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Title PV Status Report 2018
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

The necessity to limit the maximum global average temperature rise as close as possible to 1.5°C was acknowledged with the Paris Agreement, which went into force on 4th November 2016. However, the current policies in place to limit global greenhouse gas (GHG) emissions are still not sufficient to keep the temperature rise below 2°C. The burning of fossil fuels for energy purposes is still the largest source of the world's greenhouse gas emissions, accounting for 68%. Therefore, making the decarbonisation of our energy supply is the single most important component to achieve the target.

The G7 Environment, Energy and Ocean Ministerial took place in Halifax, Canada from 19 to 21 September 2018. The G7 members recognized the need to continue developing sustainable energy usage. The meeting also discussed the implementation guidelines for the Paris Agreement on climate change which are expected to be adopted during the 24th session of the Conference of the Parties (COP24), which will take place from 3 to 14 December in Katowice, Poland.

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.

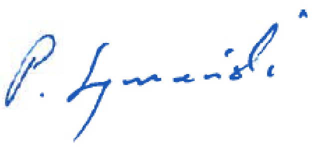
Photovoltaics (PV) is a key technology option for realising a decarbonised power sector and sustainable energy supply. Further it can be deployed in a modular way almost everywhere on the planet. Solar resources in Europe and across the world are abundant and cannot be monopolised by one country. Regardless 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 2018, the benchmark Levelised Cost of Electricity from PV system decreased by over 75% to USD 69/MWh (EUR 60/MWh). The main contribution was the decrease of module prices by over 85 % in most 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 2017, solar energy attracted 58 % of all new renewable energy investments or USD 161 billion (EUR 140 billion).

In 2017, PV industry production rose again by more than 35 % and reached a worldwide production volume of more than 110 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 16th 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, November 2018



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Acknowledgements

Over the last few years, in addition to the numerous discussions I have had with international colleagues, as well as literature and internet research, I have visited various government entities, research centres and leading industry companies in Australia, Chile, China, India, Japan, Singapore, South Africa, the United States and Europe. I would like to thank all my hosts for their kindness and the time taken to welcome me, to share their knowledge and to discuss the status and prospects of PV.

Executive Summary

For the 8th year in a row, solar power attracted the largest share of new investments in renewable energies, followed by wind power. The USD 161 billion (EUR 140 billion) investments in solar energy, accounted for 58 % of all new renewable energy investments. While the annual investment grew by 18%, the newly installed capacity of solar photovoltaic power increased by 32% to almost 100 GW in 2017.

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.

R&D spending slightly increased due to a 14% increase in global industrial spending.

The trend that the developing economies invest more in renewable energy capacity than the developed ones continued for the third year. China, India and Brazil invested almost the same amount in 2017 than in the record year 2015. On the other side, investments in developed countries have declined by 30% compared to 2015.

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 2017, no European company was listed.

According to market forecasts, the installed PV power capacity of 408 GW at the end of 2017 could triple by 2023. At the end of 2018, worldwide solar PV power is expected to exceed 500 GW capable of producing roughly 2.8 % of the worldwide electricity demand. The EU's share is about one fifth of the world-wide installed capacity and can provide about 4.5 % of its electricity demand.

Recent 100% renewable electricity scenarios have highlighted the importance of solar photovoltaics to achieve this goal and decarbonise the power sector in a cost effective manner. To realise a carbon free power supply by 2050, the installed PV generation capacity of about 500 GW at the end of 2018 has to increase to more than 4 TW by 2025 and 21.9 TW by 2050 to make it happen. The European Union needs to increase its capacity from 115 GW at the end of 2018 to more than 631 GW by 2025 and 1.94 TW by 2050. In case of a transition to a sustainable transport sector, i.e. electrification and synthetic fuels, these numbers would increase by a factor of two.

2016 already saw a number of record breaking power purchase agreements (PPA) contracts and bids below USD 30/MWh and the trend for bids below 25 USD/MWh has accelerated in sun rich regions in 2017 and 2018. These very low bids and PPAs, especially in the Middle East, but also Chile and the USA 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.

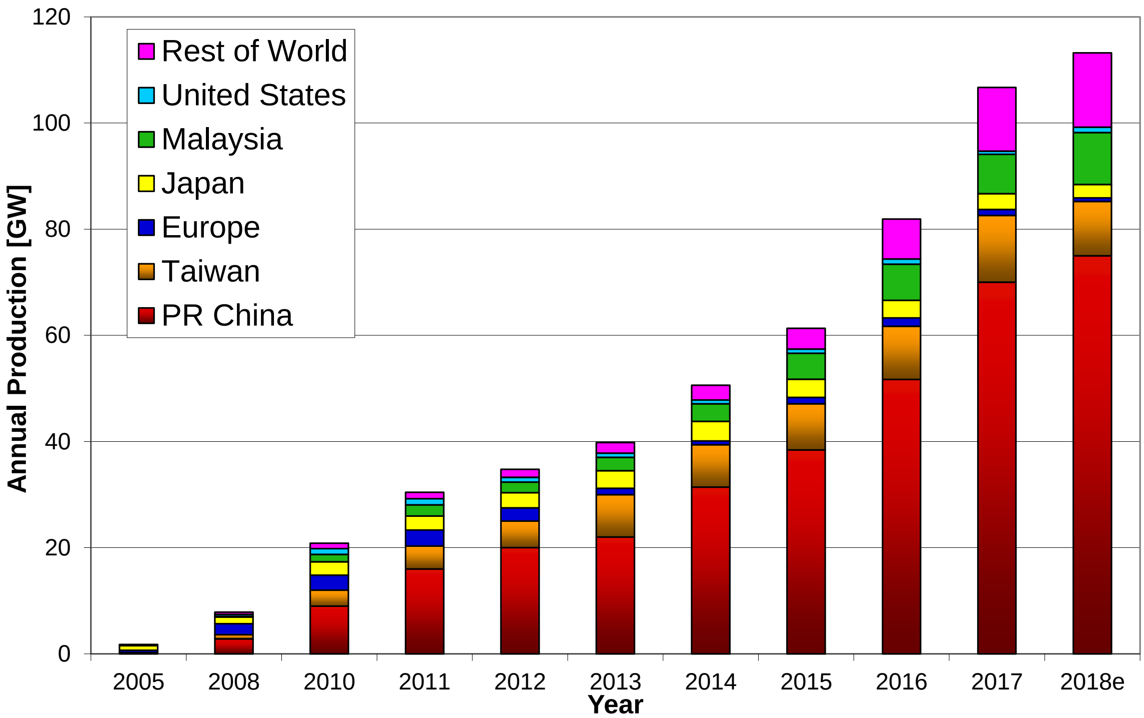
1 Introduction

Reported production data for the global solar cell production[1] in 2017 vary between 102 GW[2] and 112 GW and estimates for 2018 are in the 100 to 115 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 international colleagues, were compared to various data sources and thus led to an estimate of 107 GW (Fig. 1), representing an increase of about 30 % compared to 2016 and another 5 to 10% are expected for 2018.

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 most of these investments are 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 2018 (estimate)



Source: Photon Magazine [Pho 2012], PV News [Pvn 2015] and own analysis

Investments in renewable energy projects excluding large hydro-electric power plants increased to USD 280 billion (EUR 243 billion[3]), which was still 13 % less than in 2015

[1] 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

[2] Please note that all number are based on the current available data (October 2018) and can change, when final annual reports of public companies or country statistics are published during the year

[3] Exchange rate 2017: EUR 1.00 = USD 1.15

but slightly increased by 2% compared to 2016 [FSU 2018]. Total new installed renewable power capacity, excluding large hydro, increased from 127.5GW in 2015, 143 GW in 2016 to 158 GW in 2017.

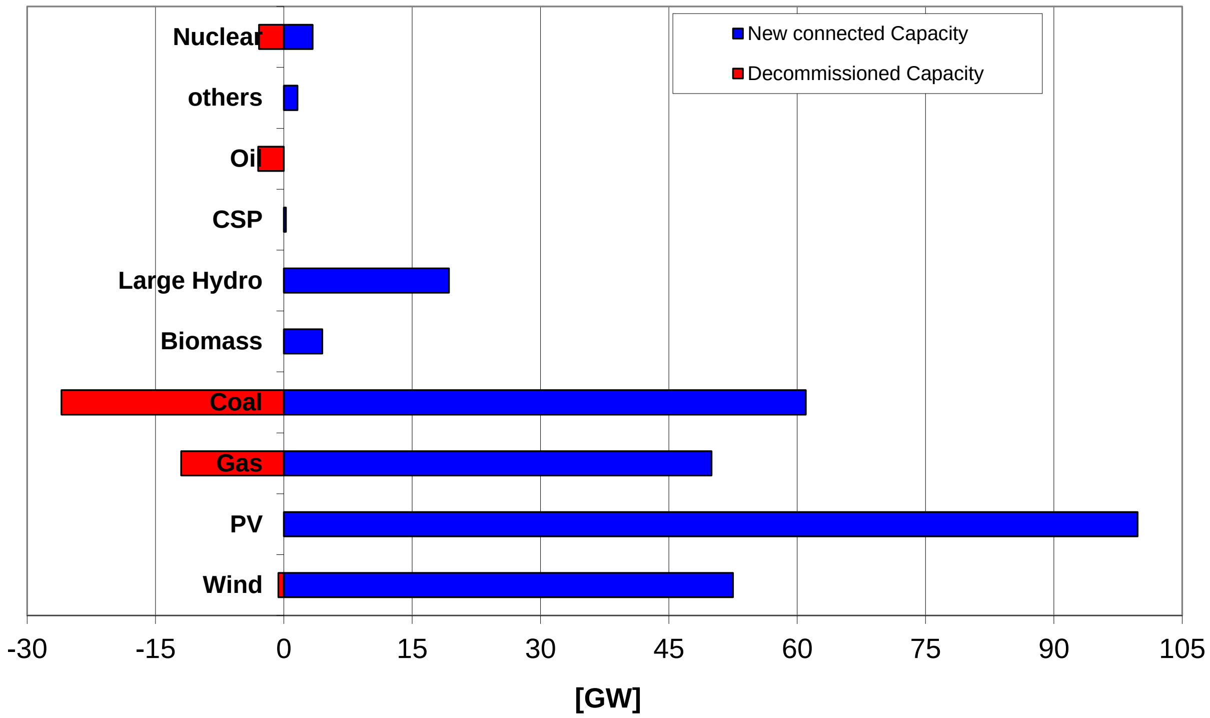
Uncertainties in production statistics

- 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 risk of double counts.

World-wide, a total of about 292.3 GW of new power generation capacity were connected to the grid year and 44.6 GW were decommissioned, resulting in 247.7 GW of new net capacity (Fig. 2) [FSU 2018, Gwe 2018, IEA 2018, Wna 2018, own analysis]. Renewable energy sources (RES) accounted for 159 GW or 54 % of all new power generation capacity (including large hydro: 177.3 GW or 61%). PV electricity generation capacity accounted for 99.8 GW, or 34 % of the new installed capacity.

In terms of new net capacity, solar PV was first with 99.8 GW, followed by wind power 51.9 GW, natural gas 38 GW, coal 35 GW and large hydro 19 GW. The net installation capacity for oil-fired power plants as negative with 3 GW.

Figure 2: New connected or decommissioned electricity generation capacity world-wide in 2017



Source: [FSU 2018, Gwe 2018, IEA 2018, Wna 2018] and own analysis

The share of electricity in the final consumption provided by renewable energy sources (excluding large hydro) increased from 8.5% in 2016 to 9.8% in 2017 [IEA 2018, Ene 2018].

R&D trends for governmental and industrial spending were different again [FSU 2018]. While the first stayed flat at USD 5.1 billion (EUR 4.4 billion), the second increased by about 14% to USD 4.8 billion (EUR 4.2 billion).

For the 8th year in a row, solar power attracted the largest share of new investments in renewable energies. The USD 161 billion (EUR 140 billion) investments in solar energy, accounted for 58 % of all new renewable energy investments. While the annual investment grew by 18%, the newly installed capacity of solar photovoltaic power increased by 32% to almost 100 GW in 2017. However, one has to keep in mind that a number of solar projects closed their financing earlier, but were only commissioned in 2017. In such cases the investment is counted for the year of the financial closure, while the capacity addition is counted for 2017.

The trend that the developing economies invest more in renewable energy capacity than the developed ones continued for the third year. Developing economies, led by China, India and Brazil invested almost the same amount in 2017 (USD 177 billion) as in the record year 2015 (USD 178 billion). Investments in developed countries have declined by 30% from USD 146 billion in 2015 to USD 103 billion in 2017. Even more pronounced is the development in the solar photovoltaic sector. Out of the USD 161 billion (EUR 140 billion) investments in solar energy, 71% or USD 115 billion (EUR 100 billion) were invested in developing economies.

As in the past years, China kept the lead with USD 126.6 billion (EUR 110.1 billion), followed by the USA with USD 40.5 billion (EUR 35.2 billion), Japan USD 13.4 billion (EUR 11.7 billion) and India USD 10.9 billion (EUR 9.5 billion).

Between 2008 and 2014, PV module prices have decreased rapidly by more than 80 %, then 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 2018].

World-wide 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[4] 10.8 billion) after the PV market grew by more than 150 % in 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 [Osb 2018]. According to BNEF the group of Tier 1 module manufacturers have a production capacity of 92 GW in 2018 [Blo 2018].

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

[4] Exchange rate 2013: EUR 1.00 = USD 1.30

capable to produce these higher efficient solar cells at lower costs. Therefore, the overall net capacity increase for 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.

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 Renewable Energy Market Report 2018 forecasts world-wide a new installed photovoltaic power capacity between 575 and 720 GW between 2018 and 2023 [IEA 2018a].

For 2018, the world market predictions vary between 95 GW according to Solar Power Europe's low scenario and 107 GW in the Q3 BNEF Global PV Market Outlook [Blo 2018, Sol 2018]. The same sources predict a range between 92 GW and 138 GW in 2019.

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

About 95 % of current production uses wafer-based crystalline silicon technology. Projected silicon production capacities for 2018 vary between 475 000 tonnes [Blo 2018] and 578 000 tonnes [Ikk 2018]. 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 blended global average was about 4.0 g/Wp in Q3 2018. According to the International Technology Roadmap for Photovoltaic polysilicon material consumption is expected to drop to values between 2.1 and 3 g/W in 2028 [Itr 2018].

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) 2018, the BNEF global benchmark for levelised cost of electricity (LCOE) in the solar sector was given with USD 69 per MWh a decrease of about 20% compared to 2017 [Blo 2018a]. The cost share of solar modules in the benchmark PV system has dropped below 30 %.

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 technical challenges are different ones 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 99.8 GW world-wide in 2017, 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. 3). The annual installation in 2017 was about the same as the total PV capacity installed until the end of 2012. Within 5 years, world-wide PV power has quadrupled to more than 400 GW at the end of 2017.

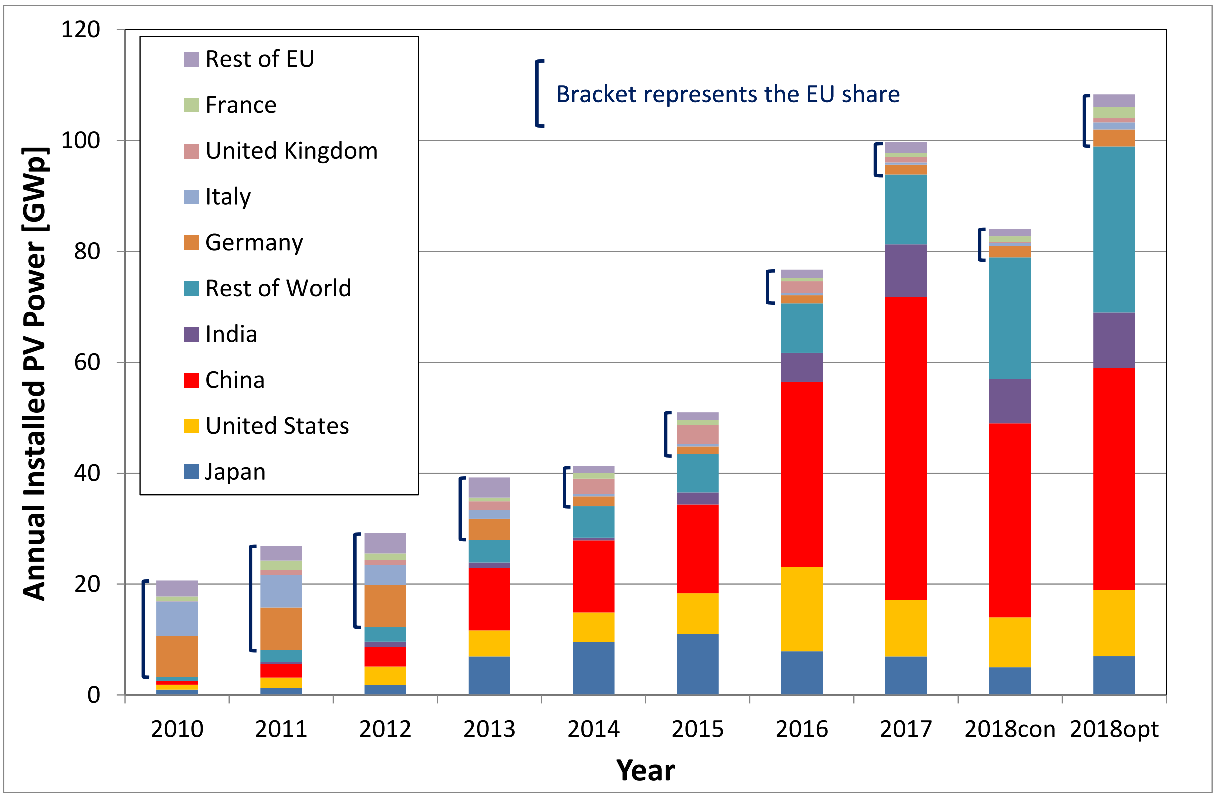
This development represents the grid connected PV market. To what extent the off-grid and consumer product markets are included is not clear, because these markets are very difficult to track. However, these segments have become smaller and smaller in relative terms.

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, air mass 1.5 light spectrum and 25 ºC device temperature) for reasons of consistency.
- Not all countries report DC peak power (Wp) for solar PV systems, but especially for larger scale system some use the utility peak AC power, which is relevant for the transmission operator. Even in the Eurostat statistics the two capacities are sometimes 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.

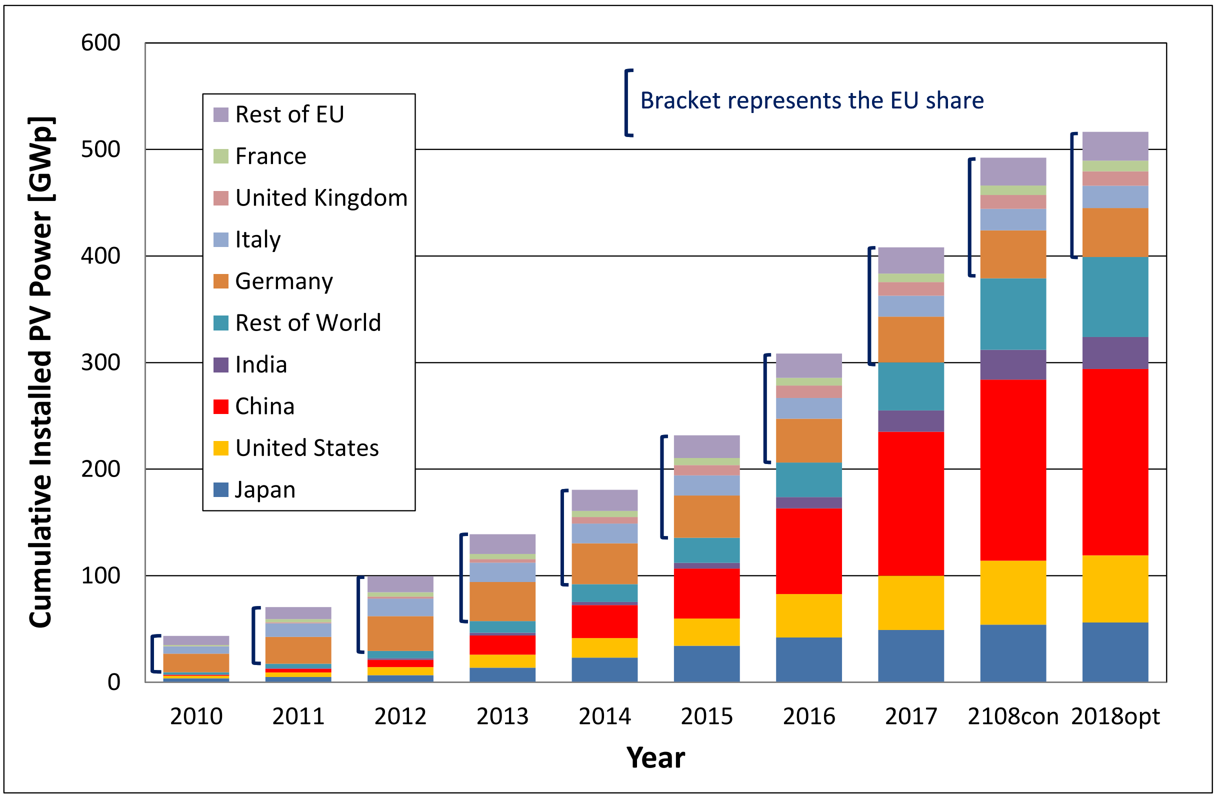
In 2015, China overtook Germany in terms of cumulative installed nominal PV power, Japan followed in 2016 and the USA already did so in the first half of 2017. In 2017, China also overtook the European Union in terms of total installed PV power capacity. With 53 GW annual installations it reached a total PV power capacity of 135 GW or 33% of the 408 GW solar PV electric power capacity installed worldwide at the end of 2017. The European Union follows with a cumulative installed PV power of 108 GW or 26% of global capacity. This is down from the 66% share in 2012, when the cumulative installed solar PV electric power had just reached 100 GW world-wide.

Figure 3: Annual PV system installations from 2010 to 2018 estimates



Source: [IEA 2018b, Sol 2018, Sys 2018] and own analysis

Figure 4: Cumulative PV installations from 2010 to 2018 estimates



Source: [IEA 2018b, Sol 2018, Sys 2018] and own analysis

2.1 EUROPE, THE RUSSIAN FEDERATION AND TURKEY

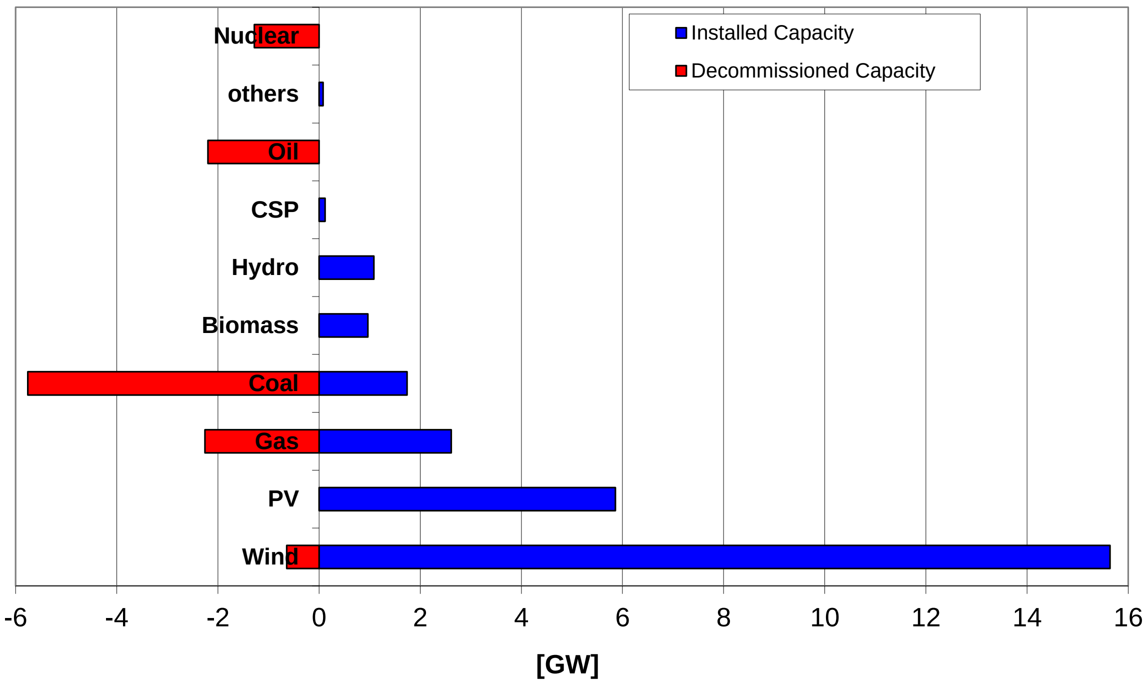
A political agreement on increasing renewable energy use in the European Union was reached between negotiators from the Commission, the European Parliament and the Council on 14. June 2018. The agreement sets a new, binding, renewable energy target for the EU for 2030 of 32%, including a review clause by 2023 for an upward revision of the EU level target [EC 2018].

Due to different energy policies, regulations and public support programmes for renewable energies in the various countries, market conditions for PV differ substantially. Besides these policy driven factors, the varying grades of liberalisation in the domestic electricity markets as well as the maturity of the PV market and local financing conditions have a significant influence on the economic attractiveness of installing PV systems.

Looking at the electricity system as a whole, a total of about 28.1 GW of new power generation capacity were installed in the EU last year and 12.1 GW were decommissioned, resulting in 15 GW of new net capacity (Fig. 5) [Ago 2018, Sys 2018, Win 2018, own analysis]. Renewable energy sources (RES) accounted for 23.7 GW or 84.5 % of all new power generation capacity. PV electricity generation capacity accounted for 5.9 GW, or 21 % of the new installed capacity.

In terms of new net capacity, wind power was first with 15 GW, followed by solar PV 5.9 GW, hydro 1.1 GW biomass plants with 0.96 GW, natural gas 356 MW, CSP (Concentrated Solar Thermal Power) 118 MW and other sources 8 MW. The net installation capacity for coal- and oil-fired power plants as well as nuclear was negative, with a decrease of 4 GW, 2.2 GW and 1.3 GW, respectively.

Figure 5: New connected or decommissioned electricity generation capacity in the EU in 2017



Source: [Ago 2018, Sys 2018, Win 2018] and own analysis

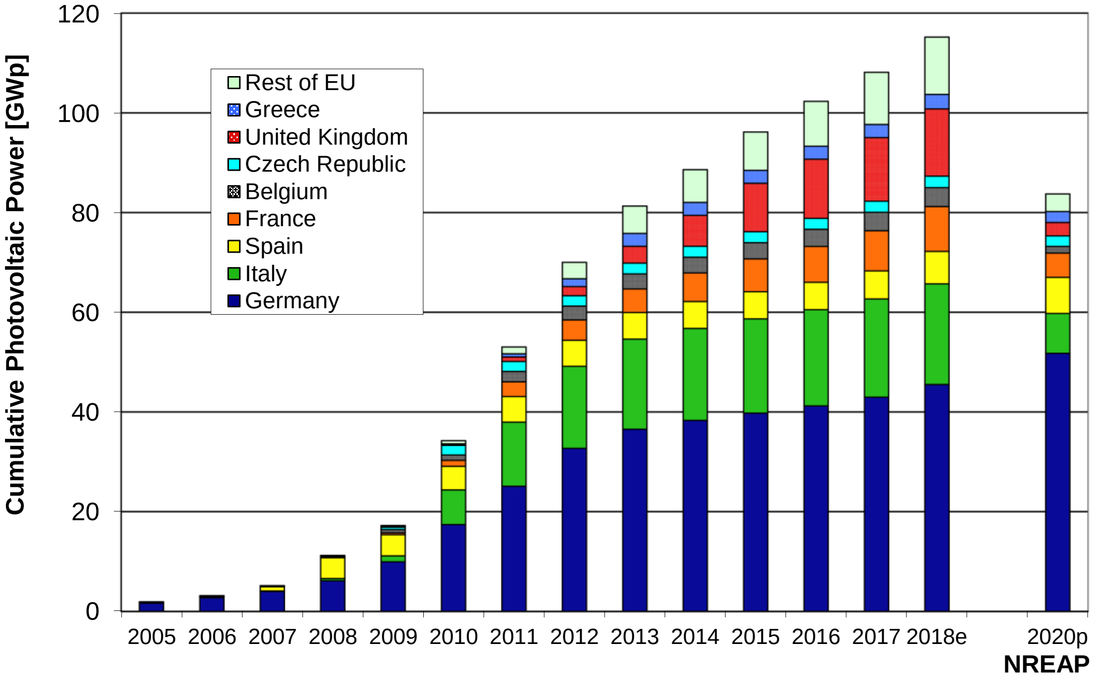
Since 2005, solar PV electricity generation capacity has increased from 1.9 GW to 108 GW at the end of 2017 (Fig. 6). Already in 2014, the 2020 National Renewable Energy Action Plan (NREAP) target of 83.7 GW was exceeded, reaching about 88.4 GW.

With a cumulative installed capacity of 108 GW, the EU has further lost ground in the worldwide market, representing now only 26% of the global total of 408 GW of solar PV electricity generation capacity at the end of 2017. This is a steep decline from the 66 % recorded at the end of 2012. The installed PV power capacity in the EU at the end of

2017 can generate around 120 TWh of electricity or about 4.5 % of the final electricity demand in the Union.

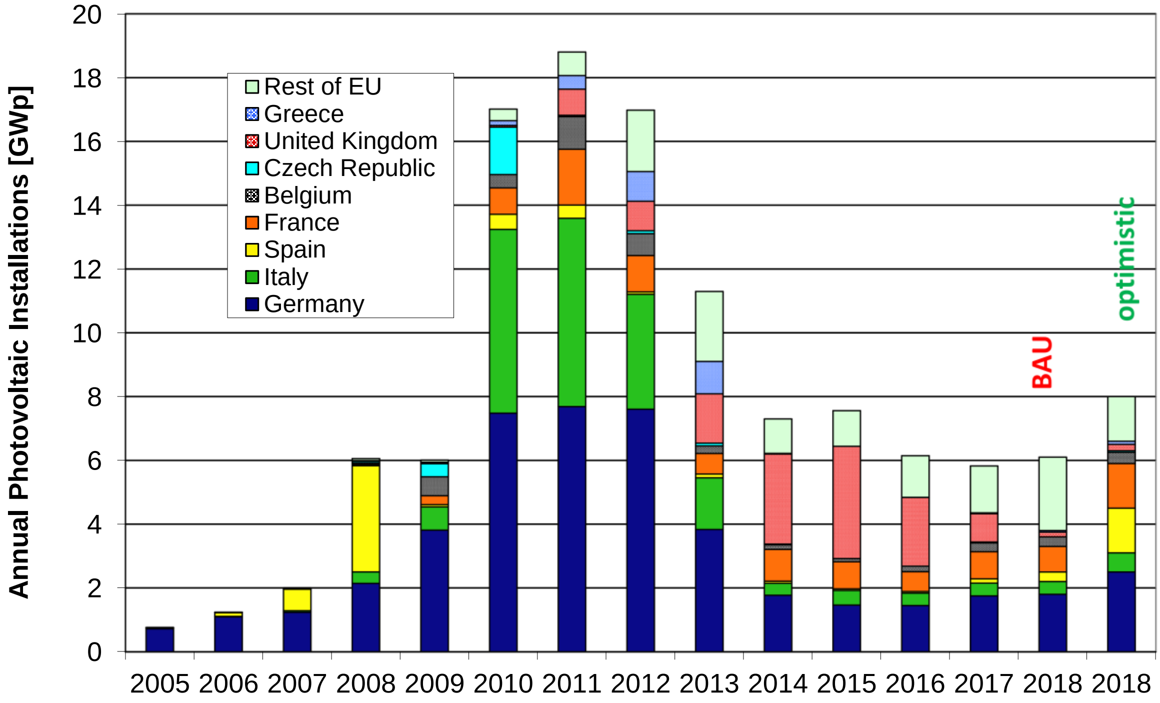
At first glance, this development appears to be a success. However, by looking at the annual installations, it becomes obvious that between 2011 and 2017 Europe's share was not only declining in relation to a growing market worldwide, but also in actual installation figures (Fig. 7). In the estimated annual installations figures for 2018 a business as usual (BAU) and an optimistic scenario are given.

Figure 6: Grid-connected PV capacity in EU compared with the NREAP target for 2020



Source: [Sol 2018, Sys 2018] and own analysis

Figure 7: Annual PV installations in EU



Source: [Sol 2018, Sys 2018] and own analysis

According to the IEA Renewable Energy Market Report (REMR) 2018, the European Union's share will drop below 20 % by 2023 due to a stagnant market of 7 to 9 GW between 2018 and 2023 in the European Union and a world-wide growth to between 575 and 720 GW world-wide until 2023 [IEA 2018a].

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, which consequently resulted in the declining PV system market in the EU.

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 2017 more than halved these local jobs and with them the positive effect on the local European economy [Ire 2018]. The 99 600 jobs (direct and indirect) left in the solar photovoltaic sector in the European Union are less than 3% of the global 3.36 million jobs in the sector [Ire 2018].

The latest New Energy Outlook (NEO) 2018 by Bloomberg New Energy Finance forecasts a slight electricity demand increase in Europe (EU-28, Island, Norway and Switzerland) from 3 454 TWh in 2017 to 3 566 TWh in 2030. The increase is driven by the increased use of electric vehicles (EV) but slowed by progress in energy efficiency [Blo 2018b]. This is in line with the estimates for the European Union that the net electricity generation will be around 3 400 TWh in 2030.

To realise the new renewable energy target of 32% by 2030, the European Union has to increase its use of renewable energy in the power sector to at least 65%. The main contributions have to come from solar and wind power. Different from a number of other scenarios, NEO 2018 does not foresee an increase in electricity from renewable energy sources except for solar photovoltaics and wind, which will have to supply 440 TWh and 1 300 TWh respectively [Blo 2018b].

The required solar photovoltaic capacity would be about 420 GW divided in 55% utility scale PV plants and 45% decentralised small systems. However, with a total installed capacity of about 110 GW, including Switzerland, at the end of 2017 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 25 and 30 GW over the next 12 years, which are needed to reach the target. In order to realise these installations, the annual market has to grow to three to four times the European market volume in 2017 [Jäg 2017, 2018].

The following sections describe market development in some EU Member States, as well as in Switzerland, the Russian Federation, Ukraine and Turkey. Not all EU Member States are covered in this report due to either small markets or limited changes in the market development. More detailed information about the progress of renewable energy implementation in the EU Member States 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] or the EUROSTAT web site.

2.1.1 Austria

In 2017, Austria installed about 150 MW of new PV systems and increased the cumulative capacity to 1.25 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].

At the end of May 2018, the Austrian Government approved the new Climate and Energy Strategy – "mission 2030" – for Austria [GoA 2018]. The main issues concerning photovoltaics are:

- Increase the share of renewables in final energy consumption to 45-50% by 2030. This corresponds to about 80 TWh of electricity or 30 TWH more than today from hydro, solar and wind.
- In 2030 renewable electricity production should cover 100% of electricity consumption.
- Investment support programme for "100,000 rooftops with local storage".
- Removal of all taxation on self-generation, currently exempted up to 25MWh.
- Change incentives to a combination of feed-in premiums, auctions and investment incentives.

According to a study by the Energy Economics Group of the Technical University of Vienna, the installed PV capacity to realise "mission 2030" should be in the range of 14 to 15 GW by 2030 , a more than 10fold increase compared to 2017 [Haa 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 renewable portfolio standard (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 systems, before starting to decline in 2012. At the end of 2017, cumulative installed capacity was over 3.8 GW with about 290 MW installed in that year [IEA 2018b]. Over 9.3 % of Belgian households are already generating their own PV electricity, and PV power supplied 2.89 TWh or 3.6 % of the country's net electricity production in 2017.

The proposal of the Belgium Parliament for a new Energy Pact 2050 was published in January 2018 [BKV 2018]. The main issues concerning photovoltaics are:

- Gradual phase-out of Belgium's 6 GW of nuclear capacity between 2022 and 2025 and increase of renewables in the power supply to 40% by 2030 (8 GW of PV, 4.2 GW onshore wind and 4 GW offshore wind).
- Increase of renewables in the power supply to 100% by 2050.
- 2 GW of large-scale storage and 3 GW of distributed small-scale storage.

The Belgian grid operator Elia published three scenarios for the Belgian electricity supply indicating that total PV power could be in the range of 5 to 11.6 GW by 2030 and in the highest scenario could go up to 18 GW by 2040 [Eli 2017]. To reach the 2030 targets of the Energy Pact, the present market size of about 300 MW only has to increase slightly over the next 12 years.

2.1.3 Denmark

The combination 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[5]) 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 received application for 4.5 GW in March and April 2016. All applications, which had not been processed and approved before 3 May 2016 were declared not eligible for the scheme.

At the 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 built 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].

In 2017, the Danish government decided to have a tender for PV systems smaller than 1 MW in 2018 and a joint tender for solar and wind power in 2018 and 2019 [Ene 2018a]. The support scheme was approved by the European Commission in August 2018 [EC 2018a].

In 2017 about 60 MW were installed increasing the total capacity to over 900 MW. PV systems generated 2.3% of the Danish electricity in 2017.

2.1.4 France

In 2017, 887 MW of new PV systems were connected to the grid in France [Rte 2018]. Total cumulative installed capacity increased to over 8.06 GW, including about 400 MW in the French Overseas Departments [Sta 2018]. Electricity production (continental France and Corsica) from PV systems was 9.2 TWh or 1.7 % of the national electricity generation [Rte 2018].

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 the first half of 2018 PV systems with a capacity of 479 MW were connected to the grid [Sta 2018]. The capacity of projects in the planning stage increased to 6 GW, of which 2.5 GW already had a signed connection agreement.

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.

2.1.5 Germany

Compared to 2016, new PV system installations in Germany saw a slight increase to 1.75 GW, with about 440 MW free-field systems as a result of previous auctions [Bun 2018]. For the first 7 months of 2018 the Bundesnetzagentur reported the registration of PV projects with 1.65 GW out of which about 480 MW free-field systems as a result of previous auctions.

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 sys-

[5] Exchange rate: EUR 1.00 = DKK 7.44

tems 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 relevant feed-in-tariffs are regularly published by the Bundesnetzagentur.

The fact that the tariff for residential PV systems smaller than 10 kWp (September 2018: EUR 0.1230/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 July 2017 a programme to support the self-consumptions for tenants of multi apartment buildings exists, but until May 2018 only about 160 PV systems with 4 MW cumulative power were installed [Bna 2018].

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 support was gradually reduced over time and the programme will now terminate at the end of 2018 [KfW 2016].

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 2018 [Adm 2018]. These figures are the same as last year and do not include the installed capacity of non-interconnected Greek islands, which — according to the Hellenic Electricity Distribution Network Operator SA — was 170 MW in April 2018 [Hed 2018].

After the European Commission approved the new auction scheme on 4 January 2018 [EC 2018b], the first renewables auction in Greece was held on 2 July 2018. The auction was held by the Regulatory Authority for Energy (RAE) and had three categories:

- PV plants of 0.5 to 1 MW (83 projects with 53.48 MW of capacity were awarded with a weighted price of EUR 78.42 per MWh)
- PV plants between 1 and 20 MW (8 projects with 52.92 MW of capacity were awarded with a weighted price of EUR 63.81 per MWh)
- wind power plants between 3 and 50 MW (170.92 MW of capacity was awarded with a weighted price of EUR 69.53 per MWh).

The lowest bid was achieved in the second category with EUR 62.97 per MWh. A second auction is planned for the end of 2018.

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, were still eligible for this scheme.

In July 2017 the European Commission approved the new renewable support scheme (METÁR) [EC 2017]. For systems with a capacity below 500 kW a feed in tariff (FiT) and for systems between 500 kW and 1 MW a feed-in premium (FiP) will be set at the beginning of each year. The approved internal rate of return (IRR) used to calculate the level of the FiT and FiP and the duration of support is 6,94 %. Systems above 1 MW are eligible for a competitive FiP determined by a bidding procedure.

In the first half of 2018, METAR, which finally came into force last October, already had some turbulences, when the government unexpectedly brought forward the application deadline for projects of 50 - 500kW to April 26, whereas in the original government decree no deadline was foreseen. No date for a bidding for larger systems has been set yet.

In 2017, Hungary connected about 90 MW of PV systems, increasing cumulative installed capacity to 380 MW by the end of 2017.

2.1.8 Italy

In 2017, Italy connected 415 MW of PV systems, increasing cumulative installed capacity to 19.7 GW by the end of 2017 according to the annual report of the Gestore dei Servizi Energetici (GSE) [Gse 2018]. 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 24.81 TWh or 7.7 % of the total electricity sold in 2017 [Ter 2018]. Solar photovoltaic power generation was 11.41 TWh or 7.2 % of the total electricity during the first six months of 2018. The highest monthly coverage was in April 2018, when PV electricity supplied 10.1 % of the Italian energy demand.

In March 2018, ENEL announced that it started the production of bi-facial silicon hetero-junction modules at its 3SUN factory in Catania, Sicily, and aims to increase the production volume to 240 MW by 2019 [Ene 2018b].

2.1.9 The Netherlands

According to the Dutch Statistical Office, PV systems with a capacity of 815 MW have been installed in 2017 bringing the total installed PV power to 2 864 MW at the end of the year [Cbs 2018]. The total generated solar electricity was 2.15 TWh or 1.85 % of the net electricity generation.

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 2018]. Over 3 700 PV projects with a combined capacity of 1.7 GW were selected in the first round of the 2018 SDE+. This brings the total approved capacity of PV systems for the two 2017 and the first 2018 allocations to 5.9 GW.

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 for systems smaller than 1 MW took place on 30th of December 2016 and the second on 29/30 June 2017. A total of 360 MW was awarded to 436 projects, out of which 40 systems with about 27 MW were installed until the end of May 2018 [Ieo 2018].

In 2017, Poland connected about 80 MW of PV systems, increasing cumulative installed capacity to 280 GW [Ieo 2018]. 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 5.6 GW[6]. 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 had decreased to EUR 23 billion at the end of 2016 [CNM 2017]. According to press reports, Moody's estimates that the deficit will decrease by over 9% from the EUR 21 billion at the end of 2017 to about EUR 19 billion at the end of 2018 [Eur 2018].

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

In 2017, new PV systems were installed with a capacity of roughly 150 MW. In the same year, electricity generated from grid connected PV systems contributed 8.4 TWh or 3.2 % of the Spanish electricity generation.

After five years of very little new PV power additions, the next three years 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_{AC} in this auction [MET 2017]. The winning consortia have to connect the systems before the 1st January 2020.

2.1.12 Switzerland

In 2017, about 240 MW of PV systems were installed in Switzerland, increasing the total capacity to 1.9 GW [Bfe 2018]. In 2017, PV power generated 1.7 TWh or 2.9% 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 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]. Prices in 2017 have not dropped significantly.

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[6] 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.

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[7] 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[8] 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), 52.43 MW of PV systems were installed at the end of July 2018. 3 projects with an additional 1 MW already have signed contracts but are not yet installed [Hro 2018].

Despite high solar radiation, solar PV system installation in **Portugal** has grown very slowly. In 2017 64 MW of PV systems were newly installed increasing the cumulative capacity to 584 MW by the end of 2017 [Dir 2018]. Electricity from Photovoltaic system provided 1.7% of the net electricity generation in 2017. According to a newspaper article, Portugal plans to connect 31 solar power plants with over 1 GW of capacity to the grid until 2021 [Sil 2018]. However, 16 of the 31 plants will only come online in 2021.

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 been 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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7 Exchange rate 2016: EUR 1 = CHF 1.10
8 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 2017 about 60 MW of new PV capacity was installed in Russia, increasing the total capacity to around 600 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 June 2018 about 150 MW of PV power was awarded to Hevel Solar and Fortum in an auction. Hevel Solar won three projects with close to 40 MW to be connected to the grid at the end of 2019, while Fortum won 7 projects with 110 MW to be operational by 2021 and 2022.

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, so far only about 20 MW were installed at the end of 2017.
Due to the fact, that systems below 1 MW fall under the category of "non-licenced plants" the market started to take off in 2014 with 40 MW installed and a fivefold increase to 208 MW in 2015, 580 MW in 2016 and almost 2.5 GW in 2017. At the end of 2017 the cumulative capacity had exceeded 3.4 GW, most of it in the category of "non-licenced" according to the Turkish transmission operator TEİAŞ [Tei 2018]. For the first two months of 2018, TEİAŞ reported the connection of about 0.5 GW of new PV systems [Tei 2018a]. According to the Turkish Solar Energy Society the installed solar photovoltaic power capacity had almost reached 4.6 GW at the end of March 2018. Market expectations for 2018 vary between 1.8 and over 3 GW, however, the high end looks uncertain after the currency turbulences in summer 2018.

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 220 MW of new PV power capacity was installed in 2017, thus increasing the total capacity to about 750 MW (excluding the approx. 400 MW in Crimea). The market expectations for 2018 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 2017, more than 76 GW of new PV electricity generation systems were installed in the region, which corresponds to roughly three quarters of the world wide new PV power installed in 2017. The largest market was China with 53 GW, followed by India with around 10 GW and Japan with about 7 GW. In 2018, a similar market size, but different country contributions is possible.

2.2.1 Australia

In 2017, about 1.35 GW of new solar PV electricity systems were installed in Australia, bringing the cumulative installed capacity of grid-connected PV systems to 7.2 GW. As in the previous years the market was dominated by grid-connected residential systems. In the first six months of 2018 PV systems with 1.25 GW have already been registered increasing the number of homes with PV systems to over 1.8 million. The national penetration of homes with PV systems has exceeded 20 %, and in some urban areas it is even more than 50 %.

The average PV system price paid by the customer for a grid-connected system fell from AUD 6/Wp (EUR[9] 4.29/Wp) in 2010 to AUD 1.24/Wp (EUR[10] 0.77/Wp) in August 2018 [Sol 2018a]. As a result, the cost of PV-generated electricity has fallen to, or is even below, the average residential electricity rate of AUD 0.29/kWh (EUR 0.18/kWh).

In 2017, PV electricity systems generated about 10.2 TWh or 3.9 % of Australia’s total electricity demand. The total renewable electricity share was 17 % and this should increase to 20 % by 2020.

2.2.2 India

For 2017, market estimates for solar PV systems vary between 9.5 and 10 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 July 2018, the total solar power capacity was 23.9 GW [GoI 2018], but Bridge to India reported a capacity of 24.9 GW at the end of June 2018 [Bri 2018].

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 2018 and 2019 are in the order of 7.5 to 10 GW and 11 to 15 GW respectively.

The range of Power Purchase Agreements (PPAs) awarded in 2016 was between INR 4 350 and 5 010/MWh (EUR11 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. The lowest bids were for 500 MW of phase III of the Bhadla solar park, Rajasthan. This capacity should be commissioned in Q4 2018.

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9 Average exchange rate for 2010: EUR 1 = AUD 1.40
10 Exchange rate 08/2018: EUR 1 = AUD 1.62
11 Exchange Rate: 1 EUR = 74 IRP

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.

At the end of 2017, about 1 GW of cumulative solar PV power was installed and market expectations for 2018 range from 150 to 200 MW.

2.2.4 Japan

In 2017, the Japanese PV market decreased by about 24 % to 7 GW. Cumulative installed capacity reached 49.1 GW at the end of 2017. According to the Institute for Sustainable Energy Policies, solar photovoltaic electricity contributed 5.7% of the total electricity generation in Japan in 2017 [Ins 2018]. This was almost twice the share of nuclear (2.8%).

Under the FiT scheme, introduced in July 2012 and amended in the following years [METI 2013], 71.7 GW_{AC}[12] had received approval until the end of September 2017. However, only 36.8 GW_{AC} had been commissioned and were in operation. Because a significant discrepancy between actual installations and permits given emerged starting already in 2013, the Ministry of Economy, Trade and Industry (METI) started to revise the list of projects according to their actual status and revoked 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 71.7 GW_{AC} approved by the end of September 2017, only 5.3 GW_{AC} or 7.4 % comprised systems smaller than 10 kWp. However, 95 % of these systems were actually connected to the grid. PV systems with capacities over 2 MW_{AC} represented 37 % of the approved capacity, but only 18 % 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. In the first auction of 2017, which had a ceiling price of JPY 21 kWh (EUR[13] 0.162/kWh), 9 projects with a capacity of 141 MW were successful. However, only 4 projects with a capacity of 41 MW actually paid the required deposit to get the approval. The second auction at the beginning of September 2018, no project was below the ceiling price of JPY 15.5/kWh (EUR 0.119/kWh), which was not disclosed to the bidder beforehand. A third auction is planned for December 2018.

New projects approved after 1 April 2017 now have three years maximum until they have to be connected. Feed in tariffs for FY 2018 were set as follows. Commercial installations (total generated power) larger than 10 kWp, receive a tariff of JPY 18/kWh (EUR 0.138/kWh) for 20 years. For residential installations (surplus power) smaller than 10 kWp the basic FiT is JPY 28/kWh (EUR 0.215/kWh, if the system is equipped with an

[12] Please note that the METI capacity statistics is AC-based and is converted by the New Energy Development Organisation in DC-figures.

[13] Exchange rate: EUR 1 = JPY 130

output control device or JPY 26/kWh (EUR 0.200/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 GW_{AC} was set for PV power in 2020, which was already surpassed in FY 2015. The 5th Strategic Energy Plan was approved by the Japanese Cabinet on 3 July 2018 [METI 2018]. This new plan aims to increase the self-sufficiency of electricity production from 8% in 2016 to 24% in 2030 and to reduce GHG emissions by 80% until 2050.

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 567 MW including about 100 MW of net-metered systems at the end of 2017 [Mes 2018]. A further 450 MW of systems larger than 100 KW were under construction in February 2018, and a further 200 MW were tendered in 2017. According to BNEF roughly 270 MW of new PV capacity was built in 2017 and market expectations for 2018 are around 580 MW [Blo 2017].

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 April 2018, the 103 MW Quweira solar photovoltaic (PV) power plant near Aqaba was connected to the grid.

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 MW_{AC} capacity. The plant should become operational in the first quarter of 2019.

There are two module manufacturers in Jordan, Philadelphia Solar in Amman and Wiosun in Aqaba.

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. The tariffs are set by the Sustainable Energy Development Authority (SEDA) for each year. For 2018 the basic tariffs for systems up to 1 MW are between MRY 0.4435 and 0.6682/kWh (EUR 0.092 to 0.181/kWh14), depending on the type and system size. For local manufacturing or use as building materials surcharges between MRY 0.05 and 0.1256/kWh (EUR 0.01 to 0.026/kWh) apply.

According to SEDA, PV systems with more than 378 MW of capacity received the FiT and were operational by the end of August 2018, jut 0.5 MW than at the end of 2017 [Sed 2018]. Between the 1 November 2016 and 2020, Malaysia aims to implement 500 MW of PV capacity under the Net Energy Metering (NEM) programme. So far, the uptake of the programme is rather slow. For 2017 and 2018 quota of 178.8 MW and 77.9 MW for the Malaysian Peninsula as well as 19.9 MW and 9.9 MW for Sabah were foreseen. The allo-

14 Exchange rate: EUR 1.0 = MRY 4.82

cated quota so are 5.2 MW and 12.1 MW for the Malaysian Peninsula as well as 21.5 kW and 13 kW for Sabah.

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 2.5 GW of solar power was installed in Pakistan at the end of 2017 [Blo 2018]. Market expectations for 2018 are in the range of 8 to 900 MW.

2.2.8 People's Republic of China

According to the National Survey Report of IEA PVPS 53 GW of solar PV power was connected to the grid in 2017 increasing the total grid connected capacity to over 131 GW [IEA 2018c]. About 14.4 GW were residential PV systems and 36.6 GW utility scale systems. Electricity production from PV systems in 2017 was 118 TWh or 1.9% of total electricity demand.

The 2018 International Energy Agency (IEA) Renewable Energy Medium-Term Market Outlook expects an addition of over 130 GW new PV capacity between 2018 and 2023, which would increase the total capacity to over 200 GW [IEA 2018a]. However, looking at the current developments, this capacity will be reached much earlier.

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 (EUR[15] 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].

On 31 May 2018, China's National Development and Reform Commission (NDRC), the Ministry of Finance and the National Energy Board issued a common statement were they announced the end of the feed in tariffs for new utility-scale solar projects and the intention to use competitive bidding in the future [NDRC 2018]. The timing of this announcement was a surprise for most in the solar industry. However, the phase out of the feed-in scheme was not completely unexpected after NEA released a draft of the Renewable Portfolio Standard and Assessment Methods, that would create a market for renewable

[15] Exchange rate September 2016: EUR 1.0 = CNY 7.45

energy certificates (RECs), for comment in March 2018. At the end of September 2018, a second draft was released for comments with an updated target of at least 35% of renewable power by 2030. The final document is expected to be published before the end of 2018.

During the first six months of 2018, already more than 24 GW were connected to the grid. It is also worth to mention that the top-runner programme, where module efficiency thresholds are 18% and 18.9% for multi and mono respectively, the poverty alleviation programme and the residential quota are unaffected from the policy change.

In the short term the end of the feed-in regime for utility scale PV systems is driving down prices for solar modules, adding to the pressure on the solar module value chain companies. This price pressure will certainly accelerate the move of manufacturers to higher efficient products, namely changing the respective market shares of multi-and mono-silicon wafers in solar cell production. Further cost reductions come not only from higher efficiencies, but thinner wafers, made possible by the rapid uptake of diamond wafer sawing, as well. Polysilicon material consumption is expected to drop from roughly 4.4 g/W at the end of 2017 to around 3 g/W in 2022.

In the longer term, the possible introduction of a renewable portfolio standard, which is currently under discussion in China, and an auctioning system could enable a steady and healthy future grow, not only of solar power capacity but the manufacturing industry as well.

2.2.9 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. This 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[16] 0.299/kWh) 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 was 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[17] 0.183/kWh) and confirmed the digression rate.

The Department of Energy (DoE) reported that, by the end of 2017, more than 6.8 GW of PV projects had applied under the Renewable Energy Law and 0.91 GW, most of it commercial systems were installed [RoP 2017].

In 2017 two companies completed their new manufacturing sites in the Philippines. SunPower with a 400 MW solar cell and module manufacturing plant and Solar Philippines with a 600 MW module manufacturing plant.

In August 2018, the Philippine utility company Manila Electric Co. (Meralco) announced that they had received a bid of PHP 2.34 (EUR[18] 0.038) per kWh for 50 MW of solar by local PV module manufacturer and project developer, Solar Philippines.

2.2.10 South Korea

In 2017, about 1.2 GW of new PV systems were connected to the grid in South Korea, bringing the cumulative capacity to a total 5.7 GW [Par 2018]. Since January 2012, Korea's RPS has officially replaced the FiTs. Besides the RPS, Korea supports PV installa-

[16] Exchange rate for 2011: EUR 1 = PHP 60
[17] Exchange rate for 2012: EUR 1 = PHP 53
[18] Exchange rate for 2018: EUR 1 = PHP 62

tions 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 rood-top systems). The new planning foresaw the installation of over 1.5 GW between July 2016 and July 2018. In the first half of 2018, the grid connected PV capacity increased by 470 MW to reach a cumulative capacity of 2.2 GW, some 200 MW short of the planned target.

Market expectations for 2018 and 2019 are in the range of 800 to 900MW and 1 to 1.1 GW respectively.

In January 2018, the Bureau of Energy under Taiwan's Ministry of Economic Affairs (MOEA) announced the FiT rates for PV electricity to be generated in 2018 [MoE 2018]. The tariffs for the second half of 2018 in the three categories are:

Type of system	Feed-in tariff [TWD (EUR[19]) per kWh]
ground-mounted	4.29 (0.120)
mounted on surface of water	4.69 (0.131)
rooftop	4.24 – 5.75 (0.119 – 0.161)

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. 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.

[19] Exchange rate: EUR 1 = TWD 35.7

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[20] scheme. The FiTs were set at THB 6.96/kWh (EUR[21] 0.183/kWh) for residential size systems, THB 6.55/kWh (EUR 0.172/kWh) for medium-sized building systems and industrial plants (< 250 kW) and 6.16 THB/kWh (0.1627 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.

In 2017 about 250 MW of new solar capacity was connected to the grid and increased the cumulative capacity to 2.7 GW.

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 2018]. Until April 2018 solar projects with a total capacity of 3.2 GW had applied or obtained a licence and should be operational at the end of 2018 [DEDE 2018].

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 2017, more than 5.2 million SHSs (50-60 W) had been installed in Bangladesh. According to the International Renewable Energy Agency (IRENA), over 133 000 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 2017 about 230 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 (EUR22 0.104 and 0.113/kWh) and the plants should be operational in Q3 2018. So far only two solar power plants with a combined capacity of 3.5 MW are connected to the grid.

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 Utilisa-

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[20] The "Adder" scheme was the Thai version of additional premium to the wholesale electricity price.

[21] Exchange rate: EUR 1 = THB 38

[22] Exchange rate: EUR 1 = BDT 98

tion 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 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, but so far limited information is available. Total installed PV power in Indonesia was estimated at around 100 MW, with more than 80% off grid, at the end of 2017.

Indonesia's local content requirements now demand 50% by 2018, and 60% by 2019 for solar PV modules after an amendments of the regulations in 2017. However, Indonesia's PV module manufacturing capacity is in the order of 90 MW, which is inadequate for the annual capacity addition required to achieve the 6.4 GW solar PV target by 2025.

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 1 GW in 2020. However, in 2017 no significant progress has been made.

In November 2017 the Green Climate Fund (GCF) – European Bank for Reconstruction and Development (EBRD) Kazakhstan Renewables Framework was approved. About EUR 560 million are foreseen for the construction of 8 to 11 renewable energy projects in Kazakhstan, with a total capacity of 330 MW. So far three solar projects with a combined capacity of 114 MW have received the approval for funding from this project. In July a tender for about 290 MW of solar capacity was launched with a closing date in October 2018.

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 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 electrifies 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.

The total installed PV capacity was estimated with 25 MW at the end of 2017. As of June 2017, solar photovoltaic power projects with over 1.5 GW capacity including 90 MW of floating PV plants had been announced. Three projects with 470 MW capacity were reported to have signed PPAs. However, little progress has been reported since.

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 county 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)23 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 counties energy demand.

The installed PV capacity has increased from 3.2 MW in 2014 to 48 MW in 2016. In 2018 a tender for a 200 MW solar PV plant was announced and prequalification documents had to be submitted by 24 June 2018.

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 reported 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, 20 MW of grid connected systems were installed in 2017, increasing the total capacity to 146 MW at the end of 2017 [EMA 2018]. In the first half of 2017 about 15 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 aims 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.

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 (operational since May 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].

23 Also used term: concentrated solar power (CSP)

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 2017, about 8 MW of PV systems had been installed, mainly in off-grid applications. According to various press reports, 7 projects with a combined capacity of over 1 GW were in the construction or planning phase 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 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 let to a trend to install more and more small PV systems to provide the basic needs of electricity.

Between 2012 and 2017 the cumulative installed PV capacity has increased from 1.5 MW to an estimated 400 MW.

2.3 Americas

2.3.1 Argentina

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, however only 7 MW were actually realised. By the end of 2017, about 25 MW (15 MW off-grid) of PV systems were operational.

In late 2015 the National Government passed the Renewable Energy Act 27191, which laid the foundation for a new promotional legal framework to promote the uptake of renewable energy [GoA 2015]. The Act was then regulated by the Presidential Decrees 531/16 and 882/16 [GoA 2016, a], which set a target of 20% of the final electricity demand by 2025.

To achieve the 2025 targets the RenovAr auction programme was launched in May 2016 and in three bidding rounds 147 projects with a combined capacity of 4.47 GW (1.73 GW_{AC} of PV projects) were successful. The median bids of the PV projects declined from USD 59.75/MWh in the first round to USD 42.84/MWh in the addition of the third round – called RenovAr 2. Despite the fact that the first projects from round 1 should become operational in 2018, most of these projects are delayed. The first RenovAr projects –two from the second round called RenovAr 1.5 - became operational in August 2018. The project in Caldenes del Oeste, San Luis, has a capacity of 25 MW_{AC} (30 MW_{DC}) and La Cumbre, San Luis 22 MW_{AC} (28 MW_{DC}). More than 500 MW are currently under construction and and most of it is scheduled to become operational 2019.

A new tender for smaller projects between 0.5 and 10 MW is foreseen for October 2018. The quota for wind and solar PV together should be 350 MW_{AC}.

2.3.2 Brazil

At the end of 2017, the Brasilein Ministry of Mines and Energy reported a cumulative installed PV capacity of 1.1 GW_{AC} [MME 2017]. In the first half of 2018 about 0.5 GW_{AC} were added [MME2018].

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 was eligible to participate in one of the two December 2017 auctions and projects with 574 MW_{AC} power were successful. For the Auction in April 2018, Brazil's energy regulator (ANEEL) had set a ceiling price of BRL 312/MWh (EUR[24] 63.67/MWh). The lion's share of the 1 GW auctioned capacity was won by solar projects with a combined capacity of 807 MW_{AC} at an average price of BRL 118/MWh (EUR 24.08/MWh).

2.3.3 Canada

In 2017, about 200 MW of new PV power were connected to the grid and increased the total cumulative installed PV capacity to 2.9 GW. 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.

[24] Exchange rate: EUR 1: BRL 4.9

- **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 and a further six provinces offer investment incentives in form of cash or tax rebates. Ontario's Long-term Energy Plan sets a target of 10.7 GW of non-hydro RES by 2021.

2.3.4 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 660 MW of PV power was connected to the grid in 2017, increasing the total PV capacity to about 1.8 GW at the end of 2017. According to the Comisión National de Energía the connected solar capacity increased to 2.25 GW until July 2018 [CNE 2018].

On 17 August 2016, Comisión National 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 were auctioned and the results announced in November 2017. The auction was divided in three time blocks, where the electricity has to be delivered.

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

The lowest bid in the 2017 power auction was $21.48/MWh, with an average price of $32.5 MWh. Enel and GPG Solar Chile submitted the lowest bids with $21.48 MWh and $24.80/MWh respectively.

Market expectations for 2018 are around 600 MW for new solar PV capacity.

2.3.5 Dominican Republic

As early as 2007, the law promoting the use of renewable energy, which set a target of 25 % renewable energy share by 2025 was passed [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 (34 MW_{AC}) of a 67 MW_{AC} solar plant was inaugurated in the Monte Plata province. At the end of 2017 it was estimated that about 110 MW were insytalled. In July the so far largest solar photovoltaic power plant with 58 MW_{AC} (73 MW_{DC}) in Guayubín, Montecristi was connected to the grid [Fss 2018]. Two additional project in Mata de Palma, San Antonio de Guerra (50 MW_{AC}) and the Canoa Solar project with 25 MW_{AC}, in Barahona, are under construction and should be connected to the grid before the end of 2018.

2.3.6 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. 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 2017 approximately 20 MW were installed to increase the total capacity to 560 MW (450 MW_{AC}). Electricity generation from PV plants in 2017 was 924 GWh or 10.3% of the total sold electricity.

2.3.7 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 2017, about 285 MW of new PV systems were connected increasing the total cumulative PV system capacity to 674 MW [Sen 2018]. 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[25] 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 CECs 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. A third auction was held in November 2017. 3.45 million CECs and 1.3 GW_{AC} was awarded to solar photovoltaic projects. The prices per MWh varied between MXN 242.10 and 298.14 (EUR[26] 10.86 – 13.27/MWh) whereas the CEC prices varied between MXN 95.82 and 149.07 (EUR 4.30 – 6.69) [Ern 2017]. The winning projects must start to deliver electricity on 1 January 2020.

On 27 September 2018, Enel Green Power México announced that it has connected its 828 MW Villanueva solar photovoltaic plant in Viesca, Coahuila and its 260 MW Don José solar park in San Luis de la Paz, Guanajuato [Ene 2018c].

2.3.8 Panama

In March 2016, the Government 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 143 MW in December 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].

2.3.9 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

[25] Exchange rate 2016: 1 EUR = 21 MXN
[26] Exchange rate 2018: 1 EUR = 22.3 MXN

in 2011, with a quota of 24 MW for PV. About 85 MW of PV systems had been installed by the end of 2012. The National Photovoltaic Household Electrification Program, launched in 2013, aimed to supply PV electricity to 500 000 households by means of 12 500 solar systems by 2016. At the end of 2017 about 100 MW of solar PV capacity was installed in Peru.

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_{AC} with 415 GWh) and USD 48.50/MWh (40 MW_{AC} with 108.4 GWh) [Osi 2016]. Start of electricity delivery is December 2018 at the latest. The next auction is planned for the second half of 2018 after there was no auction in 2017.

In March 2018, Enel Green Power Peru reported the inauguration of their 180 MW (144.5 MW_{AC}) plant in Rubí, province Moquegua [Ene 2018d]. The second project awarded in the 2016 auction to Engie with 40 MW_{AC} (44.2 MW_{DC}) was connected in May 2018 and increased the operational solar power capacity to about 320 MW.

2.3.10 United States of America

With over 10.6 GW of newly connected PV power, the United States had reached a cumulative PV capacity of almost 51.8 GW by the end of 2017 [Gtm 2018]. In terms of nominal capacity, solar accounted for 33 % of new power capacity in 2017, second only to natural gas. With over 6.2 GW utility PV installations accounted for 59% of the new installed solar photovoltaic power capacity. The top ten States — California, North Carolina, Florida, Texas, Massachusetts, Minnesota, Arizona, South Carolina, Nevada, and Virginia still accounted for almost 80 % of the US PV market, and California alone had a market share of 24.5 %.

Following the Section 201 trade case, tariffs on modules were announced in January 2018. For 2018 the tariff is 30% and declines by 5 percentage points annually to 15% in 2021. This move resulted in a slowdown of the market and market expectations for 2018 are in the 9 to 10 GW range with a moderate growth expectation to 10 to 11 GE in 2019. How the latest round of import tariffs for products from China in September 2018 will affect the market still has to be seen.

PV utility projects based on PPAs, with a total capacity of 23.9 GW, were under contract, but not yet operating in Q3 2018 [Gtm 2018a]. In Q3, 4.3 GW of these projects are under construction. In the first half about 2.6 GW of utility scale projects were installed and it is estimated that the about 6 to 6.5 GW of utility projects will be connected to the grid before the end of 2018. In addition more utility scale projects with more than 36 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 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.

2.3.11 Emerging markets

In 2014 the government of **Cuba** announced that 24% of the country's generated electricity should come from renewable energy sources by 2030. To reach this goal the government plans to install 700 MW_{AC} of solar PV capacity. According to Cubasolar, the government signed Law No 345, "On the Development of Renewable Sources and the Efficient Use of Energy," on 23 March 2018. So far it has not yet been published in the official Gazette.
In February 2015, the Cuban newspaper reported the opening of the first Cuban solar module factory with 15 MW capacity by the electronics manufacturer Empresa de Com-

ponentes Electrónicos Ernesto Che Guevara [Gra 2015].
It is estimated that about 32 MW_{AC} of PV systems were installed in Cuba in 2017. The total capacity at the end of the year was about 65 MW_{AC}.
In 2018 more than 50 solar PV projects with a capacity of over 200 MW_{AC} are either in construction or planning phase. About half of the capacity will be financed by direct foreign investments.

The **Guatemala** National Energy Policy 2013-2027 came into force in February 2013 [GoG 2013]. The National Energy Plan defines the promotion of renewable energy resources as one of its guiding principles and sets a target of 80% of electricity generation from renewable energy resources. In January 2015 a 58 MW (50 MW_{AC}) utility plant was connected to the grid in Chiquimulilla, Santa Rosa. The second 35 MW (30 MW_{AC}) stage of the plant became operational in the second half of 2015. It is estimated that about 100 MW of PV capacity was installed in Guatemala at the end of 2017.

In 2012 the government of **El Salvador** enacted the Master Plan for Renewable Energy Development (2012 – 2026), which at that had a target of 90 MW_{AC} of PV capacity by 2026. In 2014 El Salvador's power distributor Delsur conducted an auction where 4 solar projects were awarded a combined capacity of 94 MW. A second auction for 100 MW PV capacity was held in 2016. The latest auction was announced in June 2018 with a solar PV capacity of 20 MW.
In April 2017, 101 MW of solar capacity were connected to the Salvadorian grid by Neoen [Neo 2017]. The company was awarded 76 MW in the 2014 tender and negotiated an additional 25 MW with electricity distributor Del Sur. Another three 10 MW projects were connected by AES El Salvador until September 2018.

In 2009 **Jamaica** published its National Energy Strategy 2009 – 2030, which aims to provide 20% of the energy needs by renewable energy sources in 2030 [MEM 2009]. The first large solar plant at Content Village, Clarendon, with 20 MW_{AC} (28 MW_{DC}) became operational in August 2016 [Wrb 2016]. A second utility scale PV plant secured inancing at the beginning of 2018 and will be built in Paradise Park, Westmoreland, with a capacity of 37 MW_{AC} (51 MW_{DC}).

The parliament of **Nicaragua** passed the Renewable energy promotion law, which declares that renewable energy based power generation is of national interest in 2005 and prolonged the incentives for electricity from renewable energy sources in 2017 [RoN 2005]. In December 2017, the Ministry of Energy and Mines published the new regulation for self-consumption and net metering in the official gazette [MEM 2017a]. The new regulations allow the owners of solar photovoltaic electricity systems with a capacity of up to 5 MW to sell their surplus of electricity, which is not self-consumed to Nicaraguan distribution companies. The surplus electricity will be paid at 80% of the lowest price of the reference band approved by the MEM. In June 2017, the reference band for solar was discussed at about USD 70/MWh. The installed PV capacity was estimated at around 20 MW at the end of 2017.

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 as in Central Europe, there has been only limited use of solar PV electricity generation up to now. According to the latest update of the JRC resource study in Africa[27], 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 solar home system (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 in 2030.

Overall, the (documented) capacity of installed PV systems has risen to more than 3 GW by the end of 2017, almost fifty times the capacity installed in 2008. In 2018, 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.

Aures Solaire a 51/49 joint venture between Algerian firm Condor Electronics and Vincent Industrie (France) opened a 30 MW solar module factory located in the industrial zone of Ain Yagout in April 2017. Condor Electronics already owns and operates a 75 MW module plant at the same industrial zone since 2013.

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]. The solar plants should be build in the High Plains of northern and southern Algeria. However, the tender is delayed and has not been published yet.

In 2015 and 2016, PV systems with about 350 MW were newly installed, but in 2017 only very few new systems were connected to the grid. It is estimated that the total PV capacity –on- and off-grid was just about 400 MW at the end of 2017.

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.

[27] RE2nAF tool for off-grid options for rural Africa Web site: http://re.jrc.ec.europa.eu/re2naf.htm

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 2016]. A 2 MW 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 2016]. At the end of 2017 about 14 MW of PV capacity was operational. The energy and water service provider Águas de Ponta Preta on the island of Sal started the construction of a new 1.3 MW plant early 2018.

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 at that time varied between EGP 84.8 to 102.5/kWh (EUR[28]0.085 to 0.103/kWh) depending on the size of systems.

The first two rounds of the FiT programme were heavily oversubscribed and around 2 GW of PV capacity was allocated. The majority of these projects, which received a 25-year FiT contract are located in the 2 GW_{AC} Benban solar complex, near Aswan in upper Egypt. However, a significant number of projects were halted for a long time and only reached financial close in the second half of 2017 after the International Finance Corporation (IFC), the European Bank for Reconstruction & Development (EBRD) and the African Development Bank (AFDB) approved loans of almost USD 1.2 billion for 27 different projects. In December 2017, the Egyptian Electricity Transmission Company (EETC) issued a request for prequalification (RfP) for 600 MW_{AC} of solar PV capacity to be developed West of the Nile.

The first solar plant of the Benban solar complex, Infinity with 64 MW (50 MW_{AC}) became operational at the end of 2017. According to Egyptian media reports 29 plants with a combined capacity of 1.45 GW_{AC} should be connected to the grid in Q1 2019 [Egy 2018].

About 65 MW were connected in 2017, increasing the cumulative PV power to 79 MW at the end of 2017 [Blo 2017].

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 2016, EEP signed an agreement with IFC to advise on the development of up to 500 MW of solar power under the Scaling Solar initiative. The pre-qualification bid for two 125 MWAC PV plants as part of the World bank's Scaling Solar programme in November 2017 resulted in the announcement of a dozen qualified bidders in March 2018.

In October 2017, it was announced that a consortium with Enel and the Ethiopian infrastructure company Orchid Business Group, had been selected as the developers of the 100 MW_{AC} Metahara project [Ene 2017]. The plant is expected to enter into operation in 2019.

It is estimated that a solar PV capacity of about 30 MW was operational at the end of 2017.

[28] Exchange rate: 1 EUR = 9.95 EGP

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. The plant size was increased later to 50 MW and was connected to the grid by the end of 2017.

In 2016, 8 smaller projects with 16.6 MW were installed increasing the total capacity to approximately 35 MW. Total PV power capacity reached 85 MW at the end of 2017.

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[29] and PV will all compete openly. Earlier in 2007, the National Office of Electricity (ONEE) had already announced a smaller programme for 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 have been 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.

Morocco's Office National de l'Electricité et de l'Eau Potable (ONEE), provides solar power to more than 19,000 homes in more than 1,000 rural villages at the end of 2017.

It is estimated that about 30 MW of PV system capacity was installed at the end of 2017.

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

[29] Also used term: concentrated solar power (CSP)

power in Senegal. This has auctioned 100MW of solar capacity and the pre-qualification round closed in October 2016 [Com 2016].

The first utility scale projects with 20 MW solar PV at BokholIt and 22 MW in Malicounda started operation in October and November 2016. In 2017, this was followed by two 30 MW plants in Santhiou Mékhé near Méouane and in Ten Merina, near Dakar. For 2018, a capacity addition of about 40 MW is estimated.

In April 2018, the results of a 60 MW the 2017 Scaling Solar initiative in Senegal tender were announced. The solar plant located in Kahone will have a tariff of EUR 0.0380/kW and the plant in Touba will have a tariff of EUR 0.0398/kWh [SSS 2018].

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. Four 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[30] 0.265/kWh) to ZAR 0.62/kWh (EUR[31] 0.044/kWh). The long awaited fifth round with a renewable capacity of 1.8 GW was finally announced in June 2018 and should be conducted in November 2018.

Developers who had won allocations in the fourth bidding round of REIPP had to wait until April 2018 when the PPAs were finally signed.

As a result of the long delay to sign the PPAs of the fourth round, about 250 MW, less than half of the 2016 PV capacity, was connected in 2017.

Due to the country’s local content rules, more and more manufacturers along the solar value chain are setting up plants in South Africa. A non-exhaustive list of industry activities can be found in the 2017 report [Jäg 2017].

2.4.9 Emerging markets

Burkina Faso has a new National Policy for Sustainable Economic and Social Development since August 2016 [MEF 2016]. A key element is the access of the population to electricity, extremely important in a country were only 3% of the rural population have access to electricity. A tender with a total capacity of 67.5 MW was launched, but none of the projects is operational yet.

The Zagtouli PV plant was already initiated in 2013 and received financing from the EIB. The 33 MW grid connected PV plant was finally commissioned in late November 2017. In January 2018, Burkina Faso’s Ministry of Energy revealed a plan to install eight additional solar parks with a combined capacity of 100 MW in the country.

In December 2017, Wärtsilä started operation of a 15 MW (12 MW_{AC}) solar power plant for Essakane Solar SAS [Wär 2017]. The PV plant is next to a 55 MW heavy fuel oil plant and both installations provide off-grid power to the Iamgold Eassakane SA.

It is estimated that a total of 50 MW of PV capacity was installed at the end of 2017.

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

[30] Exchange rate 2012: EUR 1 = ZAR 10
[31] Exchange rate 2015: EUR 1 = ZAR 14

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. However, no details on how the programme should be executed are available yet.

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 75 MW (55 MW_{AC}) solar power plant in Garissa [Rea 2016]. It is interesting to note that the solar plant was financed through concessional funding from the Government of China. After a number of delays, construction started in the second half of 2017 and was finished in September 2018.

For 2017 the electrification of 603 schools with PV is listed in the project list of the Ministry for Energy and Petroleum [MEP 2017].

According to various media reports two solar plants with a capacity of 40 MW each, in Eldoret - Uasin Gishu county, will receive funding from the EIB with a financial closure by the end of 2018. Start of construction is foreseen in 2019 with a grid connection in 2020. A third project with 50 MW, which has a PPA with Kenya Power and Lighting Company hopes to close the financial negotiations in 2018 as well.

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 caped at a capacity of 380 MW by 2018.

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. However, until November 2017, when Africa Solar Ltd. awarded a contract to the Finnish power company Wärtsilä to build a 95 MW (75 MW_{AC}) solar PV plant, nothing had happened [Wär 2017].

It is estimated that about 30 MW of solar PV power were operational at the end of 2017.

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]. Despite that the SREP calls for a cumulative installed PV capacity of 60 MW by 2017 and 120 MW by 2020 not much has been realised yet. Cumulative PV capacity is estimated below 10 MW at the end of 2017.

In 2018, Tanzania's state-owned power utility the Tanzania Electric Supply Company Ltd (Tanesco) published a tender for the construction of several large-scale PV projects with a combined capacity of 150 MW [Tes 2018].

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 pf PV capacity was published [RoT 2017]. The tender has tow 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.

In July 2013, the Cabinet of **Uganda** approved the new Rural Electrification Strategy and Plan 2013 – 2022 [GoU 2013]. The overall objective of this plan is to increase the rural electrification rate from 7% to 26% within the given period. In 2014, the Electricity Regulatory Authority (ERA) announced that with effect from 1st January 2015, the procurement of new capacity from solar technology will be subject to a competitive tendering process initiated by the ERA in accordance with the Electricity Act, 1999 Chapter 145, Laws of Uganda [Era 2014].

Under the Global Energy Transfer for Feed–in–Tariffs (GET-FiT) Programme, launched in 2013, 2 solar PV plants with 10 MW each were built. Funding for the programme comes from the European Union, Germany, Norway and the United Kingdom. The 10 MW Soroti PV plant started operation in November 2016, followed by the Tororo plant in September 2017 [Get 2017]. The total installed capacity is estimated at 45 MW at the end of 2017.

On 21 June 2017, **Zambia** officially launched its 7th National Development Plan (SNDP) (2017-2021) [GoZ 2017]. In 2016, 97% of the electricity capacity was hydro, but it is envisaged that with increasing electricity demand (+150 to 200 MW capacity per annum will be needed) the non-hydro share will increase to 15% by 2030.

In July 2015, Zambia's Industrial Development Corporation (IDC) signed an agreement with IFC to explore development of two large-scale solar projects through Scaling Solar. The results of the first auction were announced in December 2017 [IFC 2017]. Two projects, one with 54 MW for USD 0.0602/kWh and a 34 MW (USD 0.078/kWh) project were selected.

Construction at the 54 MW solar plant in Bangweulu started in December 2017 and should be finished in October 2018.

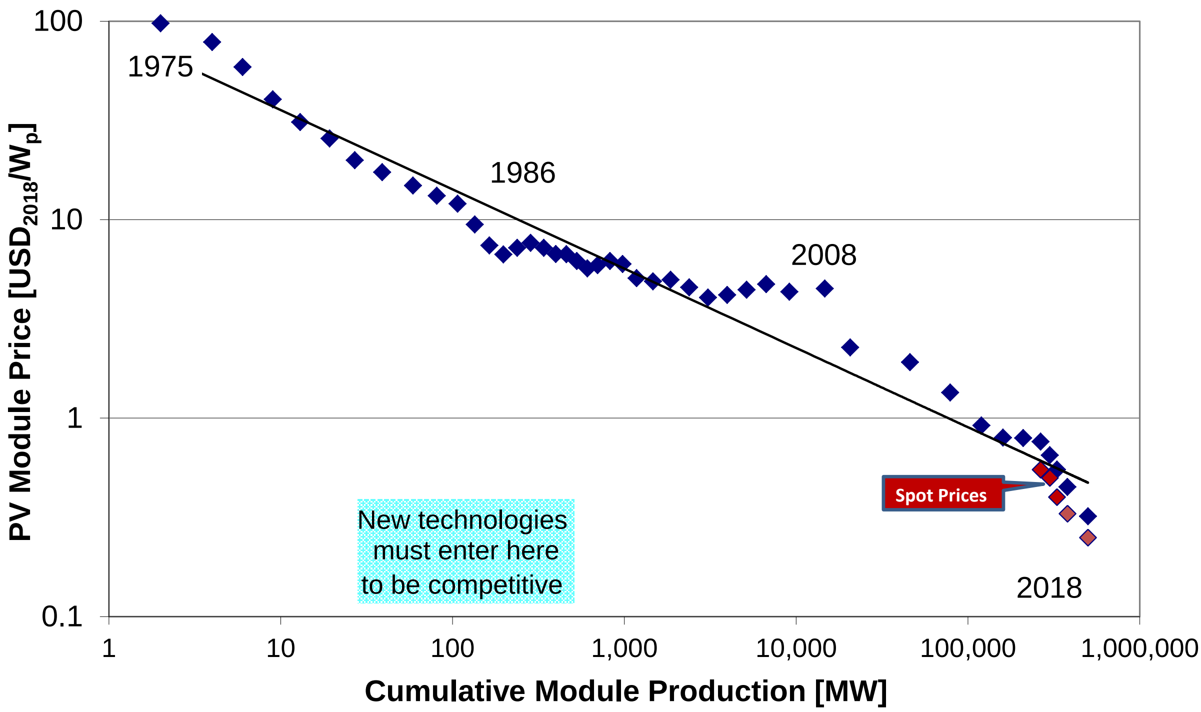
The Ngonye solar PV plant ,Lusaka South Multi-Facility Economic Zone, with a capacity of 34 MW (28 MW_{AC}) received financing from the EIB, announced in the framework of IFC's Scaling Solar programme [EIB 2018]. Construction started in August 2018 and the plant should be connected to the grid in the first quarter of 2019.

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 average selling price (ASP) of solar modules fell by 20 % for each doubling of production volume (Fig. 8). 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_{2016} 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 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 about 5% in 2017.

The market entrance of potential new technologies has to happen at prices comparable to current market prices but at production volumes a few magnitudes lower than silicon.

Figure 8: 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 since the end of 2015. 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 30 % in 2018.

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 depending on the size, type of installation and country where it is installed [Blo 2018]. 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[32]. 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 [Wan 2015].

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.

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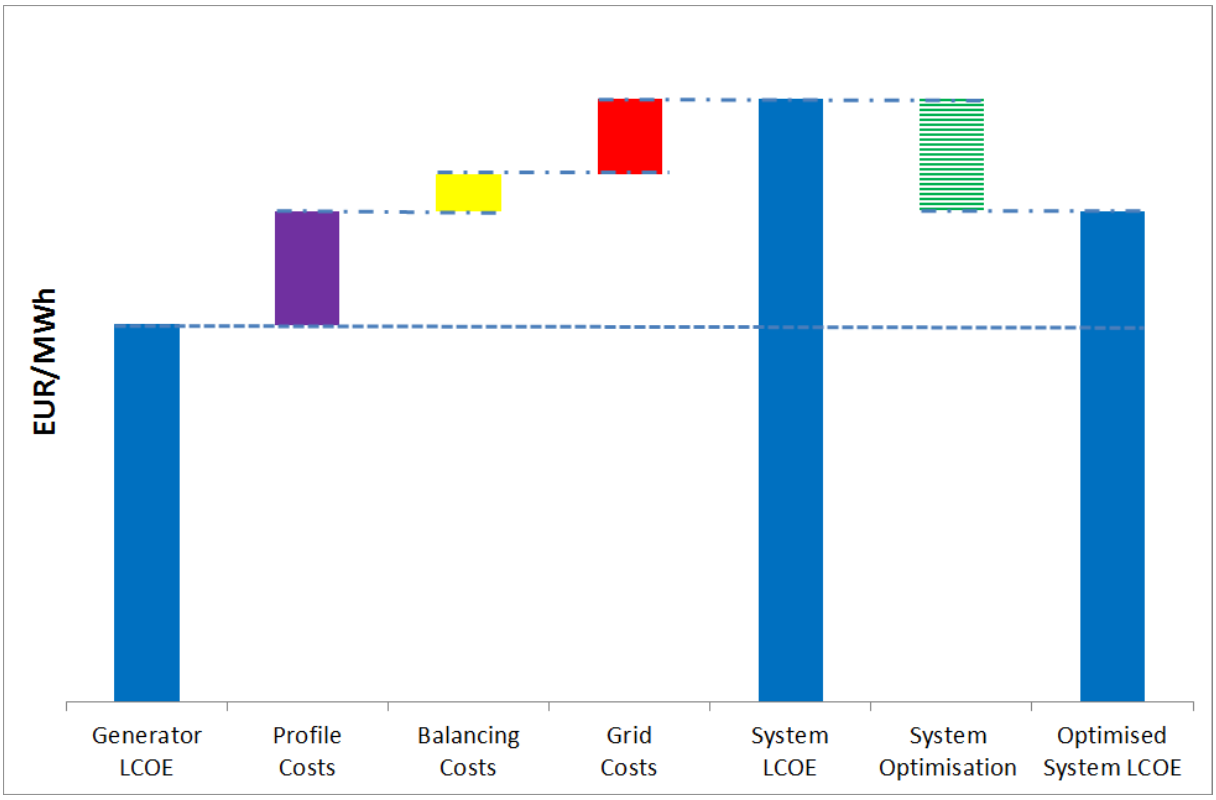
32 LCOE formula used by the National Renewable Energy Laboratory (NREL): http://www.nrel.gov/analysis/tech_lcoe_documentation.html

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.

Figure 9: Schematic of the components in a PV 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 2018 for a number of countries is reported between 140bps and 1 050 bps, whereas return of equity expectations were between 5% and 13% [Blo 2018a].

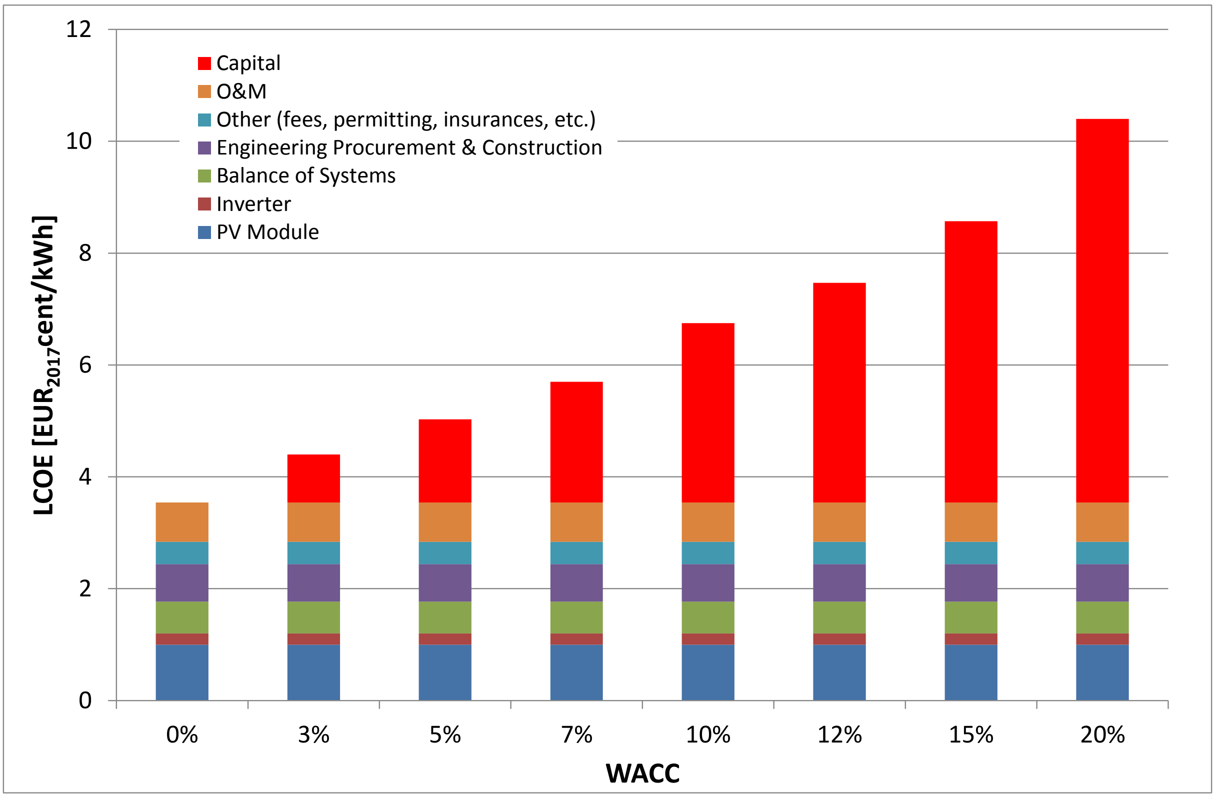
In this context, it is noteworthy to mention that the low bids and PPAs in the United Arab Emirates, Chile as well as in Africa have only been possible by a combination of excellent solar resource, high debt shares and low debt costs. In the case of Africa, the low costs of debt were possible through an exchange rate guarantee by the World Bank, lowering the investors risk as the offtake price is guaranteed in USD [WBG 2017].

To show the impact of financing on the LCOE, the following benchmark assumptions for a large scale system to be operational in 2017 were taken:

CAPEX EUR_{2018} 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 and administration costs were not considered.

As can be seen in Figure 10, 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 10: Influence of WACC on LCOE

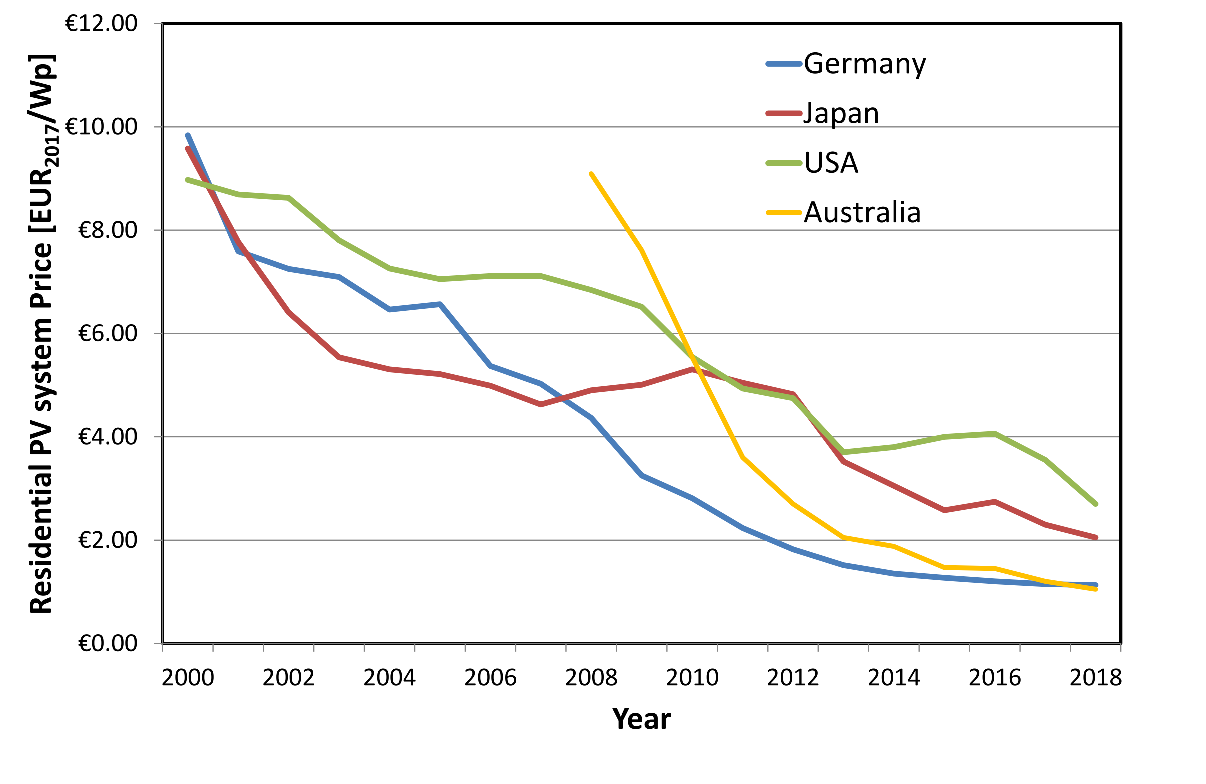


3.3 LCOE of residential grid-connected PV systems

Over the last decade, prices for residential grid-connected PV systems have decreased significantly, as shown in Figure 11. 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.

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

Figure 11: Residential PV system price development over the last decade



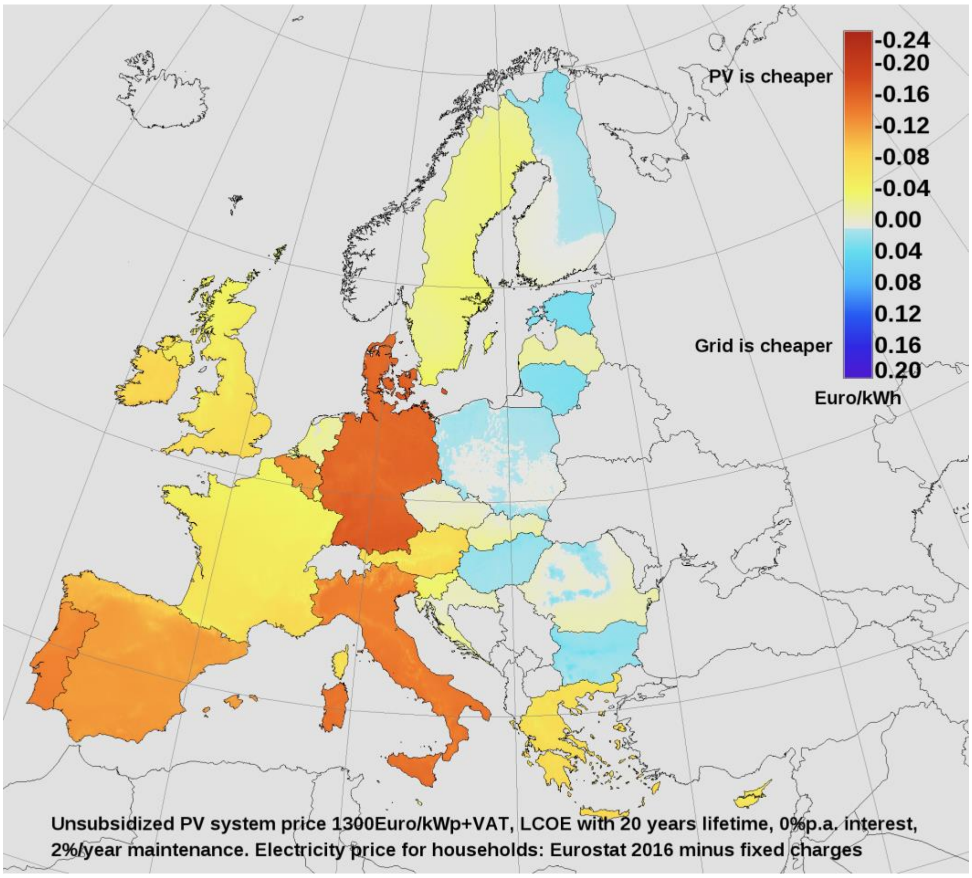
Sources: IEA PVPS, BSW, DoE SunShot Initiative, Eurostat, Solar Choice, OECD key economic data

In September 2018, the worldwide average price of a residential system without tax was given as USD 1.32/Wp (EUR 1.15/Wp) [Pvi 2018]. Adding a surcharge of EUR 0.15/Wp for fees, permits, insurance, etc., the benchmark for installed PV system costs is EUR 1 300/kWp without financing and VAT.

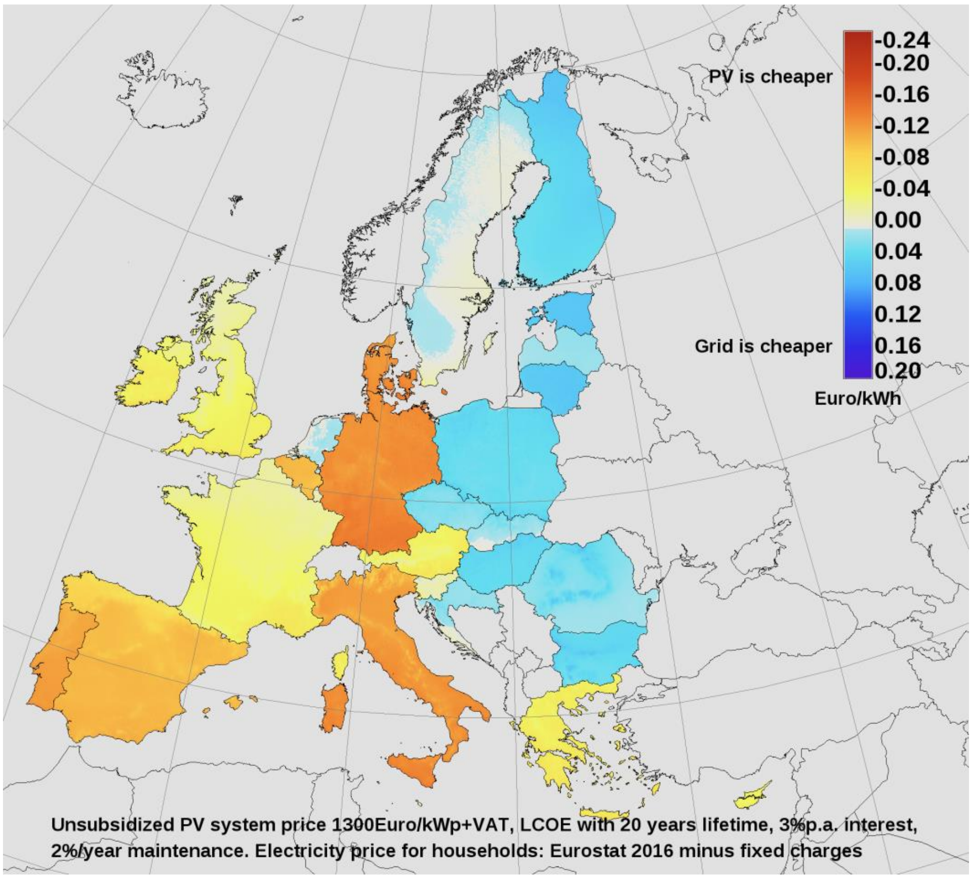
Even, if PV system purchases for a large number of consumers have become a 'credit card purchase', the wide spread differences of financing costs in different countries play a crucial role. Already in the different European Union Member States, debt costs can vary between 3 – 11%, based on the long term interest rates from the European Central Bank (ECB). 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 a benchmark price and compared it with the variable part of the electricity prices customers are paying in the European Union Member States (Fig. 12).

Figure 12 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 annual maintenance and repair (O&M) costs of 2% of CAPEX 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 lower and smoothen the influx of PV generated electricity to 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 % for residences, and 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 behaviour or control systems, which switch major loads (washing/dryer machines, heat pumps, refrigerators, air-conditioners) on when the sun is shining. However, there are limitations to such measures. 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 system owner chooses as being profitable.

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.

There is a wide range of prices for PV systems as well as electricity for customers in different countries, which defines the attractiveness of self-consumption. The level of overall PV production affects the level of self-consumption and hence the cost of the self-consumed electricity. Other parameters like the base to peak load ratio, or the composition of the electricity portfolio have big impact on the RES levels and network costs. So far, self-consumption in most countries has been limited to the owners or tenants of single family homes or small PV systems in apartment buildings.

Over the last few years, the concept of PV system use in apartment buildings has gained momentum and new economic concepts have been developed to use the electricity from a common PV system for all tenants in such a building. Different concepts, administrative provisions as well as technical regulations end electricity codes for self-consumption in multi apartment buildings exist [Jäg 2018]. So far the business opportunities are limited due to regulations, not technical requirements.

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.

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.

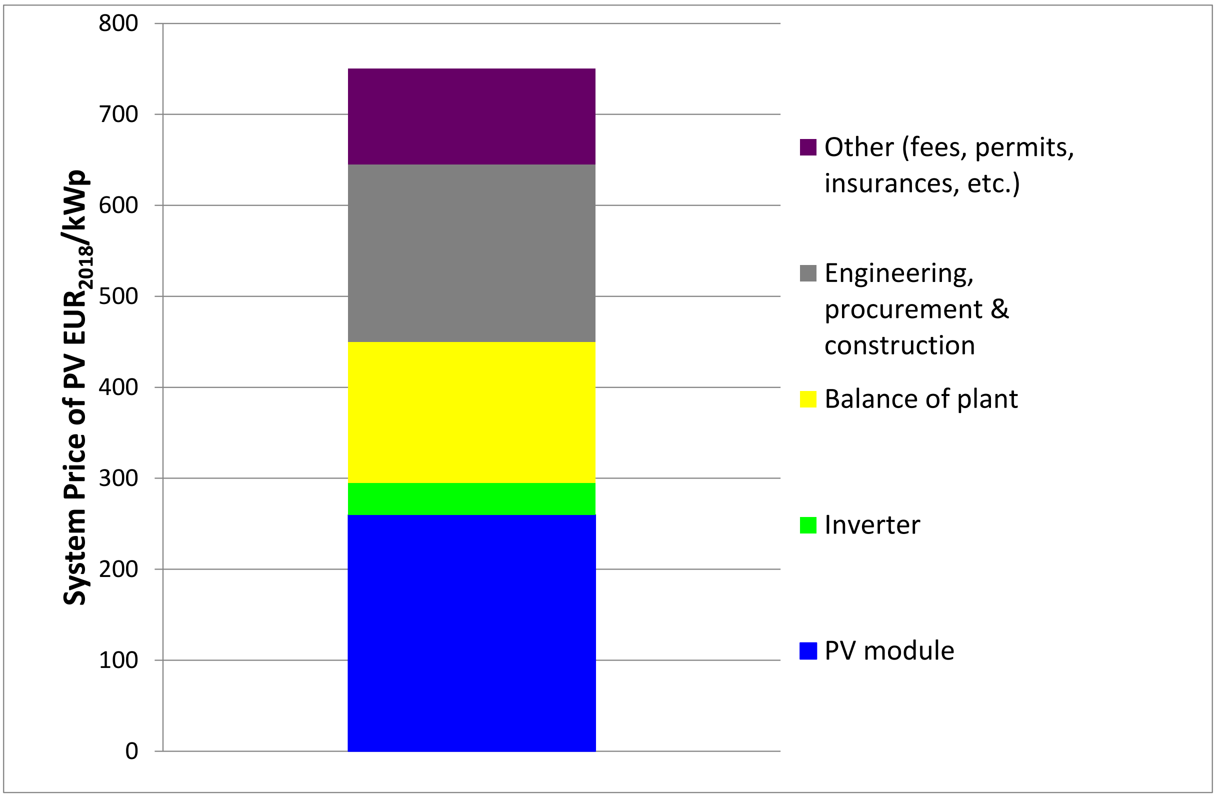
In addition, there are a number of companies, which offer the management of swarm or cluster storage facilities in cooperation with distribution network operators. However, detailed business model is still very limited.

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 this mark could almost triple by the end of 2018.

Due to the plant size, which is currently up to 1.5 GW[33] [Blo 2018c], the cost structure and LCOE is quite different from that of residential PV systems. Figure 13 shows an average cost breakdown in competitive markets. The actual cost breakdown can differ from project to project.

Figure 13: Price breakdown of utility-scale PV system



In 2016, a number of record breaking PPA contracts and bids below USD 30/MWh were 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 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 first joint solar and wind auction in Germany in April 2018 ended with contracts awarded only to solar projects for an average price of EUR 46.70/MWh [Bna 2018]. In Spain private PPAs are increasingly used to install large PV plants. Until October 2018 PPAs with more than 1.8 GW were already signed. Other examples are:

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33 Tengger Desert Solar Park, PRC

- 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)
- 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[34] 45.25 – 94.88/ MWh). It is believed that the winning solar bids are more at the higher end.
- In April 2018 Senegal's Commission de Régulation du Secteur de l'Electricité (CRSE) announced the tender results to build two 60MW solar PV plants. The winning bids were EUR 38.026/MWh and EUR 39.83/MWh. The projects will be financed under the IFC-backed Scaling Solar initiative.
- In July 2018 the results of the 2 GW Solar Energy Corporation of India solar tender were announced. The winning bids ranged between INR 2.44 and 2.71/kWh (EUR[35] 0.029 – 0.032/kWh),
- In July 2018, the French Ministry of Ecological and Solidarity-based Transition announced that it awarded 720 MW of PV to 103 projects in its fourth major large-scale solar auction, for projects ranging between 500kW and 17MW capacity. The average price for all projects was EUR 58.20 and for the category of PV plants with capacities between 5 and 17 MW it was EUR 52.00/MWh.
- In September 2018, the results of Jordan's Round 3 solar PV auction were announced. The auction received bids between USD 24.88 and 35.81/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 %.

[34] Exchange rate: 1 EUR = 4.3 PLN
[35] Exchange rate: 1 EUR = 84 INR

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 2017, the PV world market grew by over 30 % in terms of solar cell production to about 107 GW. The market for installed systems grew in the same range, and values between 96 and 103 GW were reported by various consultancies and institutions. This mainly represents the grid-connected PV market since.

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 [Osb 2018]. According to BNEF the group of Tier 1 module manufacturers have a production capacity of 92 GW in 2018 [Blo 2018].

Not all announcements will be realised, but the capacity increases along the value chain are large enough to increase the overcapacity to levels accelerating the price pressure a possible stagnant or slow 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 2017, their market share was over 95 % 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 5% in 2017. 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 $Cu(In,Ga)(Se,S)_2$ 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[36] 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.

[36] 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 2018, polysilicon spot prices were in the USD 7 to 13/kg (EUR 6.09 to 11.30/kg) range.

Projected silicon production capacities for 2018 vary between 475 000 tonnes [Blo 2018] and 578 000 tonnes [Ikk 2018]. 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 3.5 g/Wp for mono- and 4.3 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, however, production is still limited. 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 2017. 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, nameplate polysilicon production capacity had reached 70 000 tonnes and 14 GW of wafers. The wafer capacity was further increased to 30 GW at the end of 2017. The company reported production of 74 818 tonnes of polysilicon with sales of 7 316 tonnes of polysilicon and 23.9 GW of wafers for 2017.

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 6 GW at the end of 2017.

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 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 reported production and sales of more than 71 000 tonnes.

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 2017 the company had a nameplate capacity of 72 000 tonnes of capacity. The effective capacity was given with 65 800 tonnes and plans to increase to 69 000 tonnes by the end of 2018. For 2017, a production of close to 60 000 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. The total capacity of operational projects was almost 1 GW at the end of 2017.

4.3.4 Xinte Energy Co. (China)

Xinte Energy Co. (http://www.xtnysolar.com/) is a subsidiary of TBEA Silicon Co. Ltd. and 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 gird-connected and mini-grid power plants. For 2017, a production capacity of 33 000 tonnes and actual production of 29 400 tonnes was given.

4.3.5 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 1Q 2017 was 18 000 tonnes. A further expansion of the capacity to 30 000 tonnes should be finished by the end of 2018. In addition, the company manufactures wafers and had a capacity of 100 million at the end of 2016. The company reported a production of 20 200 tonnes of polysilicon, sales of 17 950 tonnes of polysilicon and 98 million of wafers in 2017. In September 2018, the company announced to discontinue its wafer business.

4.3.6 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 and should be finished by Q4 2018. The production in 2017 was estimated at about 17 000 tonnes.

4.3.7 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 2017, a nameplate capacity of 43 000 tonnes and an operational production capacity of 21 000 tonnes was reported. Actual production in the range of 15 000 tonnes was estimated.

4.3.8 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 18 000 tonnes at the end of 2016. For 2017, a production of 14 000 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.

4.3.9 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. The joint venture started operation in December 2017 and should be fully operational in the second half of 2018.

Production capacity at the end of 2017 was about 20 000 tonnes and, according to the company, a total of 11 636 tonnes of polysilicon, were produced and 13 067 tonnes sold in 2017.

4.3.10 Xinjiang East Hope New Energy Co., Ltd. (China)

Xinjiang East Hope New Energy Co., Ltd. (East Hope) is a subsidiary of East Hope Group, founded in 1982. East Hope is a newcomer with started the commercial operation of its 30 000 tonnes polysilicon plant located in Xinjiang in April 2017. The company plans to expand the capacity to 120 000 tonnes in the future. It is estimated that the company had a production of more than 10 000tonnes in 2017.

4.4 Solar cell production companies

In 2017, more than 100 companies produce solar[37] 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 about 110 GW at the end of 2017 and could increase to over 120 GW at the end of 2018.

The following section gives a short description of the 20 largest companies, in terms of actual solar cell production in 2017. 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 JA Solar Holding Co. Ltd. (China, Malaysia)

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 2018, an increase of the cell from 6.5 GW to 7 GW, module from 7 to 8.5 GW and wafers from 2.7 GW to 5 GW manufacturing capacity each is foreseen. Total sales for 2017 were reported with 7.5 GW (7.15 GW modules and 350 MW cells). It is estimated, that about 6.4 to 6.5 GW of solar cells were produced in 2017.

4.4.2 Trina Solar Ltd. (China, Malaysia, Vietnam)

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 March 2016 the company announced the official launch of operations at its new manufacturing facility in Thailand. The factory first had a solar cell manufacturing capacity of 700 MW and a module manufacturing capacity of 500 MW, and was increased to 1 GW in the meantime. In January 2017, a 1 GW solar cell and module manufacturing plant was opened in Vietnam and an additional 700 MW module factory in Malaysia became operational in in 2018.

According to the company it shipped 9 t0 9.2 GW of modules in 2017. A solar cell production of 6.4 to 6.5 GW was estimated for 2017.

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.

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[37] 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 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 8 GW of solar cells and modules (2.5 GW in China, 1.8 GW in Malaysia and 3.7 GW in Korea) as well as 1.65 GW of ingot in China. The wafer manufacturing plant in China was closed in 2017. In the spring of 2018 the company announced to build a PV module plant with more than 1.6 GW capacity in Georgia, USA.

For 2016, Hanwha Q CELLS reported a solar cell production of 4.28 GW (China and Malaysia only) and solar module shipments of 5.4 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. Construction of the plant started in December 2017.

4.4.4 JinkoSolar Holding Co. Ltd. (China, Malaysia)

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 8 GW for wafers and 5 GW for solar cells (4.55 GW in China, 450 MW in Malaysia) and 7.5 GW for solar modules at the end of 2017. A capacity increase to 9.7 GW for wafers, 7 GW for cells and 10.8 GW for modules is foreseen in 2018. For 2017, the company reported module sales of 9.7 GW, 270 MW of solar cells and 585 MW of wafers. It is estimated that 4.4 to 4.5 GW of solar cells were manufactured in 2017.

4.4.5 Longi Solar (China, India, Malaysia)

Longi Solar (http://en.longi-solar.com) is a subsidiary of Longi Group and was founded in 2000. The company focuses on monocrysrtalline solar cell and module production. According to the company they had a manufacturing capacity of 12 GW for ingots and wafers, 6.5 GW for solar modules and 5 GW for solar cells in 2017. According to the company it produced about 4.5 GW of solar cells in 2017.

The company announce major capacity increases in Q1 2018. The mono-wafer capacity is scheduled to reach 28 GW by the end of 2018. In addition, the mothballed 500 MW module factory in Andrah Paresh, India, should be reactivated and increased to 1 GW solar cell and module production capacity. The module plant should be operational in the second half of 2019, whereas the solar cell plant should be operational in January 2020.

4.4.6 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.

Together with the specialised equipment manufacturer Yongxiang, the Tongwei group owns and operates Yongxiang Polycrystalline Silicon Co., Ltd., located in Leshan City, Sichuan Province, which expanded its manufacturing capacity to 20 000 tons polysilicon in 2017. An expansion project of 50 000 tonnes was started as a joint venture with Longi Green Power in June 2017.

Tongwei Solar reported an annual production capacity of 5.4 GW for solar cells and 350 MW for solar modules at the end of 2017. The company plans to almost double this capacity to 10.4 GW until the end of 2018 and to over 20 GW by the end of the decade. For 2017, shipments of 3.85 GW solar cells are estimated.

4.4.7 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 2017 it had 1.2 GW of ingot capacity, 5 GW of wafer capacity, 5.45 GW cell capacity and 8.1 GW module manufacturing capacity (5.8 GW in China, 1.55 GW in South-East Asia, 400 MW in Brazil and 360 MW in Ontario, Canada). In 2018, the solar cell manufacturing capacity should be increased to 6.25 GW, the module manufacturing capacity to 9.1 GW and ingots to 1.6 GW. For 2016, the company reported shipments of 6.8 GW of modules. The solar cell production was estimated at 3.7 GW.

4.4.8 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 2017 was reported as 3.6 GW (1.6 GW China and 2 GW Taiwan). Total solar cell shipment of 3.26 GW was reported.

4.4.9 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 2017, it had a production capacity of 3.4 GW for ingots and wafers, 3.9 GW for solar cells and 4.2 GW for solar modules. Total reported shipments of solar modules for 2017 were 2.95 GW. Due to its OEM manufacturing activities for third parties the solar-cell production is estimated at 3 GW for 2017.

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.

4.4.10 Shunfeng International Clean Energy Ltd. (China/Germny/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 en-gaging 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 Suntech 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 2017, the annual production capacity of solar modules and solar cells, was approximately 2.4 GW and 3 GW respectively. The solar power generation business had a grid-connected annual designed installed capacity, of 1 500 MW. For 2017, total sales of 2.47 GW solar modules and 1.35 GW of solar cells were reported. Solar cell production was estimated at 2.8 GW.

4.4.11 First Solar LLC (USA/Malaysia, Vietnam)

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 2017, had an operating combined capacity of about 2 GW. For 2017, the company reported a production of 2.3 GW and shipments of 2.7 GW.

At the end of 2016, the company started to transform their production lines from the Series 4 module with an area of 0.72 m2 (approx. 120 W) to the Series 6 modules with an area of 2.4 m2 (> 420 W). Three series 6 production facilities in the USA (600 MW), Malaysia (1.2 GW) and Vietnam (1.2 GW) started commercial operation in Q2 and Q3 2018. An additional 1.2 GW factory in Ohio was announced in April 2018 and construction started in June 2018. The plant is scheduled to be in operation in the second half of 2019. Due to the high demand of First Solar's PV modules, as a consequence of the Section 201 trade case, the conversion of the remaining series 4 production lines to series 6 is postponed until the end of 2019.

4.4.12 Neo Solar Power Corporation (Taiwan, China)

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 DelSolar to become the largest Taiwanese cell producer. Solar cell production is estimated at 2.3 GW in 2017.

In October 2017, Gintech, Neo Solar Power and Solartech signed an MOU to merge into one company United Renewable Energy Co., Ltd. (UREC). After the merger had received approval from Taiwan’s Fair Trade Commission and international regulators, Neo Solar, the surviving entity, is to be officially renamed UREC in November 2018. The new company will have a solar cell production capacity of 5 GW (3.5 GW in Taiwan and 1.5 GW in China).

4.4.13 Suzhou Talesun Solar Technologies CO. Ltd. (China/Thailand)

Talesun Solar (http://global.talesun.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 4 GW of solar cells (3.2 GW in China and 0.8 GW in Thailand) and 5 GW of modules (4.2 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 2017, the module manufacturing capacity was increased by 2.2 GW to reach 5 GW at the end of the year. Shipments for 2017 are estimated in the range of 3 GW with in house solar cell production of 2.2 to 2.3 GW.

4.4.14 Aiko Solar Energy Technology Co., Ltd. (China)

Aiko Solar (http://en.aikosolar.com) 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. The Foshan factory was upgraded to the Passivated Emitter and Rear Cell (PERC) technology in 2017.

Early 2017, the company announced plans to expand its production capacity to over 8 GW of solar cells by 2022. According to the company, it had a solar cell capacity of 4.3 GW, including a new 2.65 GW PERC factory in Zhejiang, at the end of 2017. In September 2018, the company reported that its annual nameplate production capacity had increased to 5.5 GW, 5GW of P-type mono PERC cells (including bifacial) and 500 MW of high-efficiency multicrystalline solar cells.

For 2017 a solar cell production of about 2 GW is estimated.

4.4.15 GCL System Integration Technology Co. Ltd (China)

GCL System Integration Technology Co. Ltd (http://en.gclsi.com/site/index) is part of the GCL Group. GCL S.I. has five solar module production sites in mainland China and one in Vietnam, with a combined capacity of 6 GW. It also operates a 2 GW of solar cell manufacturing capacity. For 2017 the company reported shipments of 4.7 GW of solar modules and a solar cell production of about 1.9 GW was estimated.

4.4.16 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 2017, a solar cell production of about 1.8 to 1.9 GW was estimated.

4.4.17 Inventec Solar Energy Corporation (Taiwan)

Inventec Solar (http://www.inventecsolar.com/en/) 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 2.2 GW in 2017. For 2017 a solar cell production of 1.8 to 1.9 GW is estimated.

4.4.18 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 1.5 GW solar cells and 3.1 GW modules in 2017. It is estimated that about 1.5 GW of solar cells and modules were produced in 2017.

In December 2017, the company announced its intention to build a 5 GW solar cell and module manufacturing base in Changzhou, Jiangsu province.

4.4.19 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.

4.4.20 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 was 2 GW annually for ingot casting, wafers, cells, and modules in 2017. For 2017, a solar cell production of 1.5 GW was estimated. Due to the high losses in 2017, the company had to file for bankruptcy in 2018.

5 CONCLUSIONS AND OUTLOOK

In 2017, new investments in renewable power capacity (excluding large hydro-electric power plants) increased by 2% to USD 265 billion (EUR 230 billion) compared to 2016. This is about two and a half times the amount invested in conventional power projects. The total new installed renewable power capacity (excluding large hydro) increased from 138.5 GW in 2016 to 159 GW in 2017 and solar power accounted for over 62% of this capacity [Blo 2018, FSU 2018]. This record installation of new renewable power capacity was made possible by the significant reductions in renewable energy system prices, especially solar PV.

New renewable power capacity excluding large hydro accounted for 54% of all new power generating capacity. If the retired capacity is deducted, renewable power even added 72% of the new net capacity. The total of renewable power capacity (excluding large hydro) at the end of 2017 stood at 1 097 GW (2 195 GW including large hydro) and generated 2 177 TWh of electricity (6404 TWh including large hydro) worldwide. The share of electricity in the final consumption provided by renewable energy sources (excluding large hydro) increased from 8.5% in 2016 to 9.8% in 2017 [IEA 2018, Ene 2018].

R&D spending slightly increased due to a 14% increase in industrial spending.

For the 8th year in a row, solar power attracted the largest share of new investments in renewable energies and accounted for 58%, followed by wind with 38%.

The trend that the developing economies invest more in renewable energy capacity than the developed ones continued for the third year. China, India and Brazil invested almost the same amount in 2017 than in the record year 2015. On the other side, investments in developed countries have declined by 30% compared to 2015.

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 2017, no European company was listed.

If Europe wants to regain a double digit market share of the solar cell manufacturing industry (currently < 2%), 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 PV value chain. Besides the information here about the manufacturing of solar cells, the 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 100 GW in 2017. This corresponds to a CAGR of more than 40 %. In 2017, statistically documented cumulative installations worldwide accounted for 408 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 was observed in 2014/2015 immediately let to the market entry of new players, which contributed to new overcapacity in the sector. The current anticipated growth of annual installations is based on the growth of new markets outside Europe, especially in South East Asia, India, Middle East as well as Central and South America.

Driven by falling system prices and the increasing economic profitability of solar photovoltaic power, the number and volume of new PV markets worldwide is increasing. A growing number of large investors 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 already announced by the Rockefeller Brother Fund before the UN Climate Summit 2014 [BBC 2014].

With respect to the future market development of renewable power and solar photovoltaics in particular, the formal launch of an alliance of nations and states committed to moving the world from burning coal to cleaner power sources was a promising sign at COP23. In their founding declaration, the Powering Past Coal Alliance states: "To meet the Paris Agreement, analysis shows that coal phase-out is needed no later than by 2030 in the OECD and EU28, and no later than by 2050 in the rest of the world" [Ppc 2017]. In October 2018, the Alliance had already 75 members representing 28 national governments, 19 sub-national governments, and 28 businesses or organisations. The member countries represent 55 GW of coal fired power generation capacity to be phased out no later than 2030. To replace the cola generated electricity by solar power approximately 250 GW of solar Photovoltaic power would be needed.

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 economic 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 2016].

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 fu-ture,' 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. Between 2013 and 2015 energy subsidies have increased to USD 5.3 trillion [Coa 2017]. If we assume that not much has changed since then and a 60:40 % split between utility scale and residential PV plants, this amount would enable the installation of 3 600 GW of utility PV plants and 1 500 GW of residential PV systems in 2018. Together these PV systems would be able to generate over 6000 TWh of electricity or 27 % of global electricity demand. Compared to this, actual PV installations will be about 500 GW at the end of 2018.

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 third quarter of 2018, the average system price for residential systems was about AUS 1.25/Wp (EUR 0.95/Wp) in Australia, but around USD 3.20 (EUR 2.75/kWp) in the USA and JPY 260/kWp (EUR 2.00/kWp) in Japan [Blo 2018, Ikk 2018, Sol 2018a]. 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, 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 200/kWh in 2018 [Blo 2015, 2018d]. By 2025, the battery pack prices could fall below USD 100/kWh. 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 0.04/kWh (EUR 0.035/kWh) and should fall to USD 0.02/kWh (EUR 0.017/kWh) by 2025.

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 34 and 191/MWh (EUR 30 and 166/MWh) in the first quarter of 2018 [Blo 2018a], 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 high rates in the coming years. The different PV industry associations, as well as Greenpeace, the European Renewable Energy Council (EREC), the Energy Watch Group with Lappeenranta University of Technology (LUT), Bloomberg New Energy Finance (BNEF) and the International Energy Agency, have developed scenarios for the future growth of PV systems [Blo 2018b, Gre 2015, IEA 2016, 2018, Ram 2017]. Table 1 shows the different scenarios of the Greenpeace/EREC study, the Energy Watch Group/LUT study, BNEF New Energy Outlook (NEO) 2018 and the 2016 and 2018 IEA World Energy Outlook scenarios. It is interesting to note that the predicted PV capacity in the IEA scenarios has significantly increased from 2016 to 2018 but are still at the lower end. Older scenarios can be found in the previous PV Status Reports [Jäg 2013, 2014b].

With forecasted world-wide new installations between 360 and 410 GW from 2018 to 2020, even the 100% RES Power Sector scenario for 2020 is within reach [Blo2018].

Table 1: Evolution scenarios of the world-wide cumulative solar electrical capacities until 2040

Year	2017 [GW]	2020 [GW]	2025 [GW]	2030 [GW]	2040 [GW]
Actual Installations	**408**				
Greenpeace (reference scenario)		332	413	494	635
Greenpeace (advanced [r]evolution scenario)		844	2 000	3 725	6 678
LUT 100% RES Power Sector		1 168	3 513	6 980	13 805
BNEF NEO 2018		759	1 353	2 144	4 527
IEA New Policy Scenario 2016		481	715	949	1 405
IEA 450ppm Scenario 2016*		517	814	1 278	2 108
IEA New Policy Scenario 2018*		665	1 109	1 589	2 540
IEA Sustainable Development Scenario 2018*		750	1 472	2 346	4 240

*: 2025 value is interpolated, as only 2020 and 2030 values are given

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 2014a]. 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 meantime, 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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