IRENA
International Renewable Energy Agency

SUMMARY FOR POLICY MAKERS:
Renewable Power Generation Costs

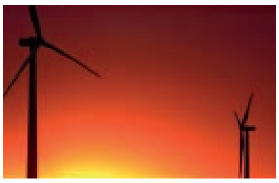
November 2012

Biomass for Power Generation

Concentrating Solar Power

Hydropower

Solar Photovoltaics



Wind Power

Introduction

Renewable energy will play a key role in the transition to a truly sustainable energy sector, with access to sustainable energy for all. In the past deployment of renewables was hampered by a number of barriers including their high up-front costs. Today's renewable power generation technologies are increasingly cost-competitive and are now the most economic option for off-grid electrification in most areas, and in locations with good resources, the best option for centralised grid supply and extension.

Renewable power generation technologies now account for around half of all new power generation capacity additions worldwide. In 2011 additions included 41 GW of new wind power capacity, 28 GW of solar photovoltaic (PV), 25 GW of hydropower, 6 GW of biomass, 0.5 GW of concentrated solar power (CSP) and 0.1 GW of geothermal power.[1]

This rapid deployment of these renewable technologies has a significant impact on costs, because of the high learning rates for renewables, particularly for wind and solar. For instance, for every doubling of the installed capacity of solar PV, module costs will decrease by as much as 22%.[2] As a consequence crystalline silicon (c-Si) PV module costs have fallen by more than 60% over the last two years to below USD 1.0/watt (W). The increasing size of global renewable markets and the diversity of suppliers has produced more competitive markets for renewable technologies.

The following sections of this paper outline the principle findings of the five costing papers on solar PV, CSP, wind power, hydropower and biomass that IRENA released in 2012 and highlight their key insights for policy makers.[3]

It is important to note that 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 analysis summarised in this paper represents a static analysis of costs. The optimal role of each renewable technology in a country's energy mix requires a dynamic modelling of electricity system costs to take into account the many complexities of operating an electricity grid.[4]

1 *IRENA costing papers (www.irena.org/publications) and REN21's "Renewables 2012 Global Status Report". Unless otherwise noted, all other data in this summary is from the IRENA costing papers.*

2 *For more information on learning rates for solar PV, see the IRENA costing report.*

3 *See www.irena.org/publications to download these free reports.*

4 *This type of analysis is part of IRENA's work on scenarios and strategies. See www.irena.org for more details.*

Insights for policy makers

Renewables can help meet policy goals for secure, reliable and affordable electricity. However, better and more up-to-date data is required.

Renewable energy technologies can help countries meet their policy goals for secure, reliable and affordable energy, expand electricity access, promote development and reduce energy price volatility. However, without reliable information on the relative costs and benefits of the available renewable energy technologies it is difficult, if not impossible, for governments to accurately assess which technologies are the most appropriate for their particular circumstances.

A renewable revolution is underway. The rapid deployment of renewable power generation technologies and the corresponding rapid decline in costs are sustaining a virtuous circle.

The levelised cost of electricity (LCOE)[5] is declining for wind, solar PV, CSP and some biomass technologies, while hydropower produced at good sites is still the cheapest way to generate electricity. These technologies, excluding hydropower, have high learning rates. This means that capital costs decline by a fixed, average percentage for every doubling of installed capacity; for solar PV modules, this can be up to 22%.

The rapid deployment of renewables, working in combination with the high learning rates for some technologies, has produced a virtuous circle that leads to significant cost declines and is helping fuel the renewable revolution.

Renewables are therefore becoming increasingly competitive. As an example, c-Si PV module costs have fallen by over 60% over the last two years to below USD 1.0/watt, and installed costs for residential PV systems are also declining. In Germany the costs of installed rooftop systems fell by 65% between 2006 and 2012 to USD 2.2/Wp, making solar PV competitive with current residential electricity tariffs.[6]

The rapid cost reductions in some renewable power generation technologies means that up-to-date data is required to evaluate support policies for renewables, while a dynamic analysis of the costs of renewables is needed to decide on the level of support.

Support policies designed to overcome the barriers and market distortions faced by renewables are driving these cost reductions and highlight the fact that the cost of supporting the deployment of renewables is much lower than a static analysis of costs would imply.

The rapid growth in installed capacity of renewable energy technologies, technology improvements and the associated cost reductions mean that even data from one or two years ago can significantly overestimate the cost of electricity from these technologies. Policy makers should take note of these rapid developments and recognise that a dynamic analysis of the cost of well-designed support measures is essential in order to decide appropriate levels of support.

5 *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.*

6 *See http://www.solarwirtschaft.de/preisindex*

Renewable technologies are now the most economic solution for off-grid electrification and grid extension in most areas, as well as for centralised grid supply in locations with good resources.

Current oil prices and the declining costs of renewable power generation technologies have made renewables the default option for off-grid electrification. Solar PV, biomass and wind are highly modular solutions to the challenge of extending electricity access to remote locations, and so help meet economic and social development goals. Renewable technologies can be significantly cheaper than diesel-fired generation, particularly in remote areas with poor or even non-existent infrastructure where transport costs can increase the cost of diesel by 10% to 100%.

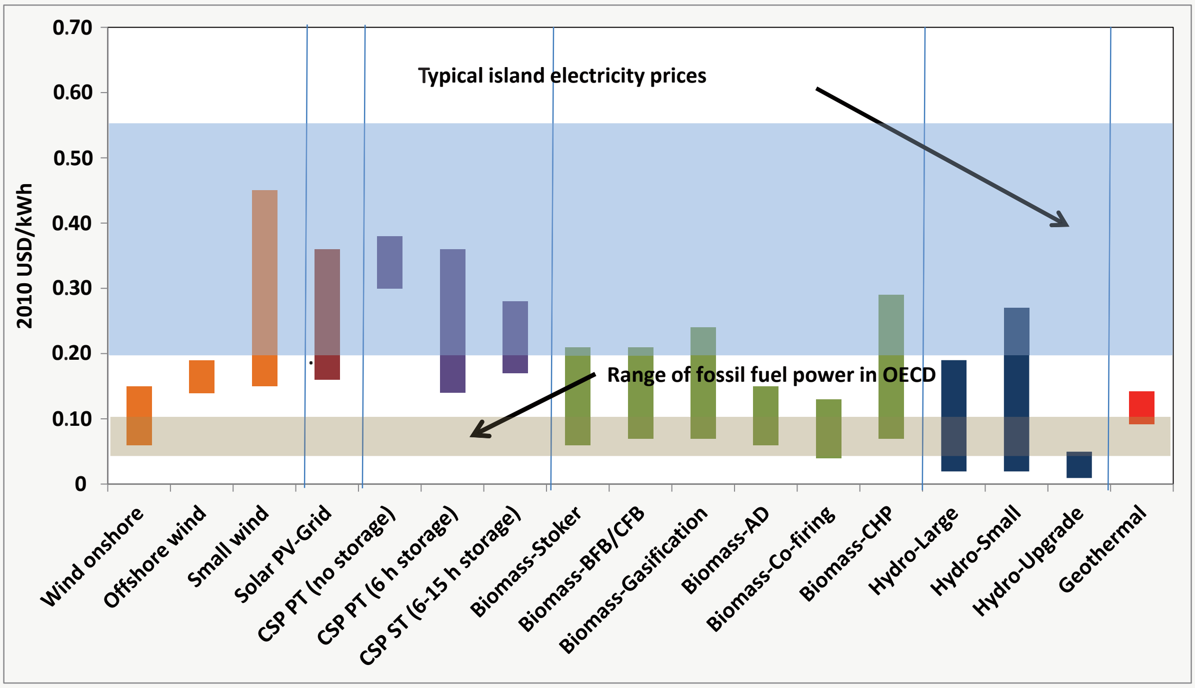


Figure 1: The levelised cost of renewable power generation technologies

Note: Assumes the cost of capital is 10%. The bands reflect ranges of typical investment costs (excluding transmission and distribution) and capacity factors. PT = parabolic trough, ST = solar tower, BFB/CFB = bubbling fluidised bed/circulating fluidised bed, AD = anaerobic digester, CHP = combined heat and power.

Figure 1 shows the cost-effectiveness of today's renewable technologies. However, the cost ranges are wide and very site-specific. As a result, there is no single "best" renewable power generation technology. It is also important to note that distributed renewable technologies, such as rooftop solar PV and small wind, can provide new capacity without the need for additional transmission and distribution investment and therefore can not be directly compared with large utility-scale renewable solutions.

Although many cost factors are technical (*e.g.* wind turbine design) or resource-related (*e.g.* wind speeds), the cost of capital can depend more on external factors such as a lack of experience in financing renewable projects of a particular type in a country. Addressing the real or perceived risks of renewable projects can have a large impact on the LCOE of renewables. For instance, the LCOE of a wind farm project is around 60% higher when the cost of capital is 14.5%, rather than 5.5%.

Different renewable power generation technologies can be combined in mini-grids to electrify isolated villages and extend existing grid networks. The complementary nature of different renewables options, sometimes deployed in combination with electricity storage, can help reduce the overall variability of supply to low levels and provide low-cost, local electrification solutions that bring economic benefits at a lower cost than diesel-fired generation.[7] However,

7 IRENA has a number of work items looking at how to achieve high levels of variable renewable penetration in electricity systems, including the role of smart grids and electricity storage. See www.irena.org for more details.

a major challenge to the economics of these electrification projects is the high cost of capital, which can be two to three times higher in developing countries than in developed ones.

The major components that determine the LCOE of renewable power generation can vary by a factor of two or more. A detailed analysis of renewable power generation technologies by country, and even region, is therefore necessary to understand opportunities.

There are four major components that largely determine the levelised cost of electricity for renewable power generation technologies – resource quality, equipment cost and performance, the balance of project costs and the cost of capital [8]. All of them can vary significantly between individual projects and countries. Each component can typically make a difference of a factor of two, in some cases even more.

As these components are largely independent of one another the breadth of possible outcomes is large. The LCOE can vary widely depending on the local resource, maturity of the market, competition, and a range of other factors. Only favourable combinations will result in economically viable projects at a particular time. A careful analysis of country-specific costs and resources is therefore required to robustly identify the most promising renewable power generation technologies.

IRENA's cost analysis programme is an ongoing effort to inform policy makers by creating a database of global renewable energy sources and the costs and performance of the various renewable technologies that can be used.

The lack of accurate, reliable data on the cost and performance of renewable technologies is a significant barrier to their uptake. IRENA's cost analysis programme is a response to a call from Member Countries for better and more objective cost data. Providing this information, with an accompanying analysis, will help governments, policy makers, investors and utilities make informed decisions about the role renewables can play in their energy sector.

IRENA plans to collect renewable energy project cost data for power generation, stationary applications and transport over the coming years and use this data in publications and toolkits designed to assist countries with their renewable energy policy development and planning. The analysis will include projections of future cost reductions and performance improvements so governments can incorporate likely future developments into their policy decisions. This work is ongoing and further efforts are required to overcome significant challenges in data collection, verification and analysis.

Comparable, verified data on the costs and performance of renewable energy technologies is often not in the public domain, but needs to be made available.

While collecting the data for IRENA's five costing reports, it became clear that there is insufficient publicly available data to allow policy makers to make robust decisions about the role of renewable power generation. Data in the public domain is often based on engineering cost estimates rather than real world project data, and little effort has been made to reconcile these two information sources. The lack of a systematic collection system for renewable energy project cost and performance data increases the risk that policy-making is based on inaccurate, old or inappropriate data. This lack of data is a significant barrier to renewable energy deployment and needs to be rectified.

By collecting data on existing costs and near-term future trends from a wide range of sources, such as industry associations, engineering reports, auction data, project developers and market surveys, IRENA is working to reduce the uncertainty that exists surrounding cost and performance estimates, which will allow governments and regulators to adopt more ambitious policies that promote renewables.

8 The analysis undertaken excludes government incentives and taxes, environmental and other co-benefits, as well as any wider electricity system balancing costs and/or benefits of renewable power generation technologies.

Key Findings of the Costing Analysis

Biomass for power generation

Many biomass power generation technologies are mature and biomass is a competitive power generation option wherever low-cost agricultural or forestry waste is available. In addition, new technologies are emerging that show significant potential for further cost reduction.

Around the world, large quantities of agricultural and forestry by-products go to waste when they could be used as a feedstock to provide power and heat. Biomass-generated electricity can be competitive with electricity from the grid, with the most competitive projects producing electricity for as little as USD 0.06/kWh. However, current new capacity additions of biomass are modest compared to the technology's potential.

Biomass-fired power generation technologies range from mature solutions to emerging technologies that have not yet been deployed on a large scale. The total installed costs of biomass power generation technologies reflect this diversity, varying between USD 1 880 and USD 6 800/kW in 2010. When biomass is co-fired with fossil fuels there are lower capital costs, between USD 140 and USD 850/kW, but this excludes the original investment in the plant. Operations and maintenance (O&M) costs can make a significant contribution (typically between 9% and 20%) to the LCOE for biomass power plants.

Secure, long-term supply of low-cost, sustainably sourced feedstocks are critical to the economics of biomass power plants. Feedstock costs can be zero for some wastes, including those produced onsite at industrial installations, such as black liquor at pulp and paper mills or bagasse at sugar mills. Sometimes their use actually saves disposal costs. Costs can be modest where agricultural residues can be easily collected and transported over short distances, but they can be much higher where significant distances are involved as many biomass feedstocks have relatively low energy density values and are therefore bulky and expensive to transport over long distances. Prices for feedstocks may significantly exceed costs in some markets if prices are set relative to the opportunity cost of competing fuels and this uncertainty can increase project risks and hence financing costs.

Concentrating Solar Power

CSP is now being deployed at scale and costs are coming down. Solar towers are emerging as a particularly important generation option in areas with high direct solar irradiation while CSP systems can also help with the integration of variable renewables when they are used in combination with low-cost thermal energy storage to generate electricity when there is no sun.

The two main CSP systems are parabolic trough and solar towers. The majority of commercial experience has so far come from parabolic trough systems. The two technologies currently have similar LCOEs (USD 0.20 to USD 0.36/kWh for parabolic troughs and USD 0.17 to USD 0.29/kWh for solar towers) assuming the cost of capital is 10%. However, the LCOE of CSP in areas with excellent solar resources could be even lower and may be in the range USD 0.14 to USD 0.18/kWh. Solar towers appear to have a greater potential for cost reductions and their lower costs for thermal energy storage will make them very attractive solutions to provide flexible electricity generation and help facilitate the penetration of wind and solar PV.

Parabolic trough plants without thermal energy storage have capital costs as low as USD 4 600/kW, although they have low capacity factors of between 20% and 25%. Adding six hours of thermal energy storage doubles capacity factors, but increases capital costs to between USD 7 100 to USD 9 800/kW. Solar tower plants with between six and 15 hours of energy storage can achieve capacity factors of 40% to as high as 80% and cost between USD 6 300 and USD 10 500/kW when energy storage is included. Storage reduces the LCOE for CSP plants and is a particularly attractive option for power systems where evening demand is high.

Increased support for CSP would help accelerate deployment and contribute to reducing costs through economies of scale and learning-by-doing.

Hydropower

Hydropower, with a global installed capacity of around 970 GW at the end of 2011, is currently the largest renewable power generation source. At good sites it provides the cheapest electricity of any generation technology.

Hydropower is a mature technology and the LCOE of currently installed projects and those coming on stream are generally low. The LCOE for large hydropower projects can range from as little as USD 0.02 to USD 0.19/kWh (costs at the upper end of this range are usually for multi-purpose dams), with a median around USD 0.04/kWh, assuming a 10% cost of capital. This makes the best hydropower power projects the most cost-competitive generating option available today. Small hydropower projects tend to have higher LCOEs, and also a wider range, while the LCOE of refurbishing or upgrading plants are lower, ranging from USD 0.01/kWh to around USD 0.05/kWh.

The range of investment costs for large hydropower plants can vary from as low as USD 1 050/kW to as high as USD 7 650/kW, with most projects in the USD 1 500 to USD 2 500/kW range. Capital costs for small hydropower projects also vary significantly and can be between USD 1 300/kW and USD 8 000/kW.

An important opportunity offered by hydropower is the possibility of adding capacity at existing schemes or creating it at dams that do not yet have a hydropower plant. These require investment costs as low as USD 500/kW.

Hydropower contributes to grid stability by providing flexibility, as spinning turbines can be ramped up more rapidly than any other generation source. Hydropower can also provide other grid services, including "black start" capability when grid-wide black-outs occur. The LCOE analysis does not include an estimate of the value of these services, as they are very system-specific.

When large reservoirs are available, hydropower can store energy for weeks, months, seasons or even years. Hydropower can therefore provide the full range of ancillary services required to achieve high penetration of variable renewable energy sources, such as wind and solar. The importance of hydropower is therefore likely to grow over time and, although it has long lead times, growth in hydropower capacity projects that respect the three pillars of sustainability will be very important in helping facilitate the high penetration of renewables where remaining resources are yet to be developed.

Solar Photovoltaics

Solar photovoltaics (PV) costs are declining rapidly due to high learning rates for PV modules and the very rapid deployment currently being experienced. If these trends continue, grid parity with residential electricity tariffs will soon be the norm, rather than the exception.

The cumulative installed capacity of solar PV grew by around 70% in 2011. Combined with the high learning rate for solar PV, this growth has resulted in significant cost declines over recent years. In the last two years alone PV module costs fell by around 60%. At the beginning of 2012, thin-film module prices (factory gate or spot) had fallen below USD 1.0/watt (W), with prices between USD 0.84 and USD 0.93/W available. The price of crystalline silicon (c-Si) modules were slightly higher, typically in the range USD 1.02 to USD 1.24/W for the most competitive markets, but by mid-2012 these had fallen further to as little as USD 0.77/W.

In 2010, Germany had the lowest PV system costs in the small-scale residential market (<5 kW) at an average of USD 3.8/W for c-Si systems. By the second quarter of 2012, this price had fallen even further to just USD 2.2/W. Grid parity with residential electricity prices will soon be the norm for solar PV systems in areas with good solar irradiation, rather than the exception. Solar PV also has the advantage that, once the domestic installation market is developed, solar PV installations can be ramped up rapidly to meet policy goals or electricity sector needs, no other power generation technology shares this flexibility.

Wind power

Wind power is now one of the most competitive renewable technologies and, in developed countries with good wind resources, onshore wind is often competitive with fossil fuel-fired generation.

After increasing for a number of years due to commodity price increases and demand outstripping supply, wind turbine prices have recently started to fall again – a trend that is likely to continue as low-cost manufacturers from emerging economies increasingly enter the global market. The typical LCOE of new onshore wind farms in 2010 was between USD 0.06 to USD 0.14/kWh, assuming a cost of capital of 10%, but at the best sites in North America projects can deliver electricity for as little as USD 0.04 to USD 0.05/kWh, making them competitive with, or cheaper than, gas-fired generation – even in this so-called "golden age of gas".

In China installed costs for onshore wind farms were as low as USD 1 300/kW in 2010, partly because wind turbine costs are 50-60% cheaper than in North America. However, higher turbine and other project costs in other major wind markets typically lead to installed costs of between USD 1 800 and USD 2 200/kW. Offshore wind farms are more expensive than onshore and cost USD 4 000 to 4 500/kW, with the wind turbines accounting for 44% to 50% of the total cost.

Conclusion

The improved competitiveness of renewables is being driven by a virtuous circle in which the rapid deployment of renewables, encouraged by support policies to overcome barriers to their use, is leading to significant and rapid reductions in cost for many renewable technologies. These falling costs suggest that policy makers should take note that the cost of supporting those renewables with well-designed support packages is declining over time and is much cheaper than a static analysis of costs would suggest.

The International Renewable Energy Agency (IRENA) has published five costing papers providing in-depth and up-to-date information on the cost of generating electricity from solar PV, CSP, wind power, hydropower and biomass. These papers fill an important information gap by providing the latest objective data on the cost and performance of these renewable power generation technologies. They are, however, just one part of the package of analysis IRENA is conducting to help support the accelerated deployment of renewables. A static analysis of costs is not sufficient to identify the least cost mix of renewables for a given electricity system, as this depends on the existing system, the location and quality of the renewable resources, the existing electricity system and a range of other factors. The cost analysis is therefore also an important input into other IRENA analysis, notably on scenarios and strategies.

IRENA's work on the costs and performance of renewables is ongoing and IRENA will continue to collect renewable energy project cost data for power generation, but will also begin collecting data for stationary applications and transport in the coming months and years. This data will form the basis of future publications and toolkits that will governments and other decision makers with their renewable energy policy development and planning.

For more information or to provide feedback, please contact Michael Taylor, IRENA Innovation and Technology Centre, Bonn, Germany; MTaylor@irena.org.

The IRENA Renewable Energy Technologies: Power Generation Cost Analysis Series

Economic factors are essential drivers of investment decisions. Objective and up-to-date cost data form the basis of sound investment decisions. The cost of many renewable power generation technologies has declined significantly, even dramatically, in recent years. Decision makers are not always aware of the exact extent of these cost reductions or current improvements in the performance of renewable power generation technologies.

IRENA has compiled a set of detailed, comprehensive cost indicators for renewable power generation options. This long-awaited dataset will provide decision makers with detailed insights on how to transform power supply systems at reasonable cost and provide secure, reliable and sustainable electricity. Cost indicators have been compiled for five key renewable power technologies taking into account local conditions. These five studies shed new light on renewable power generation costs and provide in depth analysis informed by inputs from IRENA Members that have given the Agency a clear mandate to promote the transition to a sustainable energy system based on renewable energy. These five studies are part of an ongoing series focusing on the competitiveness of renewable energy technologies.

This summary paper and all the five cost analysis papers can be downloaded from www.irena.org/Publications

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation dedicated to renewable energy.

In accordance with its Statute, IRENA's objective is to "promote the widespread and increased adoption and the sustainable use of all forms of renewable energy". This concerns all forms of energy produced from renewable sources in a sustainable manner and includes bioenergy, geothermal energy, hydropower, ocean, solar and wind energy.

As of October 2012, the membership of IRENA comprised of 158 States and the European Union (EU), out of which 101 States and the EU have ratified the Statute.

IRENA
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IRENA Secretariat
C67 Office Building, Khalidiyah (32nd) Street
P.O. Box 236, Abu Dhabi,
United Arab Emirates
www.irena.org

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