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# PV Status Report 2017

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#### Title PV Status Report 2017

Photovoltaics is a solar-power technology for generating electricity using semiconductor devices known as solar cells. A number of solar cells form a solar 'module' or 'panel', which can then be combined to form solar power systems, ranging from a few watts of electricity output to multi-megawatt power stations.

Growth in the solar photovoltaic sector has been robust. The Compound Annual Growth Rate over the last decade was over 40 %, thus making photovoltaics one of the fastest growing industries at present. The PV Status Report provides comprehensive and relevant information on this dynamic sector for the interested public, as well as decision-makers in policy and industry.

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## Foreword

In December 2015, the 21st session of the Conference of the Parties (COP21) to the UNFCCC in Paris, France ended with a landmark agreement to keep the maximum global average temperature rise as close as possible to 1.5 °C. After the signature of the European Union (EU) on 5 October 2016, the necessary number of at least 55 Parties to the Convention accounting in total for at least an estimated 55 % of the total global greenhouse gas emissions was reached and the Paris Agreement came into force on 4 November 2016.

The contribution of the EU was defined during the European Council meeting on 23-24 October 2014, when the following Conclusions on 2030 Climate and Energy Policy Framework were adopted:

- The European Council endorsed a binding EU target of at least 40 % domestic reduction in greenhouse gas emissions by 2030 compared to 1990.
- An EU target of at least 27 % is set for the share of renewable energy consumed in the EU in 2030. This target will be binding at EU level.
- An indicative target at the EU level of at least 27 % is set for improving energy efficiency in 2030 compared to projections of future energy consumption.

On 15 and 16 September 2017, Canada, China, and the European Union (EU) convened a Ministerial Meeting on Climate Action, in Montreal, which aimed to muster urgently needed support for the full implementation of the Paris Agreement on climate change as a preparation of the 23<sup>rd</sup> session of the Conference of the Parties (COP23), which will take place from 6 to 17 November 2017 in Bonn, Germany.

With the exception of the USA, all other participants from 33 countries expressed their commitment to the full implementation of the Paris Agreement. The USA reiterated its intention to withdraw from the treaty, indicating that it is open to "reengaging on terms more favourable to it."

The International Energy Agency in its Energy Technology perspectives 2017 presented a pathway for achieving the goals of the Paris Agreement. In order to reach this the power sector has to be fully decarbonised not by 2060 as modelled for a 2 °C scenario, but well before 2050.

Photovoltaics (PV) is a key technology option for realising a decarbonised decarbonised power sector and sustainable energy supply and can be deployed in a modular way almost everywhere on this planet. Solar resources in Europe and across the world are abundant and cannot be monopolised by one country. Regardless of how fast energy prices increase in the future, and the reasons behind these increases, PV and other renewable energies are the only ones offering the stabilisation of, or even a reduction in future prices.

Between the end of 2009 and the first half of 2017, the benchmark LCOE from PV system decreased by over 70% to USD 86/MWH (EUR 72/MWh). The main contribution was the decrease of module prices by over 85 % in most competitive markets, and in an increasing number of markets. Due to the continuous decrease of PV system prices and increasing electricity prices, the number of such markets is steadily increasing. Moreover, the nuclear accident which took place in Fukushima in March 2011 has brought about a shift in energy investments toward more renewables and PV systems. In 2016, solar energy attracted 55 % of all new renewable energy investments or USD 113.7 billion (EUR 103.4 billion).

In 2016, PV industry production rose again by about 30 % and reached a worldwide production volume of more than 80 GW of PV modules. The compound annual growth rate (CAGR) over the last 15 years was above 40 %, which makes PV one of the fastest growing industries at present.

The 15th edition of the PV Status Report gives an overview of current trends. Over the last one and a half decades, the PV industry has grown from a small group of companies and key players into a global business where information gathering is becoming increasingly complex. Any additional information would be most welcome and will be used to update the report.

Ispra, October 2017



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Joint Research Centre, European Commission

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## Executive summary

For the 7th year in a row, solar power with 57 % of total investment representing USD 113.7 billion (EUR 103.4 billion) took the largest share of new investments in renewable energies. Despite a 34 % annual decrease of total global investment in solar energy the newly installed capacity of solar photovoltaic power increased by 38% to over 79 GW in 2016. This capacity represents more than half of all new renewable power capacity installed in 2016. These investments were almost evenly shared between large scale solar power and distributed solar energy systems.

Over the last 15 years, the production volume of solar PV has increased with a compound annual growth rate (CAGR) of over 40 %, which makes the industry one of the fastest growing ones in the world. Until 2006, the solar cell production was dominated by Japan and Europe. After the rapid increase of the annual production in China and Taiwan since 2006, a new trend emerged in 2014 to rapidly increase production capacities in other Asian countries like India, Malaysia, Thailand, the Philippines or Vietnam.

Market development for solar PV systems did not follow the production at the same pace, which led to overcapacities and massive price pressure along the production value chain. This development triggered a consolidation of the manufacturing industry, which is still ongoing.

The developing countries kept their lead in new investments in solar energy, whereas for all renewable energies the developed countries regained the lead.

Despite a 32% decline in new renewable energy investment, China kept the lead with USD 78.3 billion (EUR 71.2 billion), followed by the USA with USD 46.4 billion (EUR 42.2 billion) and the United Kingdom with USD 24.0 (EUR 21.8 billion), while Japan saw a decline by 56% and moved to fourth place with USD 14.4 billion (EUR 13.1 billion).

Contrary to the general trend, renewable energy investments in Europe slightly increased by 1 % to USD 58.8 billion (EUR 53.5 billion) in 2016. This was due to a 53% increase in spending for offshore wind installations, which accounted for almost half of renewable energy spending or USD 28.9 billion (EUR 26.3 billion).

According to market forecasts, the installed PV power capacity of 315 GW at the end of 2016 could double by 2019. At the end of 2017, worldwide solar PV power is expected to exceed 400 GW capable of producing roughly 2 % of the worldwide electricity demand. The EU's share is about one fourth of the world-wide installed capacity, which can provide about 4 % of its electricity demand.

2016 already saw a number of record breaking power purchase agreements (PPA) contracts and bids below USD 30/MWh and a new low was observed with a USD 24.2/MWh bid for an Abu Dhabi Electricity and Water Authority's tender in September 2016. These very low bids and PPAs, especially in the United Arab Emirates and Chile are only possible through a combination of excellent solar resource, high debt shares and very low debt costs as well as the fact that some tariffs are indexed to inflation.

PV is a key technology option for implementing the shift to a decarbonised energy supply and can be deployed in a modular way almost everywhere on this planet. Over the last decades the growth of PV energy use was mainly driven by public incentives, but the shift to an economic driven use of solar PV electricity as one of the lowest cost electricity supplies is obvious.

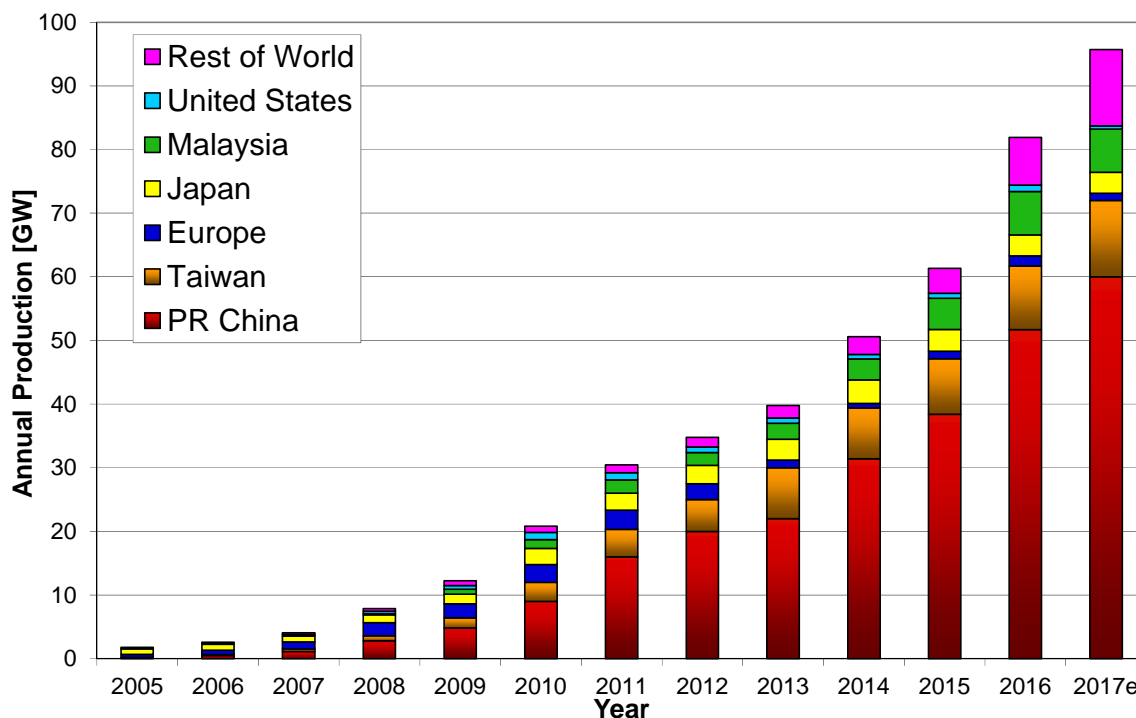
# 1 Introduction

Reported production data for the global solar cell production<sup>1</sup> in 2016 vary between 79 GW<sup>2</sup> and 84 GW and estimates for 2017 are in the 90 to 95 GW range. The significant uncertainty in these data is due to the highly competitive market environment, as well as the fact that some companies report production figures, while others report sales and again others report shipment figures.

The data presented, collected from stock market reports of listed companies, market reports and colleagues, were compared to various data sources and thus led to an estimate of 81.9 GW (Fig. 1), representing an increase of about 30 % compared to 2015 and another 10 to 15% are expected for 2017.

Since 2000, the production of solar photovoltaic devices has grown with a CAGR of over 40 %. After the rapid increase of the annual production in China and Taiwan since 2006 a new trend emerged in 2014 to increase production capacities in other Asian countries like India, Malaysia, Thailand, the Philippines or Vietnam. It is interesting to note that a large portion of these investments is done by Chinese companies. Another trend in the PV industry was the rapid increase in original equipment manufacturing (OEM) volumes since 2011, which allowed larger companies to significantly increase their shipment volumes without adding new capacity of their own.

**Figure 1:** World PV cell/module production from 2005 to 2017 (estimate)



Source: Photon Magazine [Pho 2012], PV Activities in Japan [Ikk 2017], PV News [Pvn 2015] and own analysis)

<sup>1</sup> Solar cell production mean:

- In the case of wafer silicon based solar cells, only the cells
- In the case of thin-films, the complete integrated module
- Only those companies which actually produce the active circuit (solar cell) are counted
- Companies which purchase these circuits and make solar modules are not counted

<sup>2</sup> Please note that all number are based on the current available data (September 2017) and can change, when final annual reports of public companies or country statistics are published during the year

### **Uncertainties in production statistics**

- Only a limited number of companies report production figures for solar cells or thin film modules.
- Shipment figures can include products from stock, already produced in the previous year.
- Some companies report shipments of 'solar products' without a differentiation between wafers, cells or modules.
- The increasing trend towards OEM increases the potential of double counts.

Investments in renewable energy projects excluding large hydro-electric power plants reached USD 244 billion (EUR 222 billion<sup>3</sup>), which was 21 % less than in 2015 but the total new installed renewable power capacity, excluding large hydro, increased from 127.5GW in 2015 to a record 138.5GW in 2016 [Blo 2017, FSU 2017]. R&D trends for governmental and industrial spending were opposite. While the first increased by 25% to USD 5.5 billion (EUR 5 billion), the second decreased by almost 40% to USD 2.5 billion (EUR 2.3 billion).

The two main reasons for the decrease in investments were lower CAPEX in USD for solar photovoltaics and wind projects as well as a slowdown in financings, especially in China, Japan and some emerging markets.

The new installed renewable nominal power capacity (excluding large hydro) represents 55% of all new power capacity added in 2016. The share of electricity provided by renewable energy sources (excluding large hydro) increased from 10.3 in 2015 to 11.3% in 2016.

For the 7th year in a row, solar power attracted the largest share of new investments in renewable energies. The USD 113.7 billion (EUR 103.4 billion) investments in solar energy, accounted for 46 % of all new renewable energy investments. Despite a 34 % annual decrease of total global investment in solar energy the newly installed capacity of solar photovoltaic power increased by 38% to almost 76 GW in 2016. However, one has to keep in mind that a substantial part of solar projects closed their financing already in 2015 but were commissioned in 2016. In such cases the investment is counted for 2015, but the capacity addition is associated with 2016.

The developing countries kept their lead in new investments in solar energy, whereas for all renewable energies the developed countries regained the lead.

Despite a 32% decline in new renewable energy investment, China kept the lead with USD 78.3 billion (EUR 71.2 billion), followed by the USA with USD 46.4 billion (EUR 42.2 billion) and the United Kingdom with USD 24.0 (EUR 21.8 billion), while Japan saw a decline by 56% and moved to fourth place with USD 14.4 billion (EUR 13.1 billion).

Contrary to the general trend, renewable energy investments in Europe slightly increased by 1 % to USD 58.8 billion (EUR 53.5 billion) in 2016. This was due to a 53% increase in spending for offshore wind installations, which accounted for almost half of renewable energy spending or USD 28.9 billion (EUR 26.3 billion).

Between 2008 and 2014, PV module prices have decreased rapidly by more than 80 %, before 2015 saw a short levelling out due to industry consolidation and increasing markets, mainly in China and Japan [Blo 2013, 2016]. However, since the beginning of 2016 module prices have again seen a sharp decrease in prices, which put all solar companies along the value chain under enormous pressure [Blo 2017a].

Overcapacities along the PV value chain still exist and started to build up as a result of very ambitious investments beginning in 2005. The investments in solar cell and module manufacturing equipment, excluding polysilicon manufacturing plants, peaked in 2011 at about USD 14 billion (EUR<sup>4</sup> 10.8 billion) after the PV market grew by more than 150 % in

<sup>3</sup> Exchange rate 2016: EUR 1.00 = USD 1.10

<sup>4</sup> Exchange rate 2013: EUR 1.00 = USD 1.30

2010. However, in the following years, the market growth for solar photovoltaic systems slowed and was not able to absorb the output of this massive and rapid increased manufacturing capacity. The result was a huge oversupply, which led to continuous price pressure along the value chain and resulted in a reduction of market prices for polysilicon materials, solar wafers and cells, as well as solar modules. This development resulted in the insolvency of many companies. Consequently, equipment spending declined dramatically and hit the bottom with around USD 2 to 2.5 billion (EUR 1.54 to 1.92 billion) in 2013.

Consolidation in the PV manufacturing industry has led to the closure or takeover of a significant number of companies since 2009. Despite those bankruptcies and companies with idling production lines or even permanent closures of their production facilities, the number of new entrants to the field, notably large semiconductor, construction or energy-related companies, is remarkable and makes a reasonable forecast for future capacity developments very speculative.

Since the beginning of 2014, the announcements of new capacity expansions have significantly increased and peaked in the first quarter of 2016. In 2016 and the first quarter of 2017, over 36 GW of new silicon solar cell capacities and more than 1.3 GW for thin films were announced. According to BNEF the group of Tier 1 module manufacturers have a production capacity of 82.6 GW in 2017 [Blo 2017a].

The uncertainty about how much additional capacity will be available in the future is twofold. First, a number of projects are from industry players with no solar cell manufacturing record and in countries with a limited or no infrastructure. Therefore, it is very difficult to predict if and when these capacities will eventually be realised. Second, with the ongoing cost pressure and the drive to modules with higher efficiencies, it is obvious, that older production lines will be upgraded or substituted with manufacturing capacities capable to produce these higher efficient solar cells. Therefore, the overall net capacity increase of solar cells will be much lower than the announcements imply.

Nevertheless, the general trend still is pointing in the direction of more capacity announcements despite the existing excess capacity. However, it is important to recall that the existing excess capacity is different in the four main parts of the silicon module value chain, i.e. (1) polysilicon production, (2) wafer production, (3) solar cell manufacturing, (4) module manufacturing.

The current trend is a lowering of the oversupply in the first two sectors, whereas the excess capacity gap is growing in the latter two. As a consequence, this development will continue to add pressure to the margins of most manufacturers. The overall average selling price (ASP) of modules are decreasing further, due to three main factors: (1) the already mentioned excess capacity, (2) a further contracting of high price markets like Japan and (3) a shift of supply to lower price markets and countries with extreme competitive price bids for PPAs.

Despite the continuing problems of individual companies, the fundamental industry as a whole remains strong and the overall PV sector will continue to experience significant long-term growth. The IEA's sixth Medium-Term Renewable Energy Market Report forecasts a new installed photovoltaic power capacity between 385 and 500 GW during 2017 and 2022 [IEA 2017].

After the very strong market performance in China during the first 7 months of 2017, market predictions for the 2017 PV market are in the 90 GW range. For 2018, the world market predictions vary between 58 GW according to Solar Power Europe's low scenario and 106 GW in BNEF Global PV Market Outlook [Blo 2017a, Sol 2017].

The current solar cell technologies are well established and provide a reliable product, with a guaranteed energy output for at least 25 to 30 years.

This reliability, the increasing demand for electricity in emerging economies and possible interruptions due to grid overloads there, as well as the rise in electricity prices from conventional energy sources, all add to the attractiveness of PV systems.

Over 90 % of current production uses wafer-based crystalline silicon technology. Projected silicon production capacities for 2017 vary between 450 000 tonnes [Blo

2017a] and 508 000 tonnes [Ikk 2017]. It is estimated that about 30 000 tonnes will be used by the electronics industry. Potential solar cell production will, in addition, depend on the material used per Wp (grams per Watt-peak). The current blended global average is about 4.7 g/Wp.

In general, global CAPEX for PV solar systems have converged, even if significant differences still exist due to differences in market size and local competition and factors like import taxes, local content rules or existing tax credits. In the 1st half year (H1) 2017, the BNEF global benchmark for levelised cost of electricity (LCOE) in the solar sector was given with USD 86 per MWh a decrease of about 15% compared to H2 2016 [Blo 2017b]. The main reason for this decrease was a further drop in module prices. The cost share of solar modules in the benchmark PV system has dropped below 40 %.

The influence of CAPEX on LCOE of solar PV electricity has decreased significantly and other costs like O&M (operations and maintenance) costs, permits and administration, fees and levies as well as financing costs play a more dominant role. Therefore, these variable and soft costs must be targeted for further significant cost reductions.

In countries with a developed electricity grid infrastructure, the increasing shares of PV electricity in the grid lead to a growing importance of the economics of integration. Therefore, more and more attention is focused on issues such as:

- development of new business models for the collection, sale and distribution of PV electricity, e.g. development of bidding pools at electricity exchanges, virtual power plants with other renewable power producers, and storage capacities;
- adaptation of the regulatory and legal procedures to ensure fair and guaranteed access to the electricity grid and market.

The problem is a different one in countries with a weak electricity grid or where not all citizens have access to electricity at all. The access to electricity and the design of new electricity infrastructure should be based no longer on the dependence of classical centralised power generation units, but use the new available technology options of decentralised renewable power generation sources like photovoltaics. The smart use of the locally available mix of different renewable energy sources as well as demand and supply side management has to be an integral part of every energy plan to avoid stranded investments in the future.

The cost of direct current (DC) electricity generated by a PV module has dropped below EUR 0.02/kWh in many places world-wide, although a significant additional cost component relates to transporting the electricity from the module to where and when it is needed. Therefore, new innovative and cost-effective electricity system solutions with PV as an integral part of sustainable energy solutions are needed now. The optimisation of solar PV electricity plant design and operation has direct effect on the O&M costs, which play an important role for the economics of the PV installation. With the continuous decrease of hardware CAPEX, the non-technical costs, linked to permit applications and regulations are representing an increasing share of the total costs and need to be reduced as well. Here, further public support, especially for regulatory measures, is needed.

## 2 The PV market

Annual new solar PV system installations increased from 29.5 GW in 2012 to 79.4 GW in 2016, driven by a shift to more large scale utility systems on the one hand and a worldwide reduction of PV system prices on the other side (Fig. 2).

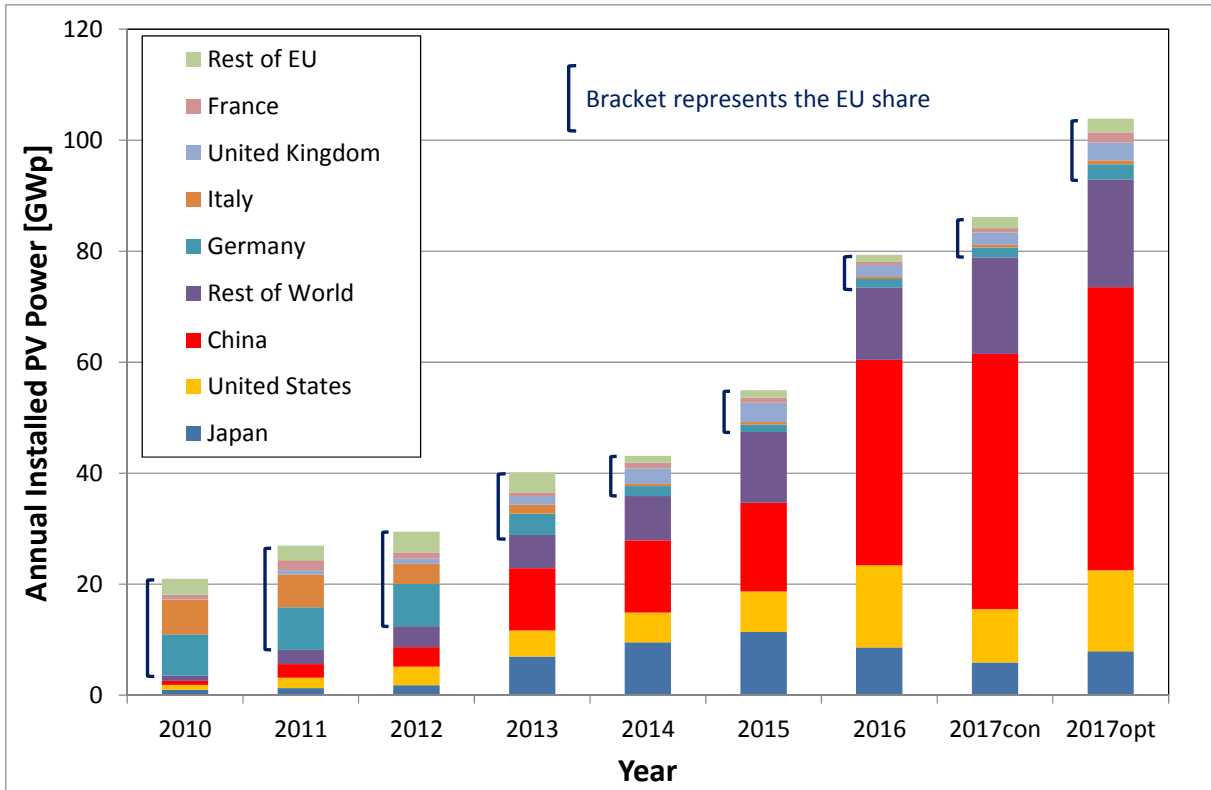
This represents mostly the grid connected PV market. To what extent the off-grid and consumer product markets are included is not clear, but it is believed that a substantial part of these markets are not accounted for as it is very difficult to track them. However, these segments have become smaller and smaller in relative terms.

### Uncertainties in market statistics

- The installation figures of this report are about the physical installation of the system hardware, not the connection to the grid. The grid connection can be delayed due to administrative reasons or in some cases missing grid capacity.
- This report uses nominal DC peak power (Wp) under standard test conditions (1 000 W irradiance and standard nominal 25 °C) for reasons of consistence.
- Not all countries report DC peak power (Wp) for solar PV systems, but especially for larger scale system the utility peak AC power, which is relevant for the transmission operator. Even in the Eurostat statistics the two capacities are mixed.
- Some statistics only count the capacity which is actually connected or commissioned in the respective year for the annual statistics, irrespectively when it was actually installed. This can lead to short term differences in which year the installations are counted and the annual statistics, but levels out in the long-run, if no double counting occurs. E.g.:  
(1) in Italy about 3.5 GW of solar PV systems were reported under the second *conto energia* and installed in 2010, but only connected in 2011;  
(2) the construction period of some large solar farms spread over two or more years. Depending on the regulations – whether or not the installation can be connected to the grid in phases and whether or not it can be commissioned in phases, the capacity count is different;
- some countries do not have official statistics on the capacity of solar PV system installations or sales statistics of the relevant components.

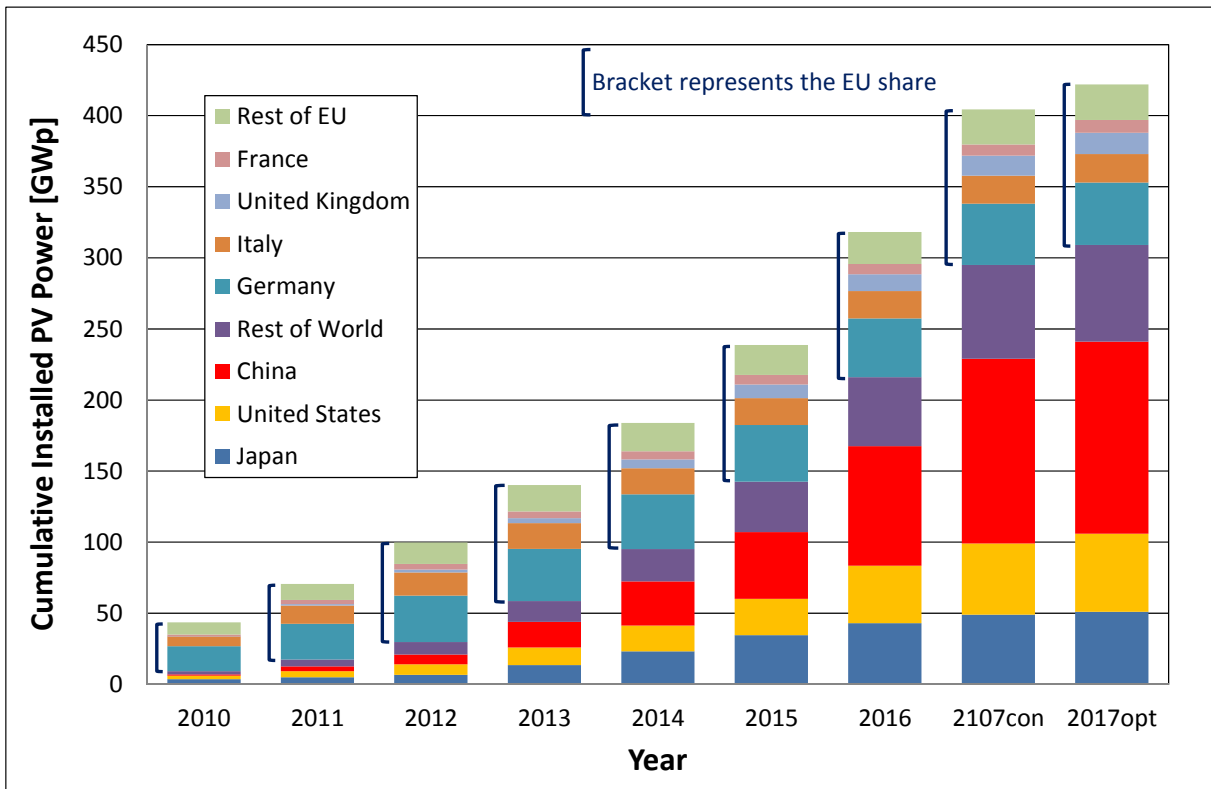
In 2015, China overtook Germany in terms of cumulative installed nominal PV power, Japan followed in 2016 and the USA already did so in the first half of 2017. With a cumulative installed PV power of almost 102 GW, the EU still accounted for 32 % of the 315 GW solar PV electric power capacity installed worldwide at the end of 2016. However, this is down from the 66 % in 2012, when the cumulative installed solar PV electric power had just reached 100 GW world-wide.

**Figure 2:** Annual PV system installations from 2010 to 2017



Source: [IEA 2017a, Sol 2017, Sys 2017] and own analysis

**Figure 3:** Cumulative PV installations from 2010 to 2017



Source: [IEA 2017a, Sol 2017, Sys 2017] and own analysis

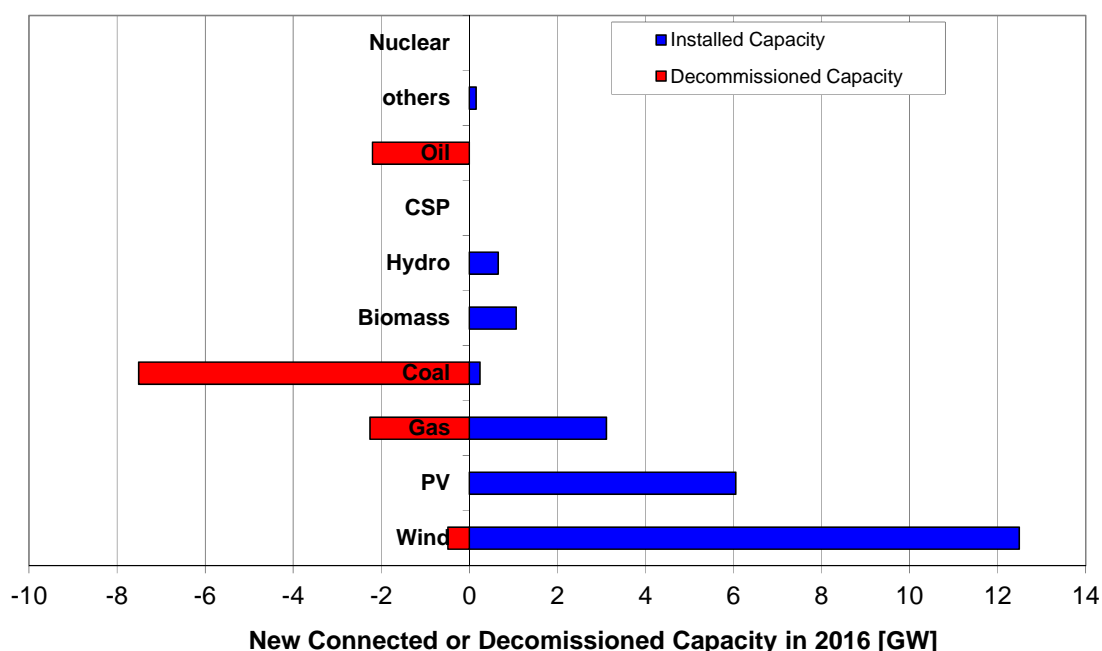
## 2.1 Europe, the Russian Federation and Turkey

Market conditions for PV differ substantially from country to country. This is due to different energy policies and public support programmes for renewable energies, especially PV, as well as the varying grades of liberalisation of domestic electricity markets.

Looking at the electricity system as a whole, a total of about 23.7 GW of new power generation capacity were installed in the EU last year and 12.4 GW were decommissioned, resulting in 11.3 GW of new net capacity (Fig. 4) [Sol 2017, Sys 2017, Win 2017, own analysis]. Renewable energy sources (RES) accounted for 20.4 GW or 86 % of all new power generation capacity. PV electricity generation capacity accounted for 6.1 GW, or 25.7 % of the new installed capacity.

In terms of new net capacity, wind power was first with 12 GW, followed by solar PV 6.1 GW, biomass plants with 1.06 GW, natural gas 859 MW, hydro 657 MW and other sources 154 MW. The net installation capacity for coal- and oil-fired power plants was negative, with a decrease of 7.3 GW and 2.2 GW, respectively.

**Figure 4:** New connected or decommissioned electricity generation capacity in the EU in 2016



Source: [Sys 2017, Win 2017,] and own analysis

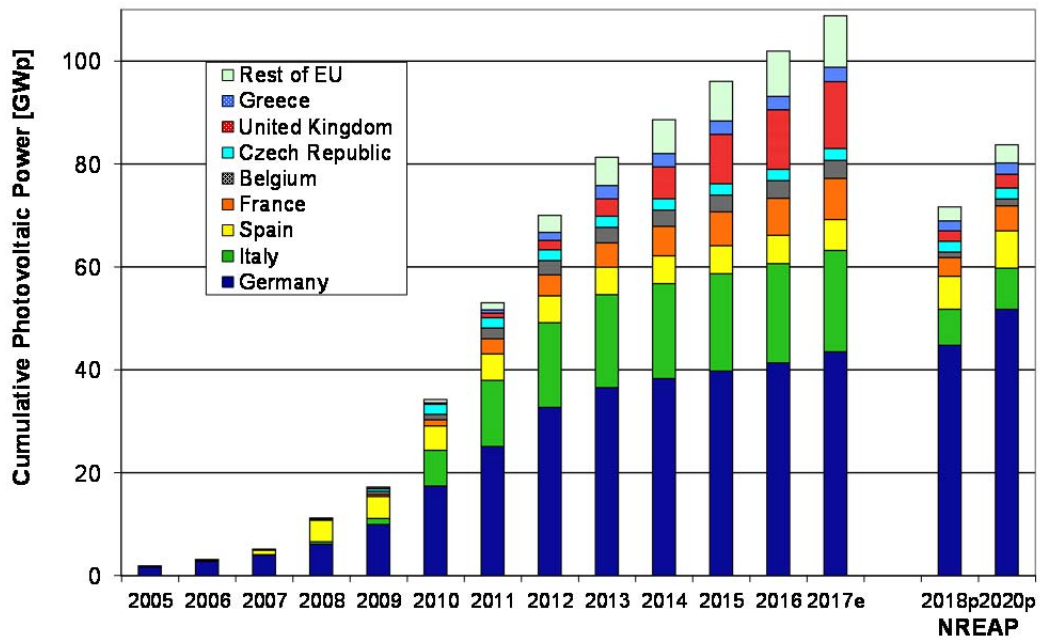
Since 2005, solar PV electricity generation capacity has increased from 1.9 GW to 102 GW at the end of 2016 (Fig. 5). Already in 2014, the 2020 National Renewable Energy Action Plan (NREAP) target of 83.7 GW was exceeded, reaching about 88.4 GW.

With a cumulative installed capacity of 102 GW, the EU was still leading in PV installations with 32 % of the global total of 315 GW of solar PV electricity generation capacity at the end of 2016, although this is down from the 66 % recorded at the end of 2012. The installed PV power capacity in the EU at the end of 2016 can generate around 110 TWh of electricity or about 4 % of the final electricity demand in the Union.

At first glance, this development appears to be a success. However, by looking at the annual installations, it becomes obvious that Europe's share is not only declining in relation to a growing market worldwide, but also in actual installation figures (Fig. 6). According to the IEA Medium-Term Renewable Energy Market Report 2017, this share will drop below 20 % by 2022 due to a stagnant market of 7 to 8 GW between 2017 and 2022 in the European Union and a growth between 385 and 500 GW world-wide [IEA 2017].

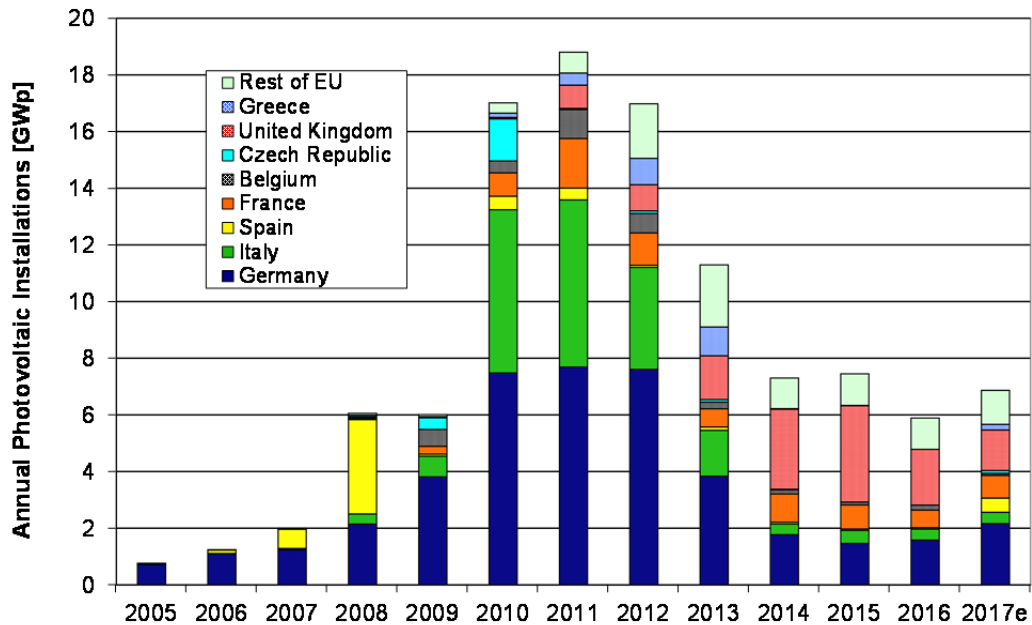


**Figure 5:** Cumulative installed grid-connected PV capacity in EU + candidate countries compared with the NREAP target for 2020



Source: [Sol 2017, Sys 2017] and own analysis

**Figure 6:** Annual installations in EU and candidate countries



Source: [Sol 2017, Sys 2017] and own analysis

What are the reasons and main consequences of this development?

Some Member States had introduced support schemes which were not designed to react fast enough to the very rapidly growing market and this led to unsustainable local market growth rates. To counteract this, unpredictable and frequent changes in the support schemes, as well as legal requirements, led to installation peaks before the announced deadlines and high uncertainty for potential investors. A number of retroactive changes have further decreased investment confidence.

One of the consequences is the effect on local jobs and the local economy: The growth of the PV industry in Europe resulted in the generation of over 260 000 jobs or 38 % of global employment in the PV sector in 2011 [Jäg 2014]. Over 75 % of these 260 000 jobs were in operating and installing solar PV electricity systems. Almost all of them were local European jobs contributing to the European gross domestic product (GDP). The steep drop in new installations from 2011 to 2016 more than halved these local jobs and with them the positive effect on the local European economy [Ire 2017]. The 115 000 jobs left in the solar photovoltaic sector in the European Union are less than 4% of the global 3.1 million jobs in the sector.

To reach the 2030 targets, up to 50 % of electricity has to be generated from renewable energy sources by 2030. It is estimated that the net electricity generation will be around 3 400 TWh in 2030. About 1 000 TWh of this should be provided by solar and wind.

In order to generate the roughly 280 TWh from solar power and under the assumption that solar thermal electricity generation would contribute between 15 and 20 TWh, solar photovoltaic power capacity has to reach 235 to 240 GW by 2030. However, with a total installed capacity of about 102 GW at the end of 2016 and annual installations between 5.7 and 7.5 GW in the last three years, it will be difficult to reach this target. New policies are needed to allow for annual installation between 9 and 10 GW over the next 14 years, which are needed to reach the target.

The situation becomes even more pronounced if one takes into account the need to increase the renewable energy targets for 2030 in order to meet the goals of the Paris Agreement. At the moment the RES Directive recast is in the parliamentary process in the European Parliament and the committee for Industry, Transport, Research and Energy (ITRE) has already voiced its point that at least 35% RES by 2030 are needed to stay on the trajectory for the needed GHG reductions by 2050. The consequences for renewable electricity would be that an additional 200 to 250 TWh, mainly from solar and wind power are needed to reach this goal. Taking these developments into consideration, it is clear that Europe has a need for additional policies to increase solar photovoltaic power and especially rooftop installations to 350 to 400 GW by 2030. In order to achieve this goal, the annual market has to grow to over three times the European market volume in 2016 [Jäg 2016, 2017, 2017a].

The following sections describe market development in some EU Member States, as well as in Switzerland and Turkey. Official and more detailed information about the progress of renewable energy implementation in the EU can be found on the Renewable Energy Mapping and Monitoring in Europe and Africa website of the Joint Research Centre (JRC) and publications listed there (<http://iet.jrc.ec.europa.eu/remea>) [Ban 2017].

### **2.1.1 Austria**

In 2016, Austria installed about 140 MW of new PV systems and increased the cumulative capacity to 1.08 GW. The Ökostrom-Einspeisetarifverordnung 2012 (Eco-Electricity Act) is the regulation which sets the prices for the purchase of electricity generated by green power plants. In addition, there is a federal investment subsidy programme for PV systems with different sizes. For each of these categories a limited budget is available. The investment can be supported with a maximum of EUR 275/kWp for add-on and ground-mounted systems and EUR 375/kWp for building-integrated systems. In addition to these federal programmes, five federal States have their own PV programmes and six States have programmes to support the installation of electricity storage.

In June 2017 the Eco-Electricity Act was changed. For 2018 and 2019 an additional budget of EUR 15 million each year to support PV systems and electricity storage was agreed [BGB 2017].

### **2.1.2 Belgium**

The three Belgian regions (Brussels, Flanders and Wallonia) have individual support schemes for PV, but one electricity market. Therefore, some regulations are regional and others are national. A common denominator is the fact that all three regions selected an

RPS system with quotas for RES. A net-metering scheme exists for systems up to 5 kWp Brussels or 10 kWp (Flanders and Wallonia) as long as the electricity generated does not exceed the consumer's own electricity demand.

In 2011, Belgian installations peaked with over 1 GW of new installations, before starting to decline in 2012. At the end of 2016, cumulative installed capacity was over 3.4 GW with about 170 MW installed in that year [IEA 2017a]. Over 8 % of Belgian households are already generating their own PV electricity, and PV power covered about 3.7 % of the country's total electricity needs in 2016.

### **2.1.3 Denmark**

The introduction of a net-metering system and high electricity prices of EUR 0.295/kWh resulted in 378 MW of PV systems being installed in Denmark in 2012. Due to this rapid development, the regime was already changed in November 2012 [GoD 2012].

The so called 60/40 programme, which went into effect on 11 June 2013 was suspended with immediate effect on 3 May 2016. Under the scheme PV power systems were eligible for a maximum reimbursement (bonus plus market price) of DKK 0.60/kWh (EUR<sup>5</sup>) 0.081/kWh) during the first 10 years of operation, and DKK 0.40/kWh (EUR 0.054/kWh) being applicable for a further 10 years.

The reason for this decision by the Danish Parliament was the fact that the transmission system operator (TSO) Energinet.dk in March and April 2016 received application for 4.5 GW. All applications, which had not been processed and approved before 3 May 2016 were declared not eligible for the scheme.

In 2016 about 70 MW were installed increasing the total capacity to 900 MW [IEA 2017a].

End of November 2016, the German Bundesnetzagentur announced the results of the first cross boarder auction with Denmark: five bids, all of them from Denmark and to be build there, totalling 50 MW won at a price of 5.38 cents per kilowatt hour (EURct/kWh) [BNA 2016]. The results of the first Danish cross border auction in December 2016 revealed even lower prices. The 9 winning tenders will get a fixed premium of 12.89 Danish øre per kWh (EUR 17.32/MWh) for 20 years on top of the Danish spot market price, which is fluctuating in the range of EUR 30 to 40/MWh [Ene 2016].

### **2.1.4 France**

In 2016, 576 MW of new PV systems were connected to the grid in France [Rte 2017]. Total cumulative installed capacity increased to over 7.1 GW, including about 400 MW in the French Overseas Departments. Electricity production (continental France and Corsica) from PV systems was 8.3 TWh or 1.6 % of the national electricity generation and 1.7 % of the gross consumption [Rte 2017].

On 22 July 2015, France's National Assembly adopted the Energy Transition for Green Growth Act. The legislation aims to reduce France's reliance on nuclear to 50 % of power generation by 2025 and increase the share of renewable energies in the final gross energy consumption to 23 % in 2020 and 32 % in 2030 [MEE 2016].

The targets for PV to achieve the 2023 goal are 10.2 GW installed PV power by 2018 and between 18.2 and 20.2 GW by 2023. Under the new support mechanism, feed-in tariffs are only available for systems below 100 kW capacity and tenders for systems above. However, there is still a difference for the larger systems: Systems between 100 and 500 kW bid for fixed tariffs, larger systems for a market premium.

In 2016, the mandatory introduction of smart meters started and should be completed by 2021. This measure provides an indirect support measure for small self-consumption systems, because it removes the grid connection costs. These costs were in general more than 12% of the price of a 3 kW system.

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<sup>5</sup> Exchange rate: EUR 1.00 = DKK 7.44

## 2.1.5 Germany

Compared to 2015, new PV system installations in Germany saw a slight increase to 1.58 GW, due to a rally in December with more than 440 MW [Bun 2017]. For the first 7 months of 2017 the Bundesnetzagentur reported the registration of PV projects with 680 MW. However, some of this capacity was installed already before 2017.

The German market growth is directly correlated to the introduction of the Renewable Energy Sources Act (Erneuerbare Energien Gesetz EEG) in 2000 [EEG 2000]. This law introduced a guaranteed feed-in tariff (FiT) for electricity generated from solar PV systems for 20 years and already had a fixed built-in annual reduction which was adjusted over time to reflect the rapid growth of the market and corresponding price cuts. However, the rapid market growth required additional adjustments. Until 2008, only estimates of installed capacity existed, so a plant registrar was introduced on 1 January 2009.

Since May 2012, the FiT has been adjusted on a monthly basis depending on the actual installation of the previous quarter. The revision of the EEG in 2014 changed the system size for new systems eligible for a feed in tariff and introduced levels of levies on self-consumption [EEG 2014]. So far systems with a capacity of less than 10 kWp are excepted form the levy. For all other systems, the levy on each self-consumed kWh increased to 40% on 1 January 2017.

Since 1 September 2015, owners of new ground mounted systems have to participate and win an auction of the Federal Network Agency. The total amount of capacities auctioned is determined by political decisions and limits this market segment.

Starting on 1 January 2016 only systems smaller than 100 kWp are eligible for a feed in tariff and since then also larger rooftop systems have to market their electricity directly or take part in auctions. The feed in tariffs valid from 1 July to 31 October 2017 are:

Systems on residential and commercial buildings or sound barriers:

PV system size [kWp]	Feed-in tariff [EUR per kWh]
up to 10	0.1260
10 to 40	0.1227
> 40 to 750	0.1101

Systems on commercial premises:

PV system size [kWp]	Feed-in tariff EUR per kWh
up to 750	0.0884

The fact that the tariff for residential PV systems smaller than 10 kWp (September 2017: EUR 0.1260/kWh) is now well below the average variable electricity rate consumers are paying (EUR 0.235- 0.275/kWh) and the fact that they are still exempt from the EEG levy makes self-consumption attractive and is opening up new possibilities for the introduction of local storage. Since 1 May 2013, the Kreditanstalt für Wiederaufbau (KfW) has been offering low interest loans with a single repayment bonus of up to 30 % and a maximum of EUR 600/kW of storage for PV systems up to 30 kWp [KfW 2013]. The maximum repayment bonus was limited to EUR 3 000 per system. A new programme started on 1 March 2016 [KfW 2016]. Since then the loan is only available if the maximum injected power into the grid is 50% or less of the nominal power rating of the PV system. The maximum eligible amount was set as 25% of EUR 2.000 per kWp if the PV system and the battery storage are installed at the same time and EUR 2.200 per kWp of the PV system if the system was installed after 31 December 2012 and more than 6 months have passed before the battery storage is added. However, the maximum eligible amount is reduced by 3% each 6 months starting 1 July 2016 and reached 16% in the second half of 2017. The maximum amount per kWp of the PV system was reduced to EUR 1.600. The total available amount per year was allocated on a first come first serve basis, which had the effect that the funds for 2016 were already exhausted in September and applicants had

to wait until January 2017 for new approvals. The programme will be terminated at the end of 2018.

### **2.1.6 Greece**

In 2009, Greece introduced a FiT scheme which started slowly until the market accelerated from 2011 until 2013, when 425 MW, 930 MW and more than 1 GW of new PV system capacity was installed respectively. This boom ended on 10 May 2013, when the Greek Ministry of Environment, Energy and Climate Change (YPEKA) announced retroactive changes in the FiT for systems larger than 100 kWp and new tariffs for all systems from 1 June 2013. During the first five months of 2013 almost 900 MW were installed and increased the total cumulative capacity to over 2.5 GW. About 2.4 GW were installed in the Greek mainland and the rest on the islands. Since the only a few tens of MW have been installed.

The Greek Operator of the Electricity Market (ADMIE) reported about 2 094 MW of installed grid-connected PV systems over 10 kW and 351 MW of rooftop PV systems up to 10 kW at the end of March 2017 [Adm 2017]. These figures do not include the installed capacity of non-interconnected Greek islands, which — according to the Hellenic Electricity Distribution Network Operator SA — was 136 MW in June 2017 [Hed 2017].

### **2.1.7 Hungary**

The Hungarian National Renewable Action Plan required by the EU Renewable Energy Directive (2009/28/EC) foresees to reach a renewable energy share of 14.65% of its gross energy consumption by 2020. As a consequence of not meeting the trajectory set out in the NREAP a new supporting scheme for electricity generation from RES was adopted in June 2016.

The existing mandatory take-off system, guaranteeing a fixed price per kWh generated, was passed out on 31 December 2016. However, all project owners, which had submitted their application before this deadline, are still eligible for this scheme.

The main changes are that the budget for the "new" off-take scheme is now capped to HUF 20 billion (EUR 65.3<sup>6</sup> million) for the period 2017 to 2020 on a first come first serve base. Systems larger than 0.5 MW are no longer eligible, but have to apply for a premium-based support scheme.

In 2016, Hungary connected about 100 MW of PV systems, increasing cumulative installed capacity to 288 MW by the end of 2016.

### **2.1.8 Italy**

In 2016, Italy connected 382 MW of PV systems, increasing cumulative installed capacity to almost 19.3 GW by the end of 2016 according to the annual report of the Gestore dei Servizi Energetici (GSE) [Gse 2017]. After the Quinto Conto Energia (Fifth Energy Bill) ended in July 2013, the only support mechanisms are now via the Scambio sul Posto (self-consumption) scheme and a tax break for the system investment costs.

According to the Italian national grid operator TERNA, electricity from PV systems provided 22.55 TWh or 7.8 % of the total electricity sold in 2016 [Ter 2017]. Solar photovoltaic power generation was 15.64 TWh or 9.58 % of the total generated electricity during the first seven months of 2017. The highest monthly coverage was in May 2017, when PV electricity supplied 11.1 % of the Italian energy demand.

### **2.1.9 The Netherlands**

According to the Dutch Statistical Office, PV systems with a capacity of 525 MW have been installed in 2016 bringing the total installed PV power to 2 040 MW at the end of the year [Cbs 2017]. The total generated solar electricity was 1.56 TWh or 1.34 % of the annual demand.

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<sup>6</sup> Exchange rate: EUR 1 = HUF 306

Since 2011, the main incentive has been a net-metering scheme for small residential systems up to 15 kW and a maximum of 5 000 kWh/year. Systems larger than 15 kW can apply for the programme to stimulate sustainable energy production (SED+), for a maximum of 950 full load hours per year, which is open for all renewable energy technologies [RVO 2017]. Over 4 300 PV projects with a combined capacity of 2.3 GW were selected in the first round of the 2017 SDE+.

#### **2.1.10 Poland**

The Polish National Renewable Action Plan required by the EU Renewable Energy Directive (2009/28/EC) foresees to reach a renewable energy share of 15.5% in the gross final energy consumption. Renewable electricity should reach 19.13% of the final energy supply by 2020.

The Renewable Energy Act of 2015 went into force in July 2016 and replaces the previous green certificate system with an auction scheme [GoP 2016]. The first auction took place on 30th of December 2016 and the second on 29/30 June 2017.

In 2016, Poland connected about 100 MW of PV systems, increasing cumulative installed capacity to 199 GW [Ieo 2017]. About half of the capacity was installed under the old green certificate system, the other half are residential small systems.

#### **2.1.11 Spain**

Spain takes the fifth place in Europe with regard to the total cumulative installed capacity, at 5.5 GW<sup>7</sup>. Most of this capacity was installed in 2008 when the country was the largest market, with over 3.3 GW [IEA 2014]. As a consequence, the Spanish Government started to introduce a number of regulations in order to limit the growth of the sector already in 2008 and suspended the remuneration pre-assignment procedures for new renewable energy power capacity in January 2012. The justification given for this move was that, until then, Spain's energy system had amassed a EUR 24-billion power-tariff deficit. The government argued that the special regime for renewable energy was the main reason for this. However, this argument was more than questionable as the deficit already amounted to almost EUR 9 billion in 2007, a time when payments under the special regime for renewable energy were still limited. After peaking in 2013 with EUR 28.8 billion the deficit has now decreased to EUR 23 billion at the end of 2016 [CNM 2017].

A more detailed description of the development of the Spanish market can be found in earlier PV Status Reports [Jäg 2016].

In 2016, new PV systems were installed with a capacity of 55 MW. In the same year, electricity generated from grid connected PV systems contributed 8 TWh or 3.1 % of the Spanish electricity generation.

After five years of very little new PV power additions, 2018, 19 and 20 will bring some change. In July 2017, the Spanish Ministry for Energy and Tourism announced the winners of the second renewable energy auction in 2017 and solar photovoltaic power projects had won 3.9 GW<sub>AC</sub> in this auction [MET 2017]. The winning consortia have to connect the systems before the 1<sup>st</sup> January 2020.

#### **2.1.12 Switzerland**

In 2016, about 270 MW of PV systems were installed in Switzerland, increasing the total capacity to 1.65 GW. In 2016, PV power generated 1.3 TWh or 2.3% of the Swiss electricity demand.

After a 40 % price decrease in 2012, prices for turnkey systems fell by a further 12 % in 2013 and a further 5 % until 2015 [Ezs 2016]. In 2016, prices for installed and connected residential PV systems (< 10kWp) were in the range of was CHF 2.000 to

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<sup>7</sup> This report gives installed DC capacities, whereas the Spanish installations were quoted as AC capacity in the past. Therefore, there is a difference between these and the numbers in the PV status reports before 2014.

3.500 per kWp without value added tax (VAT). For larger rooftop systems above 1 MWp the price range was CHF 1.250 to 1.700 per kWp [Hüs 2017].

A revised energy law came into force on 1 January 2014. The necessary implementation rules came into force on 1 April 2014, giving electricity producers the right to self-consume the electricity they produce, regardless of the technology [GoS 2014]. New installed PV systems with a capacity of between 2 and 30 kW can receive an investment subsidy instead of the FiT. The current amount is CHF 1 400 per system and an additional CHF 500 per kWp. In addition, the investment for a PV system is tax deductible in almost all cantons. Surplus electricity from systems with an investment subsidy can be sold to the grid operator at market prices between CHF 0.05 and 0.09/kWh (EUR<sup>8</sup> 0.046 and 0.082/kWh).

In May 2017, the Swiss voted to increase the available amount for renewable energy support schemes from CHF 900 million (EUR<sup>9</sup> 780 million) to CHF 1.380 million (EUR 1.200 million) per year. In addition the new energy law prohibits the construction of new nuclear power plants and the existing ones are phased out at the end of their.

### 2.1.13 UK

In 2016, PV systems with a power capacity of about 2.15 GW were connected to the grid increasing the cumulative PV power to 11.7 GW. PV systems generated about 10.3 TWh or 3.0 % of UK electricity generation in 2016.

The old FiT scheme for systems up to 5 MW closed on 14 January 2016 and a new scheme opened on 8 February 2016, with different tariff rates and rules — including a limit on the number of installations supported in various capacity bands [GUK 2016]. The new scheme offers a 'Generation Tariff' for each generated kWh and in addition an 'Export Tariff' for up to 50 % of the generated electricity, which is not consumed on-site at the time of generation (self-consumption). Both tariffs are adjusted each quarter and depend in addition whether or not the respective band caps are reached.

Larger systems can participate in Contracts for Difference Allocation Rounds. In the first round, which was held in 2015 five projects with a total capacity of 72 MW won contracts with a strike price of GBP 50 (two projects with 33 MW) and 79.23 per MWh (three projects with 39 MW). However, two of the five projects were withdrawn and one contract was cancelled. There is only confirmation of one project that was connected to the grid on 30 June 2016.

The second round planned for October 2015 was cancelled and finally took place in April 2017, but solar was not included.

The Renewable Obligation Certificate (ROC) scheme introduced in 2012 ended on 31 March 2017.

In the first seven months of 2017 714 MW of new solar systems were registered.

### 2.1.14 Other European countries, Russia and Turkey

In **Croatia**, PV systems with a capacity up to 5 MW are eligible for a FiT. According to the Croatian Energy Market Operator (HROTE), 51.45 MW of PV systems were installed at the end of July 2017. 9 projects with an additional 2 MW already have signed contracts but are not yet installed [Hro 2017].

Despite high solar radiation, solar PV system installation in **Portugal** has grown very slowly, reaching a cumulative capacity of 513 MW by the end of 2016.

After two years of rapid growth (2010/2011), the **Slovakian** market fell by almost 90 % with only 35 MW and 45 MW new installations in 2012 and 2013 and has been always below 5 W since. The total capacity of 545 MW is more than three and a half times the original 160 MW capacity target for 2020, published in the NREAP in 2010.

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<sup>8</sup> Exchange rate 2016: EUR 1 = CHF 1.10

<sup>9</sup> Exchange rate Q4 2017: EUR 1 = CHF 1.15

In the **Russian Federation** the "Energy Strategy of Russia for the period up to 2035" is still in a draft stage and aims to reduce energy intensity by 6% by 2020 and 37% over the 2021–2035 period compared to 2014. Russia started to install solar PV capacity in 2010, and since 2013, capacity installations have accelerated with the installation of the first 1 MW plant in Kaspiysk, Dagestan. In May 2016 the Russian government set a target of 5.5 GW for the installation of renewable electricity capacities including wind, solar, small hydro up to 2024 [GoR 2016]. Solar photovoltaic capacity should reach 1.75 GW. In 2016 about 70 MW of new PV capacity was installed in Russia, increasing the total capacity to 540 MW (including ca 400 MW in Crimea). As a result of the renewable energy auction in June 2017, Russia's Administrator of the Trading System allocated approximately 520 MW of PV capacity to be connected from 2018 onwards.

In March 2010, **Turkey's** Energy Ministry unveiled the 2010-2014 Strategic Energy Plan. One of the government's priorities is to increase the ratio of renewable energy resources to 30 % of total energy generation by 2023. At the beginning of 2011, the Turkish Parliament passed renewable energy legislation which defines new guidelines for FiTs. The FiT was USD 0.133/kWh (EUR 0.10/kWh) for owners commissioning a PV system before the end of 2015. If 'made in Turkey' components are used, the tariff was increased by up to USD 0.067 (EUR 0.052), depending on the material mix. To take advantage of these local procurement rules, factories have been set up by Anel Enerji, Atsco Solar and China Sunergy to produce PV modules. The first licensing round for a volume of 600 MW, which closed in June 2013, was oversubscribed by about 15 times with close to 9 GW of projects submitted to the Turkish Energy Regulatory Authority. However, no licence for PV installations above 1 MW had been approved by the end of 2013.

The market started to take off in 2014 with 40 MW installed and a fivefold increase to 208 MW in 2015 and 580 MW in 2016 and reached 0.8 GW at the end of 2016 [IEA 2017a, Jäg 2016]. Market expectations for 2017 forecast around 1 GW of new installed solar PV power.

In 2009, the **Ukraine** introduced the "Green Tariff" policy, a feed-in tariff scheme for electricity generated from renewable energy sources [Bvr 2009]. In 2012, the Ukrainian Parliament ratified a bill to simplify households' access to the feed-in scheme and which came into force on 1 April 2013. The bill included a reduction in FiTs of 16 % to 27 %, depending on the type of installations. A second amendment of the Green Tariff System, which scrapped the local requirement scheme in force since 2013, was passed in June 2015. Instead, a local content premium was introduced. Plants using components produced locally are entitled to receive an additional premium on top of the regular feed-in tariff. With this amendment, the feed-in tariff levels in local currency are adjusted every quarter based on the exchange rate of EUR to UAH. A third amendment was adopted by the Ukrainian Parliament in December 2016 and went into force at the beginning of 2017. The amendment created different rates for renewable electricity produced by households and business entities. Installations benefiting from residential tariff cannot exceed 30 kW in size.

In 2016, the Ukrainian government announced plans to open Chernobyl's nuclear wasteland for solar energy projects with a capacity of about 2.5 GW.

About 100 MW of new PV power capacity was installed in 2016, thus increasing the total capacity to over 530 MW (excluding the approx. 400 MW in Crimea). The market expectations for 2017 are between 360 and 450 MW.



## 2.2 Asia and the Pacific region

Asia and the Pacific region continued its upward trend in annual installations of PV electricity system. The reasons for this development range from falling system prices, heightened awareness, favourable policies and the sustained use of solar power for rural electrification projects. Countries such as Australia, China, India, Indonesia, Malaysia, the Philippines, South Korea, Taiwan, Thailand and Vietnam continue a very positive upward trend, thanks to governmental commitment to the promotion of solar energy and the creation of sustainable cities.

In 2016, more than 51 GW of new PV electricity generation systems were installed in the region, which corresponds to roughly two thirds of the world wide new PV power installed in 2016. The largest market was China with 35 to 38 GW, followed by Japan with about 8.2 GW and India with over 4 GW. In 2017, a market exceeding 60 GW is possible.

### 2.2.1 Australia

In 2016, about 860 MW of new solar PV electricity systems were installed in Australia, bringing the cumulative installed capacity of grid-connected PV systems to 5.9 GW. As in the previous years the market was dominated by grid-connected residential systems. In the first seven months of 2017 PV systems with 416 MW have already been registered increasing the number of homes with PV systems to over 1.7 million. The national penetration of homes with PV systems reached 18.7 %, and in some areas it already exceeds 30 %.

The average PV system price paid by the customer for a grid-connected system fell from AUD 6/Wp (EUR 4.29/Wp<sup>10</sup>) in 2010 to AUD 3.9/Wp (EUR 2.89/Wp<sup>11</sup>) in 2011, AUD 3.0/Wp (EUR 2.4/Wp<sup>12</sup>) in 2012, AUD 2.5/Wp (EUR 1.85/Wp<sup>9</sup>) in 2013, below AUD 2.0/Wp (EUR 1.38/Wp<sup>13</sup>) in the middle of 2014 and AUD 1.37/Wp<sup>14</sup> (EUR 0.95/Wp) at the beginning of August 2017 [Sol 2017a]. As a result, the cost of PV-generated electricity has fallen to, or is even below, the average residential electricity rate of AUD 0.27/kWh (EUR 0.19/kWh).

In 2016, PV electricity systems generated about 6.8 TWh or 2.6 % of Australia's total electricity generation. The total renewable electricity share was 16.3 % and this should increase to 20 % by 2020. For 2017, the market forecast is about around 1 GW.

### 2.2.2 India

For 2016, market estimates for solar PV systems vary between 4.0 and 4.4 GW, due to the fact that some statistics cite the financial year (FY) and others the calendar year. According to the country's Ministry of New and Renewable Energy (MNRE), at the end of June 2017, the total solar power capacity was 13.1 GW [GoI 2017], but Bridge to India reported a capacity of 15.6 GW Bri 2017].

In January 2010, the Indian Jawaharlal Nehru National Solar Mission (JJNSM) was launched, in the hope that it would give impetus to the grid-connected market. The JJNSM aimed to make India a global leader in solar energy and envisages an installed solar generation capacity of 20 GW by 2022, 100 GW by 2030, and 200 GW by 2050. In 2015, the target was updated by the National Solar Mission Group of MNRE to 100 GW by 2022 [GoI 2015].

Following the installation of just a few MW in 2010, in 2011 and 2012 installations began to pick up in 2013 and market expectations for 2017 and 2018 are in the order of 8.5 to 10.5 GW and 14 to 15 GW respectively.

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<sup>10</sup> Average exchange rate for 2010: EUR 1 = AUD 1.40

<sup>11</sup> Average exchange rate for 2011 and 2013: EUR 1 = AUD 1.35

<sup>12</sup> Average exchange rate for 2012: EUR 1 = AUD 1.25

<sup>13</sup> Average exchange rate for 2014: EUR 1 = AUD 1.45

<sup>14</sup> Average exchange rate for first 7 months 2017: EUR 1 = AUD 1.45

The range of PPAs awarded in 2016 was between INR 4 350 and 5 010/MWh (EUR15 58.78 to 67.70/MWh) and dropped to INR 2 440 to 3 470/MWh (EUR 32.97 to 46.89/MWh) in the second quarter of 2017.

### **2.2.3 Israel**

A FIT was introduced in Israel in 2008 and 4 years later the grid-connected PV market saw about 60 MW of newly connected capacity. In addition, in 2009, a renewable portfolio standard (RPS) was defined, although it took until 2011 to be completed. One of the main drivers behind the development of solar energy is energy security, and in November 2015 at COP21 in Paris, the government declared a new goal of 17 % alternative energy use by 2030 a significant increase from the then 2 %. On 3 August 2016, the Knesset passed a bill to eliminate taxes on residential solar and wind installations.

In December 2016, the Israeli Electricity Authority announced to hold four tender bidding rounds in 2017 and 2018 with 150 to 300 MW solar PV capacity each. The result of the first tender for PV projects up to 12 MW held in March 2017 was the allocation of around 235 MW of solar PV capacity. A second bidding round took place in July 2017.

At the end of 2016, over 900 MW of cumulative solar PV power were installed and market expectations for 2017 range from 150 to 200 MW.

### **2.2.4 Japan**

In 2016, the Japanese PV market decreased by about 19 % to 9.2 GW. Cumulative installed capacity reached 43.6 GW at the end of 2016. According to the Institute for Sustainable Energy Policies, solar photovoltaic electricity contributed 4.8% of the total electricity generation in Japan in 2016 [Ins 2017]. This was almost two and a half times the share of nuclear (2%).

Under the FIT scheme, introduced in July 2012 and amended in the following years [METI 2013], 83.1 GWAC16 had received approval until the end of FY 2016 (end of March 2017). However, only 36.2 GWAC had been commissioned and were in operation.

Already in 2013 a significant discrepancy between actual installations and permits given emerged and as a consequence, the Ministry of Economy, Trade and Industry (METI) started to revise the list of projects according to their actual status in October 2013. Then it began to revoke permits for projects that had failed to secure land and equipment by given deadlines.

Until 2010, residential rooftop PV systems represented about 95 % of the Japanese market. Since 2011, due to changes in the permit system, large ground-mounted systems as well as large commercial and industrial rooftop systems started to increase their market share and represented more than 90 % in 2016. Of the 83.1 GWAC approved by the end of March 2017, only 5.5 GWAC or 6.6 % comprised systems smaller than 10 kWp. However, 85 % of these systems were actually connected to the grid. PV systems with capacities over 2 MW represented 32 % of the approved capacity, but only 14 % of them had started operation.

On 25 May 2016, the bill for the revision of the Act on Special Measures Concerning Procurement of Electricity from RES by Electricity Utilities was enacted and put into force in April 2017. The main change besides a review of the tariffs itself is the fact that new projects with more than 2 MW capacity will have to participate in auctions. Three auctions with a volume of 1 to 1.5 GW are planned for FY2017 and 2018.

New projects approved after 1 April 2017 now have three years maximum until they have to be connected. The new feed in tariffs was set as follows. Commercial installations (total generated power) larger than 10 kWp, receive a tariff of JPY 21/kWh (EUR17 0.162/kWh) for 20 years. For residential installations (surplus power) smaller than

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<sup>15</sup> Exchange Rate: 1 EUR = 74 IRP

<sup>16</sup> Please note that the METI capacity statistics is AC-based and is converted by the New Energy Development Organisation in DC-figures.

<sup>17</sup> Exchange rate: EUR 1 = JPY 130

10 kWp the basic FiT is JPY 28/kWh (EUR 0.287/kWh, if the system is equipped with an output control device or JPY 31/kWh (EUR 0.270/kWh) without such a device for 10 years

As a consequence of the accident at the Fukushima Daiichi Nuclear Power Plant in March 2011 the country's energy strategy was reshaped. An official target of 28 GWAC was set for PV power in 2020, which was already surpassed in FY 2015. In July 2012, a METI panel proposed the long-awaited plan to reform the country's power market, and Japan's 4th Strategic Energy Plan was published in April 2014 [METI 2014]. During the COP21, Japan proposed to reduce its greenhouse gas emissions by 26 % by 2030.

### **2.2.5 Jordan**

In 2007, when renewable energy accounted for only 1 % of the energy consumption, the Government of Jordan developed an ambitious Energy Master Plan to increase the share of renewables to 7 % in 2015 and 10 % in 2020. In April 2012, Jordan implemented the Renewable Energy and Energy Efficiency Law No 13, which established a fund to support up to 500 MW of renewable power [GoJ 2012]. According to the Middle East Solar Industry Association, operational PV capacity in Jordan was about 77 MW at the end of 2016 [Mes 2017]. A further 540 MW were under execution in February 2017, and a further 200 MW were tendered in 2017. In May 2017, the Jordan News Agency reported about the inauguration of PV projects with a combined capacity of 200 MW [Pet 2017]. According to BNEF over 250 MW of new PV capacity was built in 2016 and market expectations for 2017 are around 350 MW [Blo 2017a].

In 2015, the European Investment Bank and the French government approved loans to Jordan totalling EUR 128 million for the construction of the Green Corridor project, which aims to upgrade the electricity infrastructure to be able to accommodate the planned PV projects. The upgraded infrastructure should be operational by 2018.

In October 2016, Masdar, a clean energy developer based in Abu Dhabi, UAE, signed a power purchase agreement (PPA) with Jordan's National Electric Power Company (NEPCO) for the Baynouna solar plant with 200 MWAC capacity. The plant should become operational in the first quarter of 2019.

There is one module manufacturer with a nominal capacity of 120 MW located in Amman.

### **2.2.6 Malaysia**

The Malaysia Building Integrated Photovoltaic Technology Application Project was initiated in 2000, and by the end of 2009 a cumulative capacity of about 1 MW of grid-connected PV systems had been installed.

The Malaysian Government officially launched its Green Technology Policy in July 2009 to encourage and promote the use of renewable energy for Malaysia's future sustainable development. The target was that about 1 GW must come from RES by 2015, according to the Ministry of Energy, Green Technology and Water.

In April 2011, renewable energy FiTs were passed by the Malaysian Parliament with the target of 1.25 GW being installed by 2020. For the period from December 2011 to June 2014, PV had been allocated a total quota of 125 MW. The tariffs are set by the Sustainable Energy Development Authority (SEDA) for each year. For 2017 the basic tariffs for systems up to 1 MW are between MRY 0.5041 and 0.7424/kWh (EUR 0.091 to 0.181/kWh<sup>18</sup>), depending on the type and system size. For local manufacturing or use as building materials surcharges between MRY 0.05 and 0.1395/kWh (EUR 0.05 to 0.181/kWh) apply. According to SEDA, PV systems with more than 341 MW of capacity received the FiT and were operational by the end of August 2017, while another 48 MW had already been approved but not yet started operation [Sed 2017]. Between the 1 November and 2020, Malaysia aims to implement 500 MW of PV capacity under the Net Energy Metering (NEM) programme. A cap of 100 MW a year is foreseen in Peninsular Malaysia and Sabah.

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<sup>18</sup> Exchange rate: EUR 1.0 = MRY 4.5677

Almost a dozen of companies have set up silicon solar cell or CdTe-thin film manufacturing plants in Malaysia, amounting to more than 8 GW of production capacities. In addition, there are additional smaller silicon module manufacturing companies. In total about 250 companies are involved in upstream solar PV activities such as poly silicon, wafer, cell and module production and downstream activities such as inverters and system integrators. Since 2012, these companies provide more than 25 000 jobs [Mal 2017].

### **2.2.7 Pakistan**

In December 2006, the Government of Pakistan introduced the 'Policy for Development of Renewable Energy for Power Generation', which set a target of 9.7 GW of electricity generation capacity from RES by 2030 [GoP 2006]. In 2015, a FiT was introduced ranging between USD 0.142 and 0.151 per kWh depending on the size and location of the system. The Alternative Energy Development Board (AEDB) is administering the projects receiving the tariff. According to their statistics, the yearly cumulative installed capacity within this framework was 100 MW in 2015, 400 MW in 2016 and 730 MW in 2017 [Alt 2017].

In total it was estimated that about 0.78 GW of solar power was installed in Pakistan at the end of 2015 [IEA 2016]. For 2016, BNEF gave a figure of about 0.7 GW of new installed PV systems and the market expectations for 2017 are in the 1 GW range [Blo 2017a].

### **2.2.8 The Philippines**

The Renewable Energy Law was passed in December 2008 [RoP 2008]. Under the law, the Philippines must double the energy derived from RES within 10 years. On 14 June 2011, Energy Secretary Rene Almendras unveiled the new Renewable Energy Roadmap which aims to increase the share of renewables to 50 % by 2030. The programme will endeavour to boost renewable energy capacity from the current 5.4 GW to 15.4 GW by 2030.

In early 2011, the country's Energy Regulator National Renewable Energy Board (NREB) recommended a target of 100 MW of solar installations to be implemented in the country over the next 3 years. It was suggested that a FiT of PHP 17.95/kWh (EUR 0.299/kWh<sup>19</sup>) was to be paid from January 2012 onwards. For 2013 and 2014, an annual digression of 6 % was foreseen. The initial period of the programme is scheduled to end on 31 December 2014.

On 27 July 2012, the Energy Regulatory Commission decided to lower the tariff in view of lower system prices to PHP 9.68/kWh (EUR 0.183/kWh<sup>20</sup>) and confirmed the digression rate. The new FiT for systems installed after 15 March 2016 is expected to be between PHP 7- 8 per kWh (EUR<sup>21</sup> 0.-0.150 per kWh).

The Department of Energy (DoE) reported that, by the end of June 2017, more than 5.1 GW of PV projects had been approved under the Renewable Energy Law and 0.9 GW were installed [RoP 2017]. Another 2.1 GW of projects were pending.

### **2.2.9 People's Republic of China**

According to the National Survey Report of IEA PVPS 34.5 GW of solar PV power was connected to the grid in 2016 increasing the total grid connected capacity to slightly over 78 GW [IEA 2017a]. The actual installed capacity could have been 10 to 15 % higher as some of the over 24 GW connected in the first half of 2017 was probably already installed in 2016 but not connected to the grid. Taking these figures into account, the total cumulative installed capacity could have increased to over 80 GW at the end of 2016.

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<sup>19</sup> Exchange rate for 2011: EUR 1 = PHP 60

<sup>20</sup> Exchange rate for 2012: EUR 1 = PHP 53

<sup>21</sup> Exchange rate for 2016: EUR 1 = PHP 53.5

The 2017 International Energy Agency (IEA) Renewable Energy Medium-Term Market Outlook expects an addition of over 130 GW new PV capacity between 2017 and 2022, which would increase the total capacity to over 200 GW [IEA 2017]. However, looking at the current developments, this capacity could be reached much earlier.

During the first seven months of 2017, already more than 35 GW were connected to the grid. In July 2017, the National Energy Administration (NEA) published the new implementation guide for the 13th Five Year Plan (2016 -2020) [NEA 2017]. In this guide, 86.5 GW of new PV capacity is foreseen, i.e. 54.5 GW ground mounted systems and 32 GW "Top Runner Programme" installations. Together with the 45 GW of PV capacity foreseen in the Poverty Alleviation Programme of the 13th Five Year Plan and the already connected capacity of over 110 GW at the end of July 2017, this could bring the total capacity to over 240 GW in 2020.

According to the 13th Five Year Plan (2016-2020) adopted on 16 March 2016, China intends to continue cut its carbon footprint and become more energy efficient. The share of non-fossil energy should increase from 12 % in 2015 to at least 15 % by 2020. Further targets are 18 % fewer carbon dioxide emissions and 15 % less energy consumption per unit of GDP in 2020 compared to 2015. Under this Plan, investment in non-fossil power should be RMB 2.3 trillion (EUR22 309 billion) and about RMB 2.6 trillion (EUR 349 billion) are foreseen for the upgrade of the grid infrastructure of which RMB 1.7 trillion are intended for the distribution network [Cai 2015, Wan 2016].

### **2.2.10 South Korea**

In 2016, about 0.9 GW of new PV systems were connected to the grid in South Korea, bringing the cumulative capacity to a total of almost 4.5 GW [Par 2017]. Since January 2012, Korea's RPS has officially replaced the FiTs. Besides the RPS, Korea supports PV installations by the 'One Million Green Homes Programme', a building subsidy programme, a regional development subsidy programme, and the New and Renewable Energy (NRE) Mandatory Use Programme for public buildings.

The RPS mandates utilities with more than 5 000 MW generation capacity to supply 4 % of their electricity from NRE in 2016, increasing by 1 % per year to 10 % by 2022. The renewable energy mix in the Korean RPS is defined as the proportion of renewable electricity generation to the total non-renewable electricity generation. PV had its own RPS set-aside quota of for the period between 2012 and 2015.

Under the RPS, income for power generated by RES is a combination of the wholesale system's marginal electricity price plus the sale of renewable energy certificates (RECs). Depending on the type of solar installation, the RECs are then multiplied by a REC multiplier, varying between 0.7 for ground-mounted free-field systems to 1.5 for building-adapted or floating PV systems.

### **2.2.11 Taiwan**

In June 2009, the Taiwan Legislative Yuan gave its final approval on the Renewable Energy Development Act to bolster the development of Taiwan's green energy industry. The goal was to increase Taiwan's renewable energy generation capacity by 6.5 GW to a total of 10 GW within 20 years. The targets for installed PV capacity were 750 MW by 2015 and 3.1 GW by 2030. The 2030 figures were gradually increased and stood at 8.7 GW at the end of 2015. Between 2009 and 2016, a total capacity of about 1 GW was connected to the grid.

In June 2016, just a month after the new president Tsai Inn-Weng took office, the Minister of Economic Affairs announced the new target of 20 GW PV power by 2025 (17 GW ground mounted and 3 GW roof-top systems). The new planning foresees the installation of over 1.5 GW between July 2016 and July 2018.

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<sup>22</sup> Exchange rate September 2016: EUR 1.0 = CNY 7.45

At the end of November 2016, the Bureau of Energy under Taiwan’s Ministry of Economic Affairs (MOEA) fixed the FiT rates for PV electricity to be generated in 2017 [MoE 2016]. The tariffs for the three categories are:

Type of system	Feed-in tariff [TWD (EUR <sup>23</sup> ) per kWh]]
ground-mounted	4.55 – 4.82 (0.128 – 0.136)
mounted on surface of water	4.94 – 5.24 (0.139 – 1.48)
rooftop	4.41 – 6.47 (0.124 – 0.188)

### 2.2.12 Thailand

Thailand enacted a 15-year Renewable Energy Development Plan in early 2009, with a target to increase the renewable energy share to 20 % of the country’s final energy consumption in 2022. Besides a range of tax incentives, solar PV electricity systems were eligible for a feed-in premium or ‘Adder’ for a period of 10 years. The original THB 8/kWh (EUR24 0.190/kWh) Adder (facilities in the three southern provinces and those replacing diesel systems are eligible for an additional THB 1.5/kWh (EUR 0.036/kWh)) was reduced to THB 6.5/kWh (EUR 0.155/kWh) for those projects not approved before 28 June 2010. The original cap of 500 MW was increased to 2 GW at the beginning of 2012, as the original target had been highly oversubscribed. In addition to the Adder programme, projects were being developed with PPAs.

In July 2013, Thailand’s National Energy Policy Commission (NEPC) increased the solar generation target to 3 GW and approved FiTs for rooftop ( 100 MW for systems smaller than 10 kW and 100 MW for systems between 10 kW and 1 MW) as well as community-owned ground-mounted solar plants, in addition to the Adder scheme. The FiTs were set at THB 6.96/kWh (EUR 0.166/kWh) for residential size systems, THB 6.55/kWh (EUR 0.156/kWh) for medium-sized building systems and industrial plants (< 250 kW) and 6.16 THB/kWh (0.147 EUR/kWh) for large building and industrial plants.

The 2015-2036 Alternative Energy Development Plan (AEDP 2015) was approved by the NEPC on 17 September 2015 [MoE 2015]. The plan aims to increase the use of solar energy with installation capacity of 6 GW by 2036.

At the end of August 2017, Small Power Producers (SPP) and Very Small Power Producers (VSPP) with an installed solar PV capacity of 2.5 GW had signed delivery contracts according to the Energy Regulatory Commission, Thailand [Erc 2017]. In addition there is a PV rooftop capacity of about 130 MW operational.

### 2.2.13 Emerging markets

**Bangladesh:** In 1997, the Government of Bangladesh established the Infrastructure Development Company Limited (IDCOL) to promote economic development in Bangladesh. In 2003, IDCOL started its Solar Energy Programme to promote the dissemination of solar home systems (SHS) in the remote rural areas of Bangladesh, with financial support from the World Bank, the Global Environment Facility, the German KfW, the German Technical Cooperation, the Asian Development Bank (ADB) and the Islamic Development Bank. At the end of 2016, more than 4.5 million SHSs (50-60 W) had been installed in Bangladesh [Ire 2016]. According to the International Renewable Energy Agency (IRENA), over 127 000 people work in the PV sector in Bangladesh.

The Renewable Energy Development Targets call for an additional 3 100 MW of renewable energy capacity to be installed by 2021. Most of the new capacity will be provided by solar (1 676 MW, 54 %) and wind (1 370 MW, 44 %). At the end of 2016

<sup>23</sup> Exchange rate: EUR 1 = TWD 35.5

<sup>24</sup> Exchange rate: EUR 1 = THB 42

about 190 MW of solar PV capacity was operational. There are also targets for waste-to-energy (40 MW), biomass (7 MW), biogas (7 MW) and hydro (4 MW).

In February 2017 the cabinet committee on public purchase approved the proposals for four solar power plants with a total capacity of 258 megawatt in different places across the country [Dha 2017]. The guaranteed offtake prices vary between BDT 10.2 and 11.04/kWh (EUR25 0.104 and 0.113/kWh) and the plants should be operational in Q3 2018 at the latest.

**Indonesia:** In February 2014, the Indonesian Parliament adopted a revised National Energy Plan (NEP14), which replaces the 2006 National Energy Plan and it went into force as Government Regulation No 79/2014 on 17 October 2014 [RoI 2014]. The plan aims 23 % share of NRE of the primary energy supply in 2025. Solar photovoltaic energy should contribute with a capacity of 6.4 GW. In June 2016, Indonesia's Ministry of Energy and Mineral Resources (ESDM) issued Decree ESDM 19/2016, which aims for 5 GW of new solar power to be installed within the next 2 to 3 years [MEM 2016]. The regulation sets quotas for the different parts of the country as well as FiTs, which range between USD 0.145 and 0.25 per kWh. The first nationwide total quota was 250 MW, with the largest share of 150 MW for Java, and the smallest quota for Papua and West Papua with 2.5 MW each. However, there was very little development.

In January 2017, the Ministry of Energy and Mineral Resources issued two new regulations on the Principles of Power Purchase Agreements (MD 10/2017) and on the Utilisation of Renewable Resources for Electricity (MD 12/2017) [MEM 2017]. Before the issuing of MD 12/2017, the feed in tariffs were set by the government. Now the tariffs are the result of negotiation between the country's state-owned power utility PLN and independent power producers. The regulation includes the capping of the tariff, if the regional supply costs are above the national average. On the other side, if the regional supply costs are below the national average, the maximum tariff for renewable energy plants is equal to the regional average. This mechanism applies to all renewable energy plants except geothermal and waste-to-energy plants.

Since the issuing of the new regulations, a number of PPAs with over 250 MW capacity have been signed between PNL and various developers. These plants should become operational in 2018. Total installed PV power in Indonesia was estimated at around 90 MW at the end of 2016.

**Kazakhstan:** The development of renewable energy was one of the priorities of the State Programme of Accelerated Industrial and Innovative Development for 2010-2014. The main goal is to develop a new and viable economy sector for growth, innovation and job creation. In addition, it drives the development of RES for the electricity sector in Kazakhstan and is regulated by the Law on Supporting the Use of Renewable Energy Sources, adopted in 2009 [RoK 2009]. In February 2013, the Kazakh Government decided to install at least 77 MW of PV by 2020 [GoK 2013]. In September 2014, during a conference organised by Astana Solar, plans were discussed to build 28 PV plants with over 700 MW capacity up until 2020 [Kaz 2014].

In 2011, JSC NAC Kazatomprom and a French consortium headed by Commissariat à l'énergie atomique et aux énergies alternatives (CEA) jointly began the Kaz PV project which aims to produce PV modules based on Kazakhstan silicon [Kaz 2011]. The first stage of the project was concluded in January 2013, when a new 60 W PV module production plant was opened in Kazakhstan's capital city Astana.

In January 2014, a 2 MW ground-mounted solar power plant was completed in the city of Kapchagay in the Almaty Province [Bis 2014]. At the end of 2016, the total PV capacity was estimated at about 60 MW, and should increase to 665 MW in 2020.

**Myanmar:** In 2015/16, the country has a rural electrification rate of about 34 %, with vast regions beyond the reach of the main grid. In February 2014, the government published its Draft Electricity Law which includes the possibility of setting up small power producers in Myanmar. The World Bank commissioned a study — 'Myanmar National

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<sup>25</sup> Exchange rate: EUR 1 = BDT 98

Electrification Program (NEP) Roadmap and Investment Prospectus' — which should develop a plan to realise 100 % rural electrification by 2030.

The Asia Development Bank published a report in March 2014 which revealed that about 11 % of the population in the Mandalay Region was already using PV SHS with 80 to 200 W [ADB 2014]. About 4.5 % of all villages were electrified with solar systems at the end of 2015. In the first phase (2016-2021) of the national energy plan 2016-2021, it is foreseen that 461 000 households in Sagaing, Ayeyarwady and Thanintharyi regions as well as Kayin, Chin, Rakhine and Shan states will be electrified by solar systems. In February 2017, the Department of Rural Development, Ministry of Agriculture, Livestock and Irrigation opened the tender process for 12 lots of solar PV systems for households and public facilities in 12 States.

The total installed PV capacity was estimated with 16 MW at the end of 2016. As of June 2017, solar photovoltaic power projects with over 1.5 GW capacity including 90 MW of floating PV plants have been announced. Three projects with 470 MW capacity have already signed PPAs.

In 2008, **Qatar** launched the Vision 2030, which set a national target of 2% renewable energy by 2030 and a 10 GW target for solar energy. Recently, the country set a target of generating 20% of its electricity using solar energy by 2020. This would require about 1.8 GW of capacity, however the mix between PV and solar thermal electricity generation (STEG)<sup>26</sup> is not clear yet. It is worthwhile to note, that Qatar depends by 87% on desalination for its freshwater supply and consumes about 30% of the country's energy demand.

The installed PV capacity has increased from 3.2 MW in 2014 to 48 MW in 2016.

In March 2017, Qatar Solar Technologies (QSTec), which already operates a 300 MW module factory in the Doha industrial zone that it had successfully produced its first polysilicon at its plant in Ras Laffan Industrial City [Qst 2017]. The factory has currently a manufacturing capacity of 8 000 MT of polysilicon and should be expanded to 50 000MT in the future.

**Singapore:** In June 2012, the Energy Conservation Law was published which aims to reduce Singapore's energy intensity by 35 % from its 2005 levels by 2030 [GoS 2012]. In January 2014, the Sustainable Energy Association of Singapore (SEAS) published a White Paper sketching the pathway to installing 2 GW of PV by 2025 [Sea 2014]. According to the Energy Market Authority of Singapore, 66 MW of grid connected systems were installed in 2016, increasing the total capacity to 126 MW at the end of 2016 [EMA 2017]. In the first half of 2017 about 12 MW were installed.

**United Arab Emirates (UAE):** At the moment the UAE has no federal energy policy, because the constitution gives autonomy in management and regulation of energy and resources to the individual emirates. Nevertheless, there is growing recognition of the need for coordination, consistency, and co-investment among emirates and the Ministry of Energy is now leading the country's first effort to develop a national strategy. IRENA has developed a Renewable Energy Roadmap for 2030, which calls for 21 GW of solar PV power to be installed by 2030 [Ire 2015]. According to a press report by 'The National', the UAE is aiming to generate 25 % of its electricity with clean energy (nuclear and solar) by 2030 [Nat 2016]. At the end of 2016 about 38 MW of PV power was operational.

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<sup>26</sup> Also used term: concentrated solar power (CSP)



In January 2015, a consortium led by ACWA Power (Saudi Arabia), won the bid of the 260 MW Phase II (200 MWAC) of the Mohammed bin Rashid Al Maktoum Solar Park (Dubai) with a bid of USD 5.84/kWh for a 25-year PPA starting in 2017 [Acw 2015]. The third phase of 800 MWAC was won by a consortium led by Masdar with a bid of USD 29.9 per MWh [Mub 2016]. The project will be commissioned in three steps:

- 200 MWAC by April 2018,
- 300 MWAC by April 2019 and
- 300 MWAC by April 2020.

In September 2016, a consortium led by JinkoSolar (China) and Marubeni (Japan) Abu entered a bid of USD 24.2 per MWh for the Abu Dhabi Electricity and Water Authority's (ADWEA) Sweihan solar power tender [Nat 2016a].

**Vietnam:** In December 2007, Vietnam's National Energy Development Strategy was approved. It prioritises the development of renewable energy and includes the following targets: to increase the share of renewable energies from negligible to about 3 % (58.6 GJ) of total commercial primary energy in 2010, to 5 % in 2020, 8 % (376.8 GJ) in 2025, and 11 % (1.5 TJ) in 2050. The updated Power Development Plan 2011-2020, which was approved by the Prime Minister in March 2016 set new targets for PV power: 850 MW by 2020 and 12 GW by 2030 [PMV 2016].

In April 2017, the Prime Minister of Vietnam issued Decision 11/2017/QD-TTg, which came into effect on 1 June 2017 and is due to expire on 30 June 2019. This decision introduced a feed-in tariff for grid connected systems and set minimum efficiency requirements (15% module efficiency).

At the end of 2016, about 7 MW of PV systems had been installed, mainly in off-grid applications. According to the Electricity Regulatory Authority, two solar farms with about 50 MW were under construction in June 2016, but not yet connected at the time of writing this report.

After three projects in solar-cell manufacturing stalled in Vietnam, the first solar cell and module manufacturing plant operated by Boviet Solar Technology Co. Ltd. and located in Bắc Giang, started production in June 2014. In the meantime another five companies have started solar cell manufacturing in the country.

In 2002, **Yemen** established the Renewable Energy Department under the Ministry of Electricity and Energy (MEE) with the goal of to promote and support renewable energy projects in the country. In 2009, the department was extended and reorganized into two departments for Solar Energy and Wind Energy. In the same year, the government set a target for grid connected renewable electricity at 15% for 2025.

For COP21 Yemen pledged as its Intended Nationally Determined Contribution (INDC) under the UNFCCC measures for the off-grid electrification of individual households and rural electrification measures based on renewable energy (photovoltaic systems, solar home systems (SHS), wind energy where feasible and biomass, both in stand-alone and hybrid schemes).

The target for Solar home systems is to install 110 000 systems with a capacity of 5.5 MW by 2025.

According to media reports, Sanaa received around 18 hours of power daily before the outbreak of the civil war in September 2014. In early July 2016, several neighbourhoods in the capital received around four hours of power every five days. This situation in the countryside is even worse and led to a trend to install more and more small PV systems to provide the basic needs of electricity.

Between 2012 and 2016 the cumulative installed PV capacity has increased from 1.5 MW to an estimated 30 MW.

## 2.3 Americas

### 2.3.1 Brazil

At the end of 2016, it is estimated that about 110 MW of cumulative PV systems capacity were operational. About 30 MW of this capacity was in off-grid systems. In July 2017 over 400 MW of PV power was operational including the Lapa solar park in Bahia with 158 MW [Ene 2017].

In April 2012, the board of the National Agency of Electric Energy approved new rules to reduce barriers to installing small distributed generation capacity. The rules apply to generators that use subsidised sources of energy (hydro, solar, biomass, co-generation and wind). Between 2014 and 2016 three energy auctions with solar power projects bids were held. The planned auctions in 2016 were about 12.7 GW of solar projects were technically approved as eligible were cancelled [Epe 2017].

The first three auctions had the following results:

- October 2014 auction (solar-only): over 1 GW<sub>AC</sub> was awarded to 31 projects at an average price of BRL 220/MWh (EUR<sup>27</sup><sub>2014</sub> 70.97/MWh, EUR<sub>2016</sub> 61.11/MWh). Start to deliver energy: 1 October 2017
- August 2015 auction (solar-only): over 830 MW<sub>AC</sub> were awarded to 30 projects at an average price of BRL 301/MWh (EUR<sup>28</sup><sub>2015</sub> 70.82/MWh, EUR<sub>2016</sub> 83.61/MWh). Start to deliver energy on 1 August 2017.
- November 2015 auction (solar and wind): over 920 MW<sub>AC</sub> awarded to 33 solar power projects at an average price of BRL 297/MWh (EUR<sub>2015</sub> 69.88/MWh, EUR<sub>2016</sub> 82.50/MWh). Start to deliver energy on 1 November 2018.

However, the devaluation of the Brazilian real against the USD and EUR has changed the economics of the solar PPA projects considerably. A number of companies, which have won contracts in the first auctions applied to alter the delivery start or cancel the contracts. In August 2017 Brazil's energy agency ANEEL cancelled nine solar projects totalling 249.7 MW of capacity due to a high number of projects being contracted in the first three reserve energy auctions remaining unbuilt and becoming idle.

In July 2017, Brazil has released its long-awaited 10-Year Energy Expansion Plan proposition, PDE 2026, projecting the country to reach more than 13 GW of solar PV deployment by 2026. Brazil's energy agency EPE expects non-hydro renewables to reach up to 48% of the energy mix by 2026. Under the reference scenario large scale PV plants should contribute 9.7 GW and distributed PV systems should add another 3.5 GW.

Solar technology is eligible to participate in one of two auctions planned for December 2017.

### 2.3.2 Canada

In 2016, about 220 MW of new PV power were connected to the grid and increased the total cumulative installed PV capacity to 2.7 GW [IEA 2017a]. Most of the systems are installed in Ontario, which has three programmes to support PV installations:

- **Micro-FiT:** Homeowners and other eligible participants can install a small or 'micro' renewable electricity generation project (10 kW or less in size) on their property. Under this programme, owners will be paid a FiT over a 20-year term for all the electricity produced and delivered to the province's electricity grid.
- **FiT:** This programme is for systems between 10 and 500 kW and approved projects receive a FiT for the electricity produced over a 20-year contract period.

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<sup>27</sup> Exchange rate 2014: EUR 1 = BRL 3.10

<sup>28</sup> Exchange rate 2H 2015: EUR 1 = BRL 4.25

- **Net-Metering:** Electricity consumers in Ontario who produce some of their own power from a renewable resource (systems up to 500 kW) can participate in the 'net-metering' initiative.

Most other provinces have a net-metering scheme. Ontario's Long-term Energy Plan sets a target of 10.7 GW of non-hydro RES by 2021.

### 2.3.3 Chile

On 30 December 2015, the President of Chile Michelle Bachelet, signed the Supreme Decree approving Chile's new long-term energy strategy 'Energy 2050' [GoC 2015]. The new policy sets a goal of generating 70 % of national electricity generation from renewable sources by 2050.

In the first quarter of 2012, the first MW-size PV system was installed in the northern Atacama Desert. More than 740 MW of PV power was connected to the grid in 2016, increasing the total PV capacity to about 1.6 GW at the end of 2016 [IEA 2017a].

On 17 August 2016, Comisión Nacional de Energía announced the results of electricity auction '2015/01'. The lowest bid for a PPA, fixed in USD for 20 years, came from a solar project to deliver 255 GWh/year at USD 29.1 per MWh. The average price of all winners for 12.4 TWh/year was USD 47.6/MWh.

In 2017, 2 200 TWh of electricity will be auctioned and bids can be submitted between 11 and 31 October 2017. The auction is divided in three time blocks.

- Block 1A: 11pm – 8am
- Block 1B: 8am – 6pm
- Block 1C: 6pm – 11pm.

Market expectations for 2017 are around 600 MW for new solar PV capacity.

### 2.3.4 Honduras

In 2007, Honduras enacted a law to promote renewable energy generation, with 20-year income tax breaks and a waiving of import tariffs on renewables components. In 2013, the government introduced a premium tariff for the first 300 MW to be installed until 30 June 2015. The General Electricity Industry Act, which adds a USD 0.03 premium for solar projects not eligible for the premium tariff was enacted in May 2014 [GoH 2014]. So far the Congress has approved 620 MW of solar PV power to be installed until the end of 2016. In November 2015, the National Electric Energy Company reported that 389 MW of solar PV power was connected to the grid in 2015 increasing the total capacity to 485 MW. In 2016 approximately 55 MW were installed to increase the total capacity to 540 MW (433 MW<sub>AC</sub>). Electricity generation from PV plants in 2016 was 885 GWh or 10.2% of the total sold electricity.

### 2.3.5 Mexico

In 2008, Mexico enacted the Law for Renewable Energy Use and Financing Energy Transition to promote the use of renewable energy [GoM 2008]. In 2012, the country passed its Climate Change Law, which anticipates a reduction in greenhouse gas emissions of 30 % below the business-as-usual case by 2020 and 50 % by 2050 [GoM 2012]. It further stipulates a share of renewable electricity of 35 % by 2024. A new National Energy Strategy 2012-2026 was approved in 2013, which moved the 35 % renewable electricity goal to 2026.

In 2016, about 140 MW of new PV systems were connected increasing the total cumulative PV system capacity to 420 MW. The IEA Medium-Term Renewable Energy Market Report 2016 forecasts a cumulative PV capacity of over 7 GW by 2020 [IEA 2016].

The results of the country's first power auction were published on 30 March 2016. Solar power with almost 1.6 GW and 4 TWh won contracts for PPAs between MXN 614.14/MWh

(EUR<sup>29</sup> 29.24/MWh) and MXN 1 169.78/MWh (EUR 55.70/MWh) [CNC 2016]. The second auction in September 2016 resulted in contracts for 184 MW of additional solar PV power, but in addition more than 4.9 million CELs were given to solar PV projects for a total energy production of 4.84 TWh [CNC 2016a]. All systems have to be operational on 1 January 2019. The third auction will be held in November 2017 and the winning projects must start to deliver electricity on 1 January 2010.

On 29 March 2017, Enel Green Power México announced that it has started the construction works at its 754 MW Villanueva solar photovoltaic plant in Viesca, Coahuila State [Ene 2017].

### **2.3.6 Peru**

In 2008, Peru passed the Legislative Decree 1002 which made the development of renewable energy resources a national priority. The decree states that by 2013 at least 5 % of electricity should be supplied from renewable sources, such as wind, solar, biomass and hydro. In February 2010, the energy regulatory commission Osinergmin (Organismo Supervisor de la Inversión en Energía y Minería) held the first round of bidding and awarded four solar projects with a total capacity of 80 MW. A second round was held in 2011, with a quota of 24 MW for PV. About 85 MW of PV systems had been installed by the end of 2012. No significant additions were reported during 2013. The National Photovoltaic Household Electrification Program, launched in 2013, aims to supply PV electricity to 500 000 households by means of 12 500 solar systems by 2016.

On 16 February 2016, Osinergmin announced that they had awarded two PV projects with a total capacity of 184.5 MW to deliver 523.4 GWh of electricity/year at prices of USD 47.98/MWh (144.5 MW<sub>AC</sub> with 415 GWh) and USD 48.50/MWh (40 MW<sub>AC</sub> with 108.4 GWh) [Osi 2016]. Start of electricity delivery is December 2018 at the latest. The next auction is planned for 2018 with no auction foreseen in 2017.

In November 2016, Enel Green Power Peru reported the start of the construction of their 180 MW (144.5 MW<sub>AC</sub>) plant in Rubí, province Moquegua. According to their latest press release 42 MW were already installed in June 2017 and the total installation should be finished before the end of the year [Ene 2017a].

### **2.3.7 United States of America**

With over 14.7 GW of newly connected PV power, the United States had reached a cumulative PV capacity of 40.8 GW by the end of 2016 [Gtm 2017]. In terms of nominal capacity, solar accounted for 39 % of new power capacity in 2016, representing the largest share for the first time. With 10.6 GW utility PV installations again were the largest segment within 2016. The top ten States — California, Uta, Georgia, Nevada, North Carolina, Texas, Arizona, Massachusetts, Florida and Colorado accounted for 80 % of the US PV market, and California alone had a market share of 34 %. For 2017 and 2018, a decrease in the range of 25% and 10% are expected, before growth in 2019 and 2020 returns. One of the reasons for this development is that developers, qualified with full ITC (30%), have time to complete their projects until 2020.

PV utility projects based on PPAs, with a total capacity of 21.9 GW, were under contract, but not yet operating in Q3 2017 [Gtm 2017a]. In Q3, 5.0 GW of these projects are under construction. In the first half about 2.5 GW of utility scale projects were installed and it is estimated that the about 8 GW of utility projects will be connected to the grid before the end of 2017. In addition more than utility scale projects with more than 48 GW have been announced, but not yet signed a PPA.

Many state and federal policies and programmes have been adopted to encourage the development of markets for PV and other renewable technologies. These comprise direct legislative mandates (such as renewable content requirements) and financial incentives (such as tax credits). One of the most comprehensive databases on the different support schemes in the USA is maintained by the North Carolina State University Solar Centre. The Database of State Incentives for Renewables and Efficiency (DSIRE) is a

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<sup>29</sup> Exchange rate: 1 EUR = 21 MXN

comprehensive source of information on state, local, utility and selected federal incentives that promote renewable energy. It also includes descriptions of all the different support schemes. The DSIRE website <http://www.dsireusa.org/> and the corresponding interactive tables and maps (giving details) are highly recommended.

### 2.3.8 Emerging markets

In 2006, **Argentina** passed its Electric Energy Law which established that 8 % of electricity demand should be generated by renewable sources by 2016 [GoA 2006]. The law also introduced FiTs for wind, biomass, small-scale hydro, tidal, geothermal and solar for a period of 15 years. In July 2010, amongst other RES, the government awarded PPAs to six solar PV projects totalling 20 MW. By the end of 2015, about 50 MW (15 MW off-grid) of PV systems had been installed. The first renewable energy auction RenovAr 1 received bids for more than six times the assigned 1 GW of power of which 300<sub>AC</sub> MW are assigned to PV projects. Winners include a 300<sub>AC</sub> MW solar project in Jujuy and a 100<sub>AC</sub> MW project in Salta, at a median price of USD 59.75/MWh.

Jujuy's State Energy and Mining Company (JEMSE) won 300<sub>AC</sub> MW of the tender and will construct the Cauchari 1, 2 and 3 Solar Parks. They are located Cauchari Salt Flat in southern Susques. According to media reports the modules have arrived in September 2017 and the plant should become operational in 2018.

In a second auction, called RenovAr 1.5, in November allocated another 516 MW<sub>AC</sub> at a price of USD 54.95/MWh to 20 solar PV projects. The RenovAr 2 auction was launched in August 2017 and offers can be submitted until 19 October 2017. A quota of 450 MW<sub>AC</sub> was assigned to solar PV plants [Bol 2017].

In 2017 the governor of Jujuy State announced the intention to install an additional 1 GW<sub>AC</sub> of solar PV power with electricity storage.

As early as 2007, the **Dominican Republic** passed a law promoting the use of renewable energy and set a target of 25 % renewable energy share by 2025 [GoD 2007]. At that time, about 1 to 2 MW of solar PV systems were installed in rural areas, which increased to over 5 MW in 2011. Despite the fact that Corporación Dominicana de Empresas Eléctricas Estatales signed various PPAs totalling 170 MW in 2011 and 2012, no information about the operation of significant capacities could be found. It was estimated that by mid-2014 about 10 MW of PV installations were in operation, including a 500 kW system at the Union Médica hospital in Santiago. In March 2016, Phase I (30 MW) of a 60 MW solar plant was inaugurated in the Monte Plata province. At the end of 2016 it was estimated that about 46 MW were operational.

In March 2016, the Government of **Panama** approved the National Energy Plan (NEP), 2015-2050 [GoP 2016a]. The plan includes a roadmap to use at least 70 % of RES in the energy mix by 2050. In April 2016, the National Authority of Public Services (ASEP) announced, that they will remove the cap of 500 kW for self-consumption, if the customer does not inject more than 25 % of his own consumption into the grid [Ase 2016]. According to ASEP, grid connected PV power had a capacity of 127 MW in June 2017 [Sec 2017]. In January 2015, Panama's Electricity Transmission Company (La Empresa de Transmisión Eléctrica S.A.(ETESA)) awarded in the first solar energy auction five PPAs to solar projects providing 660.2 GWh/year for prices between USD 80.2/MWh and 104.8/MWh starting from 1 January 2017 [Ete2015].

## 2.4 Africa

Despite Africa's vast solar resources and the fact that in large areas the same PV panel can produce on average twice as much electricity in Africa than in Central Europe, there has been only limited use of solar PV electricity generation up until now. According to the latest update of the JRC resource study in Africa<sup>30</sup>, solar PV electricity is the most competitive technology for almost 40 % of the total population in Africa. Until the end of the last decade, the main application of PV systems in Africa was in small SHS and the market statistics for these are extremely imprecise or even non-existent. However, since 2012, major policy changes have occurred and a large number of utility-scale PV projects are now in the planning stage. In 2015, IRENA published 'Africa 2030: A Roadmap for a Renewable Energy Future'. The roadmap identified modern renewable technology options across the sectors and across countries, which could collectively supply 22 % of Africa's total final energy consumption (TFEC) by 2030. This is more than a fourfold increase compared to the 5 % share in 2013. According to the roadmap, PV solar power should contribute 70 TWh or 4 % of TFEC produced by 31 GW of PV systems.

Overall, the (documented) capacity of installed PV systems has risen to more than 2.5 GW by the end of 2016, more than forty times the capacity installed in 2008. In 2017, the installed capacity is expected to increase by another 50 %. Current African PV targets for 2020 are in excess of 10 GW.

### 2.4.1 Algeria

In 2011, Algeria's Ministry of Energy and Mines published its Renewable Energy and Energy Efficiency Programme which aims to increase the share of renewable energy used for electricity generation to 40 % of domestic demand by 2030. The plan anticipates 800 MW of installations until 2020 and a total of 1.8 GW by 2030. In February 2014, the ministry introduced two FiT regimes, one for systems between 1 and 5 MW and one for systems larger than 5 MW. It was estimated that about 5 MW of small decentralised systems and a few larger systems in the multi-kW range were installed at the end of 2013.

According to the Renewable Energy Development Centre (CDER), the National Renewable Energy programme for Algeria (2015- 2030) now has a target of 22 GW of renewable power with a share of 13.5 GW of PV power by 2030.

In January 2017 the government adopted a decree to launch a 4 GW solar PV tender and in March 2017, the regulatory framework for the implementation was published in the Official Journal [Jou 2017]. According to media reports, the government intends to conduct the tender in three phases of 1.35 GW each. The solar plants should be built in the High Plains of northern and southern Algeria. However, at the time of finalising this report the tender has not been published yet.

In 2016, PV systems with about 80 MW were newly installed increasing the total capacity to about 380 MW.

### 2.4.2 Cape Verde

Cape Verde's Renewable Energy Plan (2010-2020) aims to increase the use of renewable energy to 50 % by 2020 through the use of PPAs. Law No 1/2011 establishes the regulations for independent energy production. In particular, it lays down the framework conditions for the set-up of independent power producers using renewable energy (15-year PPAs), and for self-production at user level. It creates a micro-generation regime, regulates rural electrification projects, and states the tax exemption on all imported renewable energy equipment. About 340 MW of PV systems are required to achieve the 2020 50 % renewable energy target.

By the end of 2012, two centralised grid-connected PV plants with 7.5 MW had been installed. In addition, there are a number of smaller off-grid and grid-connected systems. At the end of 2015, about 10 MW of PV power was operational [Ire 2016a]. A 2 MW

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<sup>30</sup> RE2nAF tool for off-grid options for rural Africa Web site: <http://re.jrc.ec.europa.eu/re2naf.htm>

solar/wind hybrid project to provide electricity and fresh water on the Island of Brava had been approved by the IRENA/ADFD Project Facility [Ire 2016a].

### **2.4.3 Egypt**

In September 2014, the Ministry of Electricity and Energy and the Regulatory Agency launched a FiT support system for solar PV and wind projects with capacity less than 50 MW. The target of the programme is to install 300 MW from small PV installations below 500 kW, and 2 GW PV plants between 500 kW up to 50 MW. The tariffs vary between EGP 84.8 to 102.5/kWh (EUR<sup>31</sup>0.085 to 0.103/kWh) depending on the size of systems. The tariffs will be adjusted if either the target is achieved or the 2-year regulatory period is elapsed, which happens first.

The first solar tender (2014) was heavily oversubscribed with more than 80 qualified applications exceeding the target by more than 50 %. The selected consortia have to close their financing by the end of September 2016. On 11 August 2015, the New and Renewable Energy Authority announced Tender No (14/2015/2016) for 200 MW in the West Nile region.

It is estimated that 76 MW of PV power was operational at the end of 2016 [Mes 2017]. According to MESIA, about 1.5 GW of solar power are under 'execution', i.e. PPA signing, awarded, construction.

### **2.4.4 Ethiopia**

In February 2013, a 20 MW module manufacturing plant was opened in Addis Ababa, **Ethiopia**. The factory is a joint project between SKY Energy International and Ethiopia's Metals and Engineering Corporation (METEC). According to press reports, the factory was upgraded to 100 MW manufacturing capacity in 2015 [Eth 2015]. Press reports confirmed the Ethiopian Electric Power Corporation (EEP) approved three solar plants with a capacity of 300 MW in the eastern region of the country [Ven 2013].

In August 2016, EEP announced to tender the tree projects, which will be located in Metahara, Umera and Mekelle [Ena 2016]. In September 2017, media reported that the technical specifications of five bidders for the first tender, the Metahara project had been approved, but the final decision, based on the financial date was still pending.

It is estimated that a solar PV capacity of about 30 MW was operational at the end of 2016.

### **2.4.5 Mauritania**

In 2011, the country set up a Master Plan for the Production and Transport of Electricity until 2030 and adopted its third Poverty Reduction Strategy Paper (PRSP) action plan (2011 – 2015) [IMF 2013]. The number of households with access to electricity rose from 30% in 2008 to 38.8% in 2014 [ONS 2014].

The PRSP has set a target of raising the share of renewable energy in the national energy mix to 15% by 2015 and 20% in 2020. As part of the actions taken, the Sheikh Zayed 15 MW solar photovoltaic plant in Nouakchott was connected to the grid in 2013. The tender for a second PV plant in Nouakchott with 30 MW closed February 2016.

In 2016, 8 smaller projects with 16.6 MW were installed increasing the total capacity to approximately 35 MW.

### **2.4.6 Morocco**

The Kingdom of Morocco's solar plan was introduced in November 2009, with the aim of establishing 2 000 MW of solar power by 2020. To implement this plan, the Moroccan Agency for Solar Energy (MASEN) was founded in 2010. Solar electricity technologies, solar thermal electricity generation<sup>32</sup> and PV will all compete openly. Earlier in 2007, the National Office of Electricity (ONEE) had already announced a smaller programme for

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<sup>31</sup> Exchange rate: 1 EUR = 9.95 EGP

<sup>32</sup> Also used term: concentrated solar power (CSP)

grid-connected distributed solar PV electricity, with a target of 150 MW of solar PV power. Various rural electrification programmes using PV systems have been running for a long time. At the end of 2012, Morocco had installed about 20 MW of PV systems, mainly under the framework of the Global Rural Electrification Program, and about 1 to 2 MW of grid-connected systems.

In February 2015, ONEE announced their plan to tender various PV power projects of 20 to 30 MW each with a total capacity of 400 MW [One 2015]. The first plants should be operational at the end of 2017. In April 2015, the World Bank announced its decision to support the first phase of 75 MW. The pre-qualification process for PV Noor I, three plants with a combined capacity of approximately 170 MW solar power was launched by MASEN in summer 2015. 20 consortia were pre-qualified by MASEN in December 2015 to submit bids for the three plants Noor Ouarzazate, NOOR Laayoune and Boujdour Noor. According to press reports, three consortia from Saudi Arabia won the bids with prices in the range of USD 60/MWh.

Two companies in Casablanca are producing PV modules — Droben Energy, a subsidiary of the Spanish Droben company, with 5 MW, and Cleantech with 15 MW capacity. In May 2016, Jet Contractors, a Moroccan construction company, announced a Joint Venture with Haereon Solar (PRC) and Société d'Investissements Energétiques (SIE) to build a 160 MW solar cell and module manufacturing plant in Morocco [Jet 2016]. The company already operates a 30 MW cell and module plant, which as phase I of the project will be converted to manufacture cells and modules according to Haeron's quality standards.

It is estimated that about 30 MW of PV system capacity was operational at the end of 2016.

#### **2.4.7 Senegal**

In 2008 the Ministry for Renewable Energy (MER) was created and the National Agency for Renewable Energies (ANER) was established in 2013. The country enacted a renewable energy law in 2010 [Jou 2011], which calls for the diversification of the counties energy supply and a promotion of the use of renewable energy sources.

In 2016 the first competitive tender solar PV projects was launched through the framework of the World Bank's 'Scaling Solar' initiative, which should enable 200 MW of PV power in Senegal. This has auctioned 100MW of solar capacity and the pre-qualification round closed in October 2016 [Com 2016].

A 20 MW solar PV plant at BokholIt started operation in October 2016, increasing the total capacity to over 30 MW of PV system capacity at the end of 2016.

In June 2017, Solairdirect, a unit of France's energy group Engie, has connected a 30 MW solar park in Senegal to the grid. The plant is located in Santhiou Mékhé near Méouane.

#### **2.4.8 South Africa**

South Africa has a rapidly increasing electricity demand and vast solar resources. In 2008, the country enacted its National Energy Act, which calls for a diversification of energy sources, including renewables, as well as fuel switching to improve energy efficiency [GoS 2008]. In 2011, the Renewable Energy Independent Power Producer Procurement Programme (IPP) was set up with rolling bidding rounds. Three rounds have already taken place: in 2011 (630 MW), 2012 (420 MW), 2013 (450 MW) and 2014 (415 MW). The overall target is 3.725 GW and that for solar PV is 1.45 GW. Between the first round (closing date: 4 November 2011) and the fourth round (closing date: 18 August 2014) the average bid price fell from ZAR 2.65/kWh (EUR<sup>33</sup> 0.265/kWh) to ZAR 0.79/kWh (EUR<sup>34</sup> 0.056/kWh). In 2016, about 540 MW of solar PV capacity was connected to the grid, increasing total PV power capacity to 1.45 GW [IEA 2017a]. With 2.6 TWh solar PV electricity provided 1.1% of the South African electricity generation. Market expectations are in the 300 MW range for 2017.

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<sup>33</sup> Exchange rate 2012: EUR 1 = ZAR 10

<sup>34</sup> Exchange rate 2015: EUR 1 = ZAR 14



Due to the country's local content rules, more and more manufacturers along the solar value chain are setting up plants in South Africa. The following is a non-exhaustive list of industry activities.

Setsolar was set up in Cape Town in 2007. The company manufactures and distributes solar modules and other system components. Its manufacturing capacity is estimated at 20 MW.

In 2011, Solaire Direct Technologies (Pty) Ltd started module manufacturing in Cape Town. With a production capacity of about 36 MW, it manufactures OEM modules for different companies as well as its own brand. It signed an OEM contract (120 MW) with ReneSola in 2013 [Sol 2013].

In 2013, ARTSolar opened a module factory in Durban with a capacity of 75 MW. The company manufactures OEM modules for different companies as well as its own brand [Art 2013]. According to a press report, the company started to expand its production capacity, but no details are available.

Early in 2014, JA Solar (PRC) announced the establishment of a joint venture with Powerway PV SA (Pty) Ltd. to build a solar-module manufacturing facility in Port Elizabeth [Jas 2014]. Production was scheduled to begin in the second quarter of 2014, with the plant targeting an initial annual capacity of 150 MW; it has the option for an expansion to 600 MW. No further details are known.

In February 2014, Photovoltaic Technology Intellectual Property (Pty) Ltd. (PTiP) officially launched its pilot production line for the manufacturing of CIGS thin-film solar modules. Equipment supplied by German company Singulus [Sin 2014].

In March 2014, Powerway PV SA, part of Powerway Renewable Energy Co. Ltd (PRC), a global solar-farm builder/system integrator, and Sungrow (PRC), the third largest inverter company in 2012, announced the setting up of a manufacturing facility in the Coega Development Corporation in Port Elizabeth [Pow 2014].

In August 2014, JinkoSolar Holding Co. Ltd. announced the opening of a 120 MW module factory in Cape Town [Jin 2014].

#### **2.4.9 Emerging markets**

In 2011, the Parliament of **Ghana** passed the Renewable Energy Bill which aims to increase the proportion of renewable energy, particularly solar, wind, mini-hydro and waste-to-energy in the national energy supply mix and to contribute to mitigating climate change [RoG 2011]. The bill sets a goal of renewable energy constituting 10 % of national energy generation by 2020. At the end of 2012, there were a few thousand SHS and a few off-grid systems providing an estimated 5 MW installed in the country. In 2012, a number of companies announced the signature of PPAs in Ghana. However, none of these projects have been realized so far. In May 2013, the Volta River Authority (VRA) inaugurated its first solar power plant at Navrongo, with a capacity of 2.5 MW. VRA planned to install a total of 14 MW by 2015, but nothing had happened so far. In April 2016, Beijing Xiaocheng Company (BXC) connected the first 20 MW of their 40 MW PV solar power plant at Onyandze to the grid [Ecr 2016].

In April 2016, Accra-based developer Strategic Power Solutions (SPS) opened a 30 MW solar module plant in Tema, outside of Accra.

A number of large scale solar power plants with a combined capacity of close to 300 MW have been announced over the last years, but none of the projects has reached the financial closure yet.

In March 2017, the government announced to restart the Rooftop Solar Programme and the Energy Commission aims to realise 200 MW of rooftop PV capacity in the medium term.

In 2008, **Kenya** introduced FiTs for electricity from RES, but solar power was only included in 2010, when the tariffs were revised [GoK 2010]. However, only a little over 560 kW of PV capacity was connected to the grid in 2011; the majority of the 14 MW of

PV systems were off-grid installations. In 2011, Ubbink East Africa Ltd., a subsidiary of Ubbink B.V. (Doesburg, the Netherlands) opened a solar PV manufacturing facility in Naivasha with an annual output of 30 000 modules. The plant produces modules for smaller PV systems, such as SHS. Current estimates for Kenya's PV market put average annual sales of home systems at 20 000 to 30 000 and solar lanterns at 80 000. It is estimated that the total capacity of SHS, telecommunication applications, diesel-PV hybrids and the few grid-connected systems will be about 25 to 30 MW at the end of 2016. In March 2016, the Rural Electrification Authority (REA) board approved the construction of a 55 MW Solar Power plant in Garissa [Rea 2016]. It is interesting to note that the solar plant will be financed through concessional funding from the Government of China. After a number of delays, construction is now scheduled to start in the second half of 2017 and a construction time of 12 months.

In various media reports it was mentioned that Kenya plans to build 4 40 MW solar power stations, but they are not yet in the list of the Ministry for Energy and Petroleum. For 2017 only the electrification of 603 schools with PV is listed there [MEP 2017].

In 2005, **Nigeria** passed the Power Reforms Act as well as the National Renewable Energy Master Plan for Nigeria which set targets for solar to contribute 5.0 MW, 75 MW, and 500 MW in 2010, 2015 and 2025, respectively. In November 2015, the government of Nigeria approved the FiT regulation, which went into force in February 2016. The tariffs apply to PV systems between 1 and 5 MW and capped at a capacity of 380 MW by 2018. However, the tariff scheme was declared illegal by the Federal High Court in Lagos on 13 July 2016 [NER 2016].

In February 2014, it was reported that Nigeria's first module manufacturing plant had been completed and is now operational with a nameplate capacity of 10 MW [Pvt 2014]. The plant was built in Sokoto by German firm JVG Thoma.

According to various press reports, the government-owned energy purchasing company Nigerian Bulk Electricity Trading (NBET) has already signed solar PPAs with 14 developers. The MWh price of these PPAs was set at USD 115 and could add about 1.4 GW to the grid starting from next year if financing can be secured.

It is estimated that about 20 MW of solar PV power were operational at the end of 2016.

At the end of 2012, **Tanzania's** Ministry of Energy and Minerals (MEM) published its Strategic Plan 2011/12-2015/16, in which the strategic objective to enhance the sustainable development and management of energy resources for national development was formulated [MEM 2012]. As a follow-up, the Scaling-up Renewable Energy Program (SREP) was published in April 2013 [MEM 2013]. The SREP calls for a cumulative installed PV capacity of 60 MW by 2017 and 120 MW by 2020. Cumulative PV capacity is estimated with 15 MW at the end of 2016.

In 2009, **Tunisia** launched its Solar Plan. It is a Public-Private Partnership spanning 2010 to 2016. The plan aims to increase the share of RES in the total Tunisian energy mix from 0.8 % to 4.3 % by 2014. The PROSOL ELEC programme to promote the installation of grid-connected systems was set up to handle investment subsidies and guaranteed loans as well as power purchase for 1 to 2 kWp solar PV systems [Ste 2013]. PV capacity is estimated at 40 MW at the end of 2016.

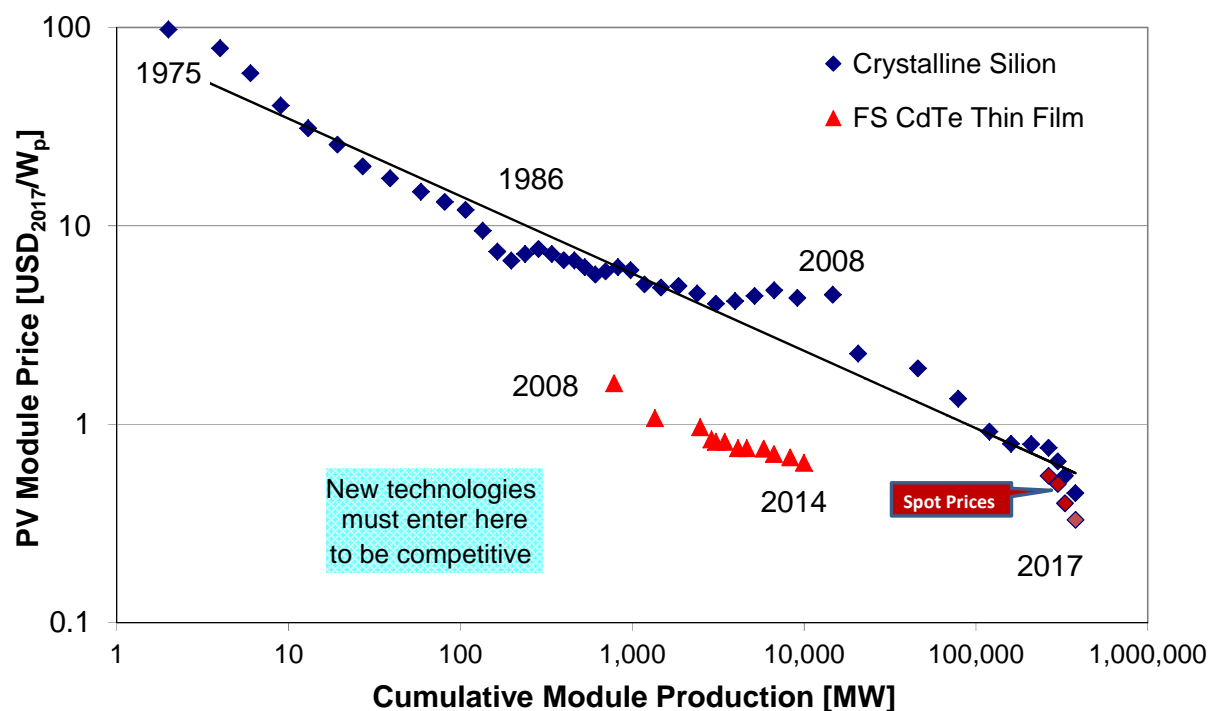
In 2017, a tender for 70 MW of PV capacity was published [RoT 2017]. The tender has two categories: for projects up to 1 MW the allocated capacity is 10 MW, and for systems not larger than 10 MW the quota is 60. Bids for solar projects must be submitted by 15 November 2017.

A 30 MW module factory run by Green Panel Technology Jurawatt Tunisie came into operation in 2014 [Jvg 2014]. The company is a joint venture between Tunisia Green Panel Tech and JVG Thoma, Germany.

### 3 Electricity costs and the economics of PV systems

Over the last four decades, solar module prices have fallen following a price-experience or 'learning' curve with an average learning rate of about 80 %, i.e. the ASP of solar modules fell by 20 % for each doubling of production volume (Fig. 7). This development was driven not only by technological developments but also by market conditions. It is interesting to note that between 2004 and the second half of 2008 the price of PV modules remained fairly constant at roughly USD<sub>2016</sub> 4 to 4.5/Wp. This occurred despite the fact that manufacturing technology continued to improve and companies significantly scaled up their production. The reason for this was the expanding markets in Germany and Spain, where the only slowly changing FiTs enabled project developers to be profitable at that price. This was coupled with the temporary shortage of polysilicon between 2004 and 2009, which limited silicon solar cell production and prevented effective pricing competition, thus providing an opening for thin-film technologies to enter the market. The temporary silicon feedstock shortage and the market entry of companies offering turnkey production lines for thin-film solar cells led to a massive expansion of investments in thin-film capacities between 2005 and 2009. The market share for thin-film modules increased until 2009, when it reached almost 20 %, although it has declined steadily since then to well below 10%.

**Figure 7:** Price-experience curve for solar modules (ASP)



Source: Bloomberg New Energy Finance (BNEF) and PV News

Between 2008 and the end of 2012, there was a massive 80 % drop in the price of modules, with 20 % in 2012 alone, creating serious financing problems for all companies and leading to the closure of a significant number of them [Blo 2013]. This drastic price drop was a consequence of the huge overcapacities as a result of the very ambitious investments spending between 2005 and 2011. Between 2013 and 2015, the price decline was relative moderate before it accelerated again towards the end of 2015 and in 2016. During the same time the volatility of the module spot prices has increased significantly.

PV system prices have followed the lowering of module prices but at a slower pace. This becomes obvious by looking at the PV module share in the system price, which shifted from almost 70 % in 2008 to less than 50 % in 2016.

Despite the fact that there is a global market for the hardware components of a PV system, e.g. modules, inverters, cables, etc., and that these prices are very similar worldwide, the prices for installed PV systems still vary significantly [IEA 2016]. The reasons for those differences are manifold, ranging from the different legal requirements for permits, licensing and connection to the grid to the different maturity of local PV markets, with impacts on competition between system developers and installers. PV system prices are changing rapidly, not only in Europe, which opens up new opportunities for PV in a rapid growing number of countries to become one of the major electricity providers in the near future.

### 3.1 LCOE

A common measure for the comparison of power-generation technologies is the concept of the LCOE<sup>35</sup>. LCOE is the price at which electricity must be generated from a specific source to break even over the project's lifetime. It is an economic assessment of the cost of the energy-generating system, including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, and cost of capital. It can be calculated using a single formula, such as:

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

where:

LCOE = average lifetime levelised electricity generation cost

$I_t$  = investment expenditures in the year  $t$

$M_t$  = operational and maintenance expenditures in the year  $t$

$F_t$  = fuel expenditures in the year  $t$ , which is zero for PV electricity

$E_t$  = electricity generation in the year  $t$

$r$  = discount rate

$n$  = financial lifetime of the calculation

This calculation delivers the LCOE of the generator, but falls short of describing the full LCOE for the total system, which covers profile cost (including flexibility and utilisation effects), balancing costs and grid costs. These cost categories have to be added to all electricity-generating technologies LCOEs, whether they are conventional or RES (Fig. 8). There are a number of reasons why the LCOEs of different power-generation technologies differ in different regions and at different times, and this has an influence on the merit-order effect. For example: (1) Full-load hours: different power-generation technologies have different full-load hours depending on the type of resource, such as hydro, solar, wind, etc., or the type of power plant, for instance base-load, medium- or peak-load plants; (2) All combustion technologies incur fuel costs, which have different degrees of volatility and associated risk, and depend on the type of delivery contract and/or geographic region; (3) Demand variations; (4) Central or decentralised power generation; (5) Weather forecasting accuracy for wind and solar; and (6) Market regulations and trading opportunities, etc.

The benchmark against which the different generator and system LCOEs must be compared are the market prices in the respective segments of a given market.

Although a considerable number of studies have calculated, estimated or modelled the value of renewable electricity from variable resources, most of them have investigated the market penetration of a single renewable energy source, like wind or solar, rather than a portfolio of different RES and optimised integration technology options [Hir 2013 and references, Uec 2013]. It should also be noted, that the current market designs still do not price-in the environmental and health costs of the different power generation technologies [Riz 2013].

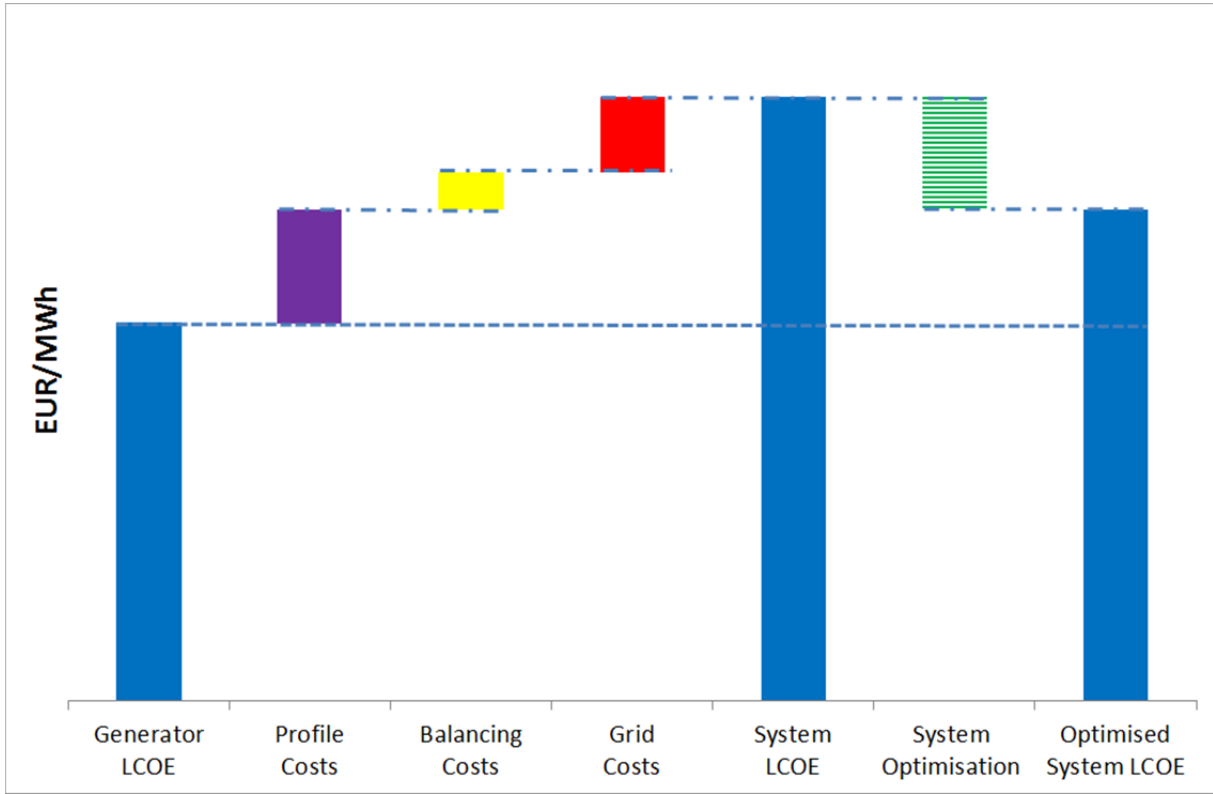
For solar PV electricity, the market value depends on the kind of application. In the case of residential or commercial systems, the benchmarks are the residential or commercial electricity retail rates. For large utility-scale solar farms, the market value is more difficult to determine and PPAs are a good indicator of how utility companies evaluate them.

The following sections show the LCOE of different PV systems and the economic and technical possibilities for PV to contribute to profile, balancing and grid costs.

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<sup>35</sup> LCOE formula used by the National Renewable Energy Laboratory (NREL):  
[http://www.nrel.gov/analysis/tech\\_lcoe\\_documentation.html](http://www.nrel.gov/analysis/tech_lcoe_documentation.html)

Figure 8: System LCOE



### 3.2 Influence of financing costs on LCOE

Over the last 40 years, hardware costs of PV systems have decreased drastically due to a combination of research activities and market development. Technical installation costs have decreased as well, driven by best practices and increasing competition levels in the installers market. Given the fact that the largest share of investments into a solar PV electricity generation system has to be done at the beginning of the project and no fuel costs are inexistent, the weighted cost of capital (WACC), often also referred as the discount rate, has a critical impact on LCOE.

The WACC can be calculated as follows:

$$WACC = \frac{E}{V} * Re + \frac{D}{V} * Rd (1 - Tc)$$

Where:

- Re = cost of equity
- Rd = cost of debt
- E = market value of the firm's equity
- D = market value of the firm's debt
- V = E + D
- E/V = percentage of financing that is equity
- D/V = percentage of financing that is debt
- Tc = corporate tax rate

As shown above, not only the equity to debt ratio but the corporate tax rate has a significant influence on the WACC. Cost of debt is very much dependent on the economic situation in a given country and the financial stability of the company looking for debt. Therefore, WACC for a given project can vary not only where it is realised, but also by whom the project is realised. The range of costs for debt in the first half of 2017 is reported between (LIBOR + 170bps) and (LIBOR + 1 500 bps) [Blo 2017b].

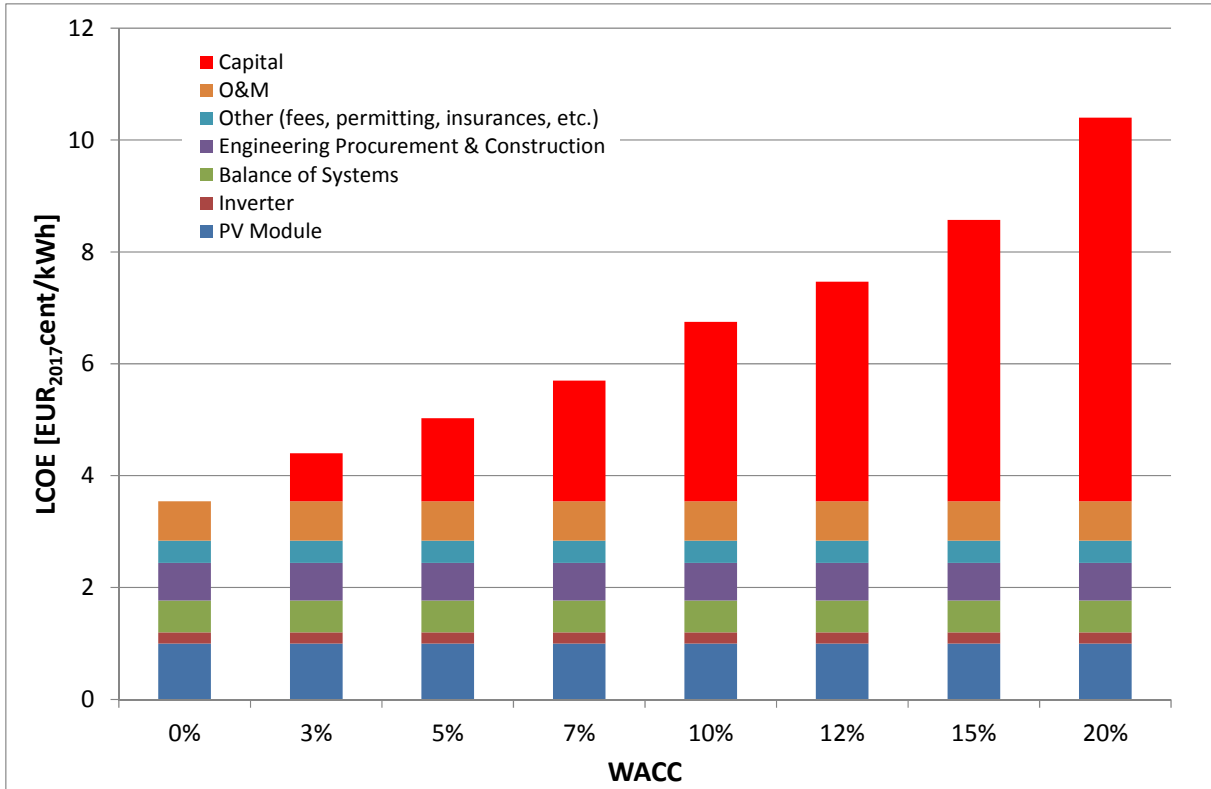
In this context, it is noteworthy to mention that the low bids and PPAs in the United Arab Emirates, Chile as well as in Africa have only been possible by a combination of excellent solar resource, high debt shares and low debt costs. In the case of Africa, the low costs of debt were possible through an exchange rate guarantee by the World Bank, lowering the investors risk as the offtake price is guaranteed in USD [WBG 2016].

To show the impact of financing on the LCOE, the following benchmark assumptions for a large scale system to be operational at the beginning of 2018 were taken:

CAPEX EUR<sub>2017</sub> 850 per kWp, operational expenditure (OPEX) EUR 12.5 per kW/year, 1 500 kWh/kW per year, financial lifetime of 20 years. Local taxes were not considered.

As can be seen in Figure 9, with a WACC of 7 %, the financing costs exceed the hardware and technical installation costs, and at a WACC of 12 %, the financing costs are more than 50 % of the total LCOE. It becomes obvious that PV electricity generation costs are more and more depending on a low financial risk environment with low financing costs than on high solar irradiation. It also highlights that the government risk mitigating policies can be more efficient to support PV development than introducing financial support when none of the energy forms are subsidised, or supported in the same way.

**Figure 9:** Influence of WACC on LCOE



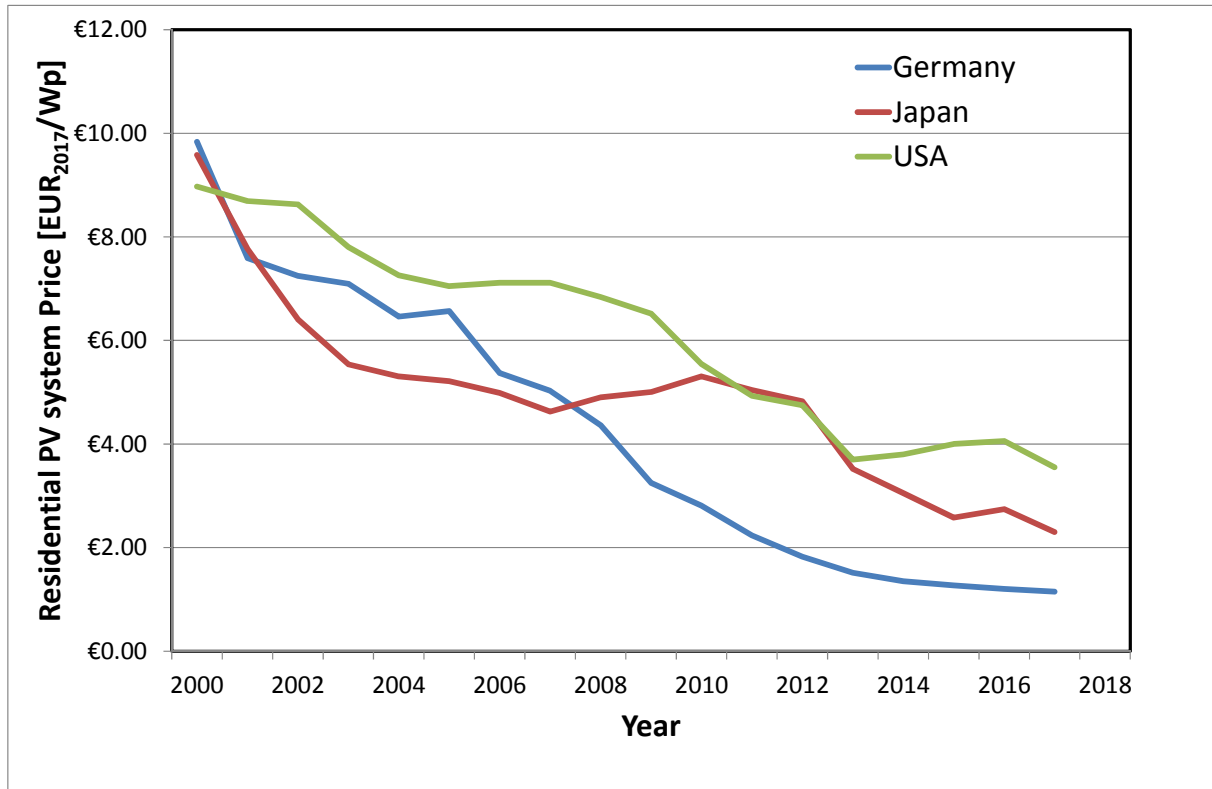


### 3.3 LCOE of residential grid-connected PV systems

Over the last decade, prices for residential grid-connected PV systems have decreased significantly, as shown in Figure 10. The increase in PV system prices in Japan, between 2007 and 2010, as well as the increase in the USA, from 2014 to 2016, are due to changes in exchange rates; in the local currency, the prices fell further.

Please note that customer in the USA receive a 30% federal tax credit, which in parts is responsible for the overall higher prices.

**Figure 10:** Residential PV system price development over the last decade



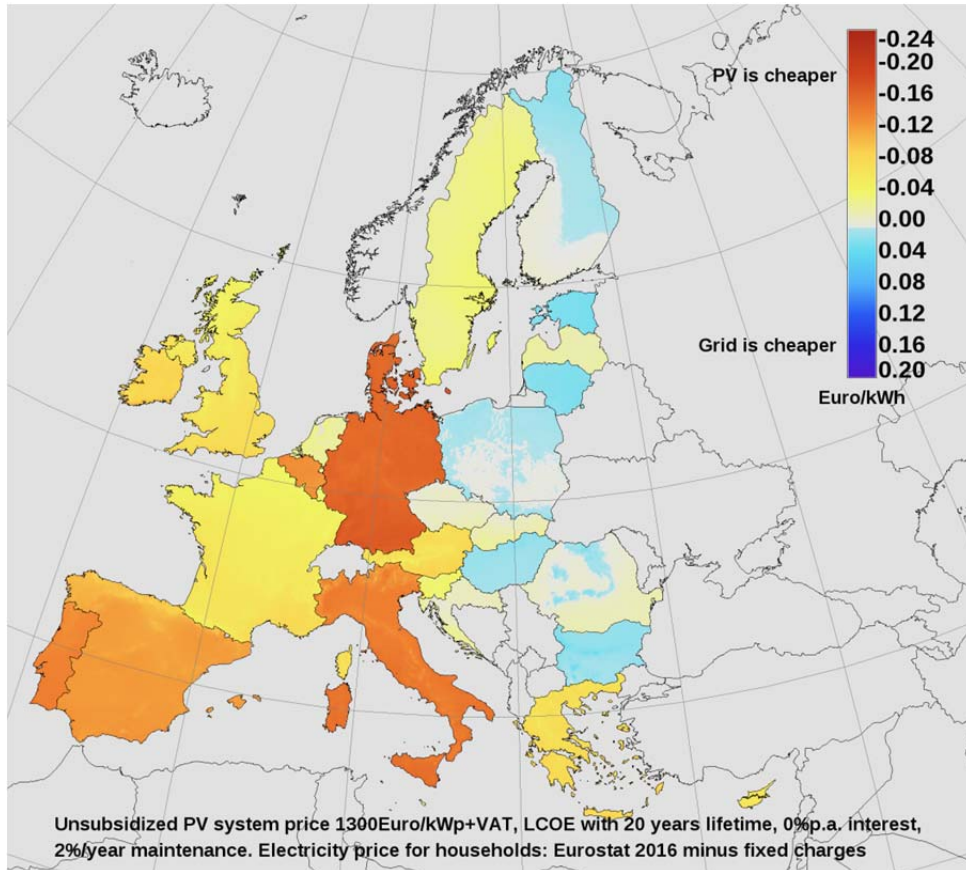
Sources: IEA PVPS, BSW, DoE SunShot Initiative, Eurostat, OECD key economic data

In September 2017, the worldwide average price of a residential system without tax was given as USD 1.53/Wp (EUR 1.28/Wp) about 20 % higher than in Europe with EUR 1.13/Wp and 30 % higher than in Australia AUD 1.37/Wp (EUR 0.95/Wp) [Pvi 2017, Sol 2017a]. Taking the European price and adding a surcharge of EUR 0.17/Wp for fees, permits, insurance, etc., installed PV system costs EUR 1 300/kWp without financing and VAT.

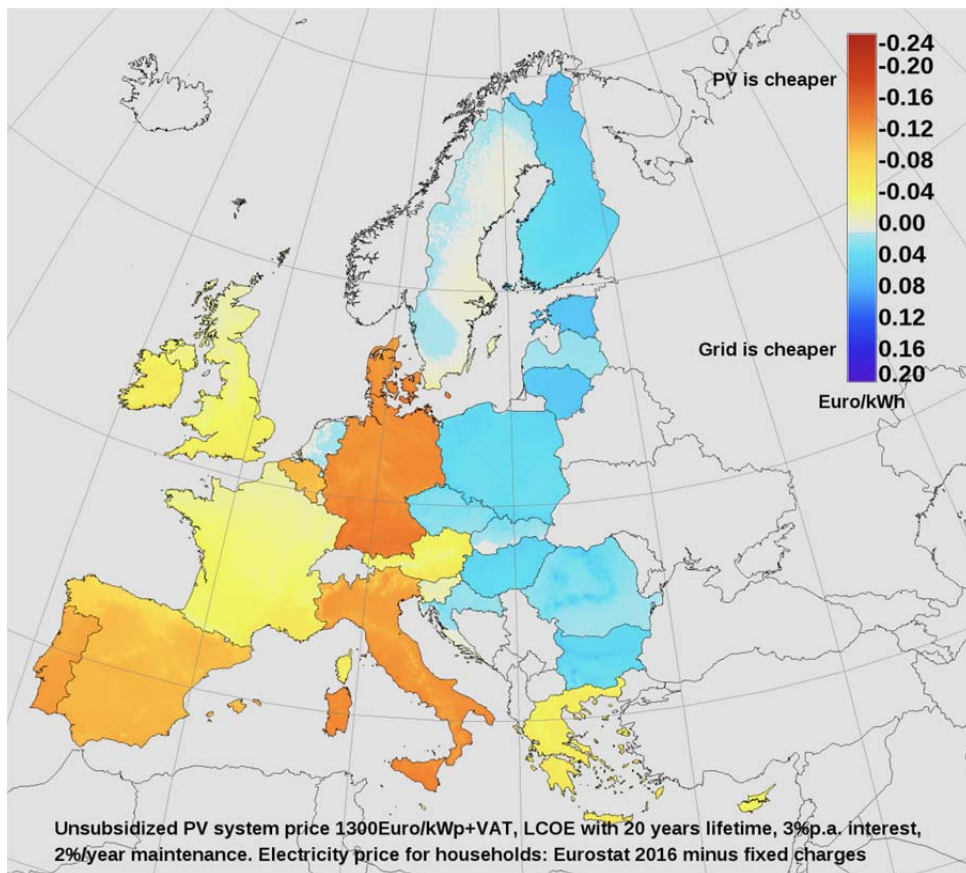
Even, if PV system purchases for a large number of consumers have become a 'credit card purchase', the wide spread differences of financing costs in the different Member States, which are based on the long term interest rates from the European Central Bank (ECB) and range between 3 – 11%, can still play a role. The influence of financing as well as the influence of the European VAT rates on investment costs and LCOE was already presented earlier [Hul 2014, Jäg 2014a].

To show the competitiveness of PV generated electricity the LCOE from PV systems was calculated using the September 2017 averaged price and compared it with the variable part of the electricity prices customers are paying in the European Union Member States (Fig. 11).

**Figure 11** Comparison of European residential electricity prices (variable part) with electricity generated by a PV solar system.



(a): Without interest for system purchase



(b): with 3% interest for system purchase

For this benchmark calculation maintenance and repair (O&M) costs of 2% was used, which are higher than in other analyses. This reflects the fact that labour costs related to O&M activities have not decreased like the hardware components. Depending on the actual radiation level, the 2% O&M costs are a main cost factor besides possible financing costs. The O&M costs cover the foreseeable repairs and exchange costs of components like the inverter, as well as the annual degradation of the solar modules as specified by the manufacturers. Adding a conservative safety margin of 0.8 EUR cent/kWh on top of the 2.0 to 2.6 EUR cent /kWh results in an electricity price of 2.8 to 3.4 EUR cent/kWh after the 20-year financial payback period, depending on the actual solar radiation.

As shown in a growing number of countries, electricity production from residential PV solar systems can be cheaper than the variable part of residential electricity prices, depending on the actual electricity price and the local solar radiation level. Therefore, using self-generated electricity provides a means to lower the electricity bill on one hand, and to avoid excessive penetration of PV generated electricity in the grid network. In the case of a PV system size that generates as much electricity as the customer uses over a year, the actual consumption during the time of generation is in general about 25 %-30 % on residences, in commercial buildings it can be more [Hul 2014a, Mos 2015].

There are in principle two methods, to increase the direct consumption ('Self-Consumption') of solar electricity. One is to use intelligent control systems, which switch major loads (washing/dryer machines, heat pumps, refrigerators, air-conditioners) on when the sun is shining. The second one requires a means to store the energy, either as electricity which requires accumulators, or as 'product', (heat-storage, cold-storage or pumped water), for use at night or rainy days. Storing electricity has the additional advantage of making energy offers to the network operator at times the operators chooses as being profitable.

**Table 1:** LCOE of PV-generated electricity for residential systems with a system price of EUR 1 300/kWp (excluding VAT, because the differences in the various countries are too large), 2 % O&M cost, an annual generation of 1 000 kWh/kWp/year and financial lifetimes of 20 years

	Price [EUR/kWp]	LCOE Product	LCOE Capital			LCOE O&M	LCOE Total		
WACC		0 %	3 %	5 %	10 %		3 %	5 %	10 %
		[EURct/kWh]							
Hardware	850	4.25	1.30	2.25	4.83	1.70	7.25	8.20	10.78
Eng. and installation	280	1.40	0.43	0.74	1.59	0.56	2.39	2.70	3.55
Other (fees, permits, insurances...)	170	0.85	0.26	0.45	0.97	0.34	1.45	1.63	2.16
Total	1 300	6.50	1.98	3.43	7.38	2.60	11.08	12.53	16.48

**Table 2:** LCOE of PV-generated electricity for residential systems with a system price of EUR 1 300 kWp (excluding VAT, because the differences in the various countries are too large), 2 % O&M costs, an annual generation of 1 300 kWh/kWp/year and a financial lifetime of 20 years

	Price [EUR/kWp]	LCOE Product	LCOE Capital				LCOE O&M	LCOE Total		
			0 %	3 %	5 %	10 %		3 %	5 %	10 %
WACC		0 %	3 %	5 %	10 %		3 %	5 %	10 %	
		[EURct/kWh]								
Hardware	850	3.27	1.00	1.73	3.71	1.31	5.57	6.30	8.29	
Eng. and installation	280	1.08	0.33	0.57	1.22	0.43	1.84	2.08	2.73	
Other (fees, permits, insurances...)	170	0.65	0.20	0.35	0.75	0.27	1.11	1.26	1.66	
Total	1 300	5.00	1.53	2.75	5.90	2.00	8.53	9.64	12.68	

Nevertheless, some fraction of the electricity generated has to be sold to the grid. The question is what kind of pricing should be used – contract, wholesale or day-ahead prices. The fact that the costs of PV-generated electricity can be equal to or lower than residential electricity costs is not yet sufficient to support a self-sustained and unsupported market.

In the second half of 2017, the average residential electricity rate, excluding the daily connection charge, in Australia varied between AUD 0.27 and 0.37/kWh (EUR<sup>36</sup> 0.186 and 0.255/kWh), which makes PV electricity generation and self-consumption very attractive. The average European residential electricity price given by Eurostat for the second semester of 2016 was EUR 0.205/kWh, including fixed charges, taxes and levies [Est 2017]. Fixed charges vary widely between EUR 20 and 170, depending on the respective Member State and electricity provider. The same holds true for the variable part of the electricity price, which can vary between EUR 0.075 and 0.28 per kWh. Nevertheless, PV-generated electricity for the lower ROI financing options, which are more realistic for private consumers, is already cheaper for a large number of European Union citizens. Denmark, Germany and Belgium had the highest prices with EUR 0.308/kWh, EUR 0.298/kWh and EUR 0.275/kWh, respectively. In September 2017, the kWh based prices of Japan’s largest utility Tokyo Electric Power Company (TEPCO) were JPY 19.52/kWh (EUR<sup>37</sup> 0.150/kWh) for the first 120 kWh per month, JPY 26.00/kWh (EUR 0.200/kWh) for everything above 120 kWh and below 300 kWh per month, and JPY 30.02/kWh (EUR 0.231/kWh) for every kWh above 300 kWh per month [Tep 2017]. In addition, customers pay a demand charge between JPY 280.80 (EUR 2.16) per month for 1 kW and up to JPY 1 684.80 (EUR 12.96) for a 6 kW connection. The Renewable Energy Power Promotion Surcharge in FY 2017 is JPY 2.25/kWh [METI 2016].

Without support, the profitability of a solar PV system depends primarily on the owner’s self-consumption, as less energy has to be purchased from the utility. In the case of a PV system size that generates as much electricity as the customer uses over a year, the actual consumption during the time of generation is in general only around 30 % if no demand shifting or local storage is applied. Therefore, 70 % of the generated electricity has to be sold to the grid. The question is what kind of pricing should be used – contract, wholesale or day-ahead prices.

The first option for improving profitability is to increase self-consumption by demand shifting and using electrical appliances like the washing machine, dishwasher, electric hot water heaters or heat pumps during the day when the sun shines. Another option is to use the difference between the PV electricity generation costs and the household retail price to invest in local storage options, be they residential or community-owned. The current investment costs for a residential battery storage system are roughly equally

<sup>36</sup> Exchange rate: EUR 1 = AUD 1.45

<sup>37</sup> Exchange rate: EUR 1 = JPY 130

divided between the batteries and the electronic control components. In the future, it is very likely that the solar inverter will include large parts of the necessary electronics, thereby lowering the costs significantly.

As an indication of storage costs, prices for battery packs for electric vehicles have declined from about USD 1 000/kWh in 2010 to below USD 227/kWh in H2 2016 6 [Blo 2015, Mck 2017]. According to media reports, Tesla claimed to be already below USD 190/kWh in early 2016 aiming to reduce the costs to USD 125/kWh with their new Gigawatt factory and the CTO of Audi was cited that the costs of 1kWh storage was currently EUR 100 [Lam 2017, 2017a]. Lithium-ion batteries have an average of 5 000 cycles, and with the above cost estimates, this would correspond to net kWh costs component for the full used battery pack of USD 0.045/kWh (EUR 0.038/kWh) and should fall to USD 0.02/kWh (EUR 0.017/kWh) by 2020. However, these costs do not yet include the investment for the power and control electronics needed to combine it with a PV system.

LCOE of residential battery storage systems do not only depend on the CAPEX (battery pack, power and control electronics and installation) and total storage cycles, but are strongly influenced by the sizing of the PV and battery systems and the actual use of the battery system, i.e. depth of discharge, overall battery system efficiency, usable annual storage cycles and actual kWh stored and used [Bau 2012, 2016]. Therefore, there is a wide range of prices of electricity from storage at EUR 0.18 to 0.36/kWh, which has to be added to the PV LCOE.

According to various consultancy reports, the electricity battery storage market is expected to grow 10-fold over the next five years and exceed EUR 6 billion by 2022. This market development, together with a further retail price increase and a PV system price reduction, could lower the LCOE of a PV system, including storage, below average European electricity retail prices and make PV electricity the lowest cost option for more than 230 million Europeans within the next 5 years.

### **3.4 Residential and commercial electricity storage models**

Some electricity providers in Europe are offering PV systems and local storage to their customers, often including maintenance services. The packages also include apps to monitor the performance of the system, use of electricity and often functionality to control the match between demand and supply. The motivation for this model is described by those companies as follows: 'This gives customers a complete and compatible package consisting of a PV system, storage device, app, and green electricity tariff.' However, no information is given at which rate the company would buy self-generated electricity.

Battery producers and storage system developers have started to offer their customers the organisation of their decentralised electricity generation and storage facilities as virtual power plants and acting as electricity providers and traders. Examples are Sonnen GmbH or E3/DC.

In Germany, KfW is offering loans with a non-repayable component for PV systems including storage with a maximum system power of 30 kWp [KfW 2016]. The loan is only available if the maximum injected power is 50 % or less of the nominal power rating of the PV system. The maximum eligible amount was 25 % of EUR 2 000 per kWp if the PV system and the battery storage were installed at the same time and EUR 2 200 per kWp of the PV system if the system was installed after 31 December 2012 and more than 6 months have passed before the battery storage was added. However, the maximum eligible amount is reduced by 3 % each 6 months starting 1 July 2016. The programme will be terminated at the end of 2018.

Another concept is 'virtual storage' for electricity generated by PV systems either for a monthly fee or a down payment for a number of years. To take advantage of this offer, the PV system owner has to be a customer of the respective service provider. The advantage of the virtual storage is that the customer has no installation and maintenance costs for the storage system and virtually infinite lifetime.

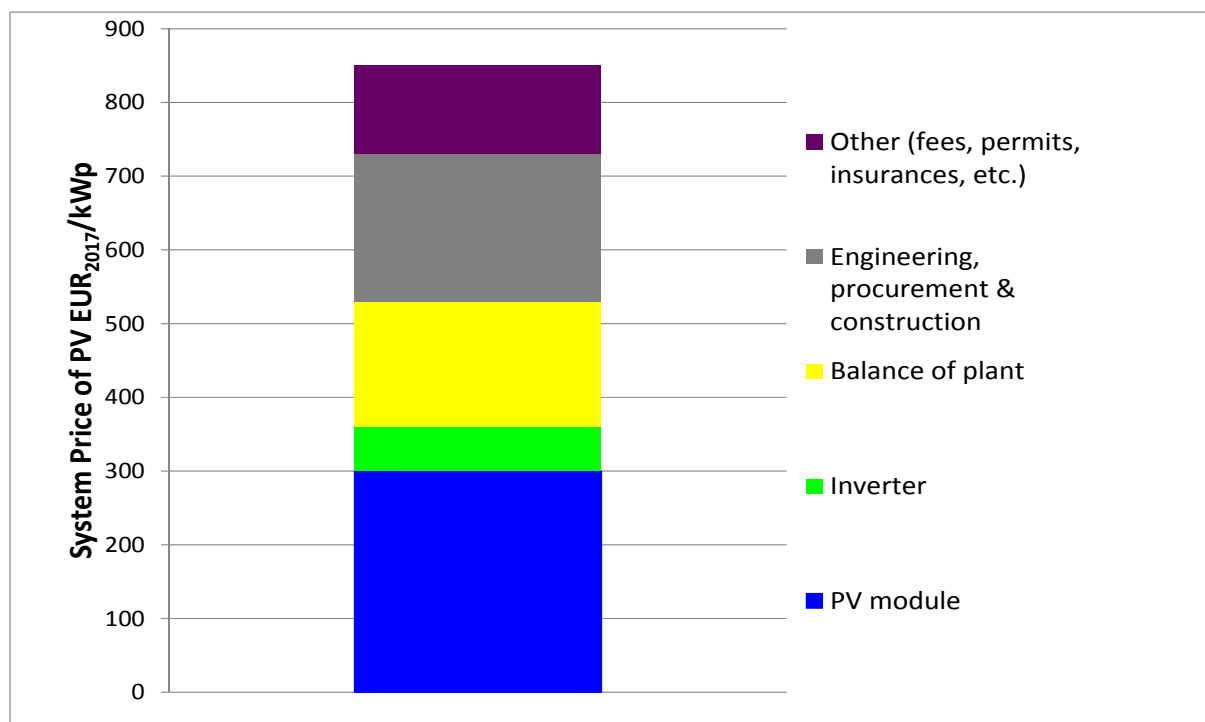
In addition, there are a number of companies, which offer the management of swarm or cluster storage facilities in cooperation with distribution network operators. However, detailed business information is still very limited.

### 3.5 LCOE of utility-scale PV systems

Utility-scale PV systems can be defined as a PV system larger than 10 MW. The first such system was installed in 2006 after the 2004 revision of the German EEG, which for the first time made such systems eligible for a FiT. The first boom occurred in 2008, triggered by the Spanish FiT, when almost 1 GW was installed. When the Spanish bubble burst, the volume dropped to less than 500 MW in 2009, before activities picked up again in 2010. At the end of 2015, about 65 GW of utility-scale PV power plants were operational worldwide and it is possible that this mark will be at 100 GW at the end of 2016.

Due to the plant size, which is currently up to 850 MW<sup>38</sup>, the cost structure and LCOE is quite different from that of residential PV systems. Figure 11 shows an average cost breakdown in competitive markets. The actual cost breakdown differs from project to project.

Figure 12: Price breakdown of utility-scale PV system



Already in 2010, Ken Zweibel published an analysis of how discount rates influence the competitiveness of solar PV electricity generation [Zwe 2010]. He calculated that with a market size of 40 GW per year system costs of USD<sub>2010</sub> 2.00/Wp (EUR<sub>2010</sub> 1.54/Wp) should be possible. Already in 2014 the market was larger than this, with utility system prices well below the calculated ones at around EUR 1 100<sub>2014</sub>/kWp (USD 1 554<sub>2010</sub>/kWp<sup>40</sup>).

In 2016, a number of record breaking PPA contracts and bids below USD 30/MWh have been reported reaching a new low with the USD 24.2/MWh bid by JinkoSolar (China) and Marubeni (Japan) for an Abu Dhabi Electricity and Water Authority's (ADWEA) tender in September 2016 [Nat 2016a]. As already mentioned, these very low bids and PPAs in the UAE and Chile are only possible through a combination of excellent solar resource (with

<sup>38</sup> Longyangxia Dam Solar Park, PRC

<sup>40</sup> United States inflation — see: <http://www.usinflationcalculator.com/inflation/historical-inflation-rates/>

load factors up to 25 %), high debt shares and very low debt costs as well as the fact that some tariffs are indexed to inflation.

Besides these extremes, it is noteworthy to mention, that the latest solar auction in Germany in June ended with contracts awarded to projects for an average price of EUR 56.60/MWh [BNA 2017]. Other examples are:

- The Salvadorean energy distribution company DelSur opened a renewable energy auction for the procurement of 170 MW capacity in October 2016. The results were made public in January 2017. 4 PV projects with 120 MW capacity were successful at prices between USD 49.55 and 67.24/MWh (EUR 41.29 and 56.03/MWh)
- Results of the June 2017 Tamil Nadu auction were between INR 3.47 and 4.00/kWh (EUR 0.0469 and 0.541/kWh).
- In July 2017 the Polish Energy Regulatory Office (ERO) published the results of the auction held on June 2017. This auction addressed RES installations with less than 1 MW of installed power. The largest share of bids came for PV installations, but wind and small hydro was eligible as well. The range of winning bids was between PLN 195 and 408/MWh (EUR<sup>41</sup> 45.25 – 94.88/ MWh). It is believed that the winning solar bids are more at the higher end.
- In July 2017, the French Ministry of Ecological and Solidarity-based Transition announced that it awarded 507.6 MW of PV to 77 developers in its second major large-scale solar auction, for projects ranging between 500kW and 17MW capacity. The average price for all projects was EUR 63.90 and for the category of PV plants with capacities between 5 and 17 MW it was EUR 55.50/MWh.

However, PPAs do only reflect partly the actual economic competitiveness of a solar project. When comparing it to other projects, it is also important to know what the tax regime for such a project or competing power projects have, e.g. in the USA PV projects qualify for the federal energy ITC programme (30 %) and the Modified Accelerated Cost Recovery System depreciation (five-year MACRS). The ITC is 30 % until 2019 then it is reduced to 26 % in 2020 and 22 % 2021. After 2023, the residential credit will drop to zero while the commercial and utility credit will drop to a permanent 10 %.

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<sup>41</sup> Exchange rate: 1 EUR = 4.3 PLN



## 4 The PV manufacturing industry

The PV industry consists of a long value chain from raw materials to PV system installation and maintenance. In general, when people talk about the PV industry, the main focus is on the solar-cell and module manufacturers. However, there is also the so-called upstream industry (e.g. materials, polysilicon production, wafer production and equipment manufacturing) as well as the downstream industry (e.g. inverters, balance of system (BOS) components, system development, project development, financing, installations and integration into existing or future electricity infrastructure, plant operators, operation and maintenance, etc.). In the near future, it will be necessary to add (super)-capacitor and battery manufacturers as well as power electronics and IT providers to manage supply and demand as well as meteorological forecasts. The main focus in this chapter, however, is still on solar-cell, module and polysilicon manufacturers.

In 2016, the PV world market grew by over 30 % in terms of solar cell production to about 82 GW. The market for installed systems grew even more by about 40 %, and values between 76 and 81 GW were reported by various consultancies and institutions. This mainly represents the grid-connected PV market since, to what extent the off-grid and consumer-product markets are included remains unclear.

In addition, the fact that some companies report shipment figures, some sales figures and others production figures adds to the uncertainty. An additional source of error stems from the fact that some companies produce fewer solar cells than solar modules, but the reporting does not always differentiate between the two and there is a risk that cell production is counted twice — first at the cell manufacturer and then again at the 'integrated' cell/module manufacturer. The difficult economic conditions contributed to a reluctance to report confidential company data. Nevertheless, the figures show a significant increase in production, as well as a growing installation market.

The fact that a significant number of companies filed for insolvency scaled back or even cancelled their expansion projects, as well as the introduction of minimum prices for solar modules in Europe and import taxes on solar cells and modules from China in the USA led to a modest temporary ease of the price pressure between 2013 and 2015. However, the slight increase in profit margins as well as the rapid expansion of some markets immediately led to an increase of new entrants in the field, notably large semiconductor or energy-related companies. In 2013, no significant capacity increase was reported, but since the beginning of 2014 the announcements of new capacity expansions have significantly increased totalling about 6.6 GW of thin film and 34 GW of c-Si solar cell capacity to be realised within the next 18 to 24 months in the second half of 2016. Not all of these announcements were realised, but the capacity increases along the value chain were large enough to increase the overcapacity to levels accelerating the price pressure in 2016 despite the rapid growing installation market. Overall it can be stated that the rapid changes in the sector and the still difficult financing situation make any reasonable forecast for future capacity developments very speculative.

## 4.1 Technology mix

After the temporary silicon shortage between 2004 and 2008, silicon prices fell dramatically, as did the cost of wafer-based silicon solar cells. In 2016, their market share was over 90 % and they continue to be the main technology. Commercial module efficiencies range widely from 12 % to 22 %, with monocrystalline modules from 16 % to 22 %, and polycrystalline modules from 12 % to 18 %. The massive increases in manufacturing capacity for both technologies were followed by the capacity expansions needed for polysilicon raw materials.

In the utility PV power plant sector, the fastest growing segment is PV systems with tracking systems. It is expected that the market share of utility scale PV plants with tracking will rise from approximately 20% in 2016 to over 40% in 2020.

In 2005, for the first time, the production of thin-film solar modules reached more than 100 MW per annum. Between 2005 and 2009, the CAGR of thin-film solar module production exceeded that of the overall industry, increasing the market share of thin-film products from 6 % in 2005 to 10 % in 2007 and from 16 % to 20 % in 2009. Since then, the thin-film share has declined to less than 7% in 2016. Reasons for this development are mainly the limited progress in efficiency improvements (tf silicon), problems of newcomers to ramp up novel manufacturing technologies for CIGS or CdTe and the limited finances of start-up companies.

The number of thin-film manufacturers which are silicon-based and use either amorphous silicon or an amorphous/microcrystalline silicon structure has declined steeply in the last 5 years due to the efficiencies still at the low end of the scale. Only a few companies use  $\text{Cu}(\text{In,Ga})(\text{Se,S})_2$ , or CdTe (cadmium telluride) as absorber material for their thin-film solar modules.

Concentrating photovoltaics (CPV) is struggling to follow the cost reduction of the other technologies and the number of companies active in the field has declined sharply over the last years. Within CPV, there is a differentiation according to concentration factors<sup>42</sup> and whether the system uses a dish (Dish CPV) or lenses (Lens CPV). The main parts of a CPV system are the cells, the optical elements and the tracking devices.

On the research level, new non-concentrating high efficiency concepts are researched to increase the cell and module efficiencies. These innovative concepts are either based on thin-film technologies only or on a combination of crystalline silicon and thin-film technologies.

The existing PV technology mix is a solid foundation for the future growth of the sector as a whole. No single technology can satisfy all the different consumer requirements, ranging from mobile and consumer applications, and the need for a few watts up to multi-MW utility-scale power plants. If material limitations or technical obstacles restrict the further growth or development of a single technology pathway, then the variety of technologies will be an insurance against any stumbling blocks in the implementation of solar PV electricity.

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<sup>42</sup> High concentration > 300 suns (HCPV), medium concentration  $5 < x < 300$  suns (MCPV), low concentration < 5 suns (LCPV).

## 4.2 Polysilicon supply

The rapid growth of the PV industry which started in 2000, led to a situation where, between 2004 and early 2008, the demand for polysilicon outstripped the supply from the semiconductor industry. Prices for purified silicon peaked in 2008 at around USD 500/kg, resulting in higher prices for PV modules. This extreme price hike triggered a massive capacity expansion, not only among established companies, but many new entrants as well.

The massive production expansions, as well as the difficult economic situation after the Lehmann collapse, led to a fall in prices throughout 2009, reaching about USD 50 to 55/kg at the end of 2009. There was a slight upwards trend throughout 2010 and early 2011 before prices started to drop again. In 2013, they started to stabilise and a slight upward trend was observed in 2014 before the price pressure started to move prices down again. In September 2017, prices were in the USD 12 to 19/kg (EUR 10 to 16/kg) range.

Projected silicon production capacities for 2016 vary between 450 000 tonnes [Blo 2017a] and 508 000 tonnes [Ikk 2017]. It is estimated that about 30 000 tonnes will be used by the electronics industry. In addition, possible solar cell production will depend on the material used per Wp. The current average worldwide is about 4.3 g/Wp for mono- and 4.8 g/Wp for multicrystalline silicon solar cells.

### 4.2.1 Silicon production processes

The high growth rates of the PV industry and market dynamics forced the high-purity silicon companies to explore process improvements, mainly for two chemical vapour deposition approaches — an established production approach known as the Siemens process and a manufacturing system based on fluidised bed reactors. It is very probable that improved versions of these two types of processes become the workhorses of the polysilicon production industry in the near future.

**Siemens process:** The Siemens reactor was developed in the late 1950s and has remained the dominant production route ever since. In 2009, about 80 % of total polysilicon manufactured worldwide was made using a Siemens-type process. It involves deposition of silicon from a mixture of purified silane or trichlorosilane gas, with an excess of hydrogen, on to high-purity polysilicon filaments. The silicon growth then takes place inside an insulated reaction chamber or 'bell jar' which contains the gases. The filaments are assembled as electric circuits in series and are heated to the vapour deposition temperature by an external direct current. The silicon filaments are heated to very high temperatures between 1 100 and 1 175 °C at which tri-chlorosilane, with the help of the hydrogen, decomposes to elemental silicon and deposits as a thin-layer film on to the filaments. Hydrogen chloride is formed as a by-product.

Temperature control is the most critical process parameter. The temperature of the gas and filaments must be high enough for the silicon from the gas to deposit on to the solid surface of the filament, but well below the melting point of 1 414 °C, so that the filaments do not start to melt. Secondly, the deposition rate must be well controlled and not too fast, otherwise the silicon will not deposit in a uniform, polycrystalline manner, making the material unsuitable for semiconductor and solar applications.

**Fluidised-bed (FB) process:** A number of companies develop polysilicon production processes based on FB reactors. The motivation for using the FB approach is the potentially lower energy consumption and continuous production, compared to the Siemens batch process. In this process, tetrahydrosilane or trichlorosilane and hydrogen gases are continuously introduced into the bottom of the FB reactor at moderately elevated temperatures and pressures. At a continuous rate, high-purity silicon seeds are inserted from the top and suspended by the upward flow of gases. At the operating temperature of 750 °C, the silane gas is reduced to elemental silicon and deposits on the

surface of the silicon seeds. The growing seed crystals fall to the bottom of the reactor where they are removed continuously.

***Upgraded metallurgical grade (UMG) silicon*** was seen as one option for producing cheaper solar-grade silicon with 5- or 6-nines purity, but support for this technology is waning in an environment where higher-purity methods are cost-competitive. A number of companies have delayed or suspended their UMG-silicon operations as a result of low prices and lack of demand for UMG materials for solar cells.

### **4.3 Polysilicon manufacturers**

The following list gives a short description of the 10 largest companies in terms of production in 2015. More information about other polysilicon companies can be found in various market studies.

#### **4.3.1 GCL-Poly Energy Holdings Ltd. (China)**

GCL-Poly (<http://www.gcl-poly.com.hk>) was founded in March 2006 and started the construction of its Xuzhou polysilicon plant (Jiangsu Zhongneng Polysilicon Technology Development Co. Ltd.) in July 2006. Phase I had a designated annual production capacity of 1 500 tonnes and the first shipments were made in October 2007. Full capacity was reached in March 2008. At the end of 2015, polysilicon production capacity had reached 70 000 tonnes and 14 GW of wafers. The wafer capacity was further increased to 18.5 GW at the end of 2016. The company reported production of 69 345 tonnes of polysilicon with sales of 9 951 tonnes of polysilicon and 17.5 GW of wafers for 2016.

In February 2016, SunEdison announced that it will shut its FBR polysilicon facility in Pasadena, Texas and the filed for insolvency in April 2016. According to a financial disclosure note by GCL-Poly, GCL bought the SBR assets of Sun Edison for USD 150 million [Gcl 2016].

The company also invested in the down-stream solar business. GCL Solar System Ltd. (SSL) is a wholly owned subsidiary of GCL-Poly Energy Holdings Ltd. and provides solar-system turnkey solutions for residential, governmental, commercial and solar farm projects, including design, equipment supply, installation and financial services. Another subsidiary is GCL Solar Power Co. Ltd. which is developing, operating and managing solar farms with a total capacity of 4 GW at the end of 2016.

#### **4.3.2 Wacker Polysilicon AG (Germany, USA)**

Wacker (<http://www.wacker.com>) is one of the world's leading manufacturers of hyper-pure polysilicon for the semiconductor and PV industry, chlorosilanes and fumed silica. The company has two production sites in Germany, Burghausen with a production capacity of about 40 000 tonnes Nünchritz with 20 000 tonnes. In April 2016, the company officially opened their factory in Charleston (TN), USA with a nameplate capacity of 20 000 tonnes [Wac 2016]. The factory was ramped up in 2016. For 2016, the company report production and sales of more than 66 000 tonnes was estimated.

#### **4.3.3 OCI Company Ltd. (South Korea)**

OCI (<http://www.oci.co.kr/>) (formerly DC Chemical) is a global chemical company with a product portfolio spanning inorganic chemicals, petro and coal chemicals, fine chemicals, and renewable energy materials. In 2006, the company started its polysilicon business and successfully completed its 6 500 tonnes P1 plant in December 2007. The 10 500 tonne P2 expansion was completed in July 2009, and with another 10 000 tonnes P3 brought the total capacity to 27 000 tonnes at the end of 2010. The de-bottlenecking of P3 took place in 2011, and increased the capacity to 42 000 tonnes at the end of that year. At the end of 2016 the company had 52 000 tonnes of capacity and increased to 72 000 tonnes in 2017. The increase comes from the takeover of the 20 000 tonnes polysilicon plant of Tokuyama, which was announced in October 2016 and finalised in May 2017. For 2016, a production of close to 50 000 tonnes was estimated.

OCI invested in downstream business and holds 89.1 % of OCI Solar Power, which develops, owns and operates solar power plants in North America. On 23 July 2012, the company signed a PPA with CSP Energy (Austin, TX), USA for a 400 MW solar project (Alamo 1-7). In 2015, the company launched its first projects in China and Mexico. The total capacity of operational projects was 515 MW at the end of 2016.

#### **4.3.4 TBEA Silicon Co. Ltd. (China)**

TBEA Silicon Co. Ltd. (<http://www.tbea.com.cn/>) was established at the State Hi-Tech Development Zone in Urumqi, Xinjiang, China by Tebian Electric Apparatus Stock Co. Ltd. (TBEA) and East Electric EMei Semiconductor Institute. TBEA is a major manufacturer of power transmission and transformation equipment including inverters for renewable energy applications. TBEA Silicon is active in the field of polysilicon manufacturing as well as grid-connected and mini-grid power plants. For 2016, a production capacity of 26 000 tonnes and actual production of 22 800 tonnes was given.

#### **4.3.5 Hemlock Semiconductor Corporation (USA)**

Hemlock Semiconductor Corporation (<http://www.hscpoly.com>) is based in Hemlock, Michigan. The corporation was set up as a joint venture between Dow Corning Corporation (63.25 %) and two Japanese firms, Shin-Etsu Handotai Co. Ltd. (24.5 %) and Mitsubishi Materials Corporation (12.25 %). In 2013, Dow Corning Corporation bought the Mitsubishi Materials Corporation share, increasing its own share to 75.5 %.

In 2007, the company had an annual production capacity of 10 000 tonnes of polycrystalline silicon, and production at the expanded Hemlock site (19 000 tonnes) started in June 2008. A further expansion at the Hemlock site, as well as a new factory in Clarksville (Tennessee) United States, began in 2009. Total production capacity was expanded to 56 000 tonnes in 2012, but the Clarksville factory was closed due to overcapacities in the market in 2014. For 2016, a production capacity of 36 000 tonnes and actual production in the range of 20 000 tonnes was estimated.

#### **4.3.6 China Silicon Corporation Ltd. (China)**

China Silicon Corporation Ltd. (Sinosico: <http://www.sino-si.com/eng/home.aspx>) was established in March 2003, with headquarters in the High-tech Development Zone, Luoyang City, Henan province. In June 2003, the company began with the construction of Phase I of a polysilicon production project with 300 tonnes per year. Since then the production capacity has been increased stepwise and was about 16 000 tonnes at the end of 2016. For 2016, a production of 15 000 tonnes was estimated.

In January 2009, the National Development and Reform Commission officially approved the establishment of a National Engineering Laboratory for polysilicon by Sinosico. On 22 January 2010, the National Key Engineering Laboratory for polysilicon production was officially opened.

#### **4.3.7 Sichuan Yonxiang Co. Ltd. (PRC)**

Yonxiang (<http://www.scyxgf.com>), is a subsidiary of Tongwei and located in Leshan City, Sichuan Province. The company's main business includes the production of high purity silicon, polyvinyl chloride (PVC) and the utilization of carbide slag cement. According to the company they have production capacity of 20 000 tonnes of polysilicon and started an expansion project of 50 000 tonnes together with Longi Green Energy Technology in June 2017. The production in 2016 was estimated at 15 000 tonnes.

#### **4.3.8 Daqo New Energy Co. Ltd. (China)**

Daqo New Energy (<http://www.dqsolar.com/>) is a subsidiary of the Daqo Group and was founded by Mega Stand International Ltd. in January 2008. Initially, the company built a high-purity polysilicon factory in Wanzhou, China, with an annual output of 3 300 tonnes in the first phase. The first polysilicon production line, with an annual output of 1 500 tonnes, started operating in July 2008. Production capacity in 2009 was 3 300 tonnes and had reached more than 4 300 tonnes by the end of 2011. According to the company, production capacity at the end of 2013 was 6 150 tonnes and an expansion of the capacity to 12 150 was achieved at the end of September 2015. A further expansion of the capacity to 18 000 tonnes was finished and started production in 1Q 2017. In

addition, the company manufactures wafers and had a capacity of 100 million at the end of 2016. The company reported a production of 13 067 tonnes of polysilicon and sales of 10 883 tonnes of polysilicon 82.4 million of wafers in 2016.

#### **4.3.9 REC Silicon ASA (Norway/USA)**

REC Silicon (<http://www.recsilicon.com>) is headquartered in Moses Lake, Washington, USA, and has production facilities in Moses Lake and Butte, Montana. The company resulted from the 2013 split of Renewable Energy Corporation into two companies: REC Solar ASA and REC Silicon ASA. In 2005, the Renewable Energy Corporation took over Komatsu's US subsidiary Advanced Silicon Materials LLC (ASiMI), and announced the formation of its silicon division business area, REC Silicon Division, comprising the operations of REC ASiMI and REC Solar Grade Silicon LLC. At the beginning of 2014, the company announced the formation of a joint venture with Shaanxi Non-Ferrous Tian Hong New Energy Co. Ltd. in China. This joint venture includes the development of an 18 000-tonne fluidised bed reactor (FBR-B) production facility.

Production capacity at the end of 2016 was about 16 000 tonnes and, according to the company, a total of 10 729 tonnes of polysilicon, were produced in 2016. The significant production decrease in 2016 was due to the curtailment of the Moses Lake plant as a consequence of the trade dispute between China and the USA.

#### **4.3.10 Tokuyama Corporation (Japan)**

Tokuyama (<http://www.tokuyama.co.jp/>) is a chemical firm involved in the manufacturing of solar-grade silicon, the base material for solar cells. According to the company, it had an annual production capacity of 5 200 tonnes in 2008 and expanded this to 9 200 tonnes in 2010. In February 2011, the company began building a new 20 000-tonne facility in Malaysia. The first phase for 6 200 tonnes started a trial production in March 2013 and the second phase for 13 800 tonnes started production in October 2014. In September 2016, OCI announced its decision to acquire new shares of Tokuyama's Malaysian subsidiary for polysilicon production [Oci 2016]. The takeover of the facility by OCI was finalized in May 2017.

A production capacity of 22 000 tonnes was reported for FY 2016 and 8 200 tonnes for FY 2017 [Ikk 2017].

## 4.4 Solar-cell production companies

In 2016, more than 100 companies still produce solar<sup>43</sup> cells down from the 350 active in 2013. The solar-cell industry has been very dynamic over the last decade, and each status report is only a snapshot of the current situation, which can change in just a few weeks. The nameplate capacity of solar cell manufacturing capacity was over 90 GW at the end of 2016 and could increase to 110 GW at the end of 2017.

The following section gives a short description of the 20 largest companies, in terms of actual production/shipments in 2016. More information about other solar cell companies can be found in various commercial market studies. The capacity, production or shipment data are from the annual reports or financial statements either of the respective companies or the references cited.

### 4.4.1 Hanwha (South Korea/China/Germany/Malaysia)

The Hanwha Group (<http://www.hanwha.com>) acquired a 49.99 % share in Solarfun Power Holdings in 2010 and the name was changed to Hanwha SolarOne in January 2011. It produces silicon ingots, wafers, solar cells and solar modules. The first production line was completed at the end of 2004 and commercial production started in November 2005. The company went public in December 2006 and reported the completion of its production capacity expansion to 360 MW in the second quarter of 2008.

In August 2012, Hanwha acquired Q CELLS (Germany/Malaysia), which had filed for insolvency in April 2012. In February 2015, the Hanwha SolarOne brand was dropped and became a part of Hanwha Q CELLS. After the closure of the manufacturing facilities in Germany in March 2015, a 60 MW cell production line remained as a R & D facility. At the end of 2016, Hanwha, with its two brands Hanwha Q CELLS and Hanwha Q CELLS Korea Corp., had a combined production capacity of 5.7 GW of solar cells and modules (2.4 GW in China, 1.75 GW in Malaysia and 1.55 in Korea) as well as 1.55 GW of ingot and 950 MW of wafer manufacturing capacity in China. In 2017 the solar cell and module capacity is increased to 6.8 GW.

For 2016, Hanwha Q CELLS reported a solar cell production of 3.86 GW (China and Malaysia only) and solar module shipments of 4.58 GW. The difference in cells was probably manufactured at the Korean plant. In March 2017, the company reported that a consortium consisting of Hanwha Q CELLS and Kalyon Enerji Yatirimlari A.S. has been awarded the tender to construct a solar power plant with 1 GW in Turkey. As part of the award criteria, the consortium will build a fully integrated solar cell and module factory with a capacity of 500 MW within the next 21 months.

### 4.4.2 JA Solar Holding Co. Ltd. (China)

JingAo Solar Co. Ltd. (<http://www.jasolar.com>) was established in May 2005 by the Hebei Jinglong Industry and Commerce Group Co. Ltd., the Australia Solar Energy Development Pty Ltd. and the Australia PV Science and Engineering Company. Commercial operations started in April 2006 and the company went public on 7 February 2007. According to the annual report of the company, the production capacity was 5.5 GW for cells and modules and 2.5 GW for wafers at the end of 2015. For 2017, an increase of the cell to 7 GW, module to 6 GW and wafers to 3 GW manufacturing capacity each is foreseen. Total sales for 2016 were reported with 4.9 GW (4.6 GW modules and 300 MW cells). It is estimated, that about 4.5 to 4.6 GW of solar cells were produced in 2016.

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<sup>43</sup> Solar-cell production capacities mean:

- In the case of wafer silicon-based solar cells, only the cells,
- In the case of thin films, the complete integrated module,
- Only those companies which actually produce the active circuit (solar cell) are counted,
- Companies which purchase these circuits and make cells are not counted.



#### **4.4.3 Trina Solar Ltd. (China)**

Trina Solar (<http://www.trinasolar.com/>) was founded in 1997 and went public on NASDAQ in December 2006. In March 2017 the company completed its Going-Private transaction, a move which is thought to be a preparation to go public in China at a later stage.

The company has integrated product lines, from ingots to wafers and modules. In December 2005, a 30 MW monocrystalline sili-con wafer product line went into operation. In February 2016, Trina completed the acquisition of all the assets from Solland Solar, with approximately 200 MW solar cell manufacturing capacity located in Heerlen, the Netherlands [Tri 2016]. A local newspaper reported that production in Heerlen stopped in January 2017 and the equipment was shipped to China [Gro 2017].

In March 2016 the company announced the official launch of operations at its new manufacturing facility in Thailand. The factory has a solar cell manufacturing capacity of 700 MW and a module manufacturing capacity of 500 MW, which can be ramped up to over 600 MW depending on future demand.

According to the company's last public quarterly report, the production capacity at the end of September 2016 was 1.8 GW for wafers, 2.3 GW for ingots and 5 GW for cells, and 6 GW for modules. Module and system deliveries of 4.5 GW were reported for the first three quarters of 2016. A solar cell production of 4.2 to 4.3 GW was estimated for 2016.

In January 2010, the company was selected by the Chinese Ministry of Science and Technology to establish a State Key Laboratory (SKL) to develop PV technologies within the Changzhou Trina PV Industrial Park. The laboratory is being established as a national platform for driving PV technologies in China. Its mandate includes research into PV-related materials, cell and module technologies and system-level performance. It will also serve as a platform for bringing together technical capabilities from the company's strategic partners, including customers and key PV component suppliers, as well as universities and research institutions.

#### **4.4.4 JinkoSolar Holding Co. Ltd. (China)**

JinkoSolar (<http://www.jinkosolar.com/>) was founded by Hongkong Paker Technology Ltd. in 2006. Starting from the upstream business, in 2009, the company expanded its operations across the solar value chain, including recoverable silicon materials, silicon ingots and wafers, solar cells and modules. In May 2010, it went public and was listed on the New York Stock Exchange. According to the company, it had manufacturing capacities of 5 GW for wafers and 4 GW for solar cells (3.1 GW in China, 400 MW in Malaysia) and 7.5 GW for solar modules at the end of 2016. A capacity increase to 7.5 GW for wafers, 4.5 GW for cells and 8 GW for modules is planned in 2017. For 2016, the company reported module shipments of 6.65 GW. It is estimated that 3.5 to 3.6 GW of solar cells were manufactured in 2016.

#### **4.4.5 First Solar LLC (USA/Malaysia)**

First Solar LLC (<http://www.firstsolar.com>) is one of the few companies worldwide to produce CdTe thin-film modules. It currently has two manufacturing sites — in Perrysburg (United States) and Kulim (Malaysia) — which, at the end of 2016, had a combined capacity of about 3.3 GW. In Q2 2017, the company reported an average module efficiency of 16.6 %. For 2016, the company reported a production of 3.1 GW, shipments of over 2.7 GW and 7 GW under O&M contracts [Fir 2017].

At the end of 2016, the company started to transform their production lines from the current Series 4 module with an area of 0.72 m<sup>2</sup> (approx. 120 W) to the Series 6 modules with an area of 2.4 m<sup>2</sup> (> 420 W). The first series 6 production lines are scheduled to come online towards the end of 2017 and series 4 production should be phased out in 2018.

#### **4.4.6 Motech Solar (Taiwan/China)**

Motech Solar (<http://www.motech.com.tw>) is a wholly owned subsidiary of Motech Industries Inc., located in the Tainan Science Industrial Park. The company started its mass production of polycrystalline solar cells at the end of 2000, with an annual production capacity of 3.5 MW. Production increased from 3.5 MW in 2001 to 1 GW in 2011. In 2009, Motech started the construction of a factory in China, which reached its nameplate capacity of 500 MW in 2011. In December 2014, Motech and Topcell Solar International Co., Ltd. agreed to merge [Mot 2014]. The merger was completed by June 2015. In September 2015, the company announced that its subsidiary, Motech (Suzhou) Renewable Energy Co., Ltd agreed to a strategic partnership with Jiansu Aide Solar Energy Technology Co. [Mot 2015].

Total production capacity at the end of 2016 was reported as 3.2 GW (1.06 GW China and 2.14 GW Taiwan), and an increase to 3.6 GW is foreseen in 2017. Total solar cell shipment of 2.94 GW was reported.

#### **4.4.7 Tongwei Solar (Hefei) Co., Ltd. (China)**

Tongwei Solar (<http://www.tw-solar.com/en/>) is part of the Tongwei Group, a private company with core business in agriculture and new energy and was set up in 2013. In 2011, Tongwei Group signed an integrated PV strategic cooperation agreement with Xinjiang Government, which included 50 000 tonnes solar-grade polysilicon project, 3 GW solar wafer and solar cell project, as well as 5 solar plants of 350 MW.

The subsidiary Sichuan Yonxiang Co. Ltd. is located in Leshan City, Sichuan Province and has a production capacity of for polycrystalline silicon of 20 000 tonnes. An expansion project of 50 000 tonnes was started as a joint venture with Longi Green Power in June 2017.

Tongwei Solar reports an annual production capacity of 3.8 GW for solar cells and 350 MW for solar modules. In January 2017, the company signed contracts for a solar cell production increase of 4 GW, of which 2 GW should be operational at the end of 2017. It is estimated that the company had a solar cell production of 2.5 GW in 2016.

#### **4.4.8 Risen Energy Co., Ltd. (China)**

Risen Energy (<http://www.risenenergy.com/en/>) was founded in 1986, and is located in Ninghai, Zhejiang. The company went public on the Shenzhen Stock Exchange on 2 September 2010. According to the company, it had a manufacturing capacity of solar cells and modules of 3.1 GW each at the end of 2016 and 4.5 GW in the third quarter of 2017. It is estimated that about 2.4 to 2.5 GW of solar cells and modules were produced in 2016.

#### **4.4.9 Canadian Solar Inc. (Canada/China)**

Canadian Solar (CSI) (<http://www.canadian-solar.com/>) was founded in Canada in 2001 and listed on NASDAQ in November 2006. CSI has established six wholly owned manufacturing subsidiaries in China, manufacturing ingot/wafer, solar cells and solar modules. According to the company, at the end of 2016 it had 400 MW of ingot capacity, 1.0 GW of wafer capacity, 2.4 GW cell capacity and 6.2 GW module manufacturing capacity (4.7 GW in China, 1.1 GW in South-East Asia, 360 MW in Brazil and 30 MW in Ontario, Canada). In 2017, the solar cell manufacturing capacity should be increased to 4.7 GW, the module manufacturing capacity to 7.2 GW, wafer to 4 GW and ingots to 1.1 GW. For 2016, the company reported shipments of 5.2 GW of modules. The solar cell production was estimated at 2.3 GW. At the end of June 2017, the company reported operation and ownership of PV power plants with 1.26 GW and contracted projects with 880 MW.

#### **4.4.10 Yingli Green Energy Holding Co. Ltd. (China)**

Yingli (<http://www.yinglisolar.com/>) went public on 8 June 2007. The main operating subsidiary, Baoding Tianwei Yingli New Energy Resources Co. Ltd, is located in the Baoding National High-tech Industrial Development Zone. The company's operations include solar wafers, cell manufacturing and module production. According to the firm, production capacity was 1.85 GW at the end of 2011. In its annual report, it reported that, by the end of 2016, it had a production capacity of 3 GW for ingots and wafers, 3.2 GW for solar cells and 4 GW for solar modules. Total reported shipments of solar modules for 2016 were 2.2 GW. Due to its OEM manufacturing activities for third parties the solar-cell production is estimated at 2.3 GW for 2016.

In January 2010, China's Ministry of Science and Technology approved an application to establish a national-level key laboratory in the field of PV technology development, the SKL of PV Technology, at Yingli Green Energy's manufacturing base in Baoding.

#### **4.4.11 Shunfeng International Clean Energy Ltd. (China/Germany/USA)**

Shunfeng Int. (<http://sfcegroup.com/en/>) is a Holding Company registered in Hong Kong. According to the company, its mission is to create a low-carbon environment. The Group is a fully integrated PV service provider engaging in solar power stations constructions and operations, solar products manufacturing as well as solar energy storage.

The group has a number of subsidiaries, which are fully or partially owned:

100 % ownership: Jiangsu Shunfeng Photo-voltaic Technology Co., Ltd. (PRC), Wuxi Sun-tech Power Co., Ltd. (PRC), S.A.G. Solarstrom Group (Germany), Sunways AG (Germany)

Partly ownership: 63 % in Suniva (USA), 30 % in Powin Energy Corporation (USA), 28 % in Shanghai Everpower Power Technology Co., Ltd. (PRC).

According to the annual Report 2016, the annual production capacity of solar modules and solar cells, was approximately 2.4 GW and 2.3 GW respectively. The solar power generation business had a grid-connected annual designed installed capacity, of 1 600 MW. For 2016, a total shipment of 1.44 GW solar modules and 1.47 GW of solar cells was announced with. Solar cell production was estimated at 2.2 GW.

#### **4.4.12 Longi Solar (China)**

Longi Solar (<http://en.longi-solar.com>) is a subsidiary of Longi Group and was founded in 2000. The company focuses on monocrystalline solar cell and module production. According to the company they had a manufacturing capacity of 7.5 GW for ingots and wafers, 5 GW for solar modules and 2.5 GW for solar cells in 2017. It is estimated that the company manufactured about 2 GW of solar cells in 2016.

#### **4.4.13 Neo Solar Power Corporation (Taiwan)**

Neo (<http://www.neosolarpower.com/>) Solar Power was founded in 2005 by Powerchip Semiconductor, Taiwan's largest DRAM company, and went public in October 2007. The company manufactures mono- and multicrystalline silicon solar cells. In 2013, it merged with DeSolar to become the largest Taiwanese cell producer. Since the end of 2014, total installed manufacturing capacity was 2.2 GW for silicon solar cells (400 MW in China, 1.8 GW in Taiwan) and 480 MW for modules. In 2016, the company increased its module capacity to 670 MW. Solar cell production is estimated at 1.9 GW in 2016.

#### **4.4.14 Gintech Energy Corporation (Taiwan/Thailand)**

Gintech (<http://www.gintech.com.tw/>) was established in August 2005 and went public in December 2006. Solar cell production at Factory Site A, Hsinchu Science Park, began in 2007 with an initial production capacity of 260 MW and increased to 1 450 MW and 350

MW in Thailand at the end of 2015. The capacity is planned to be increased to 750 MW in Thailand during 2016. In July 2015, the company announced a strategic partnership with Tongwei Solar to work together and increase the capacity to 1 GW of solar cell capacity and 450 MW of solar module capacity at Gintech (Thailand) [Gin 2015]. For 2016, a solar cell production of about 1.5 to 1.6 GW was estimated.

#### **4.4.15 Changzhou EGing Photovoltaic Technology Co. Ltd. (China)**

EGing PV (<http://www.egingpv.com/>) was founded in 2003 and operates along the complete PV industry value chain, from the production of monocrystalline furnaces, quartz crucibles, 5-8 inch monocrystalline silicon ingots, supporting equipment for squaring and wire sawing, monocrystalline silicon wafers, solar cells and solar modules. According to the annual report, at the end of 2011, the company had a production capacity of 1 GW across the complete value chain of ingots, wafers, cells and modules. Solar cell and module production capacity is reported with about 2 GW in mid 2017. A solar cell production of 1.5 GW was estimated for 2016.

#### **4.4.16 Suzhou Talesun Solar Technologies CO. Ltd. (China/Thailand)**

Talesun Solar (<http://www.talesun-eu.com/>) was established in 2010 as a wholly owned subsidiary of Zhongli Sci-tech Group. According to the company, it currently has an annual capacity of 1.8 GW of solar cells (1 GW in China and 0.8 GW in Thailand) and 2.8 GW of modules (2 GW in China and 0.8 GW in Thailand). On 2 December 2015, the company started its commercial production of solar cells and modules with a capacity of 300 MW in Rayong, Thailand [Tal 2015]. In house solar cell production is estimated at 1.4 to 1.5 GW.

#### **4.4.17 Solarworld AG (Germany/USA)**

Since its founding in 1998, Solar World changed from a solar system and components dealer to a company covering the whole PV value chain, from wafer production to system installations.

At the end of 2016, production capacities were as follows: 750 W ingots (500 MW USA, 250 MW Germany), 1.5 GW wafers (500 MW USA, 1 GW Germany), 1.5 GW solar modules (550 MW USA, 950 MW Germany) and 1.5 GW solar cell (500 MW USA, 1 GW Germany). In 2016 total shipments were reported with 1.38 GW and a cell production of 1.35 GW is estimated.

The company filed for insolvency on 10 May 2017. As part of the insolvency proceedings, the German manufacturing assets in Saxony and Thuringa were taken over by the newly founded SolarWorld Industries GmbH, a private company, which is majority owned by former founder and chairman of SolarWorld AG, Frank Asbeck and another key investor in the bankrupt firm, Qatar Solar Technologies (QST). Manufacturing restarted in August 2017. The new company has approximately 600 MW of mono ingot/wafer capacity and 1 GW of nameplate cell and module capacity.

The American part of the company, Solar-World Americas Inc., was not affected by the insolvency and operates now as an independent entity.

#### **4.4.18 Inventec Solar Energy Corporation (China)**

Inventec Solar (<http://www.inventecsolar.com>) was established by Inventec Group and WIN semiconductor as a joint venture in 2010. The company started its silicon solar cell production in 2011 and increased its production capacity of solar cells stepwise to reach 1.6 GW at the end of 2016. For 2016 a solar cell production of 1.2 GW is reported.

#### **4.4.19 Aiko Solar Energy Technology Co., Ltd. (China)**

Aiko Solar (<http://enaik.ztouch-make-hn-16255.shushang-z.cn/>) was founded in 2009 and is located in Foshan City, Guangdong Province. Commercial solar cell production

started in June 2010, with a 120 MW capacity and the expansion to 240 MW was completed in March 2011. According to the company, it had a solar cell capacity of 1.65 GW at the end of 2016 and an expansion of 2.65 GW will be operational at the end of 2017. Early 2017, the company announced plans to expand its production capacity to over 8 GW of solar cells by 2022. For 2016 a solar cell production of 1.2 GW is estimated.

#### **4.4.20 Hareon Solar Technology Co. Ltd. (China)**

Hareon Solar (<http://www.hareonsolar.com>) was set up as the Jiangyin Hareon Technology Co. Ltd in 2004 and changed its name to the Hareon Solar Technology Co. Ltd. in 2008. It has five manufacturing facilities in both Jiangsu and Anhui province, including Jiangyin Hareon Power Co. Ltd., Altusvia Energy (Taicang) Co. Ltd., Hefei Hareon Solar Technology Co. Ltd., Jiangyin Xinhui Solar Energy Co. Ltd. and Schott Solar Hareon Co. Ltd. Solar-cell production started in 2009, with an initial capacity of 70 MW. According to the company, the current production capacity is 2 GW annually for ingot casting, wafers, cells, and modules. For 2016, a solar cell production of 1.18 GW and 2.1 GW of modules was reported.

## 5 Conclusions and outlook

In 2016, new investments in renewable energy projects (excluding large hydro-electric power plants) declined by 21% to USD 244 billion (EUR 222 billion ) compared to 2015. However, this was still about double the amount invested in conventional power projects. Despite this decline, the total new installed renewable power capacity (excluding large hydro) increased from 127.5 GW in 2015 to a record of 138.5 GW in 2016 and solar power accounted for over 56% of this capacity [Blo 2017, FSU 2017]. This record installation of new renewable power capacity was made possible by the significant reductions in renewable energy system prices, especially solar PV.

Even more impressive is the fact that 55 % of all new power generating capacity connected came from renewable energy excluding large hydro. The total of renewable power capacity (excluding large hydro) at the end of 2016 stood at 938 GW (2 017 GW including large hydro) and generated 2 395 TWh of electricity (6490 TWh including large hydro) worldwide. The share of electricity provided by renewable energy sources (excluding large hydro) increased from 10.3 in 2015 to 11.3% in 2016.

In 2016, R&D trends for governmental and industrial spending were opposite. While the first increased by 25% to USD 5.5 billion (EUR 5 billion), the second decreased by almost 40% to USD 2.5 billion (EUR 2.3 billion).

For the 7th year in a row, solar power attracted the largest share of new investments in renewable energies. The USD 113.7 billion (EUR 103.4 billion) investments in solar energy, accounted for 46 % of all new renewable energy investments. Despite a 34 % annual decrease of total global investment in solar energy the newly installed capacity of solar photovoltaic power increased by 38% to over 79 GW in 2016. This capacity represents more than half of all new renewable power capacity installed in 2016. However, one has to keep in mind that a substantial part of solar projects closed their financing already in 2015 but were commissioned in 2016. In such cases the investment is counted for 2015, but the capacity addition is associated with 2016.

The developing countries kept their lead in new investments in solar energy, whereas for all renewable energies the developed countries regained the lead.

Despite a 32% decline in new renewable energy investment, China kept the lead with USD 78.3 billion (EUR 71.2 billion), followed by the USA with USD 46.4 billion (EUR 42.2 billion) and the United Kingdom with USD 24.0 (EUR 21.8 billion), while Japan saw a decline by 56% and moved to fourth place with USD 14.4 billion (EUR 13.1 billion).

Contrary to the general trend, renewable energy investments in Europe slightly increased by 1 % to USD 58.8 billion (EUR 53.5 billion) in 2016. This was due to a 53% increase in spending for offshore wind installations, which accounted for almost half of renewable energy spending or USD 28.9 billion (EUR 26.3 billion).

The PV industry has changed dramatically over the last few years. China has become the major manufacturing country for solar cells and modules, followed by Taiwan and Malaysia. Amongst the 20 biggest cell/thin-film PV manufacturers in 2016, only one had solar cell production facilities in Europe, Solarworld (Germany/USA).

If Europe wants to regain a double digit market share of the solar cell manufacturing industry, a major industry policy effort is needed to revitalise the European PV manufacturing industry. Europe still has an excellent PV R & D infrastructure along the value chain, but it will only be possible to maintain this in the long run if industry players along this value chain, including PV manufacturing, are operating in Europe.

The focus of this report is on solar cells and modules, with some additional information about the supply of polysilicon. Therefore, it is important to remember that the PV industry consists of more than that, and simply looking at cell production does not give the whole picture of the complete PV value chain. Besides the information here about the manufacturing of solar cells, the whole upstream industry (e.g. materials, polysilicon

production, equipment manufacturing) and downstream industry (e.g. inverters, BOS components, system development, installations) must also be examined.

In 1990, implementation of the 100 000 roofs programme in Germany, and the Japanese long-term strategy set in 1994, with a 2010 horizon, marked the beginning of extraordinary growth in the PV market. Before the start of the Japanese market implementation programme in 1997, annual growth rates were about 10 % in PV markets, driven mainly by communication, industrial and stand-alone systems. Since 1990, PV production has increased by three orders of magnitudes, from 46 MW to over 80 GW in 2016. This corresponds to a CAGR of more than 40 %. In 2016, statistically documented cumulative installations worldwide accounted for 315 GW.

The temporary shortage in silicon feedstock between 2004 and 2008, resulted in the market entrance of new companies and technologies. New production plants for polysilicon, advanced silicon-wafer production technologies, thin-film solar modules and technologies, such as concentrator concepts, were introduced into the market much faster than was expected a few years ago. However, the dramatic price decline for polysilicon and solar modules, triggered by the overcapacity of solar modules and polysilicon, has put enormous economic pressure on a large number of companies and is forcing the consolidation of the industry. The benchmark was set by the Chinese Ministry of Industry and Information Technology when in February 2012 it announced that it was aiming for an industrial consolidation of those companies with a polysilicon production capacity of at least 50 000 tonnes, and solar-cell manufacturers with at least a 5 GW production capacity by 2015 [MII 2012].

Companies with limited financial resources and restricted access to capital are particularly struggling in the current market environment. In 2013/2014, it was expected that the then existing overcapacity in the polysilicon, solar-cell and module manufacturing industry could ease by 2015, when the global PV market should exceed 50 GW per annum. However, the slight increase in profit margins, which could be observed in 2014/2015 immediately led to the market entry of new players, which contributed to the new overcapacity in the sector. The current anticipated growth of annual installations is based on the growth of new markets outside Europe, especially in China, South East Asia, India, Middle East and South America.

Despite the ongoing economic difficulties and political uncertainties, the number and volume of new PV markets worldwide is increasing. In addition, there are a growing number of large investors who are steadily increasing their investments in renewable energy and solar PV, like Warren Buffet, or even de-investing in fossil energy companies and shifting this investment to renewable energy, as announced by the Rockefeller Brother Fund before the UN Climate Summit 2014 [BBC 2014]. Alongside the overall rising energy prices and the need to stabilise the climate, this will continue to keep the demand for solar-power systems high. In the long term, growth rates for PV will continue to be high, even if economic conditions vary locally and lead to a short-term downturn in some of the markets.

This view is shared by an increasing number of financial institutions, which are turning to renewables as a sustainable and stable long-term investment. Even if the oil prices have retreated from their record highs in 2008, when they were close to USD 150/bbl, their volatility, possible by supply disruptions caused by political uncertainties or natural disasters is causing an economical risk.

In addition, the fact that the Paris Agreement entered into force on 4 November 2016 gives an additional impetus to decarbonise our electricity supply and attracts additional investments in renewable and in particular PV power [UNFC 2016].

Already in 2010, the Energy Watch Group estimated that worldwide spending on combustibles, fuels and electricity was between USD 5 500 billion (EUR 4 231 billion) to USD 7 500 billion (EUR 5 769 billion) in 2008 [Ewg 2010]. In 2015, the International Monetary Fund (IMF) published a working paper outlining the political importance of energy subsidy reforms reflecting the need for countries to pledge carbon reductions

ahead of the Paris 2015 United Nations Climate Change Conference in December 2015 [IMF 2015]. According to the findings of this study, post-tax energy subsidies are dramatically higher than previously estimated USD 4.9 trillion (EUR 3.8 trillion) or 6.5 percent of global GDP in 2013, and it was projected that it would reach USD 5.3 trillion (EUR 4.7 trillion) or 6.5 % of global GDP in 2015. These figures are much higher than the 2.5 % of global GDP published in a 2013 study by the same institution [IMF 2013a] and about 10 times the amount the IEA presents in the World Energy Outlook 2016 as direct subsidies for fossil fuels (USD 325 billion in 2015) [IEA 2016b].

As early as 2010, the Financial Times cited Fatih Birol, then Chief Economist at the IEA in Paris, saying that removing subsidies was a policy that could change the energy game 'quickly and substantially'. 'I see fossil fuel subsidies as the appendicitis of the global energy system which needs to be removed for a healthy, sustainable development future,' he told the newspaper [FiT 2010].

This was in line with the findings of a 2008 UNEP report Reforming Energy Subsidies [UNEP 2008], which concluded: 'Energy subsidies have important implications for climate change and sustainable development more generally through their effects on the level and composition of energy produced and used. For example, a subsidy that ultimately lowers the price of a given fuel to end-users would normally boost demand for that fuel and the overall use of energy. This can bring social benefits where access to affordable energy or employment in a domestic industry is an issue, but may also carry economic and environmental costs. Subsidies that encourage the use of fossil fuels often harm the environment through higher emissions of noxious and greenhouse gases. Subsidies that promote the use of renewable energy and energy-efficient technologies may, on the other hand, help to reduce emissions.'

The 2013 energy subsidies of USD 4.9 trillion, would have been sufficient to install 1 270 GW of PV systems at 2013 PV system prices able to generate 1 500 TWh of electricity or 6.6 % of the global electricity demand. For 2016, the figures are even more breathtaking as system prices have decreased significantly. With the assumption of a 60:40 % split between utility scale and residential PV plants the energy subsidies of USD 5.3 trillion could have been used to install 2 800 GW of utility PV plants and 1 100 GW of residential PV systems in 2016. Together these PV systems would be able to generate about 4 600 TWh of electricity or about 21 % of global electricity demand. Compared to this, actual PV installations stood at 315 GW at the end of 2016.

Following the massive cost reductions for the technical components of PV systems, like modules, inverters, BOS, etc., the next challenge is to lower the soft costs of PV system installations, such as the permits and financing costs. Despite the fact that PV system components are global commodity products, the actual prices for installed PV systems vary significantly. In the second quarter of 2017, the average system price for residential systems was about EUR 1.41/Wp (USD 1.70/Wp) in Germany, but between USD 2.88 and 4.28/Wp (EUR 2.40 and 3.60/Wp) in the USA and Japan [Blo 2017a, Fel 2017, Pvi 2017]. Competition and an increasing number of experienced installers are bringing costs further down.

In some countries, like Germany or Italy, the installed PV capacity already exceeds 30 % and 20 % of the installed thermal power plant capacities, respectively. Together with the respective wind capacities, wind and solar together will exceed 60 % and 30 %, respectively. To handle these high shares of renewable electricity effectively, new technical and regulatory solutions have to be implemented to avoid running into the problem of curtailing large parts of this electricity. Besides conventional pumped storage options, electrical batteries are becoming increasingly interesting, especially for small-scale storage solutions in the low-voltage distribution grid. According to BNEF, prices for battery packs for electric vehicles have declined from about USD 1 000/kWh in 2010 to below USD 227/kWh in H2 2016 [Blo 2015, Mck 2017]. Lithium-ion batteries have an average of 5 000 cycles, and with the above cost estimates, this would correspond to net kWh costs component for the full used battery pack of USD 0.045/kWh (EUR 0.038/kWh) and should fall to USD 0.02/kWh (EUR 0.017/kWh) by 2020.



However, batteries are only a part of the storage solution. Another important cost factor is the control electronics needed to combine the storage with a PV system and the grid. Currently, this part remains the dominant factor, but can be integrated into the inverter and will come down in price when the production volume increases. At the moment, residential PV systems with storage are still more than twice as expensive as PV systems without storage. On the other hand, in terms of size, electricity storage systems for PV systems can be compared with the PV market situation of about 10 to 12 years ago.

With benchmark LCOE from PV systems between USD 54 and 171/MWh (EUR 45 and 143/MWh) in the second quarter of 2016 [Blo 2017b], the additional storage costs already make sense in markets with high peak costs in the evening, where a shift of only a few hours is required. As early as February 2012, BYD (Build your Dreams) and the State Grid Corporation of China (SGCC) finished the construction of a large-scale utility project located in Zhangbei, Hebei Province, which combines 100 MW of wind power, 40 MW of solar PV electricity system, and 36 MWh of lithium-ion energy storage. It is interesting to note that the batteries used in this system are lithium-ion car batteries, which were used before in the BYD 36 taxi for about 4 000 cycles [Che 2014].

According to investment analysts and industry prognoses, solar energy will continue to grow at a high rate in the coming years. The different PV industry associations, as well as Greenpeace and the IEA, have developed new scenarios for the future growth of PV systems. Table 6 shows the different scenarios in the Greenpeace study, BNEF New Energy Outlook 2016 and 2017, the 2014 IEA PV Technology Roadmap and the 2015 and 2016 IEA World Energy Outlook (WEO) scenarios [Blo 2016a, 2017c, Gre 2015, IEA 2014a, 2015, 2016b]. Older scenarios can be found in the previous PV Status Reports [Jäg 2013, 2014b].

It is of interest to note that within a year the IEA scenarios in the 2016 WEO have increased the cumulative installed capacity by 17 to 23 % for 2020 and 24 to 36 % by 2030 compared to the figures given in the WEO 2015. With forecasts for new PV system installations between 280 and 310 GW from 2017 to 2019, even the high value scenarios are not unlikely to be reached [Blo 2017a].

**Table 3:** Evolution of the cumulative solar electrical capacities until 2050

Year	2016 [GW]	2020 [GW]	2025 [GW]	2030 [GW]	2040 [GW]
<b>Actual installations</b>	<b>315</b>				
Greenpeace (reference scenario)		332	413	494	635
Greenpeace ([r]evolution scenario)		732	1 603	2 839	4 988
BNEF New Energy Outlook 2016	307	578	1 046	1 831	3 917
BNEF New Energy Outlook 2017	319	651	1 077	1 740	4 499
IEA PV Technology Roadmap <sup>(1)</sup> (hi-Ren Scenario)		450	790	1 721	4 130
IEA 2015 Current Policy Scenario		361	420	569	773
IEA 2015 New Policy Scenario		397	560	728	1 066
IEA 2015 450 ppm Scenario		420	605	938	1 519
IEA 2016 Current Policy Scenario		424	592	708	991
IEA 2016 New Policy Scenario		481	715	949	1 405
IEA 2016 450 ppm Scenario		517	833	1 278	2 108

(1) 2020, 2025 and 2040 values are extrapolated, as only 2013, 2030 and 2050 values are given

[Blo 2016a, 2017c, Gre 2015, IEA 2014a, 2015a, 2016b]

These projections show that there are huge opportunities for PV in the future if the right policy measures are taken, but we have to bear in mind that such a development will not happen by itself. It will require the sustained effort and support of all stakeholders to implement the envisaged change to a sustainable energy supply with PV delivering a major part. The main barriers to such developments are perception, regulatory frameworks and the limitations of the existing electricity transmission and distribution structures.

In the Energy Technology Perspectives (ETP) 2017 the IEA states that "The investment costs associated with the 2DS across the power, buildings and transport sectors, and within the energy-intensive industries, would not require unreasonable additional financial contributions from the global economy" [IEA 2017b]. According to the ETS, the shift from a 2 °C scenario (2DS) to a 1.75 °C scenario (B2DS) in order to fulfil the pledge of the Paris Agreement would require a full decarbonisation of the power sector well before 2050.

The investments in the power sector to realise B2DS would require USD 23 trillion (EUR 19.2 billion) or 0.2% of the cumulative global GDP between 2017 and 2060 compared to USD 16.7 trillion (EUR 13.92 trillion) (0.15% GDP) for the 2DS.

It is interesting to note that the investment volume has decreased significantly compared to the estimates in 2014 [IEA 2014b]. At that time, the investment need were given with USD2012 39.6 trillion (EUR 30.5 trillion) for the 2DS and USD2012 30.5 trillion (EUR 23.5 trillion) for the 6DS scenario.

Due to the long lifetime of power plants (30 to 50 years), the decisions taken now will influence key socioeconomic and ecological factors in our energy system in 2020 and beyond.

The solar PV scenarios given above will only be possible if solar cell and module manufacturing are continuously improved and novel design concepts are realised, since the current technology's demand for certain materials, like silver, would dramatically increase the economic costs of this resource within the next 30 years. Research to avoid such problems is under way and it is expected that such bottlenecks will be avoided.

The PV industry is transforming into a mass-producing industry with its sights on multi-GW production sites. This development is linked to increasing industry consolidation, which presents both a risk and an opportunity at the same time. If the new large solar-cell companies use their cost advantages to offer products with a power output guaranteed for over 30 years, and at reasonable prices, then PV markets will continue their accelerated growth. This development will influence the competitiveness of small and medium-sized companies as well. To survive the price pressure of the very competitive commodity mass market, and to compensate for the advantages enjoyed by big companies through the economies of scale that come with large production volumes, smaller businesses will have to specialise in niche markets offering products with high value added or special solutions tailor-made for customers. The other possibility is to offer technologically more advanced and cheaper solar-cell concepts.

The global world market, dominated by Europe in the last decade, has rapidly changed into an Asia dominated market. The internationalisation of the production industry is mainly due to the rapidly growing PV manufacturers from China and Taiwan, as well as new market entrants from companies located in India, Malaysia, the Philippines, Singapore, South Korea, UAE, etc. At the moment, it is hard to predict how the market entrance of new players worldwide will influence future developments in the manufacturing industry and markets.

Over the last 10 years, not only have we observed a continuous rise in energy prices, but also a greater volatility. This highlights the vulnerability created by our current dependence on fossil energy sources, and increases the burden developing countries are facing in their struggle for future development. On the other hand, we are seeing a

continuous fall in production costs for renewable energy technologies and the resulting LCOE, as a result of industry learning curves.

It is important to remember that only about 40 % of the LCOE of PV electricity comes from the overnight investment costs. Since external energy costs, subsidies in conventional energies and price volatility risks are not generally taken into account, renewable energies and PV are still perceived as being less mature in the market than conventional energy sources and have to pay extra risk premiums for their financing. In the mean-time, financing, permits and administrative costs are much more relevant for the final costs of PV electricity. If access to financing was on the same level, LCOE costs could decrease considerably. Nevertheless, electricity production from PV solar systems has already proved that it can be cheaper than residential consumer prices in a wide range of countries. In addition, in contrast to conventional energy sources, renewable energies are still the only ones to offer the prospect of a reduction rather than an increase in prices in the future.

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## List of abbreviations and definitions

AC	alternating current
ADB	Asian Development Bank
ASP	average selling price
BNEF	Bloomberg New Energy Finance
BOS	balance of system
bps	base points (100 base points are 1%)
CAGR	compound annual growth rate
CAPEX	capital expenditure
CEL	Clean Energy Certificates
COP	Conference of the Parties
CPV	concentrating photovoltaics
CTO	chief technology officer
CSP	concentrating solar thermal power
CWaPE	Wallonian Energy Commission
°C	degree Celsius
DC	direct current
DoE	Department of Energy
EEG	Energie Einspeisegesetz (energy feed in law)
ETP	Energy Technology Perspectives
EU	European Union
FIT	feed-in tariff
FY	financial year
GDP	gross domestic product
GSE	Gestore dei Servizi Energetici
GW	Giga Watt
H1	1st half year
IEA	International Energy Agency
IMF	International Monetary Fund
IPP	independent power producers
IRENA	International Renewable Energy Agency
ITC	investment tax credit
JJNSM	Jawaharlal Nehru National Solar Mission
JRC	Joint Research Centre
KfW	Kreditanstalt für Wiederaufbau
kW	kilo Watt
LCOE	levelised cost of electricity
LIBOR	London Interbank Offered Rate

MASEN	Moroccan Agency for Solar Energy
MNRE	Ministry of New and Renewable Energy
METI	Ministry of Economy, Trade and Industry
MW	Mega Watt
NREAP	National Renewable Energy Action Plan
OEM	original equipment manufacturing
OPEX	operational expenditure
O&M	operation and maintenance
PPA	power purchase agreement
PV	photovoltaic
Q1	1st quarter
RES	renewable energy sources
ROC	renewable obligation certificate
ROI	return on investment
RPS	renewable portfolio standard
RTE	réseau de transport d'électricité
R & D	research and development
SDE+	Stimulering Duurzame Energieproductie
SHS	solar home system
SNEC	Shanghai New International Expo Centre
TSO	transmission system operator
TW	Terra Watt
VAT	value added tax
WACC	weighted cost of capital
WEO	World Energy Outlook
Wh	Watt hour
Wp	Watt peak
2DS	2 °C scenario
B2DS	1.75 °C scenario

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