Status and Trends in the U.S. Voluntary Green Power Market: 2022 Data

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Glossary

Buyer: For this report, we use the term “buyer” to broadly refer to any customer who procures voluntary green power, including residential, commercial, industrial, and governmental electricity users.

Compliance: Throughout this report, the term “compliance” always refers to compliance by load-serving entities with state mandates for renewable energy procurement (see Renewable portfolio standards).

Community Choice Aggregation: A CCA is a legal entity formed to procure power on behalf of a defined geographic area. Some CCAs procure green power on behalf of their customers.

Load-serving entities: Suppliers of retail electricity, including utilities, competitive retail electricity suppliers (in restructured markets), and community choice aggregations.

Participation/sales: Throughout this report, the term “participation” refers to the number of customers whereas “sales” refers to megawatt-hours (MWh) (renewable energy certificates [RECs]) of renewable energy bought and sold.

Power purchase agreement (PPA): A long-term contract for power and/or REC procurement between a renewable energy project and a retail electricity customer.

Renewable energy certificate (REC): A contractual mechanism representing the clean energy attributes of 1 MWh of renewable electricity generation.

Renewable portfolio standards (RPS): State laws requiring load-serving entities to procure a minimum specified quantity of renewable energy.

Voluntary green power: Renewable energy procured by retail electricity customers above and beyond what is otherwise provided by load-serving entities.

Executive Summary

Voluntary green power, for this report, refers to renewable energy procurement by retail electricity customers above what is otherwise provided by load-serving entities. This report is part of an annual series of reports synthesizing trends in the U.S. voluntary green power market. In 2022, about 9.6 million retail electricity customers procured about 272 million megawatt-hours (MWh) of voluntary green power (Figure ES-1), representing about 38% of non-hydropower renewable energy sales and about 6% of all U.S. retail electricity sales. Most of the remainder of U.S. renewable energy sales reflects renewable energy procured by load-serving entities to comply with state renewable energy mandates, also known as compliance-based procurement.

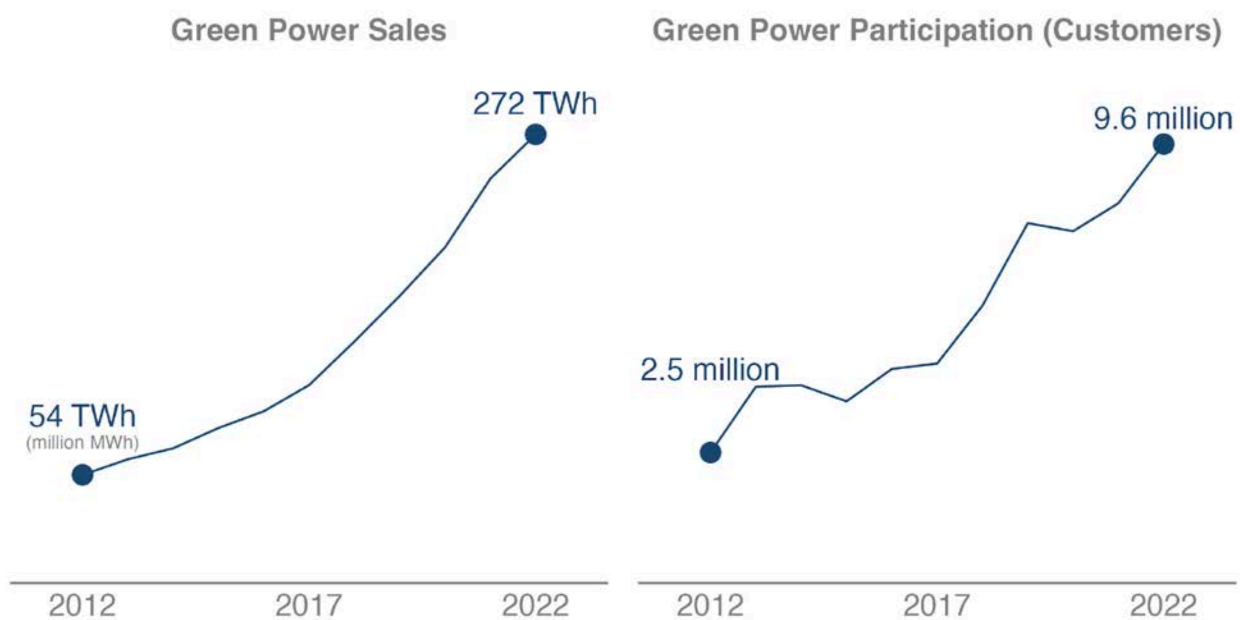

Figure ES-1. Voluntary green power sales (left) and participation (right), 2012–2022.

MWh = megawatt-hours
TWh = terawatt-hours

In this year's report, we include two topics of interest that could affect future trends in the U.S. voluntary green power market. The first topic relates to the emergence of three strategies to match green power procurement to buyers' electricity demand. Nearly all buyers continue to use annual matching, where an annual purchase of green power is matched to the buyers' annual electricity demand. Recently, some buyers have begun to promote and implement hourly matching, where green power is purchased on an hourly basis to match buyers' hourly demand profiles. Finally, other buyers have begun to explore emissions matching, where the goal is to match buyers' annual estimated emissions from electricity use to grid emissions avoided by procured green power. We explore the advantages and disadvantages of the three strategies and broadly conclude that all three strategies will likely play distinct and important roles in the future of the green power market. Our second topic addresses the implications of the federal Inflation Reduction Act (IRA) for the voluntary green power market. We summarize the Act's clean energy provisions and how those provisions could interact with the voluntary green power market.

The U.S. voluntary green power market continues to grow. We estimate that in 2022, approximately 9.6 million customers procured around 272 million MWh of green power—a 12% increase from 2021. The market owes its continued growth partly to the ongoing adaptations of green power products to evolving customer and grid needs.

We conclude with four observations from our report:

- **Green power demand continues to grow across all products;** however, power purchase agreements (PPAs) and green pricing and tariffs are growing at a higher rate than other products in terms of sales, and community choice aggregation (CCA) is growing at a higher rate in terms of customer acquisition. Although unbundled renewable energy certificates (RECs) remained the largest source of green power demand in 2022, there is an ongoing shift among nonresidential customers toward bundled procurement strategies such as PPAs and utility renewable contracts. As a result, bundled sales are likely to surpass unbundled REC sales in 2023.
- **Voluntary green power demand could overtake compliance demand soon.** Year over year, voluntary REC sales have grown closer in volume to compliance REC sales. Sustained voluntary demand, especially among large corporate customers, means that voluntary REC sales could match or exceed compliance REC sales within the next few years.
- **Future green power procurement will be based on diverse matching strategies.** A growing number of buyers are promoting and exploring diverse green power matching strategies, including annual matching, hourly matching, and emissions matching. Each strategy entails advantages and disadvantages. Broadly speaking, annual matching is the simplest and lowest-cost approach, and it benefits from existing institutions, but the marginal impacts of annual matching may decline over time. Hourly matching likely increases the impacts of procurement on decarbonization and technological innovation, though cost premiums remain a challenge for implementing hourly matching at scale. Emissions matching directly ties buyer actions to reducing emissions, but emissions matching faces substantial challenges in the development of methodologies to accurately estimate the consequential emissions impacts of green power procurement. All three approaches may plausibly play an impactful role; however, criticism has been leveled at each, and it is not known for certain whether one strategy may ultimately prove to be generally more effective in supporting renewable energy deployment than the others.
- **The IRA will alter the course of the future green power market.** The IRA includes numerous clean energy provisions that will directly affect the voluntary green power market. The most direct impacts will come from extended and expanded tax credits, which will reduce project costs and drive a significant increase in future renewable energy deployment. Most of that increased deployment will occur outside of renewable portfolio standards (RPS), meaning that the IRA provisions could substantially increase voluntary green power sales. The IRA will also affect how and where voluntary green power projects are deployed by providing incentives to site projects in specific areas, such as in low-income communities. Finally, the IRA contains new incentives for clean hydrogen production that could create a competing source of green power demand. Whether hydrogen demand for green power meaningfully affects the broader green power market will depend on the pace and scale of clean hydrogen deployment.

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1 Introduction

Many retail electricity customers demand more renewable energy than what is otherwise provided on their local grid. These customers have various options to use renewable energy, all of which involve the purchase and retirement of renewable energy certificates (RECs), accounting mechanisms that represent the clean energy attributes of renewable energy generation.[1] Renewable energy procured by these customers represents renewable energy above and beyond that otherwise procured by load-serving entities. REC procurement by retail electricity customers is commonly known as "voluntary" demand or voluntary green power, in contrast to "compliance" demand, which refers to procurement by load-serving entities (e.g., utilities, competitive retail electricity suppliers) to comply with state mandates such as renewable portfolio standards (RPS).[2] This report summarizes the state of the U.S. voluntary green power market. For similar information on the compliance market, see Barbose (2023).

In this report, we summarize data on the various products through which retail electricity customers—including residential, commercial, and industrial, and institutional (e.g., government) customers—purchase voluntary green power. This report focuses on voluntary green power sales and participation in calendar year 2022.[3] Note that, though the green power products vary substantially in terms of cost structures, contractual commitments, availability, and other factors, all green power products ultimately serve as a conduit through which RECs are bought and retired on behalf of customers. The inclusion of RECs in all green power products ensures that the associated renewable energy use cannot be double counted and claimed by other voluntary buyers or by a retail electricity supplier for RPS compliance.

For this report, the term "green power" refers exclusively to renewable energy procurement above RPS obligations. In some cases, retail electricity suppliers sell power as a single product that includes both a voluntary portion of renewable energy (i.e., above RPS) and some portion of renewables used for RPS compliance. In these cases, we factor out the portion of renewable electricity supply that was required to meet RPS obligations. This report does not include green power use where no explicit REC transaction occurs and therefore no usage data are available. This lack of data/absence of REC transaction occurs when customers own on-site systems and "retain" the RECs so that RECs are never formally retired. Output from on-site systems amounts to less than 5% of off-site voluntary green power sales (Sumner et al. 2023).

We present voluntary green power market data and trends in Section 2. In Section 3, we discuss emerging alternative strategies for green power procurement. In Section 4, we discuss how the federal Inflation Reduction Act could affect the green power market.

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[1] For more information on RECs, see EPA (2018), and Jones (2023). Note that RECs are a subset of a broader class of certificates commonly referred to as environmental attribute certificates (EACs). We continue to use the term RECs to specify that our data refer exclusively to certificates from renewable energy generation.

[2] An emerging third category is procurement by load-serving entities outside of RPS, e.g., a utility buying more renewables (and retaining the RECs) than required by RPS. Although such procurement was historically rare, most U.S. customers are now served by utilities with voluntary decarbonization targets (Smart Electric Power Alliance 2023), suggesting that procurement outside RPS is likely increasing. For now, we continue to apply the term "voluntary" exclusively to procurement by retail electricity customers.

[3] For reports on previous years, see https://www.nrel.gov/analysis/green-power.html.

2 Voluntary Green Power Market Sales and Participation

In this section, we summarize data and trends in the voluntary green power market through various visualizations. Numeric values for all figures in this section are publicly available in a workbook format at https://www.nrel.gov/analysis/assets/docs/nrel-green-power-data-v2022.xlsx. We report trends over the full decade from 2012 to 2022. For data from earlier years, visit the National Renewable Energy Laboratory (NREL) green power page at https://www.nrel.gov/analysis/green-power.html.

The U.S. voluntary green power market has grown consistently and substantially over the past decade. We estimate that about 9.6 million customers procured about 272 million megawatt hours (MWh) of voluntary green power in 2022, up from 2.5 million customers and 54 million MWh in 2012 (Figure 1).

Figure 1. Voluntary green power sales (left) and participation (right), 2012–2022.

MWh = megawatt-hours
TWh = terawatt-hours

By 2022, voluntary green power sales accounted for about 38% of all renewable energy sales in the United States, excluding large hydropower, based on data from the U.S. Energy Information Administration (EIA) (2023a). Further, voluntary sales accounted for about 44% of the total REC market (Figure 2).[4] As a result of sustained voluntary demand—particularly among large corporate customers—voluntary REC sales could possibly overtake compliance REC sales in the near future.

[4] The total REC market refers to all voluntary green power and compliance REC retirements. Although every MWh of renewable energy is associated with a REC, total renewable energy sales are generally larger than total REC market sales because 1) total REC market sales do not reflect on-site renewable energy generation and 2) load-serving entities may procure more renewables than required for RPS compliance.

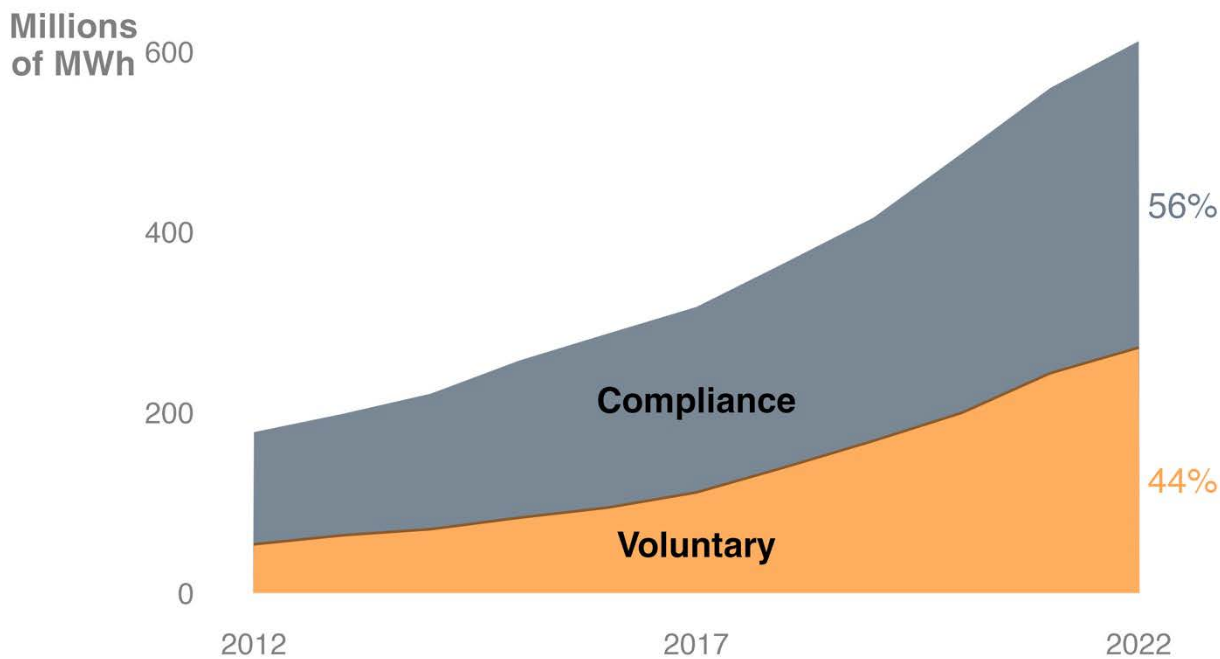

Figure 2. Renewable energy sales in voluntary and compliance markets, 2012–2022.

Compliance estimates based on data from Barbose (2023); 2022 compliance estimate based on projected value; MWh = megawatt-hours.

The voluntary green power market comprises six products through which retail electricity customers can buy voluntary RECs. Table 1 defines each of these products and summarizes our primary data sources for estimating sales for each product.

Table 1. Voluntary Green Power Product Definitions

Product	Description	Data Sources
Utility green pricing	A program wherein utilities retire RECs on behalf of residential and small commercial customers (includes community solar).	Survey, EIA (2023b)
Utility renewable contracts	Sales through utility green tariff programs wherein utilities procure power and retire RECs from specific renewable energy projects on behalf of customers who participate on a contractual basis; sales through bilateral contracts between utilities, developers, and customers.	Survey, Bloomberg New Energy Finance (BNEF; 2023)
Competitive suppliers	Nonutility retail electricity suppliers in states with restructured electricity markets that retire RECs on behalf of their customers.	EIA (2023b)
Unbundled RECs	Sales of RECs separated or “unbundled” from the underlying power.	Center for Resource Solutions (CRS; 2023)*

Product	Description	Data Sources
Community choice aggregation (CCA)	A CCA is a legal entity formed to procure power on behalf of a defined geographic area. Some CCAs procure green power on behalf of their customers.	Survey, CalCCA (2023), EIA (2023b), Green Energy Consumers Alliance (GECA; 2023), Illinois Commerce Commission (ICC; 2023), Massachusetts Department of Public Utilities (MA DPU; 2023), New York Department of Public Service (NY DPS; 2023)
Power purchase agreements (PPAs)	Sales through direct contracts between renewable energy projects and buyers, which include both power and RECs. This category includes both physical PPAs and "virtual" PPAs where the buyer does not take physical possession of the power.	BNEF (2023)

* CRS provides a certification service known as Green-e that recognizes RECs that meet specific criteria. CRS provides data on Green-e certified RECs, and NREL extrapolates a nationwide unbundled REC estimate based on historical Green-e certification rates.

Figure 3 illustrates how the composition of the voluntary green power market varies in terms of MWh sales and participation. Sales are driven by products marketed toward large, nonresidential customers, particularly unbundled RECs and, increasingly, power purchase agreements (PPAs). In contrast, participation is driven by products marketed toward residential and small commercial customers, especially community choice aggregations (CCAs), competitive suppliers, and utility green pricing programs.

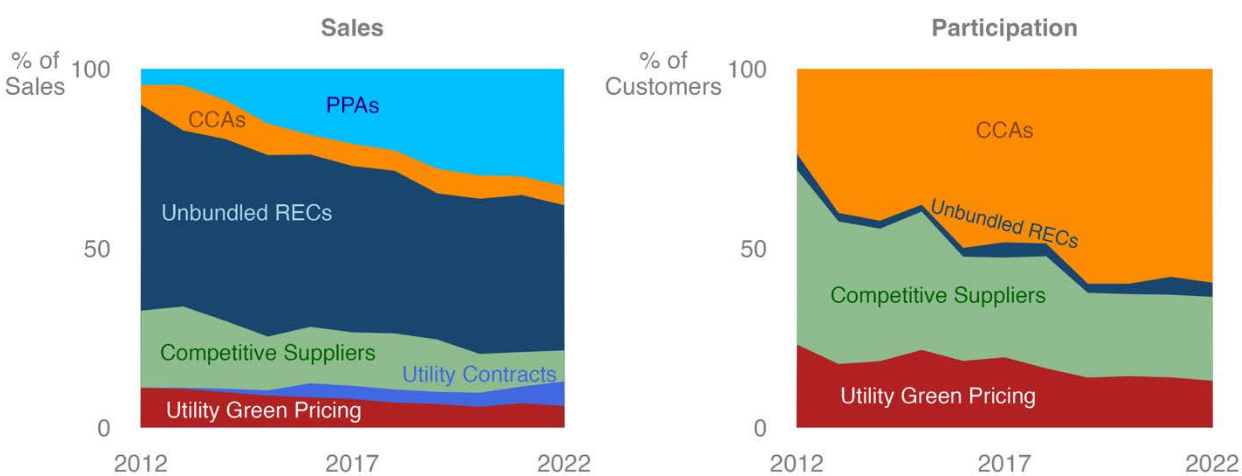

Figure 3. Shares of green power sales (left) and customers (right) over time by product.

PPAs and utility contracts collectively account for less than 1% of customers.

Figure 4 illustrates green power sales by product from 2012 to 2022, while Figure 5 illustrates green power participation by product from 2012 to 2022. Key factors driving these trends are discussed following the plots.

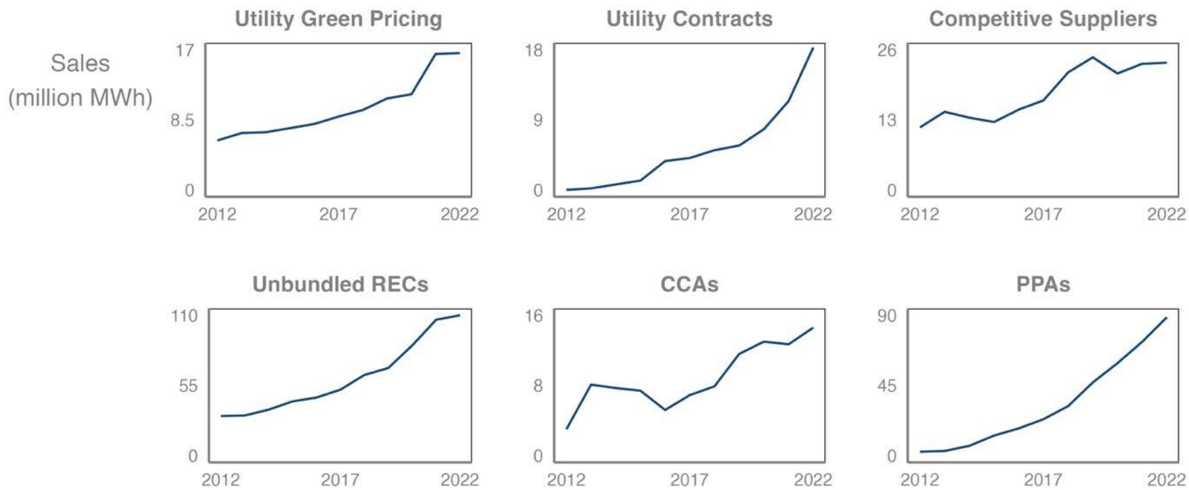

Figure 4. Green power sales by product, 2012–2022.

Plots are on different scales.

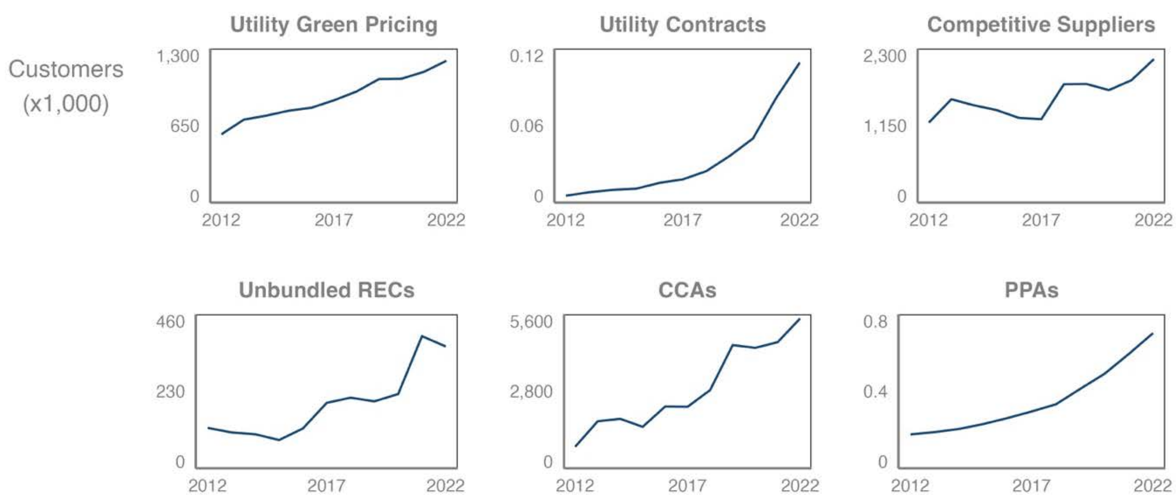

Figure 5. Green power participation by product, 2012–2022.

Plots are on different scales.

Utility green pricing participation and sales remained relatively stable from 2021 to 2022. As with other green power products, the resource composition of utility green pricing programs has evolved over time (Figure 6). Wind has been and remains the primary resource in utility green pricing programs, though its share has gradually declined over time. The share of solar has grown substantially, from around 2% of utility green pricing sales in 2013 to 32% in 2022. Meanwhile, the contribution of other resources (e.g., landfill gas, biomass, low-impact hydro) has declined significantly.

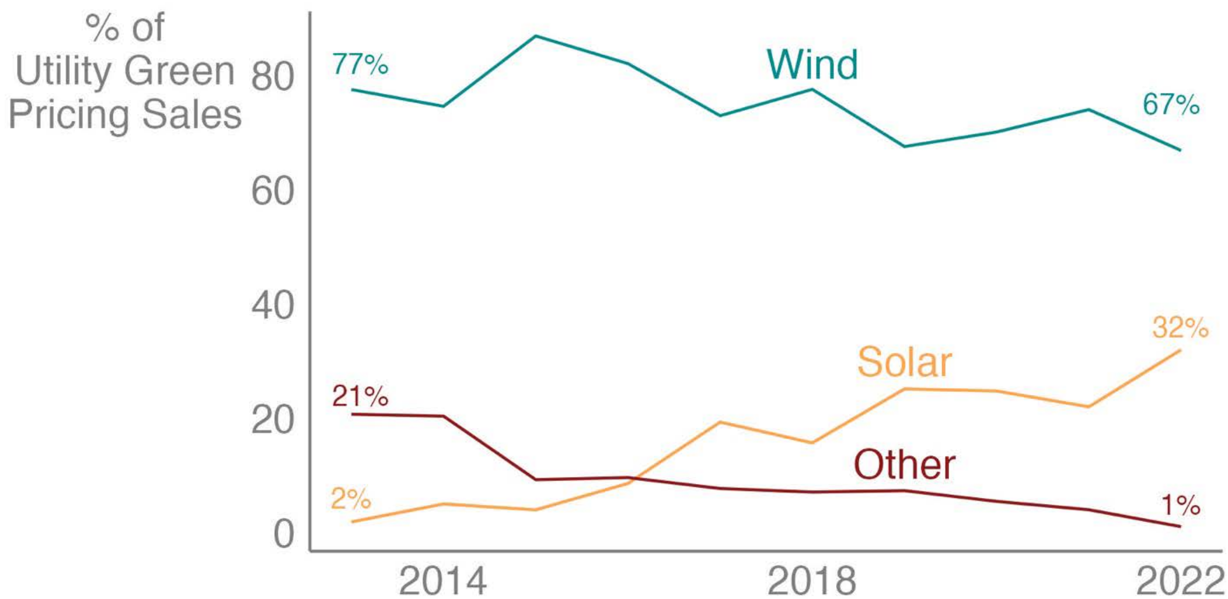

Figure 6. Estimated resource shares of utility green pricing sales: 2013–2022.

Note: Some year-over-year variation is because of the changing composition of utility survey respondents in each year.

Utility renewable contracts continue to expand, with an estimated 114 operational projects generating 18.3 million MWh of green power in 2022.[5] The utility renewable contract pipeline continues to grow, aided by two historically large deals in 2022. In the Southeast, a partnership between Meta, the Walton Electric Membership Corporation, and the Tennessee Valley Authority resulted in a renewable contract that will drive the deployment of 720 megawatts (MW) of solar in Georgia and Tennessee. In Michigan, a contract between Ford and DTE will result in 650 MW of new solar capacity deployed in the state.

Unbundled REC sales grew modestly from 2021 to 2022, and the number of customers buying unbundled RECs declined. Modest growth in 2022 may reflect a course correction after a relatively large increase in sales from 2020 to 2021. The drop in the number of customers likely represents some customers switching to other products. Although unbundled RECs remain the largest category of voluntary green power sales, there is an ongoing shift to other procurement strategies and products, especially a shift among nonresidential customers toward PPAs and utility renewable contracts.

CCA sales and participation continued to grow in 2022. California, one of the oldest CCA enabling states continues to dominate CCA green power sales and participation due to its conducive policy environment, accounting for about 79% of all CCA green power customers in 2022 (Table 2). CCA sales in California grew by 15% from 2021 to 2022 largely because of the emergence of a new CCA in San Diego. In New York, the expansion of CCAs has plateaued in recent years. After participation growing rapidly to reach 72 communities enrolled in CCAs by the end of 2020, only 8 new communities enrolled in 2021 and 2022. The recent stagnation of CCA growth in New York may be attributable to

[5] Note that utility renewable contract customer estimates reflect the number of projects, which has typically equaled the number of customers. However, some utilities are evolving green tariff programs in ways that may allow multiple customers to contract for power from the same projects. Our methodology may be adjusted in future years to reflect these changes.

regulatory restrictions in New York that affect how CCAs set prices (Dépit 2023). In 2023, new CCAs began to form in New Hampshire, some offering green power products (Dépit 2023).

Table 2. 2022 CCA Green Power Sales and Customers by State

State	Green Power Sales (MWh)	Green Power Customers
California	11,540,000	4,882,000
Illinois	93,000	11,000
Massachusetts	1,070,000	471,000
New York	844,000	219,000
Ohio	1,036,000	132,000
Total	**14,583,000**	**5,714,000**

PPA sales continue to grow as more nonresidential customers—especially corporations—sign long-term contracts to meet renewable energy targets. Note that PPAs refer to two types of contract structures. "Physical" PPAs are contracts in which the buyer procures power and RECs so that the power is physically delivered to the buyer's grid and "used" by the buyer. "Virtual" PPAs are contracts in which the power is sold into wholesale power markets and the arrangement between buyer and seller is strictly financial. Although precise estimates are lacking, available data suggest that over 90% of voluntary PPA projects and capacity are from virtual PPAs. PPA sales continue to be concentrated in Texas and Oklahoma, which together accounted for nearly half of all PPA sales in 2022 (Figure 7). At the same time, the geography of voluntary PPAs has diversified over time. PPA sales exceeded 1 million MWh in 17 states in 2022, and 5 states generated more than 5 million MWh in PPA sales: Texas (33.3 million MWh), Oklahoma (8.7 million MWh), Illinois (6.1 million MWh), Ohio (5.9 million MWh), and Kansas (5.5 million MWh).

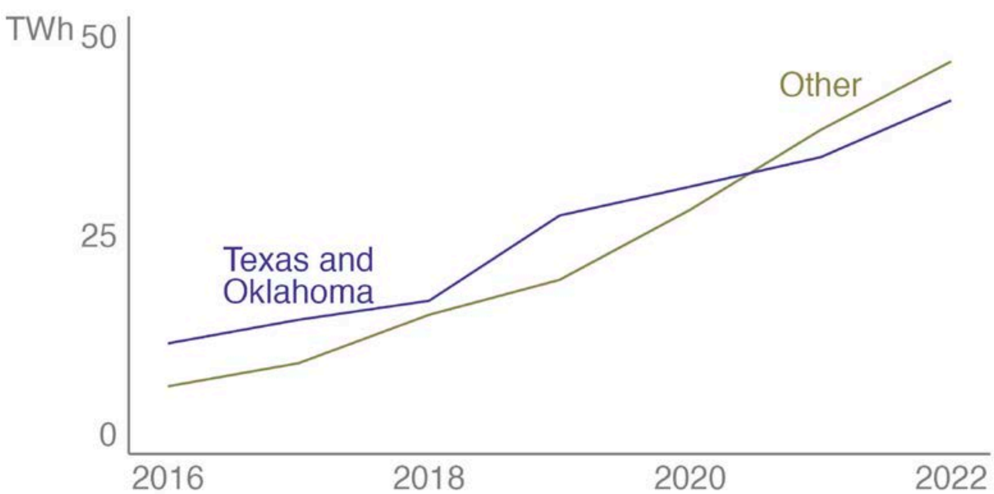

Figure 7. Geographic distribution of voluntary PPA green power generation

3 New Approaches to Green Power Matching

In contrast to commodity markets, electricity cannot be physically tracked from generator to end use, so there is no way for any customer to demonstrate that a unit of grid-connected demand used an equivalent unit of green power. All green power procurement is based on some approach to match a customer's demand to a REC purchase on an accounting basis. Buyers have recently proposed and implemented new matching strategies that could achieve distinct goals. These new approaches are not yet well understood, entail trade-offs, and pose new challenges. In this section, we define the three primary matching strategies: annual matching, hourly matching, and emissions matching. We then explore some of the advantages and disadvantages of the approaches to understand why customers are pursuing new matching strategies. Our objective in this section is to summarize the existing literature on the available options. We do not draw conclusions about which strategies may be optimal for different buyers or the market as a whole.

3.1 Three Matching Strategies

Broadly speaking, green power buyers and stakeholders are debating the merits of three matching strategies: annual matching, hourly matching, and emissions matching (Figure 8).

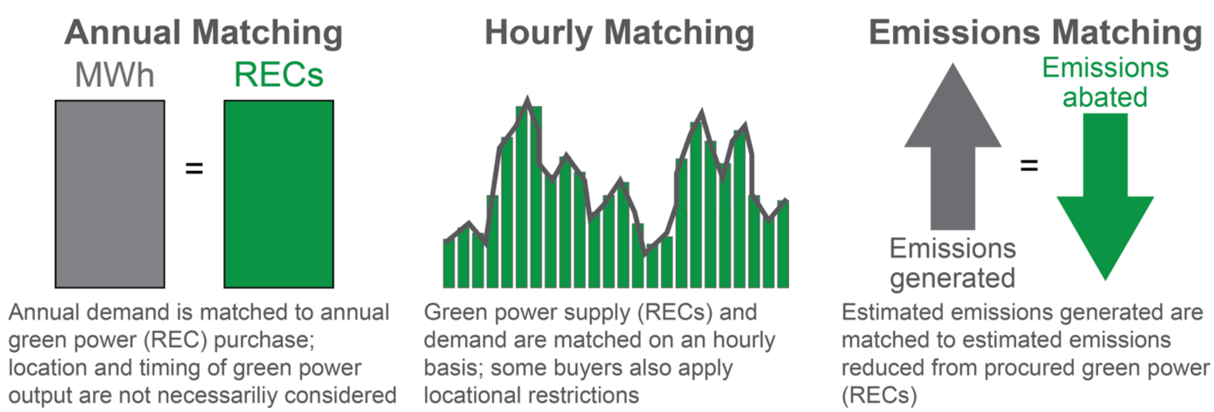

Figure 8. Green power procurement matching strategies

- Under **annual matching**, customers buy an annual quantity of RECs, bundled or unbundled, to substantiate the use of that quantity of green power on an annual basis. For instance, a customer that used 100 MWh of electricity in 2022 can buy 100 RECs and claim to have used 100% renewable electricity in 2022. Under annual matching, the geographic and temporal profile of RECs do not affect the buyer's *ability* to claim to use renewable energy. However, any specific geographic or temporal claims must be supported by the geographic and temporal profile of RECs. For instance, a buyer can claim to have used green power in Colorado only if that buyer has bought and retired RECs generated in Colorado. Annual matching is—by far—the most common green power matching strategy. Annual matching can be implemented with every form of green power procurement tracked in this report, including contractual mechanisms such as utility renewable contracts and PPAs.

- Under **hourly matching**, customers buy renewable energy (substantiated by RECs) from specific hours to match customer demand in the same hours.[6] For instance, a customer that used 1 MWh of electricity from 12 noon to 1 p.m. on a certain day would, under hourly matching, need to procure 1 REC generated from 12 noon to 1 p.m. on the same day. Proponents of hourly matching also generally call for geographic restrictions, such as buying renewable energy generated only in the buyer's region. Though hourly matching remains uncommon, several large buyers are piloting the concept, more than 100 buyers created a compact to support hourly matching, and the U.S. federal government has embraced an hourly matching strategy to procure green power for federal government end uses (Hausman and Bird 2023). Hourly matching has not been universally embraced by buyers. According to preliminary results from an ongoing survey of buyers in the Green Power Partnership, about 70% of nonresidential buyers are not currently pursuing hourly matching, 10% are pursuing an hourly matching strategy, and 20% remain unsure.[7]
- Under **emissions matching**, the goal is to match estimated greenhouse gas emissions (henceforward simply "emissions") generated by a buyer's electricity use to estimated emissions abated by procured green power (substantiated by RECs).[8] To achieve emissions matching, a customer would procure enough renewable electricity so that the estimated abated emissions of that electricity would offset the estimated emissions generated by the customer's electricity demand. The simplicity of that objective belies significant complexities and challenges in estimating abated emissions—a topic we discuss in Section 3.2.3. Emissions matching has not, to our knowledge, been implemented by any buyer at any meaningful scale. However, several large corporate buyers have committed to enabling emissions matching.

The preceding definitions are necessarily simplified for the purposes of discussion. Buyers can and do implement strategies that do not neatly fit into one of the three bins. We acknowledge that buyers could adjust matching strategies in ad hoc ways to meet buyer-specific goals. The following discussion should therefore be understood as a simplified, high-level review of different matching strategies. Further, we reiterate that the scope of our report is restricted to renewable energy procurement (i.e., RECs). All three strategies can be expanded to other forms of clean energy procurement. Nonrenewable zero-carbon resources could play particularly prominent roles in hourly and emissions matching.

3.2 Comparing Approaches

We explore some of the strengths and weaknesses of the three procurement approaches across three dimensions: impact, cost, and complexity.

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[6] We use the term "hourly" matching here for simplicity, though it is possible to implement time-based matching in subhour units. Others have used the term "24/7" matching to describe a similar concept as hourly matching.

[7] Preliminary survey results shared by the U.S. Environmental Protection Agency's (EPA's) Green Power Partnership. Note that the results provided are based on a partial response of 370 buyers, or about 57% of buyers in the Green Power Partnership. Final results are subject to change as more buyers participate in the survey.

[8] Of the three strategies, emissions matching is the most nascent and loosely defined. Other buyers may pose alternative definitions of emissions matching, but the concept generally refers to efforts to more directly account for emissions abated rather than MWh of clean energy generated.

3.2.1 Impact

Summary: All three strategies can be impactful in certain contexts. Hourly and emissions matching could increase impacts relative to annual matching, under certain circumstances, particularly as more renewables come online. These extra benefits may not yet be cost-effective to achieve under existing technologies and institutions. Still, early support for hourly and emissions matching could enable emerging clean energy technologies.

The term “impact” has many evolving connotations in the green power market. For this discussion, impact refers to how green power purchases increase renewable energy output, reduce electric grid emissions, and drive technological development relative to a world without those green power purchases. As a result, consistent with the broader use of the term in the green power market, impact has a positive connotation in this context (e.g., environmental *benefits*). For various methodological reasons, voluntary green power market impacts are difficult to estimate (O’Shaughnessy and Sumner 2023). The discussion that follows is based largely on theory and modeling from the literature, particularly in the cases of hourly and emissions matching. Further research is required to empirically estimate and more precisely understand the impacts of each matching strategy.

To analyze the potential impacts of the three strategies, we must first recognize three points. First, all three matching strategies can be impactful in certain contexts and less impactful in others (Heeter et al. 2021; Xu et al. 2021; He et al. 2021; Reed et al. 2023). Analysis of procurement impacts must be understood as a comparison of the relative impacts of different strategies, not a binary question of whether one strategy is impactful, and another is not. Second, the relative impacts of different strategies change as grids evolve. At relatively low levels of renewable energy penetration, the key driver of impact is the volume of green power deployed. However, as more renewables come online, impacts depend increasingly on where, when, and what types of green power are deployed (Xu et al. 2021; Cybulsky et al. 2023). Third, the aggregate impact of the voluntary green power market depends on two factors: 1) the number of buyers that participate in the market and 2) the *marginal* impacts of each individual buyer. Hence, all else equal, voluntary market impacts increase when market participation increases (i.e., more buyers procure green power) and/or when the marginal impacts of individual purchases increase. The three strategies affect these two factors in distinct ways.

All else equal, annual matching can maximize voluntary green power market participation. Relative to the other two strategies, annual matching is generally cheaper (see Section 3.2.2) and simpler to implement (see Section 3.2.3), making annual matching the most viable strategy for most customers. Annual matching can therefore be an impactful strategy on grids with relatively low levels of renewable energy penetration (He et al. 2021; Heeter et al. 2021). However, as more renewables come online, annual matching may yield diminishing marginal impacts. Annual matching mostly supports the deployment of relatively low-cost wind and solar. Although wind and solar are crucial for the clean energy transition, deeper grid decarbonization will require a more diverse portfolio of energy resources such as firm clean power generators[9] and energy storage. Annual matching does not necessarily support the deployment of resources needed for deeper decarbonization over more conventional sources such as wind and solar (Bird et al. 2021).

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[9] The term “firm” refers to power sources whose output does not depend on a variable resource such as solar or wind. Some examples of firm resources include geothermal, hydrogen combustion turbines, and long-duration energy storage.

Hourly matching could enhance marginal green power impacts on modern, cleaner grids (Bird et al. 2021; Xu et al. 2021; Riepen and Brown 2022; Reed et al. 2023). An argument for hourly matching is that the strategy encourages more diverse green power portfolios—and that diversity could entail greater grid and environmental benefits. To illustrate with a simple example, consider a buyer in California who wants to buy local green power. Under annual matching, the buyer would likely buy relatively low-cost solar power. In contrast, presuming that the buyer uses electricity in off-solar hours, an hourly matching strategy would drive the buyer to diversify their portfolio to procure power to meet demand in hours when solar is unavailable. Hourly matching could thus support the development and deployment of firm clean energy technologies that will be critical for grid decarbonization (Jenkins et al. 2018).

The theoretical case for the impact benefits of emissions matching is straightforward. Focusing on emissions impacts could lead customers to pursue options that reduce grid emissions more effectively than default options under annual matching. Theoretically, emissions matching could be an effective strategy for reducing grid emissions (He et al. 2021); other potential impacts (e.g., technological development) remain unclear. However, the real-world impacts of emissions matching depend critically on the development and consistent use of methodologies to accurately estimate emissions impacts (Gagnon and Cole 2022)—a challenge explored further in Section 3.2.3.

3.2.2 Cost

Summary: Annual and emissions matching allow buyers to procure resources that meet their green power goals while minimizing costs. Hourly matching could entail higher costs than the other two strategies.

Procurement costs are key considerations for green power buyers. Annual matching is likely the lowest-cost strategy in most contexts (Olson et al. 2023). Under annual matching, buyers can identify and procure resources from anywhere and anytime on the U.S. grid in ways that minimize costs while also meeting their goals. Buyers in regions with high development costs and REC scarcity (and thus high REC prices) can buy green power from regions with low development costs and plentiful RECs (and thus low REC prices). Even for buyers with regional restrictions—such as goals to buy power from the same region—the temporal flexibility of annual matching can still reduce procurement costs. Emissions matching could have similar cost benefits by allowing buyers to procure the lowest-cost resources that achieve their emissions goals (He et al. 2021), though the relative costs of emissions matching remain to be demonstrated.

Hourly matching entails higher costs than annual and emissions matching (He et al. 2021; Xu et al. 2021; Long Duration Energy Storage [LDES] Council 2022; Olson et al. 2023; Reed et al. 2023).[10] To be clear, the higher costs of hourly matching partly reflect the discipline that hourly matching imposes on buyers to diversify clean energy portfolios. That diversification requires moving away from low-cost resources (e.g., solar and wind) to costlier resources such as firm clean energy and energy storage. As a result, hourly matching cost premiums partly reflect additional benefits from the strategy. The key question is whether or when those additional benefits can be achieved cost-effectively. Costs will likely decline as more buyers explore and "learn" from early hourly matching experiences. Further,

[10] Conceptually, buyers could reduce the costs of hourly matching by matching only in a limited number of hours. However, Xu et al. (2021) find that the enhanced impacts of hourly matching accrue only at relatively complete levels of matching with relatively higher costs.

institutional reforms—such as the development of hourly matching trading platforms—could reduce cost premiums (Xu and Jenkins 2022).

3.2.3 Complexity

Summary: The three approaches entail trade-offs in terms of procurement complexity (complexity for the buyers) and institutional complexity (how difficult the strategy is to verify). Annual matching is the simplest approach for buyers, and it benefits from existing institutions for verification. Hourly matching is more complex for buyers and would require the development of new institutions for verification. Emissions matching is particularly complex and entails challenging questions about how to accurately estimate generated and abated emissions.

We explore the complexity of the three procurement strategies across two dimensions: 1) *procurement complexity* refers to how easy or difficult a strategy is to implement for buyers; 2) *institutional complexity* refers to how easy or difficult a strategy is to verify through the evolving institutional framework. Products that are simple to implement and verify will, all else equal, enjoy greater uptake and drive greater market impact. In contrast, products that are complex for buyers and more difficult to verify could have reduced market application.

Annual matching is the simplest of the three strategies across both dimensions of complexity. In terms of procurement complexity, annual matching requires knowledge only of a buyer's annual energy consumption. All additional layers of procurement complexity (e.g., procuring "local" renewables) are voluntary. In terms of institutional complexity, annual matching is already supported by established and broadly accepted legal mechanisms (Jones 2023).

Hourly matching entails greater procurement complexity for buyers. To implement hourly matching, buyers need more detailed knowledge of their own demand—possibly including methods to predict demand with reasonable accuracy. Further, as already noted, a potential impact advantage of hourly matching is that the strategy incentivizes the procurement of more diverse clean energy portfolios (Miller 2020), which adds layers of complexity for buyers (LDES Council 2022). In terms of institutional complexity, hourly matching is comparable enough to annual matching that certain institutions (e.g., tracking systems) could be replicated (Terada 2023). For instance, hourly matching could be verified using time-stamped attribute certificates (Miller 2020; Xu and Jenkins 2022).

Emissions matching is, arguably, the most complex of the three strategies. The strategy implies a "consequential" view of accounting where buyers estimate how green power procurement actions reduce grid emissions (Ekvall 2019; Ricks et al. 2023). There is, however, no consensus view on how to estimate the consequential emissions impacts of procurement actions. Some scholars have used average emissions rates (the average emissions rate of all electricity generated or consumed over a defined time period) and short-run marginal emissions (the emissions of the marginal unit of electricity generated or consumed considering only operational impacts) to assess the impacts of emissions matching strategies (He et al. 2021; Oates and Spees 2021). However, average and short-run marginal emissions rates do not account for how green power procurement actions may affect longer-term investment decisions, such as when and where to build new fossil fuel plants or when to retire existing plants. These *structural* changes can significantly affect the long-term emissions impacts of green power procurement decisions (Gagnon and Cole 2022). An alternative approach is to estimate long-run marginal emissions rates that reflect these structural changes and thus better reflect the emissions impacts of green power procurement (Hawkes 2014; Gagnon and Cole 2022; Ricks et al. 2023). The use of long-term marginal emissions rates is generally consistent with existing standards and guidance (Ekvall 2019; Woolf et al. 2020). However, no method for estimating long-run marginal emissions has been broadly accepted (Reed et al. 2023). The effective implementation of emissions matching thus depends on the future development and use of methodologies to accurately estimate the consequential emissions impacts of green power procurement. In terms of institutional complexity, emissions matching would also require the development of institutions to verify power use and emissions claims based on consensus-based methods for measuring consequential emissions impacts.

3.3 Summary

Three strategies have emerged for renewable energy use claims in the U.S. green power market: annual matching, hourly matching, and emissions matching. Each strategy entails strengths and weaknesses. All three strategies can drive renewable energy deployment and reduce grid emissions under certain conditions. At the same time, valid criticisms have been leveled at all three strategies. To summarize:

- **Annual matching** is a practical strategy that benefits from decades of experience and strong institutions. All else equal, annual matching maximizes consumer access and voluntary green power market participation by minimizing costs and procurement complexity. However, the marginal impacts of annual matching may diminish over time as more renewables come online.
- **Hourly matching** can enhance the marginal impacts of voluntary green power procurement, partly by driving buyers to invest in a broader diversity of clean energy resources. However, the relatively higher costs of hourly matching could constrain the number of buyers that can implement the strategy.
- **Emissions matching** most directly connects buyer procurement strategies to emissions impacts. As a result, emissions matching could theoretically help buyers to maximize the environmental benefits of their green power procurement. However, to fulfill the potential of emissions matching, there would need to be an accurate real-time or retrospective estimate of the full emissions consequences of green power procurement actions. A method to make such estimates would have to capture both the immediate operational consequences of the action and how the action influences later investment decisions. This is a significant challenge, with no proposed method yet achieving general acceptance.

4 Implications of the Inflation Reduction Act

In 2022, the Biden administration passed the Inflation Reduction Act (IRA). The IRA contains myriad renewable energy provisions. In this section, we explore the implications of the IRA's renewable energy provisions for the U.S. voluntary green power market. We begin by summarizing the IRA's renewable energy provisions. We then explore how the IRA's enhanced renewable energy incentives could affect the voluntary green power market. We conclude by exploring how new incentives for green hydrogen production could interact with the green power market.

4.1 Summary of Inflation Reduction Act Renewable Energy Provisions

The IRA contains numerous clean energy and climate provisions (Bipartisan Policy Center [BPC] 2022; White House 2023). Here, we focus on several provisions that could directly affect green power markets:

- **Tax credits:** The IRA extends existing renewable energy tax credits through the end of 2024 and implements new, expanded clean electricity tax credits beginning in 2025. The IRA makes tax credits more broadly accessible and valuable by allowing certain types of owners (e.g., tax-exempt entities) to apply for a direct payment of the credits and allowing credits to be transferred between taxpayers. The expanded credits cover all zero-emissions or net-negative emissions generation sources. The tax credits are scheduled to begin to phase down in 2032 but will be extended beyond 2032 if U.S. electric grid emissions remain higher than 25% of 2022 emission levels.
- **Grants and loans:** The IRA provides tens of billions of dollars in clean energy grants and loan guarantees to support renewable energy manufacturing, renewable energy deployment, and transmission network upgrades.
- **Permitting provisions:** The IRA provides funding to various agencies to pursue measures to streamline permitting for large-scale renewable energy projects.
- **Energy justice provisions:** Several IRA renewable energy provisions contain incentives for projects deployed in or to serve disadvantaged communities.
- **Hydrogen provisions:** The IRA creates new tax credits for low-carbon hydrogen production, explored in further depth in Section 4.3.

4.2 Inflation Reduction Act Impacts on Green Power Deployment

Early estimates from the literature suggest that the IRA could more than double clean energy deployment by 2030 (Bistline et al. 2023; Figure 9). Most of that increased deployment will come from green power sources such as solar and wind. A smaller share—less than one-third in most studies—will come from energy storage, nuclear, and fossil fuel generators equipped with carbon capture. The amount of that new deployment that could serve the voluntary green power market depends, in part, on growth in RPS-based compliance demand. Barbose (2023) projects compliance demand to grow from around 420 TWh in 2022 to around 650 TWh in 2030. EIA forecasts—which are generally conservative—suggest that solar and wind output will grow from around 570 TWh in 2022 to around 1,740 TWh in 2030 (EIA 2023c). As a result, a conservative estimate for an IRA-driven surplus in renewable energy demand is around 1,000 TWh of renewable energy above RPS demand by 2030—roughly 4 times the size of the voluntary green power market in 2022. Under more aggressive forecasts, such as from Jenkins et al. (2022), that surplus could be at least twice as large. Voluntary buyers will likely be a key source of demand for the power and RECs from that increased deployment.

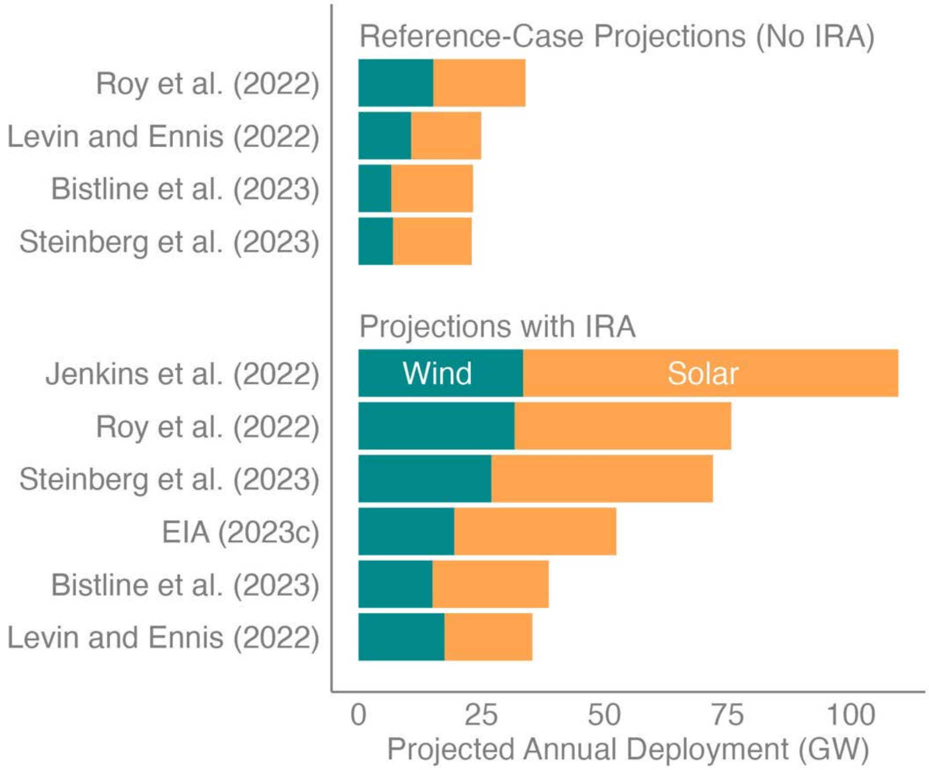

Figure 9. Projected annual solar and wind deployment with IRA impacts from select studies.

Note: All projections are based on central estimates and all studies project IRA impacts to 2030. To compare across studies, all results were converted to annual deployment impacts, though the durations of those impacts vary across the studies. GW = gigawatts.

These modeled projections from the studies show that the IRA will likely accelerate voluntary green power sales in the coming years. The magnitude of that acceleration will depend on at least three open questions:

- *Will the IRA affect state clean energy policies?* The IRA may reduce clean energy costs and accelerate clean energy deployment, as some policymakers may respond by updating RPS with more aggressive timelines to account for the IRA's clean energy provisions. Alternatively, policymakers could also consider RPS redundant and decide not to increase RPS to allow markets to drive future renewable energy deployment.
- *How will load-serving entities treat surplus RECs?* The IRA's clean energy provisions could substantially improve clean energy project economics. As a result, load-serving entities may acquire more clean energy to serve their retail electricity customers. A key open question is what load-serving entities would do with surplus RECs generated above RPS. Load-serving entities could retire surplus RECs so that their clean energy attributes would accrue to all retail electricity customers. Alternatively, load-serving entities could use surplus RECs to expand retail green power programs (e.g., utility green pricing programs, utility green tariffs, CCA green power products). Finally, load-serving entities could sell surplus RECs into wholesale REC markets.
- *How will hydrogen incentives affect REC demand?* The IRA creates new incentives for hydrogen production. Large-scale clean hydrogen production could emerge as a large new source of green

power demand, potentially crowding out other forms of green power demand. We discuss the interaction of clean hydrogen production with voluntary green power demand in Section 4.3.

Beyond increasing green power deployment, the IRA's clean energy provisions could have several impacts on the green power market, including the following:

- **Impacts on REC prices:** The IRA could potentially transform the supply of and demand for electricity. These transformations will almost certainly affect REC prices, though the nature of that impact is uncertain. Increased renewable energy deployment because of the IRA will increase REC supplies. All else equal, increased REC supplies will tend to reduce average REC prices. Importantly, supply-driven reductions in REC prices could be partly offset by demand-driven increases in REC prices if the IRA drives a significant increase in clean hydrogen production—e.g., see Section 4.3. Further, the IRA contains provisions to incentivize electrification of building energy end uses (e.g., space heating) and transportation. Increased demand for electricity—and thus RECs—could exert upward pressures on REC prices.
- **Increased REC supplies from reduced curtailment:** Solar and wind projects occasionally operate below their available capacity, a condition known as "curtailment." Curtailment typically occurs when electricity prices become negative, effectively requiring generators to pay to deliver electricity to the grid. Some generators continue to generate even under negative prices to monetize production tax credits, which are paid out only for delivered output. Historically, production tax credits have been available only for wind projects. The IRA extends production tax credits through at least 2032 and expands eligibility to include solar projects. The extended and expanded production tax credits will disincentivize curtailment (Bistline et al. 2023), thus increasing REC supplies by generating RECs that would have otherwise been curtailed.
- **Impacts on green power project siting:** The IRA contains several provisions that will affect green power project siting decisions. Specifically, the IRA contains incentives for projects to site in communities transitioning away from fossil fuel economies (e.g., coal mining communities) and in low-income communities. These equity-based provisions could dovetail with niche efforts within the voluntary market to procure green power that promotes equity and social justice, such as efforts to support workforce development in disadvantaged communities (Bird et al. 2021).
- **Increased access to direct procurement:** For several decades, the federal government has incentivized solar and wind deployment through tax credits. The use of tax credits, rather than direct payment methods such as grants, posed unique challenges. The renewable energy industry evolved to rely on tax-equity investors (e.g., banks) with sufficient tax liabilities to monetize tax credits. The need for tax equity can increase project costs and pose challenges to some buyers, especially small buyers who may struggle to attract tax-equity investors. The IRA mitigates these challenges by allowing certain entities to monetize the credits through direct payments and by allowing tax credits to be transferred among taxpayers. The IRA tax credit revisions could help smaller buyers access the types of direct procurement products (e.g., system ownership, PPAs) that have been mostly used by larger buyers. However, how the IRA provisions affect renewable energy contract structures remains to be seen.

4.3 Implications of Low-Carbon Hydrogen Incentives

Hydrogen is an alternative fuel that does not exist in natural reserves. Presently, hydrogen fuels are mainly produced industrially through steam reforming of methane, largely fossil natural gas. A low-carbon alternative is to produce hydrogen by using clean electricity to extract hydrogen from water—a process known as electrolysis. While hydrogen fuel production is currently a small industry with limited applications, a low-carbon alternative hydrogen fuel would be poised for significant growth because of its unique applications for decarbonizing hard-to-abate activities in the transportation and industrial sector (e.g., steel production). Thus, hydrogen fuels produced with low-carbon electricity could facilitate the decarbonization of processes that cannot be easily electrified. .

The IRA creates new production-based tax credits for low-carbon hydrogen where the value of the tax credit depends on the hydrogen's estimated life-cycle emissions. The maximum value of the tax credit is $3/kilogram (kg) for hydrogen with estimated per-unit life-cycle emissions lower than 0.45 kg of carbon dioxide (CO_2) per kg of hydrogen (H_2), declining to $0.6/kg for hydrogen with per-unit life-cycle emissions greater than 2.5 kg CO_2/kg H_2. Hydrogen with per-unit life-cycle emissions greater than 4 kg CO_2/kg H_2 is not eligible for the credit.

The U.S. Department of Treasury is expected to issue further guidance on how hydrogen producers must measure and verify life-cycle emissions. The Treasury guidance could allow hydrogen producers to qualify for tax credits through procurement of off-site clean power supplies (Cybulsky et al. 2023). RECs and other types of energy attribute certificates could be a component for the verification of off-site clean power supplies used for hydrogen production, though the Treasury guidance is unknown. Like the case of the green power market, an ongoing debate is exploring the efficacy of different REC matching strategies for driving low-carbon hydrogen production (Cybulsky et al. 2023; Esposito et al. 2023; Olson et al. 2023; Ricks et al. 2023).

Low-carbon hydrogen production could become another source of demand for voluntary green power in the United States. The near-term impacts of hydrogen on green power demand are limited: Existing electricity demand for electrolysis is around 5 million MWh per year,[11] or roughly 2% of voluntary green power demand in 2022. The long-term impacts depend on the construction of new electrolysis facilities, possibly in response to the IRA incentives. Ruth et al. (2020) estimate that the U.S. hydrogen industry could double or even quadruple in capacity in the coming decades with hydrogen electrolysis demand exceeding 1,800 million MWh per year,[12] a high-end estimate possibly facilitated by the IRA incentives. Hence, in the long term, annual electricity demand for hydrogen electrolysis could be around 6 times the existing U.S. voluntary green power demand. If a substantial portion of that demand seeks green power in response to IRA incentives, hydrogen demand for green power could eventually be similar in scale to voluntary green power demand.

The potential impacts of hydrogen demand on other voluntary green power buyers depend on the pace and scale of hydrogen electrolysis deployment. At one extreme, hydrogen demand may have little impact on other voluntary buyers if the hydrogen market grows in parallel to the broader voluntary green power market. Cybulsky et al. (2023), for instance, argue that near-term hydrogen demand will be too small to meaningfully affect the broader renewable energy market so that emerging hydrogen demand may not affect REC prices or other factors that affect voluntary green power buyers. At the other extreme, a rapidly scaling hydrogen industry could directly compete with the broader voluntary green

[11] Annual hydrogen production in the United States is around 10 million metric tons, of which approximately 0.1 million metric tons is produced via electrolysis (U.S. Department of Energy [DOE] 2020). As a heuristic, electrolysis requires about 50 MWh of electricity to produce 1 metric ton of hydrogen (Ruth et al. 2020), such that existing electrolysis demand is around 500 million MWh/year.

[12] Ruth et al. (2020) estimate economically potential electrolysis capacity of 37 million metric tons per year under aggressive assumptions for electrolysis cost reductions. Again assuming 50 MWh per metric ton, that capacity equates to roughly 1,850 million MWh of annual electricity demand.

power market for finite green power resources. The emergence of a large new source of green power demand could inflate voluntary REC prices and create growing competition among offtakers during project development and planning. The potential interaction of clean hydrogen production with the voluntary green power market will be an area of ongoing research.

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