10 COST REDUCTIONS TO 2025

The virtuous cycle of policy support for renewable power generation technologies leading to accelerated deployment, technology improvements and cost reductions has had a profound effect on the power generation sector. Renewables are now the economic solution off-grid and are increasingly the least-cost option for grid supply. This is changing the nature of electricity generation systems and how they are managed. Solar PV is democratising electricity production and bringing it within reach of individual households, as millions of people around the world now have rooftop PV systems. In some countries, this growth of distributed solar PV is starting to call into question the viability of traditional utility business models. The challenges faced by utilities, sometimes amplified by inflexible or outdated electricity markets, will only increase as renewable power generation costs continue to fall.

The broad reasons for this transformation of the electricity sector are simple. In the past, the most economic renewable power generation options were hydropower, biomass for power and geothermal where unexploited economic resources existed, but resources were limited. However, as a result of the cost declines for solar PV and wind, future growth can be sustained on the much larger and more widely distributed resources of solar and wind. Past barriers to the growth in new renewable power generation deployment are therefore being removed. However, new challenges are emerging, such as outdated market structures, inflexible market mechanisms for managing the electricity system, and utility business models that have not adapted to the new reality. In this context, but also because renewables still do not face a level playing field, it is important to understand the potential for future cost reductions for renewable power generation technologies in order to understand the economic potential to accelerate renewable power generation deployment.

The recent declines, and in the case of solar PV dramatic declines, in the LCOE of renewables reflect the increasing maturity of non-hydro technologies and represent a remarkable achievement. However, for a transition to a truly sustainable energy sector to be achieved, continued cost improvements need to be unlocked. This is required to ensure that in all major electricity markets renewable power generation options are, on average, the least-cost solution for almost all new electricity generation capacity required worldwide to meet either demand growth or plant retirements.[36] The fact that a large share, and in some cases the entire share, of total new annual capacity additions of a given renewable power generation technology is accounted for by the top five countries highlights how much more work is required to broaden and deepen the markets for renewable power generation technologies. This will require significant work to remove barriers, grow domestic markets to ensure competitive cost structures and setting the right market and regulatory structures. However, continued improvement in the competitiveness of renewables will also be required even if the market barriers unrelated to price, which hinder the accelerated deployment of renewable power generation technologies, are removed given the lack of a level playing field for renewables.

COST REDUCTION POTENTIALS BY TECHNOLOGY

Fortunately the outlook for cost reductions is good, particularly for the average cost of new projects. However, due to the rapid cost declines seen for solar PV modules and to a lesser extent wind turbines in recent years, the absolute cost reduction opportunities in the future will increasingly need to come from balance of system costs or balance of project costs, operations and maintenance

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[36] *It also needs to be true in the long run for high shares of variable renewable electricity penetration if the electricity sector is to play its part in preventing dangerous climate change.*

cost optimisation and reduced financing costs. Unlocking these future cost reductions will require a shift in policy focus and may also be more difficult to unlock, since they represent more fragmented stakeholders than major equipment manufacturers and project developers. Future work by IRENA in 2015 will look in much greater detail at the cost reduction opportunities and the barriers facing their realisation for the power sector.

The technologies with the largest cost reduction potential are CSP, solar PV and wind. Hydropower and most biomass combustion and conventional geothermal technologies are mature and their cost reduction potentials are not as large. There are exceptions to this, such as advanced biomass gasification technologies, enhanced geothermal, etc, but these are beyond the scope of this report.

The LCOE of wind has declined significantly, and wind power is now one of the most competitive renewable power generation options. This decline was driven by technology improvements and falls in wind turbine prices. Wind turbine prices have declined by as much as 30% since their peak in 2008/2009, with prices of between USD 930 and USD 1 376/kW in 2014 for project for which data are available (Wiser and Bollinger, 2014 and BNEF, 2014). These are 37% to 104% higher than average wind turbine prices in China. However, there is continued convergence in average prices for wind turbines, as modest declines continue in OECD countries and Chinese turbine prices stay relatively constant. In addition, there is increasing demand for today's "state of the art" technologies, and large turbines with the greatest swept areas command a price premium. The additional costs are required for more advanced materials to retain structural integrity at acceptable blade weights for the longer blades, for sturdier and quieter gear boxes and other increased structural costs to deal with greater heights and weights. Future cost reductions will therefore increasingly depend on cost trends for the larger machines, as 80 to 100 metre diameter and 100 to 120 metre diameter bladed machines will dominate the market by 2015 (MAKE Consulting, 2013).

Wind turbines are not necessarily interchangeable commodities – even at the same capacity rating – given their design characteristics, quality and their manufacturer's warranty terms and reliability guarantees vary. The extent to which wind turbine prices can converge is therefore limited. An additional issue is that the particularly low-cost characteristics of turbines in China and India are to a certain extent due to the lower materials costs (e.g. cement, steel) and labour costs in these markets, which cannot be replicated in other markets.

By 2025 installed costs for wind farms in the United States could fall to around USD 1 450/kW from their preliminary estimates of around USD 1 780/kW in 2014, assuming wind turbine prices stabilise at around USD 850/kW. Total installed costs in Europe are likely to follow similar trends, with values for 2025 of between USD 1 400 and USD 1 600/kW for the major markets. There is likely to be little change in the already very competitive cost structures in China and India, as installed cost reductions are likely to be offset by a shift to larger turbines with greater swept areas and improved capacity factors.

Average capacity factors for new wind farms may continue to rise, as the average size and hub-height of turbines grow. However, this effect may be less than implied by technology improvements if a trend to lower quality wind resource sites occurs in some major markets due to the best sites already having been exploited. As a result the LCOE of wind will continue to fall, but this may slow if, on average, poorer wind sites are being developed. With turbine cost reductions likely to slow closer to 2020, the importance of reducing balance of project costs, O&M costs and financing costs will grow. Maintenance costs in the United States are around USD 0.01/kWh, although overall O&M costs are higher and most markets have costs of around USD 0.015 to USD 0.025/kWh. If these costs cannot be brought down, they will account for an increasing share of the LCOE of wind and act as a brake on cost opportunities. Further analysis and data are needed to try to identify policy recommendations to drive down O&M costs to best-practice levels.

Despite solar PV module prices that are now significantly below the learning curve, cost reductions are likely to resume in 2015 as the market continues to grow and manufacturing innovations and economies of scale are exploited. With price reductions having been brought forward to some extent, future cost reductions will be lower in absolute terms. However, the continued growth in new capacity additions means that in percentage terms, cost reductions should not slow dramatically. By 2025, c-Si modules could be retailing for between USD 0.40 and USD 0.45/W with full recovery of capital costs. However, given even small changes in the projections of future deployment, these projections are extremely uncertain.

What is clear is that now that PV module prices have fallen so far, BoS costs and financing costs are becoming the crucial determinants of the LCOE of solar PV. This can easily be seen by comparing one of the most competitive markets, Germany, with the United States. The higher BoS costs in the United States raises the LCOE of solar PV above what it otherwise could be. Further analysis to better understand the reasons behind these differences and how to eliminate them could accelerate the rate of installed cost reductions in many markets. Reducing BoS costs to the most competitive levels will determine as much as 80% of the cost reduction potential for solar PV, outside of the most competitive markets, to 2025. This structural shift in the cost-cutting focus of the PV market is beginning, but will require significant investment in data collection and analysis in order to identify policy measures to accelerate convergence in BoS costs. Total installed costs for utility-scale projects could fall to between USD 1 100 to USD 1 200/kW by 2025 on average, although this will be heavily dependent on convergence of BoS costs to the most competitive levels. A similar dynamic could play out in the small-scale rooftop market. If BoS costs can be pushed down to very competitive levels, average installed costs could range from USD 1 600 to USD 2 000/kW by 2025.

For CSP plants, the overall capital cost reductions for parabolic trough plants by 2025 could be between 20% and 45% (IRENA analysis; Hinkley, 2011; Kutscher, 2010). For solar towers the cost reduction potential could be as high as 28% on a like-for-like plant basis (Hinkley, 2011). Alternative analysis suggests that the evolution of costs and performance is a little more complex, with the possibility that capital costs might decline by between 10% and 20% by 2017, depending on the components, although from an LCOE perspective, a better solution would be to have overall installed costs that are around the same as today, and instead use the cost reductions to increase the thermal energy storage and solar field size to increase the capacity factor from 48% to 65% (Kolb, 2011). Looking slightly further ahead to 2025 and assuming higher cost reductions (from one-fifth to one-third, depending on the components) and the switch to super-critical steam cycles, capital costs could be reduced by 30% and the capacity factor raised to 72% (IRENA analysis and Kolb, 2011).

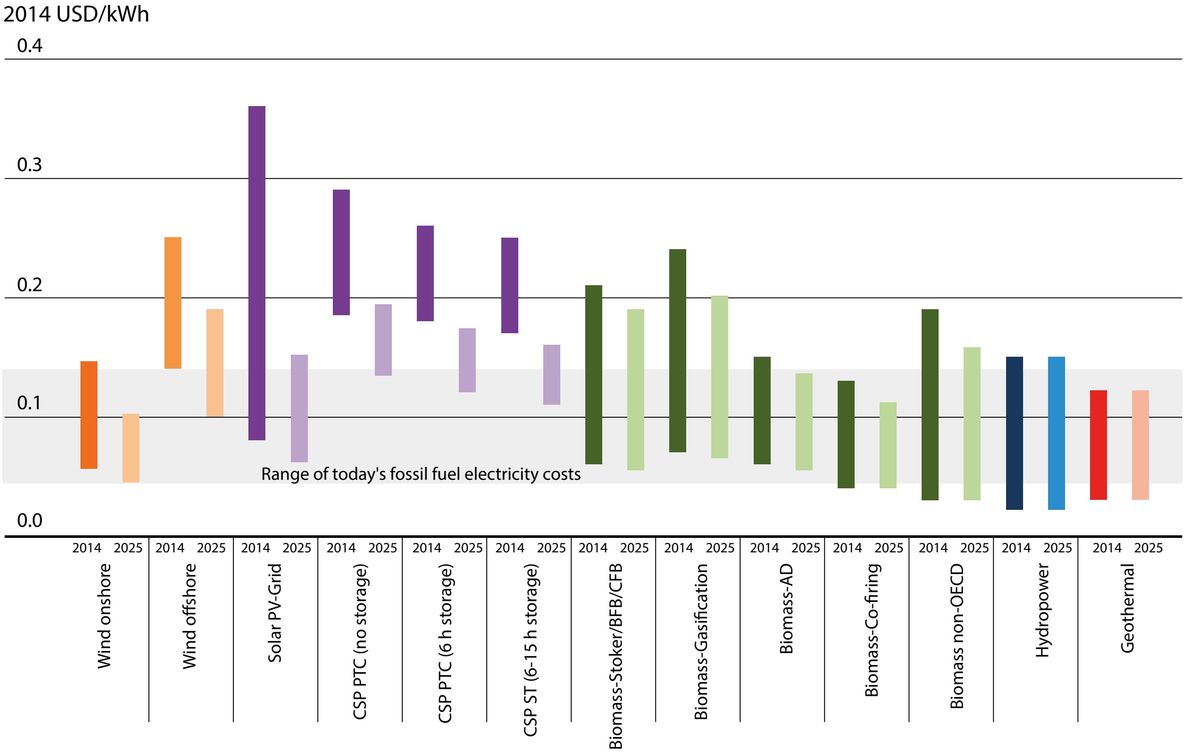
The current solar thermal electricity roadmap of the International Energy Agency, elaborated in consultation with industry, targets a capital cost range for plants with six hours' energy storage of between USD 3 250 and USD 4 800/kW in 2030 (IEA, 2014), suggesting installed costs in 2025 of perhaps USD 4 500 to USD 5 000/kW.[37]

It is assumed that there will be no decline in hydropower and geothermal costs by 2025 and that any changes in costs are due to underlying commodity price variations and general civil engineering costs. Most biomass combustion technologies are mature, although the projected growth in the market will allow modest capital cost reductions of between 10% and 15% to be possible by 2025 for the higher-cost markets for stoker, bubbling fluidised bed, and circulating fluidised bed technologies. The cost reduction potential for gasification technologies, excluding anaerobic digestion, is higher, and if deployment accelerates, capital cost reductions of 10% to 20% might be possible by 2025.

Figure 10.1 presents the cost ranges for wind, solar PV, CSP, geothermal and biomass today as well as projections for 2025 based on the assumptions already presented. For onshore wind, the lower end of the LCOE range does not shift significantly, given the already very competitive costs of today's most competitive projects. However, depending on where new installed capacity is built, the installed cost reductions projected will significantly lower the weighted average LCOE.

[37] *This would result in capacity factors of between 40% and 45% depending on the location.*

Figure 10.1: LCOE ranges by renewable power generation technology, 2014 and 2025



The typical LCOE range for solar PV will decline from between USD 0.08 and USD 0.36/kWh in 2014 to between USD 0.06 and USD 0.15/kWh in 2025. Grid parity for residential applications will increasingly be the norm in competitive PV markets and utility-scale projects will be routinely reaching wholesale grid-parity in regions with good solar resources and/or expensive fossil-fired electricity generation.

The reduction in LCOE for CSP will depend to a large extent on success in improving the current investment climate and longer-term commitments to policy support measures that can underpin deployment and learning investments. Given the low level of current deployment, just 5 GW at the end of 2014, if deployment can be accelerated, then costs will come down. Solar towers show perhaps the greatest potential for LCOE reduction. By 2025 solar towers could be producing electricity for between USD 0.11 and USD 0.16/kWh on average.

Biomass technologies will not see the lower end of their LCOE range shift significantly by 2020, given that today's cheapest options rely on low capital costs and on very cheap or even free feedstocks. However, for less mature technologies such as gasification, capital cost reductions will drive down the upper end of the range.

ANNEX
METHODOLOGY

DIFFERENT MEASURES OF COST

Cost can be measured in a number of different ways, and each way of accounting for the cost of power generation brings its own insights. The costs that can be examined include equipment costs (e.g. PV modules), financing costs, total installed cost, fixed and variable operating and maintenance costs (O&M), fuel costs (if any) and the levelised cost of energy (LCOE).

The analysis of costs can be very detailed, but for comparison purposes and transparency, the approach used here is a simplified one. This allows greater scrutiny of the underlying data and assumptions, improves transparency and confidence in the analysis, and also facilitates the comparison of costs by country or region for the same technologies in order to identify the key drivers in any differences.

The three indicators that have been selected are:

- Equipment cost (factory gate, FOB, and delivered at site);
- Total installed project cost, including fixed financing costs[38];
- Capacity factor by project; and
- The levelised cost of electricity, LCOE.

The analysis in this paper focuses on estimating the costs of renewables from the perspective of private investors, whether they are a state-owned electricity generation utility, an independent power producer or an individual or community looking to invest in small-scale renewables. The analysis excludes the impact of government incentives or subsidies, system balancing costs associated with variable renewables and any system-wide cost-savings from the merit order effect[39], except where explicitly discussed at the end of Chapter 2. Furthermore, the analysis does not take into account any CO_2 pricing, nor the benefits of renewables in reducing other externalities (e.g. reduced local air pollution or contamination of the natural environment, except where explicitly discussed at the end of Chapter 2). Similarly, the benefits of renewables being insulated from volatile fossil fuel prices have not been quantified. These issues are important, but are covered by other programmes of work at IRENA.

Clear definitions of the technology categories are provided, where this is relevant, to ensure that cost comparisons are robust and provide useful insights (e.g. off-grid PV vs. utility-scale PV). Similarly, it is important to differentiate between the functionality and/or qualities of the renewable power generation technologies being investigated (e.g. concentrating solar power with and without thermal energy storage). It is important to ensure that system boundaries for costs are clearly set and that the available data are directly comparable. Other issues can also be important, such as cost allocation rules for combined heat and power plants, and grid connection costs.

The data used for the comparisons in this paper come from a variety of sources, such as business journals, industry associations, consultancies, governments, auctions and tenders. Every effort has been made to ensure that these data are directly comparable and are for the same system boundaries. Where this is not the case, the data have been corrected to a common basis using the best available data or assumptions. It is planned that this data will be complemented by detailed surveys of real world project data in forthcoming work by IRENA.

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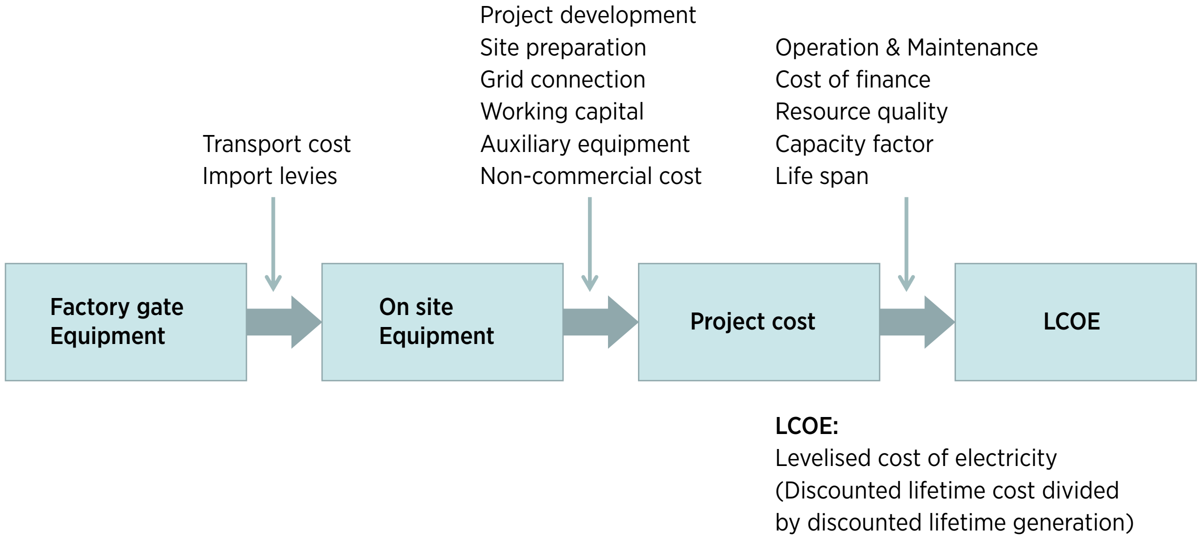
[38] *Banks or other financial institutions will often charge a fee, such as a percentage of the total funds sought, to arrange the debt financing of a project. These costs are often reported separately under project development costs.*

[39] *See EWEA, Wind Energy and Electricity Prices, April 2010 for a discussion.*

Figure A1.1: Renewable power generation cost indicators and boundaries



An important point is that, although this paper tries to examine costs, strictly speaking, the data available are actually prices, and are often not even true market average prices, but price indicators. The difference between costs and prices is determined by the amount above, or below, the normal profit that would be seen in a competitive market. The rapid growth of renewables markets from a small base means that the market for renewable power generation technologies is rarely well-balanced. As a result, prices can rise significantly above costs in the short term if supply is not expanding as fast as demand, while in times of excess supply, losses can occur and prices may be below production costs. This makes analysing the cost of renewable power generation technologies challenging and every effort has been made to indicate whether current equipment costs are above or below their long-term trend.

The cost of equipment at the factory gate is often available from market surveys or from other sources. A key difficulty is often reconciling different data sources to identify why data for the same period differ. For example, the balance of capital costs in total project costs tends to vary even more widely than power generation equipment costs, as it is often based on significant local content, which depends on the cost structure of where the project is being developed. Total installed costs can therefore vary significantly by project, country and region depending on a wide range of factors.

LEVELISED COST OF ELECTRICITY GENERATION

The LCOE of renewable energy technologies varies by technology, country and project, based on the renewable energy resource, capital and operating costs, and the efficiency/performance of the technology. The approach used in the analysis presented here is based on a discounted cash flow (DCF) analysis. This method of calculating the cost of renewable energy technologies is based on discounting financial flows (annual, quarterly or monthly) to a common basis, taking into consideration the time value of money. Given the capital-intensive nature of most renewable power generation technologies and the fact that fuel costs are low, or often zero, the weighted average cost of capital (WACC), often also referred to as the discount rate, used to evaluate the project has a critical impact on the LCOE.

There are many potential trade-offs to be considered when developing an LCOE modelling approach. The approach taken here is relatively simplistic, given the fact that the model needs to be applied to a wide range of technologies in different countries and regions.

However, this has the additional advantage that the analysis is transparent and easy to understand. In addition, more detailed LCOE analyses result in a significantly higher overhead in terms of the granularity of assumptions required. This often gives the impression of greater accuracy, but when it is not possible to robustly populate the model with assumptions, or to differentiate assumptions based on real world data, then the "accuracy" of the approach can be misleading.

The formula used for calculating the LCOE of renewable energy technologies is:

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

LCOE = the average lifetime levelised cost of electricity generation;

It = investment expenditures in the year t;

Mt = operations and maintenance expenditures in the year t;

Ft = fuel expenditures in the year t;

Et = electricity generation in the year t;

r = discount rate; and

n = life of the system.

All costs presented in this paper are real 2014 USD; that is to say, after inflation has been taken into account unless otherwise stated.[40] The LCOE is the price of electricity required for a project where revenues would equal costs, including making a return on the capital invested equal to the discount rate. An electricity price above this would yield a greater return on capital, while a price below it would yielder a lower return on capital, or even a loss.

As already mentioned, although different cost measures are useful in different situations, the LCOE of renewable energy technologies is a widely used measure by which renewable energy technologies can be evaluated for modelling or policy development. Similarly, more detailed DCF approaches taking into account taxation, subsidies and other incentives are used by renewable energy project developers to assess the profitability of real world projects.

[40] *An analysis based on nominal values with specific inflation assumptions for each of the cost components is beyond the scope of this analysis. Project developers will develop their own specific cash-flow models to identify the profitability of a project from their perspective.*