Power system in transition: technological progress, environmental targets, and business model

LIN Jiang

Lawrence Berkeley National Lab

University of California, Berkeley

Presentation Outline

- Global trends in renewable technologies
- Solar/wind trends and policies in US
- Evolving regulatory/business schemes

Why Energy Matters for Development?

- *Modern economy built on fossil energy*
  - *Each energy technology revolution has led major changes in economy and productivity*
- *Concerns over energy security is a driving force in geo-politics*
  - *The Middle-East; Russian gas supply to Europe; expanding Chinese navy*
- *Largest source of GHG emissions today, around two-thirds of global total*
  - *Planetary safety depends a total re-vamping of energy economy*
- *Providing Access to clean energy is essential to meet MDG*
  - *1.2B people lack access to electricity; 2.7B people lack access to clean cooking*
- *Largest source of air pollution, linked to 6.5 million premature deaths per year*
  - *China and India (both out-door and indoor)*

The Challenges

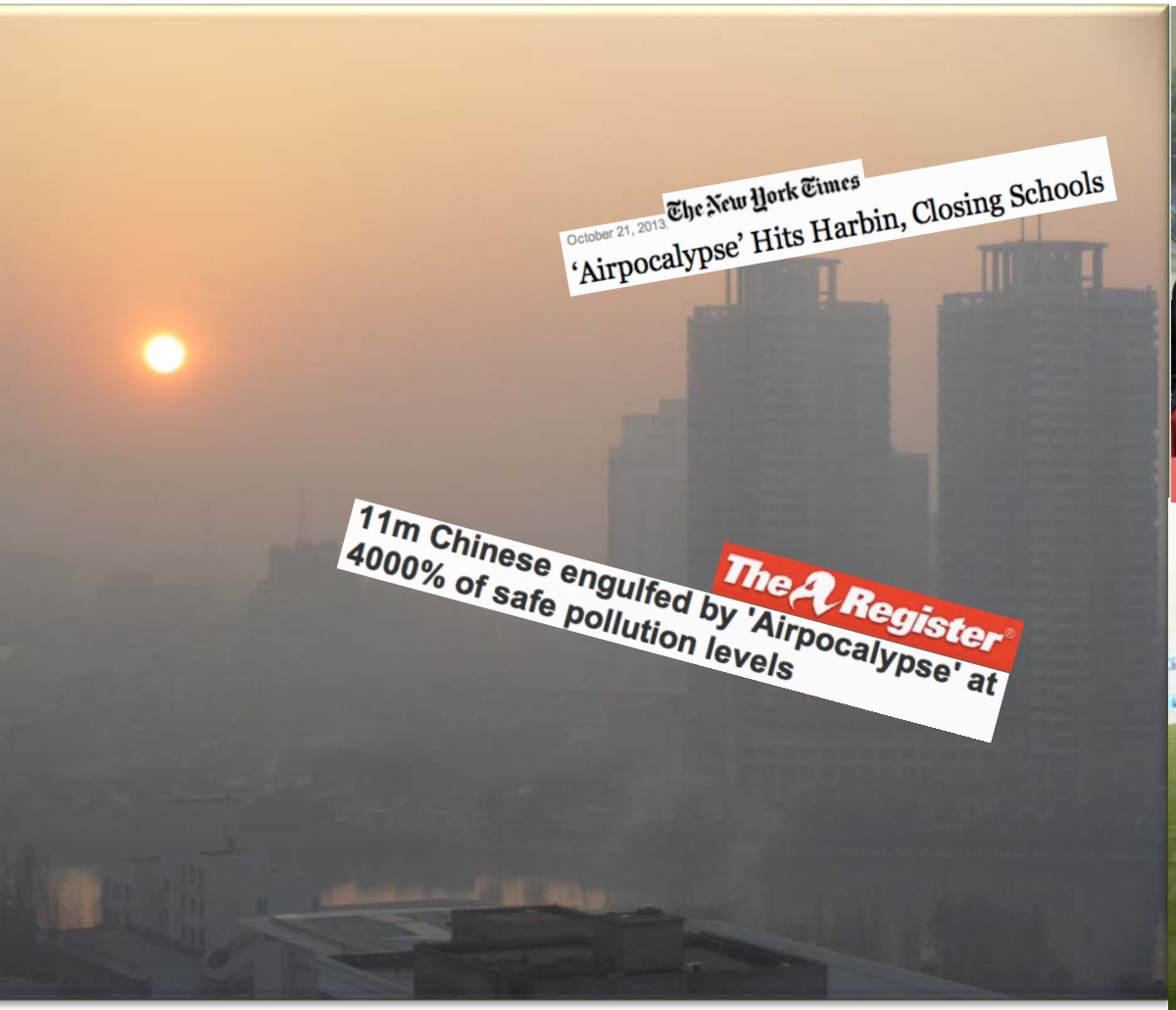
Urban Sprawl

Dangerous for People

Severe Congestion

Air Quality and Public Health

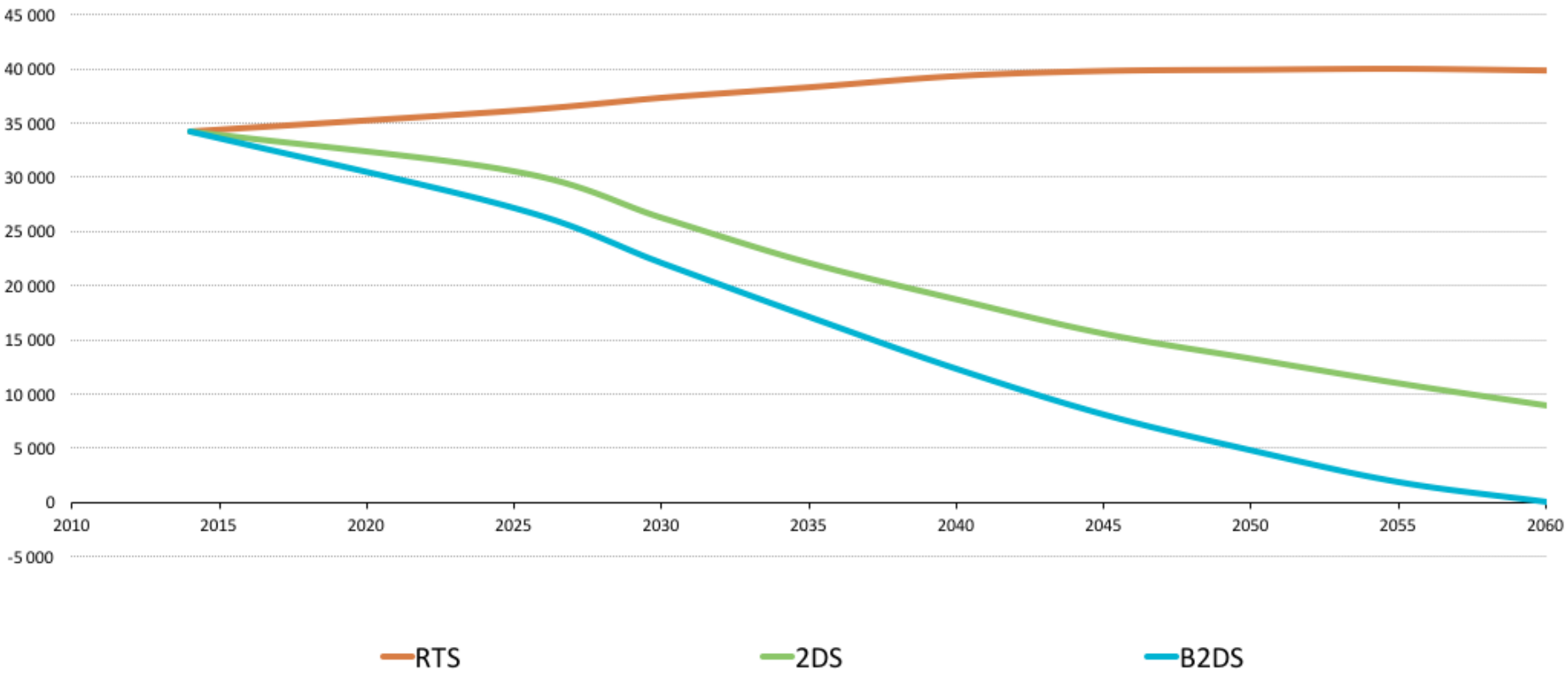
Air Quality is a major Social, Economic, and Environmental Issue in China



Global energy landscape is changing rapidly

- *Rapid technological progress, environmental and climate goals, and evolving business models*
- *Renewables supplied half of global electricity demand growth in 2016, due to rapid cost reduction in solar and wind*
  - *China leads the world in both solar and wind investment*
- *Electric car sales were up 40% in 2016, a new record year*
  - *Tesla market valuation higher than GM*
  - *Volvo stopping making pure gasoline and diesel cars in 2019*
- *Traditional energy companies facing tough challenges*
  - *Largest three coal companies went bankrupt in US*
  - *Electric utilities facing sales migration and low electricity market prices*

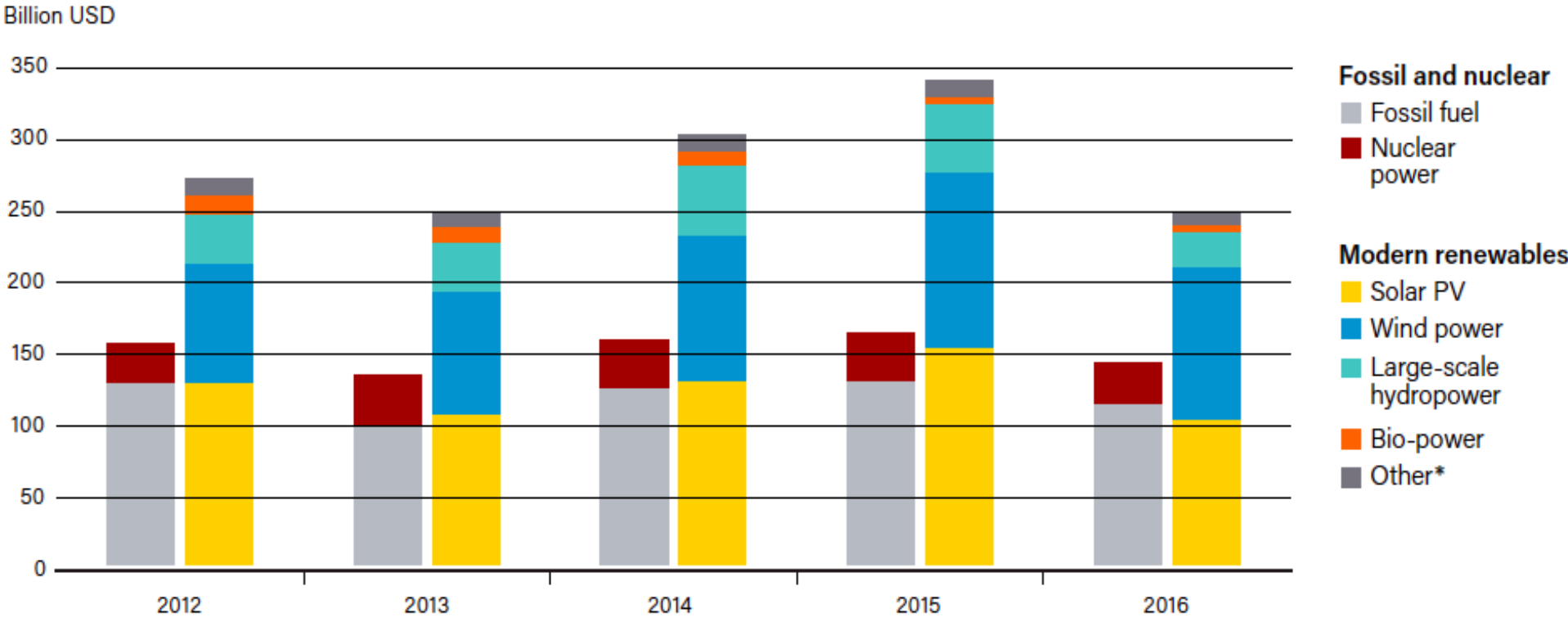
Despite rapid progress, the world is far away from sustainable path



IEA, ETP 2017

New power investment mostly in non-fossil

Figure 44. Global Investment in Power Capacity, by Type (Renewable, Fossil Fuel and Nuclear Power), 2012-2016

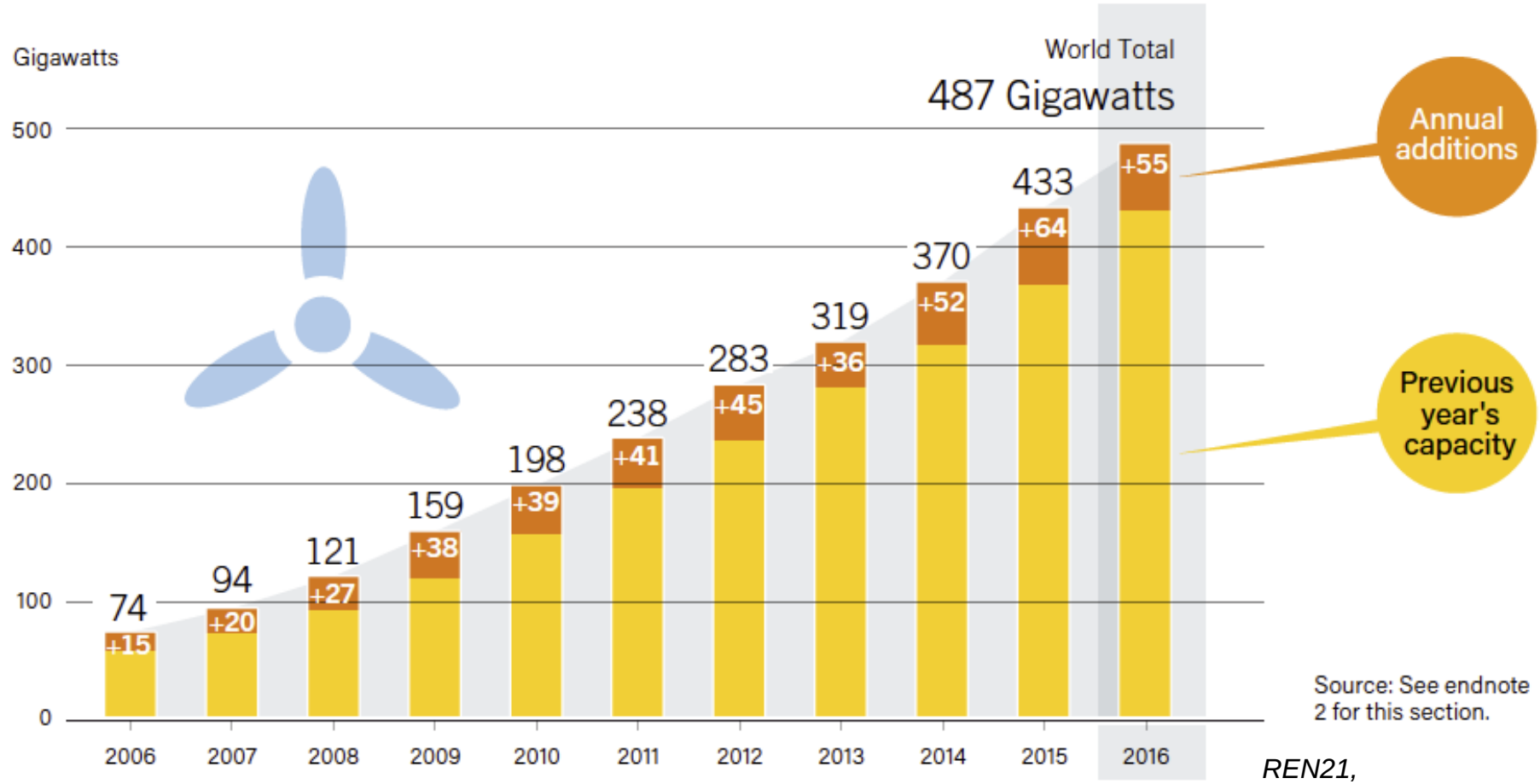


* CSP, geothermal, small-scale hydropower and ocean energy

Source: BNEF.

Global wind power grew 7 folds 2006-2016

Figure 26. Wind Power Global Capacity and Annual Additions, 2006-2016

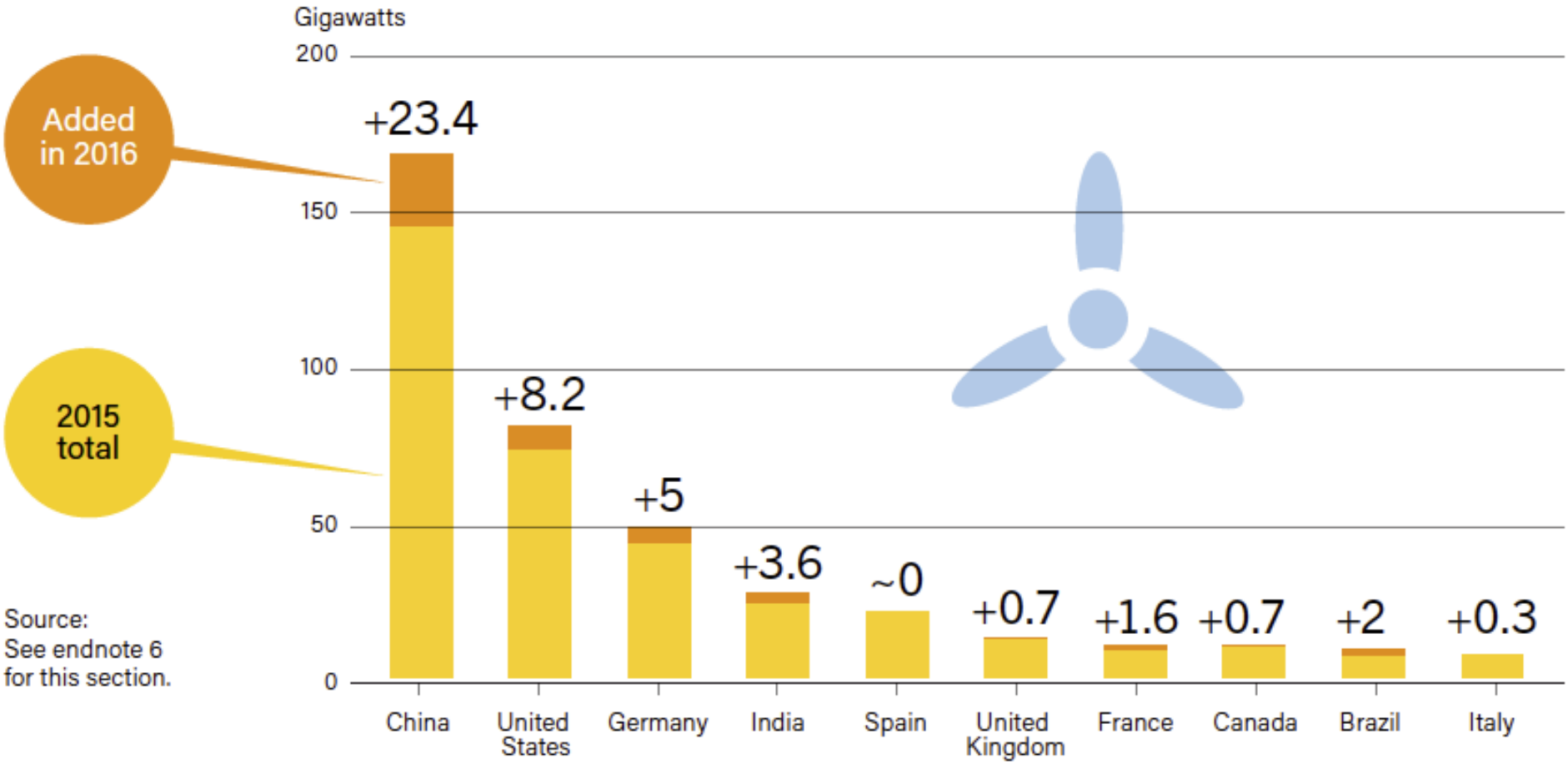


Source: See endnote 2 for this section.

REN21, Renewable 2017

Global wind top 10

Figure 27. Wind Power Capacity and Additions, Top 10 Countries, 2016

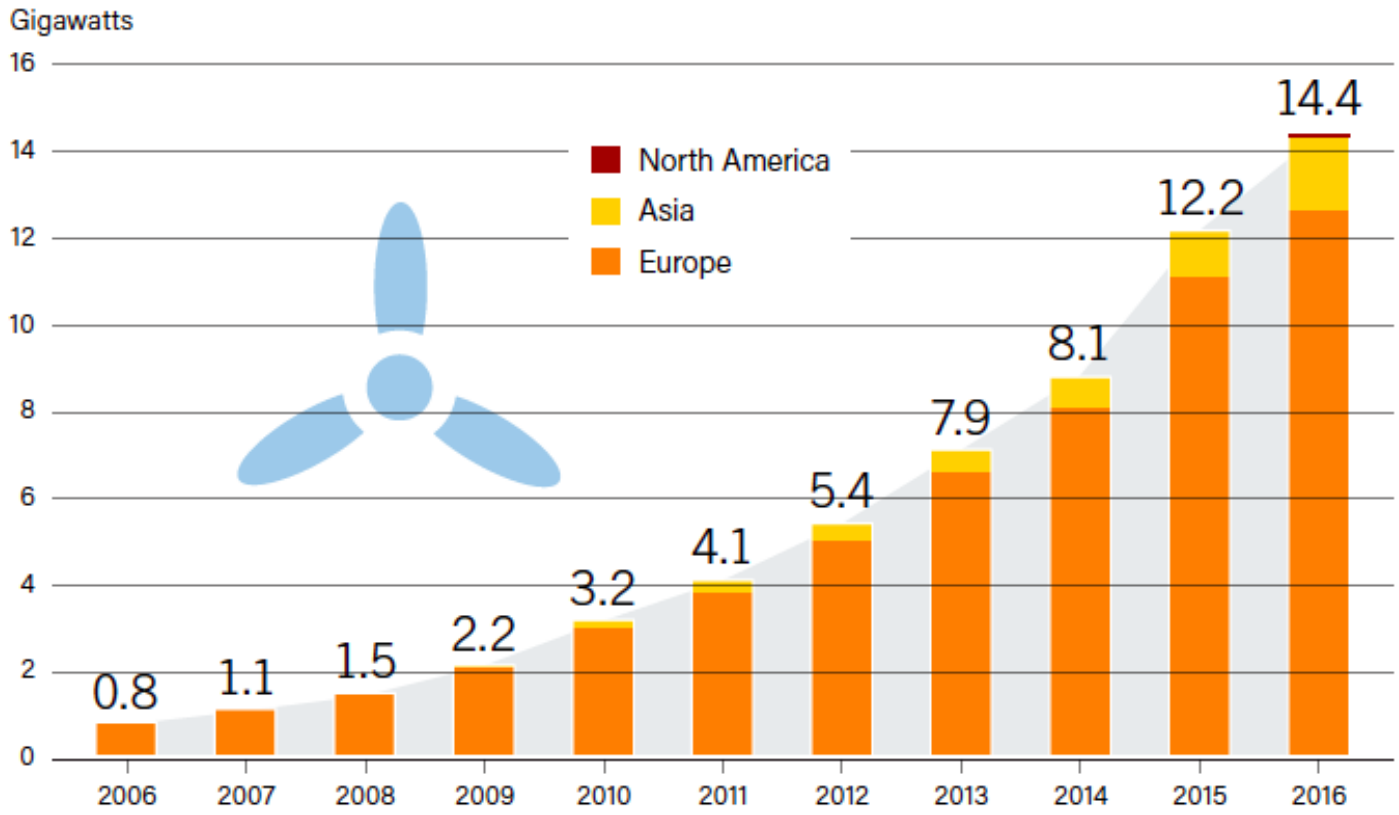


Source:
See endnote 6 for this section.

Note: Germany's additions are net of decommissioning and repowering. "~0" denotes capacity additions of less than 50 MW.

Offshore wind growing rapidly in EU

Figure 28. Wind Power Offshore Global Capacity, by Region, 2006-2016

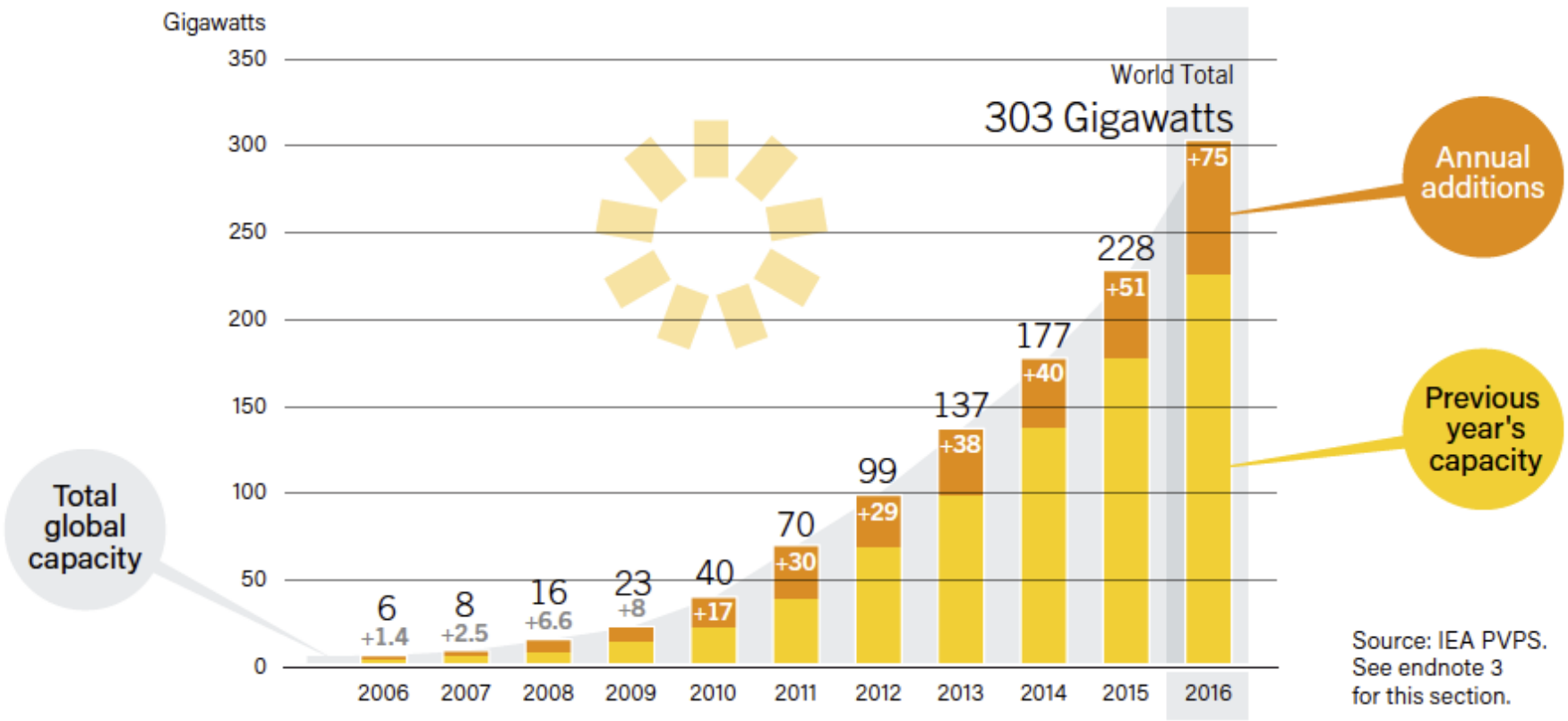


Source: See endnote 66 fo
this section.

UK 2017: 57.5 pound/MWh vs 92.5/MWh for nuclear

Global Solar 2006-2016: grew 50 times

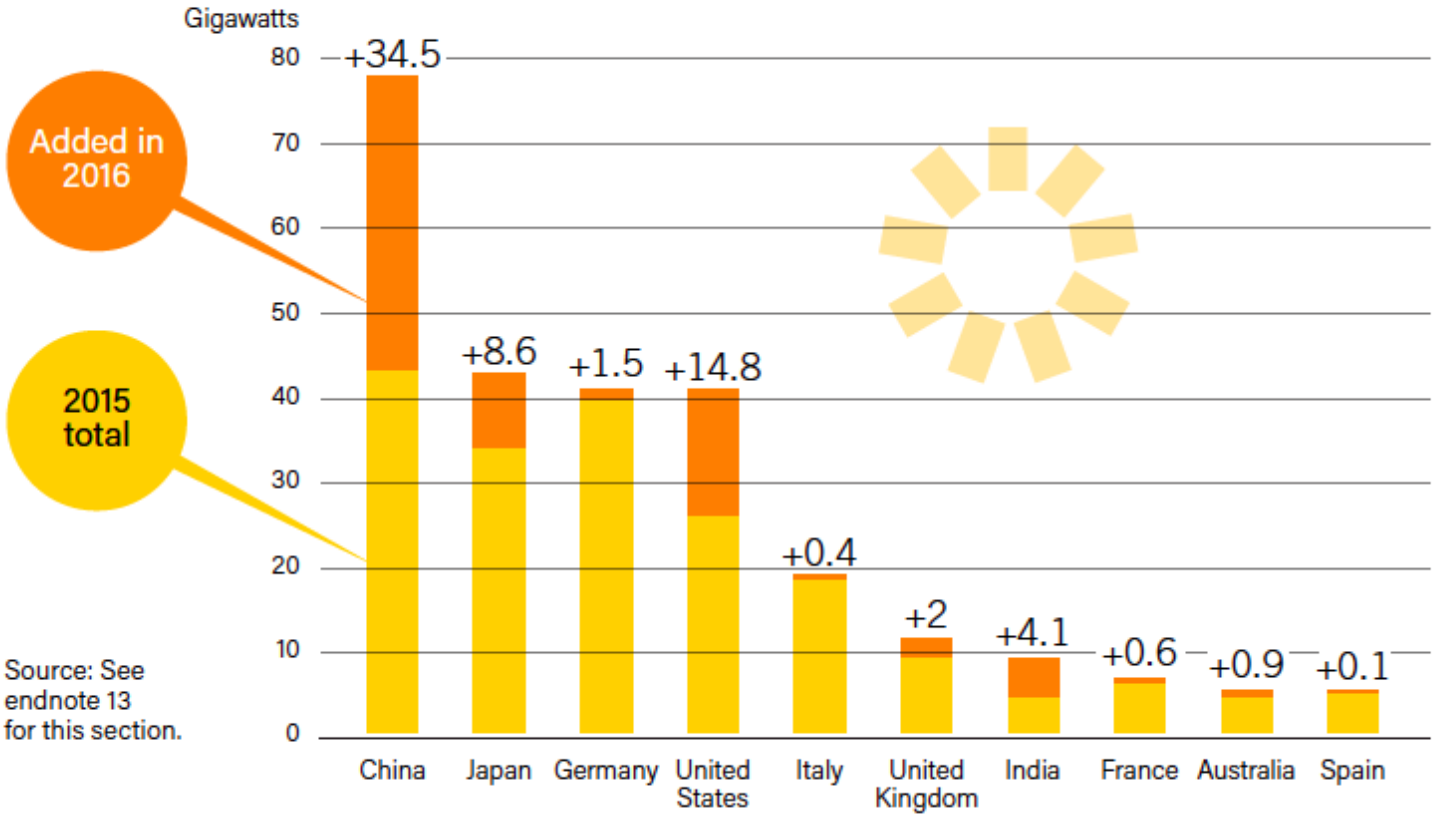
Figure 15. Solar PV Global Capacity and Annual Additions, 2006-2016



Source: IEA PVPS. See endnote 3 for this section.

Global Top 10 solar: total capacity

Figure 17. Solar PV Capacity and Additions, Top 10 Countries, 2016

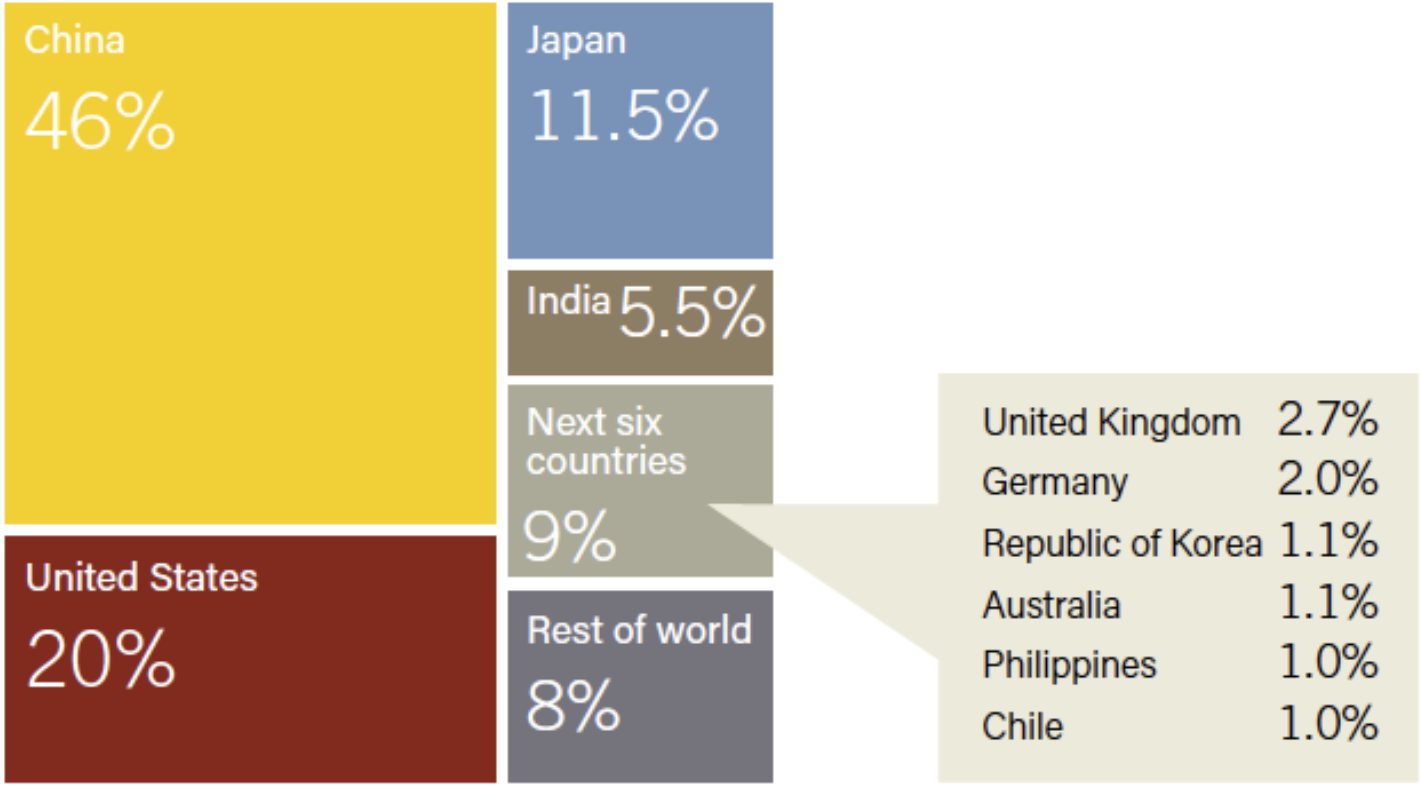


Source: See endnote 13 for this section.

CHINA ACCOUNTED FOR **46%** OF NEW CAPACITY.

Global Top 10 solar: new additions

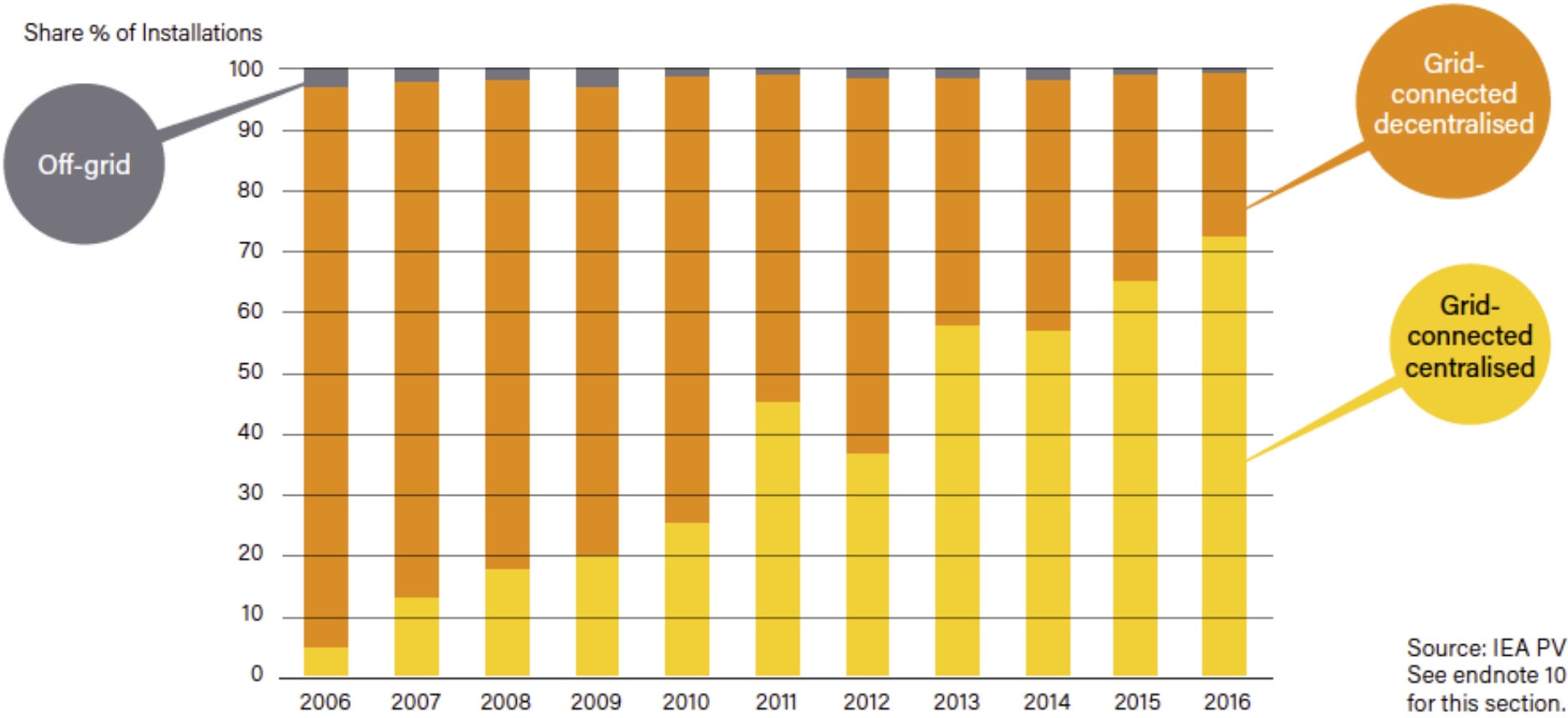
Figure 18. Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2016



Source: See endnote 86 for this section.

Central, DG, and Off-grid solar

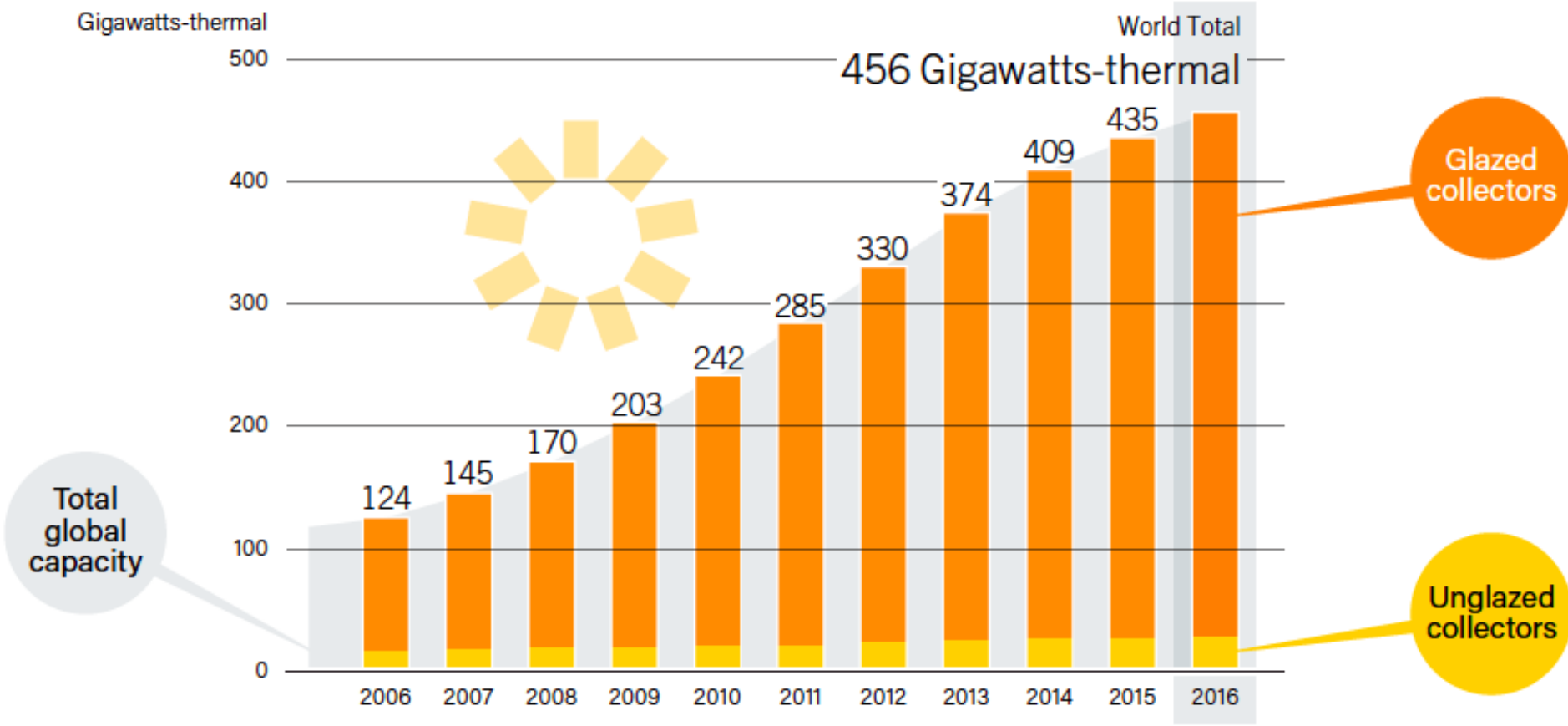
Figure 19. Solar PV Global Additions, Shares of Grid-Connected and Off-Grid Installations, 2006-2016



Source: IEA PV
See endnote 10
for this section.

Solar thermal heating and cooling

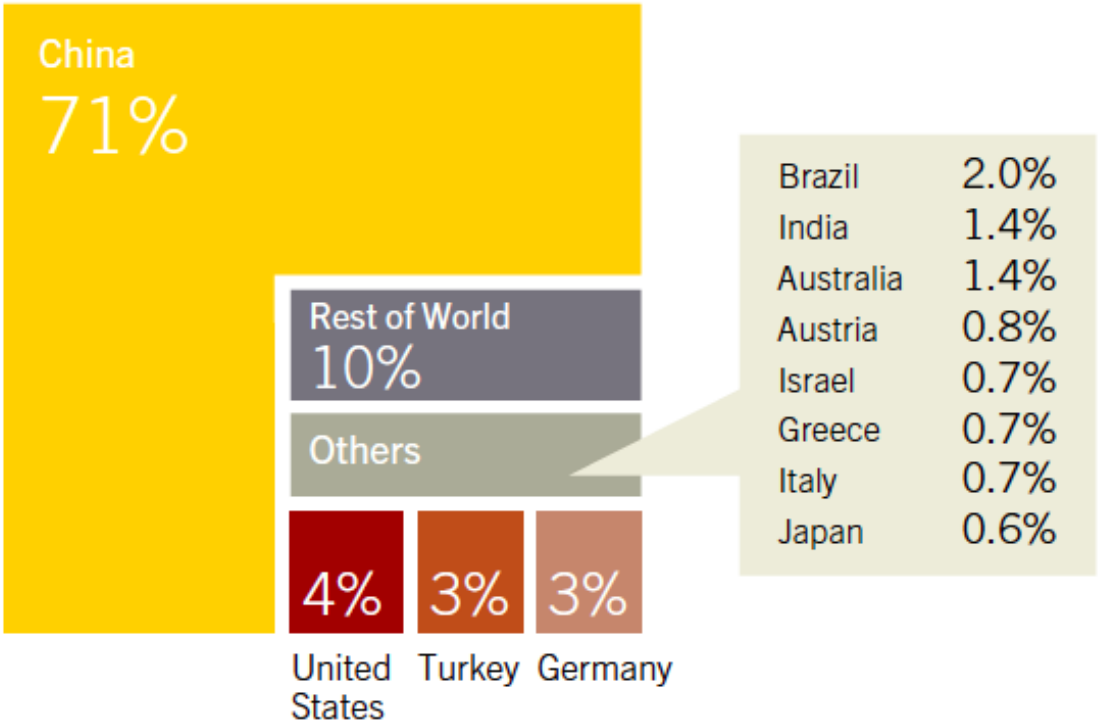
Figure 22. Solar Water Heating Collectors Global Capacity, 2006-2016

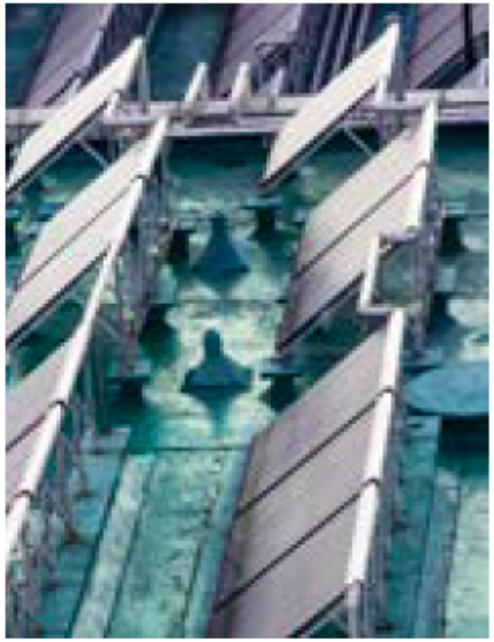


Source: IEA SHC. See endnote 2 for this section.

Solar Water Heating

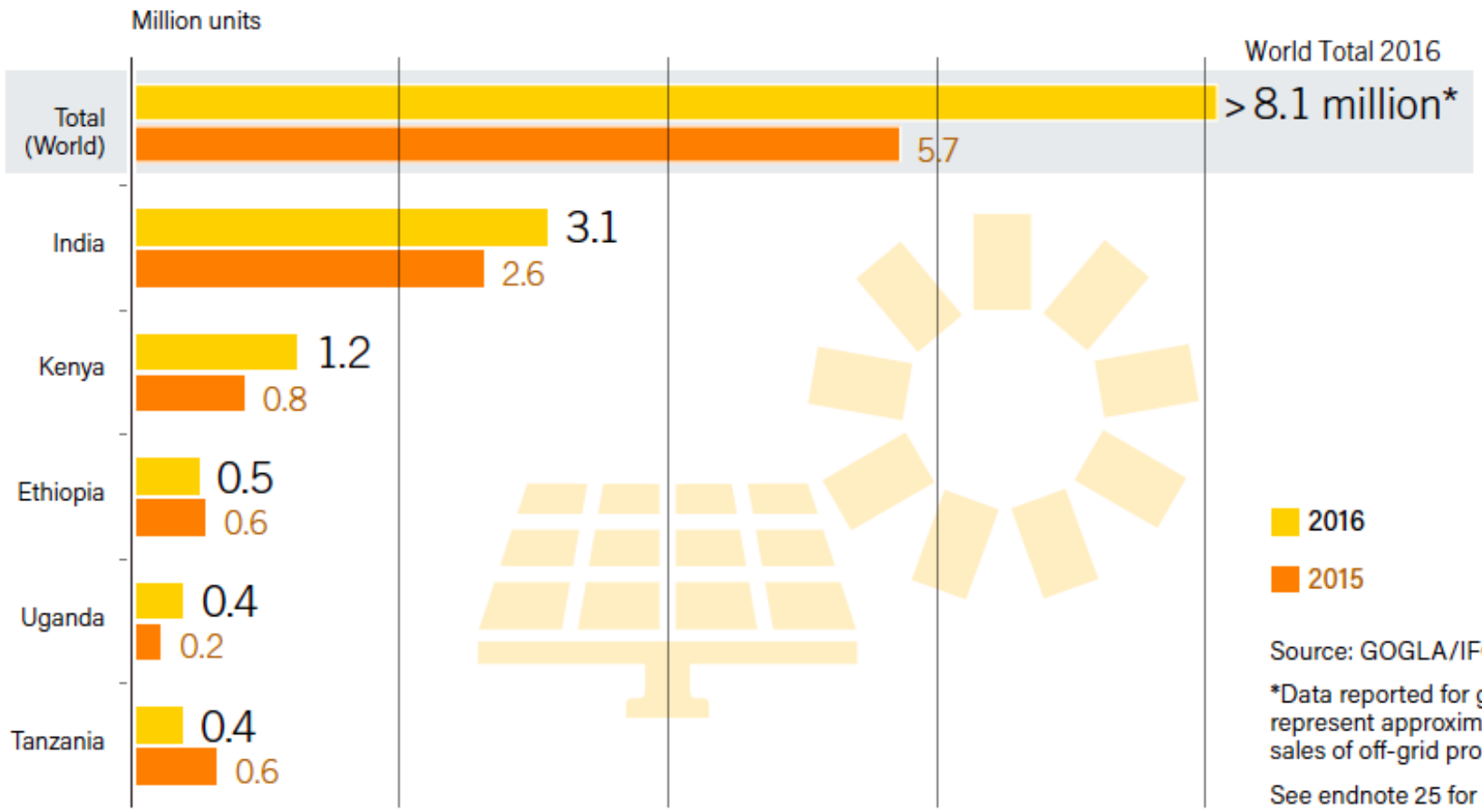
Figure 23. Solar Water Heating Collectors Global Capacity in Operation, Shares of Top 12 Countries and Rest of World, 2015





Off-grid solar systems

Figure 33. Sales of Off-Grid Solar Systems in Top 5 Countries, 2015-2016



Source: GOGLA/IFC.

*Data reported for global sales represent approximately 50% of all sales of off-grid products.

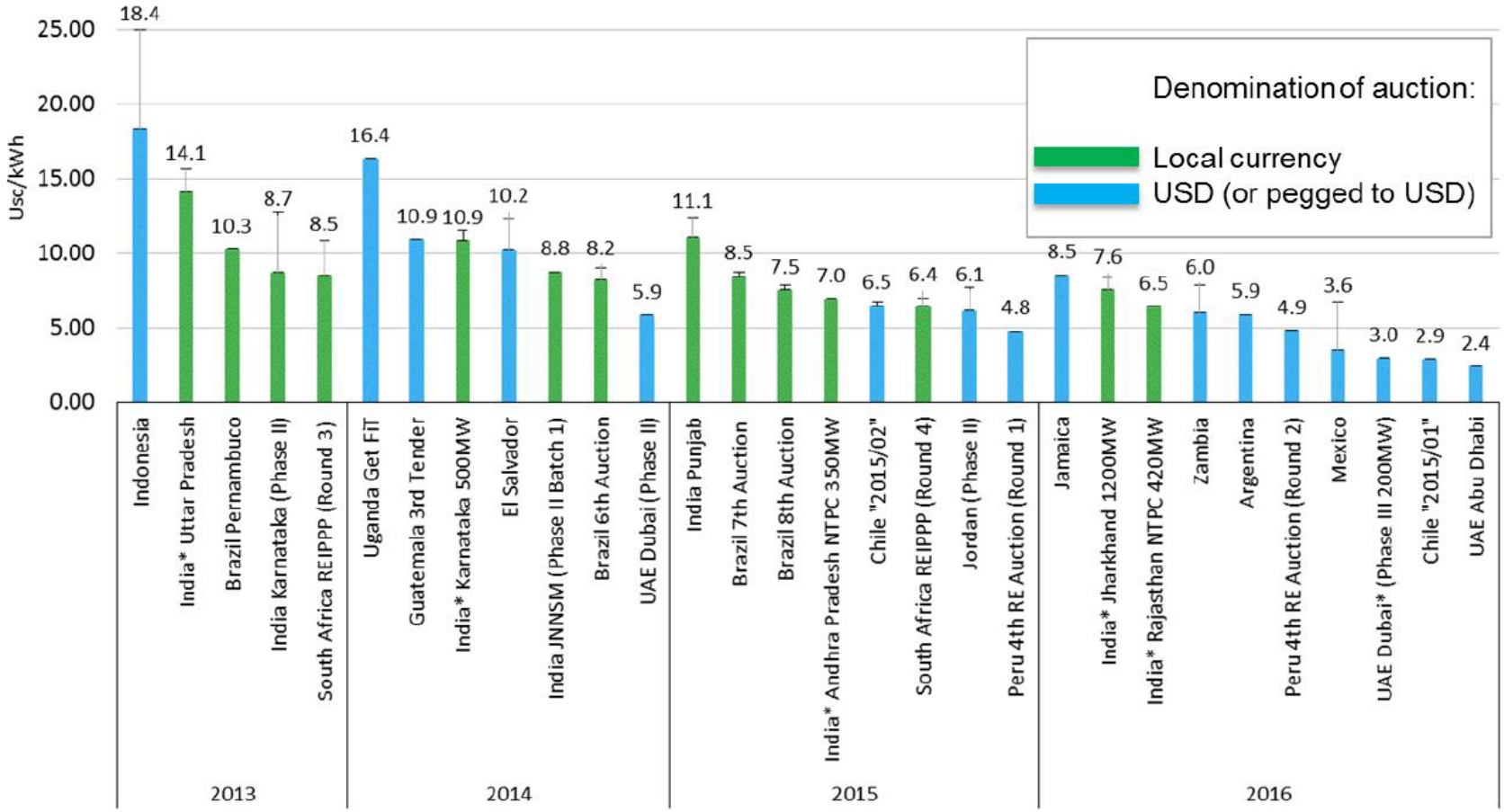
See endnote 25 for this chapter.

Multiple Deployment Drivers

- **Falling costs and improving performance**
- **Policy intervention at national and state levels**
- Business and financing innovations
  - third party ownership
  - private loans, PACE, etc.
  - shared / community solar

Solar PV is on track to become the cheapest resource

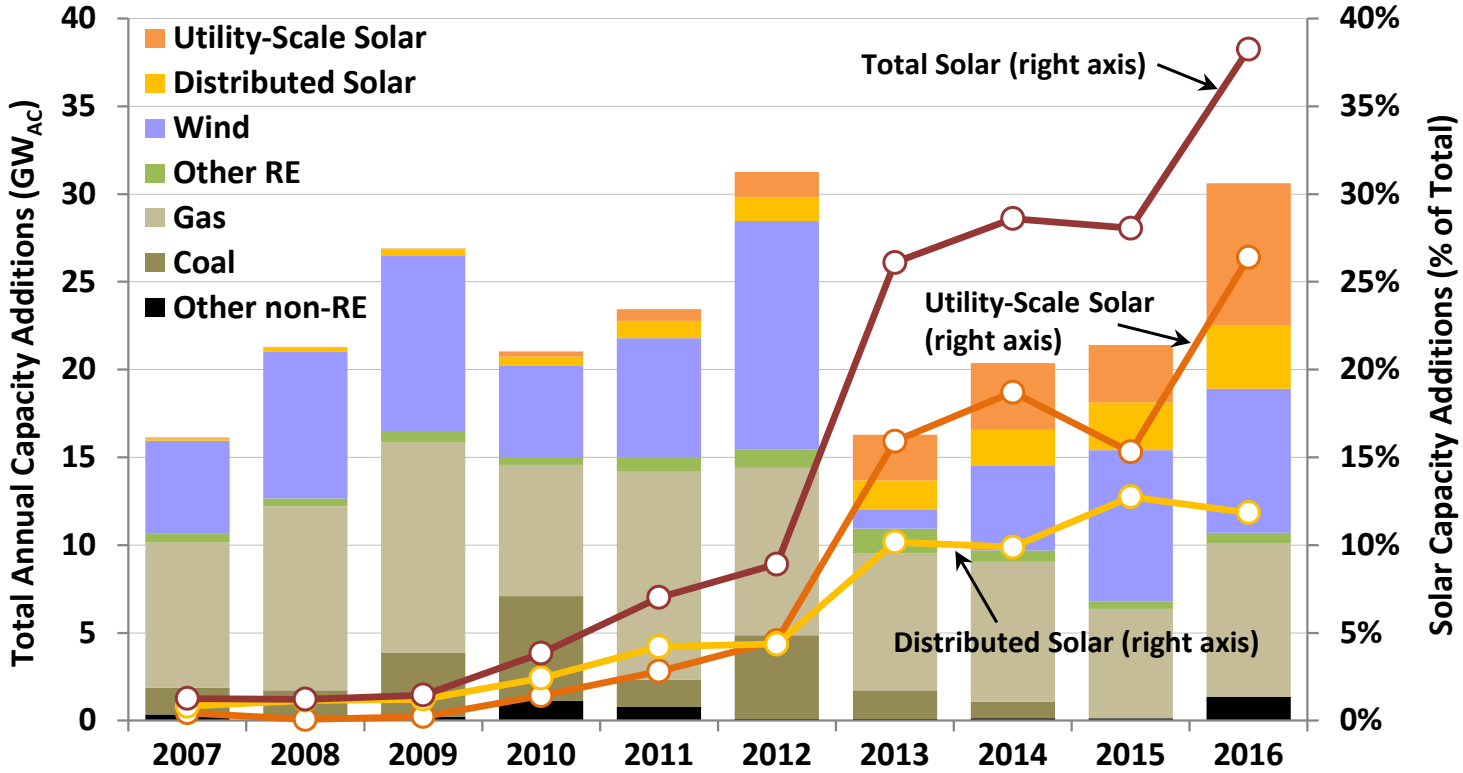
Figure 2: Results of major auctions in developing countries from 2013–2016 in nominal prices by year of announcement



Note: The lowest winning bid in each auction is shown. Bars above the lowest winning bid represent ranges of all winning bids in every auction in cases when there were several winners. Prices in Argentina, Brazil, Chile, Jamaica, Mexico, Peru and South Africa are indexed. *For India only the auctions with the highest and the lowest winning bid per year are shown (due to too many auctions being organized in India).

Source: World Bank

Solar power was the largest source of U.S. electric-generating capacity additions in 2016



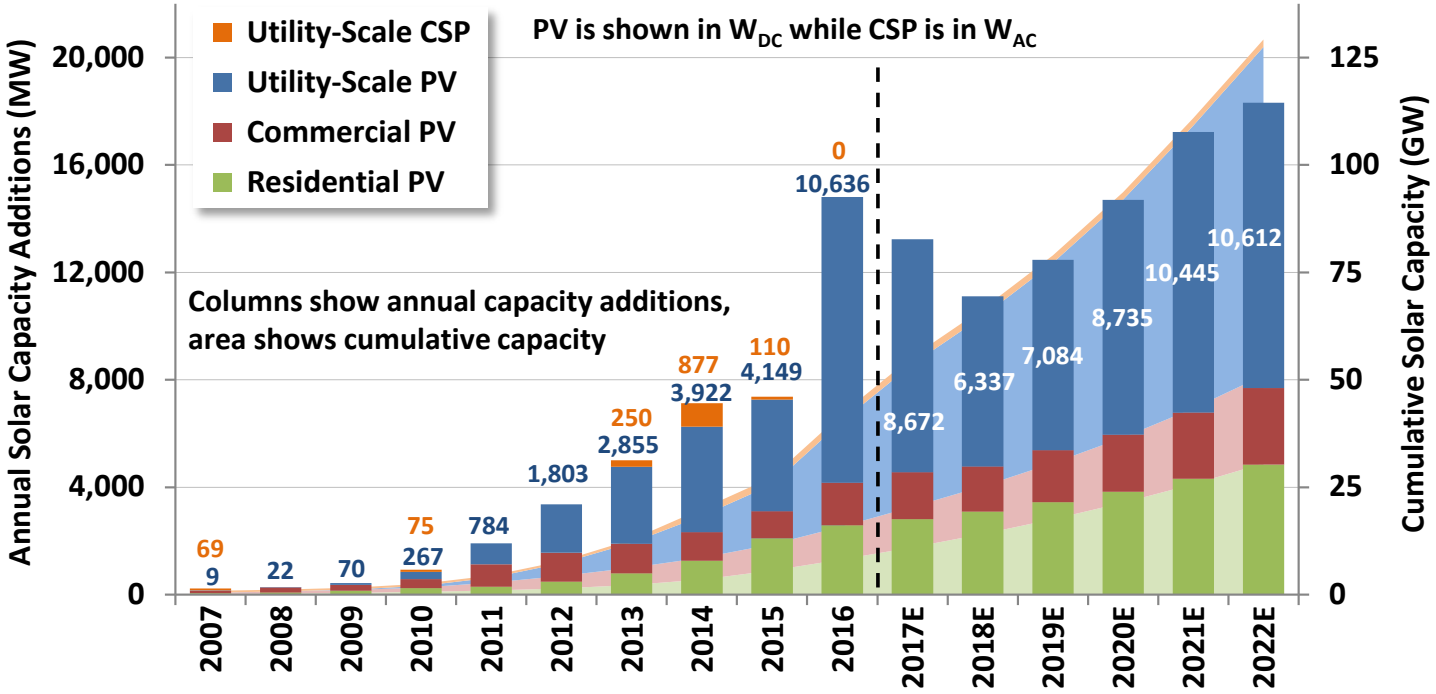
Sources: *ABB, AWEA, GTM/SEIA Solar Market Insight Reports, Berkeley Lab*

Note: This graph follows GTM/SEIA's split between distributed and utility-scale solar, rather than our 5 MW$_{AC}$ threshold

- Led by the utility-scale sector, solar power has comprised >25% of all generating capacity additions in the United States in each of the past four years
- In 2016, solar made up 38% of all U.S. capacity additions (with utility-scale accounting for 26%), and was the largest source of new capacity, ahead of both natural gas and wind

Utility-scale projects have the greatest capacity share in the U. S. solar market

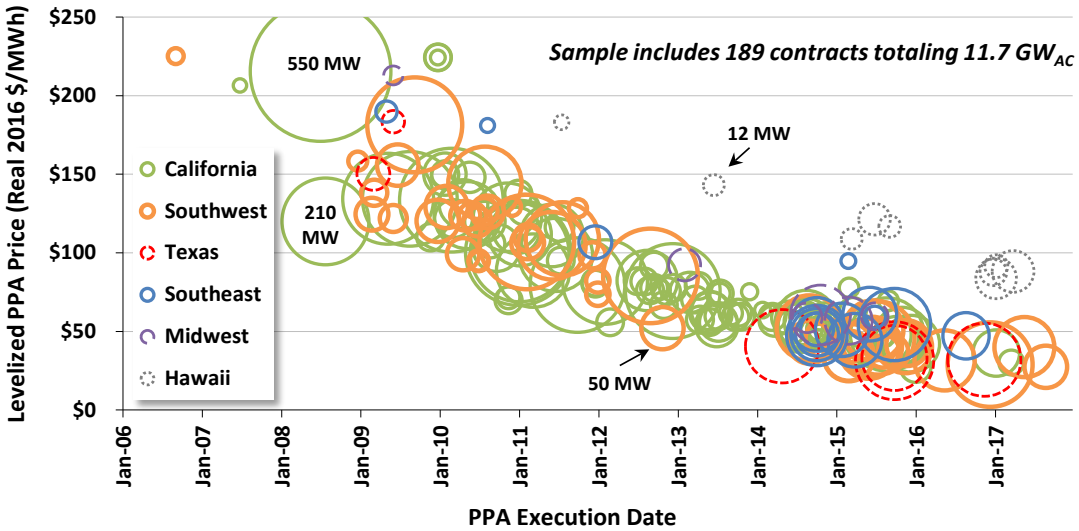
- The utility-scale sector accounted for 72% of all new solar capacity added in 2016 and 61% of cumulative solar capacity at the end of 2016

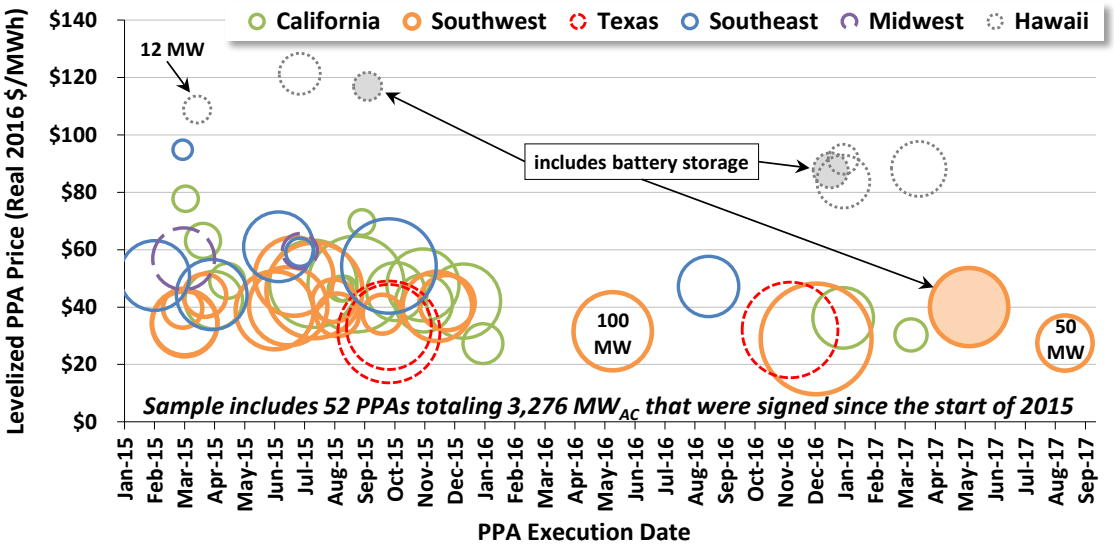


Sources: *GTM/SEIA Solar Market Insight Reports, Berkeley Lab*

We define "utility-scale" as **any ground-mounted project that is larger than 5 MW_{AC}**
Smaller systems are analyzed in LBNL's *"Tracking the Sun"* series (trackingthesun.lbl.gov)

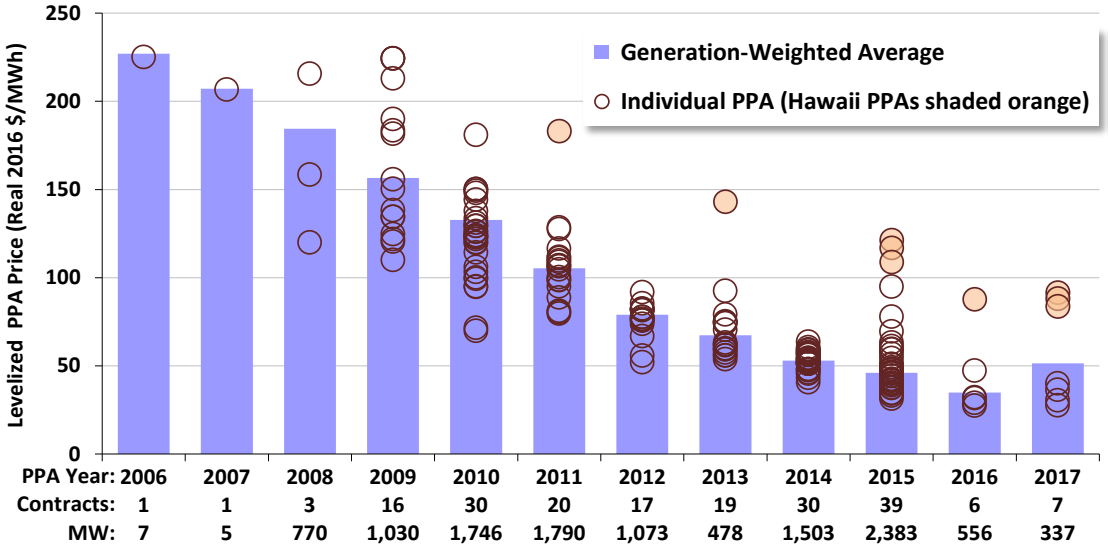
Combination of falling installed prices and better project performance enables lower PPA prices

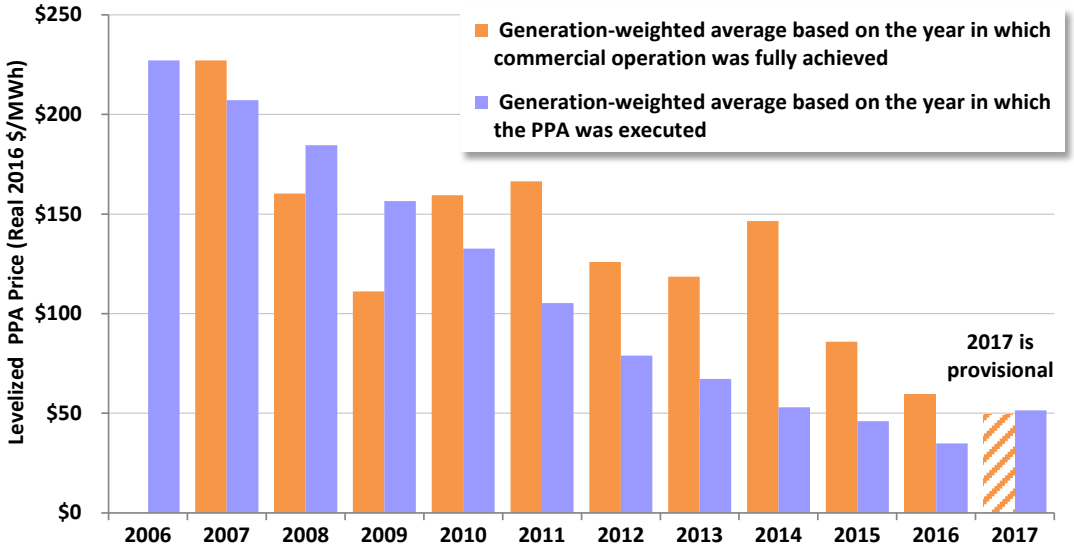




- PPA prices are levelized over the full term of each contract, after accounting for any escalation rates and/or time-of-delivery factors, and are shown in real 2016 dollars
- Top graph shows the full sample; bottom graph shows a sub-sample of PPAs signed post-2014
- CA and the Southwest dominate the sample, but in recent years the market has expanded to other regions
- Hawaii projects (included here for the first time) show a consistent and significant premium over the mainland
- Three PPAs featuring PV plus long-duration battery storage do not seem to be priced at a prohibitive premium to their PV-only counterparts
- Smaller projects (e.g., 20-50 MW) are seemingly no less competitive
- >90% of the sample is currently operational

On average, levelized PPA prices fell by >75% from 2009 through 2016

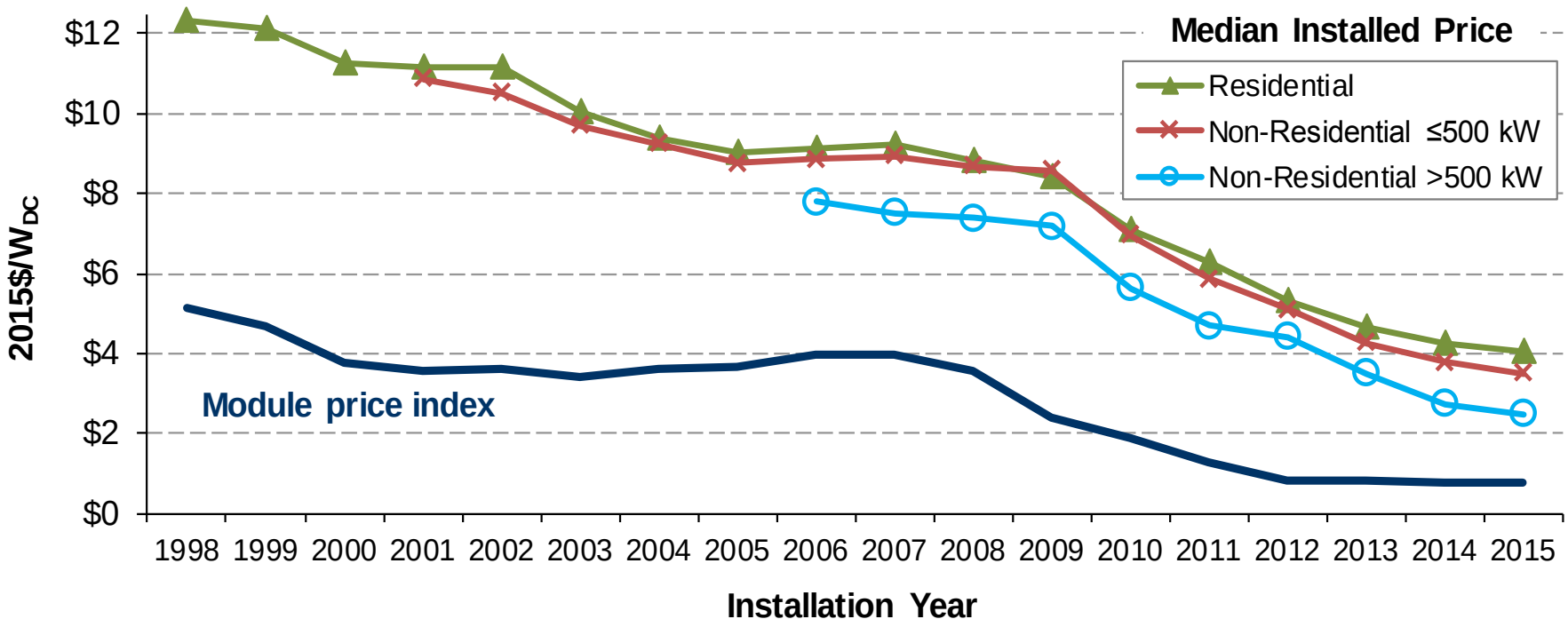




- Top figure presents the same data as previous slide, but in a different way: each circle is an individual contract, and the blue columns show the average levelized PPA price each year
- Steady downward trend in the average PPA price over time has slowed in recent years as average prices approached and then fell below $50/MWh
- Price decline over time is more erratic when viewed by COD (orange bars in bottom graph) rather than by PPA execution date (blue bars)
- Though the average levelized price of PPAs signed in 2016 is ~$35/MWh, the average levelized PPA price among projects that came online in 2016 is significantly higher, at ~$60/MWh
- 2017 is provisional and currently reflects a very small sample and a high proportion of high-priced Hawaiian PPAs, plus several PPAs with long-duration battery storage

Prices for Distributed Solar Continue to Decline

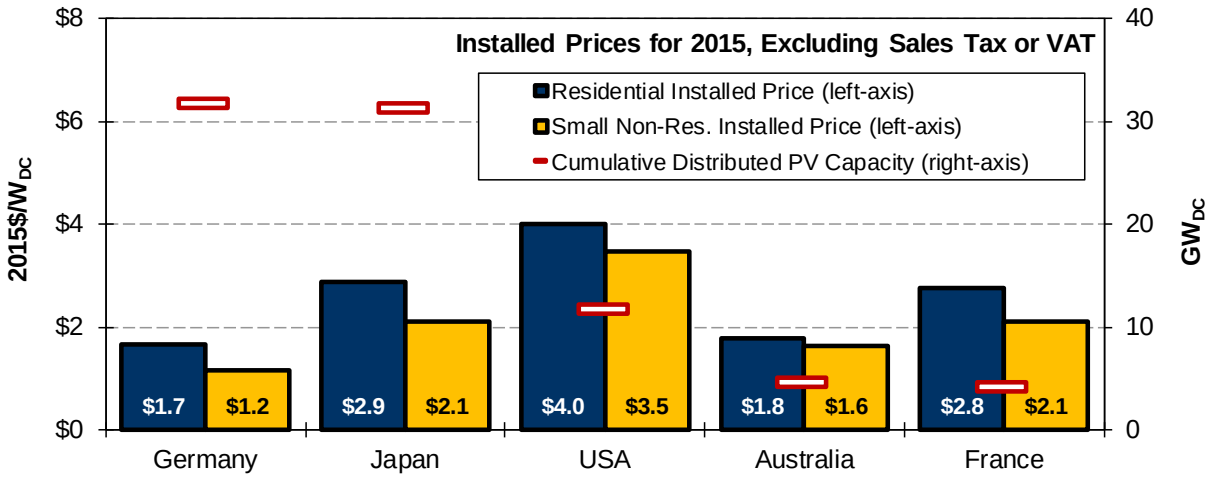
Average annual decline since 2009: **11%** per year (res.) to **16%** (large non-res). **From 2014-15: 5%** per year (res.) to **9%** (large non-res.)



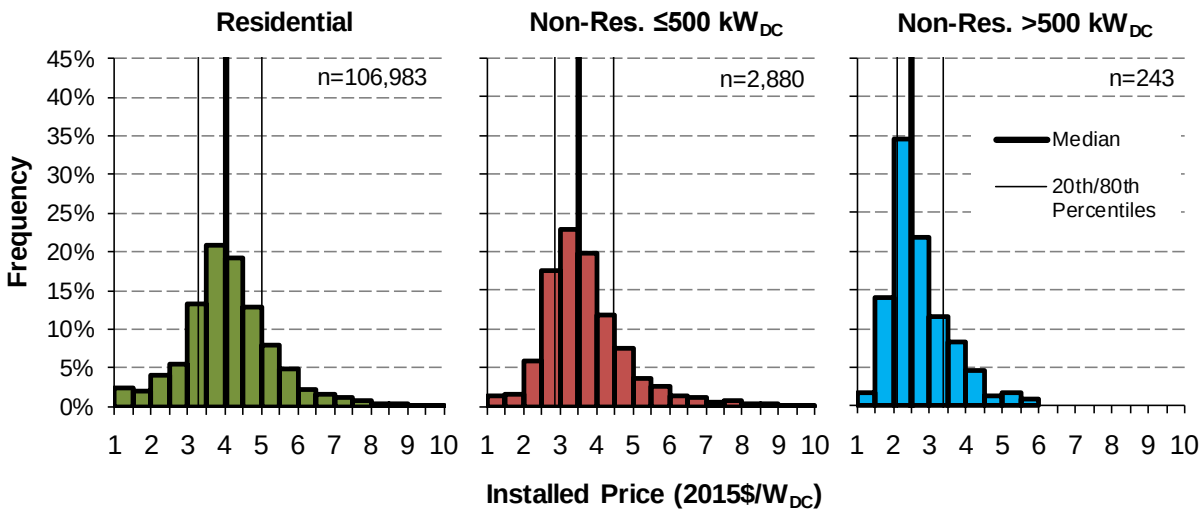
Median installed price series is based on data from 451,693 systems, assembled by Berkeley Lab (trackingthesun.lbl.gov). Module price index is from SPV Market Research.

Even Lower-Cost Systems Are Commonplace: potential for further price declines

Comparison of 2015 PV System Prices across Countries

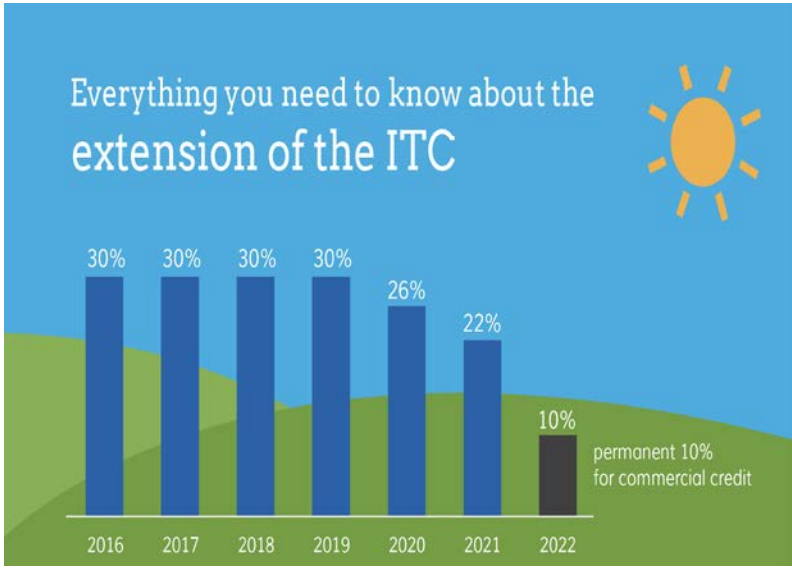


Installed Price Distributions for U.S. Systems in 2015



Federal Policy Drivers:

- 30% investment tax credit (ITC)
  - Extended to 2021 (for projects started)
  - Drops to 10% for commercial entities, phased out for residential customers

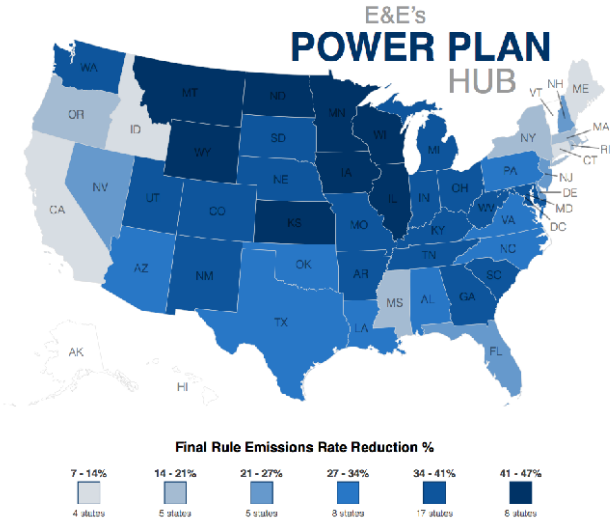


Source: http://news.energysage.com/congress-extends-the-solar-tax-credit/

- Accelerated tax depreciation
  - 5-year term
- Clean Power Plan
  - Potential impacts after 2020
  - Fate and impact highly uncertain

EPA Carbon Reduction in Power Sector

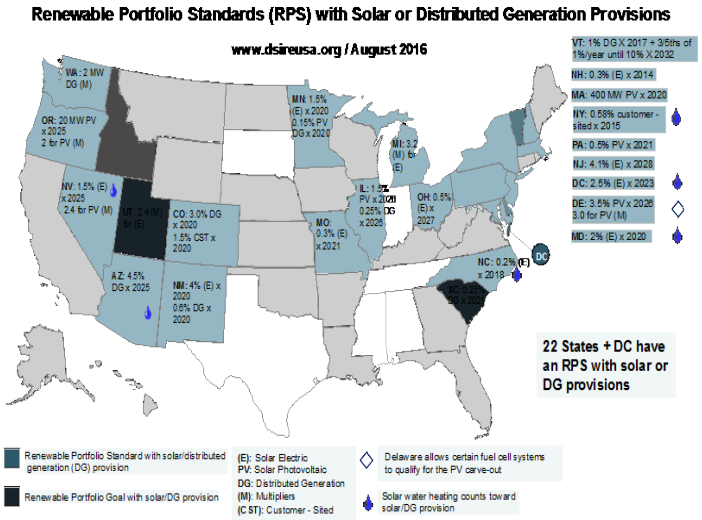
- Two components: new fossil plants, existing fossil plants
- New plants: new coal effectively precluded absent CCS
- Existing plants = Clean Power Plan (CPP), 32% reduction by 2030 relative to 2005, compliance period begins in 2022
- Many compliance options: rate- vs. mass-based, new complement, EGU vs. state measures, regional collaboration, set-asides, early incentive program→ decisions to be made at state level
- How will RE contribute? Who knows???
  - Depends on decisions, including states & obligated entities
  - EPA estimate: growth from 13% today to 20% by 2030
  - Supports growth consistent with past: deployment "floor"



State Policy Drivers

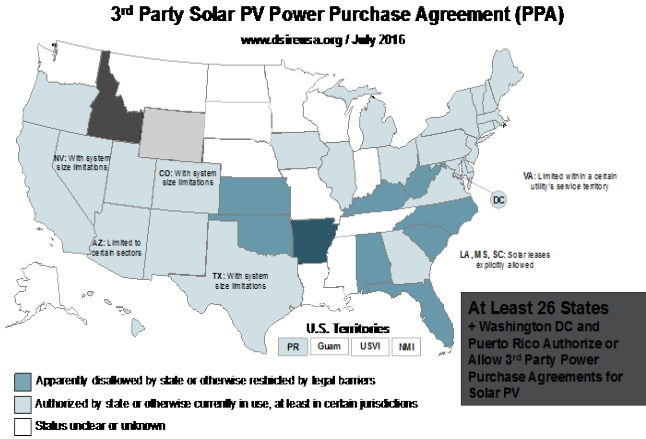
- Renewables Portfolio Standards
  - 22 States + DC have an RPS with solar or DG provisions

- Net Metering and Favorable Rates
  - 41 states and the District of Columbia require certain utilities to offer net metering to distributed solar customers as of the beginning of 2016.



- State Tax and Financial Incentives
  - State tax credits
  - State sales/property tax incentives
  - Up-front cash rebates
  - Performance based incentives

- 3rd Party Solar PV Power Purchase Agreement (PPA)
  - At Least 26 States + DC and Puerto Rico authorize or allow 3rd Party Power Purchase Agreements for Solar PV

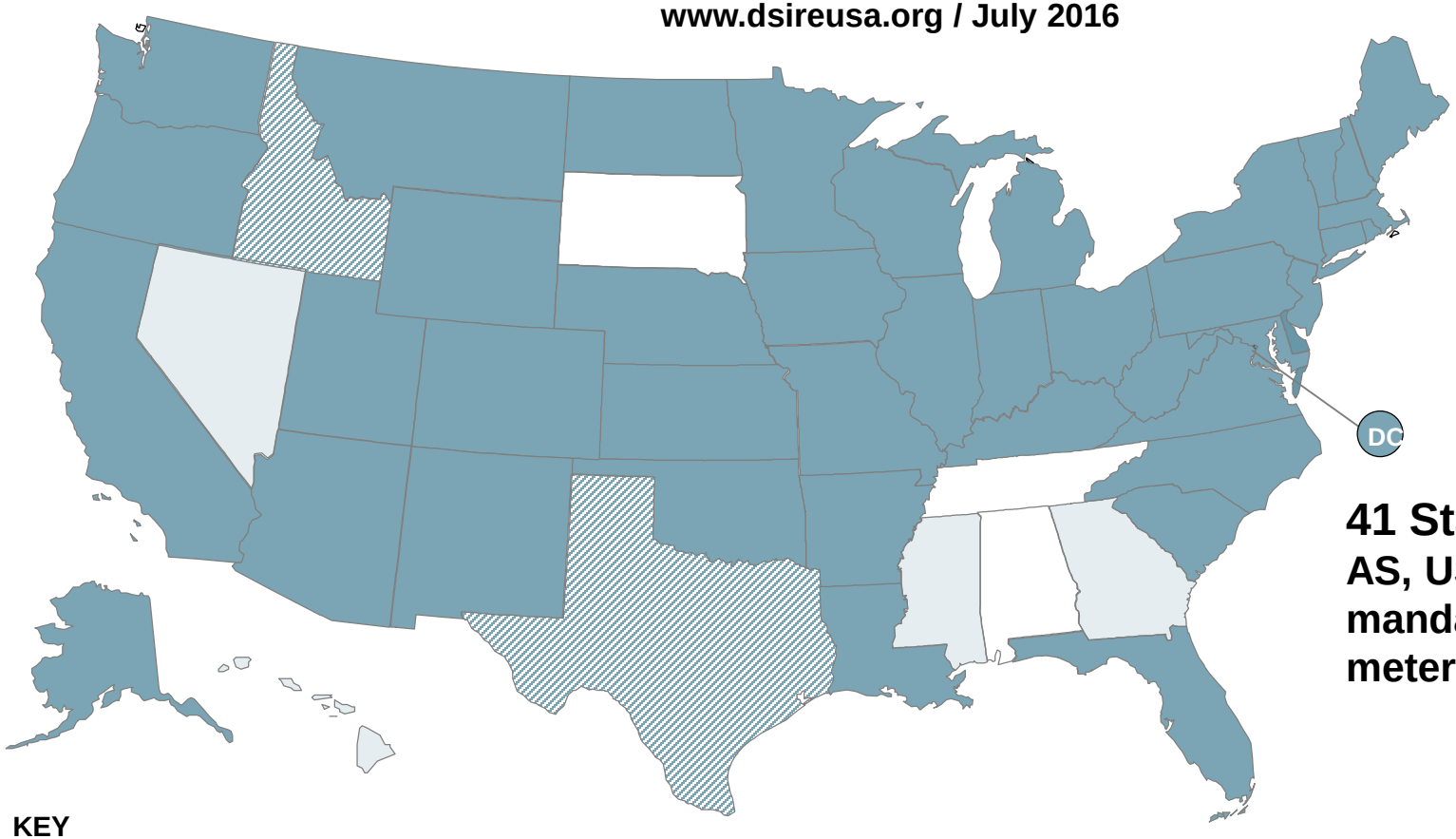


More information on solar programs and policies: http://programs.dsireusa.org/system/program/maps

Net Metering Supports Distributed PV: Designs Vary

Net Metering

www.dsireusa.org / July 2016



41 States + DC, AS, USVI, & PR have mandatory net metering rules

KEY

- State-developed mandatory rules for certain utilities (41 states + DC+ 3 territories)
- No statewide mandatory rules, but some utilities allow net metering (2 states)
- Statewide distributed generation compensation rules other than net metering (4 states + 1 territory)

U.S. Territories:

AS	PR
VI	GU

Under Net Metering, Rate Design Is Key

California has been home to among the most attractive retail rates

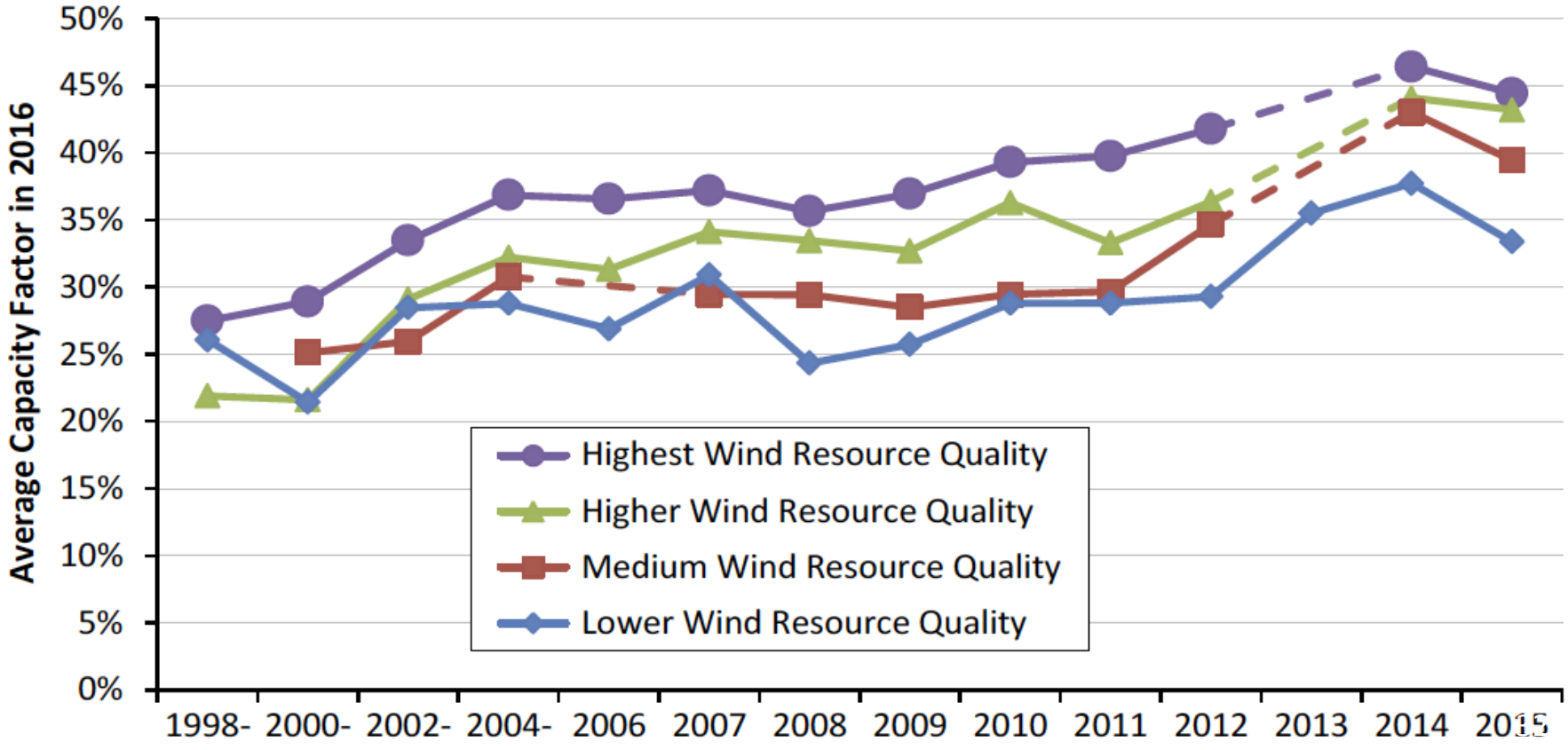
- Rate tiers that increase with usage
- Primarily volumetric rates, with low fixed charges

Rate designs that are less attractive for solar generally feature…

- Low overall retail rate levels
- Higher fixed customer or standby charges
- Demand charges tied to peak customer load

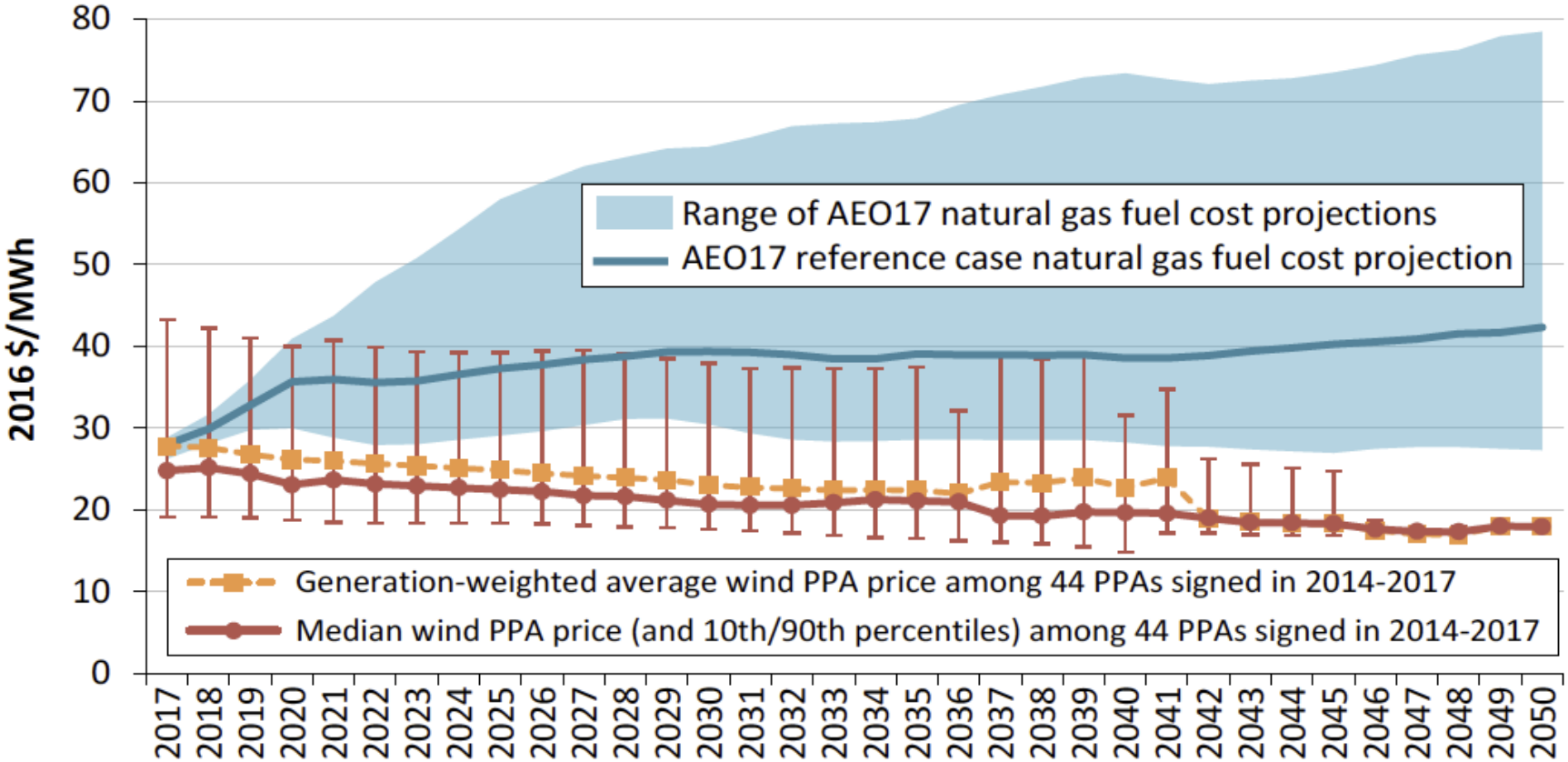
Performance Trends

Controlling for Wind Resource Quality and Commercial Operation Date Also Illustrates Impact of Turbine Evolution



Wind Power Price Trends

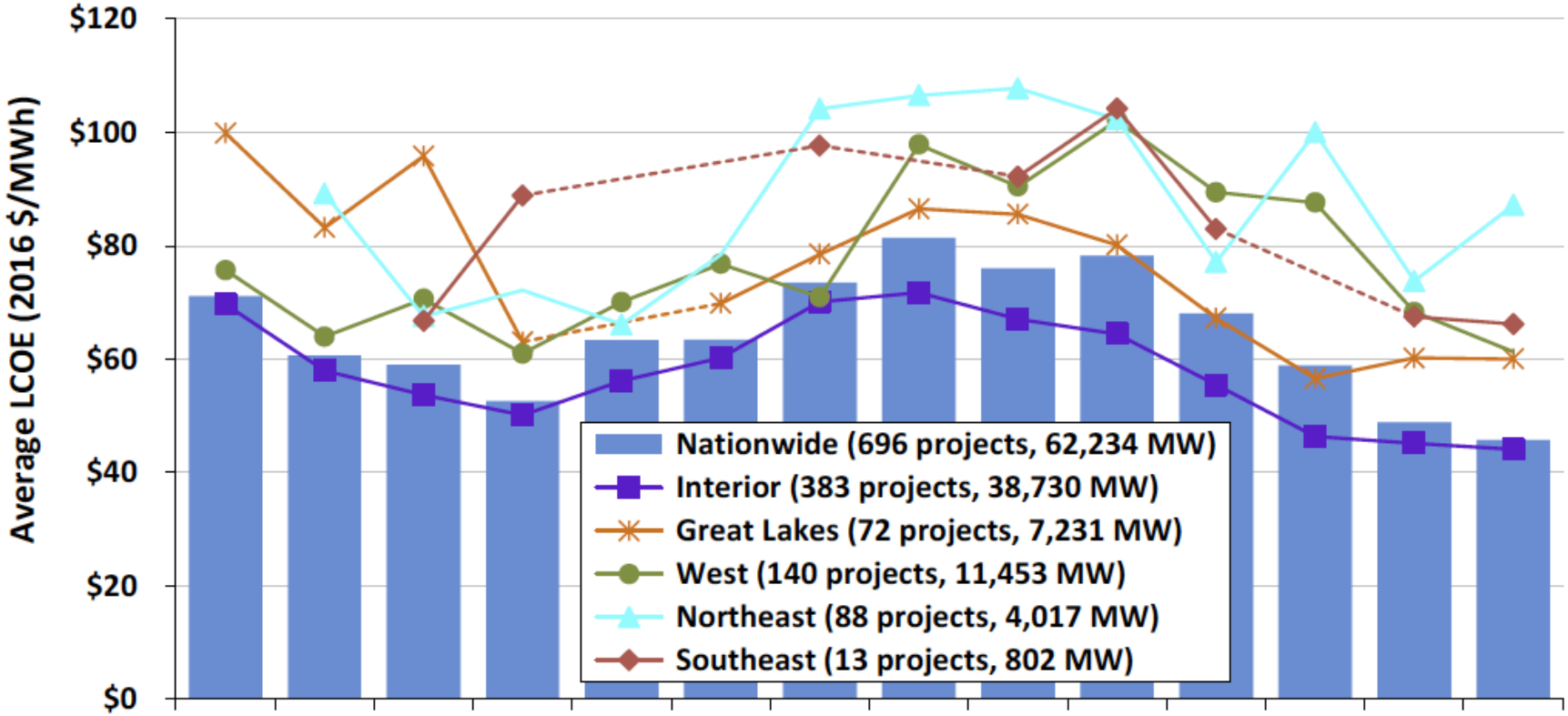
Recent Wind Prices Are Hard to Beat: Competitive with Expected Future Cost of Burning Fuel in Natural Gas Plants



- Price comparison shown here is far from perfect – ***see full report for caveats***

Wind Power Price Trends

Levelized Cost of Wind Energy Is at an All-Time Low



COD Year:	98-99	00-01	02-03	04-05	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Projects:	26	26	30	29	23	30	64	103	63	85	109	12	46	50
MW:	849	1,694	1,885	2,005	1,820	3,597	6,305	9,575	5,129	6,281	9,378	852	5,100	7,763

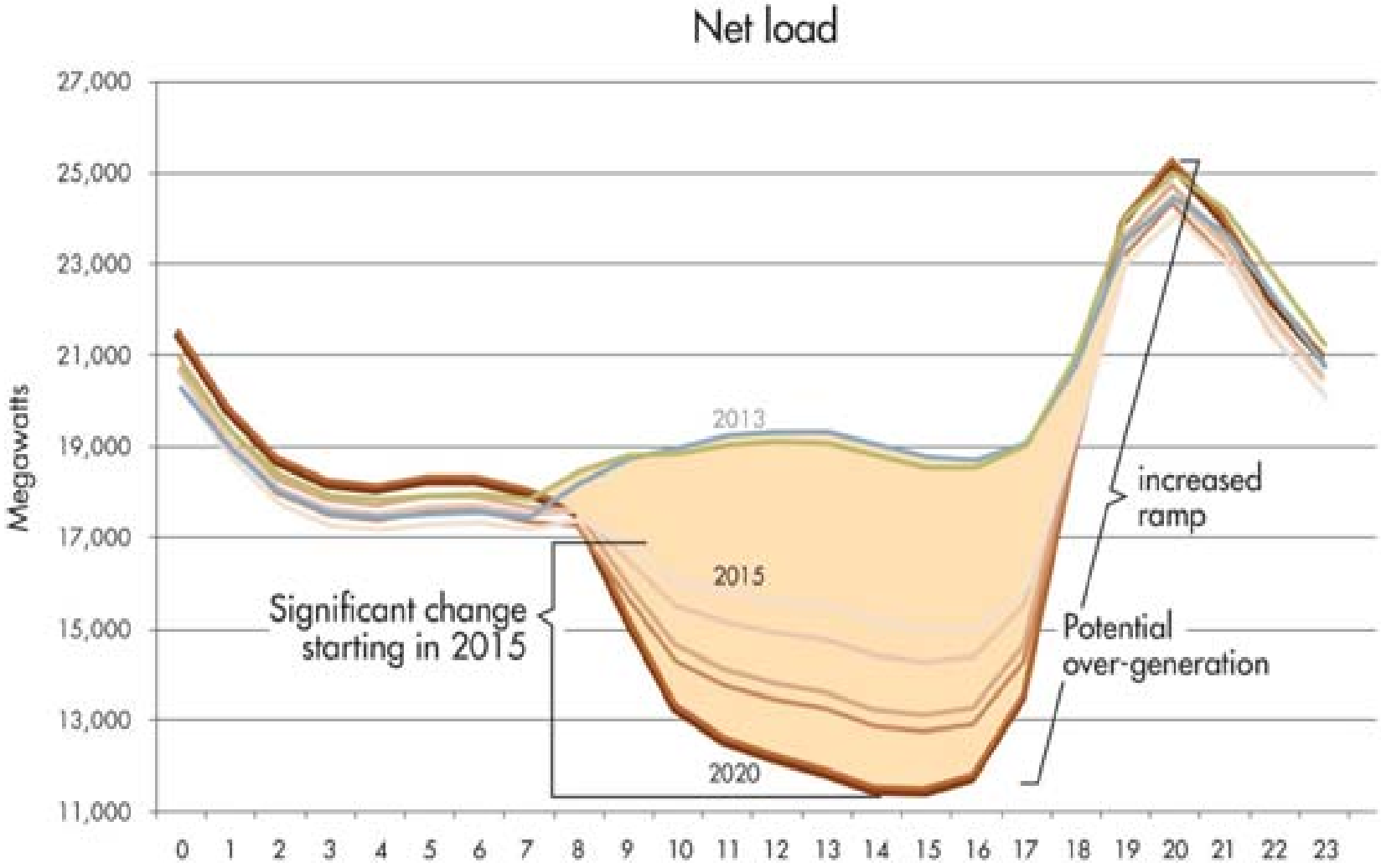
- Estimates only reflect variations in installed cost and capacity factors; include accelerated depreciation but exclude PTC

California: *the clean power frontier*

- Most ambitious goal for renewable power
  - 33% of renewables by 2020
  - 50% of renewables by 2030 (excluding hydro)
- Half of solar installation in US
- Leaders in energy efficiency in US
  - Appliance standards
  - Building codes (updated every three years)
  - "Decoupling" and strong utility efficiency programs
- Robust carbon market covering power sector

The Future: can the duck fly?

Duck Curve



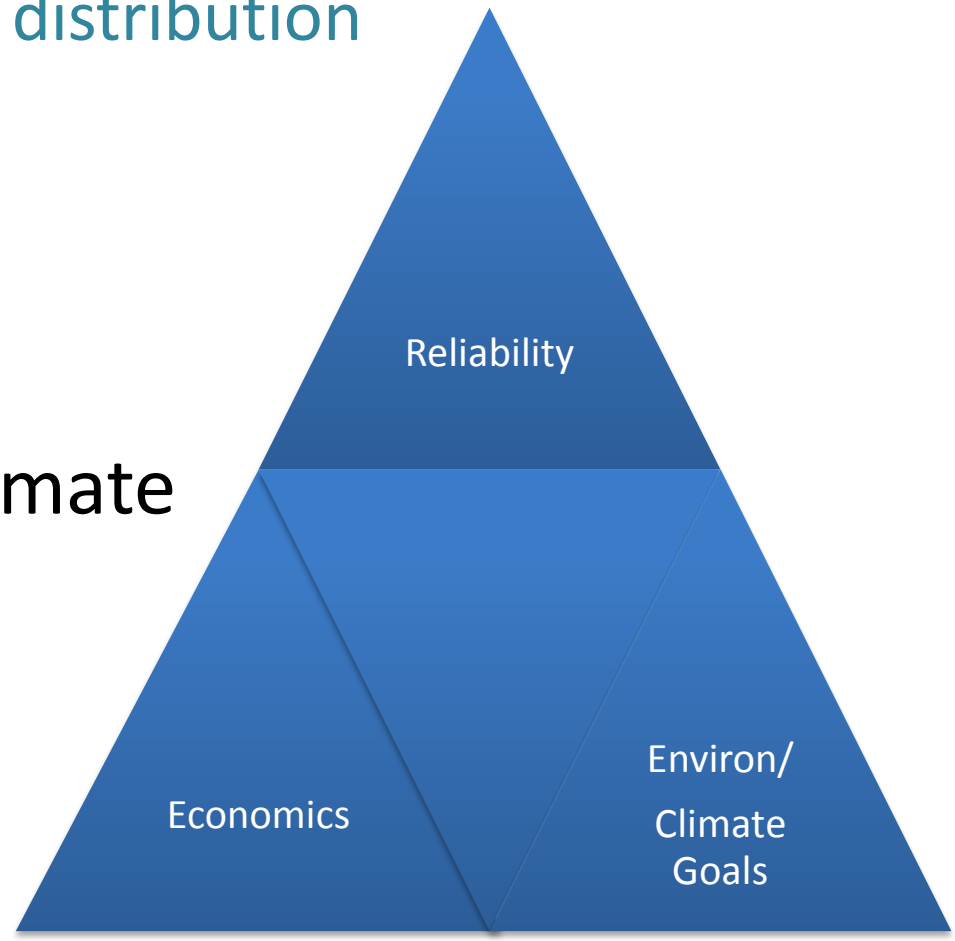
History of deregulation since 1990

- Pre-1990
  - Vertically integrated utilities
  - Cost of services regulation
- 1990 Restructuring/deregulation
  - Unbundling of generations from T&D
  - Direct access/Retail competition
  - Wholesale power markets
- Current thinking
  - ***Meeting environmental/climate targets***
  - Deregulation inactive
  - Emergence of ISO/RTO
  - Wholesale power market
  - Retail competition
  - ***Future utility model (NY REV)***

Goals of power sector reform/regulation

- Natural monopoly
  - Transmission and distribution

- Reliability
- Economics
- Environmental/Climate



History of power sector reform

- Goals
  - Reliable supply of power at least cost
- Pre-1990
  - Vertically integrated utilities
  - Cost of services regulation
- Problems
  - Overly optimistic forecast of future demand growth
  - High cost of generation
- Solutions
  - Lead to some separation of functions, ie, independent demand forecast
  - Lead to deregulation of utilities

Optimistic, or system-bias?

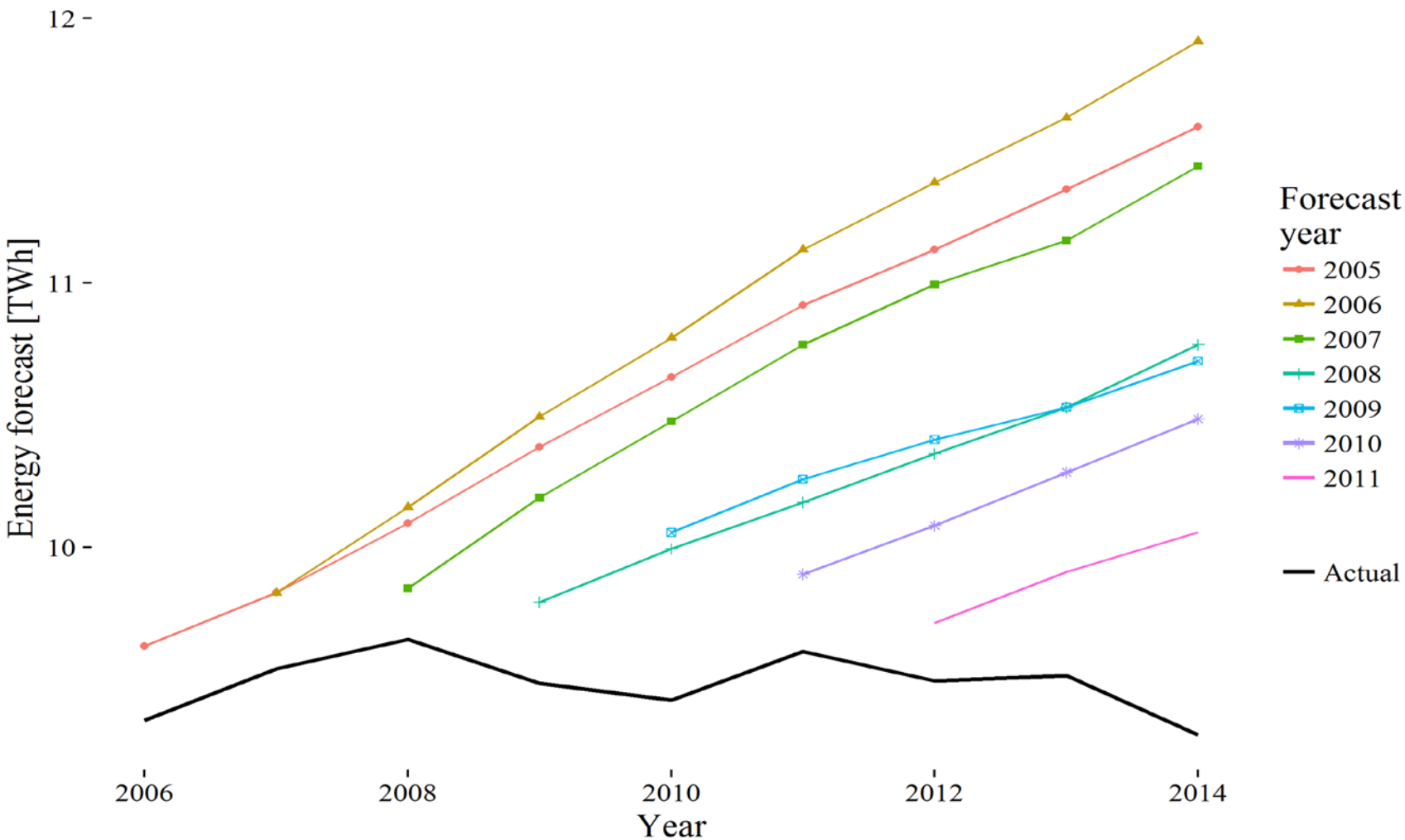
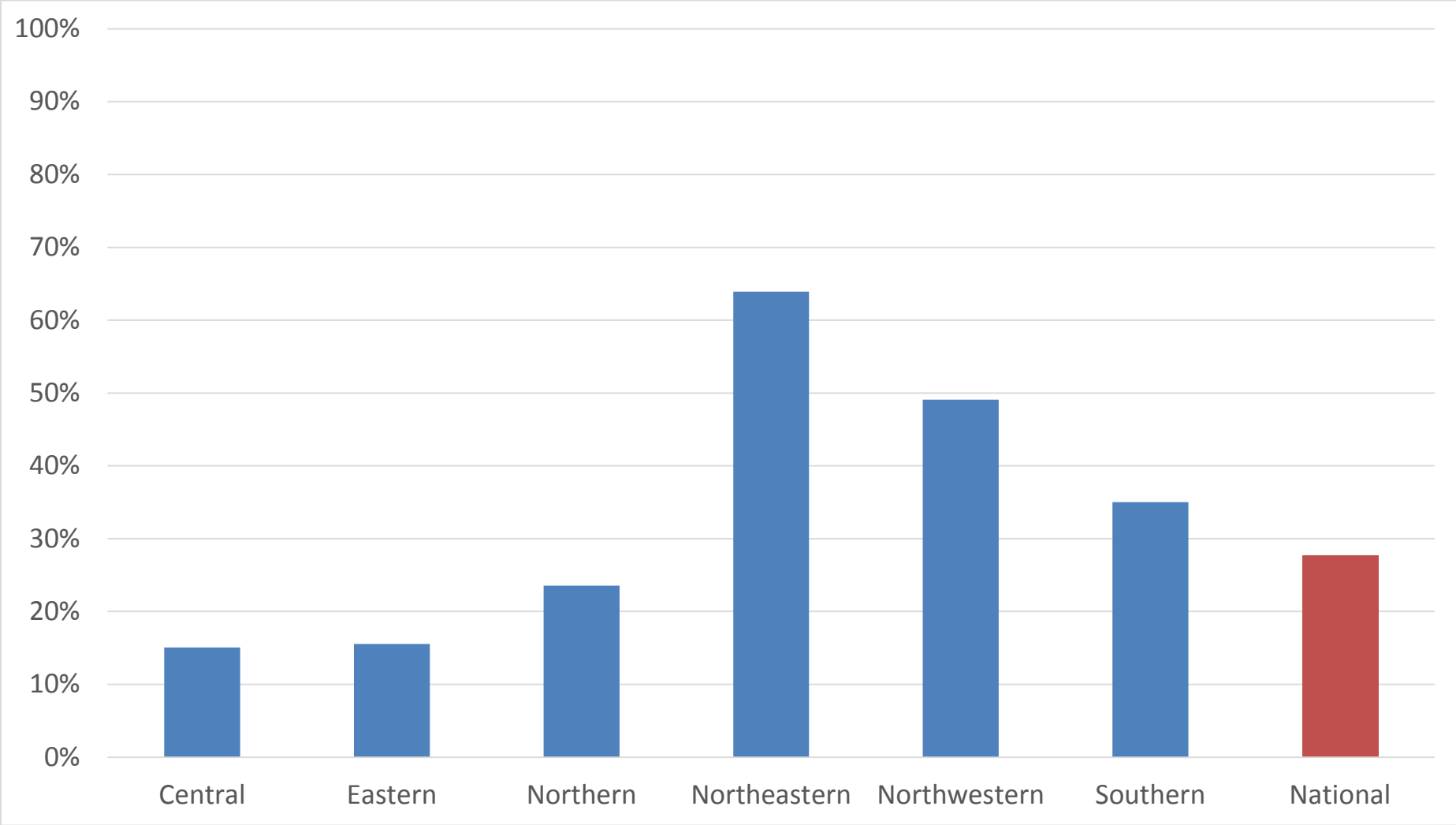


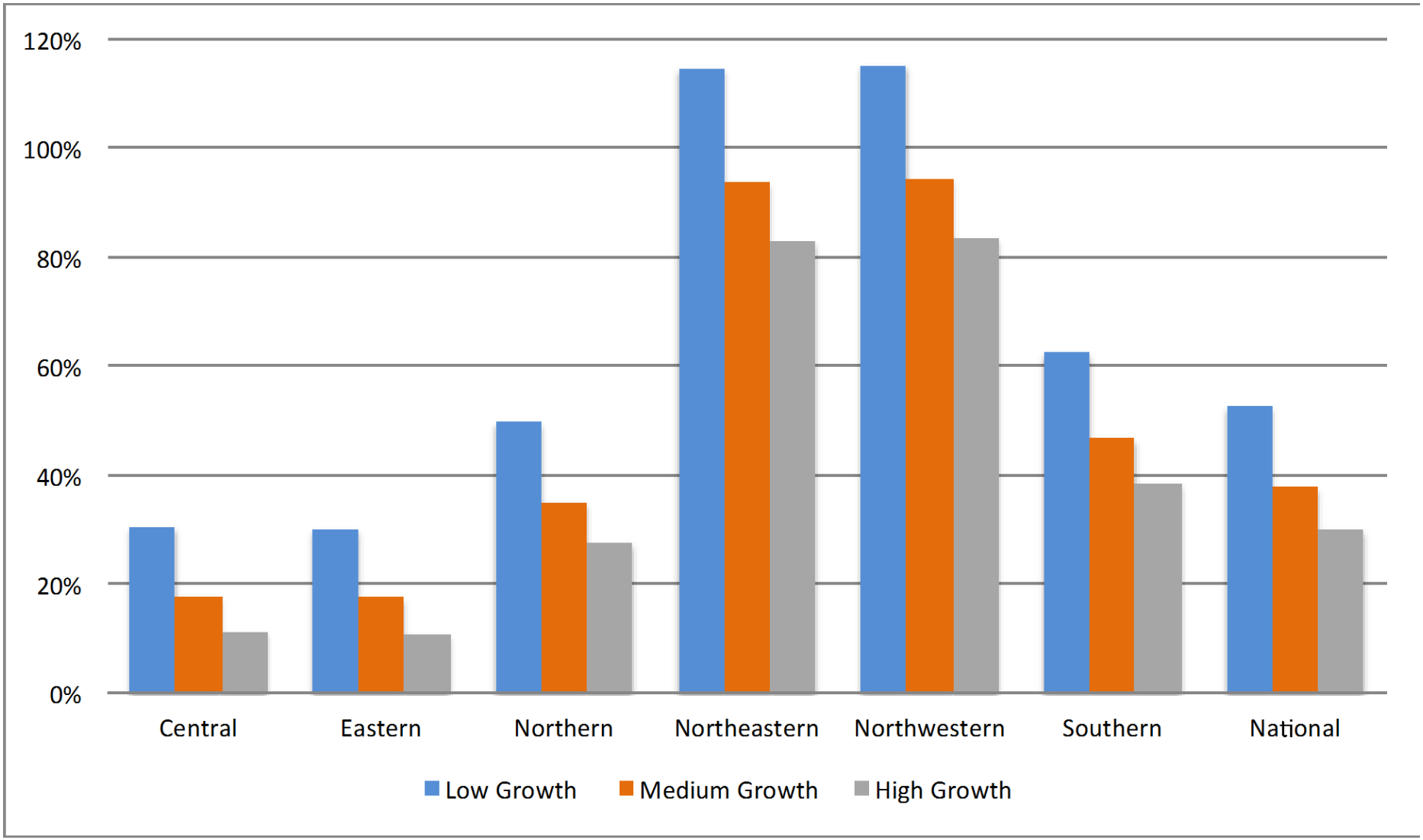
Figure ES-1 Load forecasts from seven subsequent IRPs and actual load for a Western U.S. utility.

Planning reserve margins in China, 2014



LBNL report: Excess Capacity in China's Power Systems: A Regional Analysis

Planning reserve margins in 2020 under the low, mid, high growth scenarios

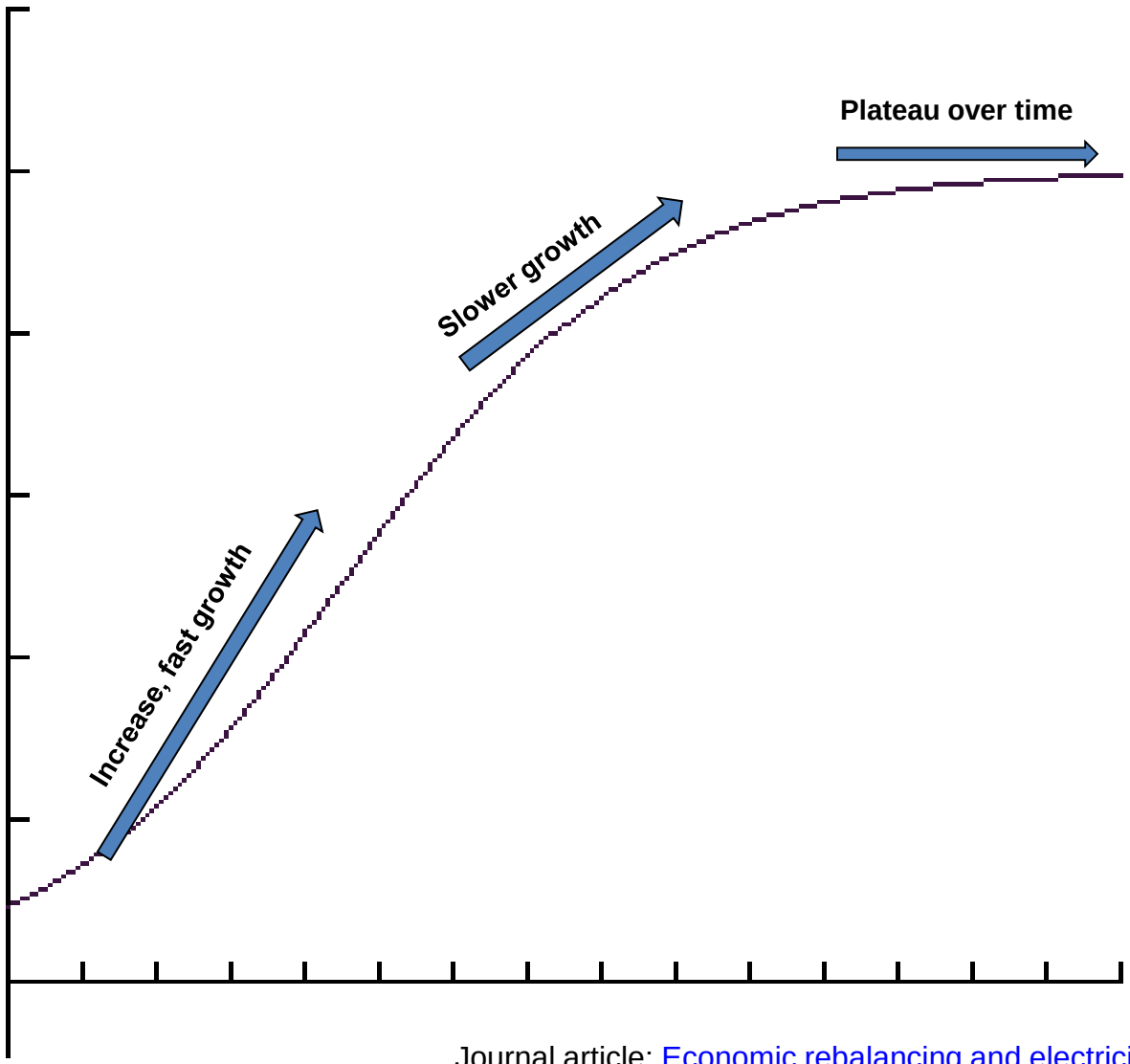


LBNL report: Excess Capacity in China's Power Systems: A Regional Analysis

Decoupling of GDP and electricity

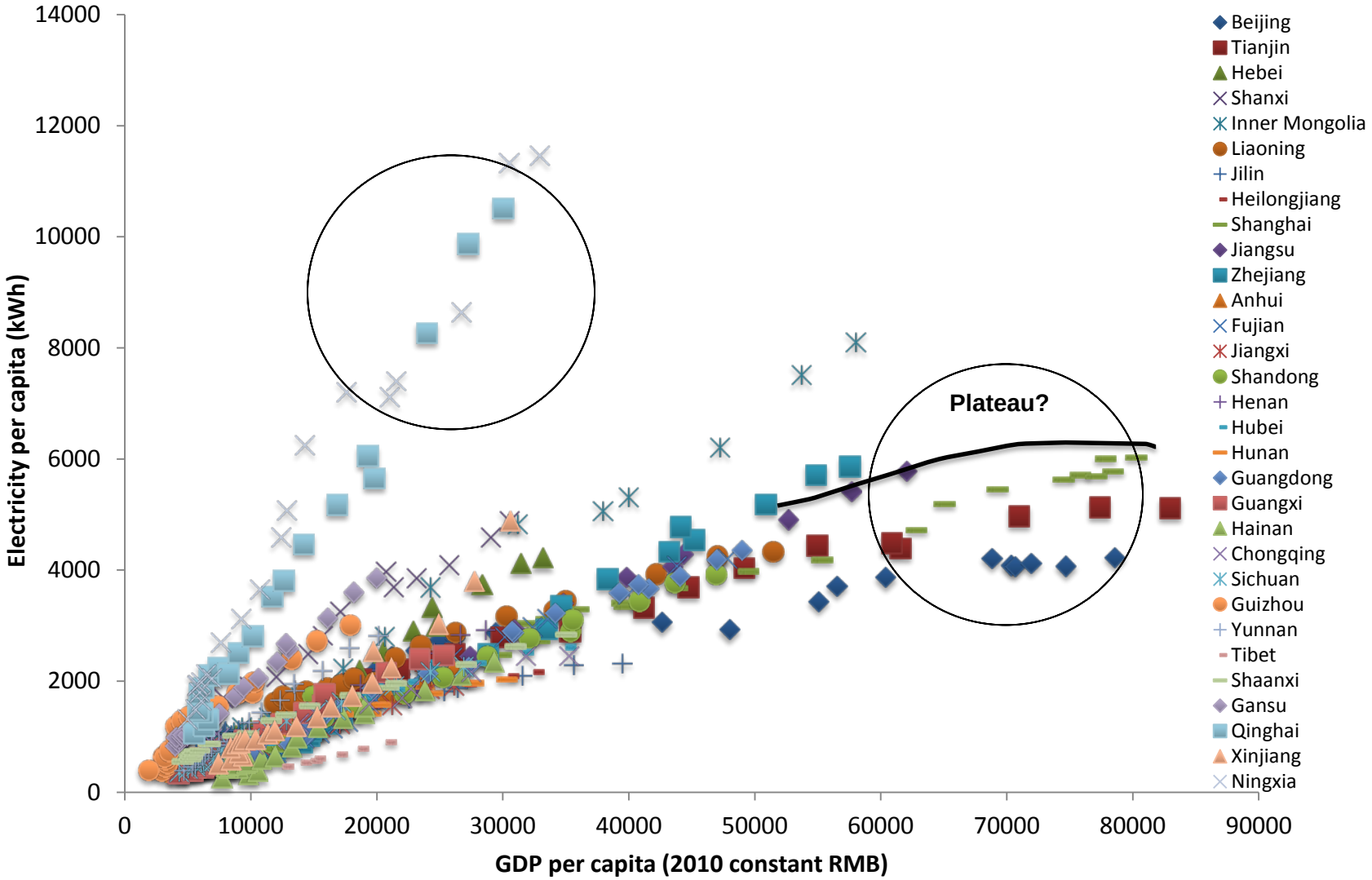
- Re-assessing China's electricity demand under the economic "New Normal"
- Is the slowdown in electricity consumption a temporary phenomenon or a long-term trend:
  - Slower economic growth
  - Significant shift in economic structure from industry to services
  - Reduction of overcapacity in major industries

What is the relationship between economic growth and electricity use?



Journal article: [Economic rebalancing and electricity demand in China]

Regional patterns?



Polynomial and logarithm model performs better: statistics

(1) $$E_{cap} = 0.0836\, GDP_{cap} - 29.37\, Tertiary + 1546$$

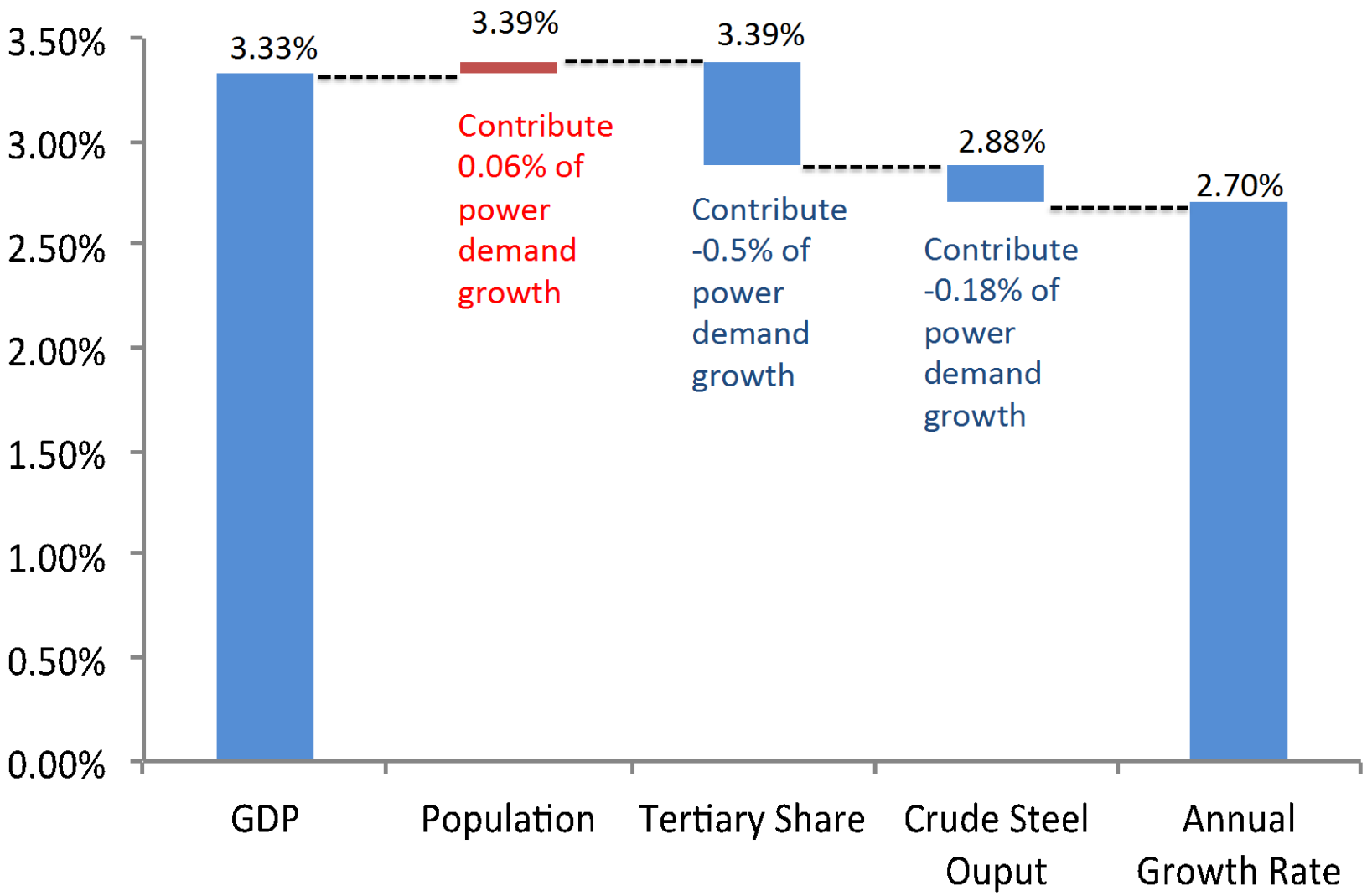
(2) $$E_{cap} = 0.133\, GDP_{cap} - 7.67E(-7)\left(GDP_{cap}\right)^2 - 20.77\, Tertiary + 733.4$$

(3) $$\ln E_{cap} = 0.836 \ln GDP_{cap} - 0.00520\, Tertiary - 0.467$$

VARIABLES	(1) Linear	(2) Polynomial	(3) Logarithm
	Electricity Consumption per capita	Electricity Consumption per capita	Log electricity Consumption per capita
GDP per capita (Real RMB)	0.0836***	0.133***	
	(0.00413)	(0.0106)	
GDP per capita square (Real RMB)		-7.67e-07***	
		(1.32e-07)	
Tertiary GDP share	-29.37***	-20.77***	-0.00520*
	(8.344)	(7.369)	(0.00291)
Log GDP per capita (Real RMB)			0.836***
			(0.0317)
Constant	1,546***	733.4***	-0.467*
	(276.2)	(239.1)	(0.238)
Observations	540	540	540
R-squared	0.528	0.554	0.662
Adjusted R-squared	0.526	0.551	0.661
RMSE	1133	1102	0.414

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

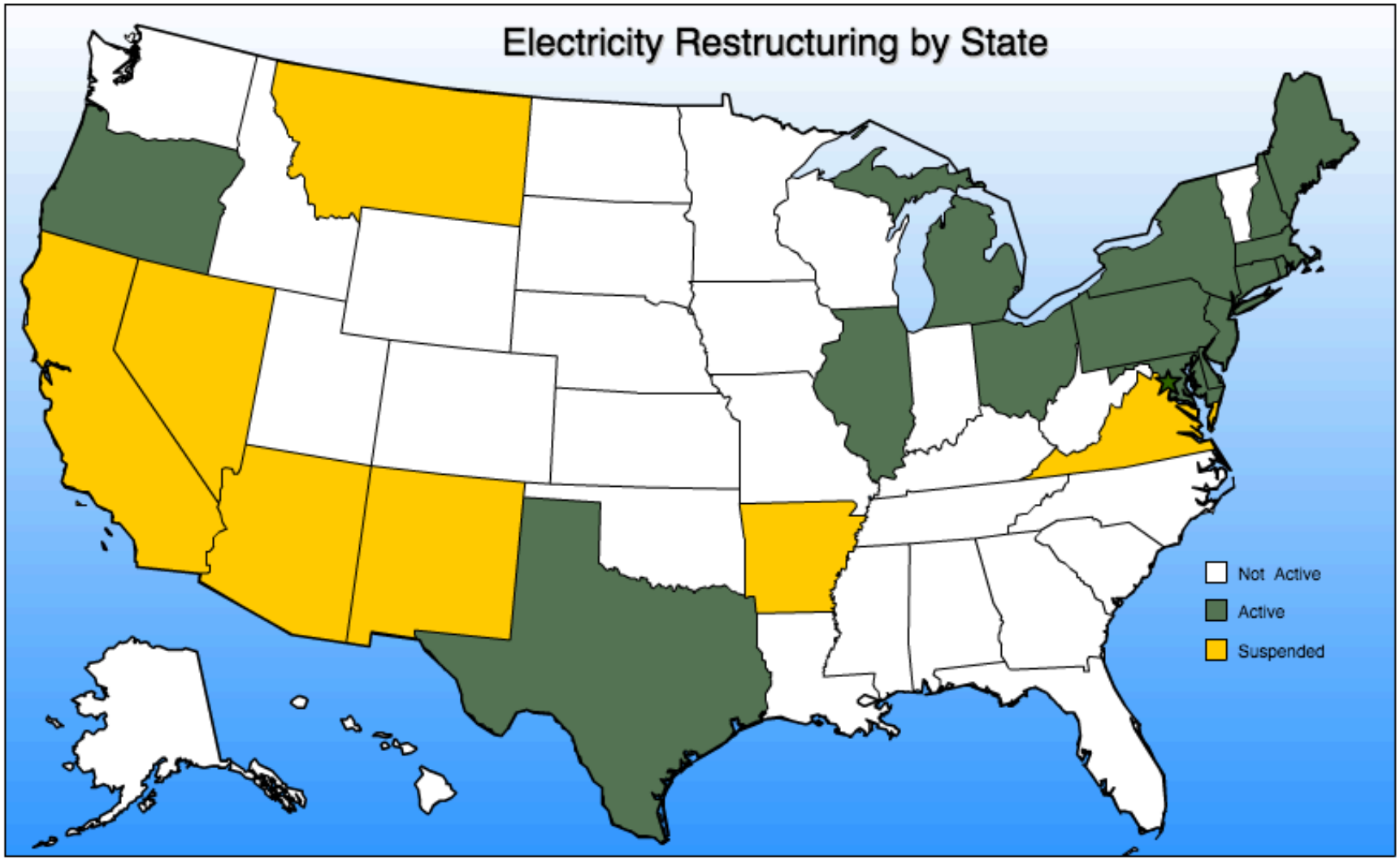
Contribution of GDP, population, structural change, overcapacity, and population to electricity demand



History of power sector reform: mid-1990s to 2010

- Goals
  - Increasing economic efficiency and reduce costs
- 1990s Restructuring/deregulation
  - Unbundling of generations/retails from T&D
  - wholesale market
  - Direct access/retail competition
- Problems: CA crisis in late 1990s
  - 2000-2001: poor market design and market manipulations led bankruptcy of two large IOUs
- Solutions:
  - Some states back to re-regulation
  - Many remain the unchanged

Deregulation has stalled in most states



Source: Energy Information Administration

Rate Impact Limited

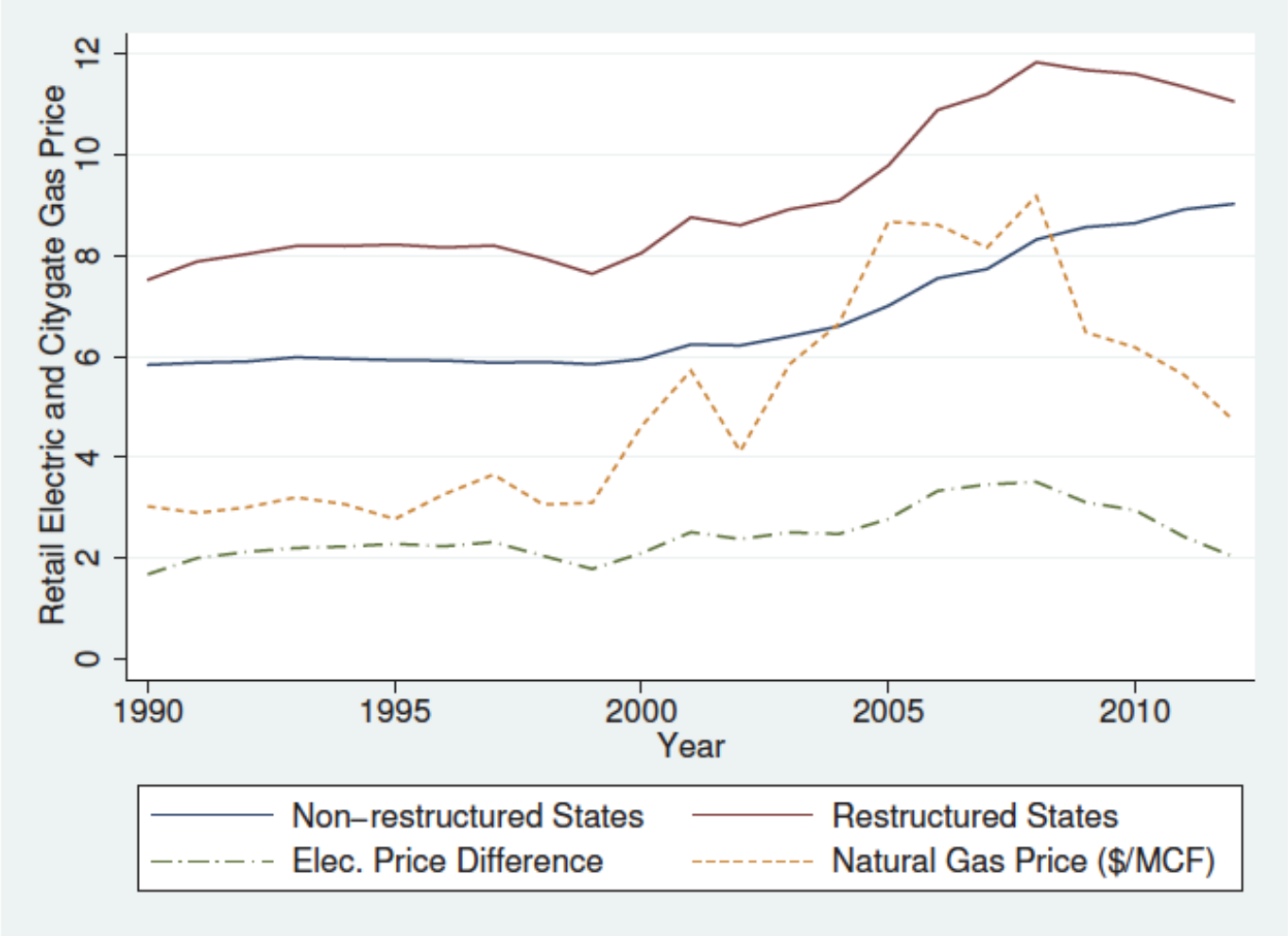


FIGURE 6. U.S. AVERAGE RETAIL RATES AND NATURAL GAS PRICES

Observation: Utility deregulation in US

- Still heavily regulated industry
- Unbundling of generation and competition improved efficiency at power plants
- Open access to transmission grid is essential
- *Improved coordination of power grids (ISO/RTO)*
- Limited impact on ***average*** consumer costs
  - Economic vs social costs?
- Other benefits unclear:
  - how to value customer choice?
- Implementation poses significant challenge

Drivers of current reforms

- Environmental/Climate Change
  - Meeting GHG targets
  - RPS
  - Clean Power Plan
- Technological
  - Rapid cost reductions and expansion of solar and wind
- Business model
  - Leasing
- Utility model
  - Customer defection
  - Declining revenue base

Lessons learned

- Utility industry is likely to remain carefully regulated
  - Wholesale market is complicated and takes time to form, needs to be carefully monitored and regulated
  - Need to balance economic, social, and climate goals
- Competitive generation has led most of the economic efficiency gains.
- Rate impact on average consumers has been limited.
- ISO/RTO have improved grid operation
- Independent demand forecast is foundational to good resource planning
- Meeting climate goals require new thinking

Research questions

- What types of models are best suited for load forecast?
  - At what geographic/demographic resolution?
- What KPIs to evaluate retail competition/choice? Wholesale competition?
- Green/economic dispatch vs Generation planning quota?
- What is the appropriate transition plan to existing Gencos if generation quota is phased out?
- What mechanism to ensure environmental and climate goals?
- What infrastructure is needed to make both production and demand more "responsive"
  - Dynamic pricing?
  - Tools to allow operators and consumers to make smart choices

Thank You!

Jiang Lin
J_lin@lbl.gov

Lawrence Berkeley National Laboratory

University of California, Berkeley

http://china.lbl.gov

http://btjrc.lbl.gov

Backup slides

Thank you!

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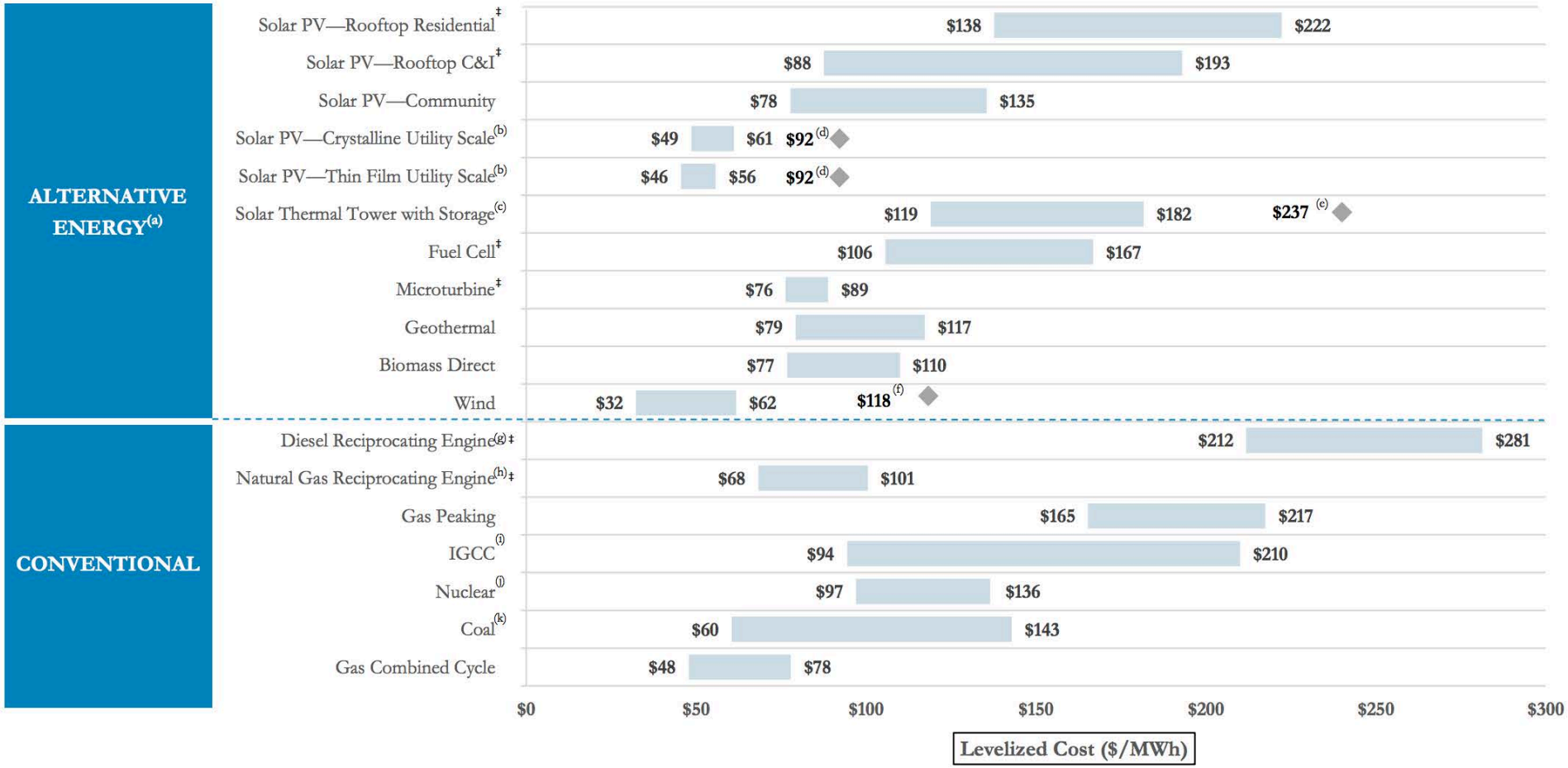
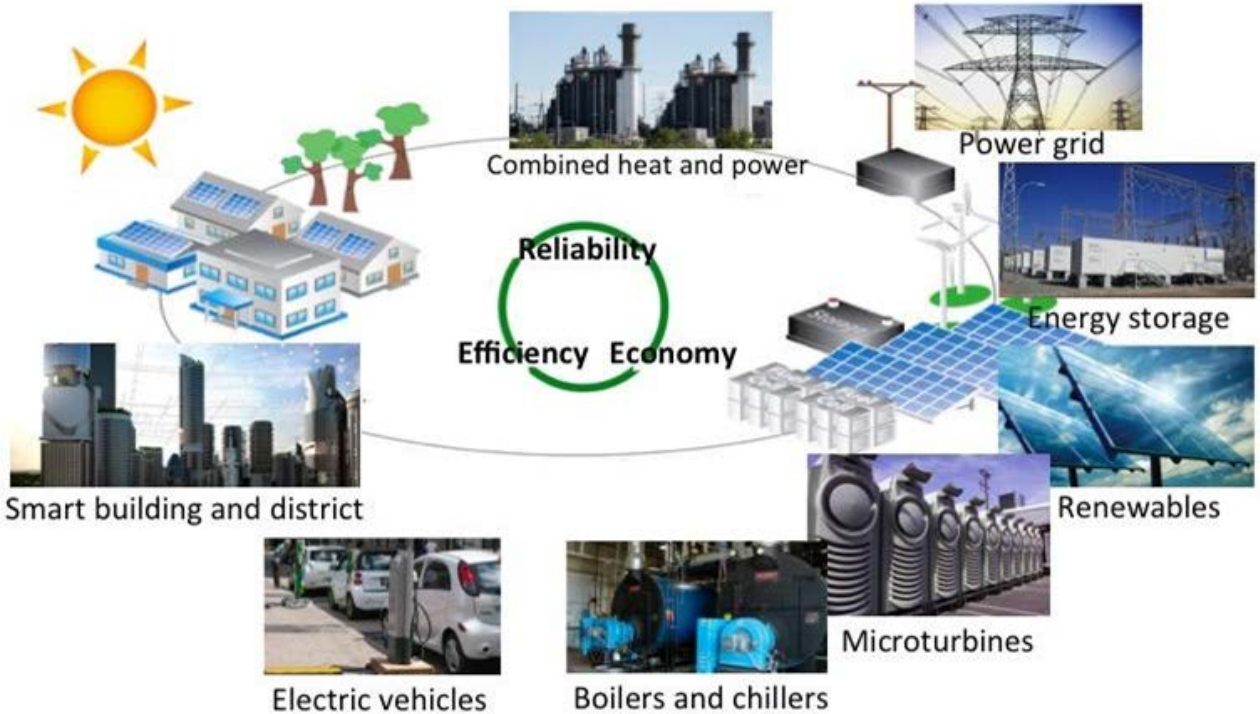
Unsubsidized Levelized Cost of Energy Comparison

Certain Alternative Energy generation technologies are cost-competitive with conventional generation technologies under some scenarios; such observation does not take into account potential social and environmental externalities (e.g., social costs of distributed generation, environmental consequences of certain conventional generation technologies, etc.), reliability or intermittency-related considerations (e.g., transmission and back-up generation costs associated with certain Alternative Energy technologies)



Model concept 建模概念



Demand side

- Lower peak energy usage
- Bring higher capacity factor and security of distribution grids

Supply side

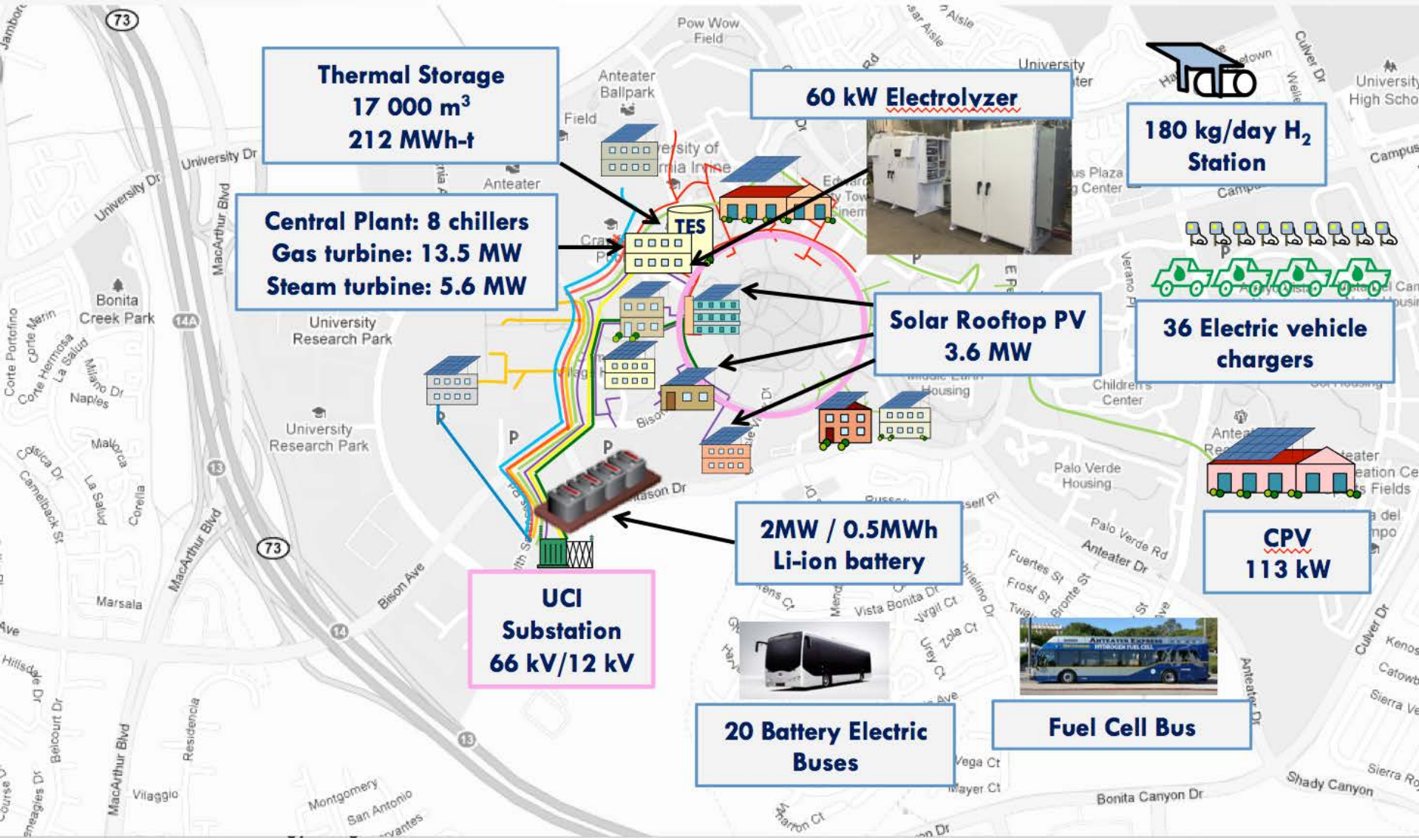
- Microgrid to integrate distributed generation and storage
- Combined heat and power

Challenge: *Coordinate both the demand and supply sides in a renewable-penetrated, storage augmented, DR-enabled microgrid*

Motivation 动机

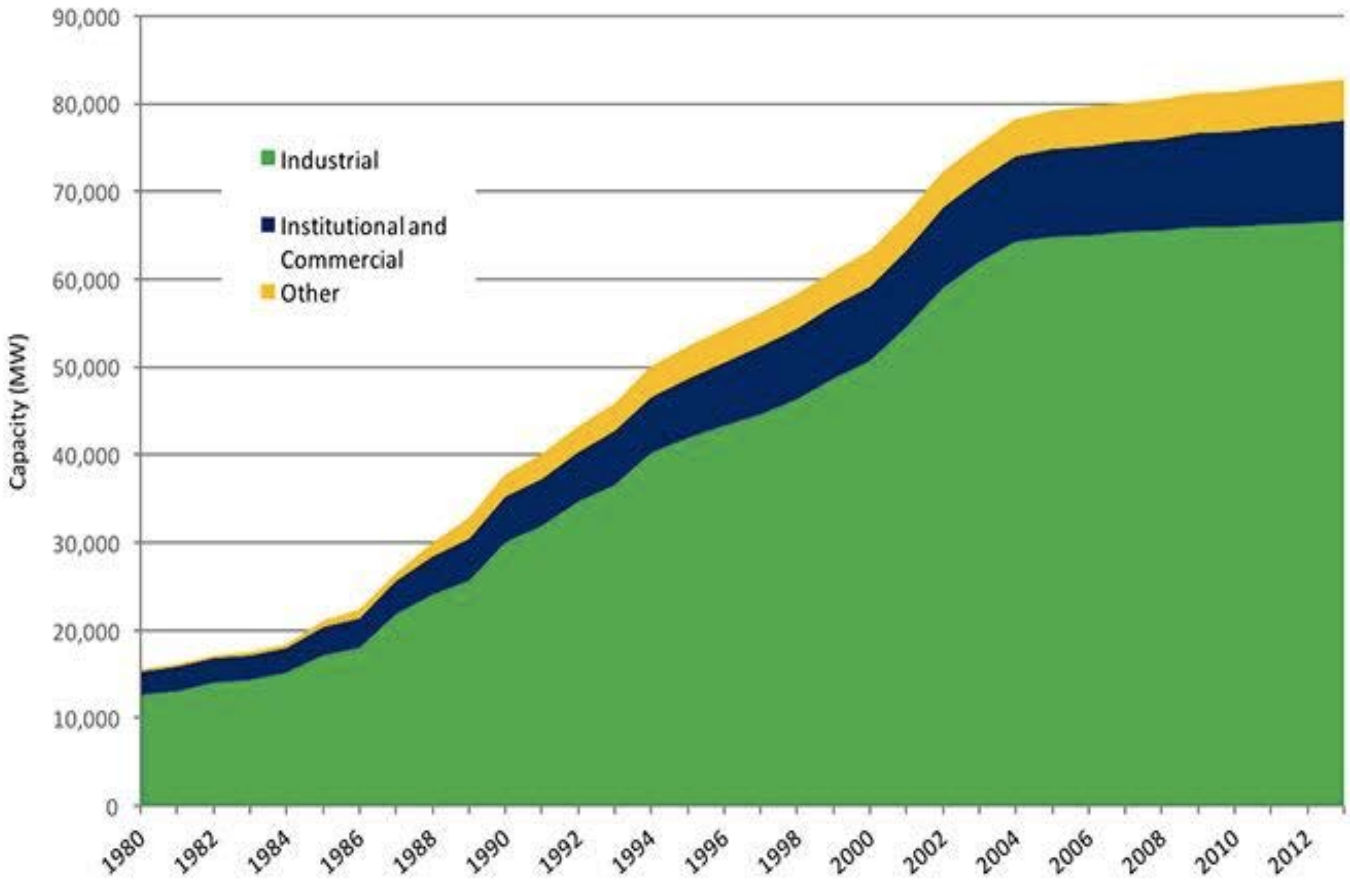
- DES as a smart ***prosumer***: 分布式能源作为一个智能能源参与者
  - Optimize operation by effective coordination of technologies (storages, CHP, etc.) in accord with renewable generation and demand response signals
  - Investigate dispatch strategies under uncertainty
- DES as a ***smart partner*** with the grid: 分布式能源是大电网的一个智能伙伴
  - Offer ancillary service for overall efficiency and grid stability
  - Encourage more demand side participation in the market and appropriately valuing demand response
- Retail market optimization 服务于能源零售市场

加州大学，欧文分校微电网/U.C. Irvine Microgrid



Trends in Distributed Generation: CHP

US CHP Capacity: 85% Industrial



Source: ACEEE, 2016. http://aceee.org/blog/2016/02/brief-history-chp-development-united

Trends in Distributed Generation in US

- Distributed Generation
  - a variety of technologies that generate electricity at or near where it will be used, such as solar panels and combined heat and power.
  - Distributed generation may serve a single structure, such as a building, or be part of a microgrid, such as at a industrial park, a military base, or a large college campus.
  - Solar, gas turbine/engines, fuel cells, biomass

- The Major sources of Distributed Generation includes
  - Rooftop solar, ***fastest growing***
  - CHP, the largest source, about 8% of power capacity

- Increasing interests in District Energy Systems with microgrids to improve resilience