IRENA
International Renewable Energy Agency

RENEWABLE POWER GENERATION COSTS IN 2020

EXECUTIVE SUMMARY

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The year 2020 was marked by the global pandemic and the subsequent economic and human toll it took as the COVID-19 virus spread. One bright spot, however, was the resilience of renewable power generation supply chains and record growth in new deployment.

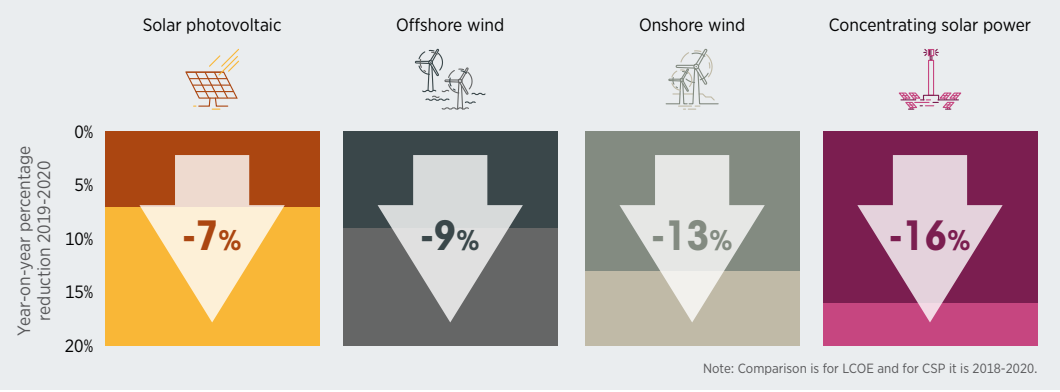
There was no disruption to the trend in continued cost declines for solar and wind power, either. In 2020, the global weighted-average levelised cost of electricity (LCOE) from new capacity additions of onshore wind declined by 13%, compared to 2019. Over the same period, the LCOE of offshore wind fell by 9% and that of utility-scale solar photovoltaics (PV) by 7% (Figure S.1).

That 13% year-on-year fall in the global weighted-average onshore wind LCOE, from USD 0.045/kilowatt hour (kWh) to USD 0.039/kWh,[1] was slightly higher than the rate of decline in 2019. The decline was driven by a 9% fall in the global weighted-average total installed cost, as China – which has lower than average installed costs – connected an estimated 69 GW to the grid in 2020, two-thirds of the new capacity deployed that year.

In 2020, the 7% year-on-year decline in the LCOE of utility-scale solar PV, from USD 0.061/kWh to USD 0.057/kWh, was lower than the 13% decline experienced in 2019. In 2020, too, the global weighted-average total installed cost of utility-scale solar PV fell by 12%, to just USD 883/kW.

The decline in LCOE terms for utility-scale solar PV was lower than it otherwise might have been, as the decline in total installed costs experienced was partially offset by a reduction in the global weighted-average capacity factor of new projects in that year.[2] This was driven by deployment in 2020 that was, on balance, weighted towards areas with poorer solar resources than those seeing deployment in 2019.[3] Similar to the situation for onshore wind, China was the largest market for new capacity, accounting for an estimated 45% of the new, utility-scale capacity added in 2020.

Figure S.1 Global weighted-average LCOE from newly commissioned, utility-scale solar and wind power technologies, 2019-2020



Source: IRENA Renewable Cost Database

1 All financial values presented in this report are real, 2020 values - that is to say, they are adjusted for the impact of inflation on a 2020 base year. LCOE calculations are made based on the methodology detailed in Annex I and exclude the impact of any financial support available.

2 All solar PV capacity factors quoted in this report are alternating current (AC)/direct current (DC) capacity factors, given all installed cost data for solar PV is quoted per-watt of direct current, which is an exception, as all other technologies are report in AC terms.

3 This result should be treated with caution, given the increasing importance of bifacial modules and single-axis trackers, where data availability lags total installed cost and has a material impact on capacity factors. Revisions to the 2020 capacity factor are possible.

The 9% year-on-year decline in the global weighted-average LCOE of offshore wind in 2020 saw the global weighted-average cost of electricity of new projects fall from USD 0.093/kWh to USD 0.084/kWh. This was a sharper decline than that experienced in 2019, as China – which has lower than average installed costs – increased its share of new capacity additions, from around one third in 2019 to around half in 2020.

The global weighted-average LCOE of new, concentrating solar power (CSP) projects commissioned in 2020 fell by 49%, year-on-year. This result is somewhat atypical, however, as the global weighted-average LCOE in 2019 was pushed up by two much delayed Israeli projects, while 2020 was characterised by the commissioning of just two plants, both in China. Looking at the figures between 2018 and 2020 reveals a compound annual rate of decline of 16% per year, which is more representative of recent rates of cost reduction.

RENEWABLE POWER GENERATION COST TRENDS, 2010-2020: A DECADE OF FALLING COSTS

The decade 2010 to 2020 represents a remarkable period of cost reduction for solar and wind power technologies. The combination of targeted policy support and industry drive has seen renewable electricity from solar and wind power go from an expensive niche, to head-to-head competition with fossil fuels for new capacity. In the process, it has become clear that renewables will become the backbone of the electricity system and help decarbonise electricity generation, with costs lower than a business-as-usual future.

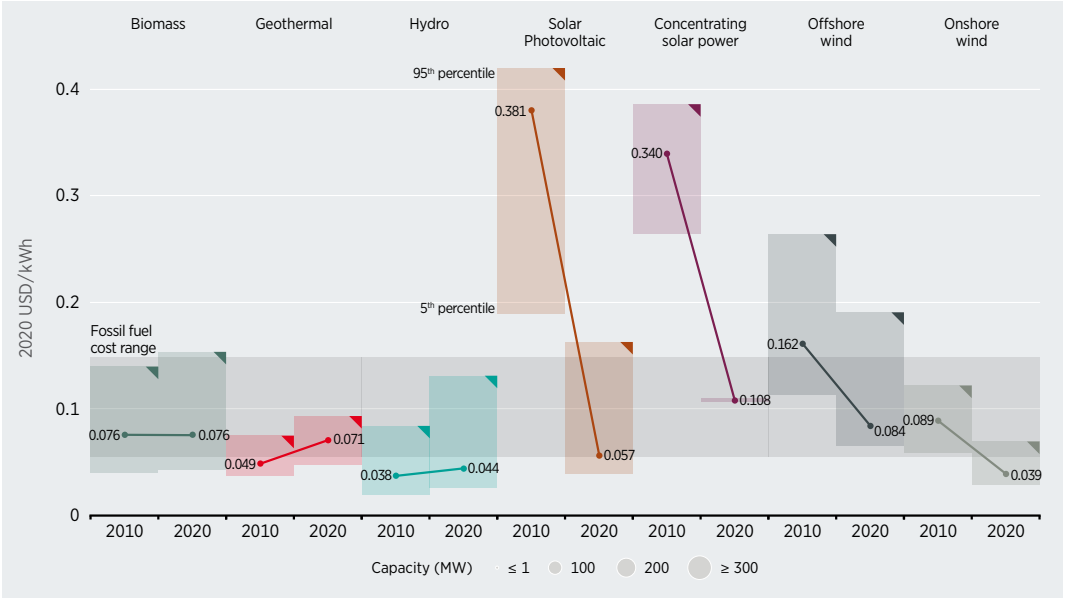
The global weighted-average LCOE of utility-scale solar PV for newly commissioned projects fell by 85% between 2010 and 2020, from USD 0.381/kWh to USD 0.057/kWh (Figure S.2), as total installed costs fell from USD 4 731/kW to USD 883/kW. This occurred as global cumulative installed capacity of all solar PV (utility scale and rooftop) increased from 42 GW in 2010 to 714 GW in 2020. This represented a precipitous decline, from being more than twice as costly as the most expensive fossil fuel-fired power generation option to being at the bottom of the range for new fossil fuel-fired capacity.[4]

The LCOE of residential PV systems also declined steeply over the period. The LCOE of residential PV systems in Australia, Germany, Italy, Japan and the United States declined from between USD 0.304/kWh and USD 0.460/kWh in 2010 to between USD 0.055/kWh and USD 0.236/kWh in 2020 – a decline of between 49% and 82%.

4 The fossil fuel-fired power generation cost range for the G20 group by country and fuel type is estimated to be between USD 0.055/kWh and USD 0.148/kWh. The lower bound represents new, coal-fired plants in China and is based on IEA, 2020.

For onshore wind projects, the global weighted-average cost of electricity between 2010 and 2020 fell by 56%, from USD 0.089/kWh to USD 0.039/kWh, as average capacity factors rose from 27% to 36% and total installed costs declined from USD 1971/kW to USD 1355/kW. Cumulative installed capacity grew from 178 GW to 699 GW during this period. Compared to solar PV, where electricity cost declines are mainly driven by falling total installed costs, onshore wind cost reductions were driven more evenly by both falls in turbine prices and balance of plant costs, and higher capacity factors from today's state-of-the-art turbines.

Figure S.2 Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020



Source: IRENA Renewable Cost Database

Note: This data is for the year of commissioning. The thick lines are the global weighted-average LCOE value derived from the individual plants commissioned in each year. The project-level LCOE is calculated with a real weighted average cost of capital (WACC) of 7.5% for OECD countries and China in 2010, declining to 5% in 2020; and 10% in 2010 for the rest of the world, declining to 7.5% in 2020. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

For offshore wind, the global weighted-average LCOE of newly commissioned projects declined from USD 0.162/kWh in 2010 to USD 0.084/kWh in 2020, a reduction of 48% in 10 years. This has transformed the outlook for offshore wind, with cumulative installed capacity of offshore wind at just 34 GW at the end of 2020, which is around one-twentieth of that of onshore wind.

Over the period 2010 to 2020, the global weighted-average cost of electricity from CSP fell 68% from USD 0.340/kWh to USD 0.108/kWh. With just two projects commissioned in 2020 – both in China – these results, however, reflect the national circumstances of that country. Having said that, the 68% decline in the cost of electricity from CSP – into the middle of the range of the cost of new capacity from fossil fuels – remains a remarkable achievement. For comparison, the global cumulative installed capacity for CSP of 6.5 GW at the end of 2020 was slightly less than a hundredth of the capacity of solar PV installed.

Between 2010 and 2020, 60 GW of new bioenergy for power capacity was added. The global weighted-average LCOE of bioenergy for power projects experienced a certain degree of volatility during this period, but ended the decade at around the same level it began, at USD 0.076/kWh – a figure at the lower end of the cost of electricity from new fossil fuel-fired projects. For the same period, hydropower added 715 GW, while the global weighted-average LCOE rose by 18%, from USD 0.038/kWh to USD 0.044/kWh. This was still lower than the cheapest new fossil fuel-fired electricity option, despite the fact that costs increased by 16% in 2020, year-on-year.

The global weighted-average LCOE of geothermal power has ranged between USD 0.071/kWh and USD 0.075/kWh since 2016. The global weighted-average LCOE of newly commissioned plants in 2020 was at the lower end of this range, at USD 0.071/kWh, having declined 4% year-on-year.

The global weighted-average cost of electricity from onshore wind fell by 56% between 2010 and 2020, from USD 0.089/kWh to USD 0.039/kWh

RENEWABLE POWER GENERATION IS BECOMING THE DEFAULT ECONOMIC CHOICE FOR NEW CAPACITY

The decade 2010 to 2020 saw dramatic improvement in the competitiveness of solar and wind power technologies. In that period, CSP, offshore wind and utility-scale solar PV all joined onshore wind in the range of costs for new capacity fired by fossil fuels, when calculated without the benefit of financial support. Indeed, the trend is not only one of renewables competing with fossil fuels, but significantly undercutting them, when new electricity generation capacity is required.

In 2020, a total of 162 GW of the renewable power generation capacity added had electricity costs lower than the cheapest source of new fossil fuel-fired capacity. This was around 62% of total net capacity additions that year. In emerging economies, where electricity demand is growing and new capacity is needed, these renewable power generation projects will reduce costs in the electricity sector by at least USD 6 billion per year, relative to the cost of adding the same amount of fossil fuel-fired generation.

Since 2010, globally, a cumulative total of 644 GW of renewable power generation capacity has been added with estimated costs that have been lower than the cheapest fossil fuel-fired option in their respective year.[5] Prior to 2016, almost all of this was being contributed by hydropower, but since then it has increasingly included onshore wind and solar PV. Of the total, over the decade, 534 GW was added in emerging economies and could reduce electricity system costs in these by up to USD 32 billion in 2021 (USD 920 billion, undiscounted, over their economic lifetimes).

Photo: Shutterstock

5 Assumes the cheapest coal-fired power generation option increased from USD 0.05/kWh in 2010 to USD 0.055/kWh in 2020, due notably to average expected lifetime capacity factors falling over this period.

The results of competitive procurement of renewables through auctions or power purchase agreements (PPA) confirm the competitiveness of renewables. Data from the IRENA Renewable Auction and PPA Database indicate that utility-scale solar PV projects that have won recent competitive procurement processes – and that will be commissioned in 2022 – could have an average price of USD 0.04/kWh (Figure S.3). This is a 30% reduction compared to the global weighted-average LCOE of solar PV in 2020 and is around 27% less (USD 0.015/kWh) than the cheapest fossil-fuel competitor, namely coal-fired plants.

The auction and PPA data suggest offshore wind costs will fall within the range of USD 0.05/kWh to USD 0.10/kWh in Europe in the period up to 2023, with new markets or delayed projects likely to have higher costs. The lower end of this range for offshore wind suggests projects will be competitive against wholesale electricity prices in a number of European markets. Meanwhile, the market for CSP is thin, but the data that is available suggests a continued decline in 2021, as this year sees the large Dubai Electricity and Water CSP project come online.

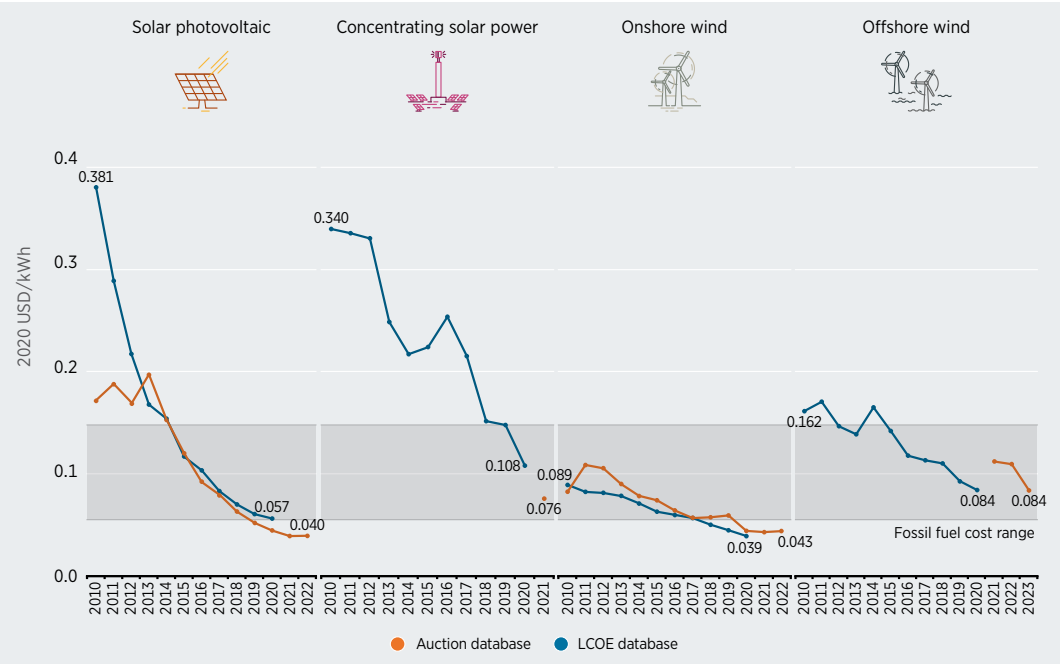
The data from the IRENA Renewable Cost Database and Auction and PPA Database therefore highlight the fact that utility-scale solar PV and onshore wind projects are, on average, able to produce power for less than the cheapest new fossil fuel-fired cost project. For offshore wind and CSP, costs will fall into the lower range for new fossil fuel-fired power plants.

Globally, since 2010, a cumulative total of 644 GW of renewable power generation capacity has been added with estimated costs that have been lower than the cheapest fossil fuel-fired option

The data also suggests that there is an increasing number of projects with very low electricity costs, at below USD 0.03/kWh. Indeed, the last 18 months has seen three record low bids for solar PV, starting with USD 0.0157/kWh in Qatar, USD 0.0135/kWh in the United Arab Emirates and USD 0.0104/kWh in Saudi Arabia. Surprisingly, values below USD 0.02/kWh are not impossible, even if they were unthinkable, even a few years ago. They do, however, require almost all factors affecting LCOE to be at their 'best' values.

These very low solar PV price levels imply that low-cost renewable hydrogen may already be in reach. The potential levelised cost of hydrogen, assuming the low solar PV and onshore wind prices from the recent auctions in Saudi Arabia, could be as little as USD 1.62/kilogramme of hydrogen (kg H_2). This compares favourably with the hypothetical cost of natural gas steam methane reforming, with today's carbon capture, utilisation and storage (CCUS) costs at between USD 1.45/kg H_2 and USD 2.4/kg H_2.

Figure S.3 The global weighted-average LCOE and PPA/auction prices for solar PV, onshore wind, offshore wind and CSP, 2010-2023



Source: IRENA Renewable Cost Database

Note: The thick lines are the global weighted average LCOE, or auction values, by year. For the LCOE data, see Figure S.2 note. The band that crosses the entire chart represents the fossil fuel-fired power generation cost range.

LOW-COST RENEWABLE POWER IS STRANDING EXISTING COAL-FIRED POWER PLANTS

As costs for solar PV and onshore wind have fallen, new renewable capacity is not only increasingly cheaper than new fossil fuel-fired capacity, but increasingly undercuts the operating costs alone of existing coal-fired power plants.

Indeed, in Europe in 2021, coal-fired power plant operating costs are well above the costs of new solar PV and onshore wind (including the cost of CO_2 prices). Analysis for Germany and Bulgaria shows all the coal-fired plants studied have higher operating costs today than new solar PV and onshore wind. In the United States and India, operating costs for coal plants are lower, however, due largely – but not completely – to the absence of a meaningful price for CO_2. Nonetheless, the majority of existing Indian and United States coal plants have higher costs than solar PV and onshore wind, due to the very competitive costs for those two renewable technologies in those two countries.

In the United States, in 2021, between 77% and 91% of the existing coal-fired capacity has operating costs that are estimated to be higher than the cost of new solar or wind power capacity, while in India, the figure is between 87% and 91%. Adjusted to a levelised cost basis, the weighted average price from auction and power purchase agreements for solar PV in India for 2021 is USD 0.033/kWh, while for onshore wind it is USD 0.032/kWh. In the United States, the respective figures are USD 0.031/kWh and USD 0.037/kWh.

It's beyond the scope of this analysis, to determine if the value of coal-fired generation is higher than its costs. However, given that, between 2015 and 2018, the cost of utility-scale battery storage in the United States fell by 71% from USD 2 152/kWh to USD 635/kWh, even the value propositions of providing firm and flexible power generation are being eroded. The growing gap between new solar and wind power costs and the existing operating costs of an increasing number of coal-fired power plants provides an idea of the size of the economic opportunity early retirement of unabated coal presents.

Table S.1 Capacity of uneconomic existing coal-fired power plants and annual savings in coal-fired generation, electricity costs and CO_2 emissions, 2021

	Coal capacity with higher operating costs than new solar and wind		Annual savings from replacing coal with new solar and wind	Annual CO_2 emissions reductions
	(GW)	+USD 5/MWh renewable integration costs (GW)	(USD billion/year)	(Mt CO_2/year)
Bulgaria	3.7	3.7	0.7	18
Germany	28	28	3.3	99
India	193	141	6.4	643
United States	188	149	5.6	332
Rest of the world	724	488	16.3	1 881
World	**1 137**	**810**	**32**	**2 973**

Source: IRENA analysis based on Carbon Tracker, 2018; Szabó et al., 2020; IEA, 2021; Öko-Institut, 2017; Booz&Co, 2014; Energy-charts.de; DIW Berlin, Wuppertal Institut and EcoLogic, 2019; Gimon et al., 2019; US EIA, 2021; and IRENA Renewable Cost Database

SOLAR AND WIND POWER TECHNOLOGIES HAVE REMARKABLE LEARNING RATES

The cost declines experienced from 2010 to 2020 represent a remarkable rate of descent. This not only has enormous implications for the competitiveness of renewable power generation technologies over the medium-term. It also has implications for other technologies that have similar characteristics and are needed in the energy transition.

Over the period 2010 to 2020 – which included 94% of cumulative installed renewable capacity additions – utility-scale solar PV had the highest estimated learning rate[6] for the global weighted-average total installed cost, at 34%. This technology also had the highest LCOE, at 39%. This is a value that exceeds virtually all previous learning rate analyses for solar PV based on data for the earlier period of deployment – when learning rates might have been expected to be higher than in later periods.

For onshore wind, the LCOE learning rate for the period 2010 to 2019 was 32% – slightly less than twice that for total installed costs. The importance of total installed cost reductions to the decline in electricity costs from utility-scale solar PV is clearly evident in Table S.2, given the closeness of the learning rates for total installed costs and LCOE. For the other technologies, performance improvements that have increased capacity factors have played a larger role in falling electricity costs. As a result, the LCOE learning rates for CSP, onshore and offshore wind are significantly higher than those for total installed costs.

Table S.2 Learning rates for solar PV, CSP, onshore and offshore wind, 2010 to 2021/3

	Learning rates	
	Total installed cost 2010-2020	LCOE 2010-2021/23
	(%)	(%)
Utility-scale solar PV	34	39
CSP	22	36
Onshore wind	17	32
Offshore wind	9	15

6 The learning rate is the percentage reduction in the price/cost for every doubling of cumulative installed capacity.

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