

# RENEWABLE POWER GENERATION COSTS IN 2014

## EXECUTIVE SUMMARY

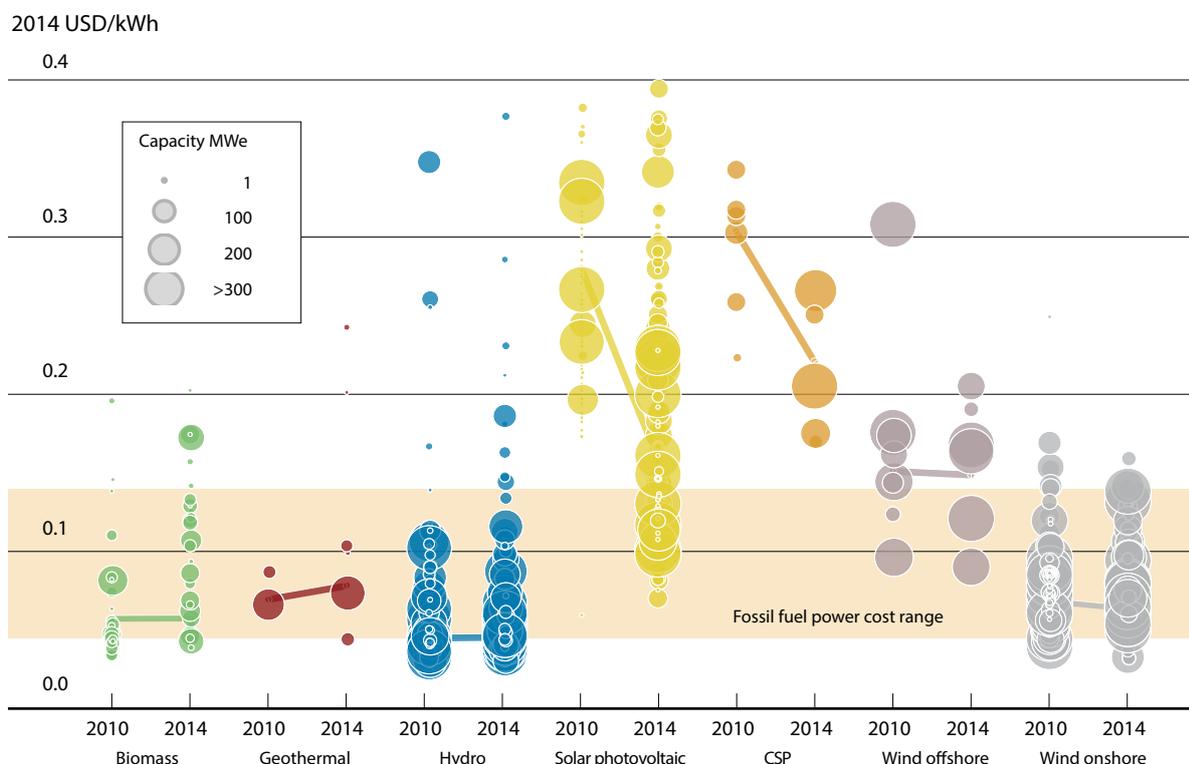
The competitiveness of renewable power generation technologies continued improving in 2013 and 2014.

The cost-competitiveness of renewable power generation technologies has reached historic levels. Biomass for power, hydropower, geothermal and onshore wind can all now provide electricity competitively compared to fossil fuel-fired power generation (Figure ES 1). Most impressively, the levelised cost of electricity (LCOE)<sup>1</sup> of solar PV has halved between 2010 and 2014, so that solar photovoltaics (PV) is also increasingly competitive at the utility scale.

Installed costs for onshore wind power, solar PV and concentrating solar power (CSP) have continued to fall, while their performance has improved. Biomass for power, geothermal and hydropower have provided low-cost electricity – where untapped economic resources exist – for many years.

Solar PV module prices in 2014 were around 75% lower than their levels at the end of 2009. Between 2010 and 2014 the total installed costs of utility-scale PV systems have fallen by 29% to 65%, depending on the region. The LCOE of utility-scale solar PV has fallen by half in four years. The most competitive utility-scale solar PV projects are now regularly delivering electricity for just USD 0.08 per kilowatt-hour (kWh) without

FIGURE ES 1: THE LEVELISED COST OF ELECTRICITY FROM UTILITY-SCALE RENEWABLE TECHNOLOGIES, 2010 AND 2014



Source: IRENA Renewable Cost Database.

Note: Size of the diameter of the circle represents the size of the project. The centre of each circle is the value for the cost of each project on the Y axis. Real weighted average cost of capital is 7.5% in OECD countries and China; 10% in the rest of the world.

<sup>1</sup> 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 cost of capital of 7.5% real in OECD countries and China, and 10% in the rest of the world unless explicitly mentioned.

financial support, compared to a range of USD 0.045 to USD 0.14/kWh for fossil fuel power plants. Even lower costs for utility-scale solar PV, down to USD 0.06/kWh, are possible where excellent resources and low-cost finance are available.

Onshore wind is now one of the most competitive sources of electricity available. Technology improvements, occurring at the same time as installed costs have continued to decline, mean that the LCOE of onshore wind is now within the same cost range, or even lower, than for fossil fuels. The best wind projects around the world are consistently delivering electricity for USD 0.05/kWh without financial support.

LCOEs of the more mature renewable power generation technologies – biomass for power, geothermal and hydropower – have been broadly stable since 2010. However, where untapped, economic resources remain, these mature technologies can provide some of the cheapest electricity of any source.

**Regional, weighted average costs of electricity from biomass for power, geothermal, hydropower and onshore wind are all now in the range, or even span a lower range, than estimated fossil fuel-fired electricity generation costs. Because of striking LCOE reductions, solar PV costs also increasingly fall within that range.**

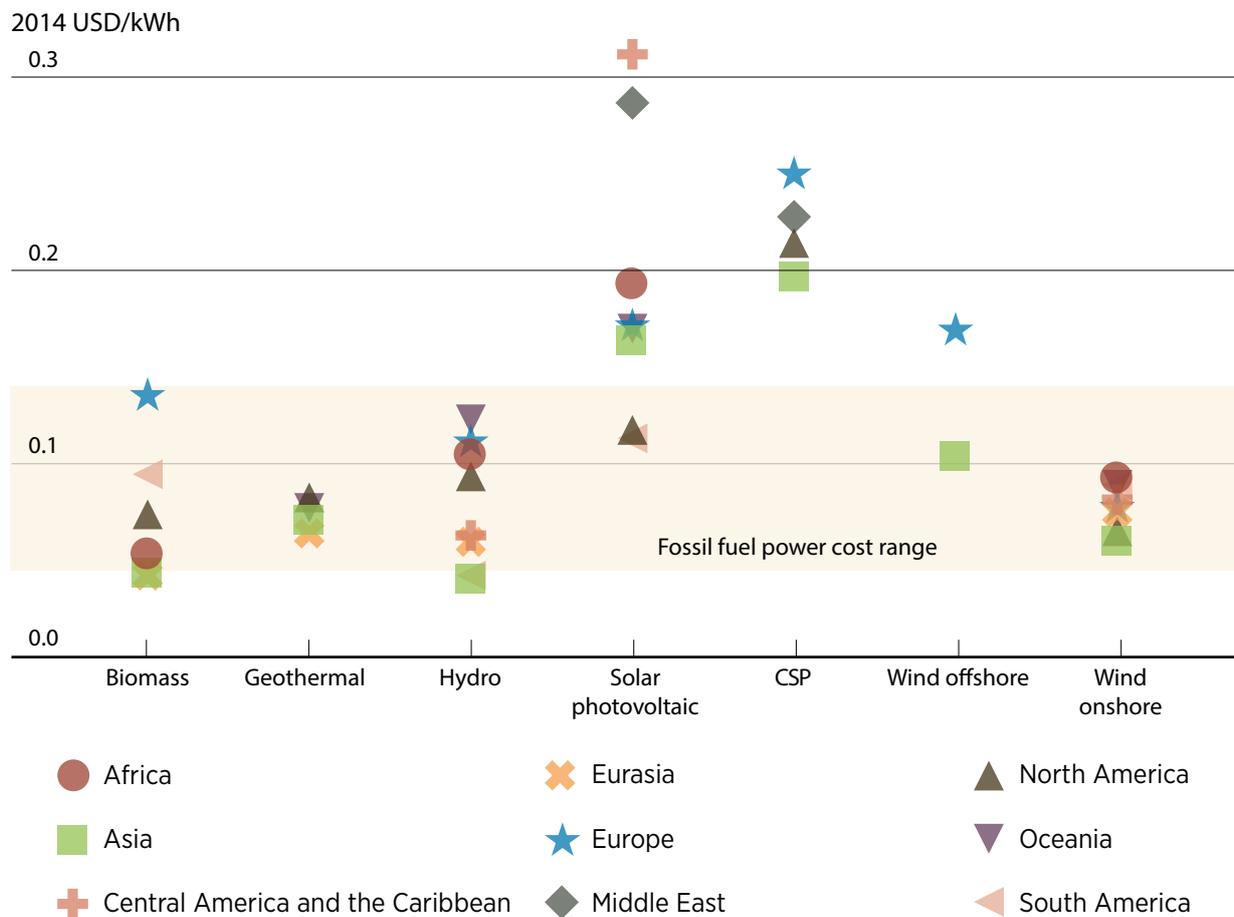
Given the installed costs and the performance of today's renewable technologies, and the costs of conventional technologies, renewable power generation is increasingly competing head-to-head with fossil fuels, without financial support (Figure ES 2).

The weighted average LCOE of utility-scale solar PV in China and North America – the world's two largest power-consuming markets – and in South America, has also now fallen into the range of fossil fuel-fired electricity costs. For utility-scale solar PV projects installed in 2013 and 2014, the weighted average LCOE by region ranged from a low of around USD 0.11 to USD 0.12/kWh (in South and North America, respectively) to over USD 0.31/kWh (in Central America and the Caribbean). But for individual projects, the range of costs is much wider. In various countries with good solar resources, projects are now being built with an LCOE of USD 0.08/kWh, while a recent tender in Dubai, in the United Arab Emirates, resulted in a successful bid for a solar PV power purchase agreement (PPA) for just USD 0.06/kWh, without financial support. Where good resources exist and low-cost financing is available, utility-scale solar PV projects that are now being built (e.g., in Dubai, Chile and other parts of the world) will provide electricity at a lower cost than fossil fuels, without any financial support. PV's growing competitiveness holds just as true in regions where indigenous fossil fuels are abundant.

Onshore wind costs continue to decline, albeit more slowly than for solar PV. The weighted average LCOE for wind ranged from a low of USD 0.06/kWh in China and Asia to a high of USD 0.09/kWh in Africa. North America also has very competitive wind projects, with a weighted average LCOE of USD 0.07/kWh due to excellent resources and a good cost structure. For hydropower, the estimated weighted average LCOE by region varies between USD 0.04/kWh in Asia and South America to a high of USD 0.12/kWh in Oceania.

CSP and offshore wind are still typically more expensive than fossil fuel-fired power generation options, with the exception of offshore wind in tidal flats. But these technologies are in their infancy in terms of deployment, with 5 GW of CSP and 8 GW of offshore wind installed worldwide at the end of 2014. Both represent important renewable power sources that will play an increasing part in the future energy mix as costs come down. The weighted average LCOE of CSP by region varied from a low of USD 0.20/kWh in Asia to a high of USD 0.25/kWh in Europe. However, as costs fall further, projects are being built with LCOEs of USD 0.17/kWh, and power purchase agreements are being signed at even lower values where low-cost financing is available. Historically, offshore wind costs rose after 2005, but this was as projects shifted further offshore and into deeper water; those costs now appear to be stabilising. The regional weighted

**FIGURE ES 2: WEIGHTED AVERAGE COST OF ELECTRICITY BY REGION FOR UTILITY-SCALE RENEWABLE TECHNOLOGIES, COMPARED WITH FOSSIL FUEL POWER GENERATION COSTS, 2013/2014**



Source: IRENA Renewable Cost Database.

Note: Real weighted average cost of capital of 7.5% in OECD countries and China; 10% in the rest of the world.

average LCOE for offshore wind varied from a low of USD 0.10/kWh for near-shore projects in Asia, where development costs are lower, to USD 0.17/kWh for projects in Europe.

The story of increased competitiveness, however, remains a nuanced one. This is because renewable power generation LCOEs per project span a wide range, due to site-specific cost factors (e.g., availability of existing infrastructure, grid connection costs, local labour rates, etc.) and the fact the quality of the renewable resource varies from one site to another. What is clear is that most renewable energy projects being built today, even with less mature technologies, are highly competitive in market terms.

**There are no technical barriers to the increased integration of variable renewable resources, such as solar and wind energy. At low levels of penetration, the grid integration costs will be negative or modest, but can rise as penetration increases. Even so, when the local and global environmental costs of fossil fuels are taken into account, grid integration costs look considerably less daunting, even with variable renewable sources providing 40% of the power supply. In other words, with a level playing field and all externalities considered, renewables remain fundamentally competitive.**

The cost of electricity from different power generation technologies can be measured in a number of ways, and each accounting method has its merits. LCOE is a static measure of costs, which provides useful insights, but to determine the true least-cost pathway for any country's electricity sector requires detailed system modelling. Variable renewables raise different questions for the electricity system, but the principle is the

same: a mix of technologies in a range of locations will be required to meet demand that varies every day. Hydropower, biomass for power, geothermal and CSP, with thermal energy storage to allow dispatchability, pose no special problems for grid operation.

There are no insurmountable technical hurdles to the integration of the variable technologies of solar PV and wind power either, and additional system costs that might be considered over and above the LCOE are modest. Cost implications for transmission and distribution systems are typically minimal. However, additional spinning reserve to meet voltage fluctuations, to allow for intermittency and provide the capacity to ride out longer periods of low sunshine or wind, can add to overall system costs. Estimates of these costs depend on a range of factors, including: the specific electricity-system configuration, existing generation assets, share of variable renewable penetration, distribution of renewable resources and their covariance, and existing market structures. However, estimated values are in the range of USD 0.035 to USD 0.05/kWh with variable renewable penetration of around 40%. While these figures must be treated with caution and are not a substitute for detailed system modelling, they give an idea of the order of magnitude to be expected.

However, even taking a systems-based approach does not adequately address the environmental and health externalities of the fossil fuels used for power generation. Without such analysis, renewables do not face a level playing field. If damage to human health from fossil fuels in power generation is considered in economic terms, along with the externalities associated with CO<sub>2</sub> emissions (assuming USD 20 to USD 80/tonne of CO<sub>2</sub>), the cost of fossil fuel-fired power generation rises by USD 0.01 to USD 0.13/kWh, depending on the country and technology. In an analysis covering 26 countries that represent about three-quarters of global power consumption (IRENA, 2014), the cost of fossil fuel-fired electricity rises to between USD 0.07 and USD 0.19/kWh if these health and environmental factors are taken into account (Figure ES 3).

**The power generation sector is being actively transformed, in a virtuous cycle with support policies stimulating increased deployment, which in turn results in technological improvements as well as continual cost reductions. Despite this, deployment is not increasing fast enough to meet the world's ambitious goals for a truly sustainable power system.**

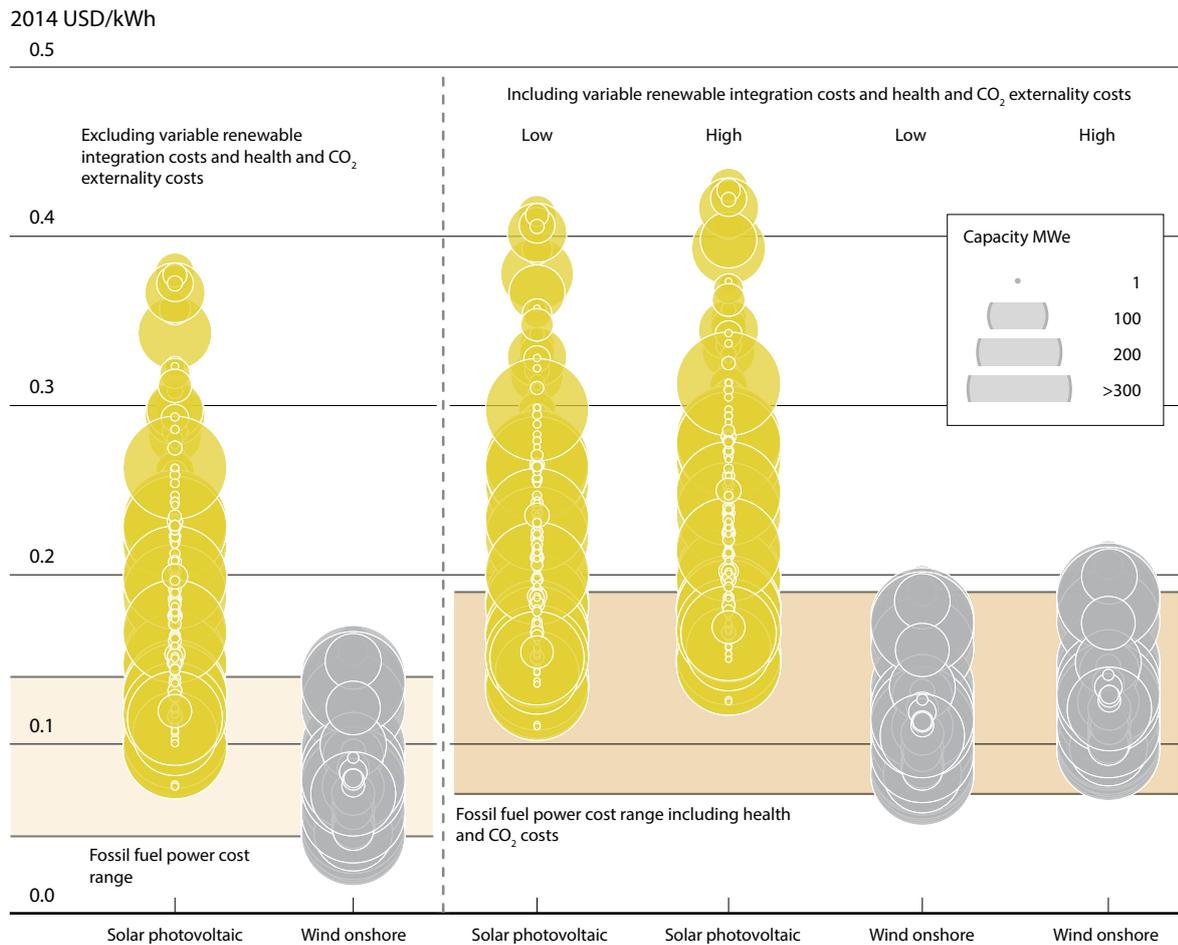
This transformation is being driven by the high learning rates for a range of renewable power generation technologies, particularly solar PV. For instance, with every doubling of cumulative installed capacity, solar PV module prices are expected to fall by 18% to 22%.

The LCOE of a power generation technology reflects multiple factors: resource quality, equipment cost and performance (including capacity factor), the balance of project costs, fuel costs (if any), operation and maintenance costs, the economic lifespan of the project, and the cost of capital. Renewable power generation equipment costs are falling, even as the technologies themselves continue becoming more efficient. The combination of these two factors has led to the continual, often rapid, decline in the cost of electricity from renewable-based technologies. Supported by forward-looking policies, learning investments in renewables have now paid off, and renewables are now highly competitive in a range of markets.

The year 2013 was a landmark year for renewables. Despite inconsistent policymaking and weak economic growth, overall renewable capacity additions reached a new record high of more than 120 gigawatts (GW), with new solar deployment exceeding wind for the first time. Figures for 2014 are still not finalised, but new capacity additions for both solar PV and wind are both estimated to have exceeded 40 GW each, suggesting another year of new renewable capacity additions exceeding 120 GW.

Despite renewable technologies accounting for around half or more of new power generation capacity additions globally from 2011 onwards, deployment is not increasing fast enough to achieve the Sustainable Energy for All goal of doubling the share of renewable energy in the global energy mix by 2030. Much work, therefore, remains to be done for the world to unlock the potential of renewables.

**FIGURE ES 3: THE LCOE OF VARIABLE RENEWABLES AND FOSSIL FUELS, INCLUDING GRID INTEGRATION COSTS (AT 40% VARIABLE RENEWABLE PENETRATION) AND EXTERNAL HEALTH AND CO<sub>2</sub> COSTS**



Source: IRENA Renewable Cost Database and analysis.

Note: Fossil fuel power costs for 26 REMAP countries. Real weighted average cost of capital of 7.5% in OECD countries and China; 10% in the rest of the world.

**Total installed costs of renewable power generation technologies vary significantly by country and region, as well as between technologies. The systematic collection of comprehensive installed cost data is necessary if electricity costs and cost-reduction potential are to be analysed with confidence.**

There is no single “true” LCOE value for a given power generation technology. Just as for non-renewable power generation technologies, the installed costs and capacity factors for renewable energy are highly technology- and site-specific. Despite the convergence in costs of renewable technologies, they can still vary widely not only within each country, but between countries. Collecting national data to analyse current costs and the cost reduction potential of renewable power technologies, therefore, is crucial and needs to be a policy priority. Such information is necessary not only to identify the reasons for differences in electricity costs, but to make policy recommendations for how to reach efficient cost levels.

The approach taken in this report is to analyse equipment costs, total installed costs, and LCOE, in order to break down changes in competitiveness into distinct factors.

Total installed costs in China and India are typically lower than in the rest of the world and range within a narrower band (Figure ES 4). Average total installed costs for renewable power generation technologies in the countries of the Organisation for Economic Co-operation and Development (OECD) are higher than in

China and India, with the rest of the world lying somewhere in between — except for onshore wind and solar PV, where installed costs in the rest of the world are higher.

In China and India, average installed costs for biomass for power, hydropower and onshore wind average between USD 1 240 and USD 1 390/kW. Remarkably, given that module costs alone averaged USD 2 646/kW in the fourth quarter of 2009, average installed costs for large-scale solar PV have fallen dramatically in China and India, to around USD 1 670/kW in 2013 and 2014. In the OECD, average total installed wind costs are estimated to be around USD 2 000/kW, with average installed costs for utility-scale solar PV of around USD 2 330/kW.

The more efficient and cleaner burning biomass power plants in the OECD have average installed costs of around USD 4 300/kW. Average total installed costs for offshore wind are estimated to have averaged around USD 4 500/kW in recent years, with CSP installed costs somewhat higher at around USD 6 740/kW, reflecting additional costs to incorporate thermal energy storage. Total installed costs for solar PV and onshore wind are now typically similar to, or lower than, the installed costs for the average coal-fired plant in OECD countries.

**Renewable power generation technologies are now the economic solution for isolated off-grid and small-scale electricity systems, such as on islands, that are reliant on diesel-fired generation.**

The volatility of oil prices and the high costs of small-scale diesel-fired electricity generation are further exacerbated in remote locations, where poor, or even non-existent, infrastructure can mean that transport costs increase the cost of diesel by 10% to 100% compared with prices in major cities.

For islands or other markets facing comparable energy challenges, the recent decline in the LCOE of renewable power generation technologies represents a historic development.

For many of the over 1.3 billion people worldwide who currently lack electricity access, renewable energy can provide their first introduction to modern energy services, largely through decentralised off-grid and mini-grid solutions. Moreover, this crucial transformation can be justified on purely economic grounds.

However, it is not just off-grid electricity systems that remain dependent on diesel at present. Given the trend in technology costs, electricity systems based predominantly on oil-fired generation – such as on most islands and in a number of mainland countries – will witness reduced system generation costs with the integration of renewables.

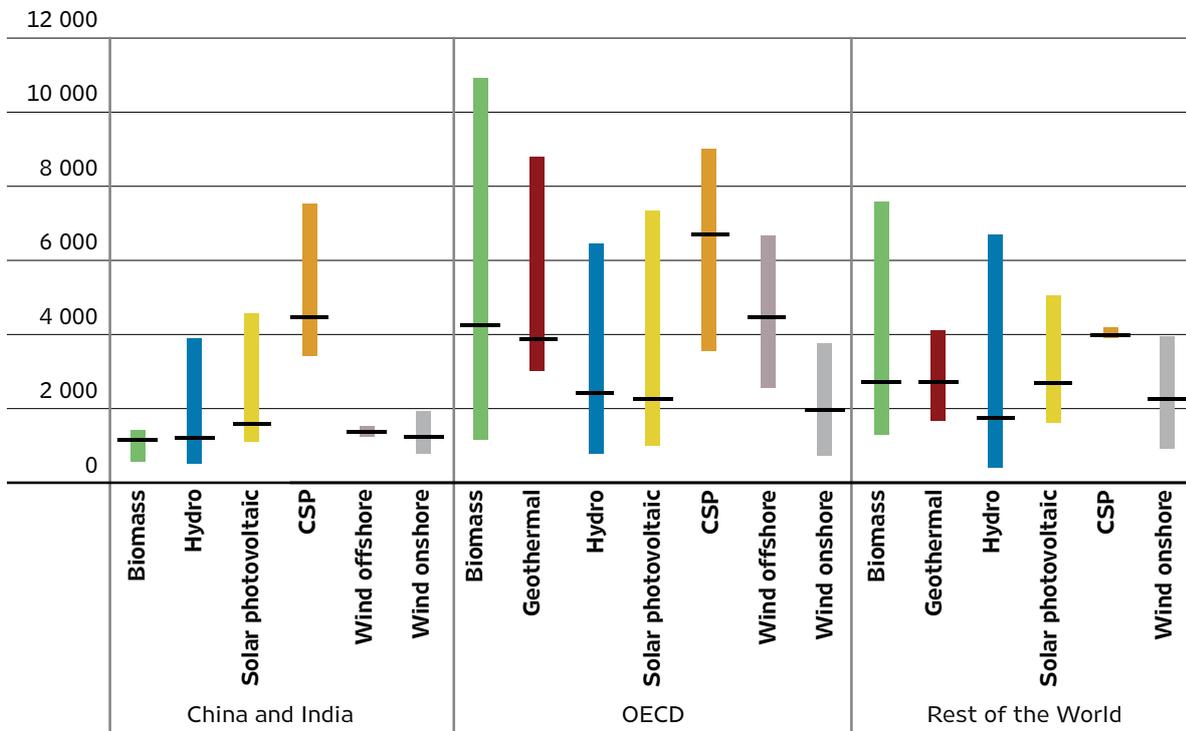
Renewables are likely to remain the most economic off-grid electricity solution, despite the recent drop in oil prices at the end of 2014 and the beginning of 2015. Oil prices remain volatile. Over 2014, they averaged around USD 98/barrel despite the drop, and they remain much higher than they were 15 years earlier. As with any commodity market, the difference between undersupply and oversupply is often on a knife edge, and price swings can be dramatic. However, history has shown that periods of low oil prices tend to be transitory, as long as the world's thirst for these finite resources rises. So for an investment with a lifetime of 25 years or more, today's oil prices are not an accurate measure on which to base an investment decision in electricity generation.

**For renewables, further cost reductions can still be expected into the future, which will further lower the weighted average LCOE. With equipment costs reaching low levels; future cost reductions could be driven by reduced balance-of-project costs, lower operation and maintenance and finance costs.**

Hydropower, geothermal and most biomass-combustion technologies are mature, with limited cost-reduction potential. The technologies with the largest remaining cost-reduction potential are CSP, solar PV and wind

**FIGURE ES 4: TYPICAL RANGES AND WEIGHTED AVERAGES FOR THE TOTAL INSTALLED COSTS OF UTILITY-SCALE RENEWABLE POWER GENERATION TECHNOLOGIES BY REGION, 2013/2014**

**2014 USD/kW**



Source: IRENA Renewable Cost Database.

Note: Ranges and weighted averages are calculated for 2013 and 2014 to ensure representative ranges for biomass, CSP and offshore wind. Weighted averages for solar PV, CSP and onshore wind would be lower if only data for 2014 was used.

power. With today's low equipment costs, cost reduction opportunities in absolute terms will increasingly hinge on non-equipment factors, such as balance-of-project, operations and maintenance and finance costs.

The industry is already shifting its cost reduction focus to these areas. Yet much more detailed cost data is required, so that ongoing cost analysis can support policy makers in ensuring that policy and regulatory frameworks are streamlined and optimised. This is particularly important, because future cost reductions will be more difficult to unlock and will depend on a more diverse range of stakeholders, not just equipment manufacturers. Careful analysis will be needed to remove the myriad of small barriers, and policy settings must be tailored to ensure all stakeholders along the value chain are incentivised and able to bring down costs.

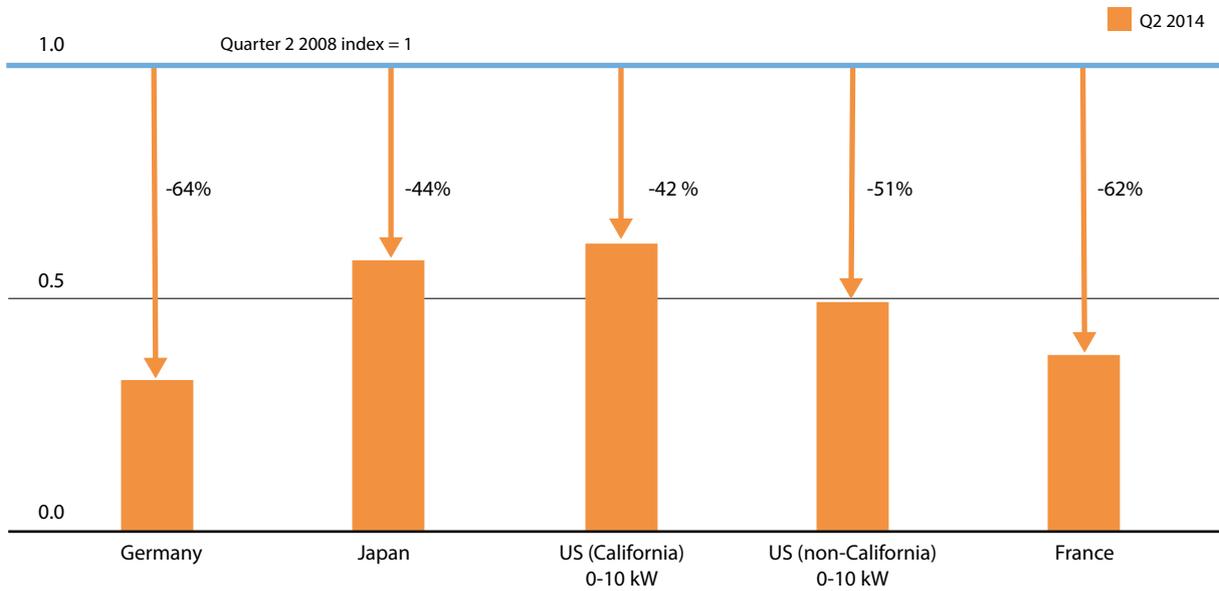
**In line with cost reductions for solar PV modules, small-scale residential solar PV costs have also declined rapidly in recent years, so that “plug parity” or “socket parity” is increasingly the norm.<sup>2</sup>**

Germany and China have developed, on average, the most competitive small-scale residential rooftop systems in the world (Figure ES 5). Germany's residential system costs have fallen from just over USD 7 200/kW in the first quarter of 2008 to USD 2 200/kW in the first quarter of 2014, a decline of 70%. Between 2008 and 2014, the average solar PV LCOE in Australia, China, Germany, Italy and the United States of residential systems fell by between 42% and 64%. The average LCOE of many systems in Germany is now up to 40% lower than the residential price. Residential-scale solar PV's continuing cost reductions pose significant challenges to the traditional utility model.

<sup>2</sup> The terms “plug parity” or “socket parity” refer to when the LCOE of residential systems is lower than the retail tariff of electricity. In this report, the comparison is made excluding all financial support. Adding in the financial support for small-scale solar PV, where available, would make the comparison even more favourable from a consumer perspective.

FIGURE ES 5: LCOE REDUCTIONS FOR SMALL-SCALE RESIDENTIAL SOLAR PV, Q2 2008 TO Q2 2014

Index of LCOE (Q2 2008 = 1)



Source: IRENA Renewable Cost Database.

The goal of this report is to reduce uncertainty about the true costs of renewable power generation technologies, so that governments can be more ambitious and efficient in their policy support for renewables. As this comprehensive report clearly demonstrates, any remaining perceptions that renewable power generation technologies are expensive or uncompetitive are at best outdated, and at worst a dangerous fallacy.

