	2,495	1,212	7	89	650	2,440
2021	**10,215**	804	998	0	3,154	1,622	20	217	1,045	2,355
Total	**44,419**	**12,015**	**1,997**	**273**	**7,764**	**5,022**	**176**	**512**	**6,312**	**10,349**

Wind MW

COD	Total	CAISO	MISO	SPP	ERCOT	PJM	NYISO	ISO-NE	West (non-ISO)	Southeast (non-ISO)
2011	**5,381**	907	2,096	1,086	150	883	74	186	0	0
2012	**10,063**	1,945	2,022	2,771	1,486	1,271	286	283	0	0
2013	**1,025**	226	326	325	149	0	0	0	0	0
2014	**3,828**	0	909	1,239	1,329	240	110	0	0	0
2015	**7,505**	284	970	1,893	3,807	355	0	196	0	0
2016	**8,226**	0	1,360	3,548	2,518	427	78	296	0	0
2017	**6,084**	46	980	2,362	1,843	800	0	53	0	0
2018	**4,819**	325	982	1,346	1,506	502	158	0	0	0
2019	**8,955**	131	3,016	1,830	3,459	489	0	29	0	0
2020	**10,031**	0	4,613	2,970	1,801	575	0	73	0	0
2021	**11,492**	401	2,723	3,776	3,927	445	205	15	0	0
	77,408	**4,265**	**19,996**	**23,146**	**21,973**	**5,987**	**911**	**1,129**	**0**	**0**