A Market Mechanism for Long-Term Energy Contracts to Support Electricity System Decarbonization

Brendan Pierpont, December 2020

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Executive Summary

The U.S. and other global economies will need to achieve net zero greenhouse gas emissions economy-wide by 2050 to minimize the risk of catastrophic climate change. A decarbonized electricity sector that supports electrification of transportation, buildings and industry is the lynchpin to achieving climate goals, so it becomes imperative to structure electricity markets and policy to mobilize capital rapidly and efficiently to support decarbonization.

This paper proposes a long-term market mechanism that is intended to work in tandem with state or national climate and clean energy policies to support efficient deployment of capital into zero-carbon energy resources, supporting a rapid transition to a decarbonized electricity system.

The market mechanism proposed here consists of three main components:

- Financial long-term, fixed price contracts for energy based on a specified production profile, structured to preserve short-term market signals and incentives for efficient operations.
- A market clearing mechanism that selects those resources with that have the highest value to the electricity system or to buyers in the long-term market, relative to contract costs.
- Allocation of contract costs and benefits to buyers by pooling contracts together and selling as a bundle, diversifying the counterparty and credit risk any one buyer or seller is exposed to.

This long-term market mechanism is intended to support low-cost financing of resources that have high value to the electricity system, relative to costs. This is a tool intended to work in parallel with a wide range of existing and future climate and clean energy policy enacted by national, state and local governments. In addition this approach is not intended to solve for electricity system resource adequacy on its own, but is complementary to effective short-term electricity market design that can value scarcity and security of supply.

Electricity markets and planning are inherently complex and involve significant trade-offs. The mechanism proposed in this paper is not intended to be a single comprehensive solution to procuring the optimal mix of electricity system resources. Instead, it is a tool to select cost-effective resources, encourage competition, and lower financing costs for capital-intensive zero-carbon resources, while minimizing complexity and adapting to market changes over time. This approach could be a valuable tool in a suite of policy and market design enhancements that could help mobilize capital into renewable energy and carbon-free resources, ensuring that our electricity system is not only low carbon, but affordable for all.

1. Introduction

The U.S. and other global economies will need to achieve net zero greenhouse gas emissions economy-wide by 2050 to minimize the risk of catastrophic climate change.[1] The threat posed by climate change to the U.S. alone justifies efforts to decarbonize our energy system. As the Fourth National Climate Assessment (2019) concluded:

> "Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth"; and "Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century."

Numerous analyses show that effective pathways to achieving net zero greenhouse gas emissions rely on rapid decarbonization of the electricity sector alongside electrification of transportation, energy use in buildings and many industrial energy uses.[2] Moreover, recent analysis shows that in the U.S., a system that generates 90% of electricity from zero-carbon sources by 2035 can cost less than today's fossil fuel dominated system.[3] A decarbonized electricity sector is the lynchpin to achieving climate goals, so it becomes imperative to structure electricity markets and policy to mobilize capital rapidly and efficiently to support decarbonization.

Electricity markets have traditionally been designed with the key objectives of reliability and affordability. But today, and moving forward as we decarbonize the electricity sector, electricity markets must also work in tandem with policy to accelerate deployment of carbon-free resources, enable continued innovation by sending appropriate market signals for long-term system needs, and promote efficient combinations of resources to ensure electricity remains affordable and capital is invested where it is most effective.

But how should electricity markets be stuctured and designed to drive large amounts of capital investment, minimize costs to consumers, and ensure that investments are made in an efficient mix of projects and technologies?

Several authors have proposed organized long-term market mechanisms to achieve these goals. In Pierpont and Nelson (2017) we proposed a two-part market which combined a long-term energy auction that sought to minimize financing costs and procure the lowest-cost sources of energy available with a short-term residual market that incentivized flexibility and real-time delivery of power when and where it was needed. However, the concept did not directly address how the long-term market would differentiate between resources with very

[1] IPCC (2018)
[2] Evolved Energy Research (2019), Energy Innovation (2019), SDSN (2020).
[3] Phadke et al (2020)

different operational characteristics, and assumed a robust planning process to inform procurement targets. In Corneli et al (2018) this model was compared side-by-side with alternate long-term market designs, including markets that optimized long-term procurement of electricity system resources. This comparison highlighted important design characteristics that differed across proposals, including how portfolios of resources are optimized, product definition, whether participation was voluntary or mandatory, and allocation of key risks. Keay and Robinson (2017) proposed a market design where "as-available" resources are procured through a long-term contracting market that differentiates from "on-demand" energy resources. The need for market mechanisms that incent efficient investment and financing are referenced in a recent study by Joskow (2019) who notes "I can see the present system changing in a way that separates investment/procurement of new generation and storage facilities of all kinds and retention of incumbent generators deemed essential to manage intermittency, from the short-term markets that 'dispatch' these facilities economically."
This paper builds on the concept laid out in Pierpont and Nelson (2017), and proposes a long-term market mechanism that seeks to address several shortcomings in the original concept. In particular, this paper more clearly defines interactions between long-term and short term markets, and seeks to address implementation challenges inhenet with the orginal concept. While this paper does not analyze the underlying problems that may drive the need for long-term market mechanisms in depth, it does highlight several key benefits that might be expected by implementing a long term market mechanism. This paper is intended to hone in on the mechanism design needed to make an efficient and workable long-term electricity market mechanism that can support efficient deployment of capital to zero-carbon energy resources, to help drive a rapid transition to a decarbonized electricity system.

2. Objectives of long-term markets

Organized long-term electricity markets could be designed to accomplish a wide variety of goals. Long-term markets can be used to ensure adequate energy or generating capacity to meet system needs, given the long time horizon of building new power plants relative to the short time horizon of forecasting weather and demand.[4] They can also facilitate investment, hedge consumer and supplier exposure to volatile prices, and enable price discovery and competition that can lead to cost reductions over time.

The long-term market mechanism proposed in this paper is intended to support least-cost procurement of energy through long-term contracts, while reflecting the value that different types of resources bring to the system. This mechanism is intended to be complementary to state and federal policies that set standards and provide incentives for carbon-free electricity, by enabling greater transparency and contracting opportunities for clean energy resources. This market mechanism is not specifically designed to address long-term resource adequacy or flexibility needs of the electricity system, beyond the extent that these needs are reflected in

[4] This gap has been narrowed somewhat as solar, wind and energy storage projects can be built more quickly, and in smaller modular increments than large thermal power plants, allowing for shorter lead time and more flexibility to adapt the resource mix as demand changes.

underlying short-term market pricing (and forward expectations of market value). This approach may be particularly valuable to energy resources with low operating costs relative to up-front capital cost, although this framework could be extended to include contracts that are better suited for flexible and dispatchable resources (as described in Section 4.8).

This market mechanism is designed with several key objectives in mind:

Enable financeable long-term contracts for energy to lower cost: The cheapest sources of new electricity supply in many parts of the world today are wind and solar. Battery costs continue to fall and are increasingly competitive with gas to serve system capacity and flexibility needs. These resources do not rely on fuel and in general require minimal costs to maintain and operate, and as a result the bulk of their cost consists of up front capital investment. While 40% of the levelized cost of a new gas power plant may be capital investment, 80-90% of the levelized cost of new wind and solar generation consists of up-front capital investment.[5] As illustrated below in Figure 1 below, capital-intensive renewable energy is far more sensitive to cost of capital than gas with high fuel costs. As policymakers, regulators, utilities and customers seek a transition to clean, carbon-free electricity, an increasing share of the cost of electricity generation will be made up of capital investment. Long-term contracts, by way of providing revenue certainty over the long term, can help lower financing costs, and consequently ensure low costs for consumers.[6]

Figure 1 - Illustrative impact on levelized cost of energy from a reduction in financing costs

	Gas CCGT ($/MWh)	**Solar PV ($/MWh)**
Levelized Cost at 12% WACC	46	40
Levelized Cost at 7% WACC	39	29
Impact of 500bp Financing Cost Reduction	**-15%**	**-28%**

Source: Author's analysis, based on parameters from Lazard (2019).

Provide transparency and standardization: In addition to reducing financing costs, long-term markets can provide greater market transparency and standardization of products to contracting activity that otherwise would be conducted on a bilateral basis. Greater transparency and standardization can encourage competition and lower barriers to entry and transaction costs, which may ultimately flow through to a lower cost of energy for consumers.[7]

Incentivize long-run dynamic efficiency: Long-term electricity markets should be designed to minimize the cost of electricity generation over the long run, by incentivizing the build out of a

[5] Lazard, 2019.
[6] Many jurisdictions have implemented support policies for carbon free energy that provide long-term revenue certainty through auctions and long-term contracts, feed-in tariffs, and contracts for differences.
[7] For example, see USAID (2019) which describes transparency and competitive benefits of auction mechanisms for renewable energy procurement.

high-value complementary mix of resources.[8] However, nothing is known with certainty, and any prediction of the optimal mix of resources over decades to come is likely to be proven incorrect. So any long-term electricity market must also be designed to be flexible and adaptable to changes in technology costs, performance characteristics and capabilities over time. For instance, long-term contract durations should be long enough to encourage low-cost financing, but short enough to avoid crowding out improved technology in the future. Similarly, rather than clearing the entire market in one iteration, long-term contracts should be procured on a rolling basis to cover only a portion of demand in any one year. Finally, a long-term market should be suited to procure a diversity of complementary resources that work together in a reliable, affordable low-carbon electricity system.

Preserve short-run operational efficiency and flexibility: Efficient short-run markets for electricity have yielded significant benefits. For the most part, they efficiently dispatch the existing fleet of power plants, optimize the utilization of existing transmission, reward flexibility and in some cases provide meaningful price signals that value reliability and resource scarcity. Efficient short-term price signals are critical for encouraging demand-side flexibility, an important resource for meeting flexibility and resource adequacy needs as the grid decarbonizes.[9] Long-term market mechanisms should be designed with care so as not to blunt or distort short-run markets and their resulting price signals. For example, long-term contract structures that result in resources self-scheduling uneconomically or being unresponsive to short-term price signals would be undesirable.

Fairly allocate risk between project investors, other market participants, and energy consumers: Any electricity market design involves making choices about the allocation of risk. Existing short-run electricity markets, for instance, typically result in consumers bearing fuel price risk. As shown in Figure 2 below, in the ERCOT market in Texas (with the exception of several instances of extreme scarcity pricing) average spot electricity prices are tightly coupled with natural gas prices indicating that electricity buyers are bearing natural gas price risk (a consequence of gas frequently being the fuel on the margin).[10] On the other hand, long-term contracts signed today could appear to be costly if market fundamentals change significantly. Long-term market mechanisms should seek to fairly allocate risks between project investors, other market participants and energy consumers, such that risks are placed with the parties best suited to bear them.

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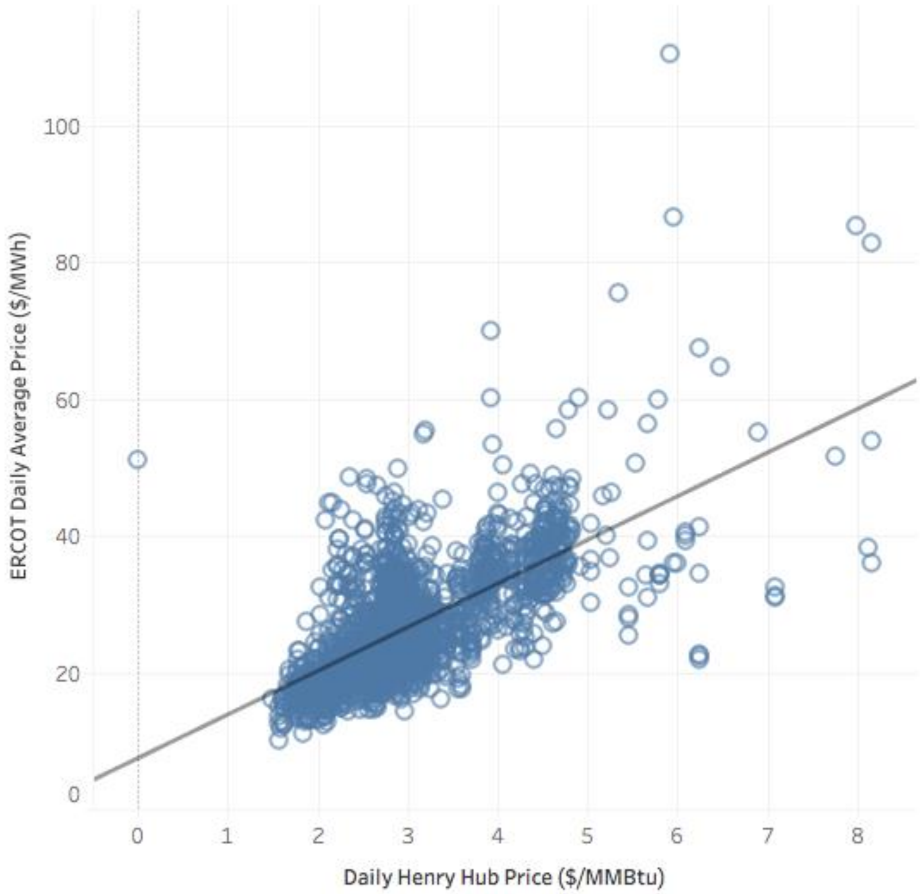
[8] Corneli et al (2019)

[9] Dyson et al (2017).

[10] Some load serving entities hedge their exposure to volatile spot market prices, and if these hedges are sufficiently long-term they may reduce electricity consumers' exposure to gas market risk. However, there is evidence that hedging is incomplete. For example, some load serving entities were left with significant exposure to high prices in ERCOT in August 2019 (S&P Global, 2019).

Figure 2 - Daily Average ERCOT Power Prices vs. Henry Hub Gas Price (2014-2019, excluding hours > $250/MWh)



Sources: ERCOT, EIA.

Limit opportunities for gaming, market power, and regulatory capture: Electricity markets are complex administrative constructs in an industry with significant invested capital. Well-designed markets limit opportunities for market participants to game market rules to extract rents, exert market power, or capture the process of determining market rules and tilt those rules in their favor. Notably, capacity constructs in U.S. regional transmission organizations involve consequential design choices around demand curve parameters and offer price mitigation, and incumbent market participants have significant influence in determining the design of this market.[11]

Integrate heterogeneous state and local policy: In the U.S. and elsewhere, electricity markets operate across political boundaries, where individual countries, states or localities may have different policy preferences and policy structures to support decarbonization of the power sector (and electrification of other sectors). For example, twenty-nine U.S. states have implemented renewable portfolio standards that vary widely from one state to another in

[11] Gramlich and Goggin (2019).

ambition and policy design,[12] while Federal tax incentives support a range of carbon-free resources, and a wide range of policies from the tax code, to regulation of air and water pollution, to innovation-supporting policies can impact electricity sector outcomes. In addition, local and municipal governments and corporations are adopting ambitious targets to reduce carbon emissions and backing these pledges through procurement of carbon-free electricity.

Long-term markets for energy should be designed to work with, not replace or impede, varying national, state and local clean energy policies. With a diversity of policies pushing toward a decarbonized grid and significant uncertainties about future policy, long-term market mechanisms need to be robust and adaptable to different types of policy designs. The concept described in this paper is intended to work in tandem with policies that support carbon-free electricity, but be flexible enough to not be dependent on any one policy design.

3. Effective long-term electricity markets rely on well-functioning short-term markets

An effective long-term electricity market mechanism is not independent from short-term electricity markets. Rather, long-term market mechanisms should depend on well-functioning spot electricity markets with efficient price formation. Short-term markets (e.g. day-ahead and real time markets based on security constrained economic dispatch) will be critical tools to support a decarbonized electricity system. There are several important functions short-term markets play as grids harness diverse sources of zero-carbon electricity and balance demand and supply in real-time. While incremental reforms to short-term markets to support low-carbon electricity system operation are described in depth in other work[13], there are several critical roles that short-term markets play, expecially with regard to interactions with long-term market design.

- **Short-run efficient dispatch:** A principal role and benefit of today's short-run electricity markets is dispatching resources to minimize production costs. It's worth noting that in spite of the benefits of optimized system dispatch, there are still places where market outcomes could be improved. For instance, several studies[14] have noted the prevalence of self-scheduled coal resources that operators commit into the market uneconomically, primarily because regulatory treatment and fuel contract obligations distort incentives for efficient operations. Moreover, as renewable energy becomes a more significant share of the electricity system, the ability to harness flexibility from renewable energy resources will be increasingly important.[15]

[12] Barbose (2019).
[13] For example, Gramlich and Hogan (2019), Hogan (2018), discussion of improvements to existing wholesale market designs in Joskow (2019).
[14] Daniel (2020), Fisher et al (2019).
[15] E3 (2018), Frew et al (2019).

- **Optimizing the use of the transmission system:** In addition to efficiently dispatching generation resources, today's short-run electricity markets typically use security-constrained economic dispatch to ensure that production costs are minimized given transmission constraints, in effect optimizing transmission utilization. This can lower curtailment of renewable energy resources, integrate a diverse and geographically widespread portfolio of resources, and reduce production costs overall.

- **Signaling time and location-specific value:** Modern electricity markets produce locational marginal prices (LMPs) for short time intervals (e.g. 5 minutes). These prices not only account for the marginal cost of producing an additional unit of energy, but reflect the impact of transmission constraints and losses as well. The resulting prices are important for assessing the value of electricity at a particular time in a particular place.

- **Value of operational reliability and scarcity:** Some electricity markets also incorporate price signals that reflect the real-time value of operational reliability and scarcity. For instance, Texas's ERCOT electricity market includes an operating reserves demand curve (ORDC) that significantly increases the market price under scarcity conditions.[16] Markets differ on how and to what extent they value resource adequacy,[17] but incorporating price signals for reliability and scarcity can be an important tool, particularly as resource adequacy needs change and shift as the electricity system decarbonizes.[18] However, the opportunity for high prices creates the opportunity for market participants to earn significant rents. Effective scarcity pricing needs to be coupled with mechanisms to mitigate market power, the ability of participants to influence the price through withholding supply. Addressing market power requires effective oversight, transparency around market activity, and robust competition (particularly from demand side flexibility resources).

- **Incentives for demand-side flexibility:** Effective short-term price signals are important incentives for demand-side flexibility. Harnessing this resource depends on whether and how retail electricity utilities pass through time-varying price signals to consumers, or utilize customer flexibility to lower costs and hedge exposure to high prices.[19] But demand flexibility can be an important resource in a low-carbon electricity system, and relies on effective electricity pricing that varies by time and place.

- **Serve as a basis for settlement:** Finally, and critically for this paper, short-run electricity pricing often serves as the basis for settling long-term financial contracts like futures and virtual power purchase agreements (VPPAs), highlighting the need for effective short-run prices.

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[16] ERCOT (2014)

[17] Some electricity markets rely on capacity markets, rather than short-term market signals, to provide price signals to incent sufficient resources. These capacity markets face substantial design and implementation challenges. Gramlich and Goggin (2019), Mays et al (2019).

[18] Gramlich and Hogan (2019), Goggin et al (2018).

[19] Dyson et al (2017), Borenstein (2007).

Short-term markets are also critical to supporting operational reliability through procurement and co-optimization of dispatch with ancillary services like frequency regulation and operating reserves. These reliability services will remain critical with the growing share of inverter-based resources like wind, solar and batteries that don't inherently provide physical inertia to the electricity system.[20]

Greater variability in demand and supply may lead to more volatile short-run prices as the grid decarbonizes, which in turn could raise financing costs for market participants. Well-designed short-term markets are the foundation of effective long-term market design. But when it comes to long-term markets, market participants face a much less standardized and transparent marketplace for long-term contracting and hedging of energy price risk.

Existing exchanges facilitate long-term electricity trading today, and have for many years. Intercontinental Exchange (ICE) and NYMEX exchanges enable trading of electricity futures, typically with monthly contracts for peak and off-peak periods.[21] These exchanges provide valuable visibility into price expectations going forward, but they lack sufficient time granularity to accurately value the output from variable resources like wind and solar, and are rarely liquid beyond 3-5 years ahead. LevelTen Energy operates a clearinghouse for long-term renewable energy power purchase agreements, and streamlines valuation and due diligence for these typically bespoke contracts.[22] While platforms like this can reduce transaction costs, the contracts that result are still bilateral and customized to the buyer and seller. Beyond these exchanges there is a substantial amount of bilateral electricity contracting activity, which typically provides little public information about pricing. Organized long-term electricity markets could bring a greater degree of transparency and competition to long-term energy procurement, potentially leading to a greater degree of contracting and hedging behavior.

4. Design of a long-term electricity market mechanism

This paper proposes a long-term electricity market mechanism that operates in parallel with an effective short-term market design and policies that support grid decarbonization. This long-term market concept has three key components:

- Financial long-term, fixed price contracts for energy based on a specified production profile, structured to preserve short-term market signals and incentives for efficient operations.

[20] Kroposki (2019).
[21] ICE (2020), CME Group (2020).
[22] LevelTen Energy (2020).

- A market clearing mechanism that selects those resources with that have the highest value to the electricity system or to buyers in the long-term market, relative to contract costs.

- Allocation of contract costs and benefits to buyers by pooling contracts together and selling as a bundle, diversifying the counterparty and credit risk any one buyer or seller is exposed to.

This approach would provide greater revenue certainty to contracted resources while reflecting the value of different time profiles of electricity production. This concept also remains flexible and compatible with a wide range of state and national policy and retail utility regulatory structures.

As described below, this concept is not designed to ensure resource adequacy for the electricity system. Rather, it is intended to be a mechanism to procure the lowest-cost sources of energy, accounting for the anticipated value of that energy. If reliability constraints are appropriately reflected in underlying spot market prices (i.e. through effective scarcity pricing), resource adequacy value will be factored into the selection of resources, and ideally the resource adequacy value of resources that participate in this market would be credited to those resources (e.g. in a capacity market regime). But to retain flexibility and adaptability to a wide range of market contexts, policy environments and regulatory structures, this long-term market mechanism does not explicitly attempt to solve for long-term resource adequacy needs of the grid.

In many ways this market design is based on current practice around structuring and valuing virtual power purchase agreements (VPPAs),[23] with some important differences. Instead of relying on heterogeneous bilateral contracts, this proposal would create a market for standardized long-term energy contracts. Figure 3 below outlines key characteristics of the proposed market mechanism.

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[23] See Zanchi and Kansal (2018) for a description of virtual power purchase agreements for corporate renewable energy procurement.

Figure 3 - Key Characteristics of the Long-Term Energy Market Mechanism

Element	**Description**
Contract structure	Long-term fixed price contract per MWh of contracted energy, at a given pricing location (e.g. market hub or zone), for a given contracted time profile of generation. Buyer pays a fixed price for contracted energy (locked in over a long-term contract) and receives the real-time market value applied to the contracted shape.
Bid price	Supplier submits a fixed price per MWh of contracted energy across all hours
Bid shape	Supplier submits an hourly profile of supply (e.g. by hour of day and month of year), as well as the total annual MWh of production, that they commit to as the basis of their contract.
Bid evaluation and clearing	This paper presents two options for clearing the market: 1. Market operator develops forward price forecasts for the entire contract term, with hourly granularity (e.g. at least by month, by hour). The shape of each bid is compared with pricing curves to determine the levelized value per MWh of expected output. This levelized value is compared to fixed price bid to determine a net value per MWh. The market clears those resources with the highest net value per MWh, up to a total aggregate MWh per year of demand. 2. Alternatively, buyers could submit a "willingness to pay" and MWh amount sought with hourly granularity (e.g. by month, by hour), and the market could clear those resources that maximize total value (cleared MWh multiplied by willingness to pay by hour of production, net of fixed price contract costs). This approach would also inform cost allocation across multiple buyers. In either case, cleared resources would be paid as bid, as is the case in many renewable energy reverse auction mechanisms.
Contract term	Determined by market operator and stakeholders, based on balance between financeability and risk of resource lock-in. A term of 10 years or more is likely to be appropriate (see section 4.6 below).
Demand covered	The market would only cover a portion of total demand, rather than being mandatory for all load in the electricity market. Participation of demand would be determined by load serving entities and state regulatory requirements or incentives for long-term contracting or hedging.

Dispatch	Cleared resources economically dispatched by short-term (day ahead and real-time) market
Performance requirements	Cleared resources commit to provide payments to the buyer based on the real-time electricity price applied to the contracted shape. If the resource under-produces it owes buyers more than it received from selling actual production into the market. If the resource over-produces it can keep any additional revenue. This puts risks related to volume and performance relative to contracted shape on the producer and gives them an incentive to maintain high performance (and potentially to hedge weather-related risks which customers / load-serving entities aren't well suited to evaluate or manage).

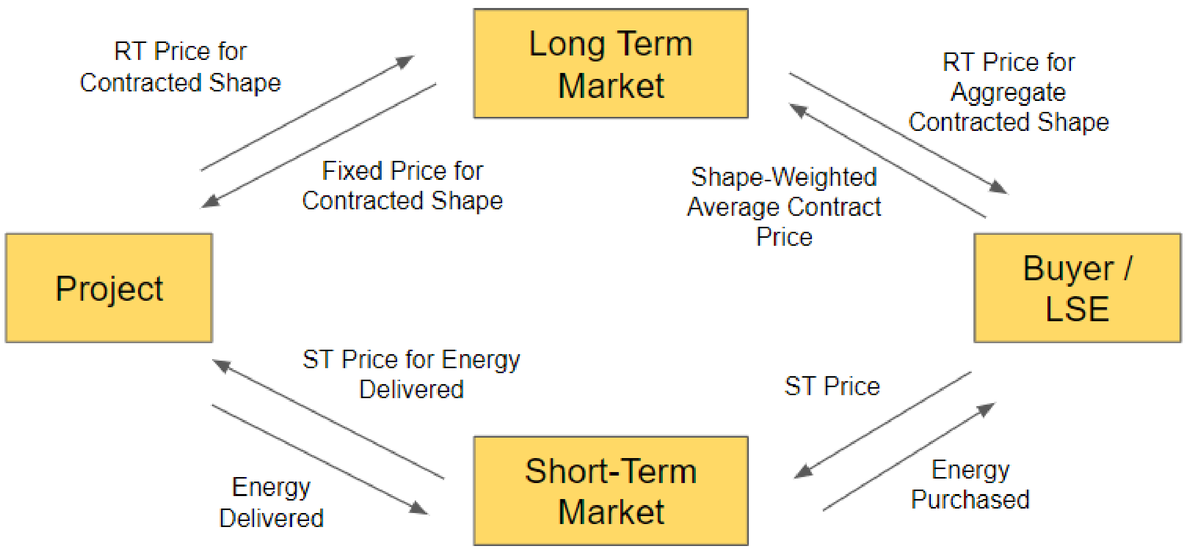
4.1. Product definition

The primary product in this long-term market would be a long-term fixed price contract, per MWh of contracted energy, priced at a specific location on the grid (e.g. market hub or zone), for a specific expected seasonal and hourly time profile of generation. Buyers of energy in this market (load serving entities) would pay a fixed price for energy in a contracted shape (which may differ from their own demand profile), and in return receive the real-time market value of energy applied to this contracted shape, essentially swapping variable short-term market revenues for fixed revenues (in effect, a contract for differences for a specific production shape).

Critically, this market product would be a financial product (trading one stream of revenues for another, settling financially), rather than a contract for physical delivery. Contracted resources would be bid into and dispatched by the short-term market, and if the resource outperforms its expected shape, it could keep any additional revenues earned. This reduces the risk that contract terms interfere with efficient short-term market pricing and operations.

This financial product differs from a firm, physical electricity contract in that it doesn't require the resource to generate electricity or be available when called upon. Grid operators remain responsible for ensuring adequate physical supply (although resources that participate in this long-term market could certainly help contribute to system resource adequacy and receive credit for their contribution). If resource adequacy constraints are reflected in short-term electricity market design (e.g. through operating reserve demand curves and other scarcity pricing mechanisms), managing the financial risk of volatile prices through long-term financial contracts (like the one proposed here) can be well-aligned with meeting resource adequacy needs.

Figure 4 - Financial and physical flows with the long term energy market



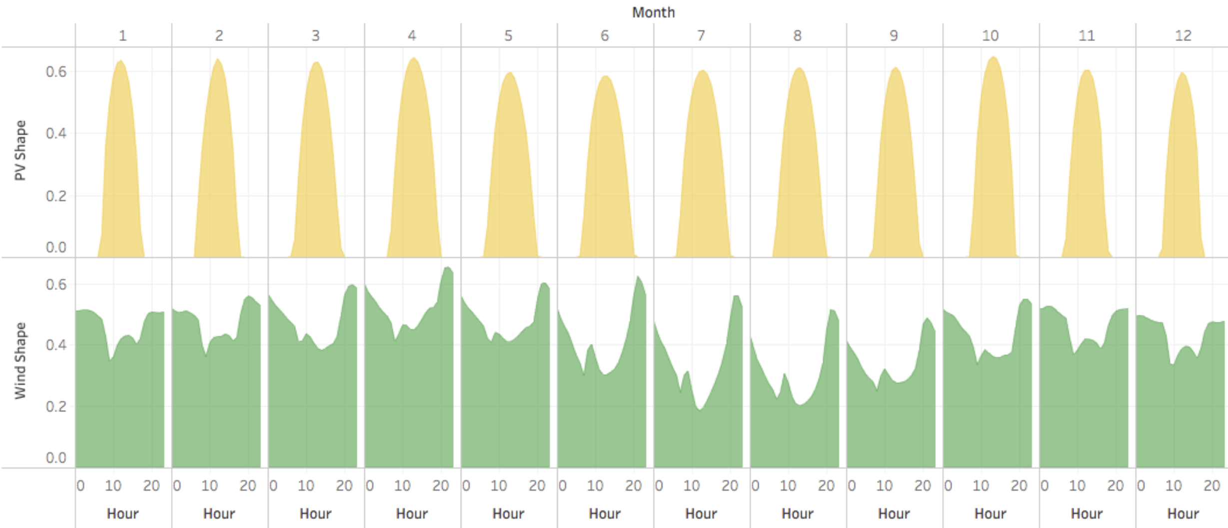
4.2. Suppliers' participation in the long-term energy market

Projects bidding into the long-term market would include two basic components of their bid: A fixed price per MWh and an expected energy shape that serves as the basis of settlement. The bid price is straightforward - it represents the fixed price for a contracted shape and amount of energy from a resource. The bid shape, however, is more complex and worth describing in more detail.

Zero-carbon resources differ significantly in their potential profile of electricity production. While some firm resources like geothermal or nuclear energy may be able to produce power continuously, lower-cost variable renewable energy sources like wind and solar are characterized by their variable output over time. Wind and solar electricity production have distinct patterns across days and seasons, and this time profile of generation can vary significantly by location (e.g. coastal vs. inland wind) and technology (e.g. wind hub height and turbine model, solar tracking and inverter loading ratio). Figure 5 shows average output by hour and month for an illustrative wind or solar project, based on five years of historical weather data for specific locations in Texas.[24] In this instance, solar output is fairly consistent across seasons, showing the same diurnal pattern, while the daily pattern of wind output changes significantly across seasons.

[24] Solar location selected is in the San Antonio region, wind in west Texas. Note that by looking at a single site, this data excludes the effects of aggregating and smoothing production profiles across multiple projects over a wide geographic area.

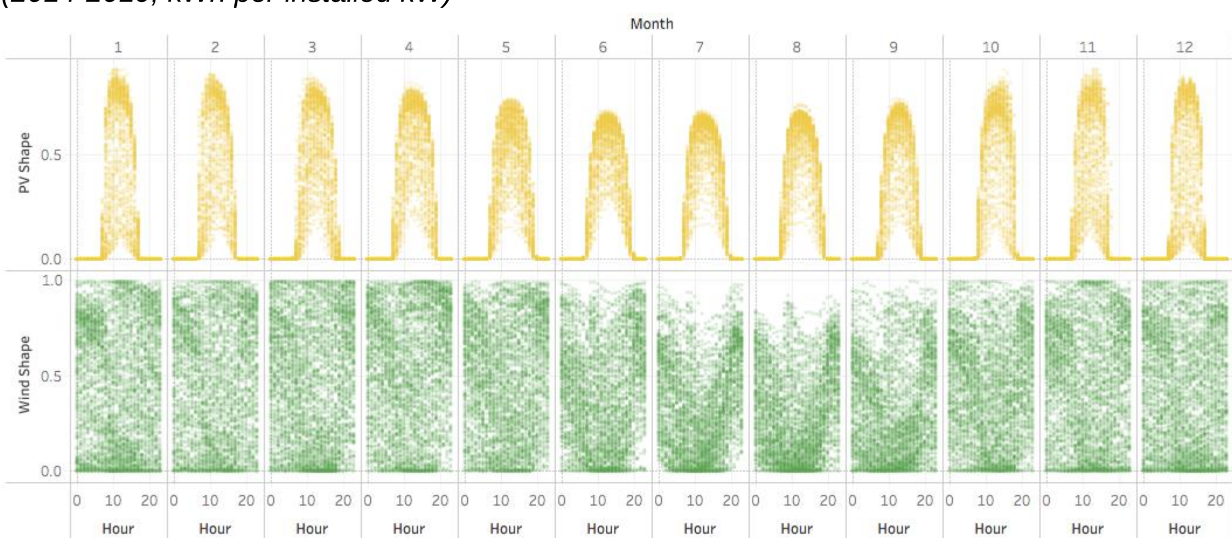
Figure 5 - Average solar and wind output by hour and month for selected locations in Texas (2014-2019, kWh per installed kW)



Source: Hourly production estimates from renewables.ninja

While the graphs above show production profiles on average for a given month, solar and wind both vary day to day and hour to hour with changing weather patterns, introducing greater uncertainty into production. Figure 6 below shows the hourly production over five years for these same solar and wind locations in Texas, showing significant differences between resources and across seasons in the amount of certainty that a resource will produce a given shape.

Figure 6 - Hourly solar and wind output by hour and month for selected locations in Texas (2014-2019, kWh per installed kW)



Source: Hourly production estimates from renewables.ninja

Rather than administratively assessing or modeling the potential contribution of different resource types, the long-term market mechanism leaves it up to suppliers to bid in the shape they are willing to commit to using as a basis of settlement. Since suppliers will receive revenues based on what they actually produce and sell into the short-term market, but settle their contract based on the real-time price applied to the contracted shape, they are exposed to the possibility that their production doesn't match their contracted shape. By allowing suppliers to choose a production shape they're willing to commit to, suppliers will have an incentive to manage risks associated with variability, potentially by combining variable renewable energy with storage or aggregating multiple diverse resources in a portfolio.

In this long-term market mechanism, resources like geothermal or nuclear could potentially bid a flat production shape, essentially taking on the performance risk associated with delivering constant output. In theory, resources with high variable costs could bid for those hours they expected to have the highest value, but these resources would likely have much more value and a better risk profile as flexible resources participating in short-term electricity markets.

In addition, suppliers may choose to hedge or insure against the risk of not matching a given production profile, and a market product based on a contracted shape would give a strong incentive for them to do so. Even today, corporate renewable energy buyers have deployed "Volume Firming Agreements" that allocate the risk of weather-driven production variability to a third-party insurer.[25]

Finally, to limit speculation, bidders into this long-term market would need to be able to demonstrate creditworthiness or meet some level of bonding requirement. These requirements need to address the risk of suppliers defaulting on the long-term contract without making requirements so onerous that they stifle competition and participation from smaller project developers.

4.3. Buyers' participation in the long-term energy market

The buyers in the long term energy market will primarily be load serving entities. Large customers that buy electricity directly from the wholesale market and those looking to hedge their exposure to short-term prices may also be able to participate (as long as their demand is not double-counted with load serving entities). Some buyers may face incentives or requirements (e.g. driven by state regulation) to enter long-term contracts or hedge a portion of their electricity purchases against short-run market price volatility, while others may participate voluntarily. In jurisdictions where retail electricity providers are regulated, a long-term energy market could be a complementary tool to support least-cost competitive procurement of energy. In regions with competitive retail providers, local distribution co-ops, small municipal utilities or community choice aggregators, a long-term energy market may provide an attractive and easily accessible option for contracting for energy needs.

The long-term electricity market mechanism ideally would be offered as a voluntary market product, not a mandatory market that covers all demand. Retail electricity regulators could

[25] Utility Dive (2018), Microsoft (2018).

require hedging or long-term contracting that covers some portion of their demand, which this standardized market product could satisfy (but retail utilities would be free to enter other bilateral contracts if they better met their needs).

There are two potential models for how buyers would participate in this market, depending on how the market is cleared (as discussed below in section 4.4).

In the first option, the buyer's side of the market is very simple. Buyers would submit the quantity of energy (e.g. annual MWhs) they're seeking to purchase through the market. Those buyer demands would be aggregated into a total demand for the market, used for clearing the market as described below. The market would clear those contracts with the highest net value, so buyers in this market would essentially be signing up to buy a bundle of the highest value contracts (relative to an expectation of future prices). However, this does not necessarily guarantee that the bundle of contracts purchased is effective at reducing exposure to high scarcity-driven spot prices, leaving a role for other types of hedging or utilizing demand flexibility to reduce the cost burden from extremely high scarcity pricing.

In the second option, buyers would submit an hourly profile (e.g. by month and hour) of both their willingness to pay (i.e. price the buyer is willing to pay for a long-term contract that covers each hour), alongside a quantity of MWh they wish to procure through a long-term contract. As described below, this information could be used to clear those resources that have the highest value in aggregate to buyers, net of the the fixed contract costs of those resources.

Finally, a critical aspect in any long-term contracting activity is counterparty risk.[26] In this market mechanism, contracts would be pooled and buyers pay a weighted average price for their share of the pool of contracts procured in a given auction. To ensure that long-term contracts to suppliers were financeable, buyers would need to be obligated to stay in their contract for the entirety of the term. But since payments to a given project would be coming from many load serving entities, their counterparty risk would be diversified. If a buyer were to default on their obligations, their portion of the pooled purchases could be re-offered in subsequent auctions to other buyers, or contracted energy may be reduced, leaving a resource to offer a portion of their output into short-term or bilateral markets instead. Without full participation from all demand in a market, and automatic assignment of costs to load, this market would not be without counterparty risk. But by pooling across many buyers, this risk could be diversified and significantly mitigated relative to pure bilateral contracting.

4.4. Valuing Contracts and Clearing the Market

Once bids are received, they need to be compared on an apples-to-apples basis, in spite of having very different production profiles and costs. While there are many potential ways of doing this, this paper proposes two potential approaches to clearing the long-term market.

[26] Gramlich and Lacey (2020).

The first of these approaches relies on assessing the long-run value of the production profile bid by each resource in the market against an hourly price forecast (at least at the same level of granularity as bid shapes, e.g. by hour and month). This approach is potentially the simplest, but relies significantly on the construction of a price forecast with which to evaluate each bid.

The second approach would be to clear the set of resources that has the greatest value to buyers, based on an hourly willingness to pay for a long-term fixed price energy contract (with hourly granularity, by hour and month), up to that buyer's total demand (again, by hour and by month). The market would take fixed price bids and production shapes from suppliers, and hourly willingness to pay and MWh demand from buyers, and select those resources that maximize value to buyers, net of fixed price contract costs. While this approach introduces greater complexity and a more significant administrative burden on buyers, it has the advantage of depending only on parameters submitted from sellers and buyers and may lead to a more diverse range of resources and a better match for buyers' demand profile. In addition, this clearing mechanism would enable cost allocation of long-term contracts to the buyers to which they have the most value.

4.4.1. Clearing based on a forward hourly price forecast

The simplest way of clearing this long-term market mechanism would be through an assessment of the long-run value of the shape bid by each resource in the market. This assessment could be based on an hourly price forecast (at least at the same level of granularity as bid shapes, e.g. by hour and month). Once the value per MWh is established for each bid, the cost per MWh (the fixed price bid by the supplier) would be subtracted from the estimated value to determine a net value per MWh for each bid.

By ordering bids from highest net value to lowest net value, the market could be cleared based on the total demand in MWh per year. It may be necessary to limit cleared bids to only those that have a positive net value to ensure that buyers are purchasing a bundle of contracts that are expected to reduce energy costs over the long run. Cleared resources would then be paid their fixed contract price as bid (rather than a uniform clearing price).[27] Figure 7 outlines the process of evaluating and clearing the market under this approach, while Figure 8 illustrates this mechanism visually.

[27] Paying winning contracts their bid price implies that bids would need to remain sealed to limit gaming, however, given the need for market transparency, the market operator could make data on the weighted average contract price and weighted average net contract value for cleared resources available to the public.

Figure 7 - Bid evaluation process

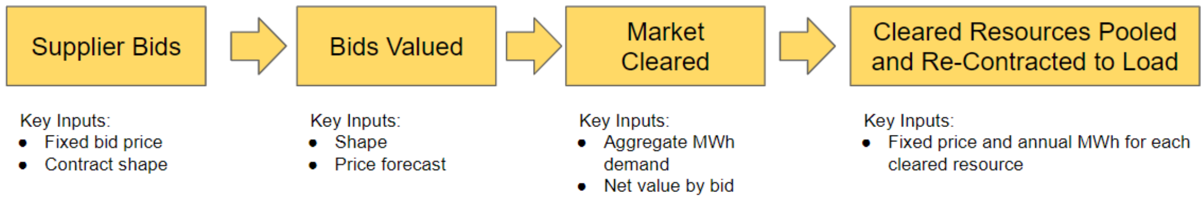
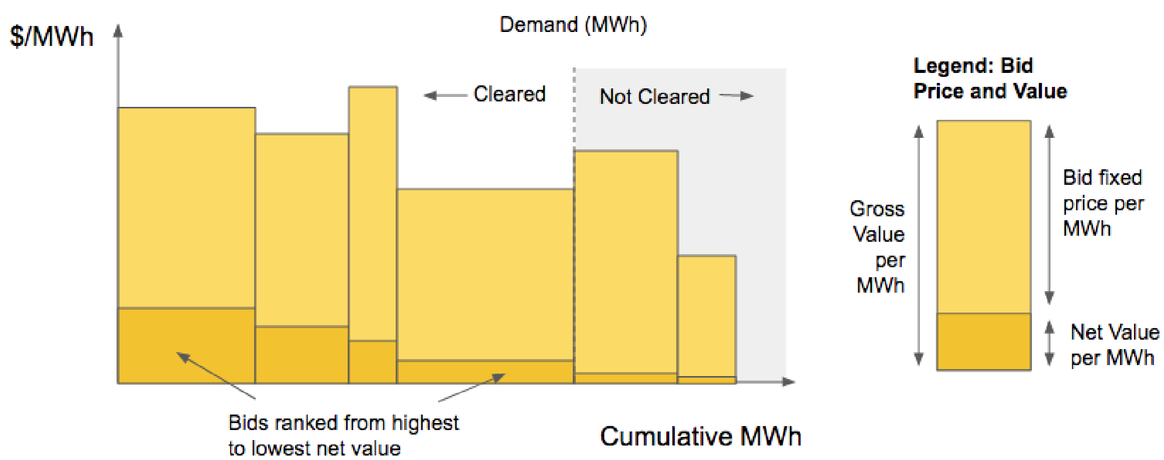


Figure 8 - Illustration of clearing the long-term energy market: bids are ranked from highest to lowest net value, with the highest net value contracts clearing



The development and application of a forward price forecast is a key component of this approach to clearing the long-term energy market. As a result this aspect of the mechanism may be where there is the greatest opportunity for subjective judgement or influence over market outcomes. The process of developing a forward price forecast should be independent, transparent and objective, and based on market fundamentals.

There are several ways the market operator could construct a forward price curve to value resources in the long-term market:

- In some cases there may be traded electricity futures that could serve as a basis for forward price projections. These typically lack intraday granularity (contracts are typically traded for peak and off-peak periods by month), and only near-term contracts for major pricing locations are traded with significant liquidity.

- Market operators can conduct dispatch modeling based on expected new entry, fuel price projections, and projections for demand growth and demand profiles. However, the result of this type of exercise is very dependent on input assumptions and could be contentious to serve as the basis for valuing and clearing a market. This forecasting task is similar to analysis that should underlie any prudent bilateral contract.

- Market operators could rely on trusted third-party forward curves, which are often derived from a mix of traded futures and modeling.

However an hourly forward pricing projection is derived, it should be developed in an independent and transparent process with ample opportunities for stakeholders to engage the process, examine assumptions and ensure that this critical piece of the long-term energy market is fair and objective. In addition, this forward pricing projection should be revised ahead of each iteration of the market (e.g. once per year), to account for expected new resource additions and retirements, and other changes in underlying market and policy conditions. This allows the market mechanism to adapt to a changing electricity system and avoid locking in assumptions about the value of different types of resources.

Treatment of Uncertainty

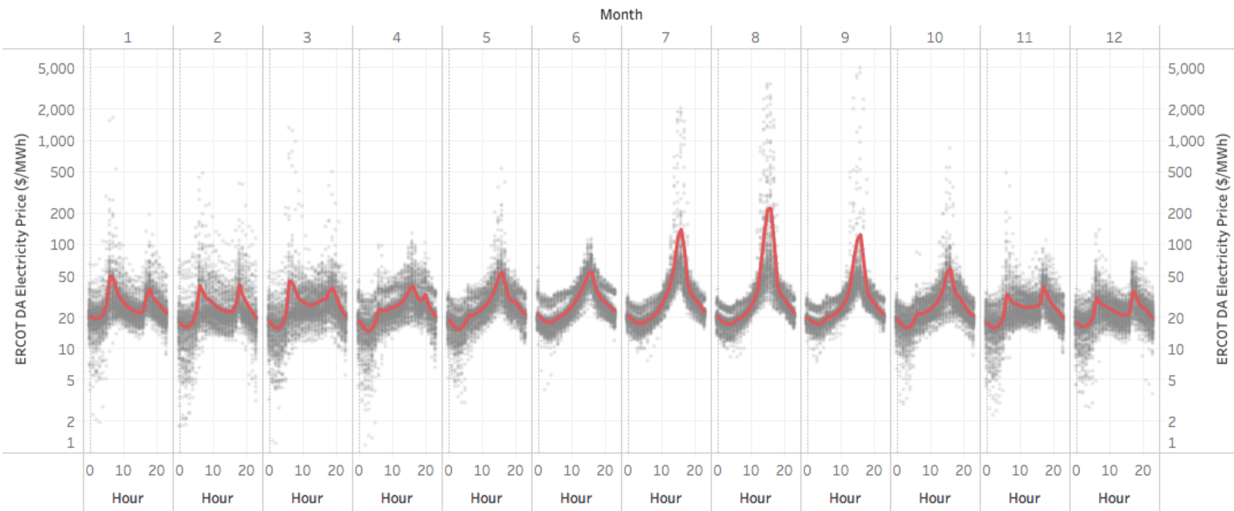
Market forecasts are inherently uncertain. While this methodology for valuing bids and clearing the market is deterministic, it is worth highlighting the degree of uncertainty associated with electricity market pricing. Figure 9 below shows both the average (as a red line) day ahead electricity market price in ERCOT from 2014 to 2019, alongside the actual hourly prices for the same time period (as grey points). Average historical prices do not capture the level of uncertainty associated with electricity prices, and understate the value of hedging exposure to particular periods.

There are ways to address this uncertainty, but they lead to more complex analytical approaches and potentially less transparency in the market's valuation methodology. For instance, monte carlo simulation is often used in valuing energy contracts, where pricing (and in the case of variable renewable energy, often production) are drawn from a statistical distribution over a given time frame to evaluate a contract over a wide range of potential outcomes.[28]

This paper doesn't address this challenge in detail, other than to recognize that the valuation function of the long-term energy market may need to incorporate some assessment of uncertainty and the value of hedging extreme price volatility, especially if coupled with a short-term market with robust scarcity pricing. A decarbonized electricity system, dominated by abundant zero marginal cost resources for many hours of the year, may lead to even greater price volatility and uncertainty about when scarcity pricing may occur, making a probabilistic assessment more valuable.

[28] See Mosovski and Titus (2018).

Figure 9 - Average (red) and hourly (grey) day-ahead ERCOT electricity price (2014-2019, log scale)



Source: Hourly prices from ERCOT

4.4.2. Clearing the market based on buyers' willingness to pay and demand profiles

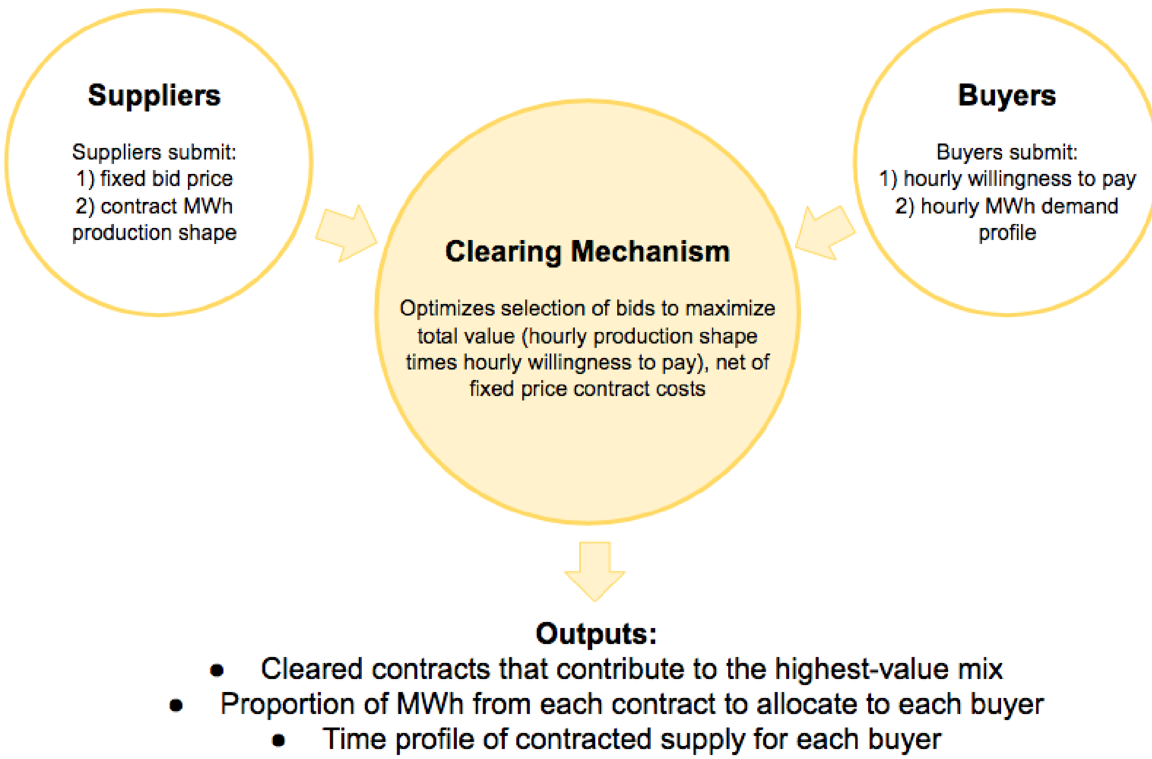
An alternative approach to clearing this long-term market relies on buyers submitting their willingness to pay for long-term contracted energy, alongide the quantity of MWh they seek to purchase, both in hourly profiles with the same level of granularity as suppliers' bids (e.g. by hour and month). The clearing mechanism would then take fixed price bids and production shapes from suppliers, combined with the willingness to pay and MWh demand from buyers, and select those resources that maximize the total, aggregate value to buyers, net of fixed price contract costs, up to the demand submitted by buyers for each time block.

This approach has several distinct advantages over the first, price forecast-based method of valuing bids. Rather than relying on an exogenous, third-party assessment of market value to determine the value of each bid, the willingness to pay approach relies on buyers' own assessments of the value of energy in each time period, which can incorporate both expected energy value as well as the value of hedging against price volatility. Rather than clearing all resources with the highest net value (which may lead to a single type of resource dominating the market if costs and production profiles are similar), the willingness to pay approach may result in a greater diversity of resources. For example, if solar is generally the highest-value resource relative to expected market prices, the price forecast-based clearing approach may just clear solar resources, even if they far exceed buyers' demand in the hours of high solar production. The willingness to pay approach would only clear those solar resources that provided incremental value in meeting buyers' demand, and if high-solar hours were saturated, the clearing mechanism may choose resources with complementary production profiles (to the extent that they are add to total value).

Noteably, this approach would not guarantee that cleared resources fully cover buyers' demand in each hour. If there are not enough suppliers bidding resources in for certain time blocks, or if buyers' willingness to pay in some hours is too low to justify contracting for additional resources given the costs of those resources, this approach to clearing the market still may not procure resources that meet demand in every hour. However, the resulting mix of cleared long-term contracts will likely be a better fit with buyers' demand profile and higher value to those buyers than simply relying on a pre-determined price forecast to to evaluate bids and clear the market.

Figure 10 below illustrates this approach to clearing the market, highlighting the parameters from suppliers' bids and buyers' offers, and how the mix of cleared resources could be optimized.[29]

Figure 10 – Market clearing mechanism based on willingness to pay



One additional advantage to this approach to clearing the market is inherent in the process of optimizing which contracts are selected to maximize the value of contracted energy. Clearing this market involves determining how the hourly MWh of each supplier gets divvied up to each

[29] This approach can be summarized as an optimization problem that selects which bids clear, and allocates the hourly MWh from each cleared bid to each buyer in a way that maximizes the total value (sum of MWh cleared multiplied by willingness to pay in each hour for each buyer from each bid, minus MWh cleared times fixed price from each cleared bid) of cleared resources in aggregate, subject to each buyer's total amount procured in each hour not exceeding their submitted demand. This approach allows for cleared supply to be less than demand in some or all hours if there are no fixed price bids that increase the total value of the mix procured.

buyer in the way that maximizes the total value to buyers in aggregate, net of the fixed-price contract cost. This allows for an accounting of which buyers are receiving what proportion of each cleared supplier contract, which can serve as the basis for cost allocation of the portfolio across buyers.

As in the first approach to clearing the market, long-term contracts would be paid as bid. To provide a degree of price transparency, the market operator could publish the weighted average price of cleared resources by generation technology or for all cleared resources as a whole – however clearing the market would not based solely on suppliers' costs, but also reflective to the incremental value of each resource to buyers.

4.5. Frequency of clearing the market

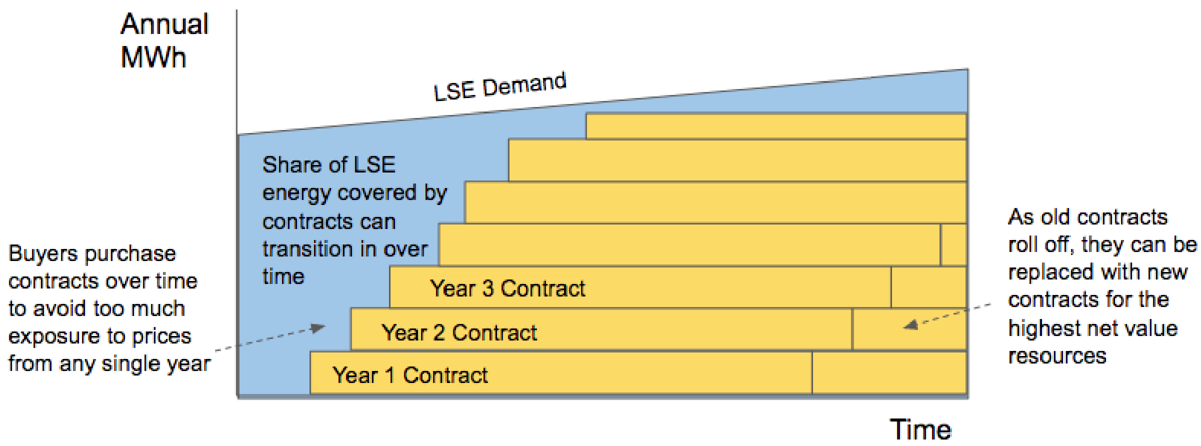
Regardless of which clearing mechanism is used, the long-term energy market mechanism described above should be run at regular intervals, potentially every year. This envisions load serving entities covering only a portion of their electricity demand with long term contracts in any single iteration of the market.

There are several benefits to running the long-term energy market more frequently. Technology costs can change rapidly over time, and as the underlying resource mix in the market changes, so too will the value of different production shapes. Running the market more frequently gives load serving entities the opportunity to tap into lower-cost or higher-value opportunities as cost and value shift over time.

However, a market that is run frequently must have a low administrative burden for both market operators and participants, highlighting the importance of well-defined market products and a systematic process for evaluating bids and clearing the market.

As explained in Pierpont and Nelson (2017), and shown in Figure 11 below, long-term contracts of different vintages can be layered together, resulting in an overall weighted average contracted cost of energy that reflects the highest-value resources over time. This stacking of procurement from different vintages also allows buyers to ease into procurement from this market, as existing resources retire, contracts expire, or new purchase and contracting obligations arise. It also facilitates adoption of new zero carbon technologies as they become commercial.

Figure 11 – Long-term contracts of different vintages can be layered together over time to meet load serving entities' demand



4.6. Contract length and project lifetimes

Similar to the frequency of running the market, the duration of resulting contracts is an important parameter in allocating risk between suppliers and energy buyers. A contract that is too short may not allow suppliers to realize any benefits in terms of reduced financing costs. Contracts that are too long risk locking customers into a contract that may no longer be supported by underlying market fundamentals and could become a barrier to new entry from innovative and newly commercialized technologies.

Picking a contract length likely requires extensive analysis and input from market participants. However, contracts that last 10 years or more are likely to be needed to drive significant reductions in financing costs for new supply.

However, the economic life of most new electricity resources is well beyond 10 years. New solar and wind power plants are often built with the expectation that they will be in operation for 30 years or more. If contract lengths are less than the expected economic life of new resources, there must be solid expectations for re-contracting opportunities or spot market sales to support the residual value of new renewable energy assets. Otherwise, project developers may seek to fully recover capital costs in an accelerated manner, resulting in higher costs.

4.7. Performance Requirements

Any long-term electricity market design should have strong incentives for resources to perform as expected and manage operational risk. The long-term energy market mechanism proposed here does this by placing production-related risks on the supplier. Payments to suppliers and settlement against real-time prices are based on the contracted energy production shape, rather than actual energy produced. Moreover, sellers would be exposed to the risk that their actual production deviates from their contracted energy shape, as well as the real-time electricity price when this deviation occurs. This would have several important consequences.

First, it would leave risks associated with volume and shape-matching with the supplier. This preserves incentives to maintain high availability, while also incentivizing suppliers to manage production variability risk (e.g. through the addition of storage, or through hedges such as volume firming agreements).

In addition, truing up contracts based on a contracted shape reduces the incidence of curtailment risk on suppliers and places that risk primarily with energy consumers. Buyers would pay a fixed price for a predetermined shape. If curtailment (and accompanying low or negative electricity prices) are more prevalent than expected, the real-time electricity price passed through to buyers would be lower, and producing less because of curtailment wouldn't come with a significant penalty as the value of electricity at that time may be low, zero, or negative.

Linking settlement to a contracted shape also enables suppliers to keep excess energy revenues earned when production exceeds the contracted shape. Suppliers may choose to bid more or less conservative shapes depending on the level of risk exposure they're willing to take.

Figure 12 below describes how this long-term market mechanism would allocate specific risks among suppliers and buyers.

Figure 12 - Allocation of key risks in the long-term electricity market

	Supplier	**Buyer / LSE**
Shape risk (e.g. generation-weigted price of a given production shape)	**Low** - receives fixed price for a contracted shape	**High** - bears the risk that energy at some times in the shape has less value than anticipated
Curtailment risk	**Low** - receives fixed price for a contracted shape, regardless of actual production	**High** - bears the risk that energy at some times in the shape has less value than anticipated (curtailment hours are likely also low-price hours)
Output / performance risk vs. a given shape (e.g. weather variability for wind and solar)	**High** - supplier is responsible if actual production falls short of contracted shape	**Low** - gets the real-time value of a contracted shape, which offsets cost of serving load
Buyer demand vs. contracted shape (i.e. residual exposure to spot prices)	**None** - supplier only exposed to prices and production vs. shape	**High** - shape may not match demand profile or effectively hedge high price periods

Basis risk (difference between fixed price and variable price settlement locations)	**High** - earns real-time nodal price in spot market, but settles long-term contract against hub or zonal price (so supply and demand can settle at the same pricing location)	**Low** – pays fixed price, receives zonal or hub spot price
Value forecasting risk	**High** - contract could be undervalued if price forecast or willingness to pay isn't an accurate measure of value to the electricity system	**High** - market may clear contracts that have lower value than anticipated
Demand forecasting risk	**Low** - generally insulated if buyer purchases too much or too little	**High** - responsible for contracts if load is less than anticipated

4.8. Potential variations

While this proposal outlines a product based on a predetermined contracted hourly shape (e.g. by month and hour of day), the general framework could be extended to include contracts that are better suited for flexible and dispatchable resources. This would allow the same type of revenue certainty to resources with capabilities that support the grid's flexibility and resource adequacy needs.

For instance, rather than contracting for a particular shape, storage resources could contract to shift energy from the lowest-value hours to highest value hours of each day, while dispatchable resources could contract for generation when prices rise above a given strike price. Fundamentally, these contracts could also be evaluated by comparing with a time-granular forward curve, and settled against real-time prices (i.e. pay the actual daily difference between highest-price and lowest-price hours, or actual price when the price exceeds a strike price). However, incorporating these types of resources into an optimization based on buyers' willingness to pay creates additional complexity that this paper has not explored.

In addition, depending on the accompanying policy context, the long-term energy market product could be constrained only to carbon-free resources, or separated into markets for carbon-free energy and carbon-producing energy. This could enable the long-term market to facilitate procurement for clean energy standard policies or utilities with long-term decarbonization goals, but also raises several key challenges. Since contracted shapes do not necessarily equal production, the market would need a way of validating that contracted shapes are matched with carbon-free energy production in actual operations. In addition, the market would need to ensure that clean energy attributes aren't double-counted across the long-term energy market and any other policy procurement mechanism. Finally, regulatory jurisdiction over this type of long-term electricity market could be much more complicated if it was used as a procurement mechnanism to meet state policy goals together with long-term contracting for energy.

5. Implementing a long-term energy market

Implementation of a long-term energy market raises a number of practical challenges. This market design concept is designed to be readily implementable, but there are a number of unresolved questions that remain to be answered. In the U.S. context, many of these challenges are related to the division of jurisdiction between federal and state government. This section walks through several of these key questions in turn.

- **Who operates the market:** There are a number of entities that are potentially well-placed to operate the long-term energy market mechanism outlined above. This market could be operated by a grid operator (e.g. a regional transmission operator or independent system operator in the US), who may have the market insight to develop forward prices, implement more complex market clearing mechansism, and has experience operating short-run markets. However, this long-term market could also be run by a government agency (national or subnational) in parallel with procurement of resources to achieve state policy targets. The market could also be run by a third-party - for instance existing power purchase agreement aggregators and brokers, as well as commodities exchanges, could be well placed to operate this type of long-term market.

- **Voluntary or mandatory market:** This market would be voluntary for suppliers - they would be able to participate in the market to whatever extent they desire. Some suppliers may want to lock in a price for all of their output, or only a portion of their output, while others may want to participate only in the short-term market where flexible resources may realize more value. The decision as to whether procurement through this market would be mandatory for buyers is more complicated. It is possible that by facilitating financing cost savings and working well with climate and clean energy policy, this market could be the lowest-cost source for procuring energy and would be attractive to buyers without a mandate to participate. However, requiring load to participate simplifies the allocation of costs of these resources to load, and mitigates credit risk issues (since all of the load will be in the market there will likely always be a buyer, even if a single entity faces financial challenges). Ideally, states could require load serving entities in their jurisdiction to participate, and regional markets could form where multiple states require participation.

- **Interactions with clean energy policy:** The long-term market mechanism proposed here is meant to complement national and sub-national clean energy policy. For instance, states could provide incentives or additional payments for carbon-free electricity sources, or place a cost on carbon dioxide emissions that change the relative value of resources in the long-term electricity market. In addition, as mentioned above, this mechanism could be extended to separate contracts with zero-carbon resources to help support procurement to meet clean energy policy objectives.

- **Interactions with retail utility regulation:** In locations with regulated, vertically integrated or distribution/retail utilities, the long-term energy market may provide a benchmark to compare bilateral long-term contracts or the economics of utility-owned generation, as well as an actual procurement opportunity for those utilities to meet their customer needs at lower cost.

- **Creditworthiness of buyers:** As described in Gramlich and Lacey (2020), the creditworthiness of buyers is an important determinant of whether long-term contracts are financeable. While the long-term market may diversify credit risks across numerous buyers, it may not eliminate credit risk entirely. If buyers are not sufficiently creditworthy, the long-term market operator could develop additional tools for mitigating credit risks (e.g. reserves, credit requirements, or a buyer of last resort). The pool of contracted resources and buyers would need rules that fairly address the allocation of costs and risks in the event that a participant defaults, otherwise credit risk issues may pose a barrier to participation.

- **Retail price signals:** This long-term market design is intended to preserve efficient short-term electricity pricing, which can be an important signal of the value of demand flexibility and other demand-side resources. While retail price signals are the domain of retail utility regulators, this market design should both help retail customers and their energy providers hedge price volatility, while preserving the opportunity for those customers that can respond effectively to volatile prices to do so.

6. Conclusion and next steps

Meeting the challenge of climate change requires building an electricity system that runs on zero-carbon resources. Electricity markets will need to do more than address the operational challenges associated with high shares of variable, zero marginal cost resources. They will need to work hand-in-hand with clean energy and climate policy to drive investment in the mix of resources that meets demand with carbon free power at the lowest cost.

Long-term electricity market mechanisms have an important role to play, but care should be taken to ensure that long-term electricity markets don’t harm the effectiveness of short-term markets in dispatching resources efficiently and signaling the value of electricity across time and location. Moreover, any long-term market mechanism should be designed to emphasize transparency, limit complexity, and reduce opportunities for market rules to be influenced or biased by incumbents who may stand to benefit.

The market concept outlined in this paper attempts to address these concerns, through a market product, contract structure and market clearing processes that are simple and transparent but still selects resources based on the value they bring to the system. However, significant work remains to further develop, test and validate this concept. In particular a deeper analysis of the allocation of key risks will be needed, particularly as progress toward a carbon-free electricity system drives greater volatility in short-term market pricing. In addition, interactions with existing and future clean energy and climate policy at multiple levels of government, and with retail utility regulation will introduce significant complexity to implementing this and any long-term electricity market design.

But the prize is significant. Well-designed long-term electricity markets may be a critical tool to drive down financing costs and mobilize capital into renewable energy and carbon-free resources, ensuring that our electricity system is not only low carbon, but affordable for all.

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