5 SOLAR PHOTOVOLTAICS

	2010	2013	2014	2010-2014 (% change)
New capacity additions (GW)	16	39	40+	150%+
Cumulative installed capacity (GW)	39	139	179+	360%+
Regional weighted average installed cost utility-scale (2014 USD/kW)	3 700- 7 060	1 690 – 4 250	1 570 – 4 340	-39% to -58%
Regional weighted average utility-scale LCOE (2014 USD/kWh	0.23 – 0.5	0.12 – 0.24	0.11 – 0.28	-44% to -52%
Residential LCOE in selected countries (2014 USD/kWh)	0.33 – 0.92	0.15 – 0.49	0.14 – 0.47	-49% to -58%

Notes: 2014 deployment data are estimates. n.a. = data were unavailable or not enough data to provide a robust estimate.

Highlights

- Solar PV module prices in 2014 were around 75% lower than their levels at the and 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 global average 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 financial support. Even lower costs are being realised, down to USD 0.06/kWh, for utility-scale solar PV where excellent resources and low-cost finance is available.
- LCOE reductions have seen the costs for utility-scale solar PV increasingly fall within the fossil fuel-fired electricity cost range in 2014, without financial support.
- The LCOE of residential systems in selected countries has fallen by between 42% and 64% since 2008.
- With today's very low solar PV module prices, the greatest source of future cost reduction potential is in the balance of system costs, notably the soft costs, and through reduced finance costs.

Introduction

Solar photovoltaics (PV), also called solar cells or just PV, are electronic devices that convert sunlight directly into electricity. The modern form of the solar cell was invented in 1954 at Bell Telephone Laboratories. The term "photovoltaics" is derived from the physical process whereby the conversion of light (photons) to electricity (voltage) occurs, the so-called "PV effect".

In 1966, the National Aeronautics and Space Administration (NASA) of the United States launched the first Orbiting Astronomical Observatory, powered by a 1 kilowatt (kW) photovoltaic array. In 1977, global PV production capacity exceeded 500 kW. In 2002, total installed solar PV capacity exceeded 2 GW and 10 years later, in 2012, it surpassed 100 GW. In 2013, new additions of solar PV alone came to 39 GW and for the first time exceeded the new capacity additions of wind in a given year. The year 2014 was estimated to have been another record year, with total installed PV capacity likely to have exceeded 180 GW worldwide at the end of the year. In short, solar PV has come of age and mature commercial solutions are now available to provide competitive power in a complete range of applications from outer space, off-grid and on-grid, from solar lanterns to utility-scale PV parks at the scale of hundreds of MW.

Solar PV systems are one of the most "democratic" renewable technologies, in that their modular size means that they are within the reach of individuals, co-operatives and small- or medium-sized businesses that want their own generation facilities and the ability to lock in electricity costs. These small-scale systems represent the largest number of solar PV systems installed, but utility-scale ground-mount projects still represent the largest share of total installed capacity.

Solar PV is now a mainstream and mature technology. However, unlike most mature technologies, its costs are continuing to decline and solar PV is increasingly commercially attractive to project developers and to small-scale residential or commercial consumers. Its competiveness is compounded by the fact that many major markets are experiencing significant year-on-year increases in electricity prices.

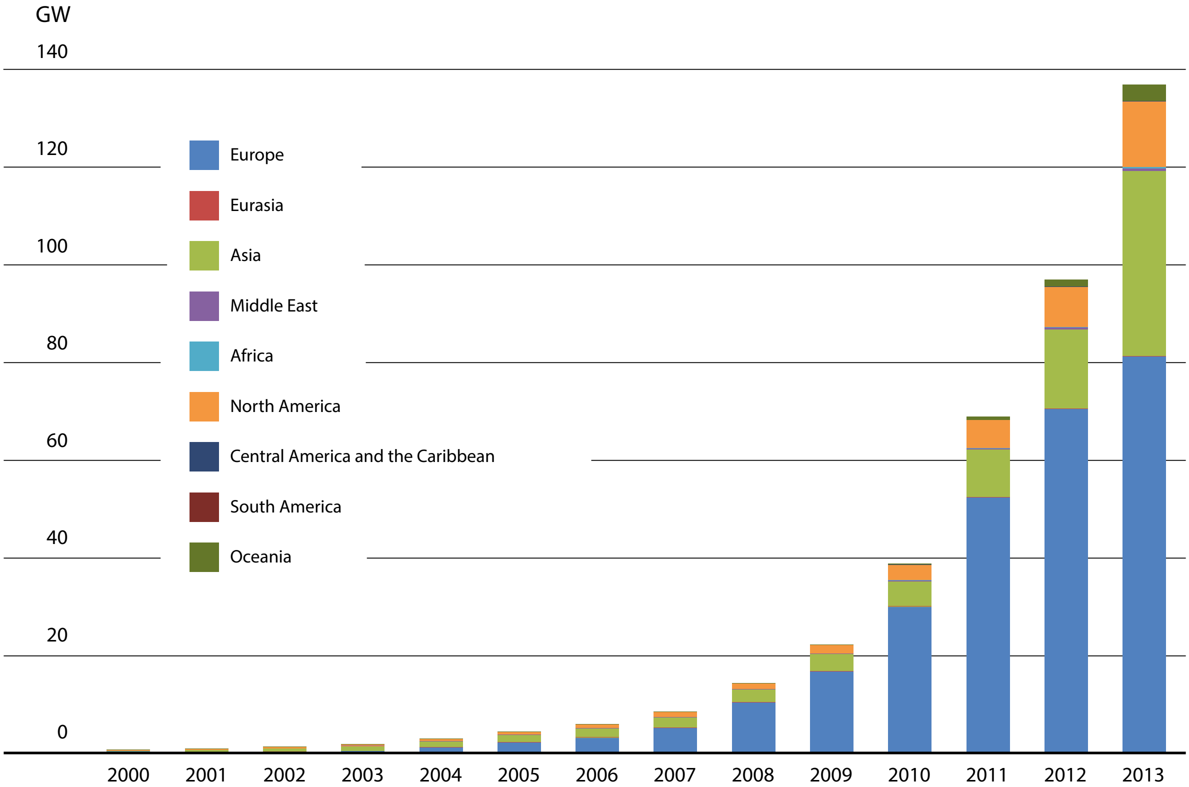
A solar PV system consists of the module, other electrical and hardware components (i.e. the inverter, electrical cabling, module mounts, controls, etc.). The solar PV systems are then mounted on rooftops or in fields.

Unlike Concentrating Solar Power (CSP) systems, solar PV systems operate in the presence of both direct and diffuse solar irradiation. The higher the level of solar resource, all other things being equal, the lower the system's levelised cost of electricity (LCOE) will be. Siting solar PV systems in areas with high solar resources (usually expressed as annual mean figures in kWh/m^2/year or as kWh/m^2/day) will therefore minimise the cost of electricity.

A wide range of PV cell technologies are available on the market today, using different types of materials, and an even larger number will be available in the future. PV cell technologies are usually classified into three generations, depending on the basic material used and their level of commercial maturity:

- First-generation PV systems (fully commercial) use the wafer-based crystalline silicon (c-Si) technology, either single crystalline (sc-Si) or multi-crystalline (mc-Si).
- Second-generation PV systems are based on thin-film PV technologies and generally include three main families: 1) amorphous (a-Si) and micromorph silicon (a-Si/μc-Si); 2) Cadmium-Telluride (CdTe); and 3) Copper-Indium-Selenide (CIS) and Copper-Indium-Gallium-Diselenide (CIGS). They are called "thin-film" because the semiconducting materials used for the production of the cell are only a few micro-metres thick. Some of these technologies are being deployed at commercial scale, but others are at an earlier stage of development.
- Third-generation PV systems include technologies, such as concentrating PV (CPV) and organic PV cells, which are still in a demonstration phase or have not yet been widely commercialised, as well as novel concepts under development.

Figure 5.1: Global cumulative installed solar photovoltaic capacity, 2000-2013



Source: IRENA

First and second generation PV technologies dominate the market today and will continue to do so in the near future, so they are the focus of this report.

Crystalline silicon-based PV modules currently dominate the solar PV market (around 90% of new installations by capacity), as their mature nature, relatively high efficiency and low cost make them a very attractive commercial choice.[19] The thin-film solar PV sector has undergone significant consolidation in recent years and deployment appears to be stabilising at around 4 GW, with 4.1 and 3.9 GW deployed in 2012 and 2013, respectively (GlobalData, 2014). Thin-film technologies have some advantages under specific operating conditions, so they are likely to continue to play an important role in the suite of technology options in order to maximise yield and minimise LCOE, despite the fact they have struggled to displace c-Si modules to date.

[19] *Standard c-Si PV modules are estimated to have accounted for 89% of solar capacity installed in 2014, with premium c-Si suppliers contributing a further 3%. Thin-film panel manufacturers, led by a few major players, supplied nearly 8% of the end-market demand in 2014. (Photon Consulting, 2014).*

Solar PV trends since the year 2000

Since 2013, the leading countries for PV deployment have shifted from Europe to Asia, due to the rapidly growing installation rates in both China and Japan. India is also one of the faster growing markets, with a total of 1 GW of new capacity in 2013.

China is now the largest market in the world for new solar PV, surpassing Germany, although Germany still has the largest cumulative installed capacity – at 38 GW. In late April 2014, China's National Energy Administration (NEA) announced that over 12.9 GW of solar PV capacity had been installed in 2013 (NEA, 2014). The Japanese solar PV market grew quickly following the introduction of Feed-in Tariffs (FiT) in July 2012. Japan installed 7 GW of solar capacity in 2013 alone. The United States has remained among the top three countries, having added 4.7 GW of new PV capacity in 2013. The outlook in Germany is for lower new installed capacity in 2014, as the German Federal Network Agency announced a significant drop in figures for newly installed capacity compared with the previous year, with around 2 GW of new PV capacity likely to have been added in Germany in 2014 (PV magazine, 2014).

Table 5.1: Solar photovoltaics deployment in China and Japan by market segment, 2012 and 2013

	China		Japan	
	2012 (MW)	2013 (MW)	2012 (MW)	2013 (MW)
Utility-scale	1 050	12 120	17	3 648
Commercial	910	750	17	1 899
Residential	1 540	130	1 684	1 406
Total Installed	**3 500**	**13 000**	**1 718**	**6 953**

Source: GlobalData, 2014.

Table 5.2: Detailed breakdown of solar PV cost components

PV Module	Inverter	BOS/Installation
Semiconductor • Raw materials (Si feedstock, saw slurry, saw wire) • Utilities, maintainence, labour • Equipment, tooling, building, cost of capital • Manufacturer's margin **Cell** • Raw materials (eg. metallization, SiNX, dopants, chemicals) • Utilities, maintainence, labour • Equipment, tooling, building, cost of capital • Manufacturer's margin **Module** • Raw materials (eg. glass, EVA, metal frame, j-box) • Utilities, maintainence, labour • Equipment, tooling, building, cost of capital • Shipping • Manufacturer's margin • Retail margin	• Magnetics • Manufacture • Board and electronics (capacitors) • Enclosure • Power electronics	• Mounting and racking hardware • Wiring • Other • Permits • System design, management, marketing • Installer overhead and other • Installation labour

Source: GlobalData, 2014.

Up to now, solar PV deployment has undergone challenges and changes but overall deployment has been increasing continuously. The total installed capacity of solar PV most likely surpassed 180 GW worldwide in 2014 (BNEF, 2014a; Photon Consulting, 2014; and IRENA analysis) with over 40 GW added in 2014.

Different support schemes can lead to very different trends in deployment by market segment within a country. As shown in Table 5.1, in 2013 the Chinese market focused very heavily on utility-scale projects, adding 10 GW within a year. In contrast, the Japanese market which grew strongly at the same time experienced a more even distribution between the utility, commercial and residential markets.

SOLAR PV CAPITAL COSTS

PV is a mature, proven technology that has achieved grid parity in a number of markets.[20] With continued cost reductions, grid parity will soon be the norm, rather than the exception. PV is a renewable, secure energy source with very high plant reliability and is not exposed to any fuel price volatility.

The capital cost of a PV system is composed of the PV module cost and the BoS cost. The cost of the PV module – the interconnected array of PV cells – is determined by raw material costs, notably silicon costs, cell processing/manufacturing costs and module assembly costs. The BoS cost includes items such as the cost of the structural system (e.g. structural installation, racks, site preparation and other attachments), the electrical system costs (e.g. the inverter, transformer, wiring and other electrical installation costs) and the soft costs of system development (e.g. customer acquisition, permitting, labour costs for installation, etc.). The cost of the battery or other storage system, if any, in the case of off-grid applications also needs to be added. Table 5.2 presents a detailed breakdown of the components that make up the total installed cost of a solar PV system.

As solar PV module prices have declined, the importance of the BoS cost is increasing, particularly the soft costs. This has important ramifications for policy-makers, as price declines for solar PV modules will now be more modest in absolute terms and will no longer be a major driver of cost reductions for solar PV systems in the future. Policy-makers must now turn their attention to driving down BoS costs. This will bring a new set of challenges, as a much more diverse range of cost drivers have an important role in the BoS, from permitting procedures and costs, to installation labour, to customer acquisition costs.

[20] The term "grid parity" is often used loosely and inconsistently. In this report, it is used to represent the point at which the LCOE of PV, without financial support, is the same or lower than the relevant electricity price (i.e. residential electricity tariff for small-scale systems), excluding taxes, over the period during which solar PV generates electricity. Other definitions include a price equal to, or lower than, the price of peak, shoulder or base-load electricity generation. In some cases, it will include or exclude taxes and subsidies.

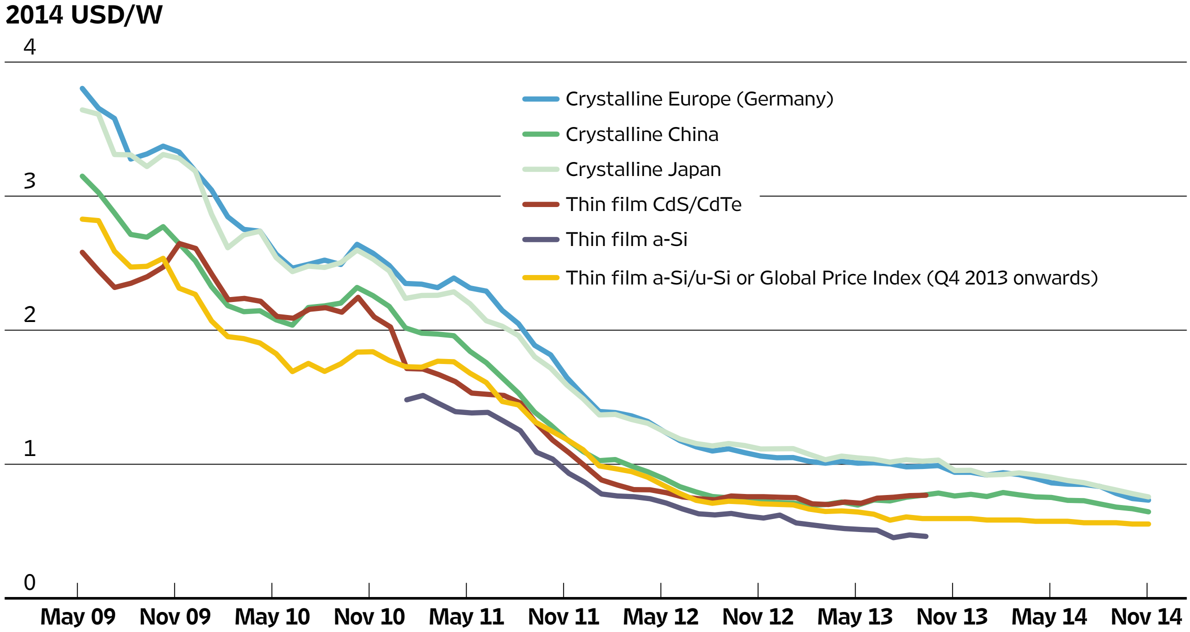
SOLAR PV MODULE PRICES

Solar PV modules have high learning rates (18% to 22%) and rapid deployment – around 40% growth in cumulative installed capacity in each of 2012 and 2013. These factors have resulted in PV module prices declining by around 75% between the end of 2009 and the end of 2014 (Figure 5.2). In 2010, solar PV module prices declined by between 13% and 29%, depending on the market and manufacturing country source for the modules. In 2011, price declines accelerated and reductions of 39% to 49% occurred. In 2012, module price declines slowed down somewhat, to between 15% and 29%, and in 2013 price declines were between 12% and 18%, although exchange rate fluctuations and trade dispute results saw Chinese module prices actually rise by around 7% over the year. In 2014, the downward trend has been restored, to a range of between 7% for thin-film modules and 22% for German-manufactured modules. In the years 2013 and 2014, higher-cost module manufacturers in Europe and Japan experienced faster reductions in PV module costs than their low-cost competitors in China, which contributed to reducing the gap in prices.

The slowdown in the rate of price reductions in 2013 and 2014 was driven by solar PV module manufacturers consolidating margins and, in many cases, trying to return to positive margins after a period of manufacturing overcapacity and severe competitive pressures in the industry.

There is a growing international market for solar PV modules. However, although to some extent they are becoming "commoditised", important differences remain in costs and performance of modules from different manufacturers. For this reason, and due to different local conditions relating to importation and taxes, there will be a range of prices among individual markets. These variations by country can be significant. Figure 5.3 presents the evolution in the ratio of average solar PV module prices sold in various countries, relative to the average price in China. The ratio of module prices in other countries to those in China

Figure 5.2: Average monthly solar PV module prices by technology and manufacturing country sold in Europe, 2009 to 2014



Sources: GlobalData, 2014 and pvXchange, 2014.

experienced increased variation between 2011 and 2013, but the differentials – for Japan in particular – have narrowed in late 2013 and into 2014.

In addition to variations in the average selling price of solar PV modules by country, there is also variation within a country depending on the size of the system. Small-scale systems will typically have higher module prices than large-scale systems, where margins over wholesale market prices can be reduced significantly. This variation can be considerable – in Italy in 2013, small-scale rooftop systems were between 2.2 and 1.8 times as expensive as large-scale (> 1 MW) ground-mount PV systems. As the price of modules has declined, this premium for small-scale system module prices has increased, and has become particularly pronounced for sub-3 kW systems in 2013. The declines in average module prices by system closely reflect the average decline in PV module selling prices in Europe at the wholesale level – of around three-quarters. The exception, which has resulted in the increasing price premium shown in Table 5.3, was for the smallest systems of 3 kW or less, which saw price reductions of 69%. These price ratios are specific to Italy and other markets experience different ratios.

Solar PV is based on semi-conductor technology which helps to explain, in part, its high learning rate and sustained cost reductions as deployment has increased. The main drivers of the cost reductions in solar PV modules include:

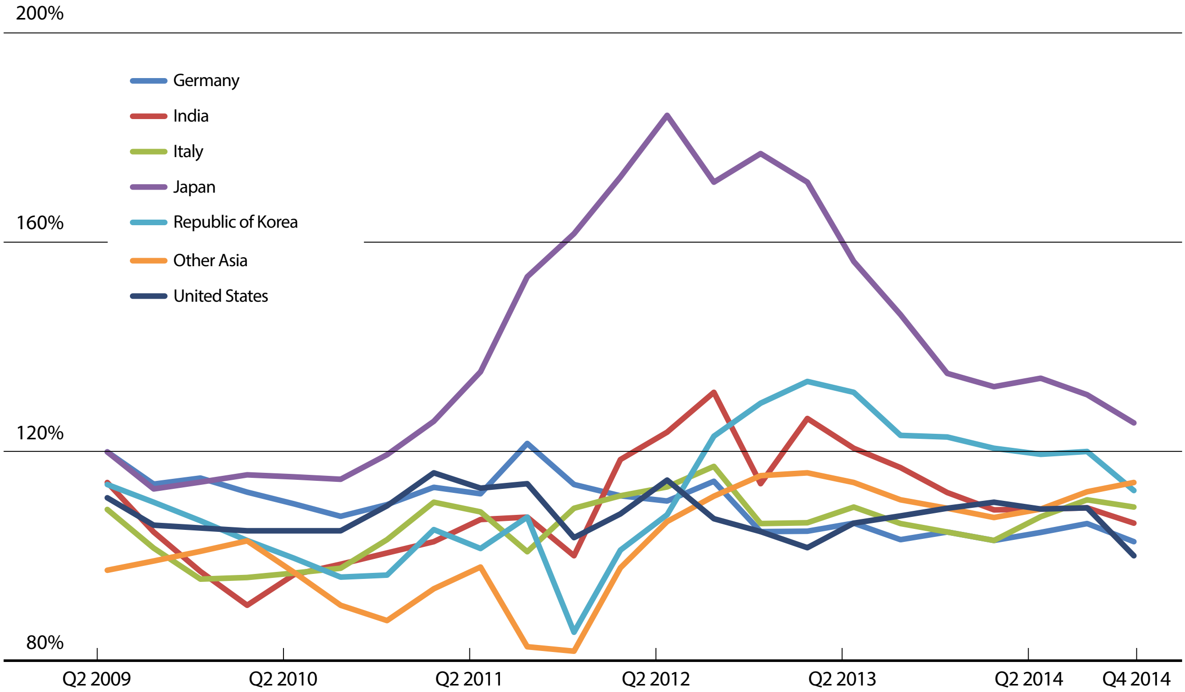
» Efficiency improvements: These occur in two areas – materials efficiency (i.e. reducing materials use and hence costs) and the efficiency of the solar PV module in converting sunlight into electricity (which also reduces materials costs by reducing the area required per watt).

» Economies of scale: Larger, integrated factories can achieve significant cost reductions by scaling up processes to a large scale, providing more competitive equipment prices, amortisation of fixed costs over larger throughput, etc.

» Production optimisation: This is an ongoing source of cost reduction opportunities based around more efficient processes and their integration, leading to optimisation of production at each phase.

With learning rates of 18% to 22% for solar PV modules and cumulative installed capacity doubling every couple of years, solar PV module prices would be expected to have fallen rapidly. Between the fourth quarter of 2010 and that of 2012, when the major price drop occurred, the main driver of the solar PV module price reduction,

Figure 5.3: Average differentials relative to China for solar PV module selling prices in various countries, by quarter



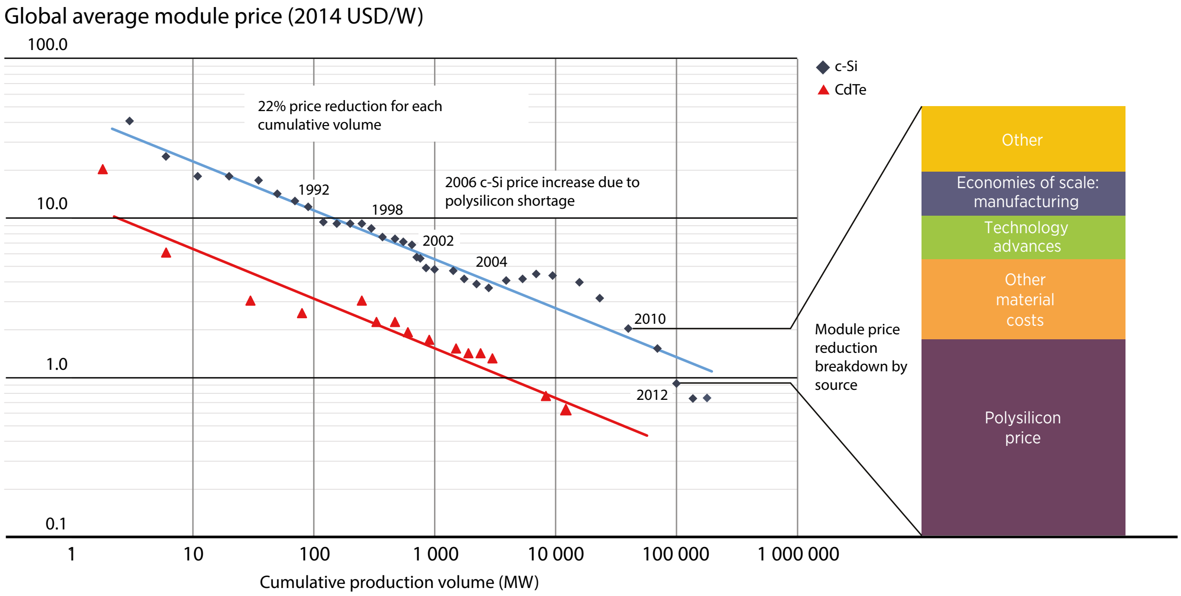
Source: GlobalData, 2014.

Table 5.3: Solar PV module prices by PV system size in Italy, 2008 to 2013

	Module price by size (2014 USD/W)						
	Rooftop			Ground-mount			
	1-3 kW	3-20 kW	20-200 kW	200-1000 kW	>1000 kW	Price premium (1-3 kW/> 1000 kW)	Price premium (3-20 kW/> 1000 kW)
2008	6.6	6.4	5.8	5.0	4.5	46%	43%
2009	5.6	5.4	4.7	4.1	3.5	61%	57%
2010	4.0	3.7	3.1	2.8	2.4	65%	53%
2011	3.2	3.1	2.6	2.2	2.2	47%	40%
2012	2.0	1.7	1.5	1.2	1.1	88%	63%
2013	1.8	1.5	1.1	0.9	0.8	117%	83%
Decline, 2009 to 2013	-69%	-73%	-77%	-77%	-77%		

Source: IRENA Renewable Cost Database/GSE.

Figure 5.4: Solar PV crystalline silicon and thin-film module cost learning curve



Sources: Based on data from EPIA and the Photovoltaic Technology Platform, 2011; GlobalData, 2014; GTM Research, 2014; Liebreich, 2011; pvXchange, 2014 and IRENA analysis.

accounting for almost half of the reduction, was a decline in polysilicon prices (45%), followed by other material costs (19%), greater economies of scale in module manufacturing (11%) and technology advancements (10%), while all other factors contributed a total of 16% (GTM Research, 2014).

With prices of solar PV modules at all-time lows, prices in 2012 significantly overshot the expected learning curve (Figure 5.4). This was the result of significant overcapacity in module manufacturing and cut-throat competition that saw many module transactions occur at cash-cost, or in some cases even lower, as financially stressed manufacturers tried to maintain cash flows. In 2013, despite record solar PV installations of around 39 GW, global PV manufacturing capacity, including c-Si and thin-film, exceeded 63 GW (Photon Consulting, 2014). An additional 10 GW of new module production capacity may have been added in 2014 (GTM Research, 2014). The competitive pressures in the solar PV module manufacturing industry are therefore likely to remain intense, although – unlike in recent years – profitability for the major manufacturers has improved and is now on a more sustainable footing.

The rapid decline in c-Si PV module prices due to manufacturing overcapacity has reduced the price advantage of thin-film PV module manufacturers. This has led to considerable consolidation in the thin-film industry, which should put the remaining manufacturers on a more secure financial footing. However, it remains to be seen whether the specific technological advantages – such as better performance in low-light conditions or hot climates – are sufficient for thin-film modules to substantially increase their share of new installations from current levels.

Despite the pause in reductions in average module selling prices in 2014, current prices are still significantly below the learning curve. They are also now so low that continued cost reductions, based on learning rates of 18% to 22%, will not yield large absolute cost reductions, as in the past. This means – in most countries – that BoS costs, and in particular the soft costs, will provide the largest opportunity for future cost reductions in absolute terms and represent the next great challenge for the solar PV industry.

Balance of system costs

BoS costs include all the cost components required for a solar PV system, excluding the module costs and includes the hardware costs (e.g. inverters, electrical cabling, racking, etc.) and the soft costs

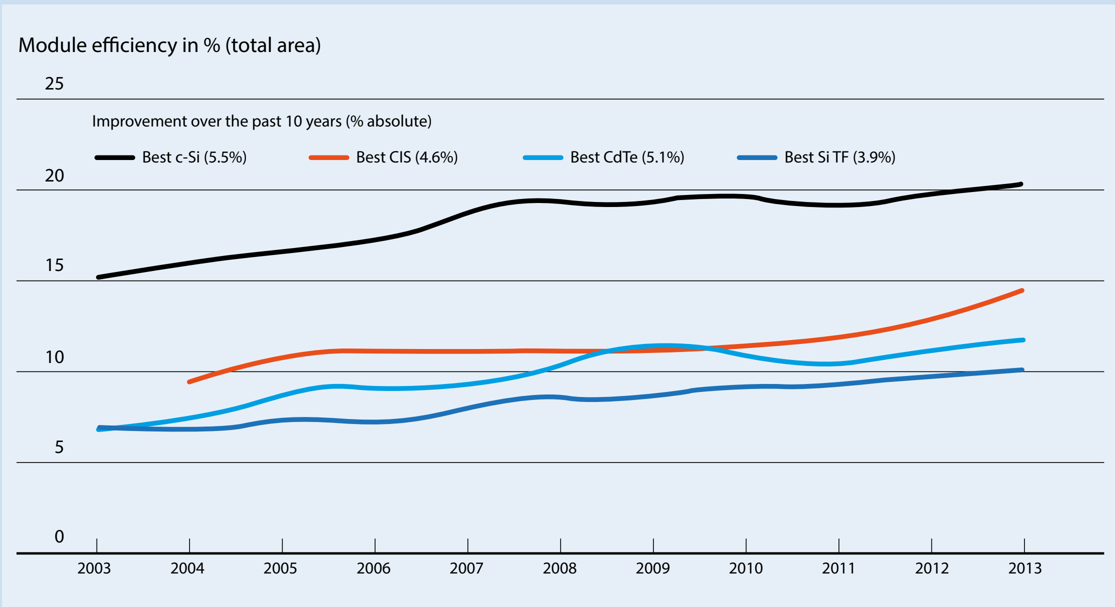
BOX 5.1

Solar photovoltaic module efficiency trends and their impact on costs

The efficiency of solar PV modules has increased in absolute terms over the past ten years. Crystalline silicon PV modules are not only the most efficient, but saw the greatest absolute increase in efficiency from around 15% to almost 21% in 2012. The increase in efficiency in percentage terms for the different technologies, represented an improvement of between one-third and two-thirds. (Fraunhofer ISE, 2014). These practical efficiency levels for modules that have been commercialised and are available for sale are significantly lower than the best results that can be achieved at the cell level in the laboratory, under ideal conditions and production processes that are not necessarily economic at a commercial scale. For instance, III-V multi-junction concentrator solar cells are capable of achieving efficiencies of around 44% at the cell level and new records continue to be set.

The impact of solar PV efficiency is somewhat different than conventional electricity technologies, where knowing the efficiency and capital cost is essential for determining the LCOE. With solar PV modules, efficiency improvements have a direct impact on capital costs in kW terms and it is through this effect that efficiency improvements reduce the LCOE of solar PV. As the efficiency of a solar PV module increases, less surface area is required to create a module of a given wattage, thus reducing the price per kW. Thus, although module efficiency trends will be a critical source of cost reductions in the future, for the purposes of examining historical trends in cost competitiveness, it is not necessary to discuss efficiency trends in detail, as their impact has already been largely captured in observed module prices.

Figure 5.5: Solar photovoltaic module efficiency trends, 2003 to 2012

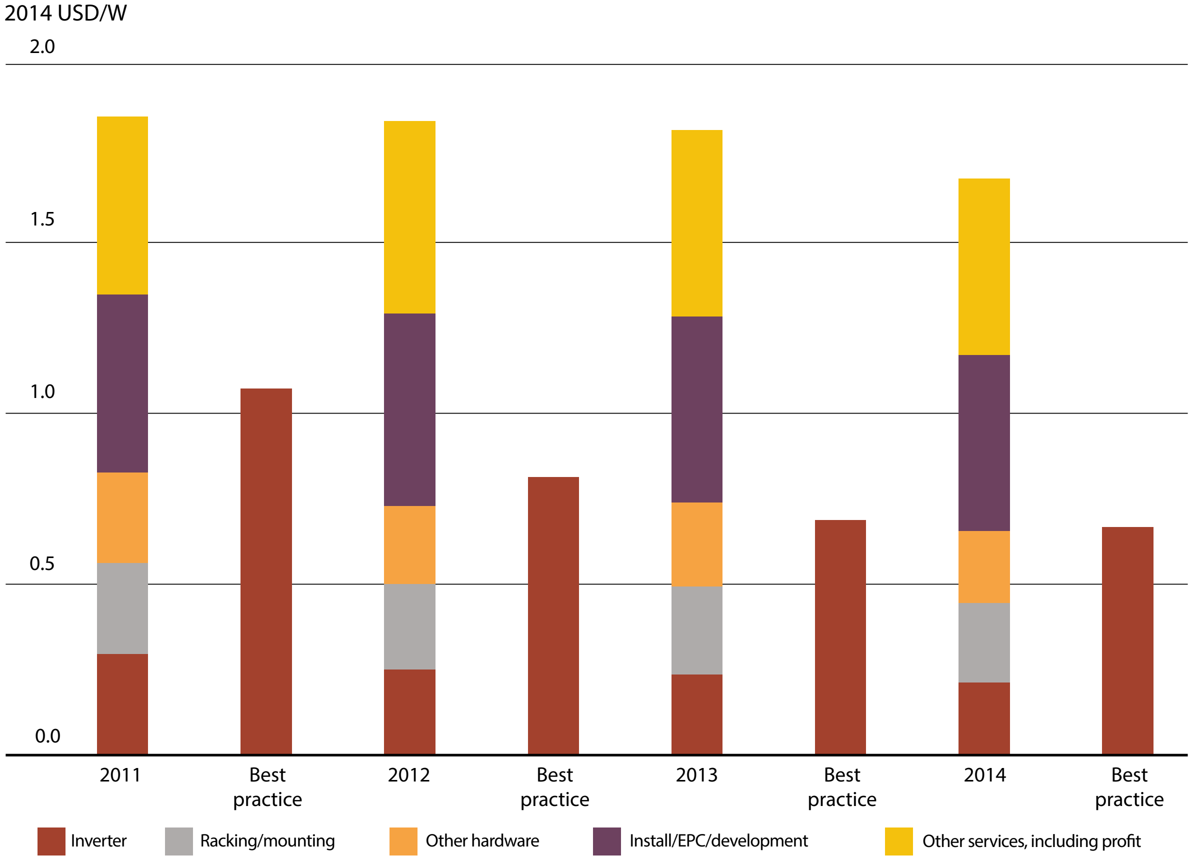


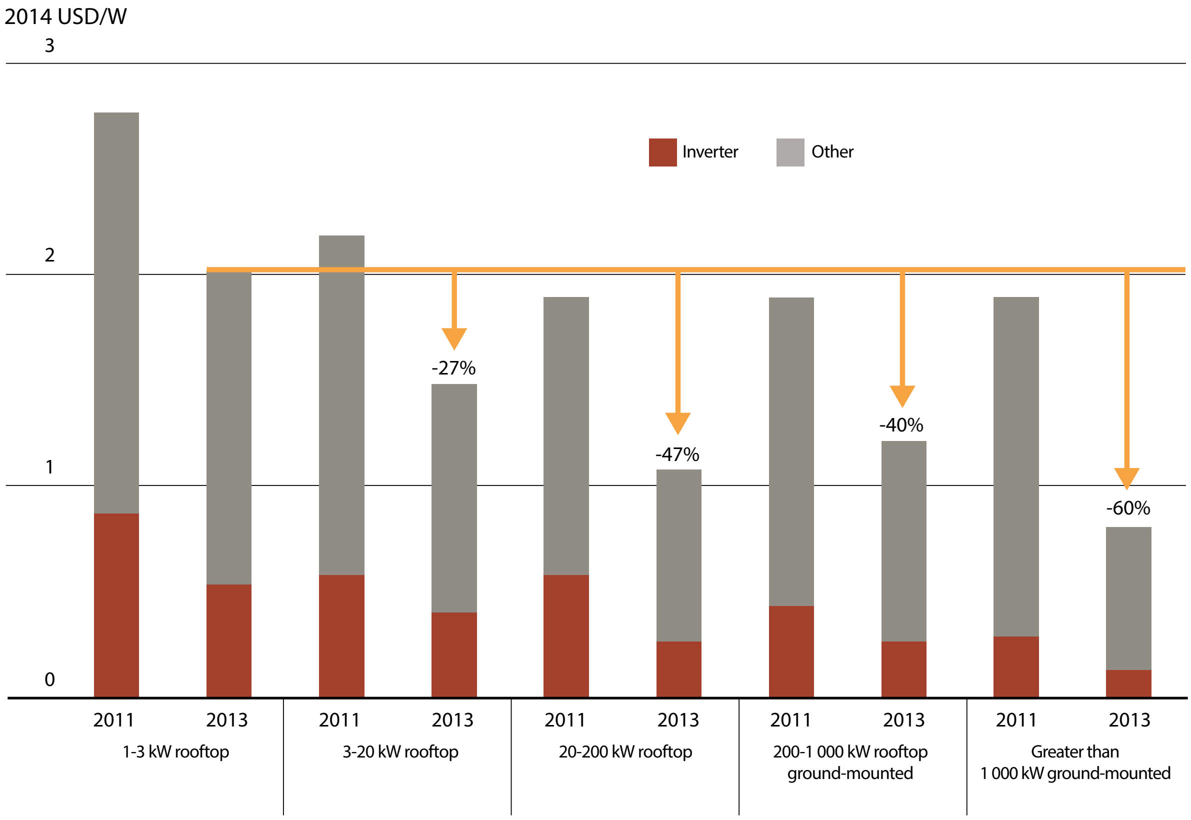
Source: Fraunhofer ISE, 2014.

(e.g. customer acquisition, installation, permitting, etc.). The order of magnitude of the BoS costs per kW for a solar PV system varies significantly by country and also by market segment. All other things being equal, small residential rooftop systems will have on average higher BoS costs than large rooftop installations on commercial buildings or multi-family dwellings, while large ground-mounted commercial systems will have even lower BoS costs than these large rooftop systems.

Large utility-scale projects will typically have the lowest BoS costs per kW, as important economies of scale and purchasing power accrue to these systems. However, there can be some exceptions, notably the addition of single or two-axis tracking systems on utility-scale projects in order to raise their capacity factor. This hierarchy of cost levels will typically hold true on average within a country; however, differences in BoS costs for the same market segment can still be large.

Figure 5.6: Global average balance of system cost breakdown and global best practice and BoS costs in Italy by project size, 2011-2014





Source: GSE, 2014; Photon Consulting, 2014.
Note: Global average figures are rough estimates.

BoS and installation costs include:

- The inverter, which converts the direct current (DC) PV output into alternating current (AC);
- The components required for mounting and racking the PV system;
- The combiner box and miscellaneous electrical components;
- Site preparation and installation (i.e. roof preparation for residential systems, or site preparation for utility-scale plants), labour, costs for installation and grid connection;
- Battery storage for off-grid systems; and
- System design, management, installer overheads, permit fees, project development costs, customer acquisition costs and any up-front financing costs.

Local market conditions and the regulatory environment can have a significant impact on the BoS costs and wide variations typically exist within a country and between countries. The variation is typically largest for small-scale residential systems, while for utility-scale projects BoS costs will typically converge rapidly as the market in an individual country grows and project development experience and market scale push down costs.

Figure 5.6 presents the trend in the global weighted BoS costs of solar PV systems, to give an order of magnitude for BoS costs and show the trend between 2011 and 2014. Between 2011 and 2014, inverter costs declined by 29%, other hardware costs by 20% and racking and mounting of PV systems by 12%. Installation, engineering, procurement, construction and development costs, as well as other service costs, have only declined by around 1% in this period as growth in small-scale systems in relatively high-cost markets in North America and Japan accelerated, at the same time that lower-cost markets slowed in 2013 and 2014. Best practice BoS overall costs have been reduced by about 38% from 2011 to 2014. Best practice BoS costs in 2014 were around 60% lower than the global average, indicating a widening in the gap since 2011, when the difference between global average and best practice costs was 43%.

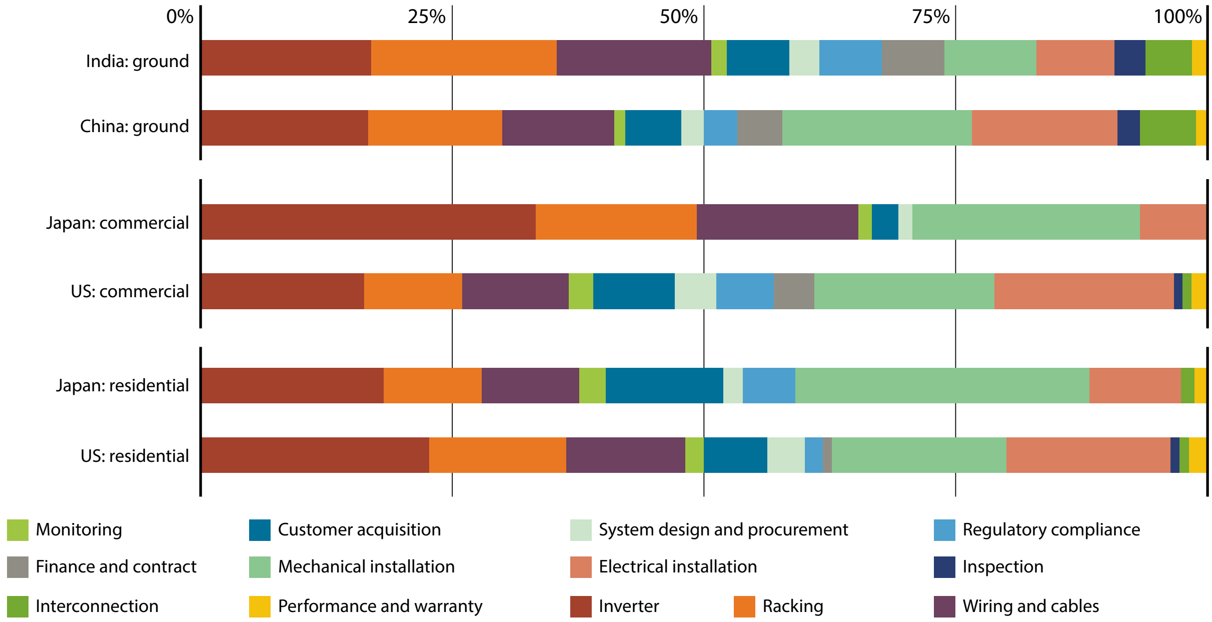
Although global averages are useful to track, BoS costs vary depending on whether the project is rooftop or ground-mounted and on the scale of the system. The data on the bottom of Figure 5.6 present the difference between BoS costs per watt in Italy according to the size of the system and whether it is mounted on the ground or a rooftop. Between 2008 and 2013, BoS costs fell by 55% for the smallest systems and 77% for the largest systems. In 2013, BoS costs for rooftop systems in the 3 to 20 kW range were 26% lower than for rooftop systems in the 1 to 3 kW range. Rooftop systems in the 20 to 200 kW range had BoS costs 47% lower than the 1 to 3 kW range systems, while ground-mounted systems in the 200 to 1 000 kW range had BoS costs that were 40% lower and utility-scale ground-mounted systems above 1 000 kW had BoS costs 60% lower.

BoS costs in 2014 were estimated to have averaged around USD 0.8/W in China, India and Italy for utility-scale ground-mounted systems, and USD 0.84/W in Germany (Photon Consulting, 2014). Other major markets for utility-scale projects in 2014 had higher BoS costs, with Spain estimated to have had average BoS costs for utility-scale ground-mounted systems of USD 1.07/W, while in the United Kingdom they were estimated to be USD 1.35/W, in South Africa they were USD 1.5/W and in Romania they were USD 1.56/W. These variations reflect the maturity of markets and supply chains, but also in many cases the efficiency of support mechanisms since solar system pricing is often value-based to some extent and influenced by the support levels in place.

Although BoS costs for smaller-scale commercial and residential systems are typically higher than utility-scale systems, the BoS costs of large commercial rooftop installations can still be quite competitive. For instance, in 2013, the average BoS costs for large commercial rooftop systems (20 to 200 kW) in Italy were lower, at around USD 1.08/W, than for utility-scale ground-mounted systems in the United Kingdom, South Africa and Romania.

Figure 5.7 provides a more detailed breakdown of BoS costs for two countries in each market segment: utility-scale ground-mounted, commercial sector rooftop and residential rooftop. Inverters and

Figure 5.7: Detailed balance of system cost breakdown for indicative utility-scale, commercial and residential systems in selected countries, 2014



Source: Photon Consulting, 2014

mechanical installation typically represent a smaller share of the BoS costs in utility-scale systems compared with smaller-scale projects in the commercial and residential sectors, while financing costs, interconnection and inspection costs tend to take up a larger share.

With module prices at all-time lows, future reductions in module prices in absolute terms will be modest. BoS cost reduction opportunities, and an understanding of their evolution over time, will be critical to unlocking reductions in the LCOE of solar PV. Figure 5.8 presents the evolution of an index of BoS costs for residential solar PV systems plotted against the cumulative deployment of solar PV in the residential sector in each country.[21] While there is a clear downward trend in all cases, there are two very distinct groups of countries for which data is available. The data for Germany and Italy suggest that they have been able to achieve a much more efficient cost structure for residential BoS costs through FiT declines and raising the scale of the residential sector market to ensure competition and economies of scale. Given the slowing of both these markets in 2014, the evolution of their BoS costs in 2015 and beyond will yield important information on BoS system reduction potentials under more challenging market conditions.

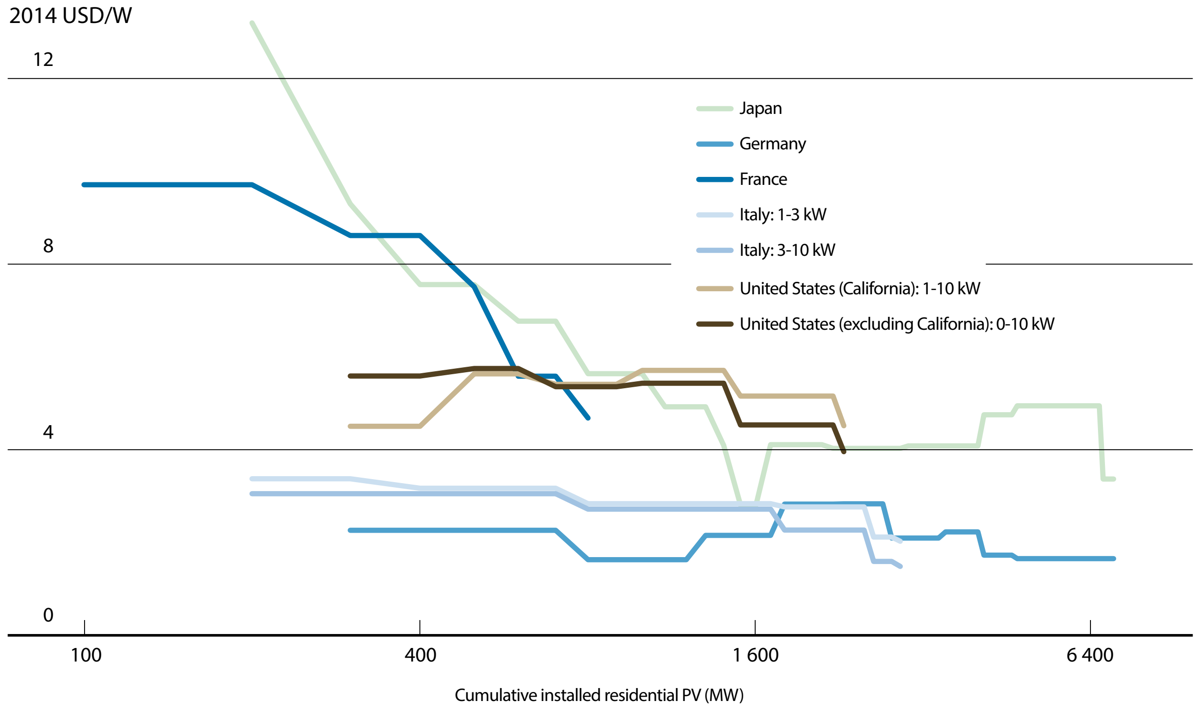
The case in Germany in particular will be pivotal to discovering what are the realistic lower limits of BoS costs. Germany has one of the most competitive residential solar PV markets in the world and has led the way in showing just how competitive small-scale PV can be in the right conditions, but the BoS costs in Germany have been largely flat in 2013 and 2014. This raises a number of interesting questions about BoS costs that will have a critical impact on future cost reductions for small-scale PV and their competitiveness. Of particular concern is whether the current BoS costs in Germany represent a lower limit with today's solar PV systems for small-scale projects, given current regulatory and business models.[22]

If this is the case, urgent research needs to be undertaken to identify what needs to change in order to ensure continued BoS cost reductions in Germany. At a global level, this is currently not a

[21] The absolute values of these BoS calculations should be treated with caution, as reliable data for small-scale residential system module prices are not always available. Another point to note is that, although the BoS costs are plotted against residential deployment only, there is some argument for using total deployment in a given country as it could be expected that there are some spillover benefits from the total scale of deployment of solar PV in a country in terms of cost for small-scale residential systems.

[22] This is not a concern per se for Germany, as solar PV has already reached grid parity and with residential electricity prices projected to continue to rise, the competitiveness of solar PV is set to improve in any event.

Figure 5.8: Residential solar PV system balance of system cost evolution by country, 2008 to 2014



Source: IRENA Renewable Cost Database, with additional data from CPUC, 2014; GSE, 2014 and Photon Consulting, 2014.

threat to continued cost reductions for small-scale solar PV, as highlighted in Figure 5.8, because reducing BoS costs to the competitive levels seen in Germany and China will yield large cost reductions and improved competitiveness. However, the evolution of BoS costs in Germany and China for small-scale residential systems over the next few years could provide important information about medium- to long-term cost reduction expectations.

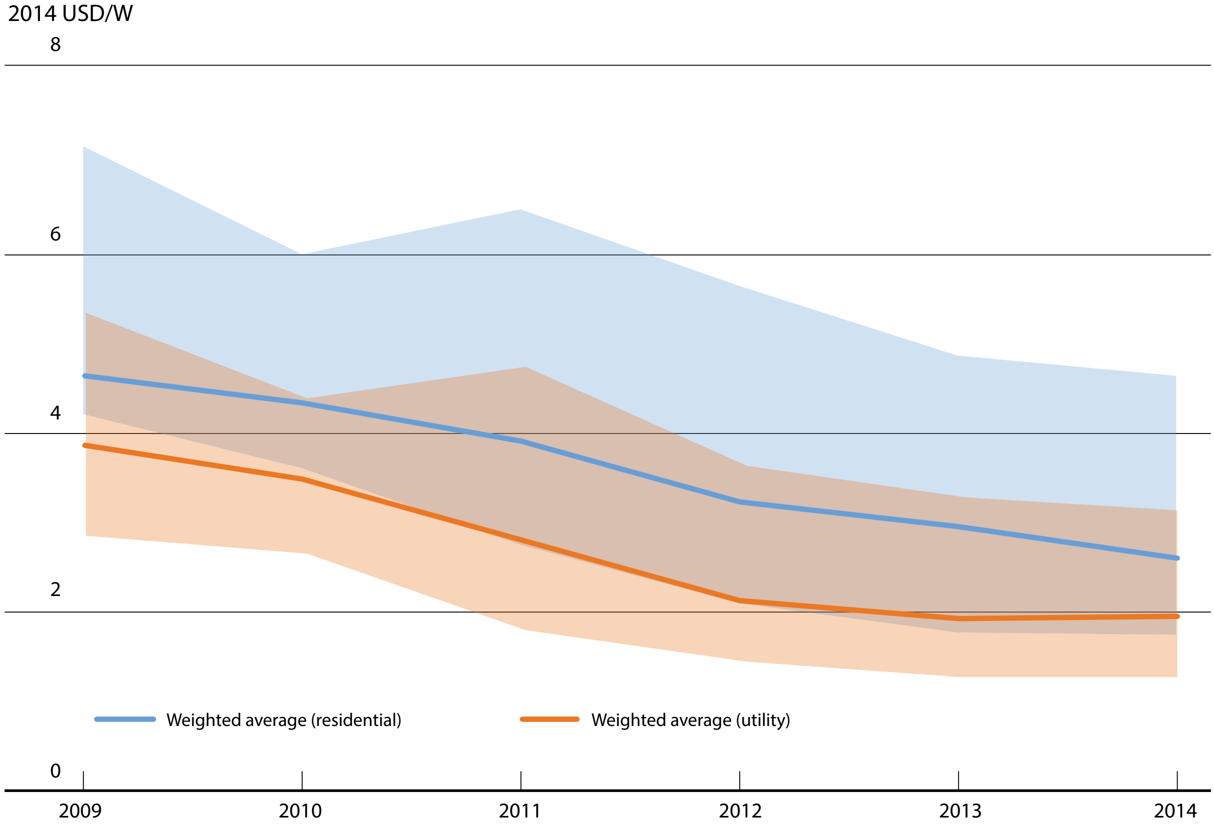
Total installed costs

Total installed costs for solar PV systems have fallen rapidly since 2008 as deployment has experienced exponential growth, driving down not only module costs, but BoS costs as well (Figure 5.9). Figure 5.9 presents the range for country average installed costs by year for all major PV markets for utility-scale projects (turnkey project costs) and residential projects. This does not represent the true range of project costs, as significant variation around the average country value exists (this will be discussed in more detail below), but it provides an indication of the trend in total installed costs in these two market segments. The total installed costs for residential systems have continued to decline into 2014, as opportunities to reduce BoS costs have allowed continued cost reductions even as module price reductions slowed to very low levels. The situation for utility-scale projects is somewhat different, as BoS cost reduction opportunities in competitive local markets for utility-scale projects have been relatively limited in comparison to residential systems.

However, examining high level trends in global aggregated solar PV installed costs is of limited value. The reality is that all of the individual markets for solar PV at the residential and utility scales are evolving at different rates and their respective maturities and local support policy structures have a significant impact on their current cost structures. Even within individual markets there is a huge variation in reported costs for solar PV systems and the reasons for this are often not well understood.

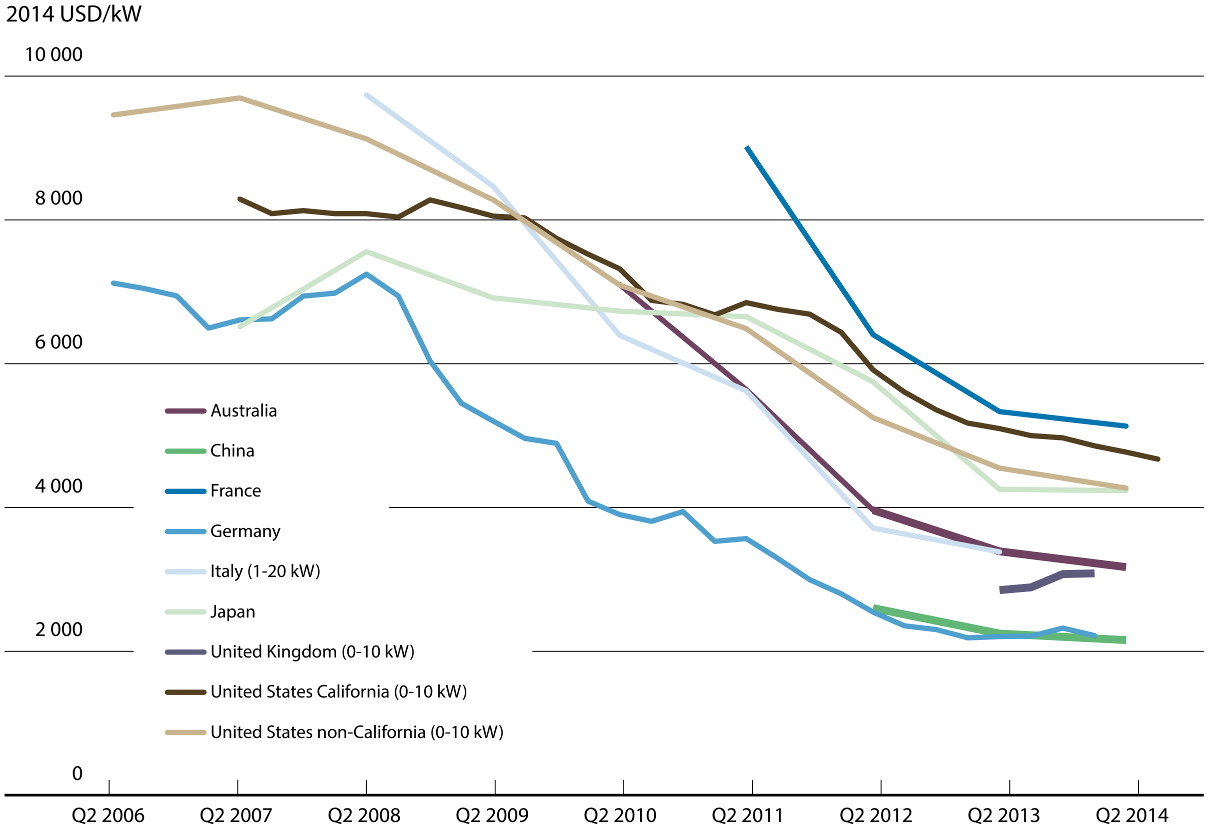
Figure 5.10 presents the evolution of the average total installed cost for residential sector solar PV systems between 2006 and 2014. Germany and China have, on average, the most competitive small-scale residential rooftop systems in world. Germany's residential system costs have fallen from just over USD 7 200/kW in the first quarter of 2008 to USD 2 200/kW in the first quarter of 2014.

Figure 5.9: Estimated global average installed costs for utility-scale and residential solar PV systems and the range of country averages, 2009 to 2014



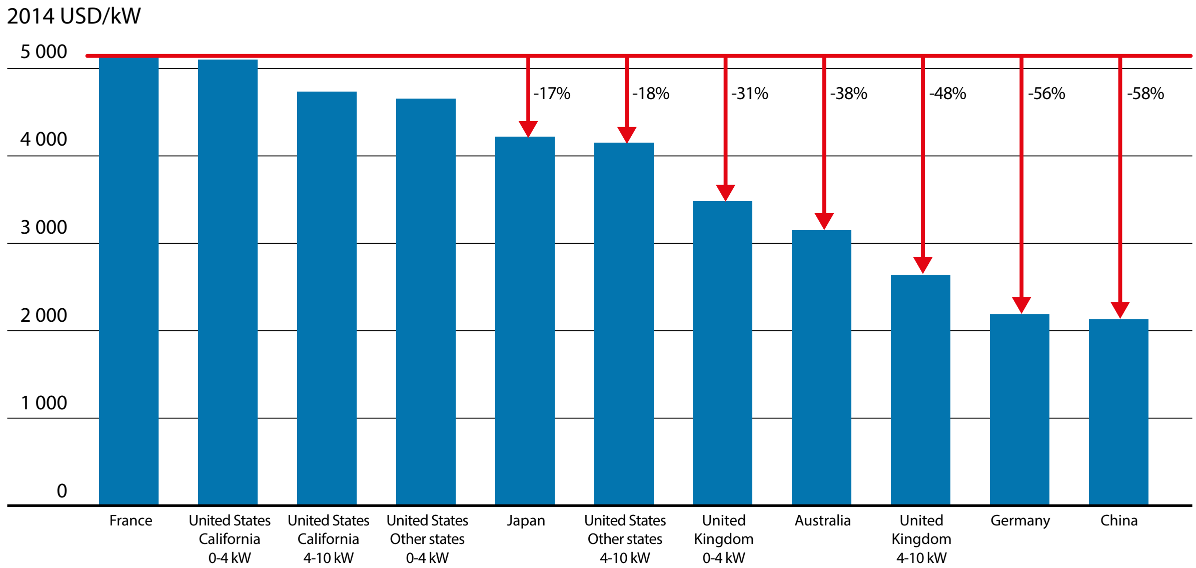
Source: IRENA Renewable Cost Database and Photon Consulting, 2014.

Figure 5.10: Average total installed cost of residential solar PV systems by country, 2006 to 2014



Source: IRENA Renewable Cost Database; CPUC, 2014; GSE, 2014; IEA PVPS, 2014; and Photon Consulting, 2014.
Note: Annual data for Australia, China, and Italy; quarterly data for the remaining countries.

Figure 5.11: Estimated average total installed PV system costs in the residential sector by country, 2014



Source: IRENA Renewable Cost Database; DECC, 2014; GSE, 2014; IEA PVPS, 2014; and Photon Consulting, 2014.

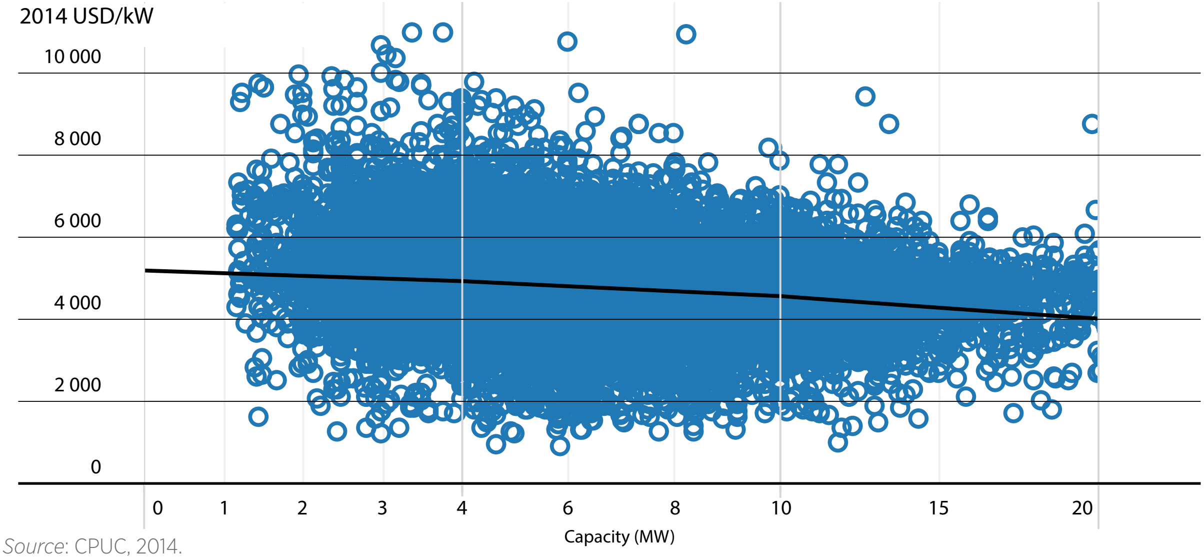
Residential systems in the United States (outside of California), Italy and France all experienced similar rates of decline, but total installed costs remain significantly higher, at an average of around USD 4 300/kW, USD 3 300/kW and USD 5 100/kW, respectively, in 2014. This ranges from around 50% to more than 130% higher than in Germany and China. The United Kingdom is an interesting case with respect to the evolution of deployment and installed costs in the residential sector. Large-scale deployment in the residential sector in the United Kingdom began in 2011, and in 2013 and early 2014 costs were at quite competitive levels of between USD 2 800 to 3 100/kW.

Figure 5.11 provides a more detailed comparison of market segments in 2014. In 2014, the highest country average for residential PV system total installed costs was almost 2.4 times higher than the lowest country average. At an average of around USD 2 200/kW, the residential PV systems in Germany and China were the cheapest and were lower in cost than utility-scale projects in many countries. The difference in installed costs between small systems of up to 4 kW and slightly larger residential systems of 4-10 kW is significant and ranged from 22% to 31% in 2013 and early 2014 in Italy and the United Kingdom. The difference is lower in the United States, with 1-4 kW systems having costs of between 2% and 11% higher than the larger 4-10 kW systems in 2013 and 2014.

However, given the wide range of variation in costs within individual country markets, there will be some overlap of the total installed costs even in countries at opposite ends of the average total installed cost range. Comparing the average total installed costs of residential systems in the United States and Germany provides an extreme example of this, as demonstrated by the data for residential systems in California (Figure 5.11 and 5.12). The bulk of installations in California are plus or minus 50% of the weighted average, but outliers are numerous. This wide variation in costs for residential systems in absolute terms in California is difficult to explain, as it extends to variations within individual cities, so is not a function of geographic location. Recent analysis is shedding more light on these issues, finding that they are due to state and federal policies, differences in market structure, and other factors that influence demand and costs (Gillingham, 2014). Interestingly, in addition to system characterisitcs (discussed below) it was concluded that search costs, installer density, financial support levels and imperfect competition have a significant impact on solar PV prices.

Part of the variation in installed costs relates to scale and system characteristics for the smaller-scale systems, site-specific costs and also the fact that any variations in total project costs are magnified with small-scale systems on a per kW basis. The data for the evolution of total installed costs by

FIGURE 5.12: TOTAL INSTALLED PV SYSTEM COSTS FOR RESIDENTIAL SYSTEMS IN CALIFORNIA BY SYSTEM SIZE, 2014



Source: CPUC, 2014.

size tend to support this idea for solar PV systems installed in the residential sector in California (Figure 5.12). There is a clear downward trend in total installed system costs by size in the residential sector, with a narrowing of the variation, particularly beyond system sizes of 12 kW, where perhaps more competition and better-informed customers, given the magnitude of the investment, may combine to narrow the range of total installed costs.

Figure 5.13 presents the total installed costs of utility-scale solar PV projects in the IRENA Renewable Cost Database.[23] Similar to the case in the residential sector, the total installed costs of utility-scale solar PV vary significantly but, according to the data available, they have experienced a downward trend between 2011 and 2014. Globally, smaller utility-scale systems (1-5 MW) have seen their weighted average installed costs fall by 37% between 2011 and 2014, while large-scale utility plants of 5 MW or more have seen weighted average installed costs fall by 35%. This is slightly more than the reduction of 30% implied by the global average calculations for utility-scale projects in Figure 5.9 – where central estimates of turnkey prices (not individual project costs) for systems in all major utility-scale markets were compared.

[23] *Where the IRENA Renewable Cost Database does not have a representative sample of projects installed for a country in a given year, a balance total has been added for that county to ensure average costs are representative. Nevertheless, care must still be taken in interpreting the results presented here.*

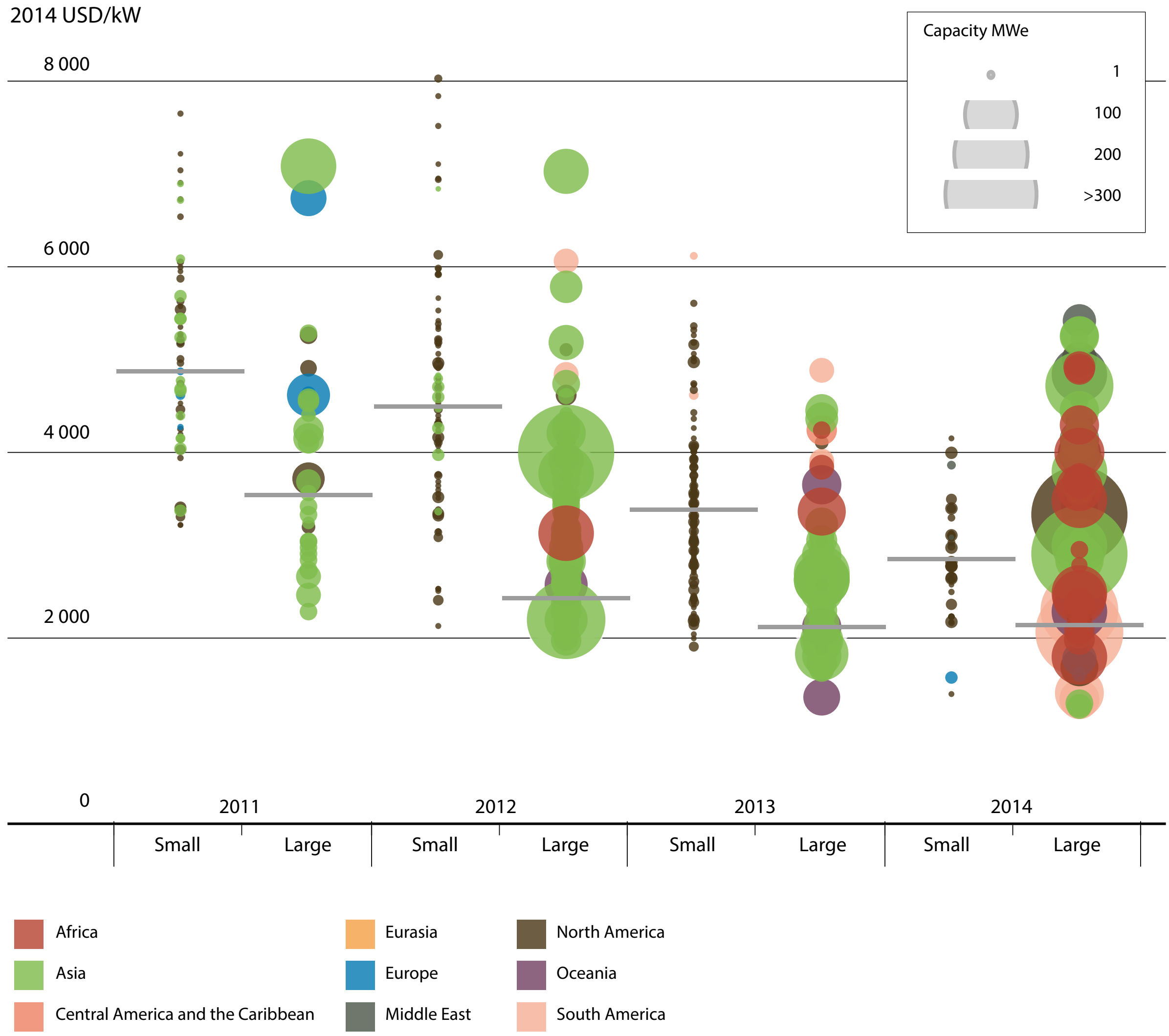
Between 2011 and 2014, the most competitive projects have continuously reduced costs – from lows of around USD 3 200/kW for small-scale projects and USD 2 200/kW for large-scale projects in 2011, to lows of around USD 1 300 for both size groups in 2014. This is a decline of 65% for smaller utility-scale projects (1-5 MW) and 41% for larger (> 5 MW) projects in just three years, with a trend to large-scale projects with available cost data, at least in the IRENA Renewable Cost Database.[24]

The range of installed costs for small utility-scale projects in 2011 was between USD 3 200 and USD 7 600/kW, while for large-scale utility projects the range was between USD 2 200 and USD 7 050/kW. By 2014, the range for smaller utility-scale projects had declined to between USD 1 300 and USD 6 800/kW (based on data from CPUC, 2014 and Photon Consutling, 2014 to supplement the IRENA Renewable Cost Database) and for larger projects it had declined to between USD 1 300 and USD 5 400/kW.

The data in the IRENA Renewable Cost Database by region for utility-scale projects show a wide range of installed costs in 2013 and 2014 (data for 2013 and 2014 is presented to provide a more representative sample from the database), where module prices were little changed (Figure 5.14). It is noticeable that regions and countries with large land masses

[24] *The data in the IRENA Renewable Cost Database are not necessarily a representative sample of project sizes however, so care must be taken in implying any contribution from economies of scale for larger projects to the trend in average costs.*

Figure 5.13: Total installed PV system costs and weighted averages for small and large utility-scale systems, by region and capacity, 2011 to 2014



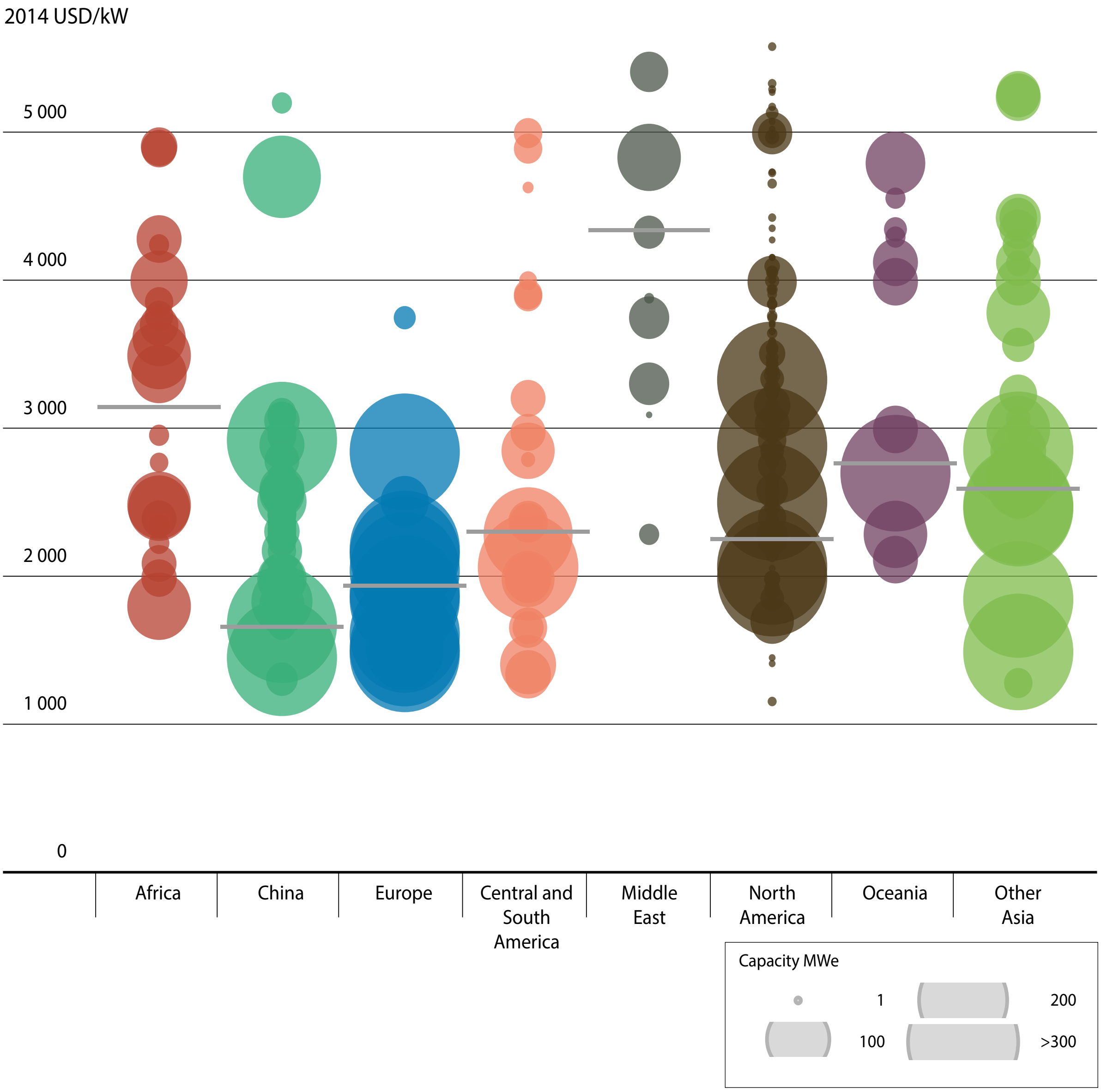
Source: IRENA Renewable Cost Database; CPUC, 2014; NREL, 2014; and Photon Consulting, 2014.

and competitive tendering or auction systems have seen a trend towards larger-size systems, notably in the United States, in China and in Central and South America. The most competitive projects have installed costs as low as USD 1 300/kW, while the upper cost range for projects is around USD 5 400/kW. In Africa, the total installed costs for utility-scale projects in 2013 and 2014 spanned the range from USD 1 820 to USD 4 880/kW, while in Central and South America the range was from USD 1 350 to USD 5 000/kW and in Other Asia (including Japan) the range was from USD 1 290 to USD 5 240/kW. The typical range for total installed costs of utility-scale projects in Europe and North America in 2013 and 2014 was between USD 1 300 and USD 3 750/kW, and USD 1 300 and USD 5 580/kW, respectively (IRENA and LBNL, 2014). The data in the IRENA Renewable Cost Database for total installed costs of utility-scale projects in China ranged from USD 1 320 to USD 3 090/kW for typical installations, but there remain outliers. The data available for other regions are modest and indicative at best.

Solar PV capacity factors

Capacity factors vary with the solar resource available and whether or not the systems have tracking systems (single or two-axis). Capacity factors for PV are typically in the range of 10% to 25% for fixed tilt systems, but values outside of this range are possible for exceptional sites or where siting is not optimal (e.g. tilt-angle or shading).

Figure 5.14: Total installed PV system costs by project and weighted averages for utility-scale systems by region and capacity, 2013 and 2014



Source: IRENA Renewable Cost Database; CPUC, 2014; NREL, 2014; and Photon Consulting, 2014.

However, average values can be very misleading for a country or a region, as solar resources are very site-specific (Table 5.3) and "micro-climates" can mean that even sites that are geographically very close together can show a wide discrepancy in capacity factors. Accurate solar resource mapping is therefore essential to the identification of the best sites for solar.

The weighted average capacity factor for utility-scale projects in Asia, outside of China and India, is around 14%, while in China it is around 17%, in Africa around 22%, and in India around 21% (Figure 5.15). In South America, where excellent resources are being exploited at present, the average capacity factor for utility-scale projects is around 27%. In North America, where utility-scale deployment in 2013 was concentrated in California and Arizona, average capacity factors have been around 22%. Adding tracking systems can significantly raise these capacity factors but this must be traded off against the additional cost of the tracking system.

The Levelised Cost of Electricity of Solar PV

The rapid decline in the total installed costs of small- and large-scale solar PV systems is mirrored

Figure 5.15: Utility-scale solar photovoltaic capacity factors by regionSource: IRENA Renewable Cost Database.

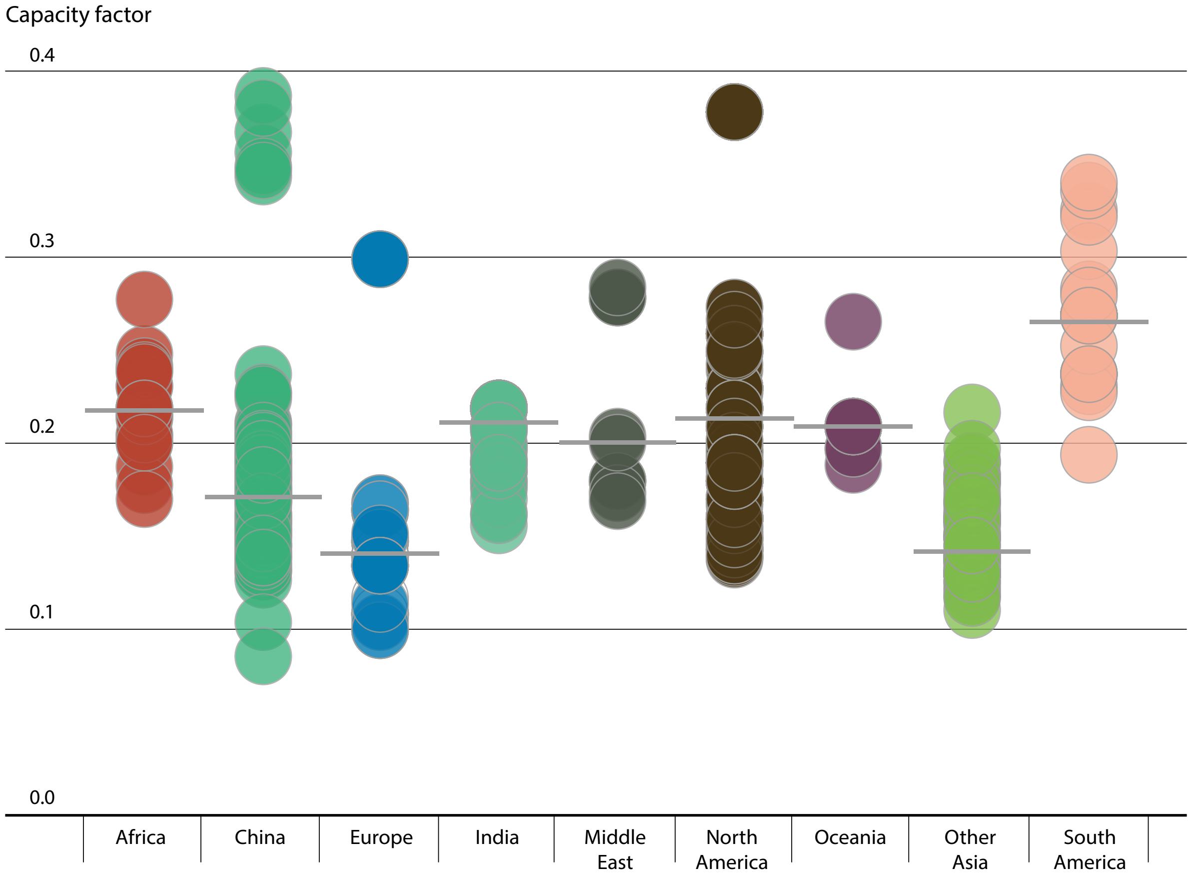


Table 5.4: Solar PV capacity factors by location and tracking system in the United States

	Fixed tilt	One-axis tracking	Two-axis tracking
Seattle, WA	14%	18%	19%
Miami, FL	20%	25%	26%
Phoenix, AZ	24%	31%	33%

Source: NREL, 2011.

in the trends for the LCOE of solar PV. With residential electricity tariffs rising around the world since 2000, as the result of increases in fossil fuel prices, residential grid parity (sometimes referred to as "socket" or "plug" parity) is becoming the norm rather than an exception. The challenge for utility-scale deployment remains real, but in areas of excellent solar resources and high electricity spot prices, even the once long-off goal of competitive utility-scale solar PV has been achieved. Solar PV merchant plants are being developed in Chile without any financial support, to meet growing demand, while power purchase agreements in the southwestern part of the United States are being signed at prices competitive with fossil fuels.

Promoting the development of competitive markets for solar PV in regions with the best solar resources will help to lower the LCOE of solar PV and meet the growing, and sometimes currently unserved, electricity demand in emerging economies that often have excellent solar resources. However, transport costs and poor local infrastructure are serious barriers in many parts of Africa and elsewhere in the sunbelt to achieving competitive installed cost levels.

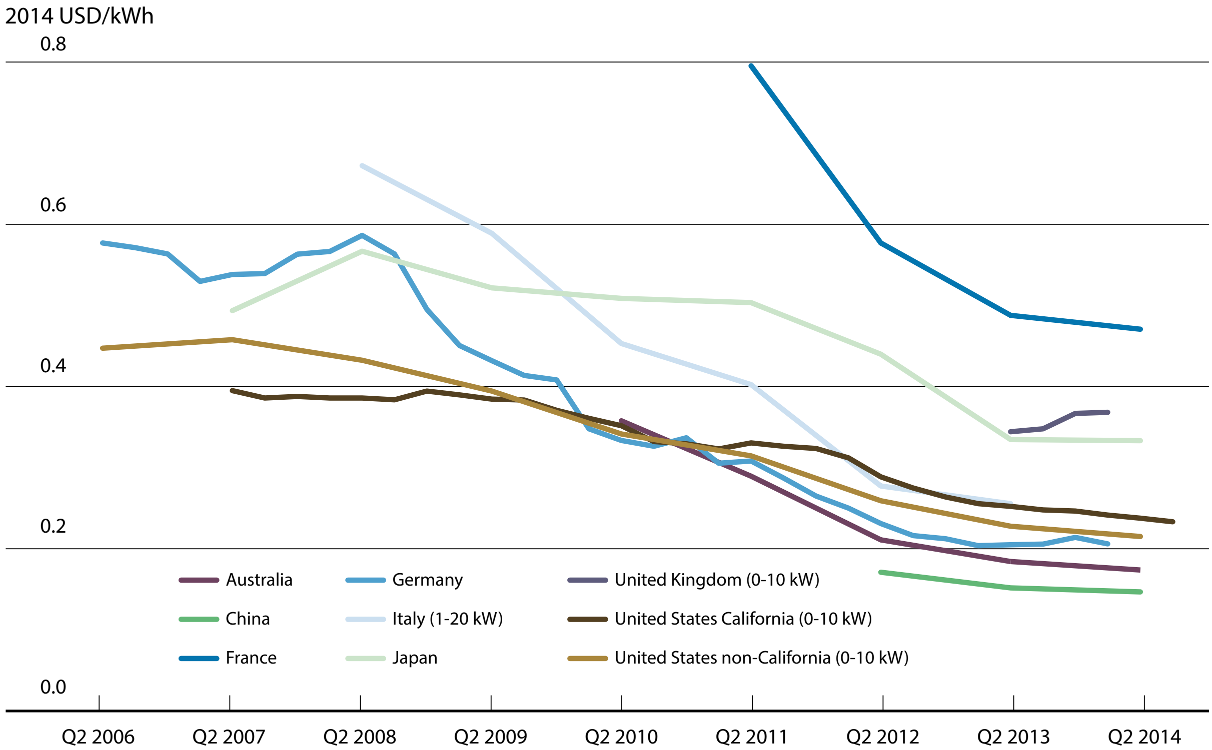
The global average utility-scale LCOE of solar PV is estimated to have declined by around half between 2010 and 2014, from around USD 0.32/kWh to just USD 0.16/kWh in 2014. The estimated global average LCOE of utility-scale solar PV declined by

14% between 2010 and 2011, 34% between 2011 and 2012 and by a further 8% between 2012 and 2013. The LCOE was little changed between 2013 and 2014, despite continued modest declines in installed costs in virtually every major market. The reason for this is the estimated continued shift in market growth in 2014 away from traditional low-cost markets, such as Germany, to some markets with higher cost structures, notably Japan and the United States. This has resulted in the estimated global average installed costs, and hence LCOE, being little changed in 2014 compared with 2013 despite continued declines in individual countries. This result needs to be treated with caution, however, as full data were not available for 2014 and both deployment and cost numbers are likely to change from what is presented here. It remains to be seen what impact those changes will have on the global average LCOE for utility-scale solar PV in 2014.

The average LCOE of residential PV systems without battery storage was estimated to be between USD 0.38 and USD 0.67/kWh in 2008 for the data presented in Figure 5.16. But this declined to between USD 0.14 and USD 0.47/kWh in 2014 with the reduction solar PV module prices seen since 2008 in the countries examined in Figure 5.16. The LCOE of electricity for residential systems declined by around 42% between 2008 and 2014 for small systems (0-4 kW) in California and by 44% for the larger 4-10 kW systems; in other parts of the United States the decline was 52% and 54%, respectively, for these residential systems. The LCOE of French residential systems is estimated to have declined by 61% between 2008 and 2014, while the LCOE of Japanese residential systems fell by 42%. The estimated LCOE of residential systems in Italy fell by 59% between 2008 and 2013 for systems of 1-3 kW in size, while they fell by 66% for larger systems of 3-20 kW in size, for an average decline of around 63%. Between 2010 and 2014, the average LCOE of residential systems in Australia declined by 52%. A shorter time series is available for China, which has very competitive LCOE levels.

Cost reductions mean that the LCOEs of the latest utility-scale projects in 2014 are increasingly competitive. Figure 5.18 presents the LCOE ranges and capacity-weighted averages for utility-scale PV projects between 2010 and 2014. The range of the LCOE has declined from between USD 0.18 and USD 0.61/kWh in 2010 to between USD 0.08 and USD 0.50/kWh in 2014. The ranges remain wide, but there has been a rapid reduction in the global weighted average LCOE of utility-scale solar

Figure 5.16: Levelised cost of electricity of residential solar photovoltaic systems by country, 2006 to 2014



Source: IRENA Renewable Cost Database; BSW, 2014; CPUC, 2014; GSE, 2014; LBNL, 2014; and Photon Consulting, 2014.

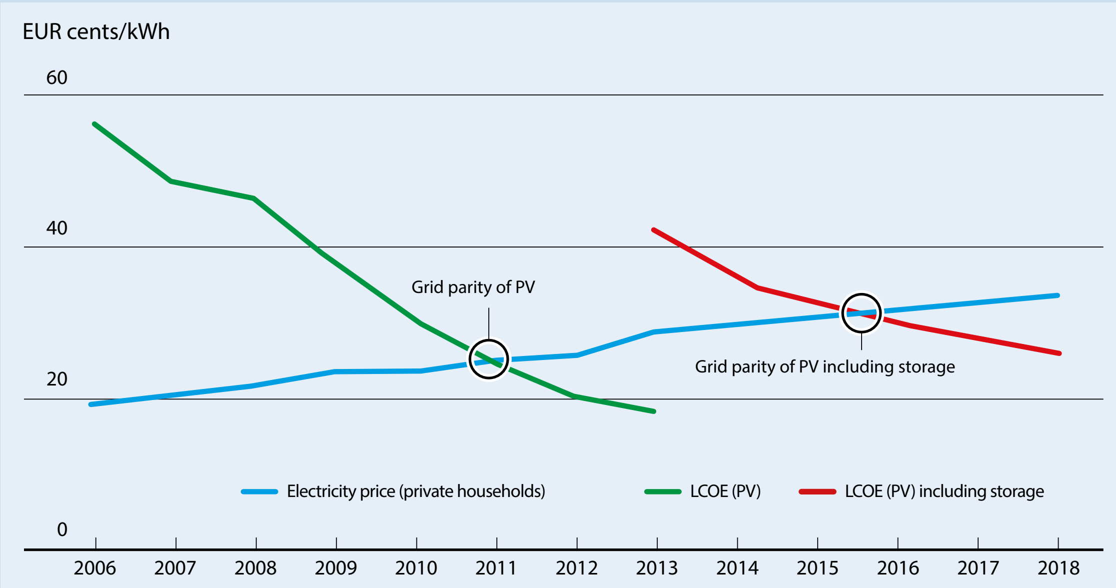
BOX 5.2

Declining feed-in tariff rates and battery costs

As FiTs for residential solar PV systems are reduced, there will be a growing number of countries where the FiT is significantly below the retail electricity price. For instance, in Germany, new systems installed at the end of 2014 will receive an approximate FiT value of between EUR 0.12 and EUR 0.15/kWh, depending on their size (Bundesnetzagentur, 2014), while retail tariffs are around EUR 0.30/kWh. The value of self-consumption has therefore increased significantly, as the value of the electricity saved is now twice that of the revenue received from the FiT.

When combined with the falling costs of lithium-ion (li-ion) battery systems, which offer better performance than lead-acid batteries, the economics of self-consumption will potentially become very favourable. Recent analysis suggests that by 2016 these factors will work together to result in PV-storage parity in Germany, assuming a 5 kWh battery pack and a starting point of EUR 2 300/kWh in 2013 for li-ion battery packs, with costs declining over time (Figure 5.17). This analysis excludes any subsidies, so any government support for PV-storage systems would bring forward the point of competitiveness. This coming PV-storage parity will further increase the pressure on existing power generation utilities. Although it will not make sense for consumers to become totally self-sufficient, they will have an incentive to increase the level of self-consumption and market growth could potentially decouple from financial support levels and become self-sustaining.

Figure 5.17: Grid parity of PV-storage in Germany

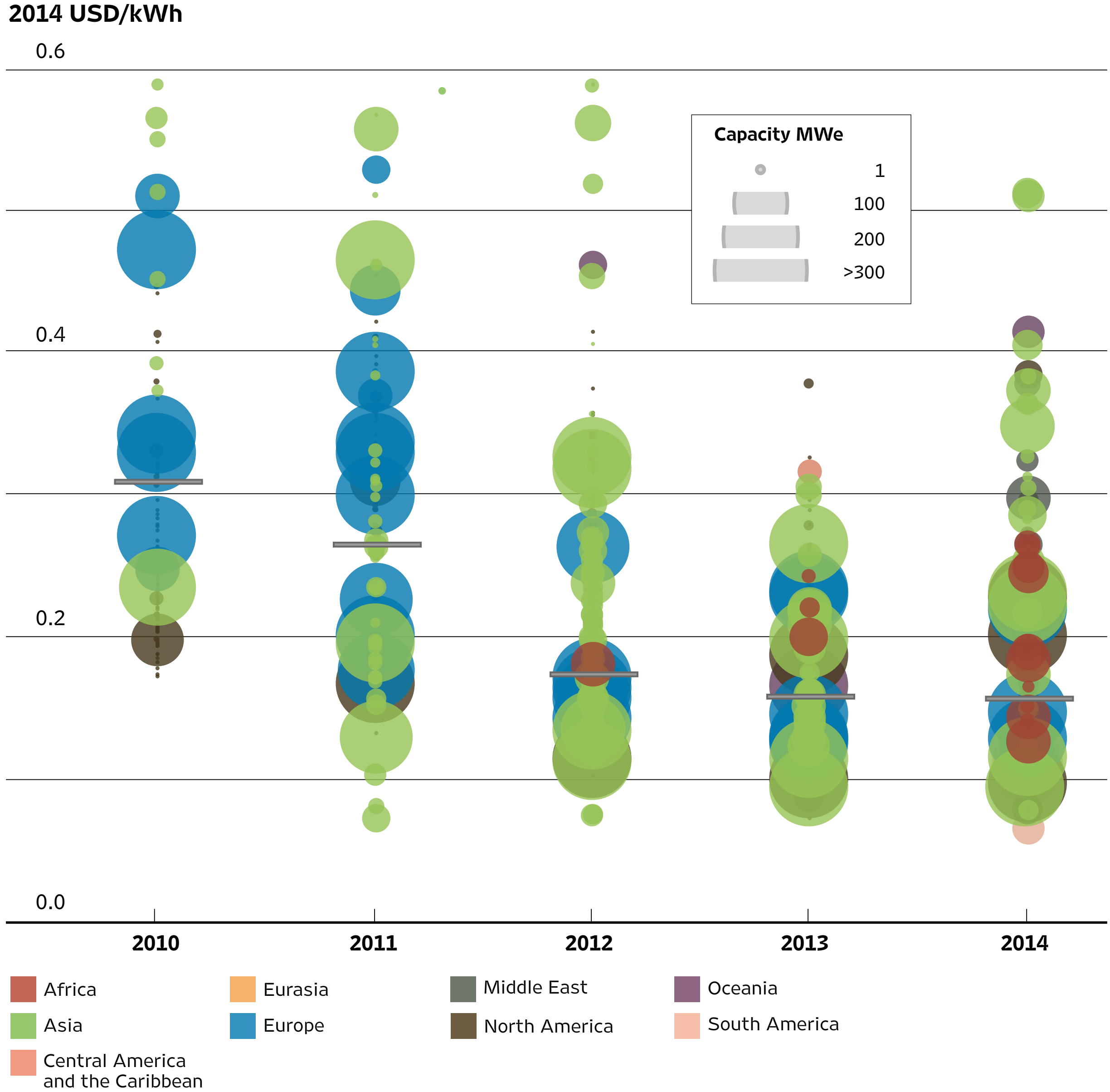


Source: EuPD Research/ BDEW 2013.

PV as module prices declined rapidly to 2012. The slowing in LCOE reductions in 2013 and 2014 reflects the slowing in module price declines and also a trend to greater deployment in some higher cost markets.

Figure 5.19 presents the LCOE data by country and region, but only for 2013 and 2014 when module prices were similar. Central and South America have the lowest estimated weighted average LCOE, of around USD 0.11/kWh; while, North America – specifically the United States – is also very competitive with a weighted average LCOE of USD 0.12/kWh. Average installed costs are somewhat higher in the United States than in China, but the excellent solar resources in the United States compensate for this to some extent. South America is also emerging as a very competitive

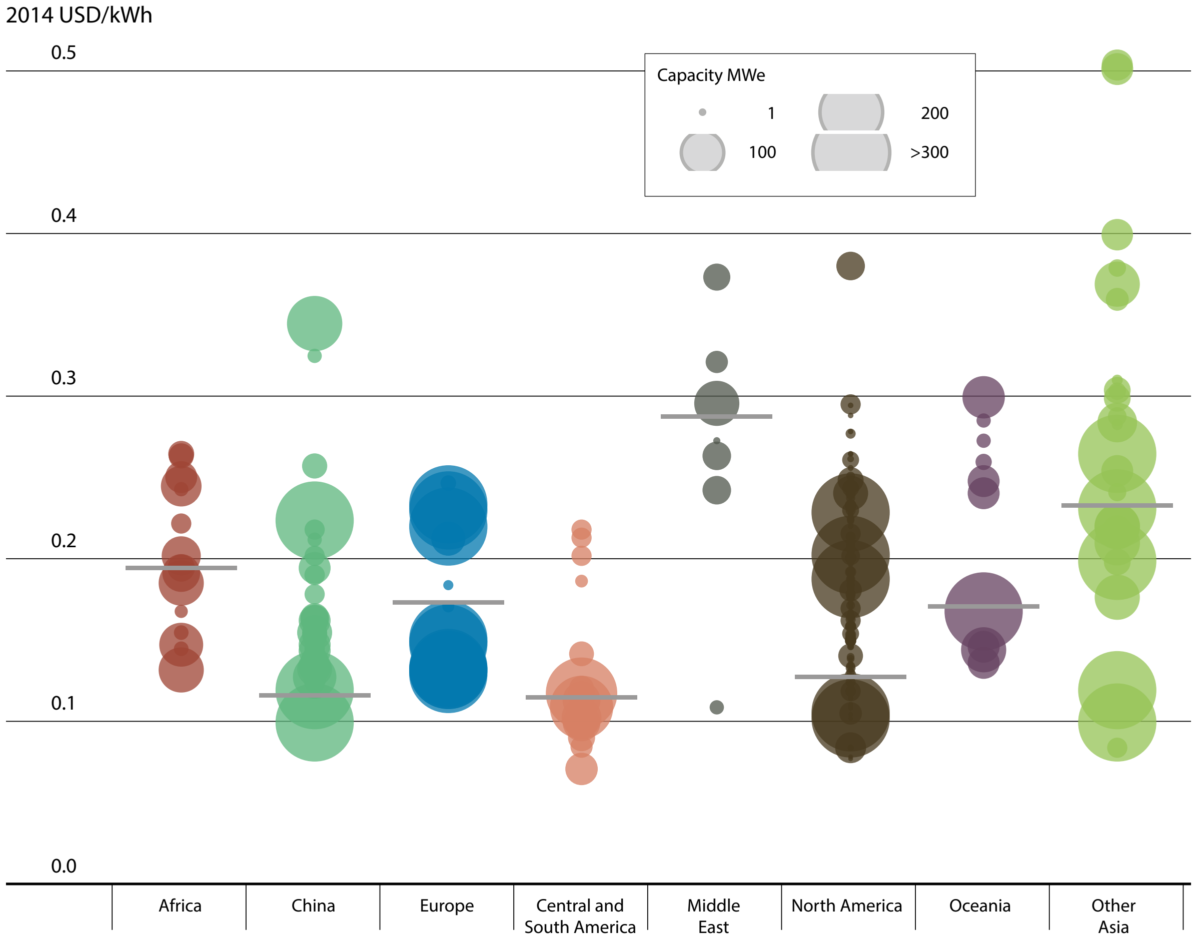
Figure 5.18: Levelised cost of electricity of residential solar photovoltaic systems by country, 2010 to 2014



Source: IRENA Renewable Cost Database and Photon Consulting, 2014.

solar PV market, where excellent resources and competitive cost structures are emerging to make highly competitive projects. As already noted, utility-scale solar PV in parts of Chile is competitive with wholesale electricity prices and no financial support is required. This trend will become increasingly the norm as witnessed by the recent PPA announcement in Dubai that saw the winning bid for a 100 MW solar PV plant come in at just USD 0.06/kWh (DEWA, 2014).

Figure 5.19: Levelised cost of electricity of utility-scale solar photovoltaic systems by country and region, 2013 and 2014



Source: IRENA Renewable Cost Database and Photon Consulting, 2014.