Renewable Power Generation Costs in 2017

KEY FINDINGS AND EXECUTIVE SUMMARY

IRENA
International Renewable Energy Agency

KEY FINDINGS

- **After years of steady cost decline for solar and wind technologies, renewable power is becoming an increasingly competitive way to meet new generation needs.**
- For projects commissioned in 2017, electricity costs from renewable power generation have continued to fall.
- **Bioenergy-for-power, hydropower, geothermal and onshore wind projects commissioned in 2017 largely fell within the range of generation costs for fossil-based electricity.**[1] Some projects undercut fossil fuels, data collected by the International Renewable Energy Agency (IRENA) shows.
- The global weighted average cost of electricity was USD 0.05 per kilowatt-hour (kWh) from new hydropower projects in 2017. It was USD 0.06/kWh for onshore wind and 0.07/kWh for bioenergy and geothermal projects.
- The fall in electricity costs from utility-scale solar photovoltaic (PV) projects since 2010 has been remarkable. The global weighted average levelised cost of electricity (LCOE) of utility-scale solar PV has fallen 73% since 2010, to USD 0.10/kWh for new projects commissioned in 2017.
- Three key cost reduction drivers are becoming increasingly important:
    1. technology improvements;
    2. competitive procurement;
    3. a large base of experienced, internationally active project developers.
- **Continuous technological innovation remains a constant in the renewable power generation market.** With today's low equipment costs, however, innovations that unlock efficiencies in manufacturing, reduce installed costs or improve performance for power-generation equipment will take on increasing significance.
- **These trends are part of a broader shift across the power generation sector to low-cost renewables.** As competitive procurement drives costs lower, a wide range of project developers are positioning themselves for growth.
- **The results of recent renewable power auctions – for projects to be commissioned in the coming years – confirm that cost reductions are set to continue through 2020 and beyond**. Auctions provide valuable price signals about future electricity cost trends.
- Record low auction prices for solar PV in Dubai, Mexico, Peru, Chile, Abu Dhabi and Saudi Arabia

1. The fossil fuel-fired power generation cost range for G20 countries in 2017 was estimated to be between USD 0.05 and USD 0.17/kWh.

in 2016 and 2017 confirm that the LCOE can be reduced to USD 0.03/kWh from 2018 onward, given the right conditions.

- **Onshore wind is one of the most competitive sources of new generation capacity.** Recent auctions in Brazil, Canada, Germany, India, Mexico and Morocco have resulted in onshore wind power LCOEs as low as USD 0.03/kWh.
- **The lowest auction prices for renewable power reflect a nearly constant set of key competitiveness factors.** These include: a favourable regulatory and institutional framework; low offtake and country risks; a strong, local civil engineering base; favourable taxation regimes; low project development costs; and excellent resources.
- **Electricity from renewables will soon be consistently cheaper than from most fossil fuels.** By 2020, all the renewable power generation technologies that are now in commercial use are expected to fall within the fossil fuel-fired cost range, with most at the lower end or undercutting fossil fuels.
- **The outlook for solar and wind electricity costs to 2020 presages the lowest costs yet seen for these modular technologies, which can be deployed around the world.** Based on the latest auction and project-level cost data, global average costs could decline to about USD 0.05/kWh for onshore wind and USD 0.06/kWh for solar PV.
- Auction results suggest that concentrating solar power (CSP) and offshore wind will provide electricity for between USD 0.06 and USD 0.10/kWh by 2020.
- **Falling renewable power costs signal a real paradigm shift in the competitiveness of different power generation options.** This includes cheaper electricity from renewables as a whole, as well as the very low costs now being attained from the best solar PV and onshore wind projects.
- **Sharp cost reductions – both recent and anticipated – represent remarkable deflation rates for various solar and wind options.** Learning rates[2] for the 2010-2020 period, based on project and auction data, are estimated at 14% for offshore wind, 21% for onshore wind, 30% for CSP and 35% for solar PV.
- Reductions in total installed costs are driving the fall in LCOE for solar and wind power technologies to varying extents. This has been most notable for solar PV, CSP and onshore wind.

2. The learning rate is the percentage cost reduction experienced for every doubling of cumulative installed capacity.

EXECUTIVE SUMMARY

For new projects commissioned in 2017, electricity costs from renewable power generation have continued to fall. After years of steady cost decline, renewable power technologies are becoming an increasingly competitive way to meet new generation needs.

In 2017, as deployment of renewable power generation technologies accelerated, there has been a relentless improvement in their competitiveness. Bioenergy for power, hydropower, geothermal and onshore wind projects commissioned in 2017 largely fell within the range of fossil fuel-fired electricity generation costs (Figure ES.1), data collected by the International Renewable Energy Agency (IRENA) shows. Indeed levelised cost of electricity (LCOE)[1] for these technologies was at the lower end of the LCOE range for fossil fuel options.[2]

The global weighted average LCOE of new hydropower plants commissioned in 2017 was around USD 0.05 per kilowatt-hour (kWh), while for onshore wind plants it was around USD 0.06/kWh. For new bioenergy and geothermal projects, the global weighted average LCOE was around USD 0.07/kWh.

The fall in electricity costs from utility-scale solar photovoltaic (PV) projects since 2010 has been remarkable. Driven by an 81% decrease in solar PV module prices since the end of 2009, along with reductions in balance of system (BoS) costs, the global weighted average LCOE of utility-scale solar PV fell 73% between 2010 and 2017, to USD 0.10/kWh. Increasingly, this technology is competing head-to-head with conventional power sources – and doing so without financial support.

Offshore wind power and concentrated solar power (CSP), though still in their infancy in terms of deployment, both saw their costs fall between 2010 and 2017. The global weighted average LCOE of offshore wind projects commissioned in 2017 was USD 0.14/kWh, while for CSP, it was USD 0.22/kWh. However, auction results in 2016 and 2017, for CSP and offshore wind projects that will be commissioned in 2020 and beyond, signal a step-change, with costs falling to between USD 0.06 and USD 0.10/kWh for CSP and offshore wind.

1. The LCOE of a given technology is the ratio of lifetime costs to lifetime electricity generation, both of which are discounted back to a common year using a discount rate that reflects the average cost of capital. In this report, all LCOE results are calculated using a fixed assumption of a real cost of capital of 7.5% in OECD countries and China, and 10% in the rest of the world, unless explicitly mentioned. All LCOE calculations exclude the impact of any financial support.

2. The fossil fuel-fired electricity cost range in 2017 was estimated to range from a low of USD 0.05 per kilowatt-hour (kWh) to a high USD 0.17/kWh, depending on the fuel and country.

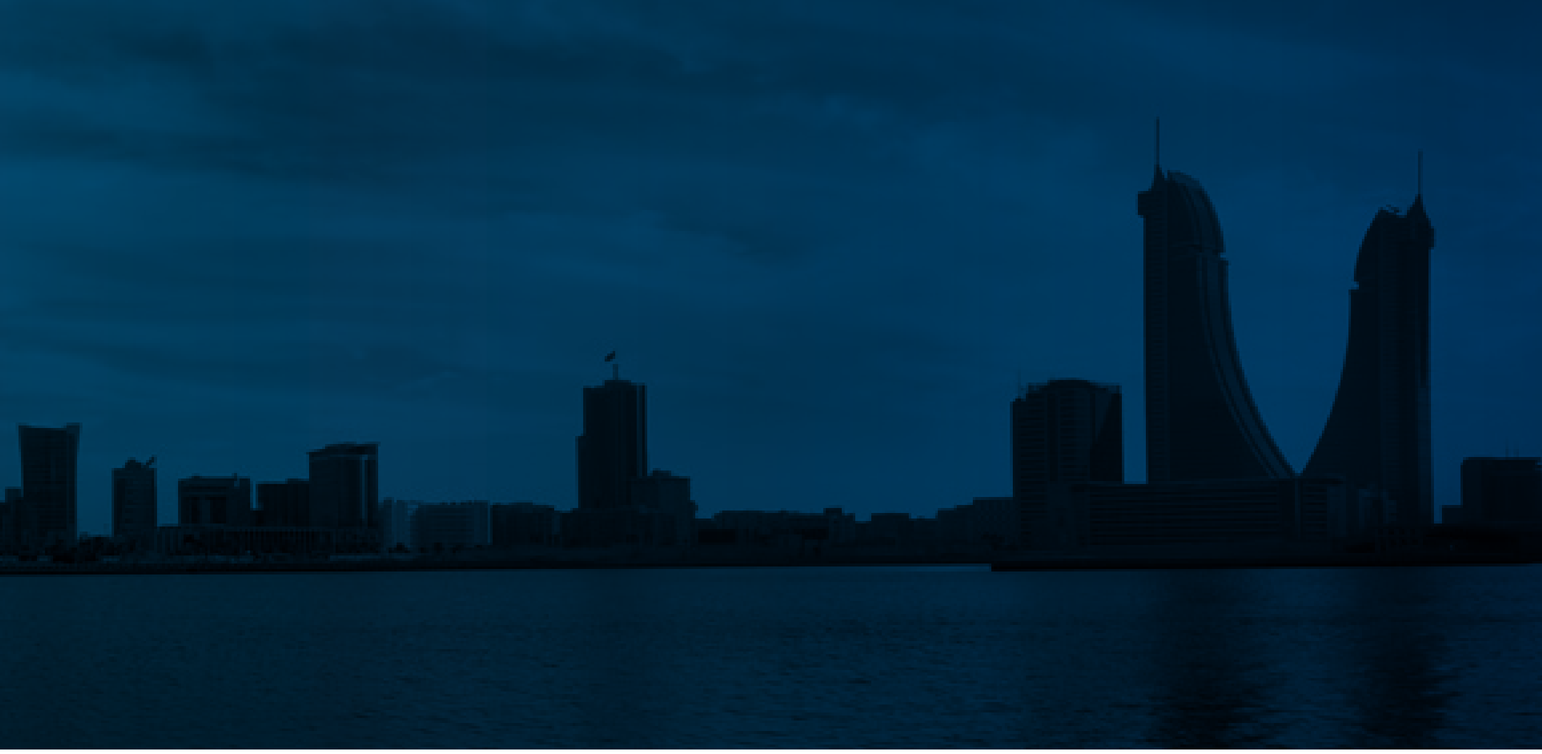
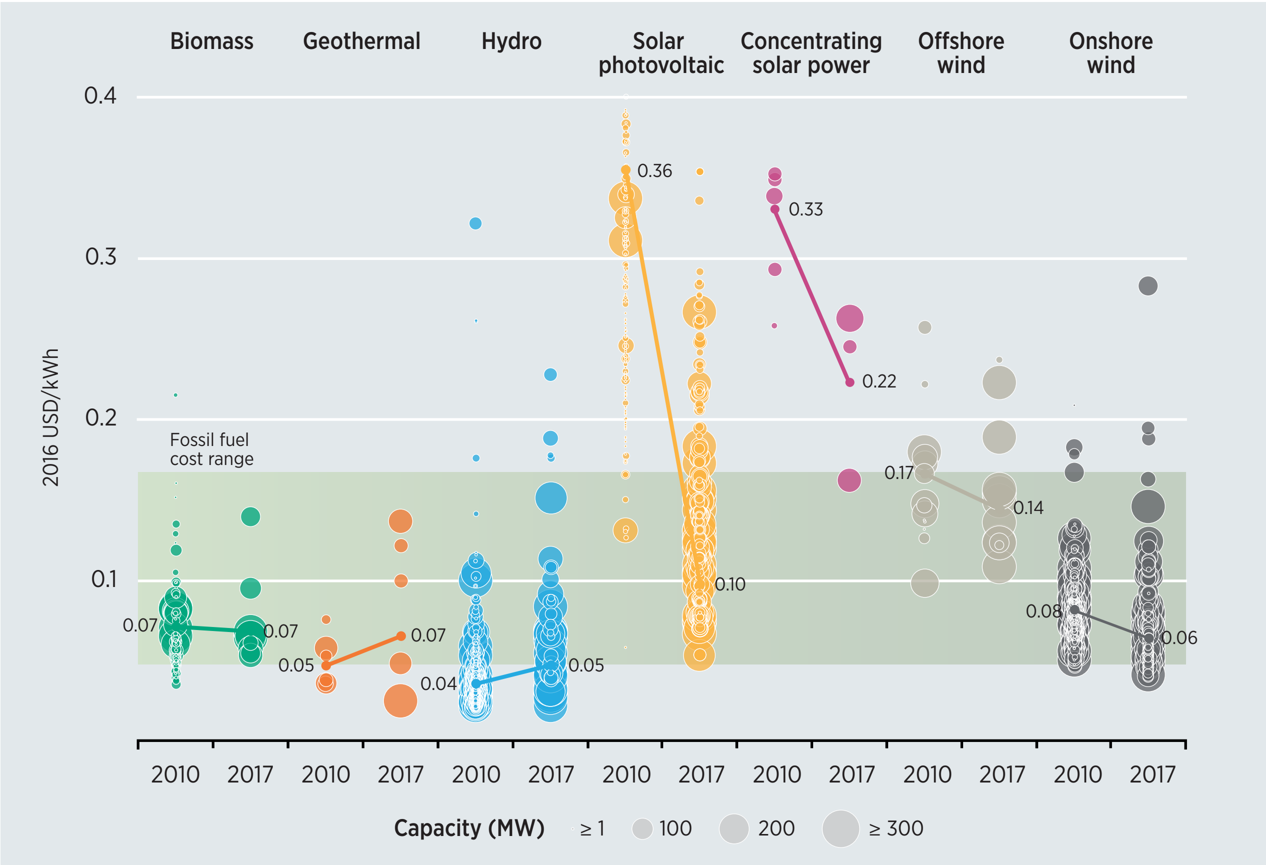


Figure ES.1 Global levelised cost of electricity from utility-scale renewable power generation technologies, 2010-2017



Source: IRENA Renewable Cost Database.

Note: The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE value for plants commissioned in each year. Real weighted average cost of capital is 7.5% for OECD countries and China and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Three main cost reduction drivers have emerged for renewable power: 1) technology improvements; 2) competitive procurement; and 3) a large base of experienced, internationally active project developers.

Historically, technology improvements have been vital to the performance increases and installed cost reductions which have (in addition to industrialisation of the sector and economies of scale) made solar and wind power technologies competitive. Competitive procurement — amid globalisation of the renewable power market — has emerged more recently as another key driver. Along with this comes the emergence of a large base of experienced medium-to-large project developers, actively seeking new markets around the world. The confluence of these factors is increasingly driving cost reductions for renewables, with effects that will only grow in magnitude in 2018 and beyond.

Continuous technology innovation remains a constant in the renewable power generation market. Indeed, in today's low equipment cost era, technology innovations that unlock efficiencies in manufacturing, as well as power generation equipment — in terms of performance improvements or installed cost reductions — will take on increasing importance. Bigger wind turbines with larger swept areas harvest more electricity from the same resource. New solar PV cell architectures offer greater efficiency. Real-time data and 'big data' have enhanced predictive maintenance and reduced operation and maintenance (O&M) costs. These are just a few examples of the continuous innovation driving reductions in installed costs, unlocking performance improvements and reducing O&M costs. Technology improvements, therefore, remain a key part of the cost reduction potential for renewable power. At the same time, the maturity and proven track record of renewable power technologies now reduces project risk, significantly lowering the cost of capital.[3]

These trends are part of a larger dynamic across the power generation sector, prompting a rapid transition in the way the industry functions. In many parts of the world, renewable power technologies now offer the lowest cost source of new power generation. In the past, typically, there was a framework offering direct financial support, often tailored to individual technologies (e.g., solar PV) and even segments (e.g., varying support for residential, commercial and utility-scale sectors, sometimes differentiated by other factors such as whether they are building-integrated or not). Now, this is being replaced by a favourable regulatory and institutional framework that sets the stage for competitive procurement of renewable power generation to meet a country's energy, environmental and development policy goals. Around the world, medium-to-large renewable project developers are adapting to this new reality and increasingly looking for global opportunities to expand their business. They are bringing, not only their hard won experience, but access to international capital markets. In competition with their peers, they are finding ways to continuously reduce costs.

The results of recent renewable power auctions – for projects to be commissioned in the coming years – confirm that cost reductions are set to continue to 2020 and beyond.

In addition to the IRENA Renewable Cost Database, which contains project level cost data for around 15 000 utility-scale projects, IRENA has compiled a database of auction results and other competitive procurement processes for around 7 000 projects. Although care must be taken in comparing the results of these two databases, as an auction price is not necessarily directly comparable to an LCOE calculation,[4] analysis of the results of the two databases provides some important insights into the likely distribution of renewable electricity costs over the next few years.

3. The generally low cost of debt since 2010 has combined to enhance this effect as not only have risk margins fallen, but the base cost of debt as well.

4. At a minimum, the weighted average cost of capital (WACC) is not going to be the same. For an LCOE calculation, the WACC is a fixed and known value, whereas the WACC of a project in an auction is unknown and subsumed in the range of other factors that determined the price bid by an individual project developer.

Record low auction prices for solar PV in 2016 and 2017 in Dubai, Mexico, Peru, Chile, Abu Dhabi and Saudi Arabia have shown that an LCOE of USD 0.03/kWh is possible from 2018 and beyond, given the right conditions. These include: a regulatory and institutional framework favourable to renewables; low offtake and country risks; a strong, local civil engineering base; favourable taxation regimes; low project development costs; and excellent solar resources.

Similarly, very low auction results for onshore wind in countries such as Brazil, Canada, Germany, India Mexico and Morocco have shown that onshore wind is one of the most competitive sources of new generation capacity. For CSP and offshore wind, 2016 and 2017 have been breakthrough years, as auction results around the world have confirmed that a step change in costs has been achieved and will be delivered in projects commissioned in 2020 and beyond. Indeed, auction results in 2016 and 2017 suggest that projects commissioned from 2020 onwards for both technologies could fall in the range USD 0.06 and USD 0.10/kWh.

Competitive procurement, particularly auctions, is spurring further cost reductions for power from solar and wind power technologies. Still, achieving low costs depends on supporting factors, such as access to low-cost finance, a conducive policy environment and good auction design. The key policy drivers (outlined in IRENA, 2017, *Renewable Energy Auctions: Analysing 2016*) are confirmed by the latest auction results.

Electricity from renewables will soon be consistently cheaper than from fossil fuels. By 2020, all the power generation technologies that are now in commercial use will fall within the fossil fuel-fired cost range, with most at the lower end or even undercutting fossil fuels.

Even by 2020, projects contracted via competitive procurement will represent a relatively small subset of annual new renewable power generation capacity additions – and trends in auction results may not remain representative of LCOE trends at a project level. Nevertheless, recent auction results show that cost reductions will continue for CSP, solar PV, onshore and offshore wind through 2020 and beyond. While the validity of comparing LCOE and auction prices for individual projects must be done with caution, the volume of data available and the consistent trends between the two datasets provide some confidence in the overall trend.

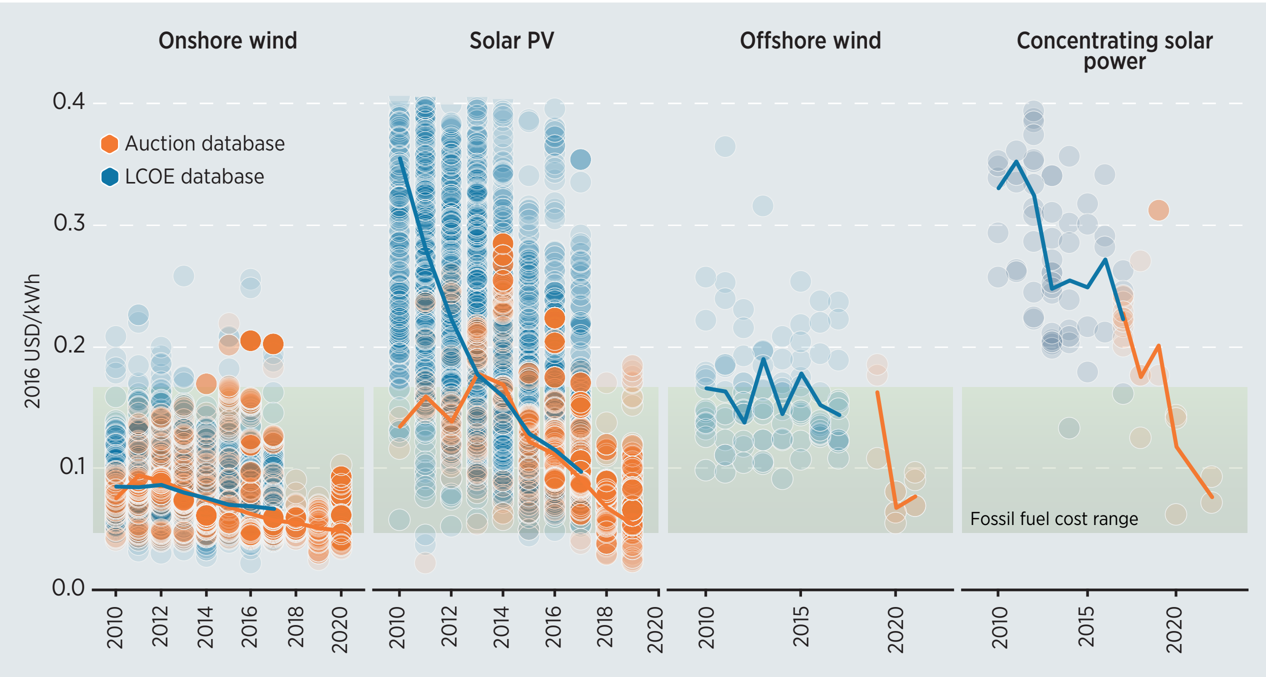
Analysing the the trends in the LCOE of projects and auction results to 2020 suggests that average costs for onshore wind could fall from USD 0.06/kWh in 2017 to USD 0.05/kWh by 2020. The recent auction results for offshore wind from 2016 and 2017 in Belgium, Denmark, the Kingdom of the Netherlands, Germany and the United Kingdom suggest that for projects that will be commissioned in 2020 and beyond, costs could fall in the USD 0.06 to USD 0.10/kWh range. Indeed, in Germany, two projects that will be commissioned in 2024 and one in 2025 won with bids that did not ask for a subsidy over market rates. A similar story has emerged for CSP, where a project in South Australia to be commissioned from 2020 will have a cost of USD 0.06/kWh, while in Dubai, a project that will be commissioned from 2022 onwards will have a cost of USD 0.07/kWh.

Solar PV auction data needs to be treated with somewhat more caution. This is because the distribution of projects is concentrated in higher-irradiation locations than recent capacity-weighted deployment. Even so, if the auction results available do accurately represent global deployment trends, then by 2019 or 2020, the average LCOE for solar PV may fall to below USD 0.06/kWh, converging to slightly above that of onshore wind, at USD 0.05/kWh.

The outlook for solar and wind electricity costs to 2020, based on the latest auction and project-level cost data, presages the lowest costs yet seen for these modular technologies that can be deployed around the world.

By 2019, the best onshore wind and solar PV projects will be delivering electricity for an LCOE equivalent of USD 0.03/kWh, or less, with CSP and offshore wind capable of providing electricity very competitively, in the range of USD 0.06 to USD 0.10/kWh from 2020 (Figure ES.2). Already today, and increasingly in the future, many renewable power generation projects can undercut fossil fuel-fired electricity generation, without financial support. With the right regulatory and institutional frameworks in place, their competitiveness should only further improve.

Figure ES.2 The levelised cost of electricity for projects and global weighted average values for CSP, solar PV, onshore and offshore wind, 2010-2022



Source: IRENA Renewable Cost Database and Auctions Database.

Note: Each circle represents an individual project or an auction result where there was a single clearing price at auction. The centre of the circle is the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE, or auction values, by year. For the LCOE data, the real WACC is 7.5% for OECD countries and China, and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Decreasing electricity costs from renewables as a whole, and the low costs from the best solar PV and onshore wind projects, represent a real paradigm shift in the competitiveness of different power generation options. Solar and wind power will provide very affordable electricity, with all the associated economic benefits. Furthermore, their low costs mean that previously uneconomic strategies in the power sector can become profitable. Curtailment – previously an unthinkable economic burden for renewables – could become a rational economic decision, maximising variable renewable penetration and minimising overall system costs.

Similarly, very low prices in areas with excellent solar and wind resources could open-up the economic potential of "power-to-X" technologies (e.g., power to hydrogen or ammonia, or other energy dense, storable mediums). At the same time, low prices make the economics of electricity storage more favourable. This could turn a potential drawback of electric vehicles (EVs) – their potentially high instantaneous power demand for recharging – into an asset. In effect, EVs can take advantage of cheap renewable power when it is available, while potentially feeding electricity back into the grid when needed.

This, however, needs to be balanced against the increased costs of integrating variable renewables and the increased flexibility required to manage systems with very high levels of variable renewable energy (VRE). To date, these integration costs have remained modest, but they could rise as very high VRE shares are reached (see IRENA, 2017, *IRENA Cost and Competitiveness Indicators: Rooftop Solar PV*), especially without complementary policies across the power sector. For instance, if transmission expansions fail to keep pace with deployment, renewable power sources could face curtailment.

The sharp cost reductions for CSP, solar PV, onshore and offshore wind – both recent and anticipated – represent remarkable deflation rates.

Conventional wisdom has been a poor guide in estimating the rate of cost reductions from solar and wind power technologies. It has underestimated the capacity of technology improvements, the industrialisation of manufacturing, economies of scale, manufacturing efficiencies, process innovations by developers and, competition in supply chains to all continuously drive down costs faster than expected in the right regulatory and policy setting.

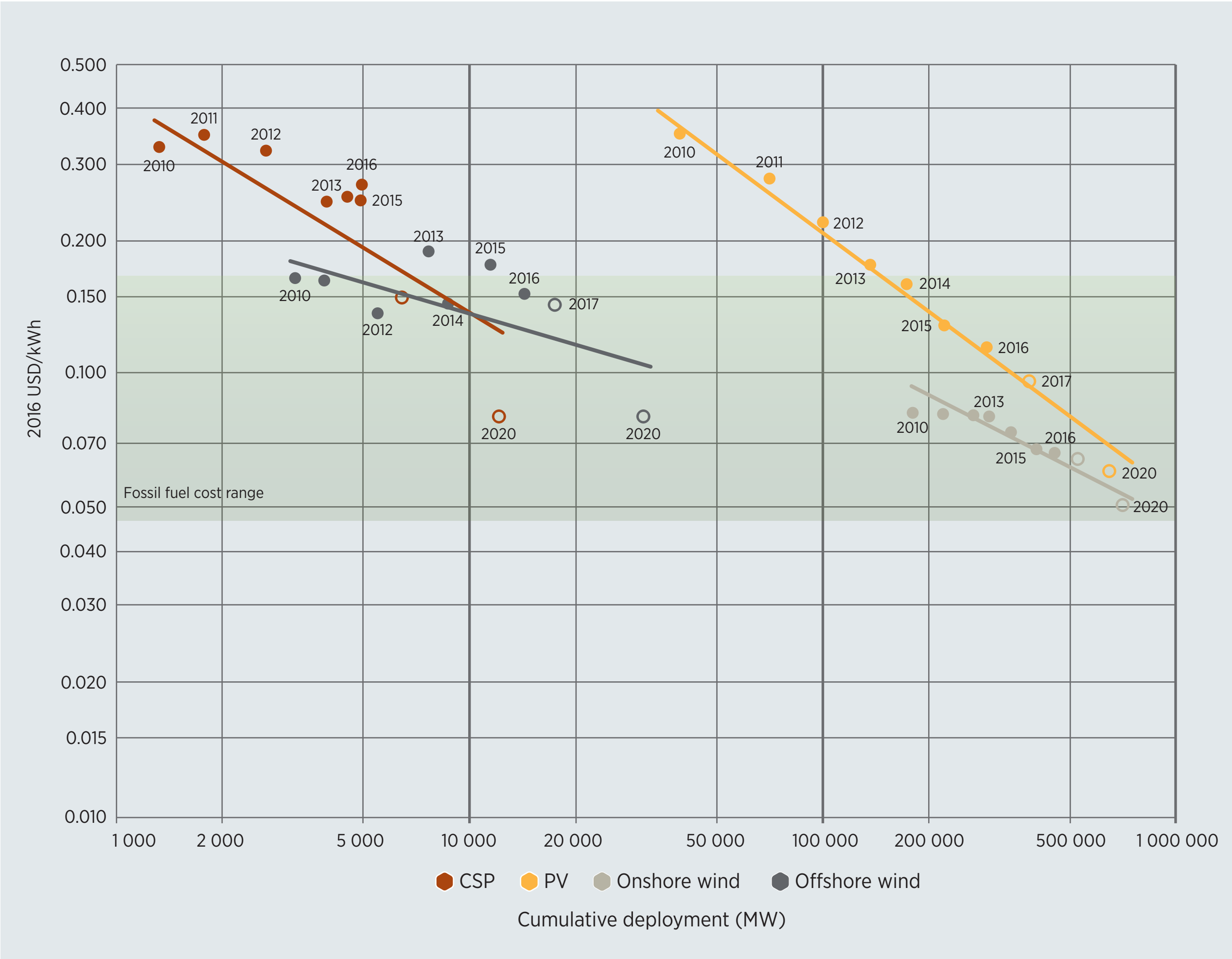
The decline in the cost of electricity experienced from 2010 to 2017, and signalled for 2020 from auction data, is plotted against cumulative installed capacity in Figure ES.3 for the four main solar and wind technologies. A log-log scale is used to allow easy interpretation as learning curves. The learning rate for offshore wind (i.e. the LCOE reduction for every doubling in global cumulative installed capacity) could reach 14% over the period 2010-2020, with new capacity additions over this period estimated to be around 90% of the cumulative installed offshore wind capacity that would be deployed by the end of 2020.[5]

For onshore wind, the learning rate for 2010 to 2020 may reach 21%, with new capacity added over this period covering an estimated 75% of cumulative installed capacity at the end of 2020. CSP has a higher estimated learning rate of 30%, with deployment between 2010 and 2020 representing an estimated 89% of cumulative installed capacity by the end of that period.[6] Solar PV has the highest estimated learning rate – 35% between 2010 and 2020 – with new capacity additions over this timescale that are estimated to be 94% of cumulative capacity by its conclusion.

5. Global cumulative installed capacity of CSP is projected to be 12 GW by 2020, for offshore wind 31 GW, solar PV 650 GW and onshore wind 712 GW. This is based on IRENA, 2017; GWEC, 2017, Wind Europe, 2017, SPE, 2017 and MAKE Consulting, 2017.

6. Extending the horizon to 2022 to take into account the likely commissioning of the Dubai Electricity and Water Authority project increases uncertainty over total deployment values, but in most scenarios would not materially change the learning rate.

Figure ES.3 Learning curves for the global weighted average levelized cost of electricity from CSP, solar PV and onshore and offshore wind, 2010-2020



Source: IRENA Renewable Cost Database; IRENA Auctions Database; GWEC, 2017; WindEurope, 2017; MAKE Consulting, 2017; and SPE, 2017.

Note: Each circle represents an individual project, or, in some cases, auction result where there was a single clearing price at auction. The centre of the circle is the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE or auction values by year. For the LCOE data, the real WACC is 7.5% for OECD countries and China, and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

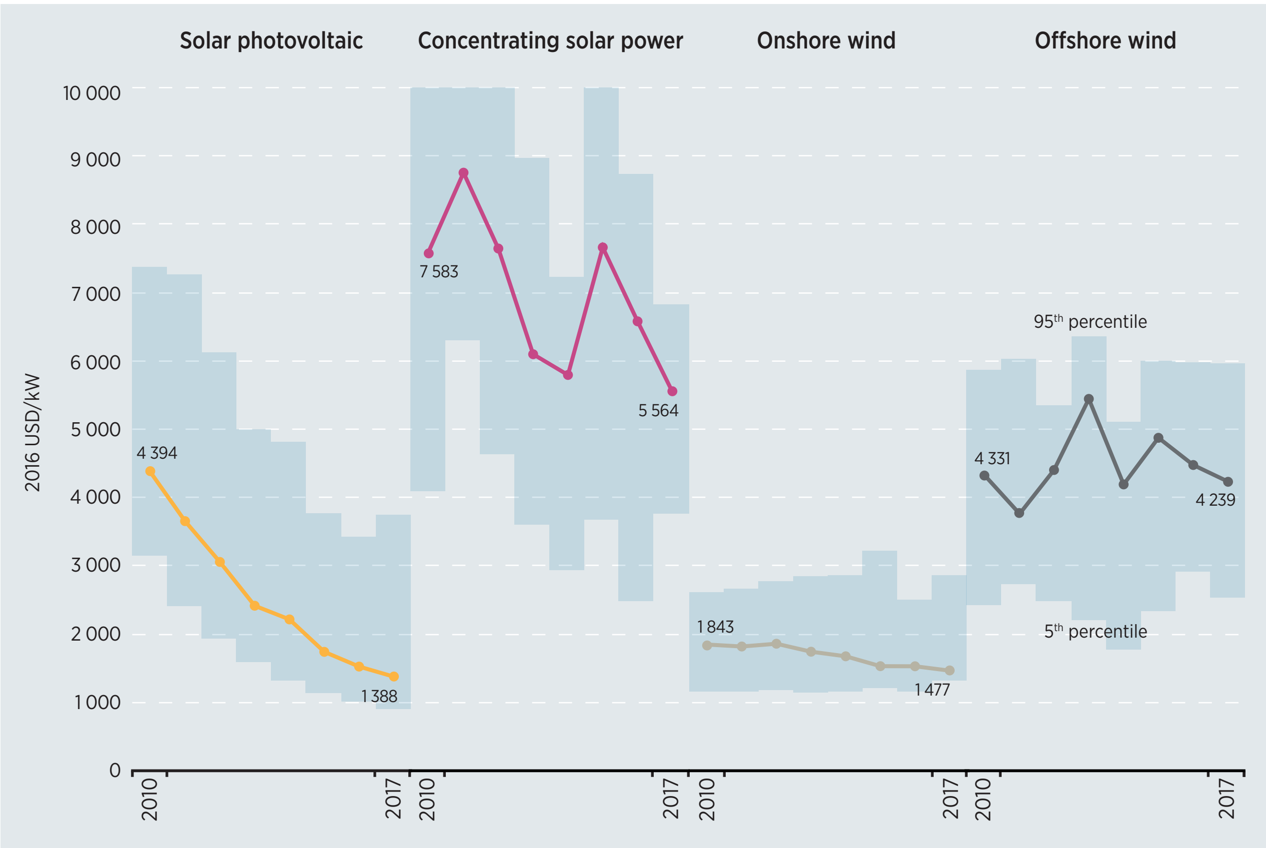
Onshore wind is one of the technologies with the longest histories of available cost data. Data in the IRENA Renewable Cost Database shows that the learning rate for the cost of electricity from this source is higher for the period 2010-2020 than the learning rate estimated for the period 1983-2016. This will, in all probability, be in part due to a lower WACC from the auction results than is used in the LCOE calculations. This is unlikely to explain all of the difference, however. The data therefore tends to suggest that the learning rate for onshore wind, at least, is currently higher than the long-term average.

The modular, scalable nature solar and wind power generation technologies, and the replicability of their project development process, rewards stable support policies with continuous cost reductions. This has already made onshore wind and solar PV highly competitive options for new generation capacity. Auction results suggest that CSP and offshore wind should follow a similar path. A comparable process is playing out for electricity storage. Wherever renewable power technologies can be modular, scalable and replicable, decision makers can be confident that industrialisation and the opening of new markets will yield steady cost reductions in the right regulatory and policy environment.

Reductions in total installed costs are driving the fall in the LCOE for solar and wind power technologies, but to varying extents. They have been most important for solar PV, CSP and onshore wind.

On the back of price declines for solar PV modules, the installed costs of utility-scale solar PV projects fell by 68% between 2010 and 2017, with the LCOE for the technology falling 73% over that period. The total installed costs of newly commissioned CSP projects fell by 27% in 2010-2017, with a 33% LCOE reduction overall. Installed costs for newly commissioned onshore wind projects fell by 20%, with a 22% reduction in LCOE. For offshore wind, the total installed costs fell by 2%, with a 13% reduction in LCOE over the same period.

Figure ES.4 Global weighted average total installed costs and project percentile ranges for CSP, solar PV, onshore and offshore wind, 2010-2017



Source: IRENA Renewable Cost Database.

ABBREVIATIONS

ACP	Alternative Compliance Payment
CAD	Canadian dollar
CARICOM	Caribbean Community
CCS	carbon capture and storage
CEER	Council of European Energy Regulators
CfD	Contract for Difference
CSP	concentrating solar power
DNI	Direct normal irradiance
EC	European Council
ECOWAS	Economic Community of West African States
EJ	exajoule
EU	European Union
EUR	euro
FIT	feed-in tariff
GBP	British pound
GDP	gross domestic product
GSR	Global Status Report
GW	gigawatt
GWh	gigawatt-hour
GWth	gigawatt-thermal
ILUC	indirect land-use change
INR	Indian rupee
IPP	independent power producer
IRENA	International Renewable Energy Agency
IRP	integrated resource plan
kW	kilowatt
kWh	kilowatt-hour
LSE	load-serving entities
MDG	Millennium Development Goal
MEMEE	Ministry of Energy, Mines, Water and Environment (Morocco)
MENA	Middle East and North Africa
Mtoe	million tonnes of oil equivalent
MW	megawatt
MWh	megawatt-hour
NDRC	National Development and Reform Commission
NREL	National Renewable Energy Laboratory (US)
OECD	Organisation of Economic Cooperation and Development
PPA	Power Purchase Agreement
SDG	Sustainable Development Goal
TWh	terawatt-hour
VRE	Variable Renewable Electricity

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ISBN 978-92-9260-040-2

This is a summary of: IRENA (2018), *Renewable Power Generation Costs in 2017*, International Renewable Energy Agency, Abu Dhabi.

ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

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