Renewables: The True Costs

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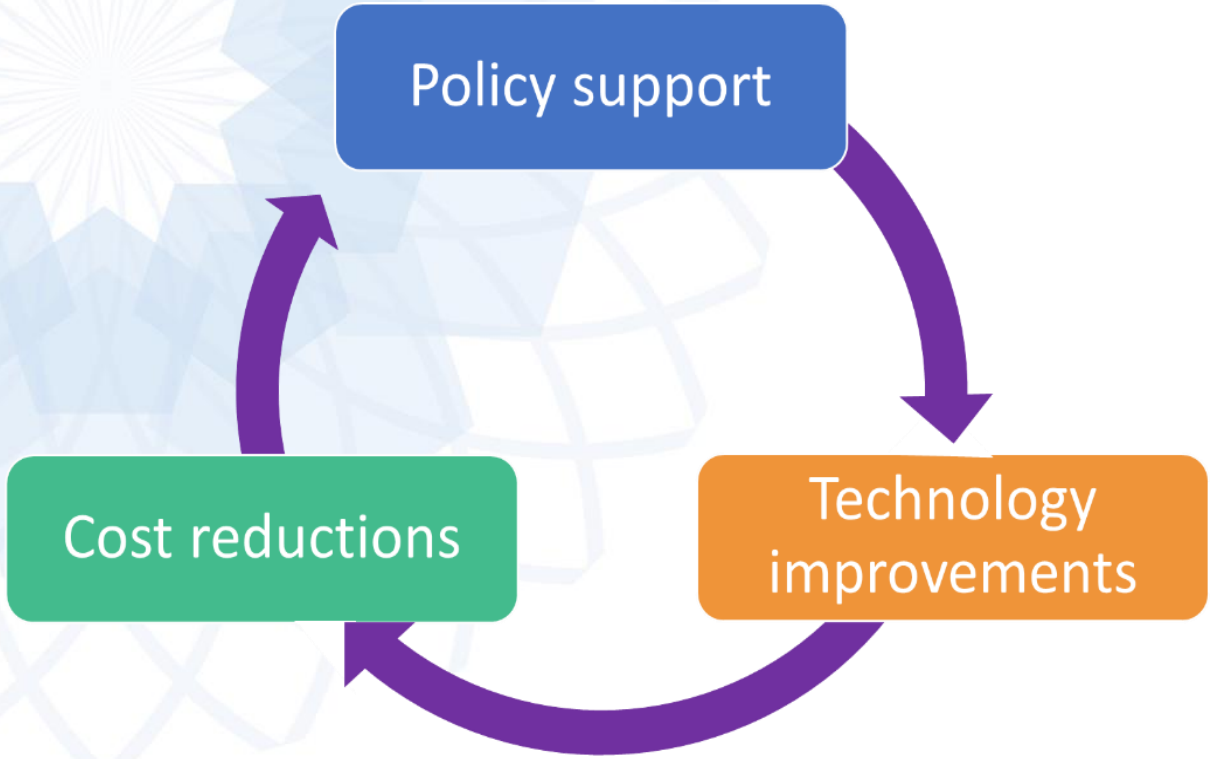
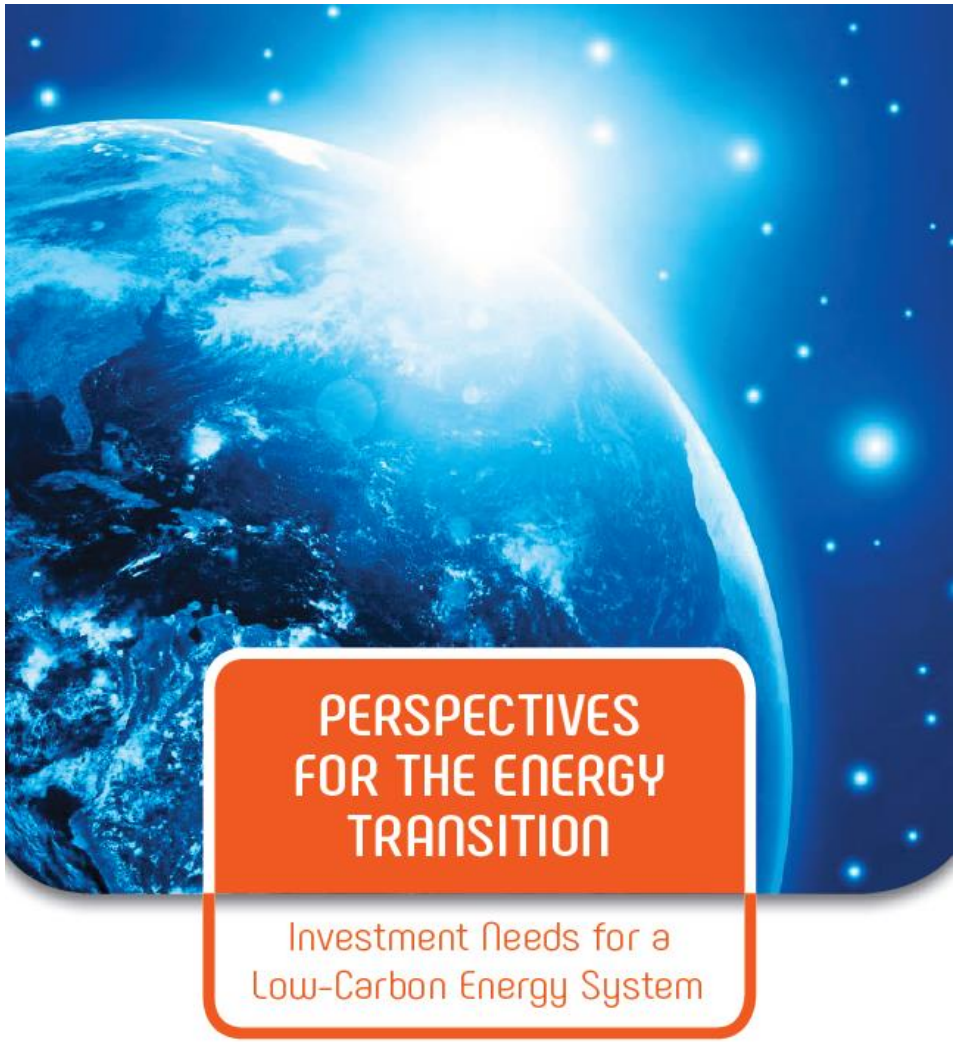
The Energy Sector is Being Transformed



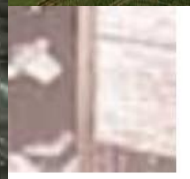
A ***virtuous cycle*** is unlocking the ***economic***, ***social*** and ***environmental*** benefits of renewables



So what does a real transformation look like anyway?

IRENA
International Renewable Energy Agency

So what does a real transformation look like anyway?



Renewable cost analysis at IRENA

Fills an important gap in knowledge

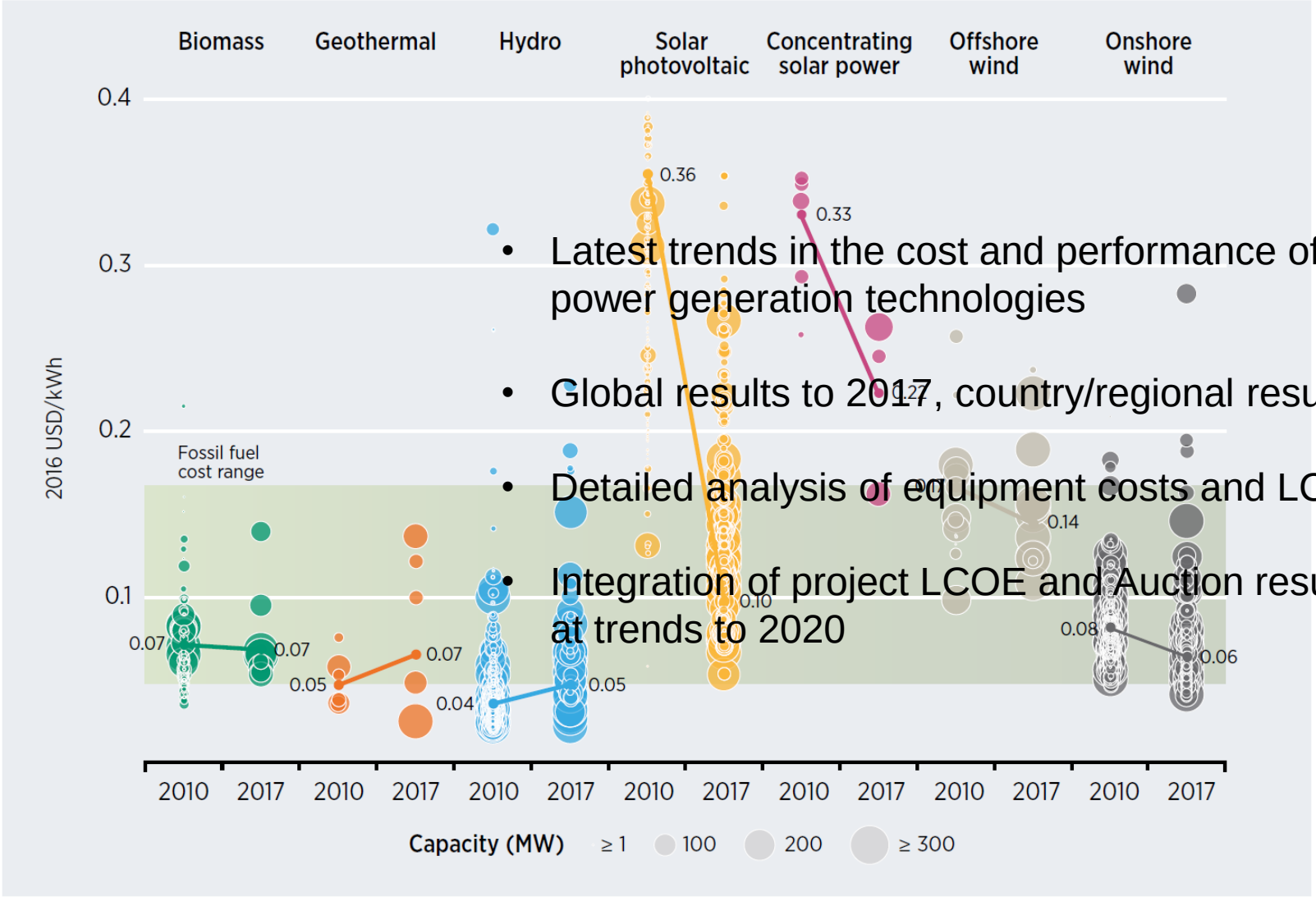
World-class database of costs

Cutting edge analysis, not just data

Energy technologies and facilitating techs

Recent cost evolution

IRENA
International Renewable Energy Agency



- Latest trends in the cost and performance of renewable power generation technologies
- Global results to 2017, country/regional results to 2016
- Detailed analysis of equipment costs and LCOE drivers
- Integration of project LCOE and Auction results to look at trends to 2020

Source: IRENA Renewable Cost Database.

Costs continuing to fall for solar and wind power technologies

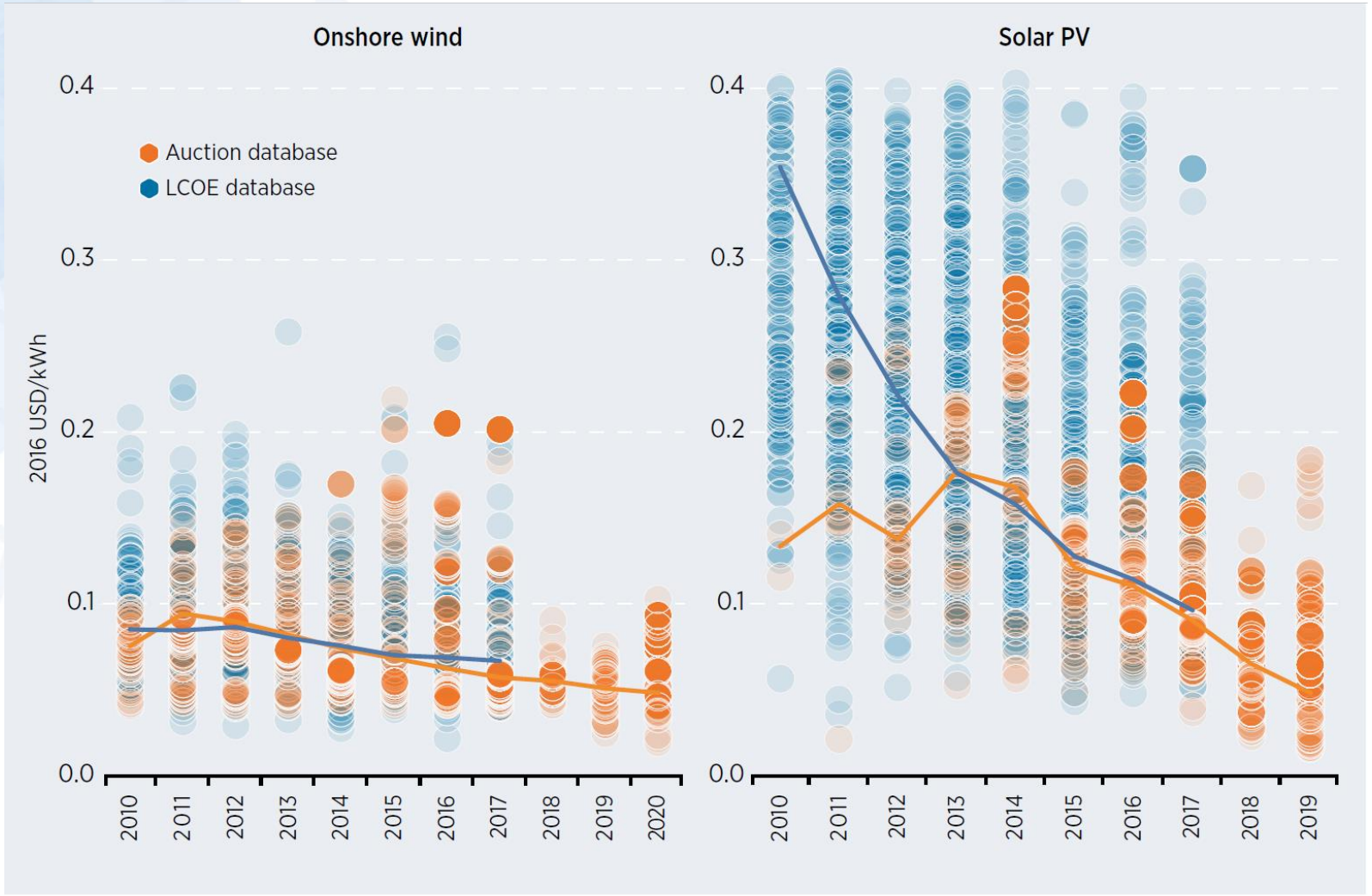
All technologies falling into competitive range

Remarkable rate of cost deflatio for solar & wind

All commercial RE power to be competitive by 2020/22

ers: Technology, Competitive Procurement, Exp. Develo

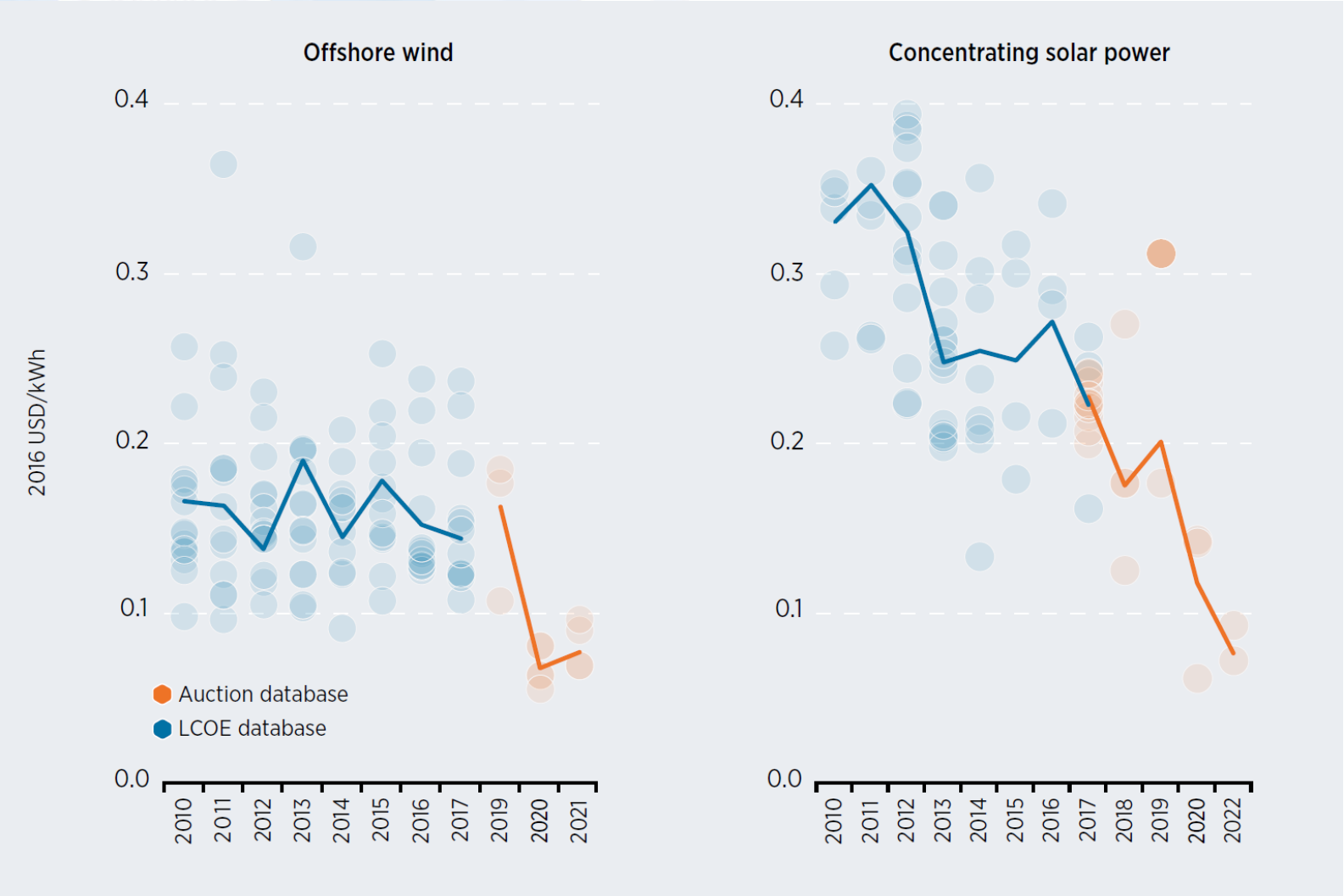
Onshore wind and solar PV: LCOE/ Auction trends



Source: IRENA Renewable Cost Database and Auctions Database.

Note: Each circle represents an individual project or auction result, while the solid line is the capacity-weighted average from

Offshore wind and CSP: LCOE/ Auction trends

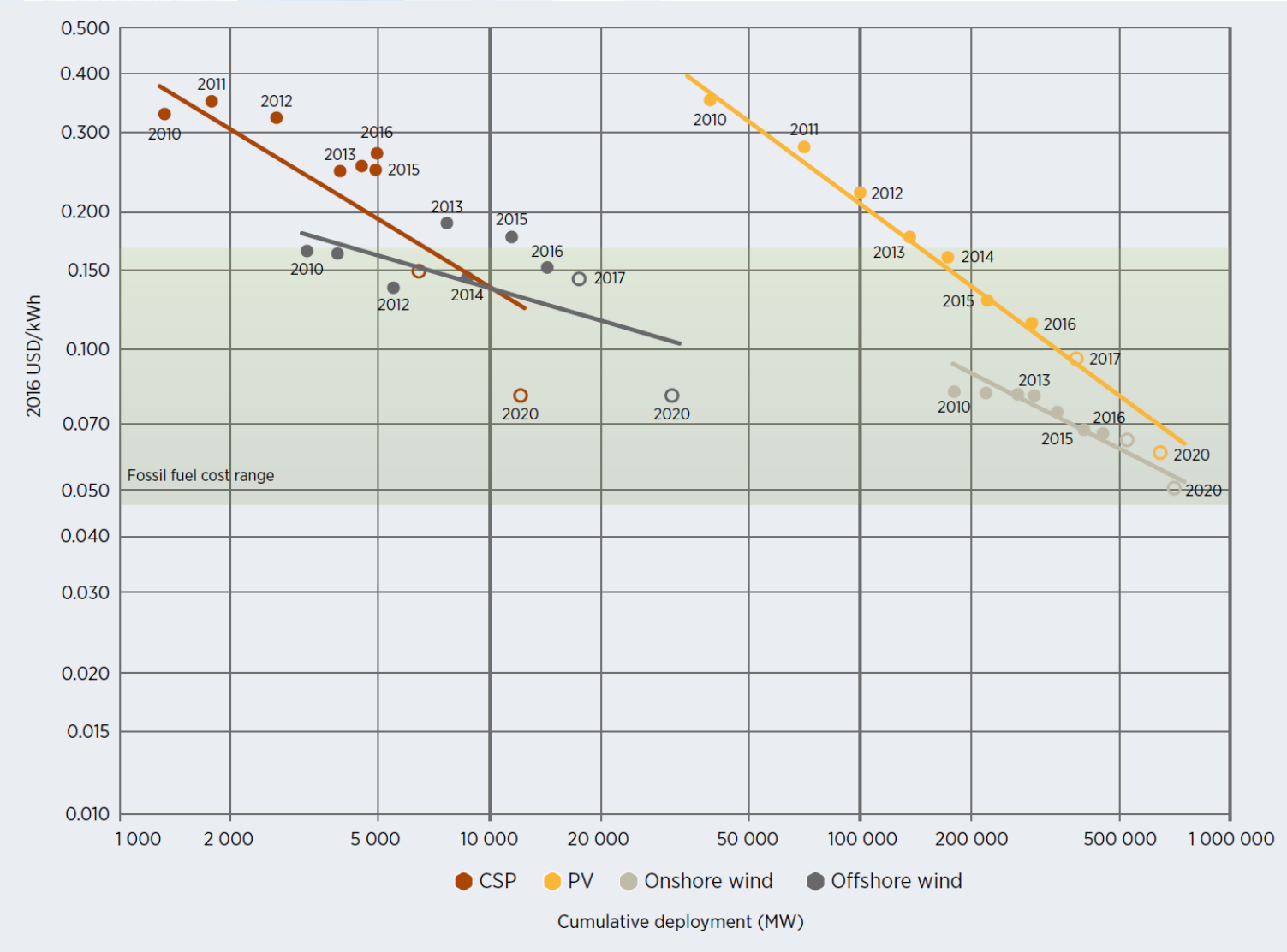


Remarkable rate of decline vs deployment

(13 GW and 5 GW at end of `16)

Source: IRENA Renewable Cost Database and Auctions Database.

Learning Rates: Remarkable Deflation in Costs



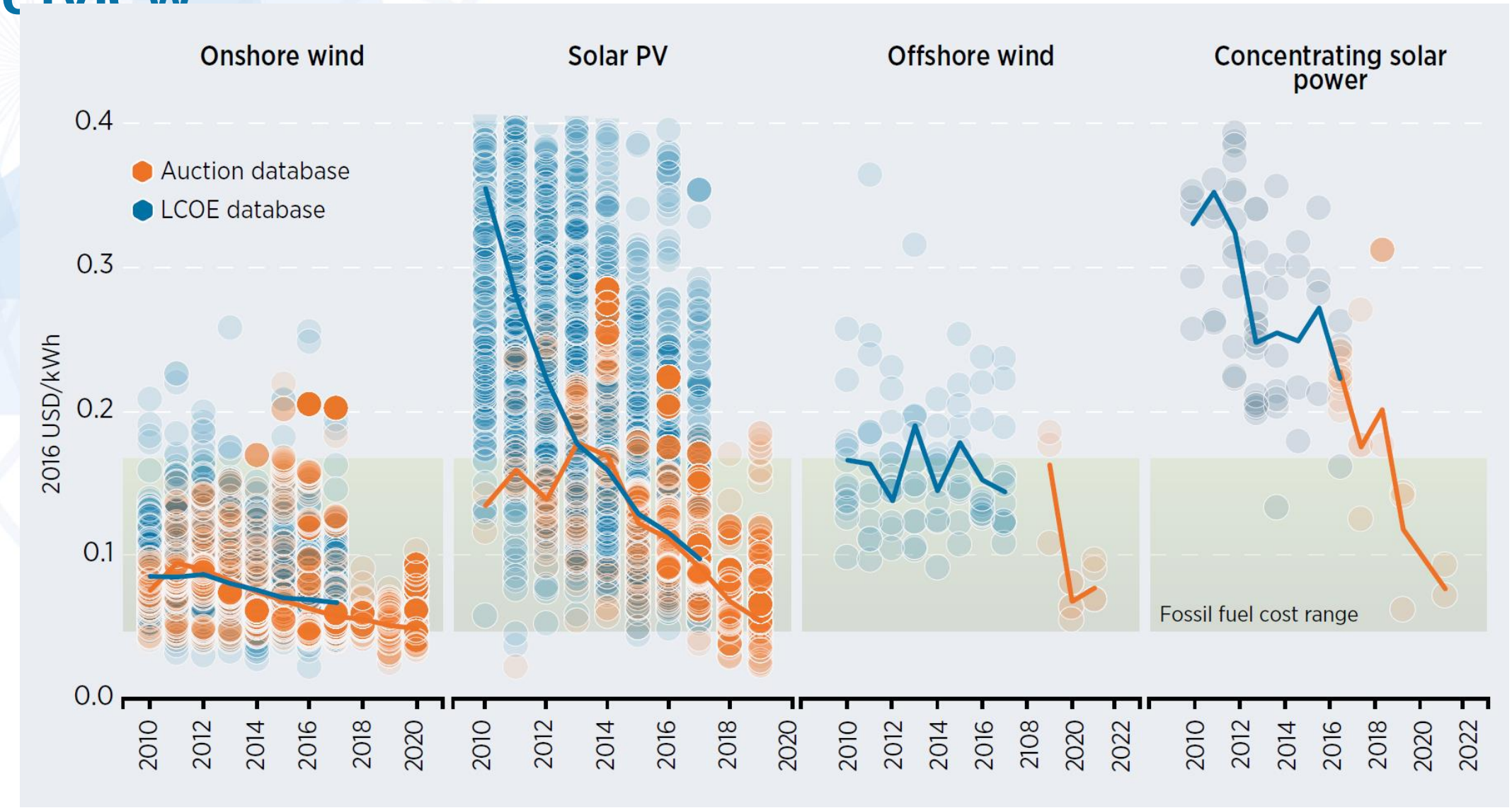
14%: Offshore wind

21%: Onshore wind

30%: CSP

35%: Solar PV

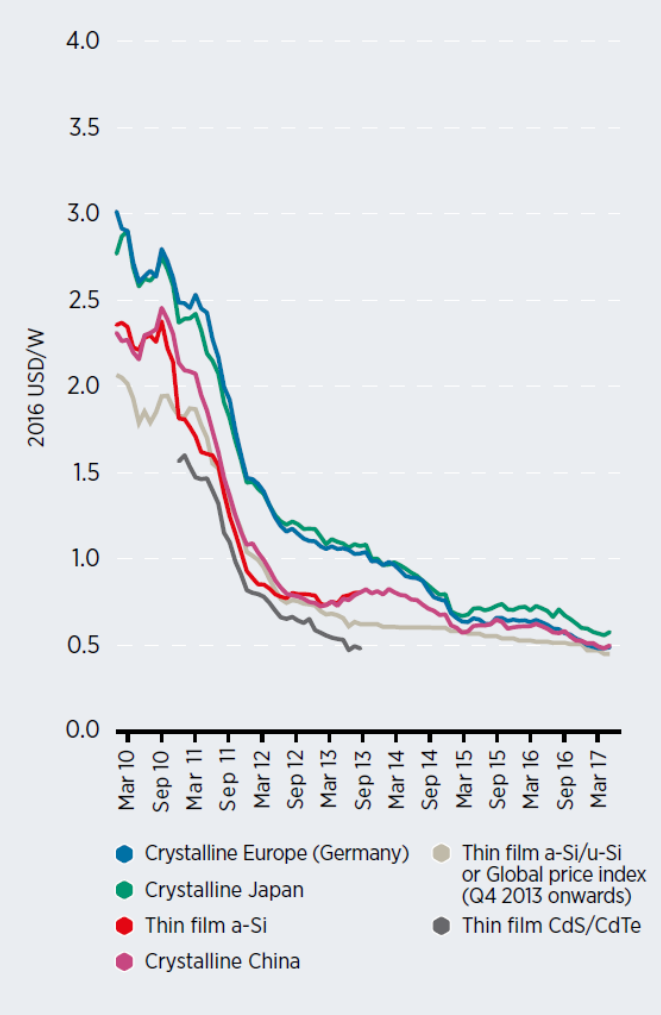
Solar & Wind: LCOE/ Auction Price Evolution Overview



DEEP DIVE BY TECHNOLOGY

Solar PV module price trends

Module prices in Europe decreased by 83% from the end of Q1 2010 to the end of Q1 2017



Source: GlobalData, 2017; pvXchange, 2017; Photon Consulting, 2017.

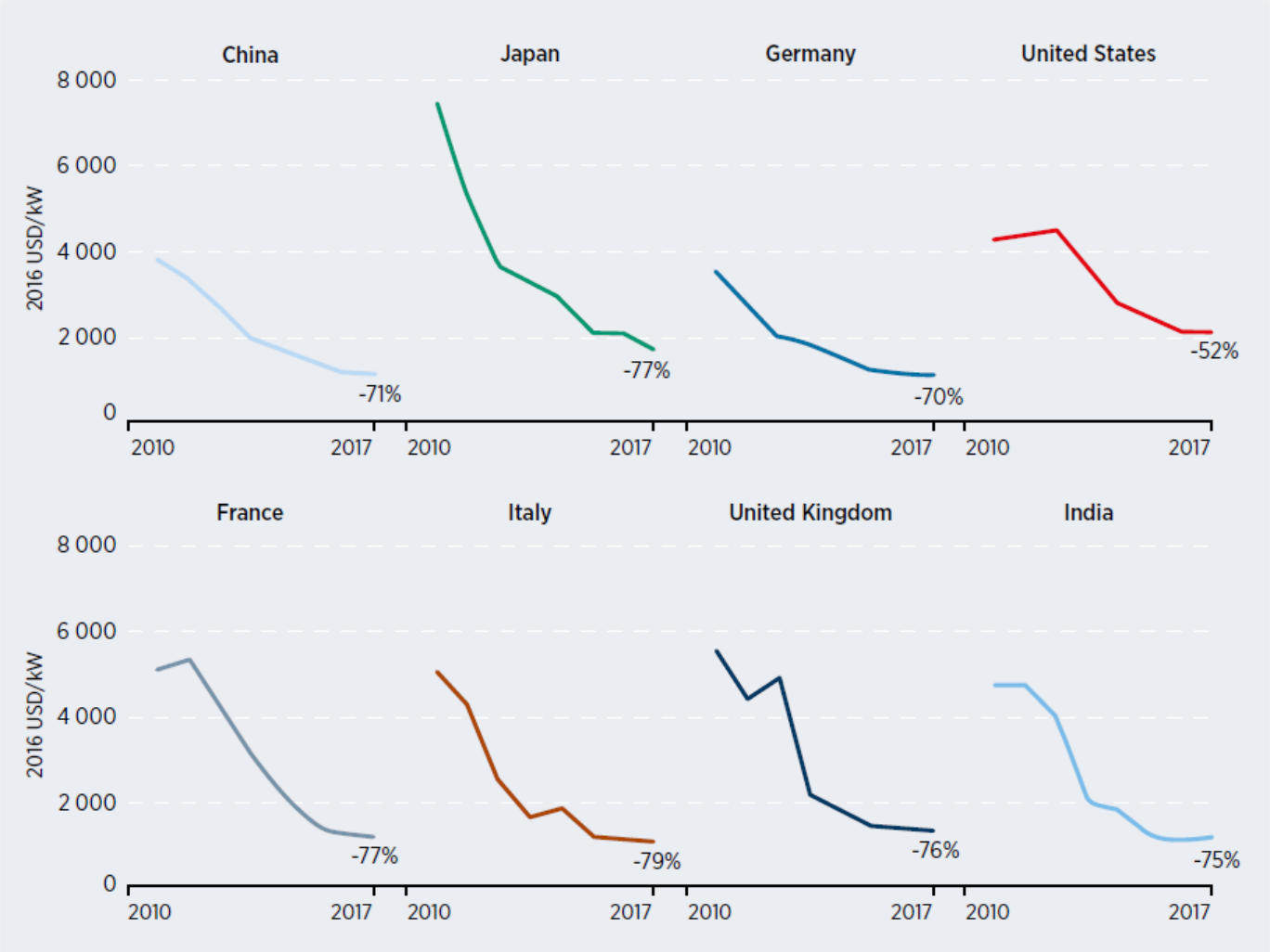
Module costs declined 80% betwee
2010 and end of 2016.

During this period, 87% of the cumu
global PV capacity installed at the e
occurred.

Import treatment and individual market preferences result in a wide range of module prices depending on the market
(Range here from USD 0.43 to 0.61/W in 2016).

Total installed costs of solar PV

Between 2010 and 2017 the global weighted average cost of utility-scale PV decreased by 68%



Source: IRENA Renewable Cost Database.

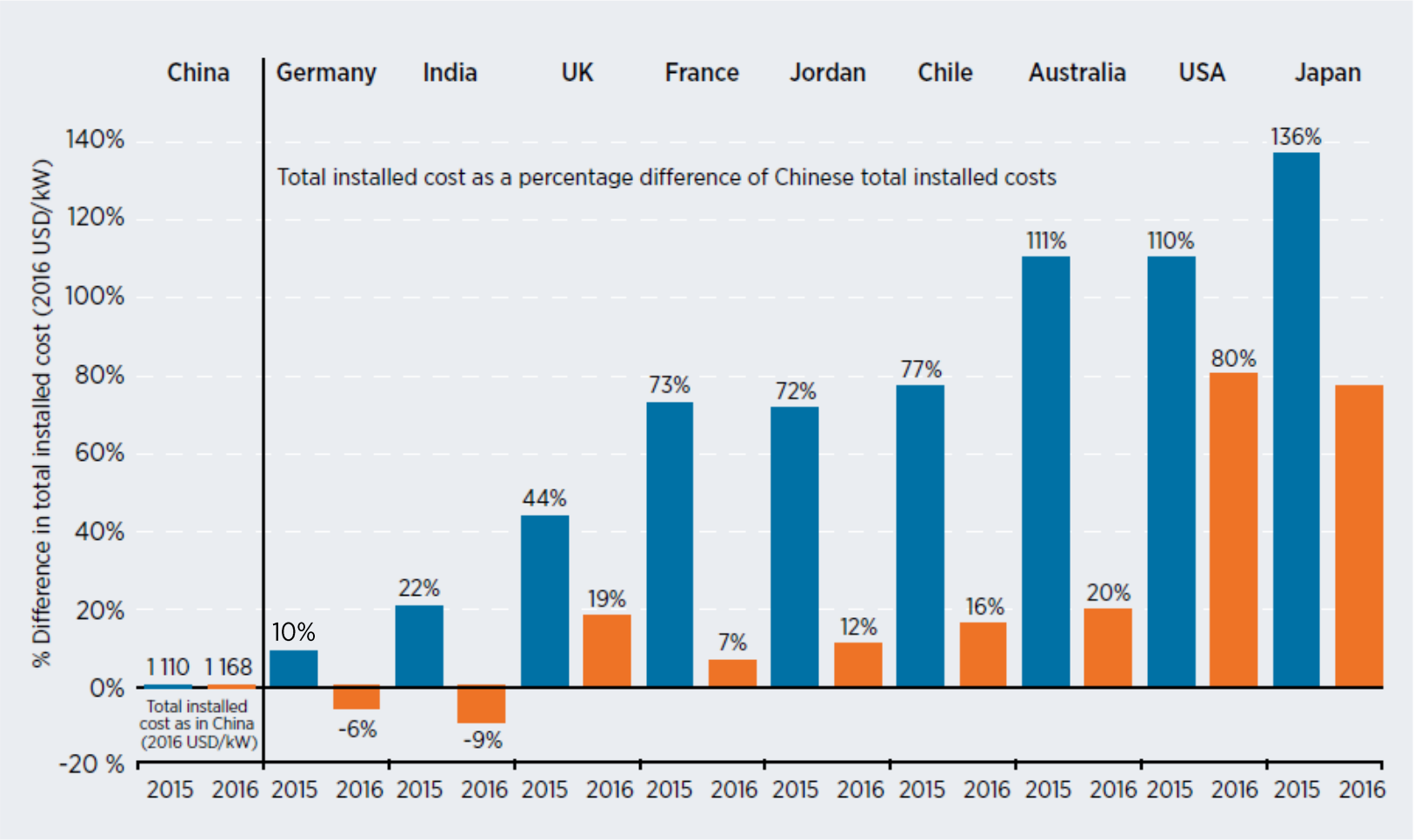
Global capacity weighted average total installed cost of newly commissioned utility-scale PV projects during 2017 is estimated at USD 1388/kW (a 10% decline from 2016).

Chinese, German and Italian projects all close to USD 1 100/kW during 2017.

Cost differentials declining, but…..

Total installed cost trends in selected markets

However, for a range of countries, the cost differentials compared to China have been declining



Source: IRENA Renewable Cost Database.

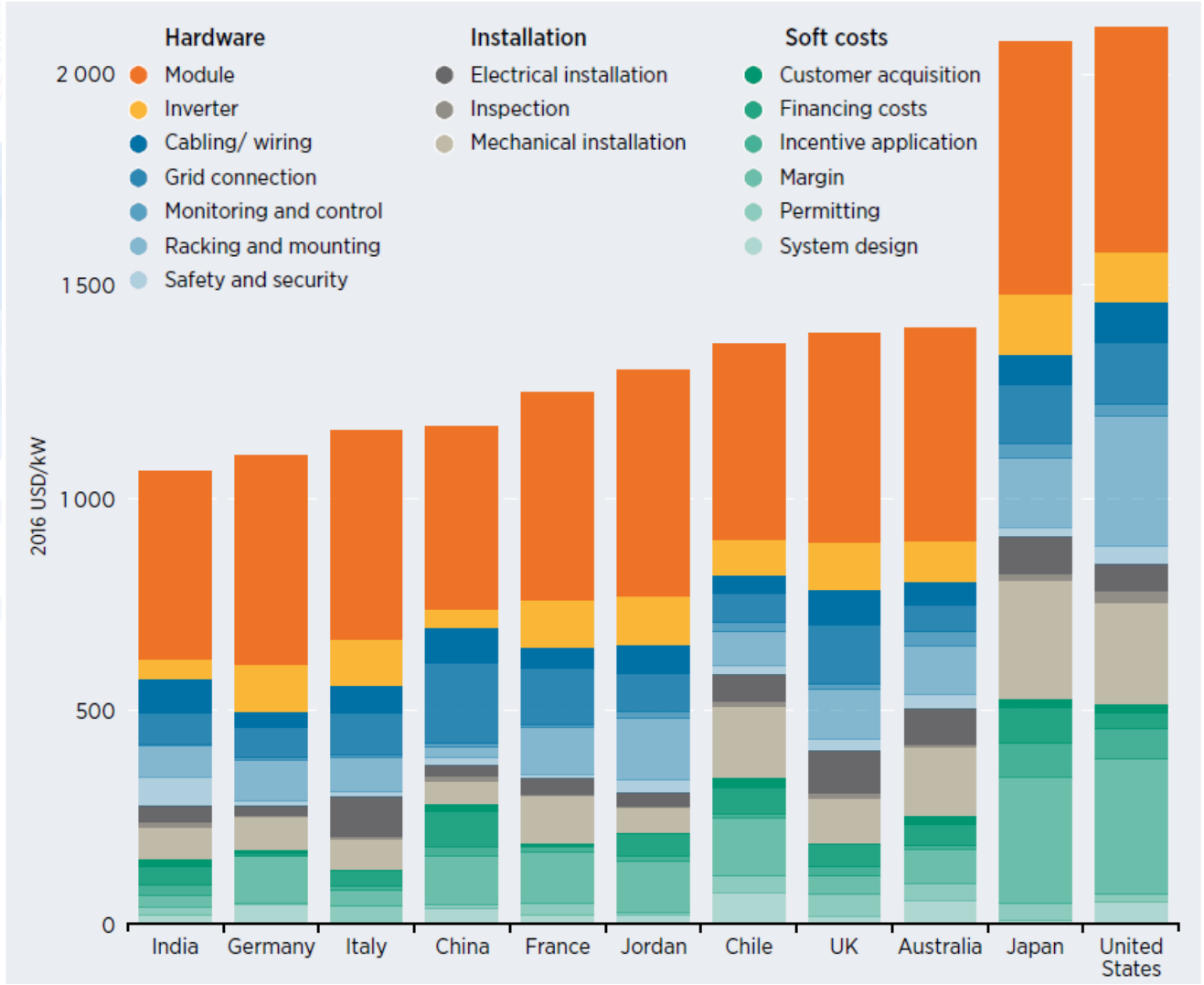
During 2016, percentage difference compared to Chinese levels was -9% and 80%.

Significantly narrower than in 2015 (10% to 136%).

Cost differences among markets are expected to continue to decline

Total installed cost trends in selected markets

Most cost reductions are happening at the balance of system costs level

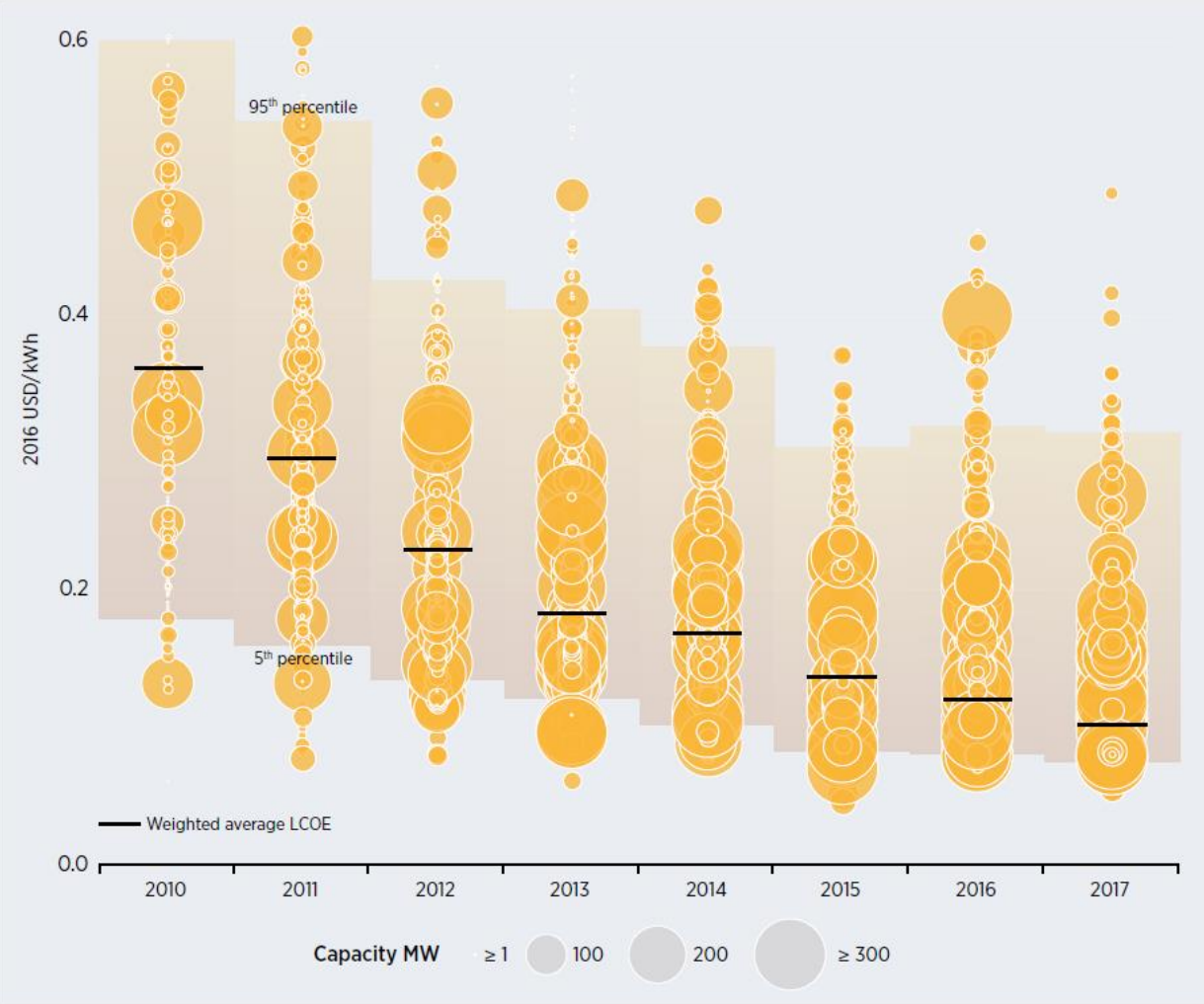


This detailed breakdown of utility-scale solar PV costs by country in 2016 shows that markets that significantly reduced the differential over Chinese installed costs did so by driving down BoS costs towards more competitive levels

Countries with competitive installed cost levels have, on average, balance of system costs (excluding the inverter) that make up about half of the total installed cost

Levelised cost of electricity of solar PV

Between 2010 and 2017 the average LCOE of utility-scale PV decreased by 73%



Source: IRENA Renewable Cost Database.

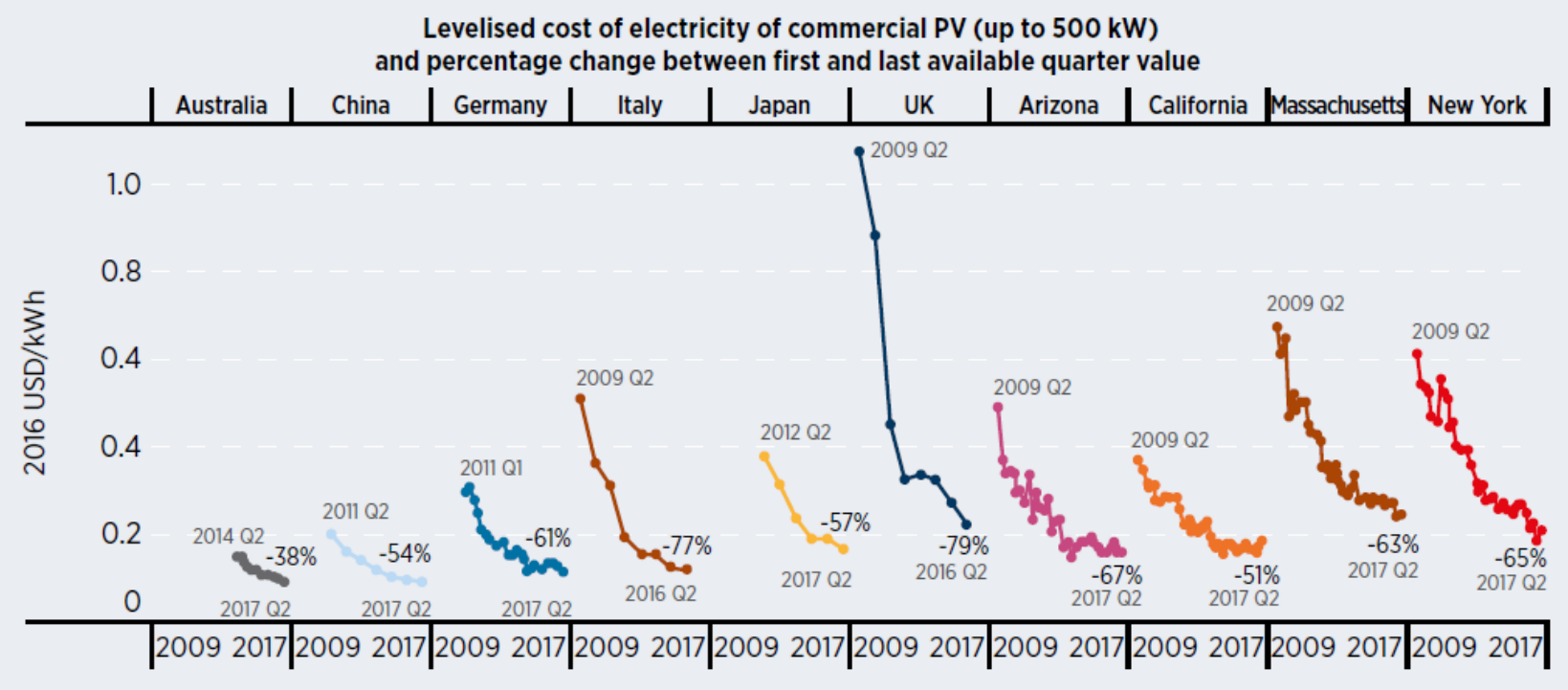
Between 2010 and 2017, the global weighted average LCOE of utility-scale PV plants is estimated to have fallen by 73%,
from around USD 0.36 to USD 0.10/kWh.

Estimated decline between 2016 and 2017 was 15%

The range of costs has also narrowed:
The 5th and 95th percentile range of the LCOE declined from:
Between USD 0.18 and USD 0.60/kWh in 2010
to
between USD 0.07 and USD 0.31/kWh in 2017

Solar PV cost trends in the commercial sector

Economic opportunities have caused significant growth in the commercial sector in recent years



Lowest average LCOE was around USD 0.10/kWh in Australia Q2 2017, after having decreased 38% between Q2 2014 and Q2 2017.

On the high end, LCOE estimates for the UK and some US markets are about twice that level during Q2 2017.

The total installed costs of commercial sector solar PV for system sizes up to 500 kW have often followed a similar
downward trend than utility-scale segment

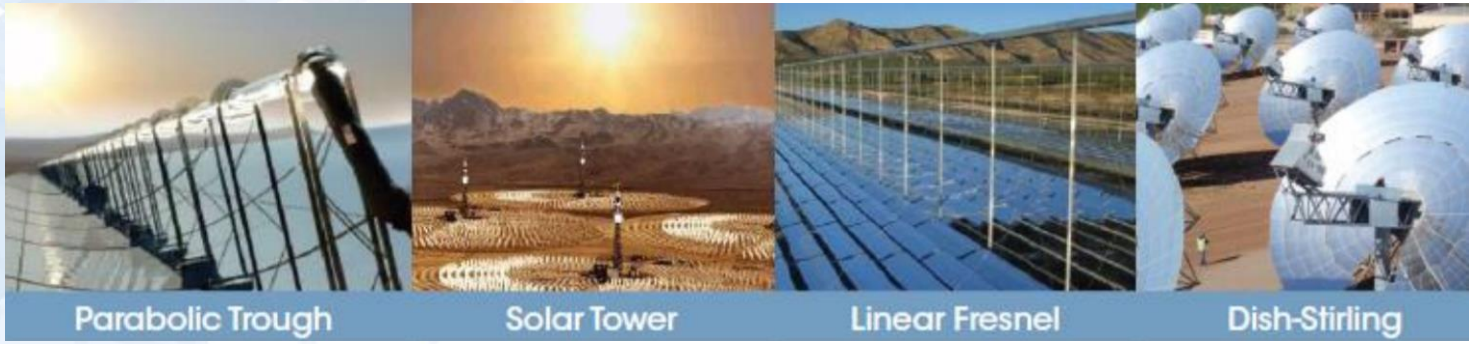
Lowest total installed commercial PV costs in Germany and China, at USD 1 100/kW and 1 150/kW, respectively in Q2 2017.

The highest cost market remains California at USD 3 650/kW

Source: IRENA Renewable Cost Database.

CSP Technology

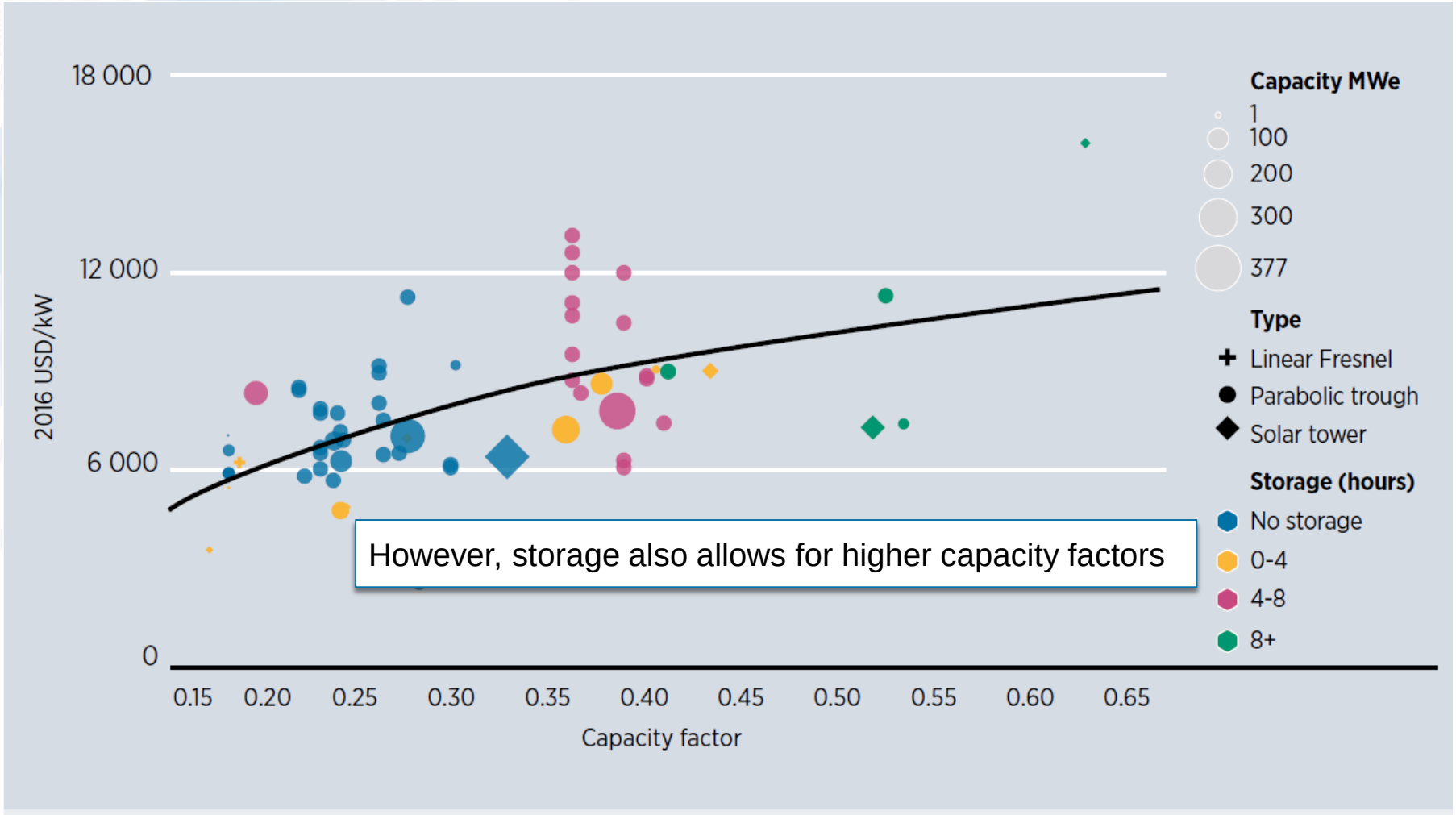
Total installed costs for plants with thermal energy storage tend to be higher than without



- Deployment is still low compared to other technologies (~5 GW)
- Cost reduction potential is good.
  IRENA analysis is focusing on parabolic trough (PT) and solar tower (ST)
- Solar towers have greater cost reduction potential with higher operating temperatures and lower cost thermal energy storage
- Cheap thermal energy storage allows dispatchable power
  -> potentially more valuable generation (particularly in high RE scenarios)

Installed cost trends CSP

Total installed costs for plants with thermal energy storage tend to be higher than without



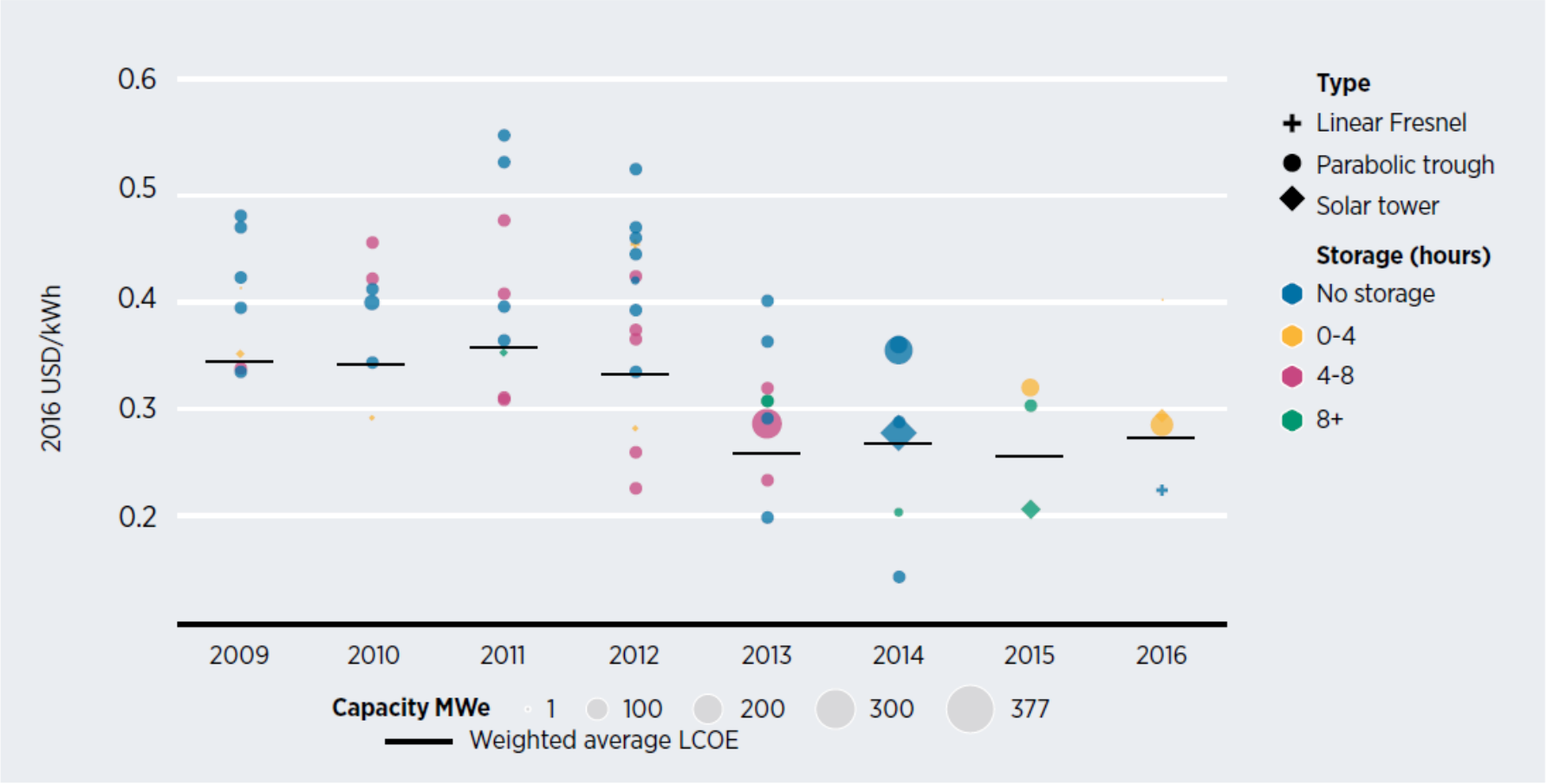
Total installed costs for CSP plants can range between USD 2 550 and USD 11 265/kW for systems with no storage

Adding four to eight hours of storage, however, can see this range increase to between USD 6 050 and USD 13 150/kW

Source: IRENA Renewable Cost Database.

LCOE cost trends of CSP

A downward trend in LCOE started in 2012 with geographical shift away from Spain



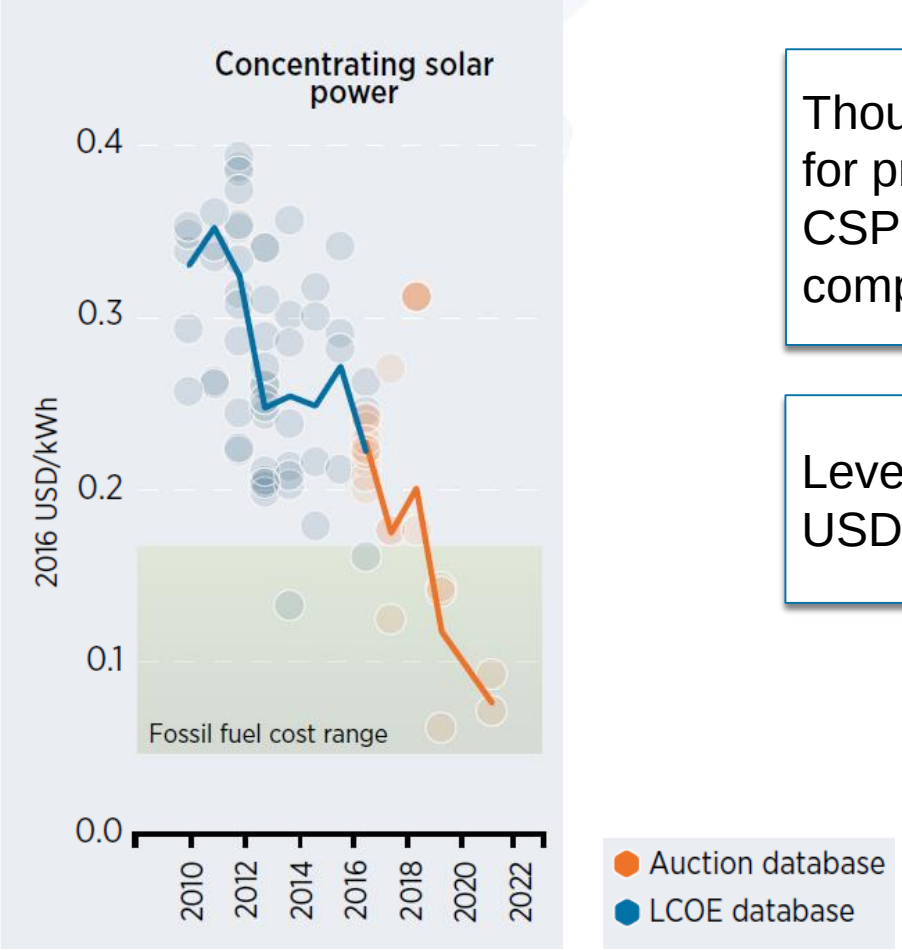
Source: IRENA Renewable Cost Database.

The weighted average LCOE of CSP plant during 2016 was estimated to be USD0.27/kWh (a fifth lower than in 2009)

IRENA data also suggests a weighted average LCOE of USD 0.22/kWh during 2017 (with total installed costs of about USD 5 550/kW

LCOE cost trends of CSP

A decreasing trend can be expected moving forward



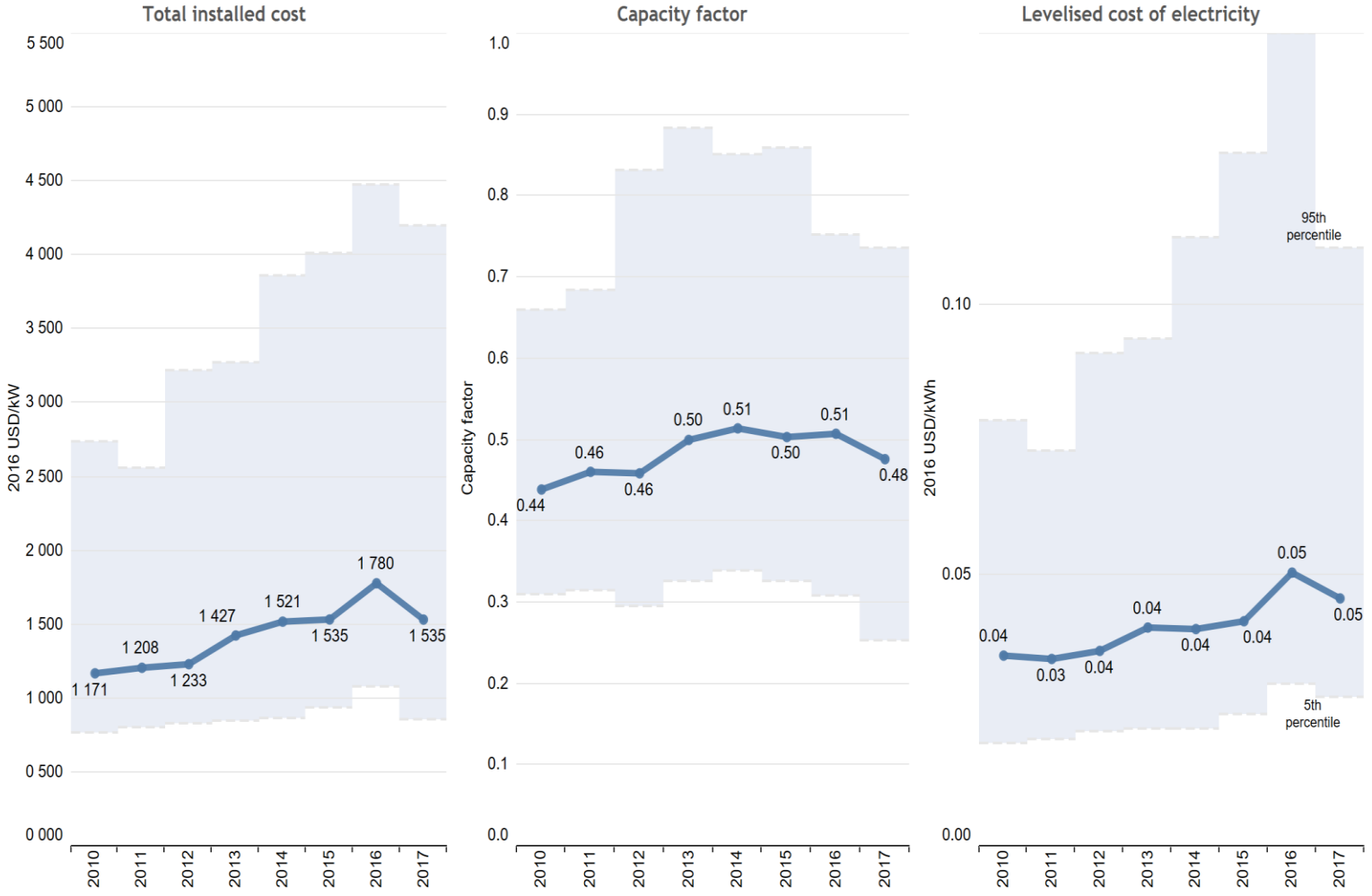
Source: IRENA Renewable Cost Database.

Though not directly comparable, recent auction results for projects to be commissioned in 2020-2022 point to CSP projects being capable of providing electricity very competitively compared to fossil fuels.

Levelised costs of electricity values in the range of USD 0.06-0.10/kWh can be expected for that period.

Hydropower trends

Hydropower produces some of the lowest-cost electricity of any generation technology and is the largest source of renewable electricity generation today (3 996 TWh in 2015).

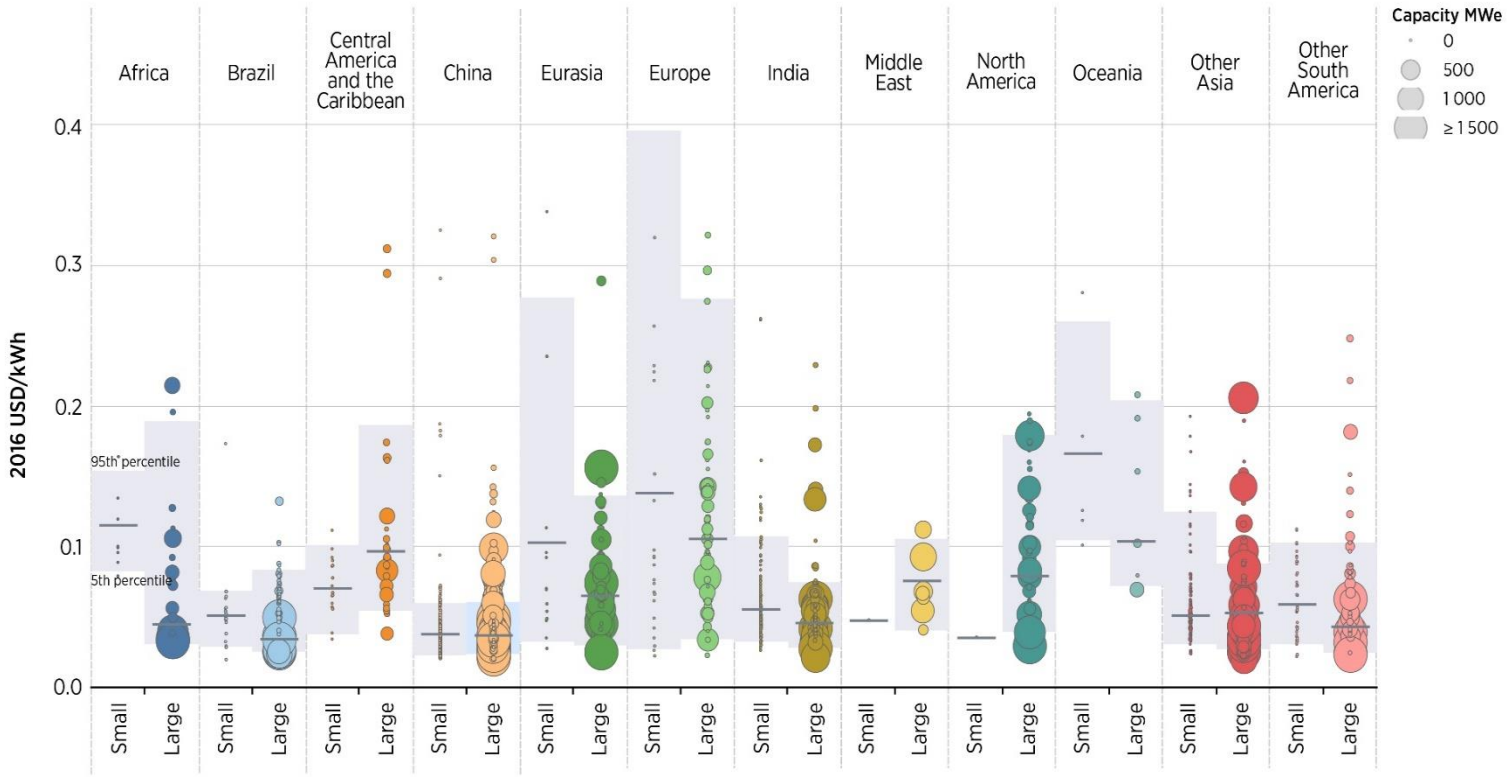


- Deployment has accelerated in Asia and South America. Development in logistically challenging locations reflected in CAPEX & LCOE increases.

- The LCOE of large-scale hydro projects at excellent sites can be as low as USD 0.02/kWh
- The global weighted in 2017 average was USD 0.047/kWh

Hydropower – regional LCOE

The weighted average LCOE is below USD 0.10/ kWh for almost all regions, ranging between USD 0.04 and 0.06/ kWh.

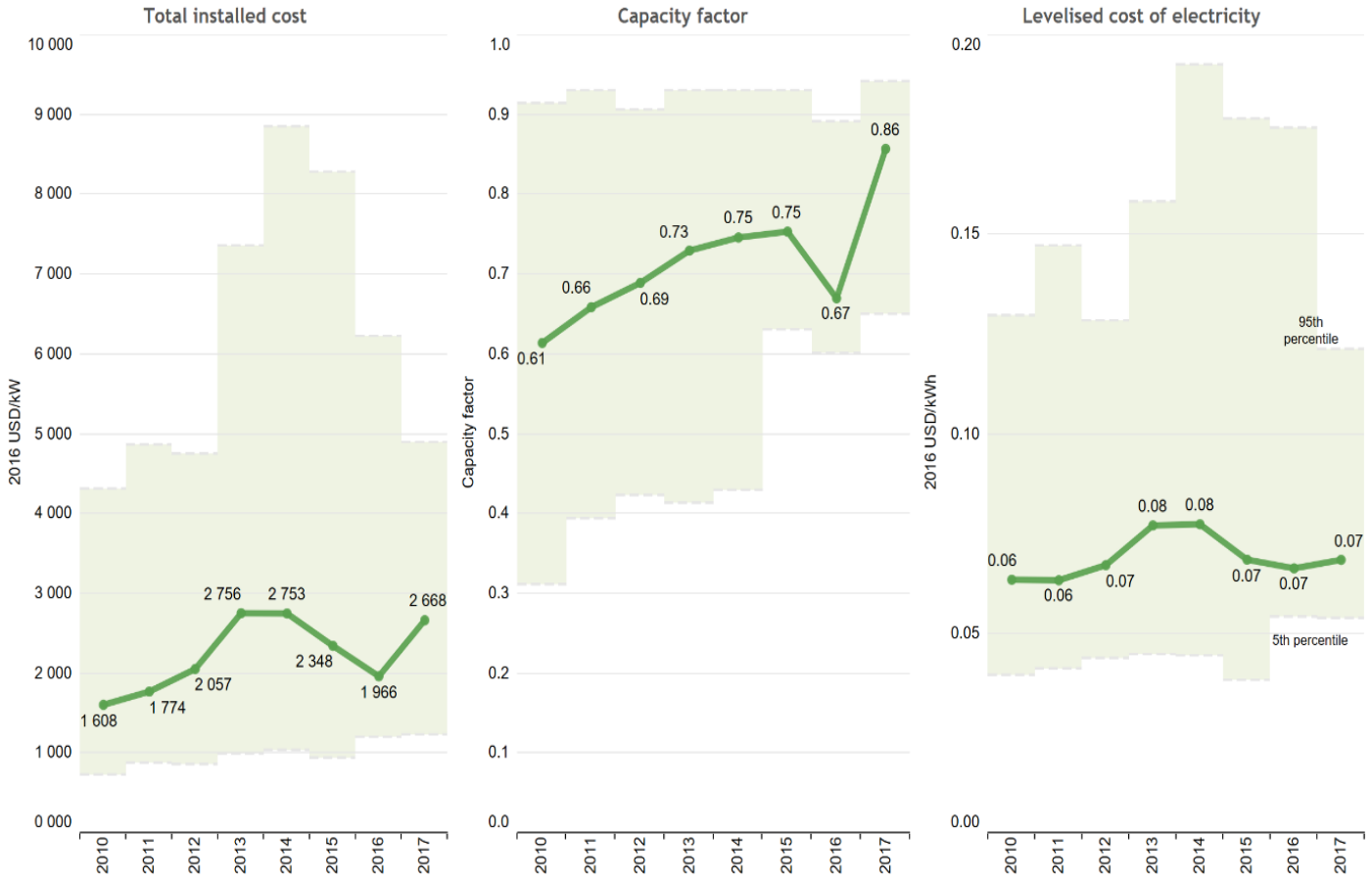


- The weighted average country/regional LCOE of all projects, large and small, ranged from a low of USD 0.04/kWh in Brazil to a high of USD 0.11/kWh in Europe.

- The LCOE of small hydro plants is usually higher than the LCOE of large hydro plants, by 10%-40%.

Bioenergy trends

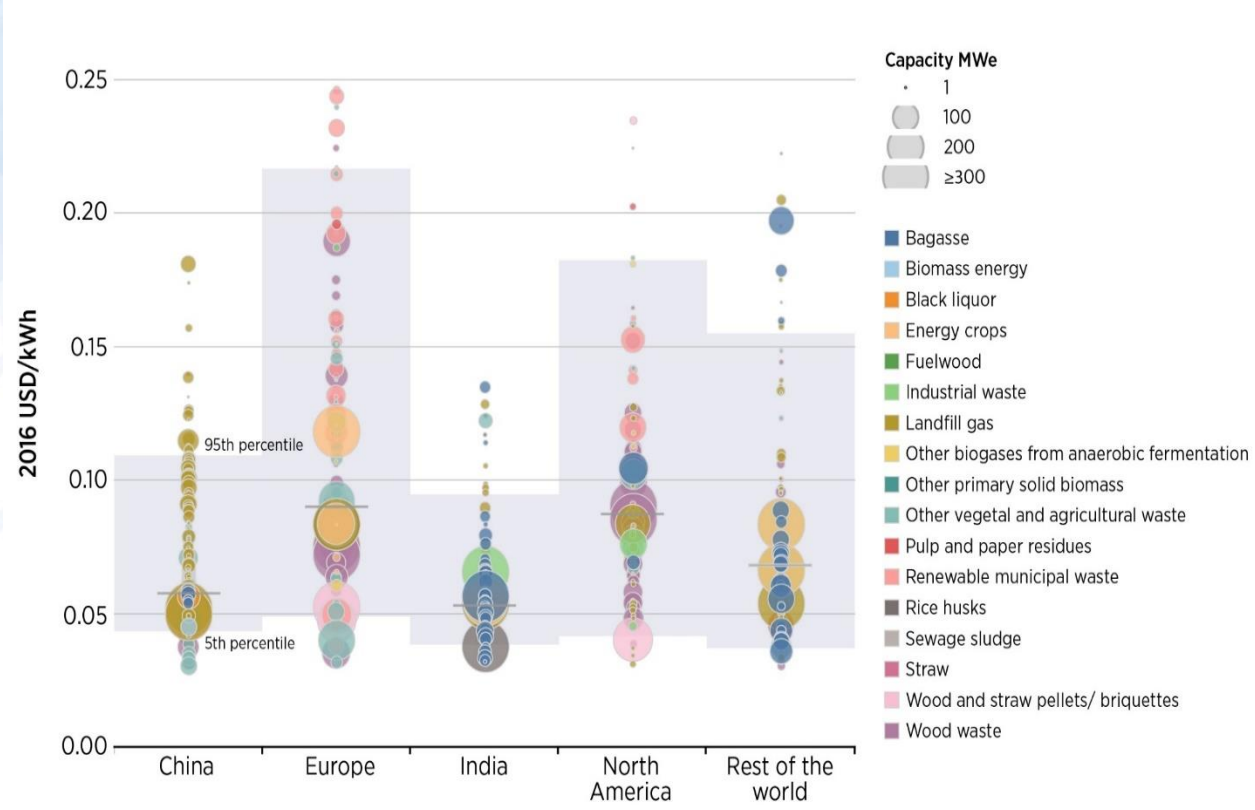
Deployment of new bioenergy projects for power is smaller than for hydro, PV and wind and results in more year-to-year volatility in the characteristics of newly commissioned projects.



- Shift to more sophisticated, bioenergy plants capable of performing with a range of heterogenous feedstocks
- LCOE of newly commissioned bioenergy projects has increased over time reflecting more sophisticated technology choices.

Bioenergy – regional LCOE

The wide range of bioenergy-fired power generation technologies and feedstock costs translates into a broad range of observed LCOEs for bioenergy-fired electricity

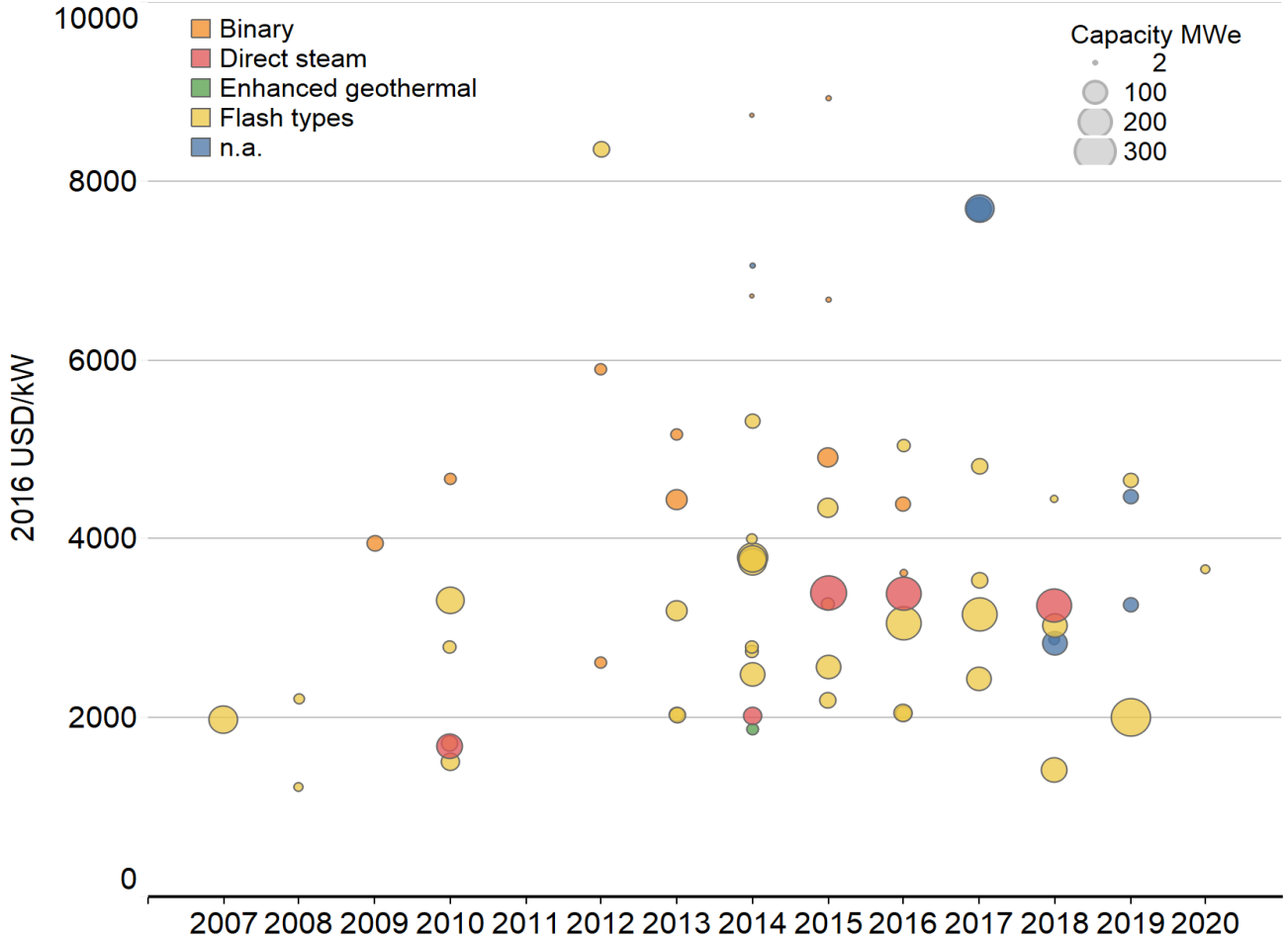


- Where capital costs are relatively low – and low-cost feedstocks are available – bioenergy can provide competitively priced, dispatchable electricity generation with an LCOE as low as around USD 0.04/kWh.

- The weighted average LCOE in Europe and North America is higher, at around USD 0.08/kWh-USD 0.09/kWh, reflecting more advanced technology choices, stringent emissions controls and higher feedstocks costs.
- The weighted average LCOE of biomass-fired electricity generation is around USD 0.05/kWh in India and USD 0.06/kWh in China mainly due to less expensive technology choices and cheaper feedstocks

Geothermal trends

LCOE of geothermal projects appears to be trending downwards

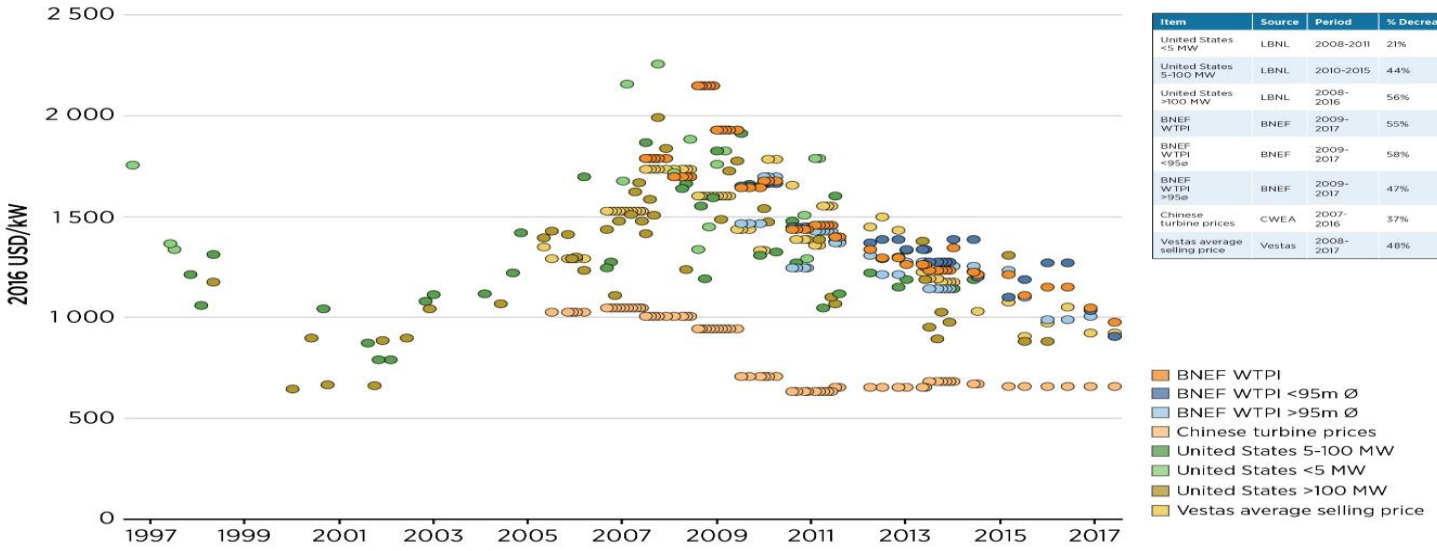


- Between 2007 and 2014, the trend in LCOE was increasingly in line with rises in capital costs accounted for by costs increases in engineering and EPC and in drilling associated with surging oil and gas markets.

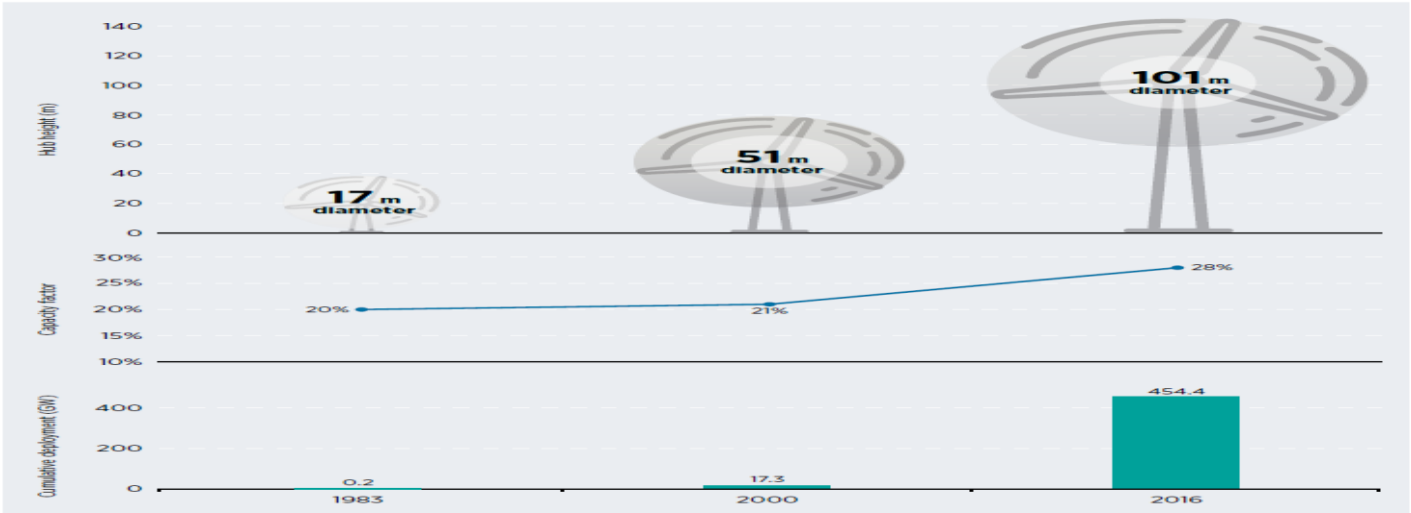
- For projects commissioned in 2014 and up to 2020, the LCOE of geothermal power plants appears to be trending downwards, in line with the general decrease in total installed costs observed.

Wind trends

Wind turbine costs have declined significantly while capacity factors have increased due to better technology (higher hub heights and rotor diameters)



Item	Source	Period	% Decrease
United States <5 MW	LBNL	2008-2011	21%
United States 5-100 MW	LBNL	2010-2015	44%
United States >100 MW	LBNL	2008-2016	56%
BNEF WTPI	BNEF	2009-2017	55%
BNEF WTPI <95ø	BNEF	2009-2017	58%
BNEF WTPI >95ø	BNEF	2009-2017	47%
Chinese turbine prices	CWEA	2007-2016	37%
Vestas average selling price	Vestas	2008-2017	48%

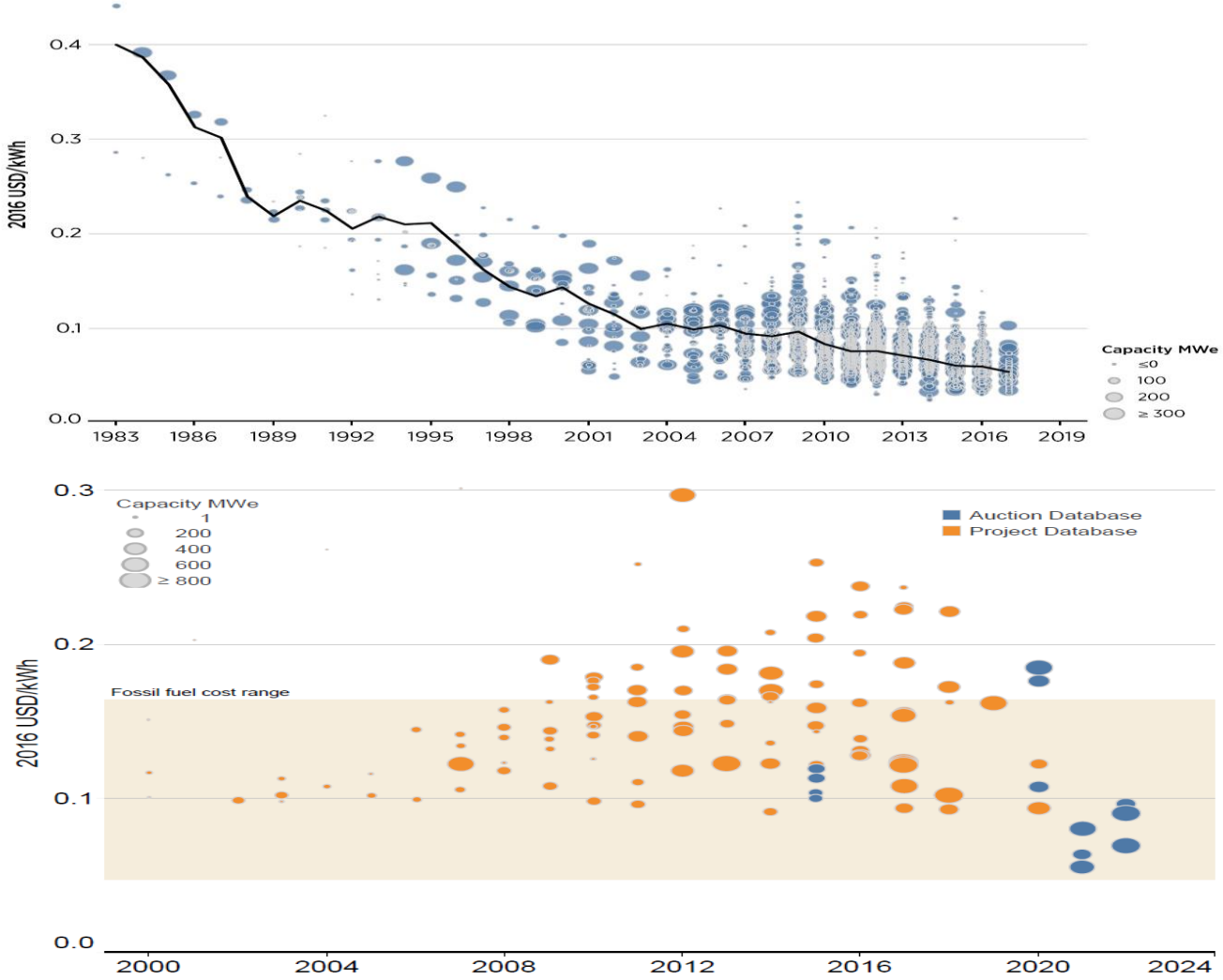


Source: IRENA Renewable Cost Database.

- Globally, wind turbine costs have declined by half, on average, in 2017 in comparison to peaks observed between 2007 – 2009
- Rotor diameters and hub heights have doubled from 2000 to 2016
- Capacity factors have increased by a third from 2000 to 2016
- Installed capacity increased by 26 times from 2000 to 2016

Wind – Global LCOE

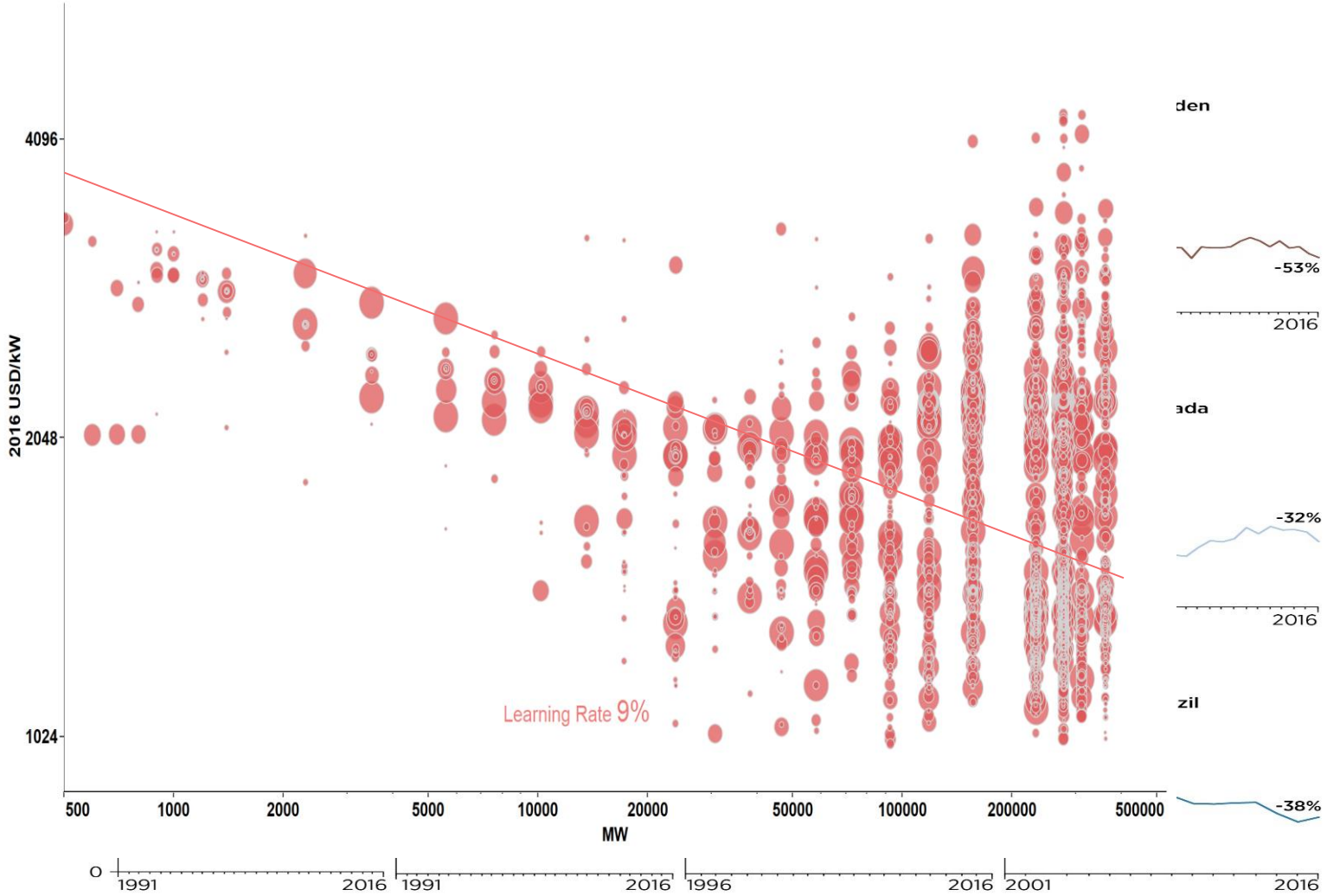
LCOE of onshore is estimated at USD 0.06/kWh in 2017 while LCOE of offshore is USD 0.14/kWh



- Globally, the LCOE of onshore wind declined by 85% from 1983 to 2017
- Globally, the LCOE of offshore wind declined by 18% from 2010 to 2016
- Offshore wind auction in 2016 and 2017 will deliver projects in the range of USD 0.06 to USD 0.10/kWh by 2020 to 2022

Onshore wind learning curve

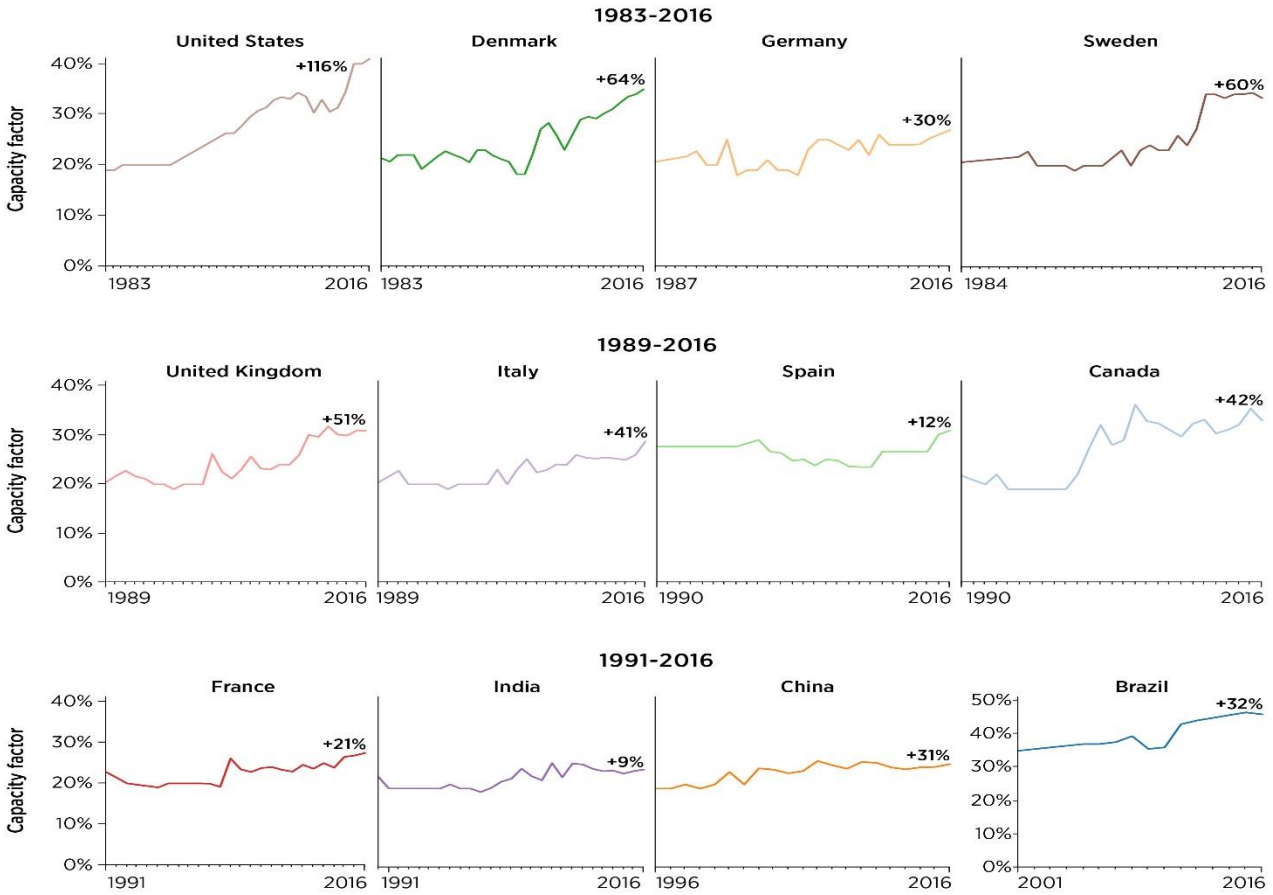
Onshore wind installed costs have declined significantly in all sampled countries



- Installed costs fell the most, 68% in the United States, 53% in Denmark and 50% in Germany, key early adopters
- In the second wave of deployment, installed costs declined the most in Spain by 52%
- India and China have seen cost reductions of 56% and 67% respectively.

Onshore wind learning curve

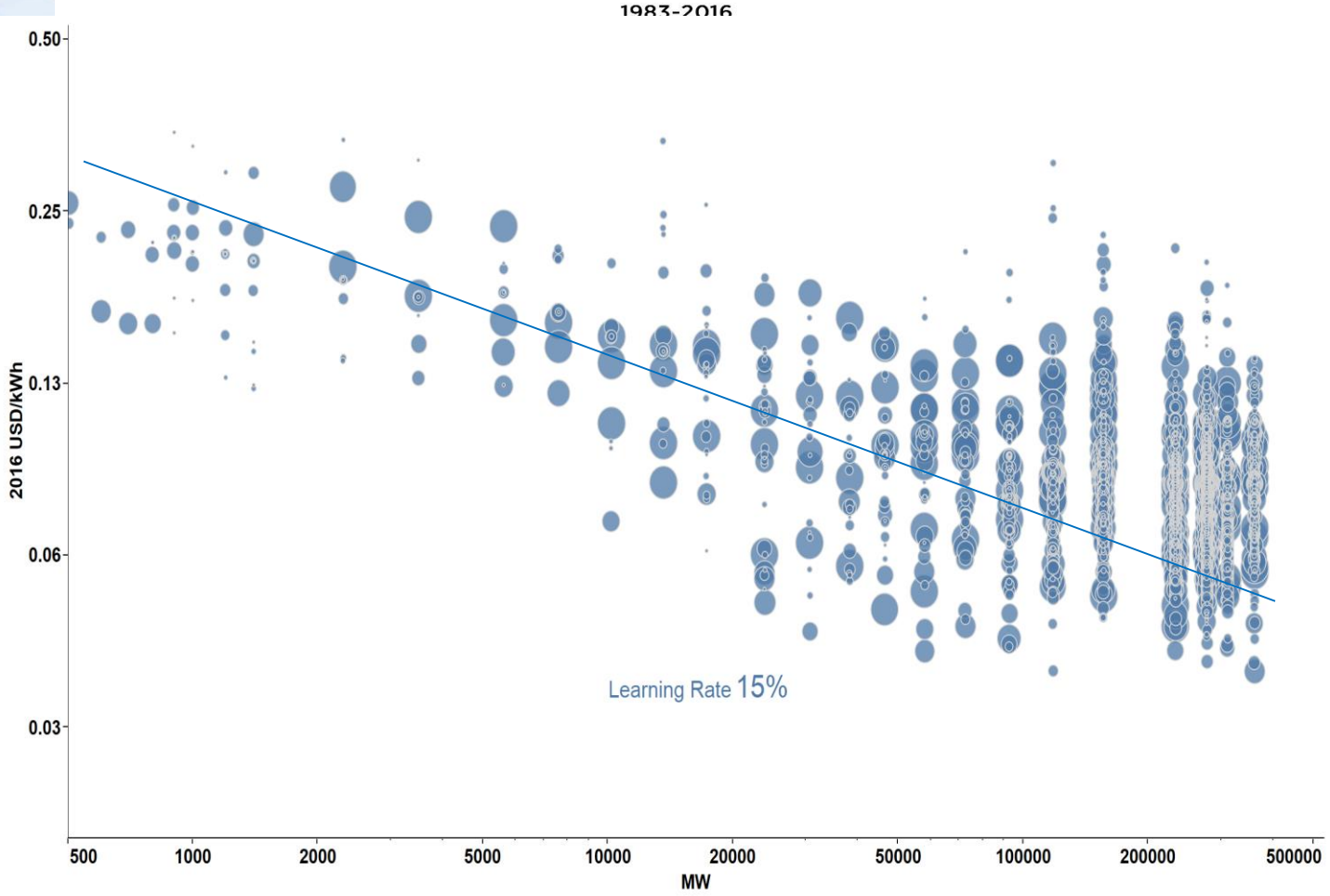
Capacity factors have increased in all sampled countries



- Capacity factors have increased, on average, from around 20% in 1983 to 28% in 2016
- Capacity factors more than doubled in the US in the same time frame while in Denmark they increased by 64%
- Sweden has also seen a significant increase in capacity factors, 60%

Onshore wind learning curve

The LCOE of onshore wind has declined significantly in all sampled



- United States and Denmark have seen the largest LCOE declines, from 1983 to 2016, 89% and 81% respectively.
- Depending on the start date, other significant LCOE declines are India (77%), China (71%) and United Kingdom (79%)

FROM COSTS TO ANALYSIS: IRENA COST AND COMPETITIVENESS INDICATORS: ROOFTOP SOLAR PV

IRENA COST AND COMPETITIVENESS INDICATORS

What are the indicators?

1. PV installed cost trends,

2. Effective electricity rate when the solar PV system is generating, and

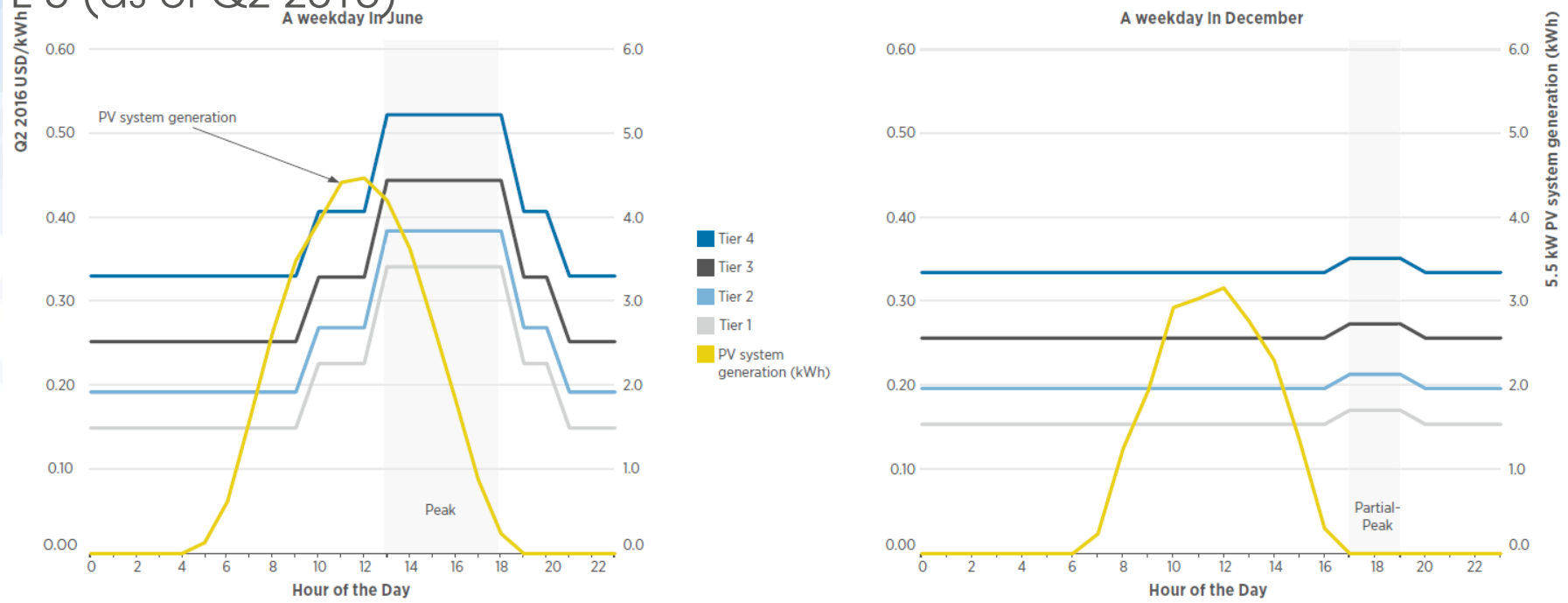
3. The location-specific levelised cost of electricity (LCOE) of the PV system

Rooftop solar PV

IRENA COST AND COMPETITIVENESS INDICATORS

Time-of-use rate schedules can highlight the value of solar PV if not too complex

Electricity rates by tier and PV generation profile in a weekday in June (left) and in December (right) in San Francisco, schedule E-6 (as of Q2 2016)



Source: IRENA analysis based on PG&E, 2016.

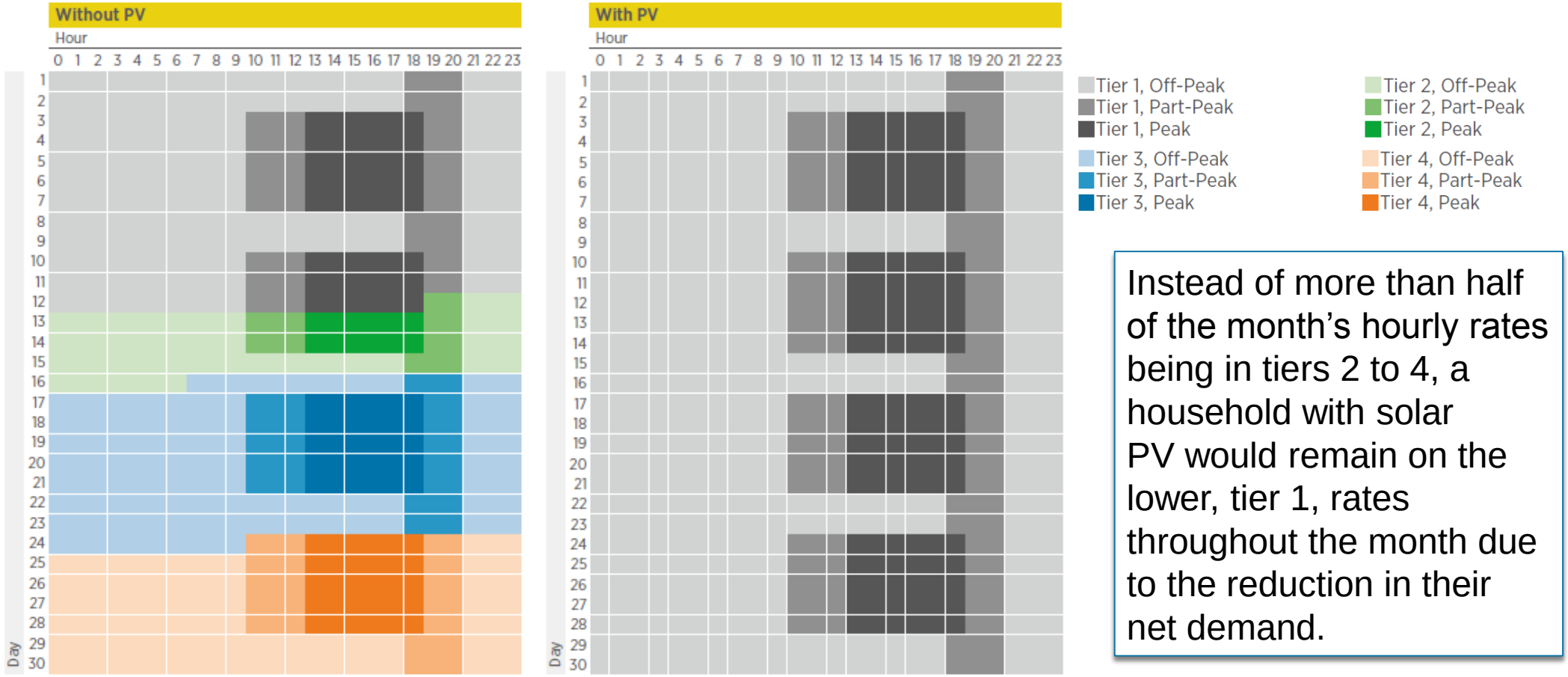
Higher summer electricity rates correspond well with high irradiation months and the overlap with the daily PV production profile

Higher electricity rates are in effect as electricity consumption increases (higher rate “tiers”)

IRENA COST AND COMPETITIVENESS INDICATORS

Solar PV has the potential to shift monthly electricity consumption and avoid the higher charges

Quantity of hours by tier and TOU period in June in San Francisco (schedule E-6) for a modelled household based on net consumption without (left) and with (right) a solar PV

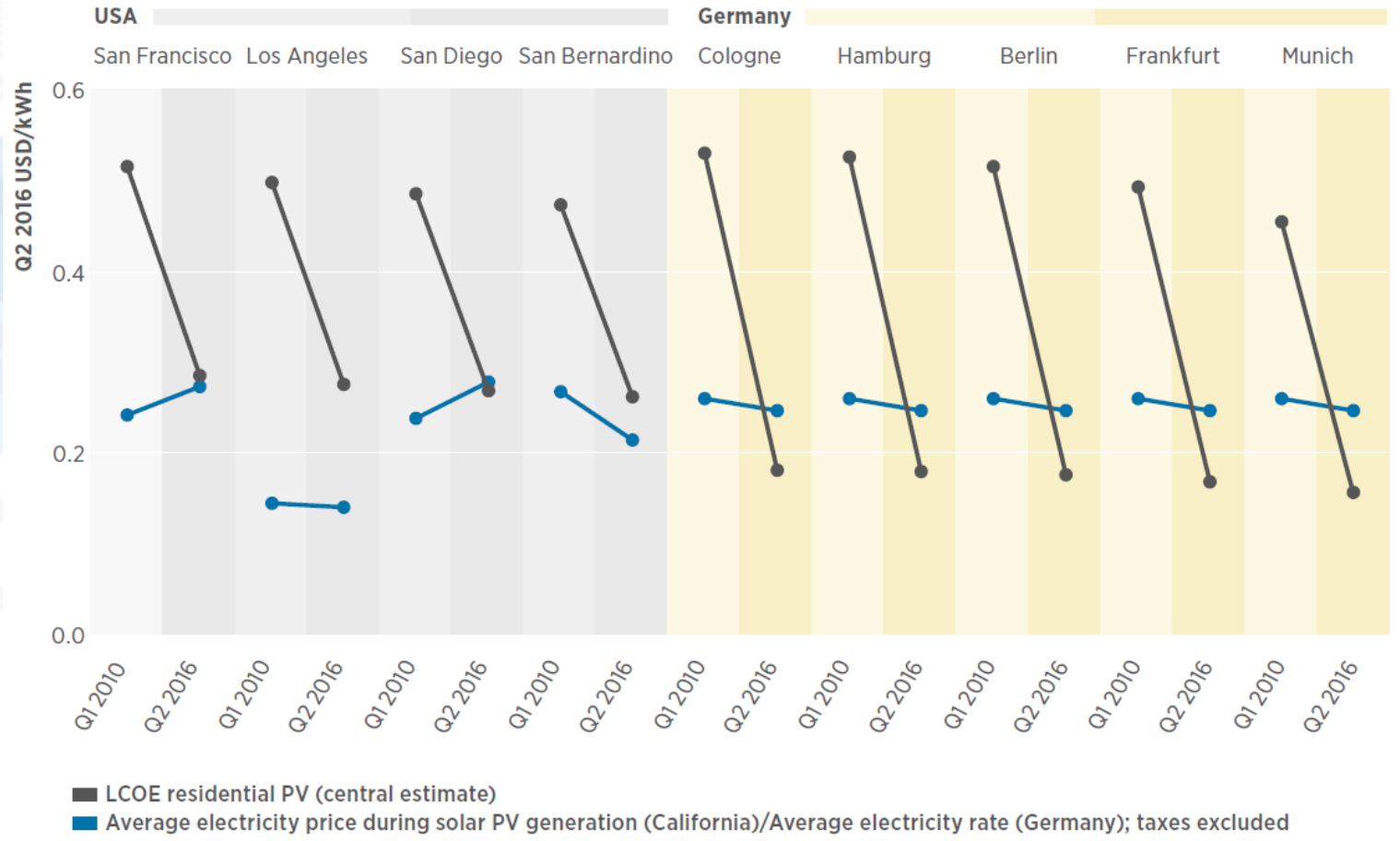


Instead of more than half of the month's hourly rates being in tiers 2 to 4, a household with solar PV would remain on the lower, tier 1, rates throughout the month due to the reduction in their net demand.

Source: IRENA analysis based on PG&E, 2016.

IRENA COST AND COMPETITIVENESS INDICATORS

The costs of electricity from residential rooftop solar PV are falling rapidly



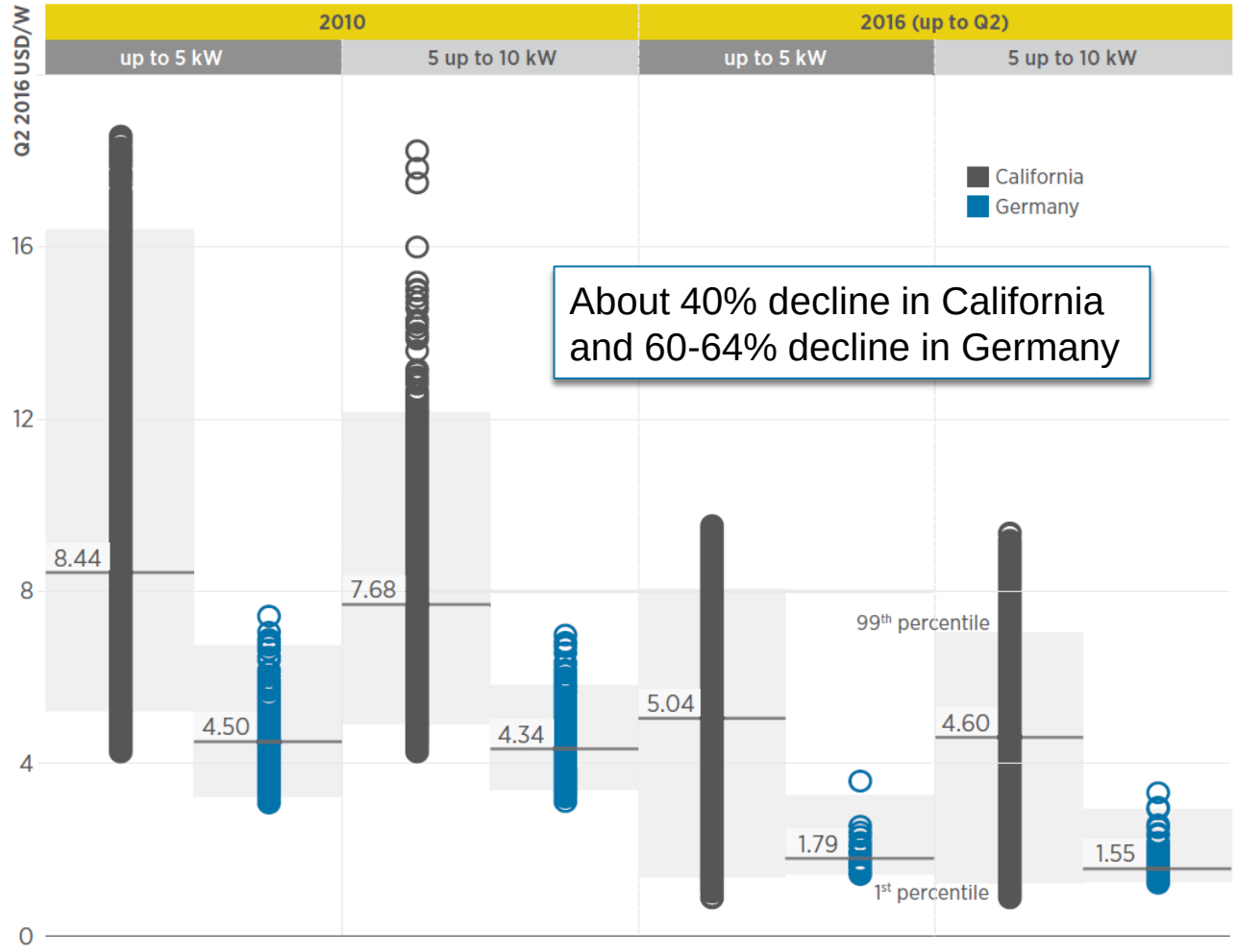
Source: IRENA analysis based on CEC and CPUC, 2016a; LADWP, 2016; PG&E, 2016; SDG&E, 2016; SCE, 2016; BDEW, 2016a.

In just over six years, median LCOE estimates have fallen by and average 45% for cities in California and an average 66% in German cities

The median LCOE of residential solar PV fell below the average effective electricity tariff that applies to these residential customers in six out of the nine cities analysed in this report

IRENA COST AND COMPETITIVENESS INDICATORS

Residential solar PV LCOE reductions, largely driven by total installed cost reductions



About 40% decline in California and 60-64% decline in Germany

Technology improvements in solar PV modules, manufacturing advances, economies of scale and reductions in balance of system costs have driven down PV installed costs

Between 2010 and 2016, the median residential PV system cost declined by around two-thirds in Germany and two-fifths in California

Source: IRENA analysis based on CEC and CPUC, 2016a; EuPD Research, 2017a.

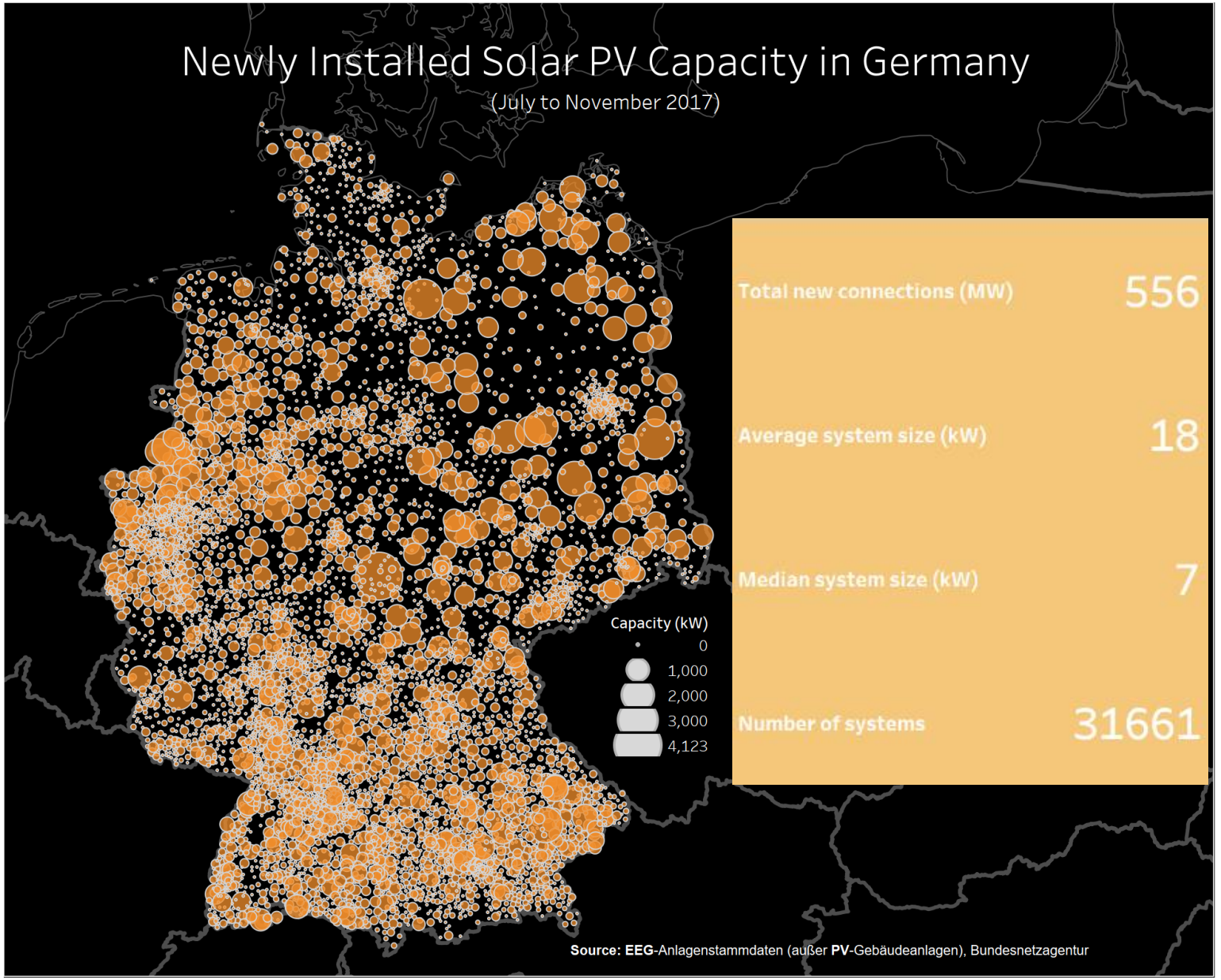
IRENA COST AND COMPETITIVENESS INDICATORS

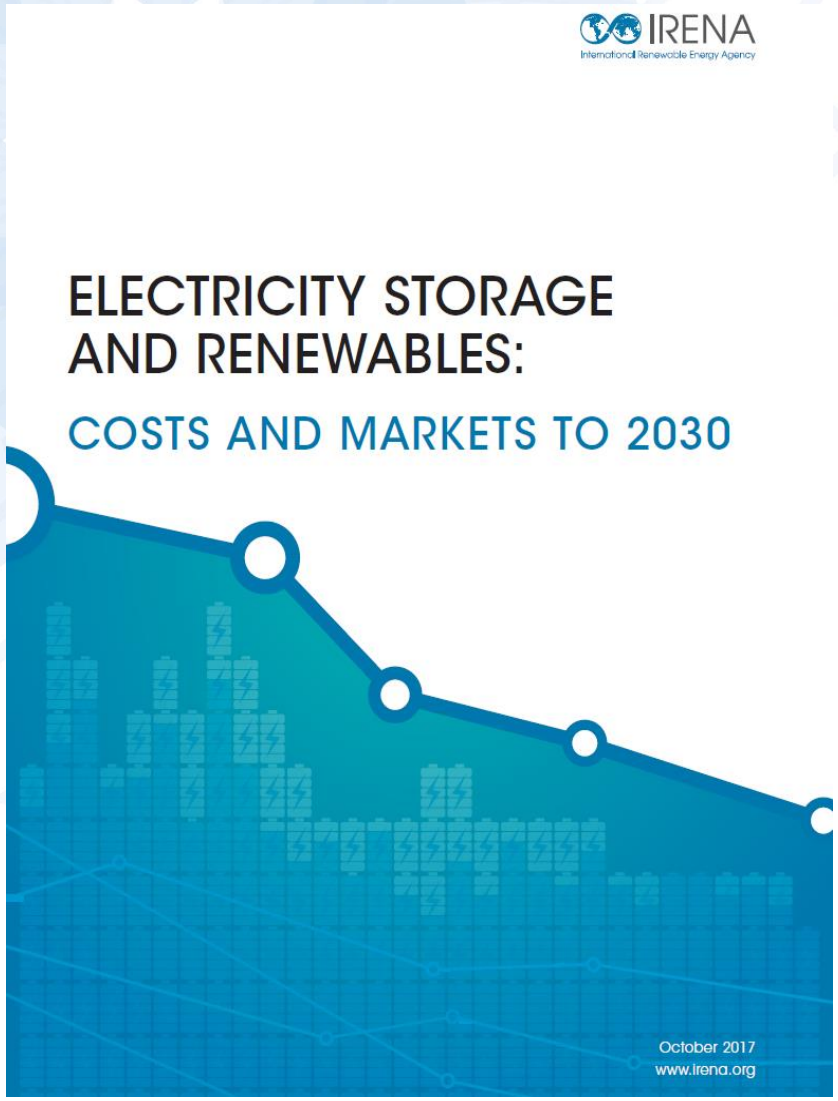
Small-scale PV in German

PV costs have fallen rapidly

Germany has one of the most competitive small-scale solar PV markets in the world

Solar PV remains an economic option for consumers





ELECTRICITY STORAGE: COSTS & MARKETS TO 2030

AT THE HEART OF THE ENERGY SECTOR TRANSFORMATION

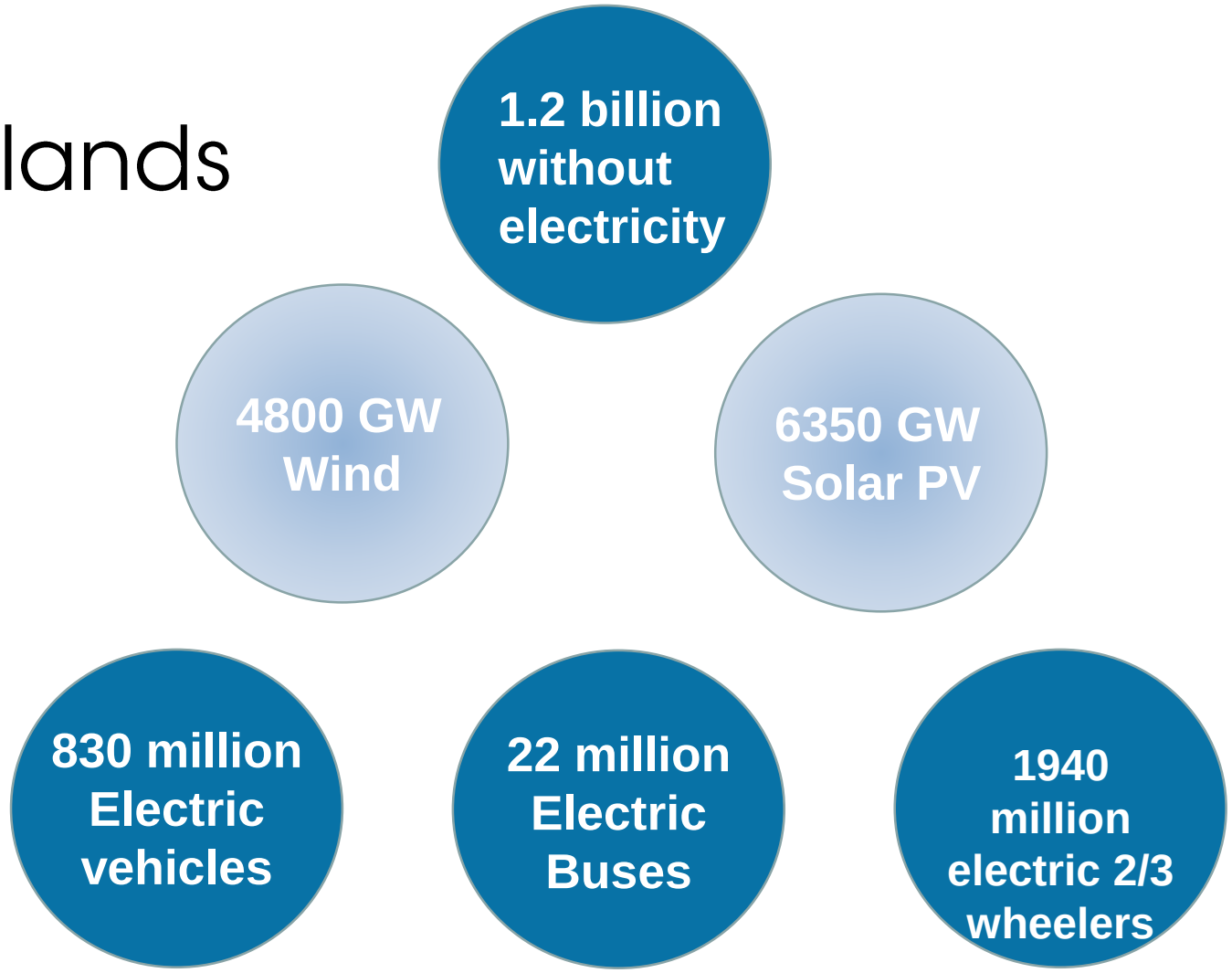
Multiple drivers of electricity storage

2050

Off-grid, mini-grids & islands

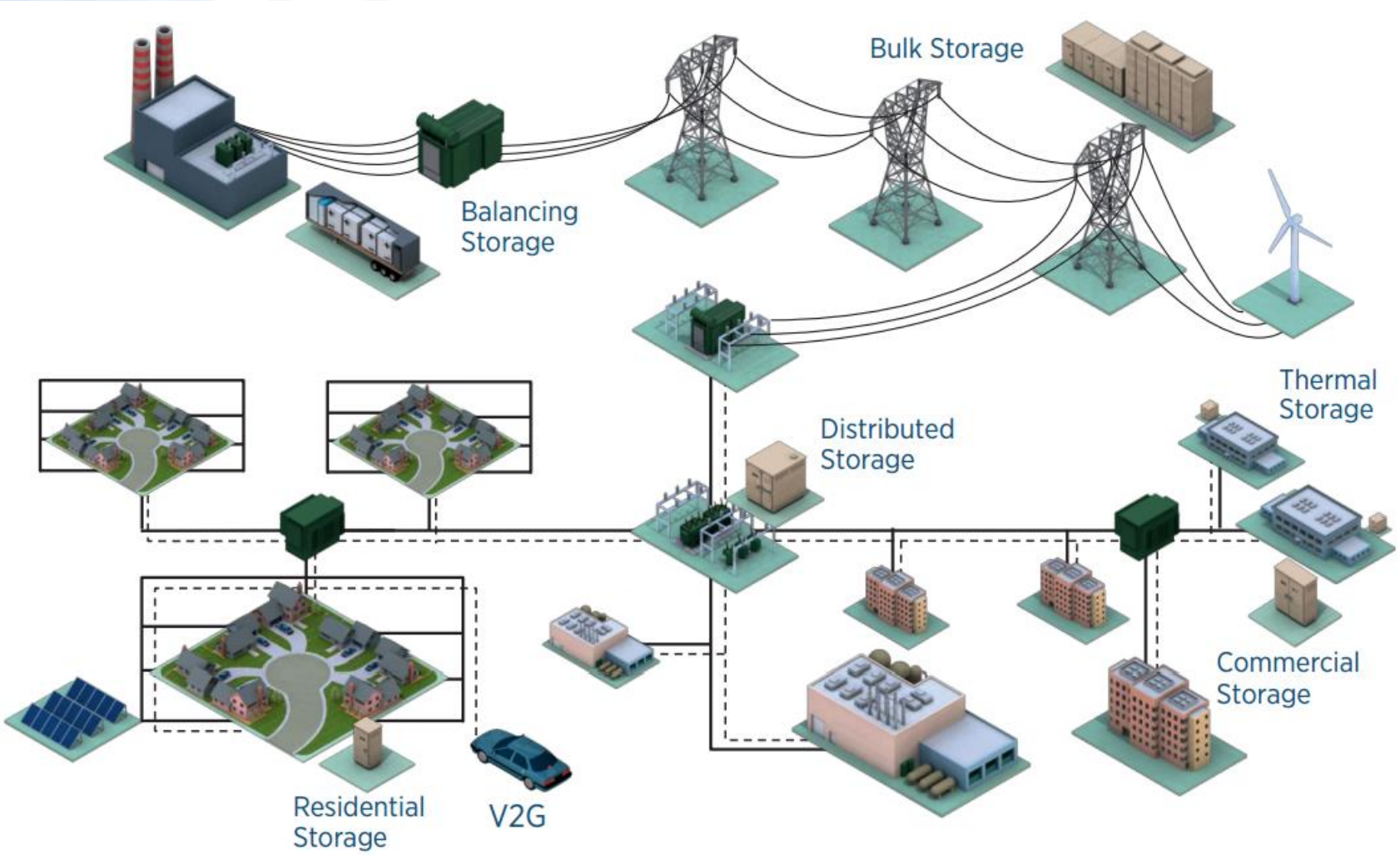
High shares of VRE

Electromobility

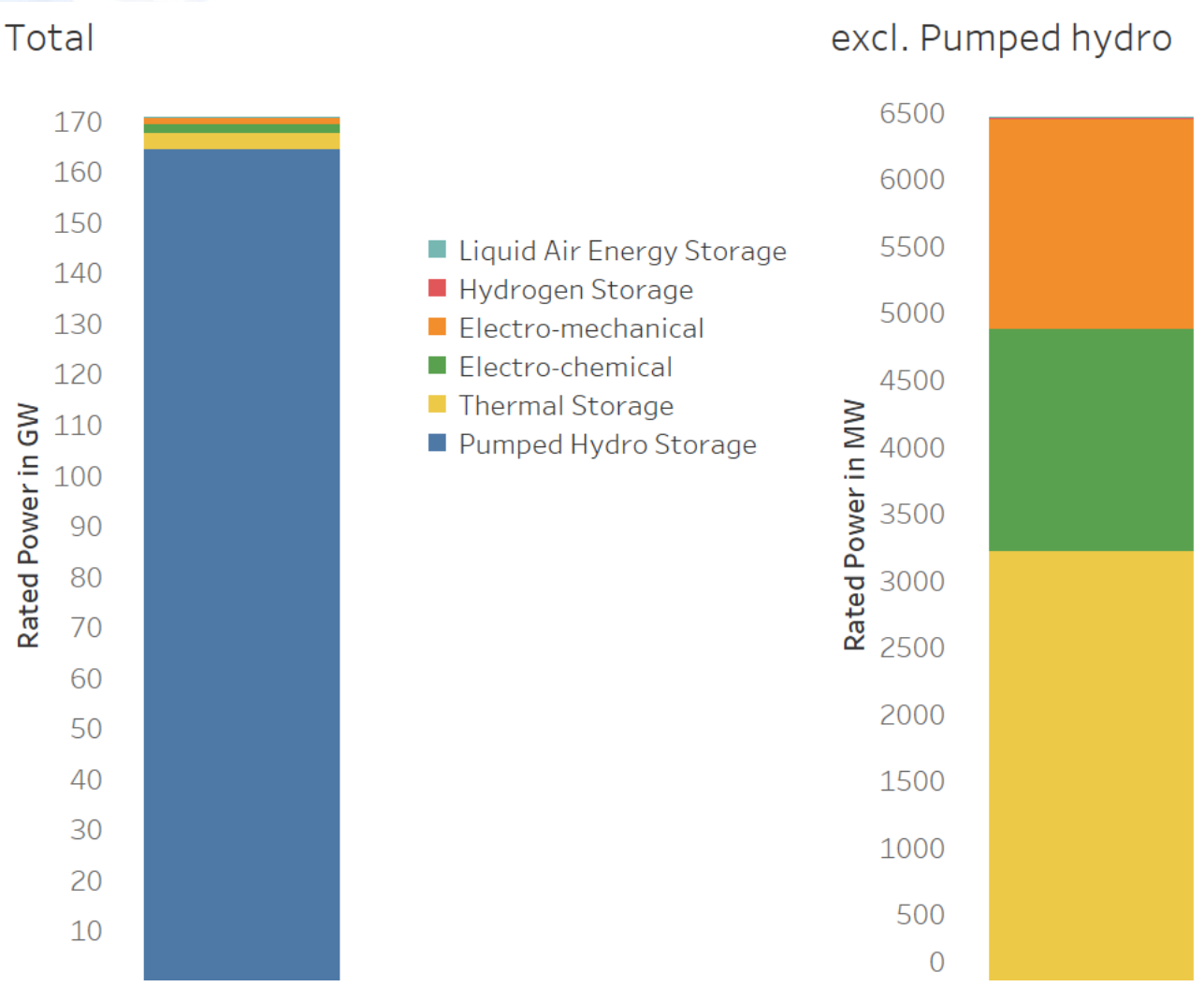


Power systems

Potential locations and applications of electricity storage



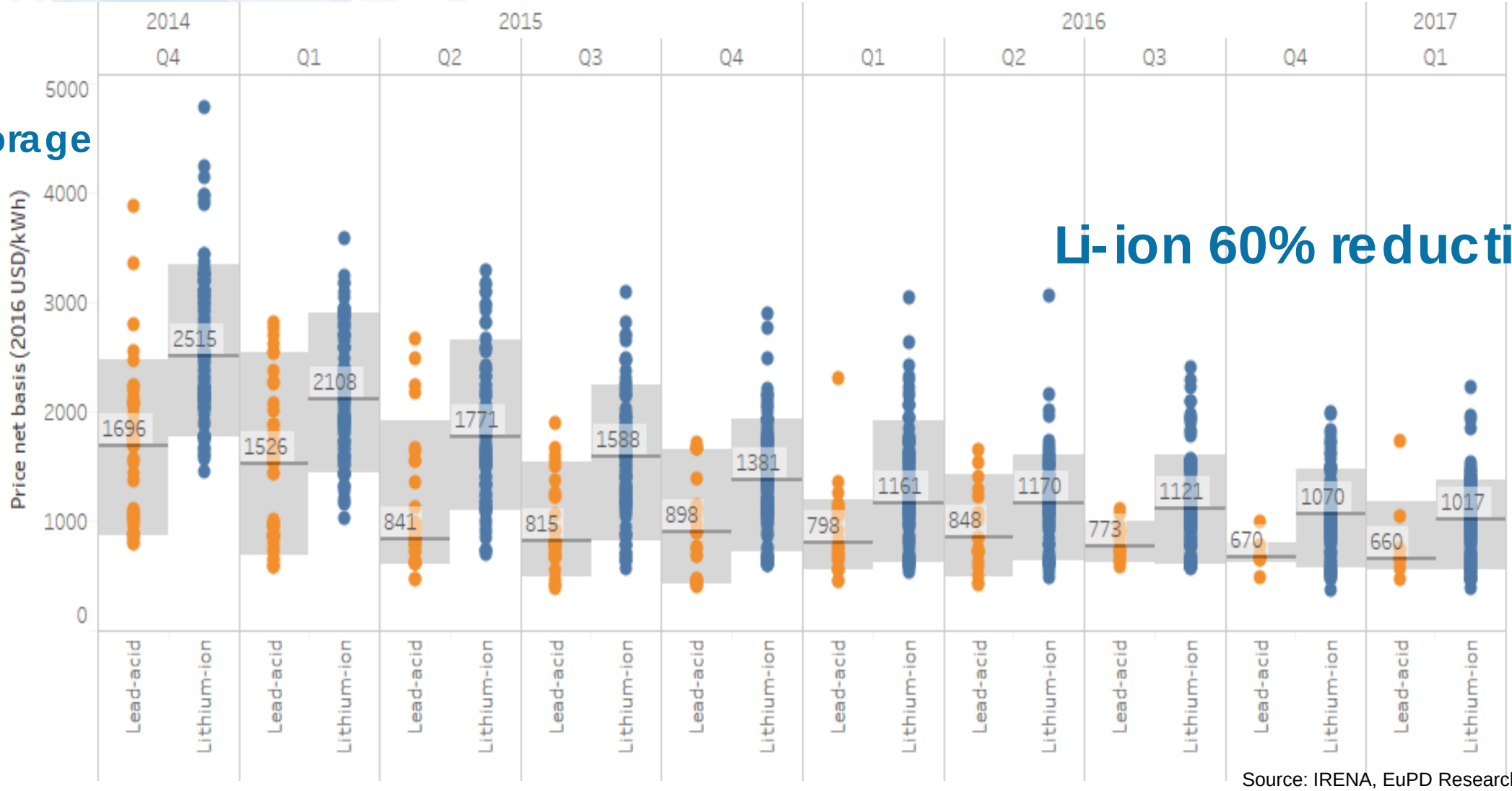
Stationary storage today



- Source: DOE

Small-scale: rapidly falling prices

Home storage



Li-ion 60% reduction!

Source: IRENA, EuPD Research

Median prices for lithium-ion based residential storage system offers in **Germany** have declined roughly 60% Q4 2014 to Q1 2017

Note: Horizontal bar shows median offer price, grey range 10th and 90th percentile.

ELECTRICITY STORAGE FOR STATIONARY APPLICATIONS

KEY FINDINGS

Costs of storage are falling and performance improving to 2030

Installed energy costs to fall 50-66% by 2030

Performance improvements

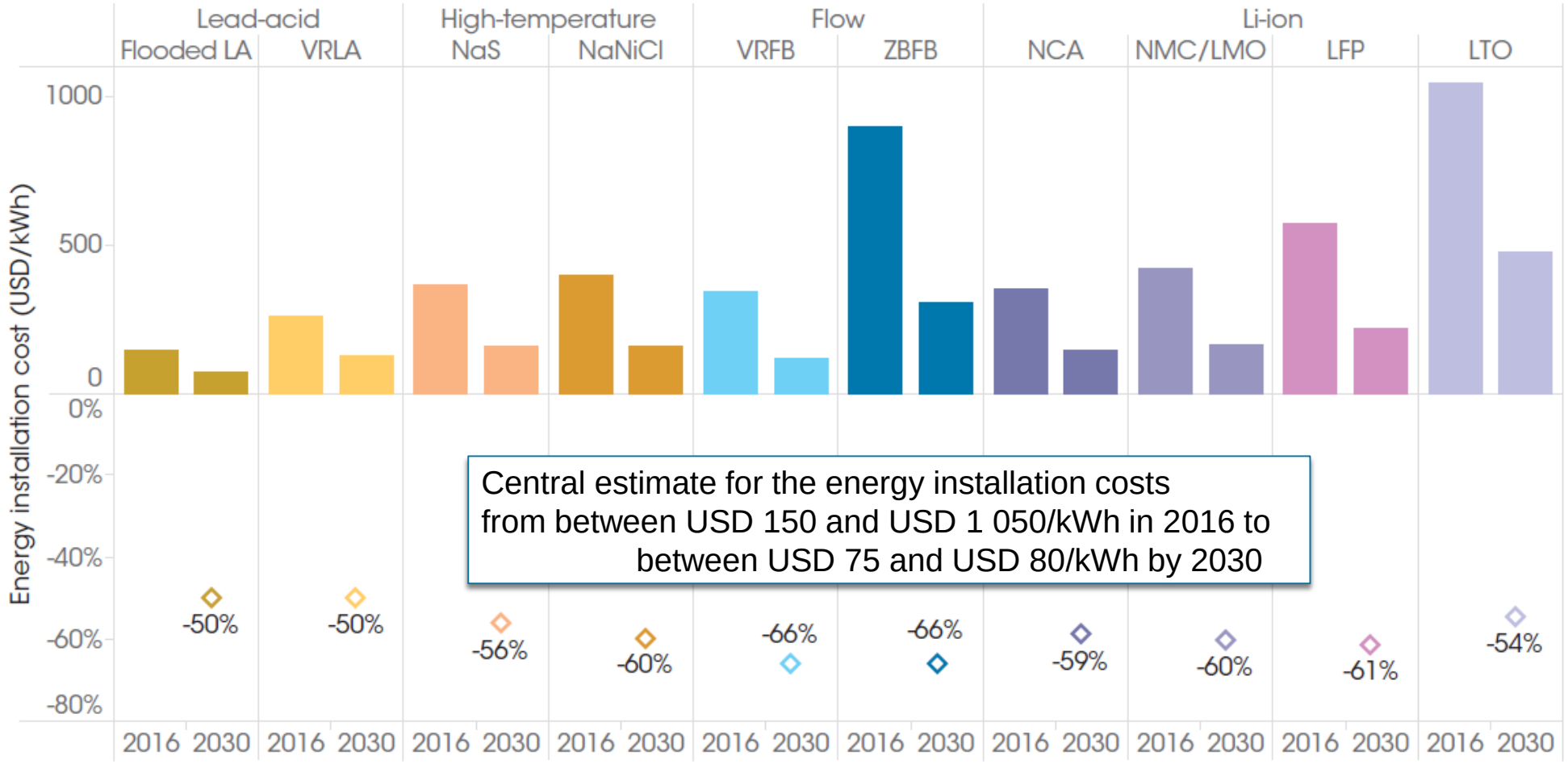
Market to support range of technologies

Overall market for electricity storage to grow 2-3X

Battery storage by 17-38X

Current prices of different storage technologies

Current energy installations costs (USD/ kWh of storage) Reference case 2016



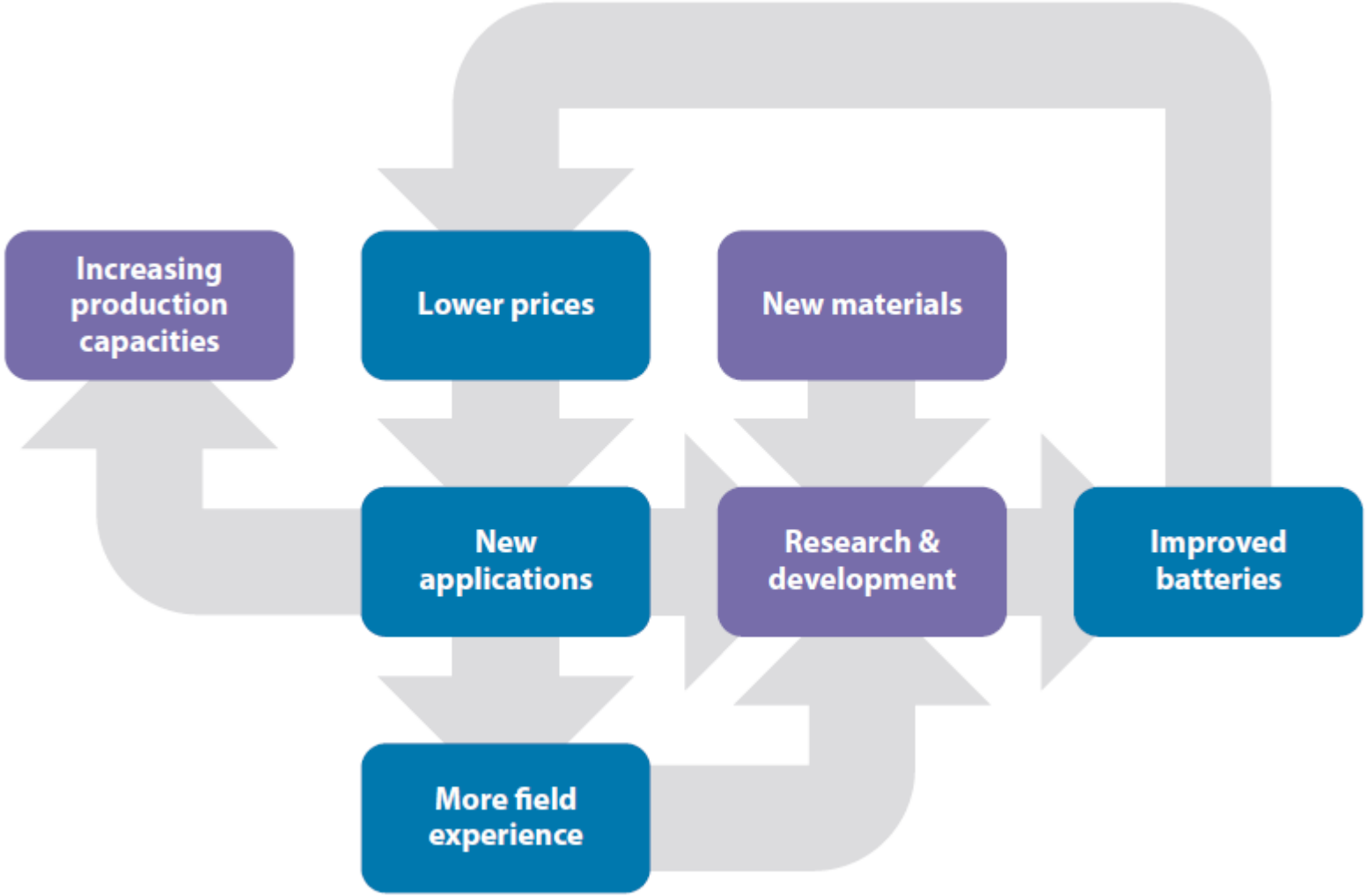
Central estimate for the energy installation costs from between USD 150 and USD 1 050/kWh in 2016 to between USD 75 and USD 80/kWh by 2030

The total installed cost of a Li-ion battery could fall by an additional 54-61% by 2030 in stationary applications

A drop for Li-ion batteries for stationary applications to between USD 145 /kWh and USD 80/kWh

Note: LA = lead-acid; VRLA = valve-regulated lead-acid; NaS = sodium sulphur; NaNiCl = sodium nickel chloride; VRFB = vanadium redox flow battery; ZBFB = zinc bromine flow battery; NCA = nickel cobalt aluminium; NMC/LMO = nickel manganese cobalt oxide/lithium manganese oxide; LFP = lithium iron phosphate; LTO = lithium titanate.

Cost reduction drivers of battery electricity storage systems



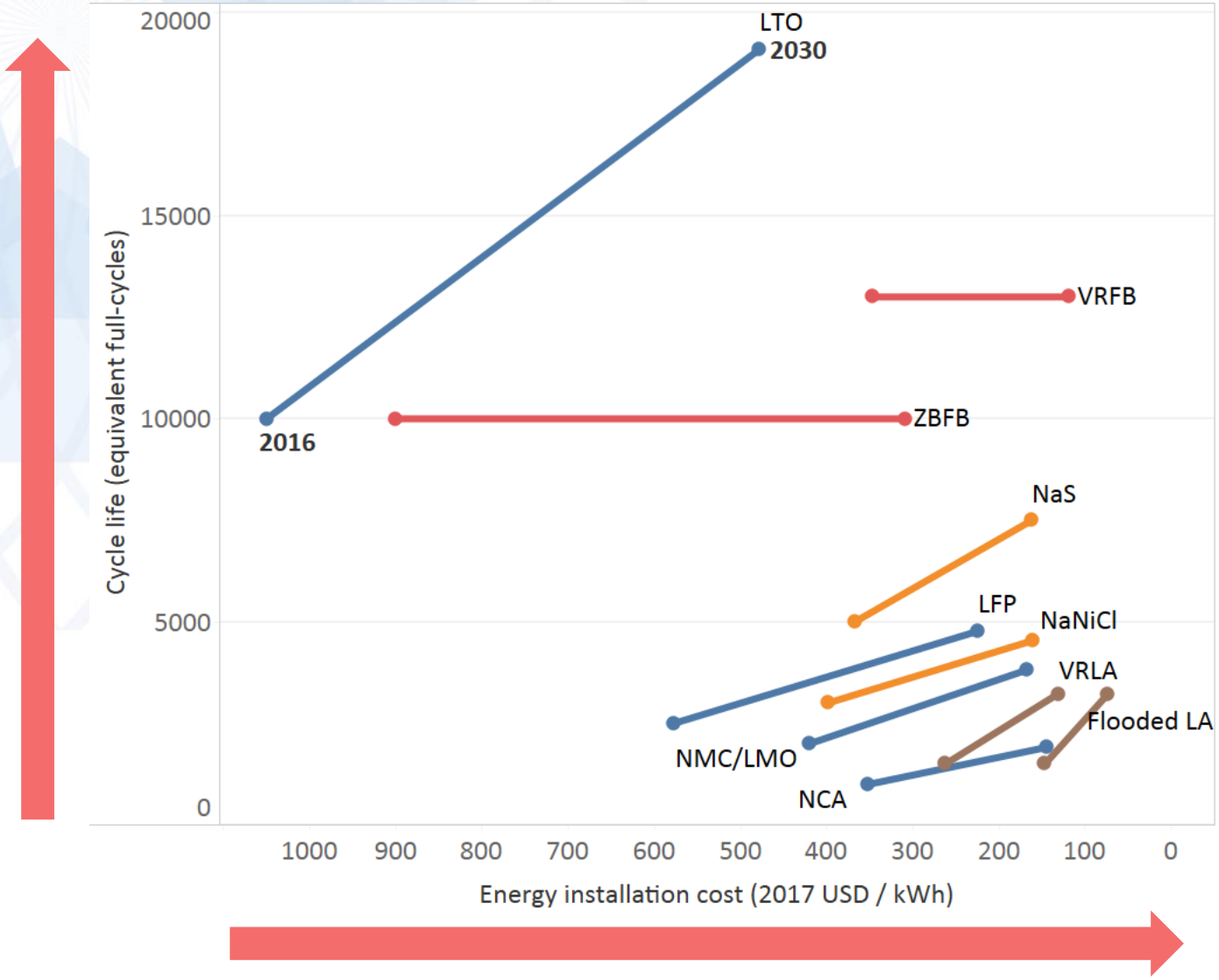
- Drivers are not exclusive to Li-ion, as other storage technologies are likely to experience a similar dynamic as their deployment grows.
- However, with the dominance of Li-ion batteries in the EV market and the synergies in the development of Li-ion batteries for EVs and stationary applications the scale of deployment that Li-ion batteries likely to be of magnitude higher than for other battery technologies.

Main drivers: Lithium-ion

- Differentiation between 4 different technologies
  - NMC/LMO, NCA, LFePO4 and Titanate
- International transition towards electro mobility leads to substantial scale effects (NCA NMC/LMO)
  - 70% price reduction since 2012
- > 170 GWh / year production capacities projected for 2020
  - Tesla Gigafactory / BYD / CALB /…
  - LG Chem / Foxconn / CATL / …

- Innovative developments
  - Mass production
  - Utilize silicon in anode
  - Durable LMO cathodes
  - 5 V electrolytes
  - Lithium-Sulphur
  - Lithium-Air

Cost declines and performance increases for batteries

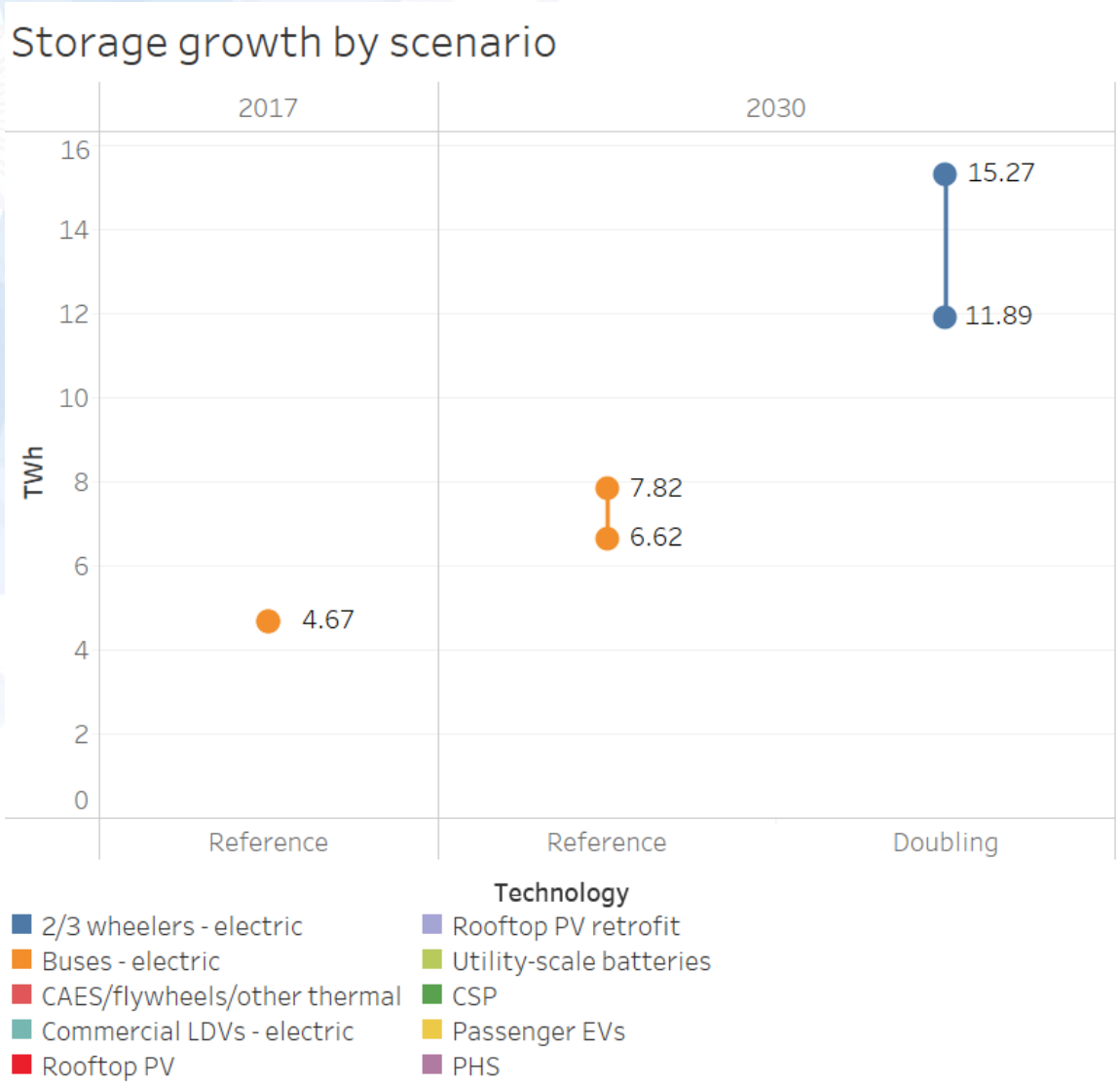


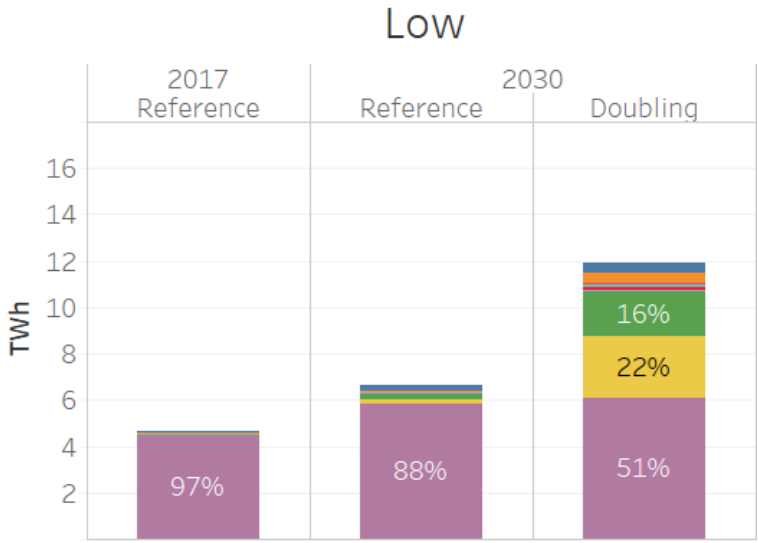
Note: prices shown are for utility-scale stationary applications (EV or small-scale residential applications could have different values)

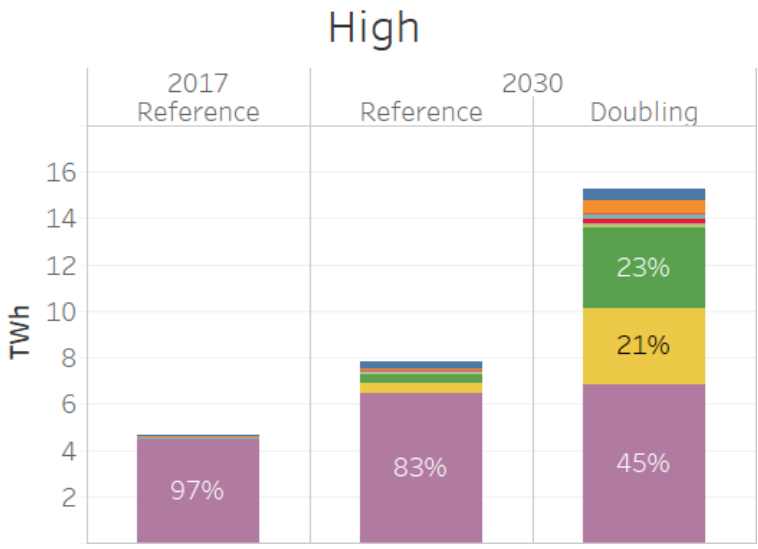
- Flooded LA
- VRLA
- NaNiCl
- NaS
- ZBFB
- VRFB
- NCA
- NMC/LMO
- LFP
- LTO

MARKET OUTLOOK 2030

Growth in the electricity storage market to 2030

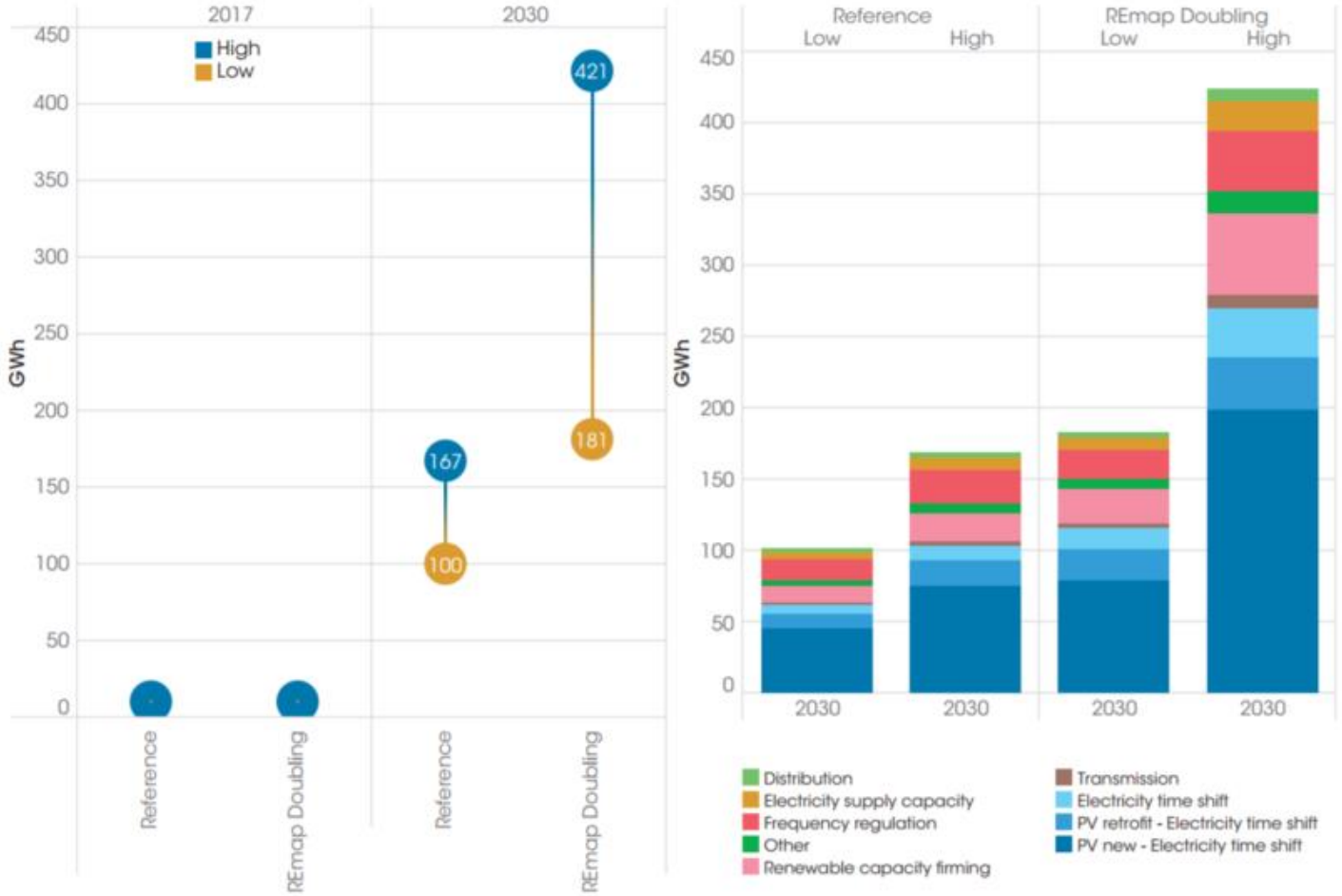






Growth of battery market

Total battery capacity in stationary applications could increase from a current estimate of 11 GWh
to between 100 GWh and 167 GWh in 2030 in the Reference case



In Doubling case, battery capacity can grow to 181-421 GWh by 2030 (at least 17-fold growth from current market)

Electricity storage to 2030

At the heart of the next phase of energy transition

Needed, today tomorrow and in long-term

Cost reductions and performance improvements drive competiveness

EVs likely to dominate, so V2G potentially very important

Different applications, will support different storage technologies

Renewables are increasingly competitive

The winners are customers, the environment and our future

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