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London Economics International LLC

Studying the impact of environmental policies on electricity market design

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Can competitive energy markets survive the transition to "clean" generation technology?

- **A number of emerging trends can be observed from current electricity markets that suggests a dramatic change in generation supply mix in coming years**
  - efficiency advancements in intermittent generation technology and energy storage options
  - the need to reduce carbon emissions
  - customer involvement on the grid through demand response and distributed generation
  - aging thermal generation fleets approaching retirement
- **Europe is seeing a rapidly evolving energy supply mix due to various renewable subsidies (FIT, RPS, etc.) and other policy decisions**
  - Demanding de-carbonization goals also contributing to forced retirement of certain existing class of generation technologies, which is creating room in markets for new technologies
  - Similar issues are also pertinent in North America, as renewable technologies approach grid parity and competitive markets attempt to integrate renewables in increasingly greater quantities
- **Economists are aware of the challenge but more attention has been given to integrating renewables with more ancillary services markets or new commitment rules, rather than selecting an appropriate market design**
- **Looking at historical experience is not sufficient – historical market prices and outcomes are impacted more by fundamentals unique to each market (resource mix, consumption patterns) and legacy regulations and policies**

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Simulation modeling of various market designs suggests that there is no "silver bullet" – all market designs have shortcomings

- **We chose to simulate California market outcomes because of its aggressive renewable and de-carbonization policies and goals**
  - We modeled the California market, 2017-2030, with an assumption that RPS goals (50% by 2030) will be achieved through long term PPAs, essentially "outside the market"
  - We considered market prices, retirement and investment, resulting resource adequacy, total costs to consumers and total carbon emissions
- **Energy-only market versus an energy & capacity market were considered, in addition to California's current "central planner" market design**
  - Higher levels of renewable penetration may not work well with energy-only market as renewables depress the energy only price
  - Central planner market may have highest cost to consumers because of the bifurcated nature of market and "hidden" cost of early retirement and need for new entry earlier than would otherwise arise
  - Capacity market may not be perfect – capacity market prices may be undermined by pace of renewable investment, especially if that renewable investment is being motivated by out of market agreements (RPS subsidies)
- **Lessons learned: customers and policymakers will need to make tradeoffs**
  - Even markets designed specifically for resource adequacy – like the capacity market – may not be able to withstand significant levels of "out of market" intervention
  - Although the central planner market has lower costs and highest resource adequacy, it will burden consumers with higher costs in the long run because of bifurcated scheme and central planner's risk aversion (which amounts to more investment)

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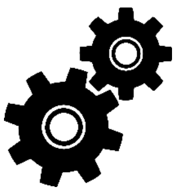
Agenda

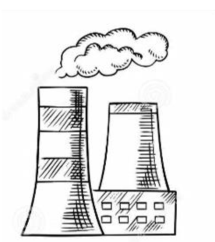
1	**What does economic theory suggest?**
2	Current context for change in Europe
3	Observations from modeling a real world market
4	Concluding remarks
5	Appendix A: Introduction to LEI
6	Appendix B: LEI Modeling Tools

While researchers agree on the challenges to market design posed by increased intermittent generation, there is less consensus on the best way to tackle the problem

- **Both academic researchers and system operators are in agreement that the transition to high penetration levels of intermittent generation poses unique challenges to system operations, market rules, and existing market designs**
  - For example, persistence of low and negative pricing events and "squeezing out" phenomenon affecting thermal generation (see Henriot & Glachant, 2013)



Impact on existing market operations



Impact on existing thermal generation

Possible transitions to ensure resource adequacy and security of supply

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Increasing intermittent integration has increased complexity of system operations challenges for the operation of many existing market designs

- **Ackerman et al. (2009) showed that increasing wind generation has resulted in adjusting of market designs, with incorporation of curtailment rules, some of which may reward wind generators**

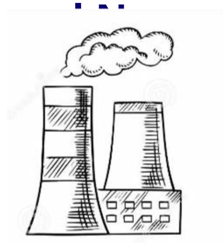
- **Another challenge has been how to set market rules that align the objectives of developers and society (consumers). For example, developers have been shown to adversely select sites for wind generation based on availability of ancillary services rather than resource optimization as shown by MacGill (2010) in Australia**

- **Some market practitioners have also proposed a different set of ancillary services (see Ela et al., 2012) – two RTOs in the US have in fact implemented fast ramp products to support system ramp recently**

- **Day-ahead markets have been challenged to improve forecasting accuracy to better integrate intermittent generation; Aparicio et al. (2012) discuss market rule revisions to solve this problem**
  - Some operators such as ERCOT and Germany’s TSOs have several prediction horizons prior to the operating day via a centralized system
  - Spain’s operator allows prediction companies to compete to provide the most accurate forecasts for generation companies

Everyone agrees that it will be vital to ensure resource adequacy, but criticisms of capacity markets abound – in part because it isn't a "market"

- **Capacity markets are becoming exceedingly common - in both Europe and in the Americas - for to maintenance of resource adequacy**
  - Varying "flavors" of capacity market – spot versus forward, ICAP versus UCAP, single clearing price auctions versus bilateral or pay-as-bid, with or without the demand curve
- **Cramton et al. (2013) and Jenkin et al. (2016) describe industry shifts to low SRMC technologies which has increased levels of support that are needed to keep thermal generators profitable and online to maintain system adequacy requirements**
  - System adequacy measures are also called into question with researchers asking whether the current benchmarks and metrics are in line with industry trends
- **Work by Hach, Chyong and Spinler (2015) suggests that capacity markets improve affordability and reliability by lowering the generation bill when compared to energy-only markets, using UK electricity market as an example**
  - But many also say that the UK capacity market is too nascent and therefore hasn't yet demonstrated that it can solve resource adequacy problems in the long run
- **More recently, Jenkin et al. (2016) shows that price volatility can also be a feature in capacity markets, demonstrating this using capacity auction prices in PJM [illegible] York ISO ("NYISO")**
  - Will volatility undermine the investor signal based on "predictable" revenues?



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Researchers have not identified a market structure that simultaneously allows for economic efficiency, security of supply and least cost

- **To evaluate the outcomes of a specific market design, Green (2008) describes metrics for measuring the success of wholesale market design, among which are:**
  - operational efficiency,
  - incentives to invest in generation capacity and
  - efficient location decisions for new investments
- **Increased integration of RES may be a signal of success of renewable support policies, but the strain on existing generation and adequacy challenges has resulted in policies that support the very technologies that renewable generation has sought to push out**

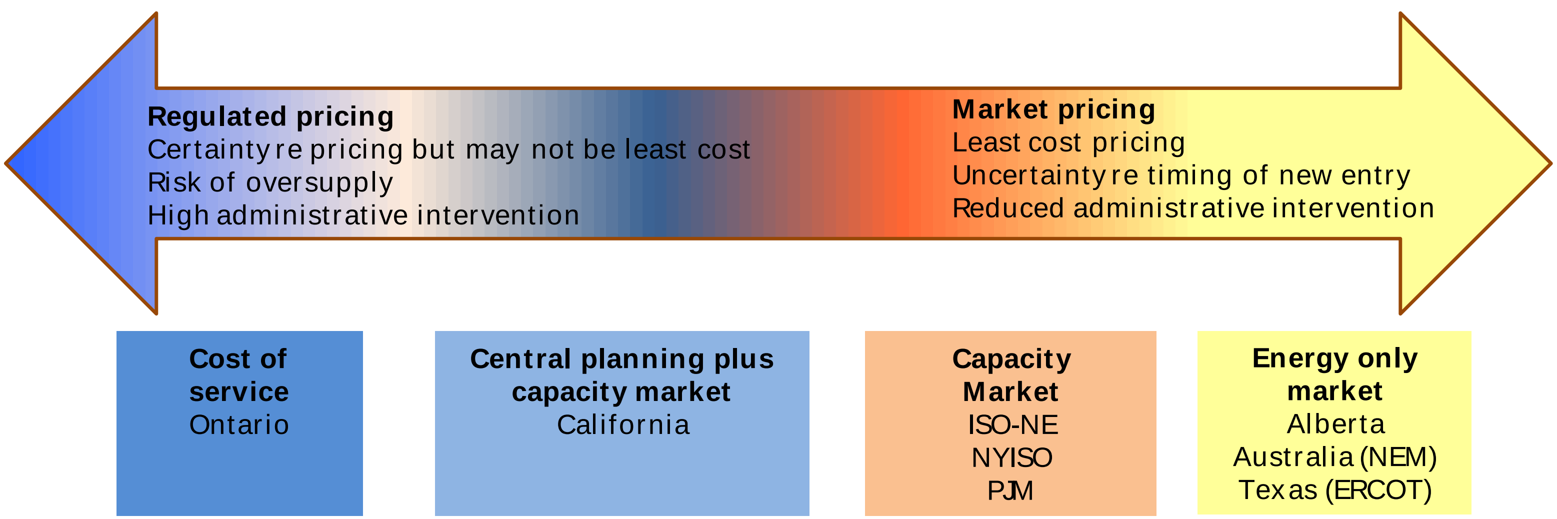
Successfully integrating renewables

Cochran et al (2012) describe global best practices in renewables integration and can be summarized into 5 strategies:

1. Leading public engagement, particularly on new transmission (to unlock potential)
2. Integrated planning processes - covering generation, transmission and system operations
3. Developing rules for market evolution enabling system flexibility such as shorter dispatch intervals (e.g. 5 minutes or 15 minutes)
4. Expansion of access to diverse resources or geographic footprint
5. Improving system operations to allow for more precise system operations, e.g. forecasting tools

Market design options lay across a wide spectrum that includes central planning, capacity and energy-only market designs

- **Under an energy only market, investment signals need to be provided by the spot price**
- **Capacity mechanisms are set up to ensure the availability of a determined amount of generation capacity for certain period (e.g., reserve margin) – some element of regulatory intervention**
- **Under a central planner model, a procurement agency is given a mandate to enter into sufficient contracts to assure that the desired conditions met**
  - Such as Reserve Margin target, RPS), or even more narrowly defined target

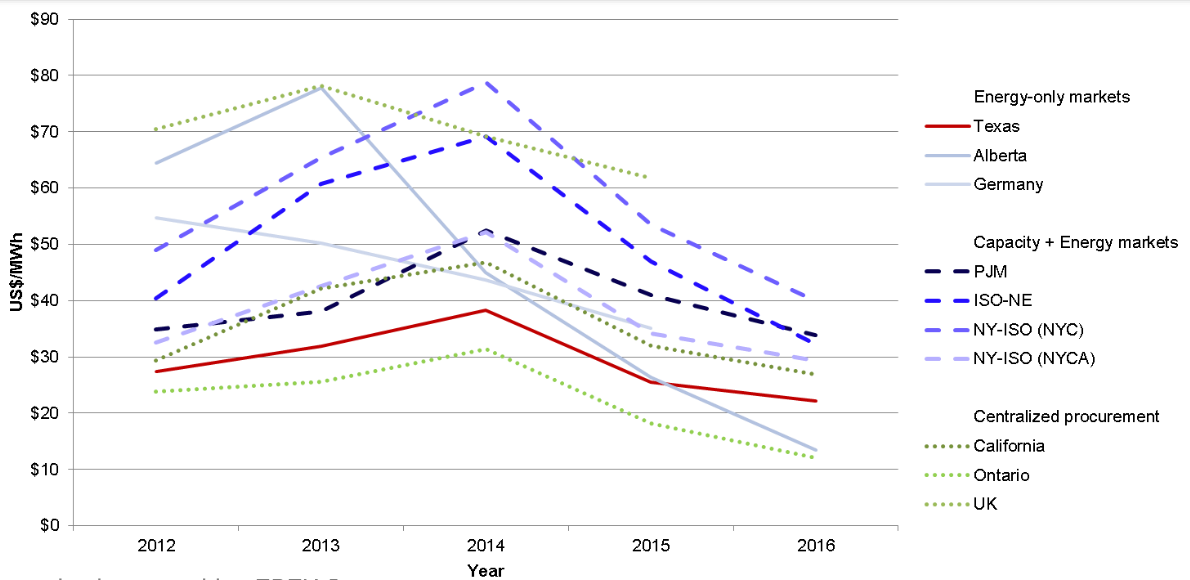


- **Variations on capacity markets/reserve margin obligations exist (i.e., mandatory forward contracting obligations)**
- **Notably, central planning and markets are not mutually exclusive (i.e., California, UK)**

Review of historical all-in electricity prices for different markets, categorized by market design, suggests that market design alone is unable to account for price differences

- **We have reviewed historical all-in market prices for electricity under the three broad market design categories taking into account historical monthly exchange rates**
  - Distribution of all-in prices does not align solely with market design - other factors play a role in determining electricity prices
  - Electricity market price outcomes also note explained by levels of renewable penetration
- **History therefore provides an incomplete picture – that is why we embarked on forward-looking simulation modeling approach**

Historical all-in market prices under different market designs (US$/MWh)



Sources: Commercial third party database provider, EPEX Spot

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European countries started with energy-only markets, but some have moved to energy & capacity market design

Jurisdiction	Operator	Market Design	Supply Mix/ Energy Profile
France	• Reseau de Transport d'Electricite ("RTE") • Power traded on EEX and EPEX Spot	• Energy-only	Nuclear-dominated (76%) generation profile, with hydro (11%) and thermal power (6%) providing the balance
Germany	• Four TSOs: Tennet, Elia, Amprion, Transnet BW • Power traded on EEX and EPEX Spot	• Energy-only • In discussions to implement a capacity mechanism	Diversity of resources, renewables comprising 50% of installed capacity, coal 26% and natural gas at15%
Ireland, Republic of	• Single Electricity Market Operator (SEMO)	• Energy and capacity market • Transitioning to second generation	Natural gas-dominated (45%), with coal (22%) and renewables (15%), mostly wind, providing the bulk of the rest
Italy	• Terna - Rete Elettrica Nazionale S.p.A (Terna) • Trading occurs on the Italian Power Exchange (IPEX)	• Energy and capacity market • Capacity market recently launched	Natural gas (38%), renewables (20%), hydro (18%) and coal (18%) comprise a diverse electricity supply system
Spain & Portugal ("MIBEL")	• OMIE (Iberian Energy Market Operator)	• Energy and capacity market	Spain has a diverse supply mix with nuclear (21%), wind (19%), natural gas (17%) and coal (16%) Portugal is renewables-dominated with hydro and wind (53%) leading over coal (23%) and natural gas (13%)
United Kingdom	• National Grid Electricity Transmission ("NGET")	• Energy and capacity market	Thermal-power dominates generation with natural gas (29%), coal (22%) and nuclear (21%)

European electricity markets will see rapid technological shifts in next 10 year due to decarbonization goals and supply security

- **Over past decade, end-users have financed a large renewable build out via various feed-in tariffs in countries such as Denmark, Germany, Italy and Spain**
- **Partly as a result of the boom that resulted from feed-in-tariff programs, the delivered cost of electricity in some European jurisdictions are among the highest among developed jurisdictions**
  - In 2013, only Bulgaria had residential rates lower than the US average (for comparative purposes, US retail price at 12.12 cents/kWh, and the European average of 26.7 cents/kWh)
- **European Commission enacted the industrial emissions directive ("IED") as a key de-carbonization policy tool in 2011**
  - As part of an environmental permitting scheme heavy emitters face decision point to either retrofit or retire
- **Recent political commitments to transition away from conventional fossil fuel have accelerated the shift towards cleaner generation**
  - The UK has committed to shutting down its entire coal-fired generation fleet by 2025, with France making a similar commitment, but with an earlier promised date of 2023
- **In spite (or as a result) of the renewable investment, there remains an uncertainty about resource adequacy as market incentives for new gas fired investment are weak**
  - Wholesale electricity prices are represented by the PEP index, and in February 2016, they averaged €30/MWh in February 2016, the lowest since March 2007

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We have used the California market as "Guinean pig" in our analysis due to its ambitious decarbonization and renewables goals

Why California?

We chose California because:

- **Long history with competitive electricity markets in California**
  - Energy market in existence for almost two decades; after the energy crisis, California policymakers moved to a more centrally planned market
  - LEI has modeled California's market for over 15 years – even prior to the start-up of CAISO
- **Many parallels to European Union member states**
  - Large electricity market (195 TWh) with increasing interconnection to neighboring states
- **Diversity of generation mix**
  - While close to 60% of California's market was served by natural gas in 2015, renewables (solar, wind, geothermal, hydro) held a share of over 25%
- **Ambitious decarbonization and renewables goals**
  - California has established a Renewable Portfolio Standard ("RPS") goal of 50% by 2030
  - California has a separate emissions reduction policy which targets an economy-wide reduction of emissions of 40% of 1990 levels by 2030

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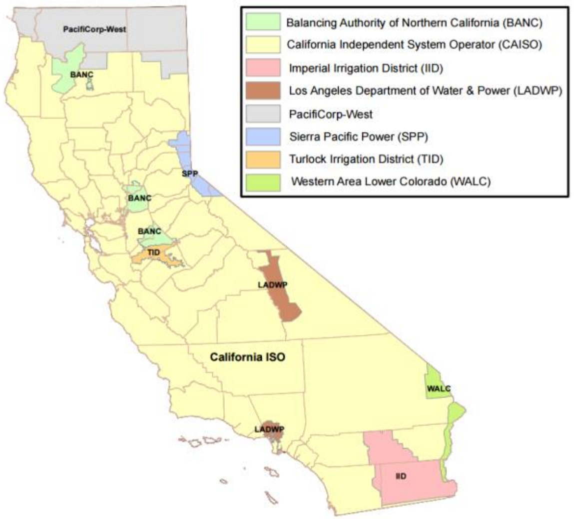
California is one of the largest markets in the US in terms of installed capacity, and one of the most aggressive in terms of clean energy strategy



California	
Population (2015)	38.8 million
Installed capacity (2015)	79.4 GW
Generation (2015)	195 TWh
System Operator	CAISO
Wholesale Renewable Capacity (2015)	19.1 GW
Distributed Generation (2015)	8.2 GW

Sources: California Energy Commission

- **Natural gas has been the dominant fuel for the past decade, representing about 60% of generation in 2015**
  - In-state renewables accounts for ~20% of total generation in 2015
- **With coal already part of a mandated phase-out, it is an insignificant portion of the fuel mix**
- **Nuclear generation is also on the decline as Pacific Gas & Electric's decision to retire the 2.2 GW Diablo Canyon plant**
  - In addition, the one of Palo Verde nuclear units (there are three units) will see its NRC license expire on 2045, reducing imported nuclear generation
- **California can be described as a "bifurcated" market – new investment is catalyzed through long term PPAs with the utilities, sanctioned by the state regulators**
  - Existing generation competes for energy and capacity in spot markets
- **California's future evolution is colored by its experiences such as the energy crisis in 2000-2001**

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In all our scenarios, we begin with the presumption that high level of renewable penetration - 50% of retail sales – is achieved with long term contracts

Which Market Design can Handle Such Levels of Renewable Entry and Sustain the Market?

I. Central planner

Bifurcated design

- long-run contracts for all new generation that provides full return but mandates participation in spot markets (energy and RA)
- existing generators without contract participate in the spot energy and resource adequacy ("RA") capacity markets
- Resource adequacy achieved by central planner's actions

II. Energy & Capacity

Dual 'market' approach

- generators – existing and new – compete in centralized capacity market (with price schedule in demand curve keyed off hypothetical peaking generator's costs)
- all resources participate in spot energy market
- resource adequacy achieved in principle if capacity market parameters set to proper target

III. Energy-only

Classic market approach

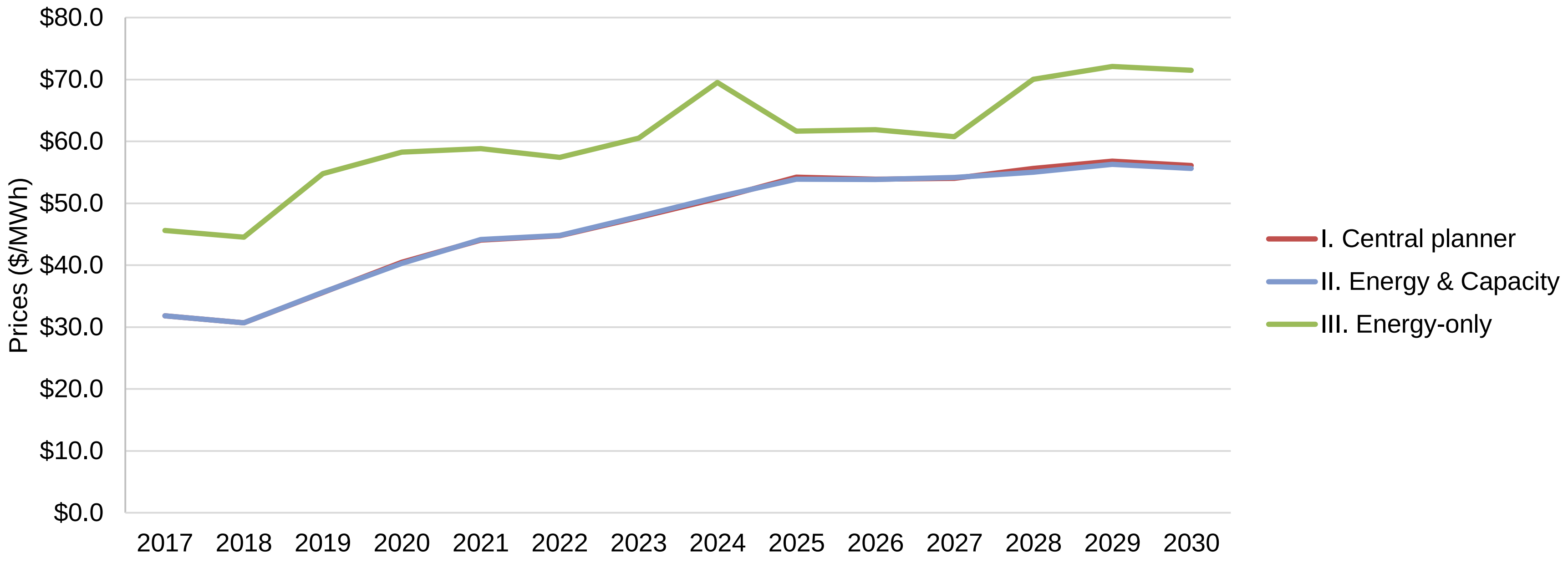
- all generators must seek compensation through spot energy market
- energy prices must be allowed to rise above SRMC
- Resource adequacy is not guaranteed as there is no effective reserve margin requirement; new investment enters market only if economic

- **Amongst all three cases, we have kept the following factors constant:**
  - RPS achieved through out of market intervention (50% by 2030)
  - CO_2 allowance prices and natural gas prices escalating with time, based partially on exogenous factors
  - Demand levels and net imports same between market design cases
  - generating capacity with awarded PPAs (existing and under construction) same across all cases and acts as price-taker

Energy market prices in case 1 and 2 are almost identical (and generally rising with gas prices) but under case 3, energy prices include a bidding premium above SRMC (and are sensitive to supply changes)

- In the early years in all cases, prices increase with rising fuel prices and demand growth.
- Case I and II prices flatten in later years, reflective of increased solar entry to meet the RPS compliance target of 50%
- In Case III, energy prices fluctuate inversely in response to changes in the supply mix: new entry of renewables drive down prices, while increased retirements post 2025 drive prices back up

Annual average energy market spot prices (2017-2030, nominal US$/MWh)



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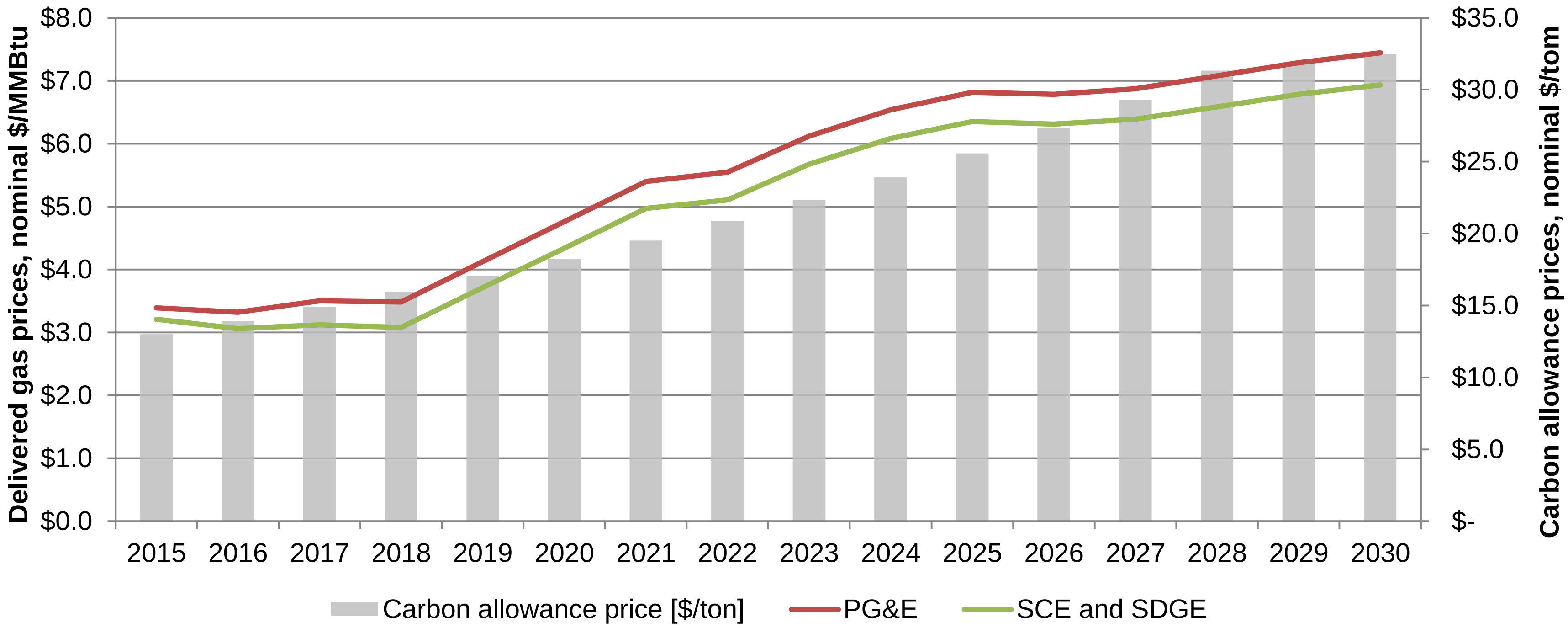
Major drivers of SRMC include fuel prices and CO_2 allowance prices: both are escalating in nominal terms over forecast time horizon

- The near term (2017 and 2018) delivered gas prices are based on the three-month average forward prices, and in the longer term, delivered gas price projections developed use the price of a reference supply point from EIA's *Annual Energy Outlook* 2016 and a long run transportation basis
- Carbon prices developed based on WCI rules and state's goal for carbon emissions reduction (power sector is assumed to achieve its pro rata share)

Projected gas and CO_2 allowance costs (2017-2030, nominal US$/MMBtu and US $/ton)



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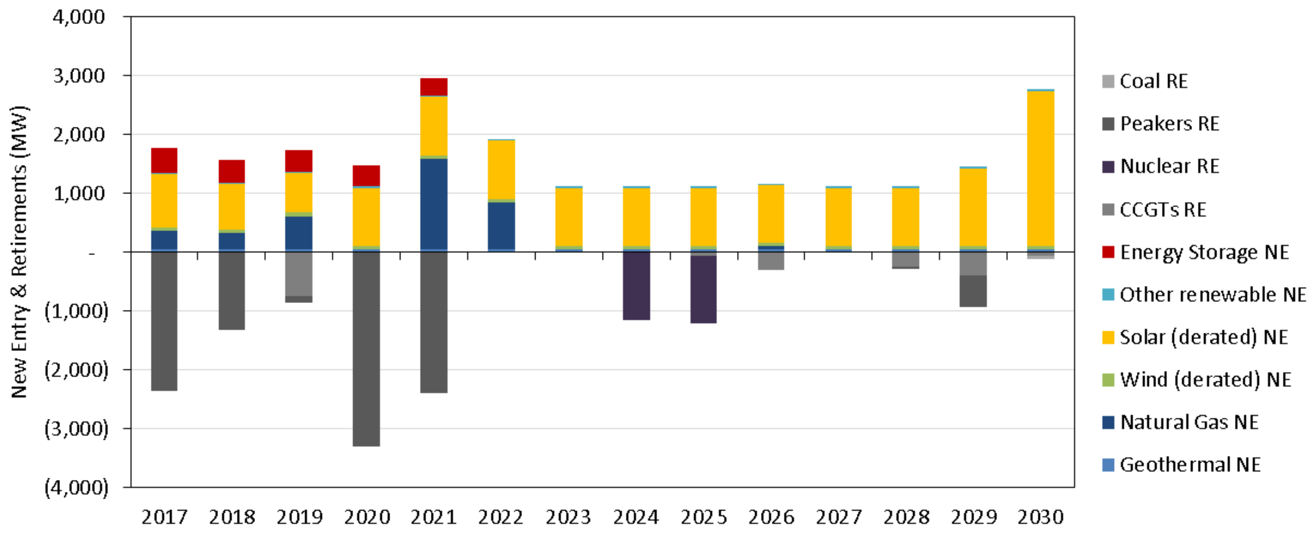
California will see significant retirements of existing thermal plants due to environmental regulations, but utilities have procured replacement through RFOs; majority of planned new entry is renewable to meet RPS

- Retirement of existing plant in near term driven by water cooling regulations
- Planned new entry is primarily renewable investment to meet RPS (some of this capacity already acquired through RFOs and PPA commitments)

Known retirements (only) and planned new entry for California (2017-2030, MW)



- In addition to known retirements, we simulated economic retirements, which differ by case
- Economic new entry is unlikely in any case – we see that market prices – even with capacity prices are not sufficient to attract significant new thermal investment

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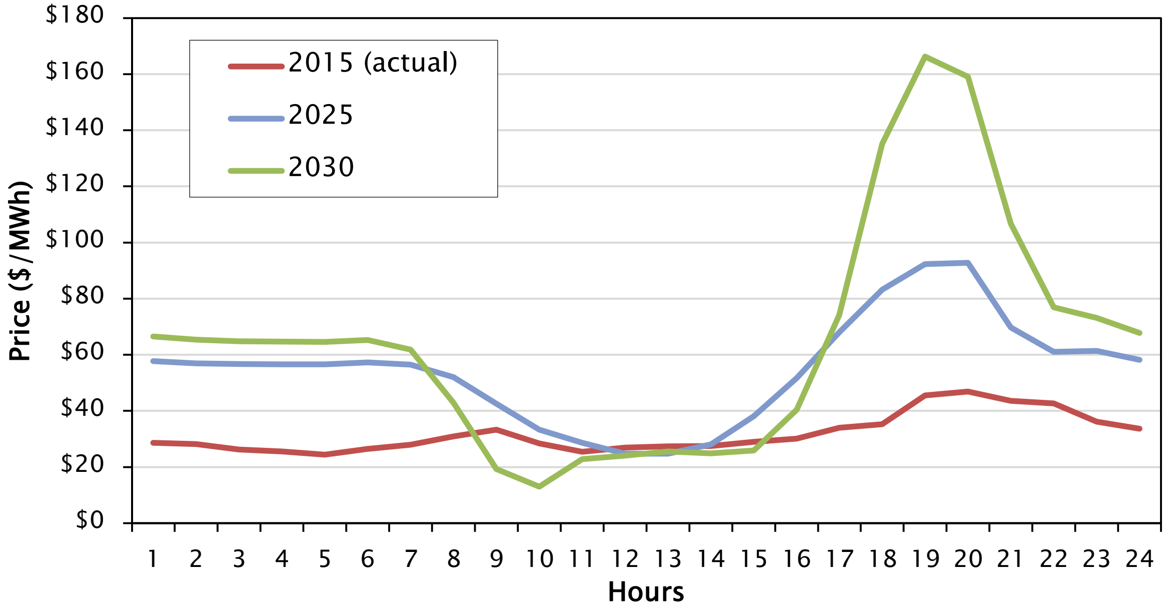
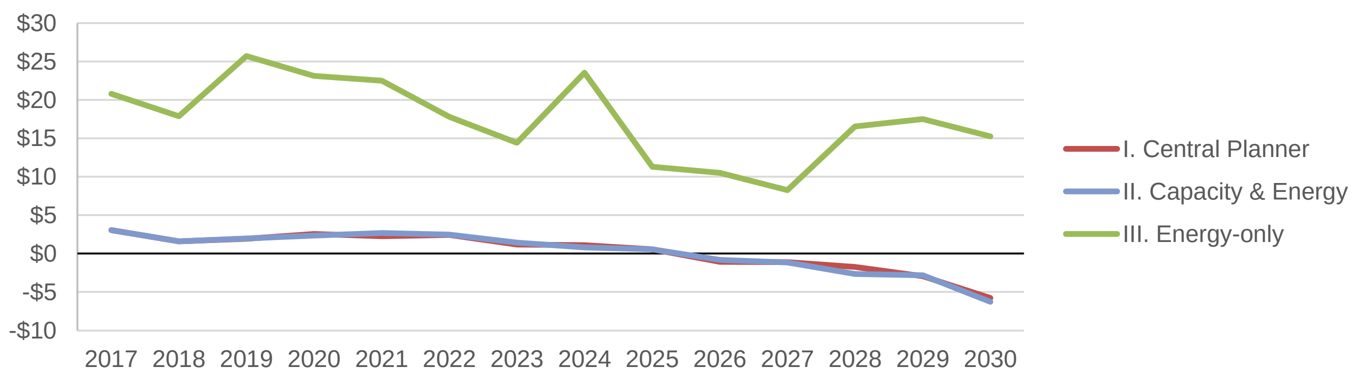
Increased renewable penetration, particularly solar results in the depression of traditional afternoon peak prices

Hourly price profile under Case I across sample year in forecast timeframe (nominal US $/MWh)

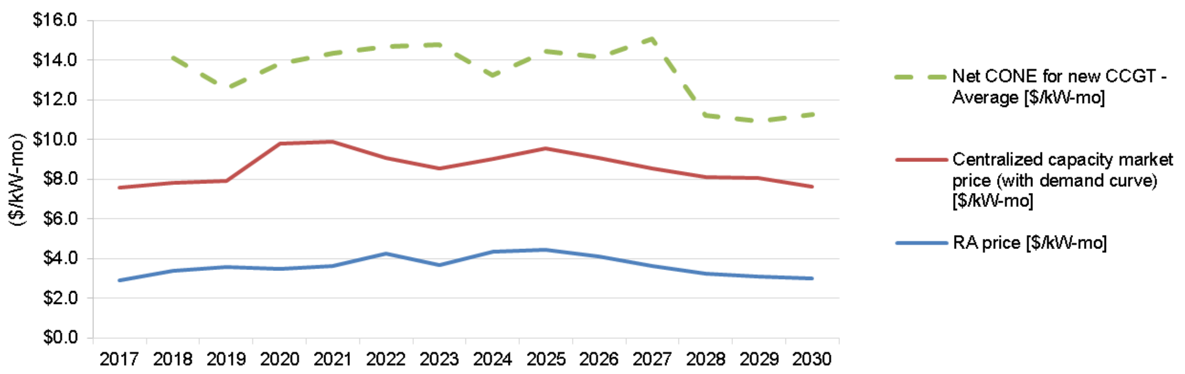


Peak – Off-peak Prices (nominal US $/MWh)

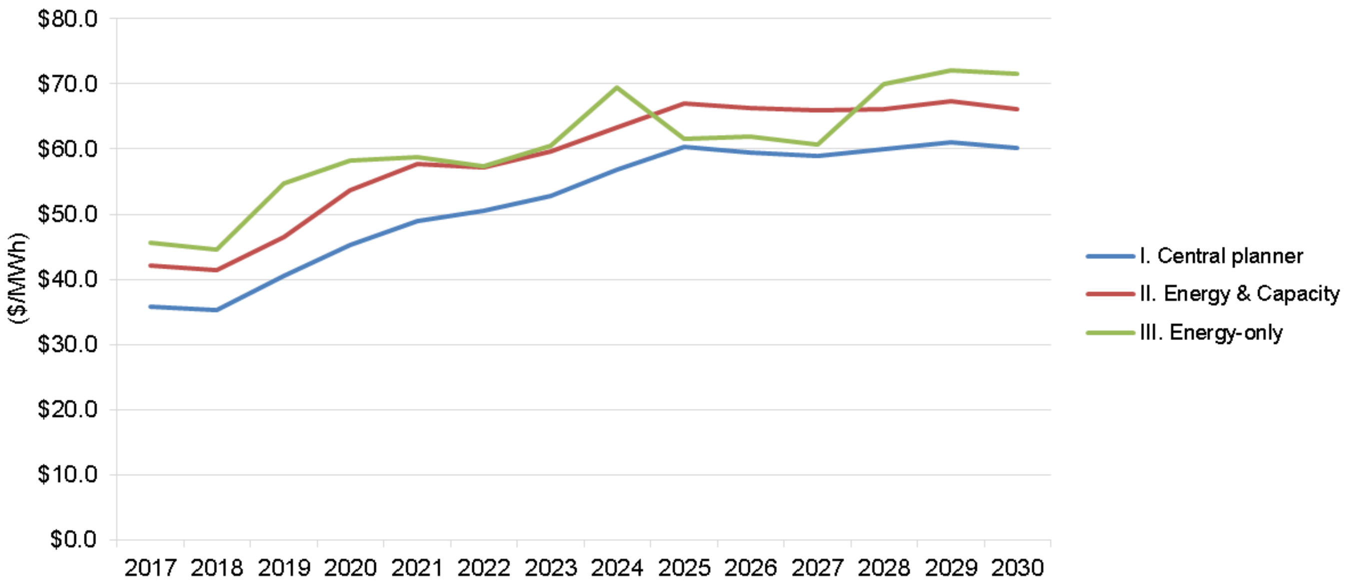


By design, capacity market prices under the RA market are much lower than the price outcomes from centralized capacity market with demand curve

Projected capacity prices (2017-2030, nominal US $/kW-month)



Total all-in prices (2017-2030, nominal US $/MWh)



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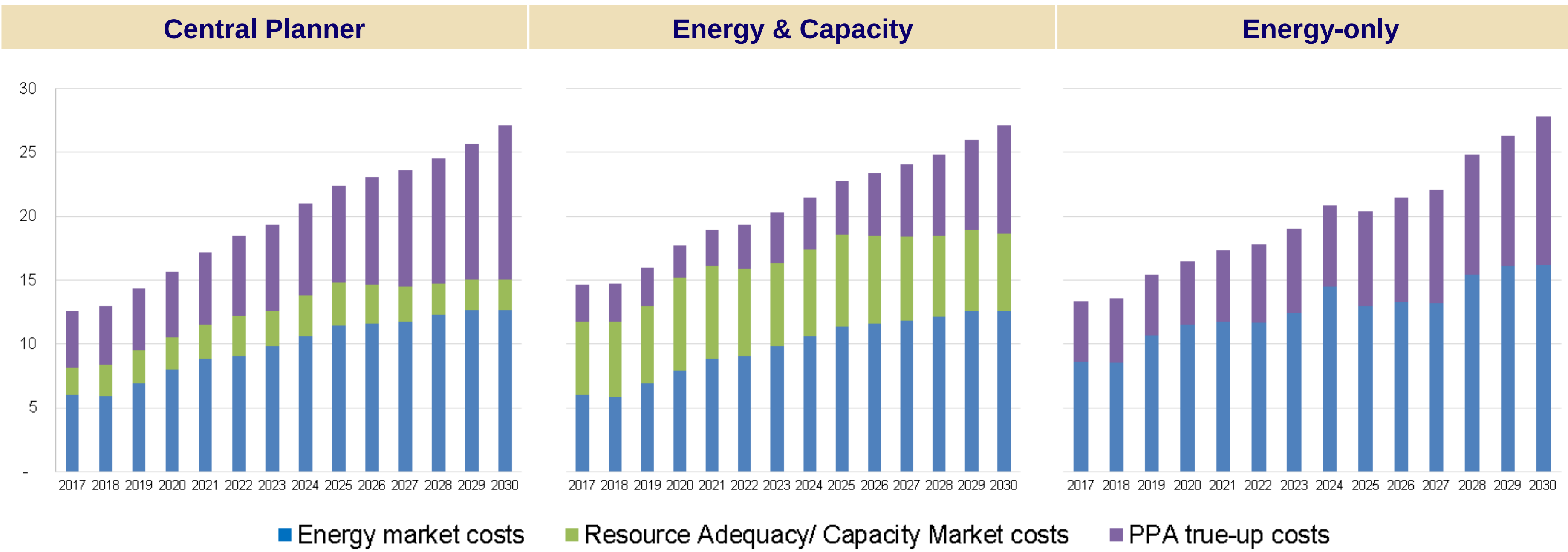
Although market costs are generally similar between the three market designs, on a net present value basis, the energy-only market is lowest cost

Total costs to consumers, including PPA true-up costs (nominal US $ billions)



Total cost to consumers for sample years (nominal US $ billions)

	2017	2021	2025	2029	2030	NPV at 10% discount rate
I. Central Planner	$12.6	$17.1	$22.4	$25.7	$27.1	**$133.4**
II. Energy & Capacity	$14.6	$18.9	$22.7	$26.0	$27.1	**$142.3**
III. Energy-only	$13.4	$17.3	$20.4	$26.3	$27.8	**$134.0**

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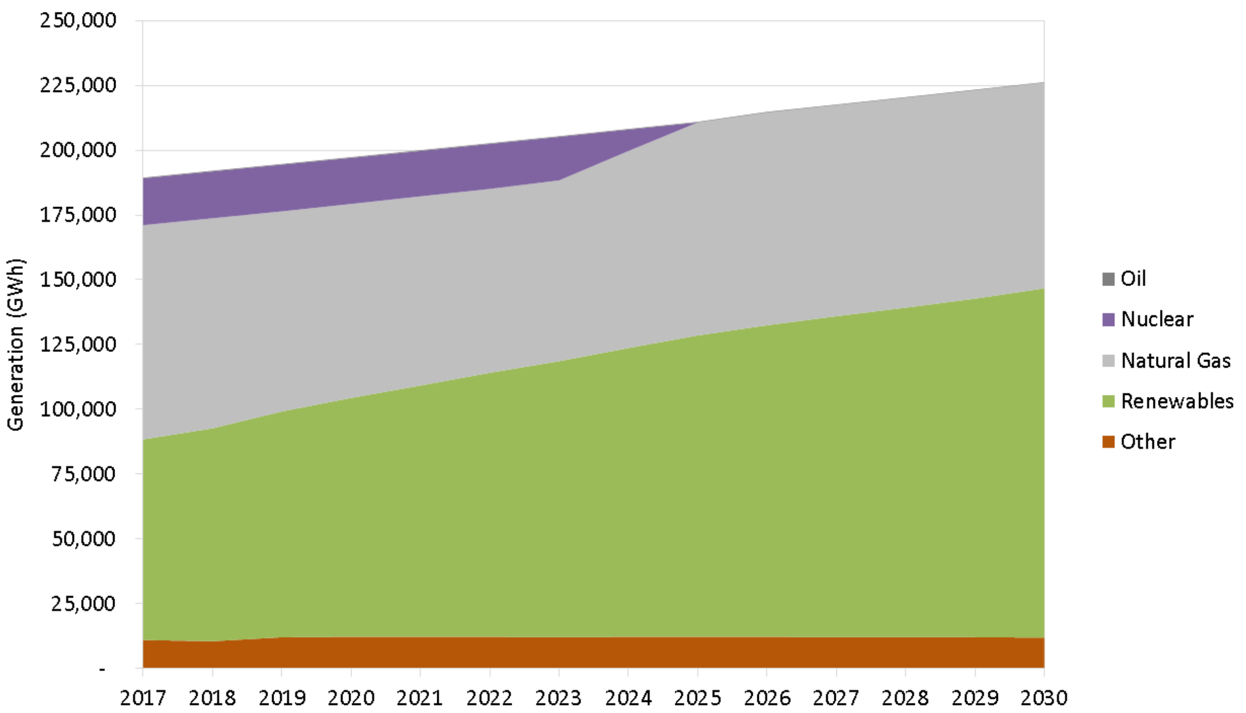
Renewable generation dominates the energy supply mix across all the cases, with gas generation slowly losing market share over time

Generation mix under Central Planner market design (2017-2030, GWh)



- **We see a <u>decline</u> in the share of natural gas through to 2025 from 44% to about 34% in all three cases as a result of increasing share of low cost renewable generation, with solar in particular increasing over the modeling horizon from 9% in 2017 to 22% by 2030**
- **Following the exit of all nuclear generation in 2025 following the shutdown of Diablo Canyon, the decline of natural gas stabilizes across all cases, as the market seeks to fill 10% of lost generation**

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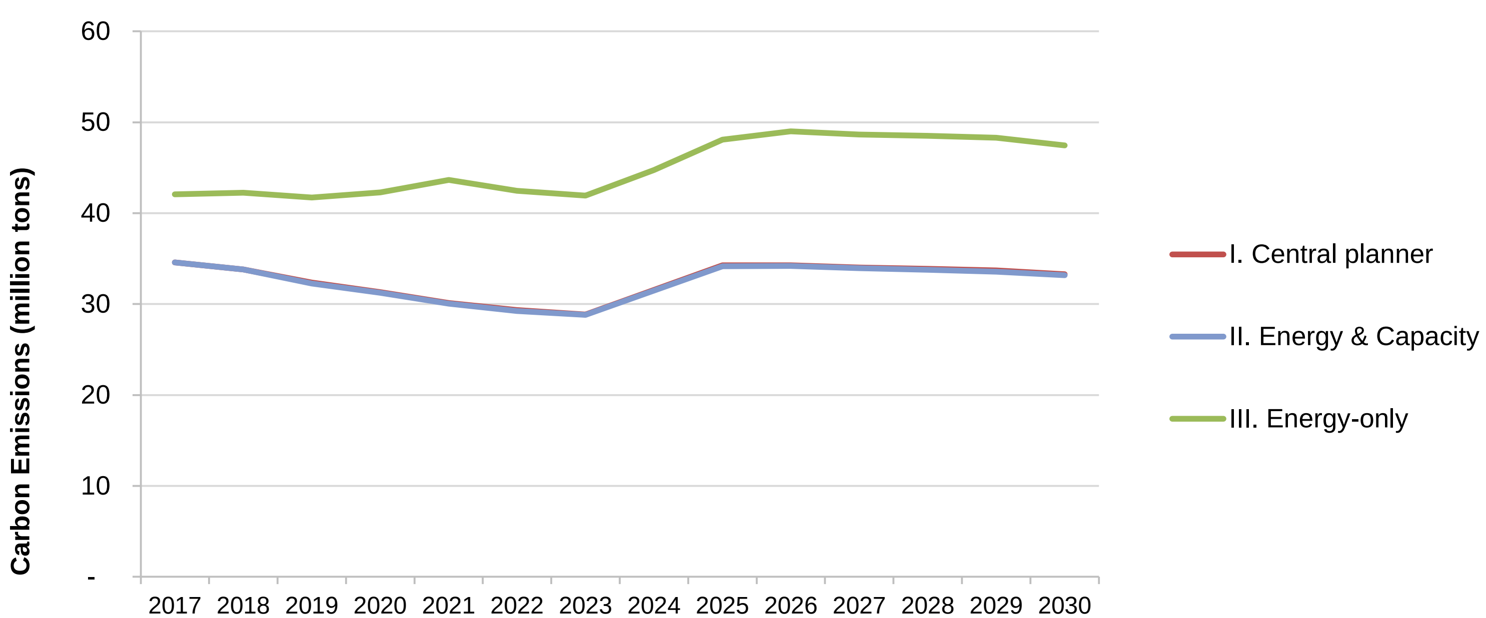
Carbon emissions will respond to dispatch dynamics in the market: if less efficient gas is being employed (or more gas is being burned altogether), that will lead to higher carbon emissions

- **In the energy-only market, generation portfolio owners bid in such a way that less efficient gas is price-setting more often which raises emissions**
- **In all three cases, we see an increase in carbon emissions between 2023 and 2025 to compensate for nuclear shut down in 2025**

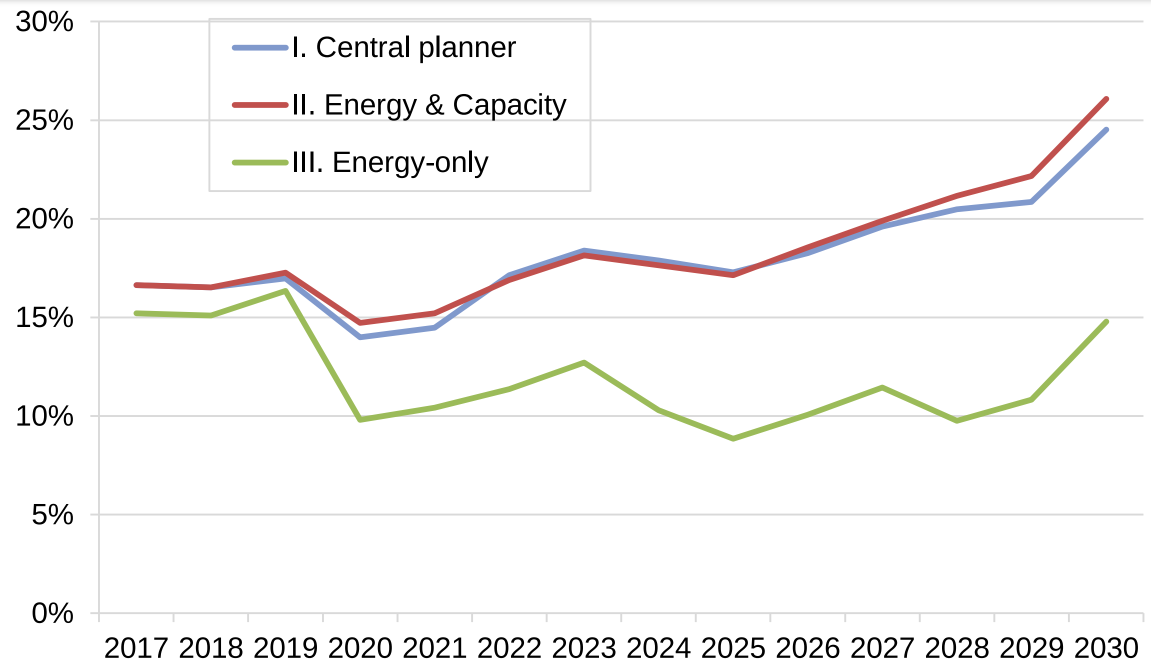
Total CO_2 emissions for California electricity sector (million short tons)



Energy-only market results in significant more retirements and therefore lower levels of resource adequacy; there are also subtle differences between central planner and energy & capacity market design

- **Without any additional remuneration beyond the markets, the energy-only market results in significantly higher retirements, with at least 4.5 GW more retirements than the other cases. This is visible in a lower reserve margin in the modeling horizon**
- **The energy and capacity market maintains a higher reserve margin over the central planner over the modeling horizon. This is because better remuneration in the capacity market prompts fewer retirements and therefore greater levels of system adequacy**

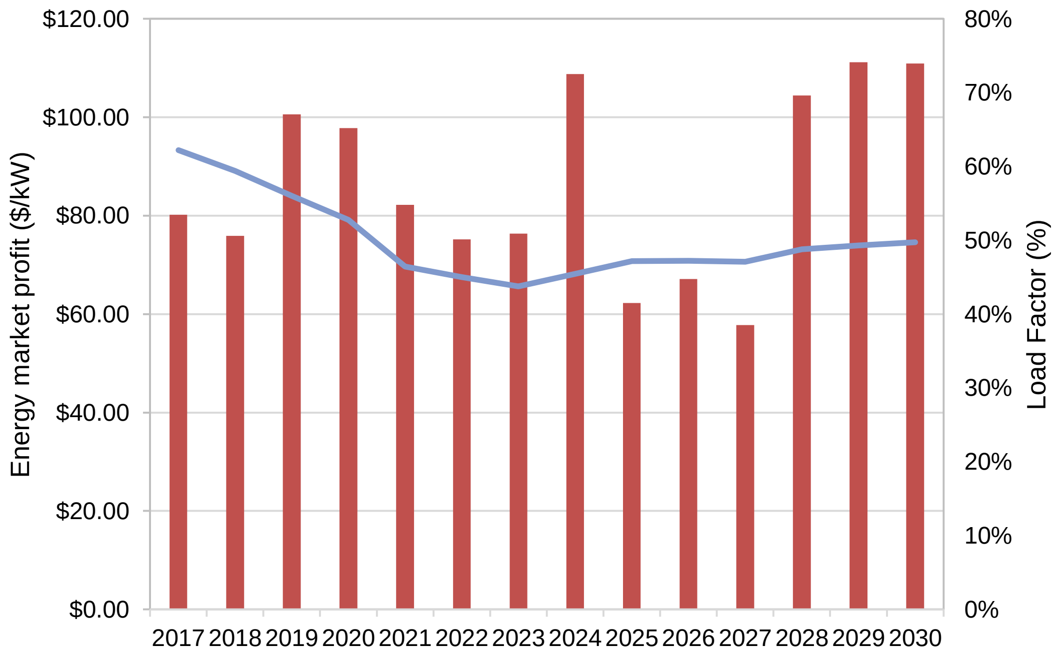
Resulting reserve margins (2017-2030), *renewable capacity derated*



Energy-only market design is not sustainable with significant zero-SRMC intermittent resources: resource adequacy suffers with increased frequency of unserved (VoLL) events

- **We see increased retirement of thermal generation, with majority of the retirements seen in gas peakers and gas steam turbines (14,000 MW cumulative, or 29% of the gas fleet by 2030)**
- **VoLL events rise to as much as 117 hours per year by 2030 (traditional planning standard of 1 day in 10 years implies 2.4 hours/year)**

Performance of CCGTs under Case 3: energy market profits (nominal US $/kW) and annual capacity factor, %



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Central planner model appears to offer highest resource adequacy at a comparable price to the energy & capacity market design, but…

- **Under central planner, 35% of the total costs to consumers are "hidden" as PPA true-up costs, and subject to the negotiating abilities of the IOUs/regulator**
  - Central planner may be exposed to choose – for a variety of non-economic reasons – to make investments that are not least cost/efficient
  - Also, although long term PPAs may reduce financing costs), risks of stranded assets (and early retirement) after PPA expires may increase financing costs over time
- **Modeling results highlight that retirements are greatest under this bifurcated market design due to the low prices of the RA capacity market – more than 1,000 MW more retired by 2030 as compared to energy & capacity market**
  - More retirements will lead to more investment (at a higher cost to consumers)
  - Central planners are not omnipotent (they can make mistakes) and will likely be risk-averse (and therefore over-build) – further raising costs to consumers
- **Energy market essentially becomes a mechanism for optimized dispatch decisions in the short run – but even then, it may not prevent curtailments of renewable resources**
  - California policymakers have recognized this risk – that's why they support expansion of the EIM

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Energy & capacity market prevents existing generation from retiring, but it is also subject to regulatory influence and "management"

- **Centralized capacity market is not really a "market" – it's a regulatory construct that can be packaged in the form of auctions, but ultimately, it will mean that some portion of generators' revenues would be subject to administered pricing**
- **The administered pricing will be represented in either the demand curve or price caps/price floors (and penalties for non-compliance)**
  - Experience shows that ISOs can indirectly affect outcomes through various rules related to the setting of the target reserve margin, capacity qualifications, determination of the shape of the demand curve, and the selection of the "reference" technology (net CONE that sets the demand curve)
  - Experience also shows that regulators do intervene as well when prices are deemed "too low" or "too high" and create new rules or advocate for changes to the :reference" technology
- **Capacity markets will not deliver the intended investment signal if they are not relevant to new entrants (e.g., RA capacity price) or if new entrants are not able to rely on the price signal (due to volatile capacity prices, which have occurred with vertical demand curves)**

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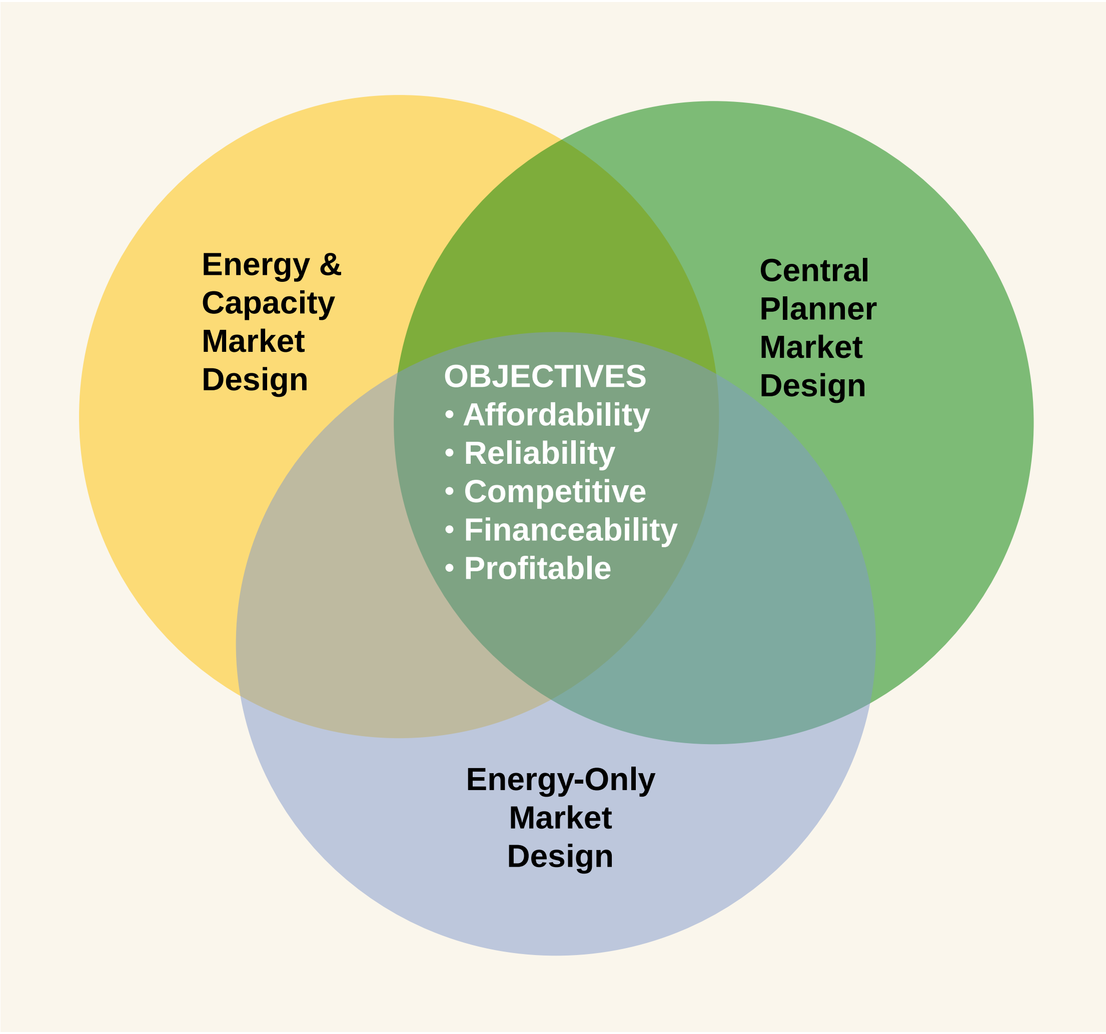
Market designs represent boundaries between market and regulatory frameworks to deliver objectives



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- **Three market designs represent boundaries of electricity market design to deliver objectives**
  - Energy only – relies on market
  - Centralized Capacity Market – balances market vs perceived need for regulatory intervention to ensure reliability
  - Central Planner – relies primarily on regulation; markets automate certain implementation steps
- **Balance tension amongst different stakeholder objectives**
  - Market prices earned by generators versus costs to consumers
  - In theory, objective of maximizing prices should result in the same outcome as cost minimization objective… but in reality, there are different constraints and priorities

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Many economists and policymakers acknowledge that conventional market designs may not be able to sustain the investment signal, and our modeling shows that there is no "silver bullet"

- **The magnitude and pace of change in electricity markets will be unprecedented in coming years as technology costs for renewables decline**
- **But we don't have a market design that is suited to ensuring sufficient resource adequacy in the face of substantial $0 SRMC resources**
  - Relative balance of market revenues will move away from energy markets to capacity markets over time – but will capacity markets be enough?
  - Will we trust central planners to be efficient?
- **A review of economic literature highlights the concerns – but a concrete solution has not yet been identified**
  - Historical analysis of market prices is not sufficient to suggest a clear "winner" for market design
  - Theoretical considerations are not sufficient to consider the actual operating dynamics: for example, even if robust carbon pricing ($50/ton +) is reflected in energy markets, it may not be enough to sustain gas generation under substantial levels of renewables
- **Of the three alternative market designs modeled on California, we observe that there is no clear "winner" and there are tradeoffs between resource adequacy and costs**
  - Consumers need to be brought into the discussion of market design strategies: how much do they value resource adequacy?

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Agenda

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LEI is a global economic, financial and strategic advisory firm, specializing in analysis of the energy sector

London Economics International LLC ("LEI") combines detailed understanding of specific network and commodity industries, such as electricity generation and transmission, with sophisticated analysis and a suite of proprietary quantitative models to produce reliable and comprehensible results.

LEI has extensive experience in several areas, including:

GENERATION:

- **working with generation owners to forecast market conditions and evaluate future revenues**
- **Assessing the impact of new generation resources on capacity and energy prices**

TRANSMISSION:

- **Helping in the assessment of the establishment of independent transcos**
- **Evaluating the market impact from proposed transmission projects**

RENEWABLES:

- **Working with developers to value potential revenue streams from Renewable Energy Credits ("RECs") and/or emissions offsets**
- **Counseling governments and regulators on creating policies which efficiently incentivize investment in renewable energy**

NATURAL GAS:

- **Assessing the synergies between the natural gas and electric power industries**
- **Examining performance-based ratemaking and total factor productivity for natural gas distribution companies**

ASSET VALUATION, PRICE FORECASTING & MARKET ANALYSIS

REGULATORY ECONOMICS, PBR & MARKET DESIGN

TRANSMISSION

RENEWABLE ENERGY AND PROCUREMENT

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LEI team has numerous energy sector clients around the world

My team and I have extensive experience working on market design issues and advising various clients on real world problems in the electricity sector

Julia Frayer,
Managing Director,
London Economics International LLC

- **I manage LEI's quantitative financial and business practice area, and also specialize in market and organizational design issues related to electricity. Sample projects include:**
  - Development of market rules in competitive markets, related to energy market dispatch, capacity product (and performance), ancillary services, market power arrangements, and transmission rate design and cost allocation;
  - cost of capital estimation and rate-setting analysis;
  - short- and long-term forecasting of wholesale power prices;
  - valuation of generators and vertically-integrated utilities;
  - assessment of retail market design including provider-of-last resort portfolios and contracts;
  - advice on and design of procurements, energy sales agreements; and structuring request for proposals and sale processes for energy assets and derivative contracts;
  - Retail market design and renewable investment vehicles.
- **My team and I have worked in all deregulated North American power markets since the late 1990s, but also in developing markets in Asia, Central & South America, Southeast Asia**

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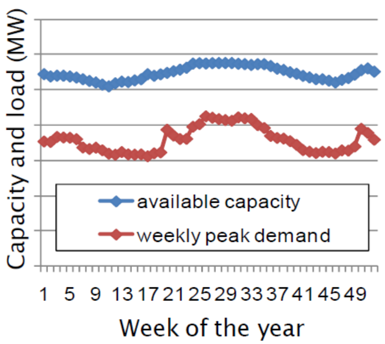
Agenda

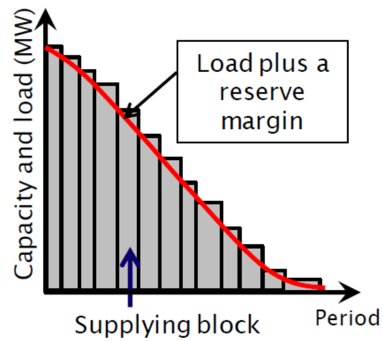
1	What does economic theory suggest?
2	Current context for change in Europe
3	Observations from modeling a real world market
4	Concluding remarks
5	Appendix A: Introduction to LEI
6	**Appendix B: LEI Modeling Tools**

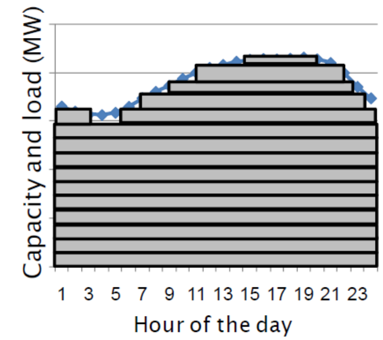
LEI's propriety production cost network model, POOLMod, is used to simulate hourly system dispatch

POOLMod employs a three-stage simulation process

1 Weekly	2 Daily	3 Hourly
Maintenance Schedule	Commitment	Dispatch







- **The maintenance schedule is determined on a weekly basis**
- **In general more plants are on maintenance during spring and fall seasons**
- **The "automatic" algorithm is used to allocate plants maintenance**

- **Periods in the day are sorted from the highest load to the lowest load**
- **POOLMod commits plants to meet the first period's capacity target**
- **Subsequent periods are treated in a similar manner**

- **Dispatch committed plants to meet the capacity target for the period (no reserves), incorporating forced outage rate ("FOR") and technical features (like start costs, and min on/off times)**
- **The price is determined based on the marginal cost of the resource needed to meet the last MW of demand in each period, or, if ConjectureMod is used, the offer price (based on a estimated daily bid markup)**

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POOLMod employs a game theoretic model - ConjectureMod – to determine "profit-maximizing" above SRMC bidding for suppliers under an energy-only market design

When used with POOLMod, ConjectureMod relaxes the "competitive bidding" assumption and introduces strategic offer behavior to replicate real world outcomes

Steps in ConjectureMod

1 Define strategic players in market

ConjectureMod

2 Estimate the degree to which market participants can increase offers above SRMC

50 iterations

POOLMod

3 Simulate Dispatch based on offers from ConjectureMod to produce realistic price trends

- **ConjectureMod derives the optimal bidding strategy for each designated "strategic" participant by forming a 'conjecture' about the bidding of competitors, and then estimating the participant's profit maximizing bids assuming each competitor follows that conjecture**
- **In this iterative game, each strategic player 'conjectures' that their strategic competitors will bid their profit maximizing bid from the previous iteration**

Theory behind ConjectureMod

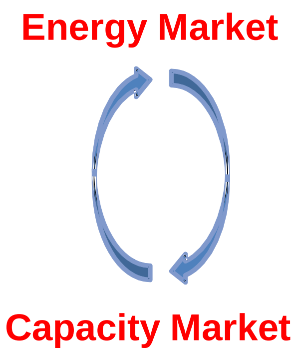
ConjectureMod is closely modeled on an approach set out by noted game theorist and electricity market expert, Dr. Robert Wilson. Each bidder ***i*** predicts what each other bidder j is bidding for its supply function:

$$P_j(q_j) = MC_j(q_j)$$

or j's marginal cost at output level q_j. Then, for each demand level D bidder ***i*** chooses its offered bid pair $(P_i(q_i;D),q_i)$ to maximize its net profit in view of its residual demand function given D and its prediction of other bidders' supply functions

LEI's Capacity Market simulator is adaptable to the market rules specific to a jurisdiction, forecasting clearing prices in a spot (or forward) capacity marketplace, with or without a demand curve

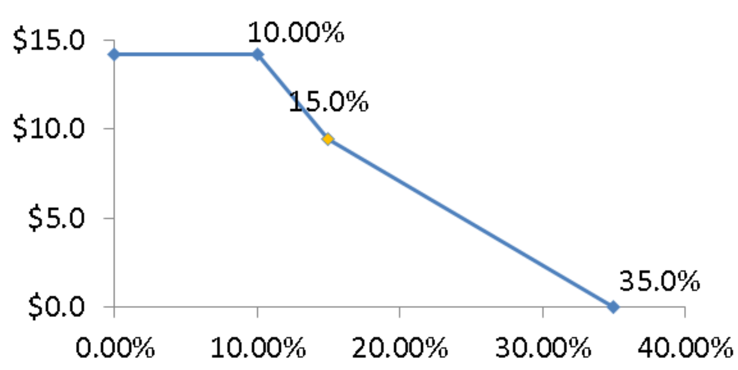
Capacity market outcomes results in new entry and retirement decisions of generators, which then affects the energy market dynamics



Check retirements & new entry dynamics

Clearing price in capacity market set according to basics of supply & demand

Modelled Demand Curve for California



Developing a Centralized Capacity Market for California

- Prices set based on total supply versus the demand curve (based on notional peaker)
- All existing capacity offer into the market as price takers and new entry will commit to market only when its expected profits are sufficient to allow for commercially reasonable return (so capacity prices converge to net CONE for the relevant technology)
- Retirements take place when expected profits from all markets are insufficient to cover minimum going forward fixed costs for three consecutive years
- New renewable entry assumed to enter to satisfy policy objectives (such as Renewable Portfolio Standards), and can earn 9derated) capacity revenues
- Demand-side resources and imported capacity also added to capacity market dynamics, consistent with current RA rules