European Commission

JRC SCIENCE FOR POLICY REPORT

PV Status Report 2016

Arnulf Jäger-Waldau

October 2016

EUR 28159 EN

Joint Research Centre

Contact information
Name: Arnulf Jäger-Waldau
Address: European Commission, Joint Research Centre (JRC), Directorate C – Energy, Transport and Climate, Via E. Fermi 2749, I-21027 Ispra (VA), Italy
E-mail: arnulf.jaeger-waldau@ec.europa.eu

JRC Science Hub
https://ec.europa.eu/jrc

JRC 103426

EUR 28159 EN

Print	ISBN 978-92-79-63054-5	ISSN 1018-5593	doi:10.2790/749737
PDF	ISBN 978-92-79-63055-2	ISSN 1831-9424	doi:10.2790/682995

Luxembourg: Publications Office of the European Union, 2016

How to cite: Arnulf Jäger-Waldau; PV Status Report 2016; EUR 28159 EN; doi:10.2790/682995

Title PV Status Report 2016

Abstract
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 15 years 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.

PV Status Report 2016

October 2016

Arnulf Jäger-Waldau
European Commission, Joint Research Centre,
Directorate C, Energy Efficiency and Renewables Unit
Via Enrico Fermi 2749, TP 450 I — 21027, Ispra (VA), Italy

EUR 28159 EN

PREFACE

In December 2015, the 21st session of the Conference of the Parties (COP21) to the UNFCCC in Paris, France ended with a landmark agreement to keep the maximum global average temperature rise as close as possible to 1.5 °C. With the signature of the European Union (EU) on 5 October 2016, the necessary number of at least 55 Parties to the Convention accounting in total for at least an estimated 55 % of the total global greenhouse gas emissions have deposited their instruments of ratification, acceptance, approval or accession with the Depositar [UNFC 2016]. Therefore, the Paris Agreement will enter into force on 4 November 2016 just 3 days before COP22 (7-18 November 2016) will start in Marrakesh, Morocco.

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

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

On 8 October 2016, at the Climate Ministerial during the Annual Meetings of the World Bank Group — International Monetary Fund the President of the World Bank Group Mr Jim Yong Kim stressed the point that there is no prospect of achieving the goals set out under the historic Paris Climate Change Agreement if current plans for coal-fired stations, especially those planned for Asia, are built. He called on Ministers to accelerate the transition to low carbon as a matter of urgency and said:

'Many countries want to move in the right direction. We can and should all help to find renewable energy and energy efficiency solutions that allow them to phase-out of coal. Key to this is creating the right policy environment, building the business environment, implementing good practices like solar auctions, and de-risking investments in clean energy technology. Private sector interest in renewables is picking up but accelerating that interest will need a big increase in concessional finance that is:

- Well targeted and 'follows the carbon';
- Leveraged and blended to crowd in the private sector; and
- Available quickly, at scale and easily deployed.'

Photovoltaics (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. 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.

From 2008 to the second quarter of 2016, residential PV electricity system prices fell by over 80 % in most competitive markets, and in an increasing number of markets the cost of PV-generated electricity is already cheaper than residential electricity retail prices. It is interesting to note that module prices decreased even more, by over 80 %, during the same period and now represent less than half of the costs of an installed PV system. Due to falling 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 2015, solar energy attracted 56 % of all new renewable energy investments or USD 161 billion (EUR 142.5 billion). Asset financing for PV energy systems amounted to USD 148 billion (EUR 131 billion) out of which about USD 67 billion (EUR 59.3 billion) went to small distributed PV systems.

In 2016, PV industry production rose again although more modestly than in previous years, increasing by about 20 % and reaching a worldwide production volume of about 60 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 14th edition of the PV Status Report gives an overview of current trends. Over the last 15 years, the PV industry has grown from a small group of companies and key players into a global business where information gathering is becoming increasingly complex. Any additional information would be most welcome and will be used to update the report.

Ispra, October 2016

Piotr Szymanski
Director, JRC Directorate C: Energy, Transport and Climate

ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
ASP	average selling price
BNEF	Bloomberg New Energy Finance
BOS	balance of system
CAGR	compound annual growth rate
CAPEX	capital expenditure
CEL	Clean Energy Certificates
COP	Conference of the Parties
CPV	concentrating photovoltaics
CWaPE	Wallonian Energy Commission
°C	degree Celsius
DC	direct current
DoE	Department of Energy
EEG	Energie Einspeisegesetz (energy feed in law)
EU	European Union
FiT	feed-in tariff
FY	financial year
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
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 year
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
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

CONTENTS

Executive Summary

For the 6th year in a row, solar power with 56 % of total investment representing USD 161 billion (EUR 146 billion) took the largest share of new investments in renewable energies. These investments were almost evenly shared between large scale solar power and distributed solar energy systems.

Over the last 15 years, the production volume of solar PV has increased with a 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.

In 2015, for the first time, investments in developing economies for renewable energies were larger than the investments in developed ones. In contrast to Europe, where new investments in renewable energy declined, new investments increased in almost any other world region. According to the current market trends, this development will continue if no new policies are introduced in Europe.

According to market forecasts, the installed PV power capacity of 235 GW at the end of 2015 could double until 2018. At the end of 2016, worldwide solar PV power is expected to exceed 310 GW capable to produce roughly 1.5 % of the worldwide electricity demand. The EU's share is about one third of the installed capacity, which can provide about 4 % of its electricity demand.

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

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

1. Introduction

Reported production data for the global solar cell production[1] in 2015 vary between 56 GW[2] and 61 GW and estimates for 2016 are in the 65 to 75 GW range. The significant uncertainty in these data is due to the highly competitive market environment, as well as the fact that some companies report production figures, while others report sales and again others report shipment figures.

The data presented, collected from stock market reports of listed companies, market reports and colleagues, were compared to various data sources and thus led to an estimate of 60 GW (Fig. 1), representing an increase of about 20 % compared to 2014 and a similar increase is expected for 2016.

The production volume in 2015 was about 200 times that of 2000, with a CAGR of over 40 %. After the rapid increase of the annual production in China and Taiwan since 2006 a new trend emerged in 2014 to increase production capacities in other Asian countries like India, Malaysia, Thailand, the Philippines or Vietnam. It is interesting to note that a large portion of these investments is done by Chinese companies. Another trend in the PV industry was the rapid increase in original equipment manufacturing (OEM) volumes since 2011, which allowed larger companies to significantly increase their shipment volumes without adding new capacity of their own.

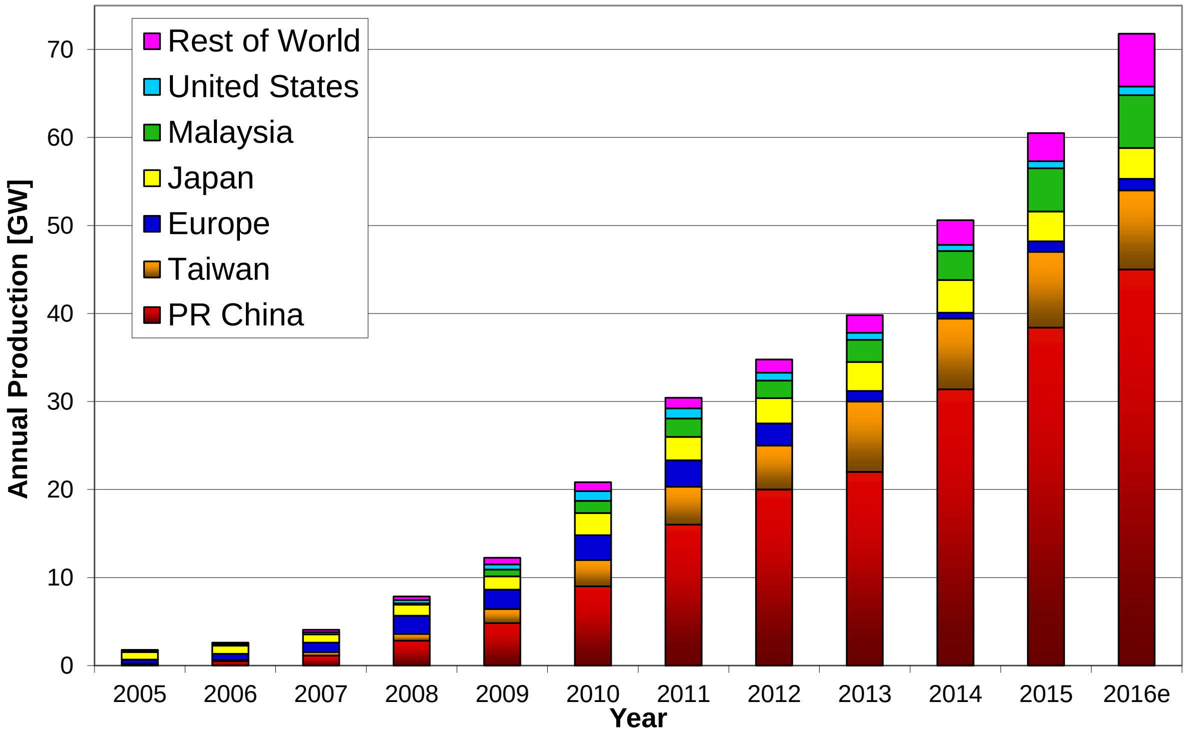

Figure 1: World PV cell/module production from 2005 to 2016 (*data source*: Photon Magazine [Pho 2012], PV Activities in Japan [Ikk 2016], PV News [Pvn 2015] and own analysis)

---

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 (September 2016) and can change, when final annual reports of public companies or country statistics are published during the year.

Uncertainties in production statistics

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

In 2015, worldwide new investments in renewable energy reached a new record high. Investments in renewable energy projects excluding large hydro-electric power plants reached USD 286 billion (EUR 260 billion[3]), which was 5 % higher than in 2014 and even exceeded the previous record of USD 278 (EUR 214 billion[4]) in 2011 [FSU 2016]. This new record was achieved despite significant strengthening of the dollar and exchange rate changes, which lowered the dollar value of investments in other currencies. Also it is worthwhile to mention, that the previous record in 2011 coincided with the peak spending of various ‘green stimulus’ programmes as well as the German and Italian solar rooftop boom. Another interesting development is the fact that corporate and government research and development (R & D) spending.

The largest share of these new investments went into large asset finance (USD 199 billion) and small and distributed capacity investments (USD 67 billion). This investment resulted in a new commissioned renewable power capacity, excluding large hydro, of 134 GW or 53.5 % of all new power generation capacity in 2015.

For the 6th year in a row, solar power attracted the largest number of new investments in renewable energies. The USD 161 billion (EUR 146 billion) investments in solar energy, accounted for 56 % of all new renewable energy investments. After a 23 % decline of total global investment in solar energy from USD 154.8 billion in 2011 to 119.1 billion in 2013 investments increased again in 2014 (+ 21 %) and 2015 (+ 12 %) to USD 143.8 billion and USD 161 billion respectively [FSU 2016]. At the same time, annual new solar PV system installations increased from 26.9 GW in 2011 to 51.7 GW in 2015, 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 hand.

The most remarkable change from 2014 to 2015 is that for the first time more investment in renewable energy was done in developing economies (+ 19 % and USD 156 billion) than in developed ones (-8 % with USD 130 billion).

The leading country in new renewable energy investment was China with 17 % growth at USD 102.9 billion (EUR 93.5 billion), followed by the USA with 19 % growth at USD 44.1 billion (EUR 40.1 billion) and Japan at USD 36.2 billion (EUR 32.9 billion), which was about the same as 2014.

Contrary to the development in other world regions, renewable energy investments in Europe fell by 21 % to USD 48.8 billion (EUR 44.4 billion) in 2015. Compared to 2011 the decline has even been even larger with 60 % mainly due to a mix of drastic reduction of support policies and even retroactive cuts for existing projects in a number of Member States, the economic downturn — mainly in Southern Europe — and the significant cost reductions of solar PV system prices. A nota-

[3] Exchange rate 2015: EUR 1.00 = USD 1.10
[4] Exchange rate 2011: EUR 1.00 = USD 1.30

ble exception from this trend was the United Kingdom (UK), which recorded an increase in renewable energy investments of 25 % to USD 22.2 billion (EUR 20.1 billion) in 2015.

Overcapacities along the PV value chain were a result of the very ambitious investments starting in 2005 and peaking with equipment spending, excluding polysilicon manufacturing plants, of about USD 14 billion (EUR 10.8 billion) in 2011 after the PV market grew by more than 150 % in 2010. Then 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.

As a result, these overcapacities 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. Between 2008 and 2014, PV module prices have decreased rapidly by more than 80 %, before they started to level out and only decreased moderately over the last two years due to industry consolidation and increasing markets, mainly in China and Japan [Blo 2013, 2016].

These rapid price declines put all solar companies under enormous pressure and access to fresh capital was and still is key to survival. Consolidation in the PV manufacturing industry has led to the closure or takeover of a significant number of companies since 2009 [Wes 2015]. 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 totalling about 6.6 GW of thin film and 34 GW of c-Si solar cell capacity to be realised within the next 18 to 24 months.

However, a closer look reveals that a large proportion of the thin film expansion announcements are already cancelled again and a moderate capacity addition of 1 to 2 GW will be realised until the end of 2016. The uncertainty about new capacities additions for crystalline silicon solar cells is twofold. First, a number of projects are from industry players with no solar cell manufacturing record and in countries with a limited or no infrastructure. Therefore, it is very difficult to predict if and when these capacities will eventually be realised. Second, with the ongoing cost pressure and the drive to modules with higher efficiencies, it is obvious, that older production lines will be upgraded or substituted with manufacturing capacities capable to produce these higher efficient solar cells. Therefore, the overall net capacity increase of solar cells will be much lower than the announcements imply

Nevertheless, the general trend still is pointing in the direction of more capacity announcements despite a growing fear of oversupply. For 2016, capital expenditure (CAPEX) of new investments in manufacturing is expected to be more than USD 4.5 billion. CAPEX for a 1 GW solar silicon solar cell and module plant has been reduced from about USD 680 million in the USA and USD 510 million in China [Goo 2011] in 2011 to USD 430 million (USA) in 2H2014 [Pow 2015] to USD 190 million in China in 2015 [Blo 2016a]. According to the information gathered at the 10th SNEC International Photovoltaic Power Generation Conference and Exhibition (SNEC 2016) in May 2016, CAPEX for silicon solar cell and module manufacturing equipment (made in China), without infrastructure and building, can be as low as about USD 60 million for 1 GW capacity.

It should be noted that the level of oversupply and excess capacity will be different in the four main parts of the silicon module value chain, i.e. (1) polysilicon production, (2) wafer production, (3) solar cell manufacturing, (4) module manufacturing. The current trend is a lowering of the oversupply in the first two sectors, whereas the excess capacity gap is growing in the latter two. As a consequence, this development will continue to add pressure to the margins of most manufacturers. The overall average selling price (ASP) of modules are decreasing further, due to three main factors: (1) the already mentioned oversupply, (2) contracting high price markets like Japan and (3) a shift of supply to lower price markets like China or countries with extreme competitive price bids for PPAs.

Despite the continuing problems of individual companies, the fundamental industry as a whole remains strong and the overall PV sector will continue to experience significant long-term growth. In August 2016, the IEA published its fifth Medium-Term Renewable Energy Market Report, and raised the predicted increased capacity to over 600 GW of cumulative PV installations in 2022 [IEA 2016].

Market predictions for the 2016 PV market vary from 56 GW according to Bloomberg's New Energy Outlook, 66 GW in Greentech Media's Global demand Monitor, 66.7 GW by Mercom Capital's Solar Market update and 76.7 GW in Solar Power Europe's high scenario [Blo 2016b, Gtm 2016, Mer 2016, Sol 2016].

For 2017, analysts draw a mixed picture varying between a 10 % market de- or increase, depending on the market assumptions for 2016. The biggest uncertainty currently is the future market development in China. The ongoing technology development and heightened cell and module efficiencies require an upgrade of older facilities in order to stay competitive.

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

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

Over 90 % of current production uses wafer-based crystalline silicon technology. Projected silicon production capacities for 2016 vary between 415 000 tonnes [Blo 2016c] and 426 000 tonnes [Ikk 2016]. It is estimated that about 28 000 tonnes will be used by the electronics industry. Potential solar cell production will, in addition, depend on the material used per Wp (grams per Watt-peak). The current blended global average is about 4.9 g/Wp.

In general, global CAPEX for PV solar systems have converged, even if significant differences still exist due to differences in market size and local competition and factors like import taxes, local content rules or existing tax credits. In the 1st half year (H1) 2016, the BNEF global benchmark for levelised cost of electricity (LCOE) in the solar sector was given with USD 99 per MWh [Blo 2016d], and the cost share of solar modules in the benchmark PV system has dropped to about 40 %.

2016 saw new PPAs and bids for PV solar electricity well below the benchmark and a record bid as low as USD 24.2 per MWh [Nat 2016]. The tender was for a nominal 350 MW tender of the Abu Dhabi Electricity and Water Authority's (ADWEA) Sweihan solar power project, but it is expected that the actual size of the project will be much larger. At the time of writing, no PPA had been signed yet.

The influence of CAPEX on LCOE of solar PV electricity has decreased significantly and is nowhere higher that 40 %. Other costs like O&M (operations and maintenance) costs, permits and administration, fees and levies as well as financing costs make up the rest. 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 cost of direct current (DC) electricity generated by a PV module has dropped to below EUR 0.03/kWh, 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 overall for the integration of PV electricity are needed to establish PV electricity as an integral part of sustainable energy solutions. 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 53.7 GW in 2015, driven by a shift to more large scale utility systems on the one hand and a world-wide reduction of PV system prices on the other side (Fig. 2).

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

Uncertainties in market statistics

- The installation figures of this report are about the physical installation of the system hardware, not the connection to the grid. The grid connection can be delayed due to administrative reasons or in some cases missing grid capacity.
- This report uses nominal DC peak power (Wp) under standard test conditions (1 000 W irradiance and standard nominal 25 ºC) for reasons of consistence.
- Not all countries report DC peak power (Wp) for solar PV systems, but especially for larger scale system the utility peak AC power, which is relevant for the transmission operator. Even in the Eurostat statistics the two capacities are mixed.
- Some statistics only count the capacity which is actually connected or commissioned in the respective year for the annual statistics, irrespectively when it was actually installed. This can lead to short term differences in which year the installations are counted. This can lead to differences in 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 and it is almost certain that Japan will follow in 2016. With a cumulative installed PV power of almost 95 GW, the EU still accounted for 40 % of the 235 GW solar PV electric power capacity installed worldwide at the end of 2015. However, this is down from the 66 % in 2012, when the cumulative installed solar PV electric power had just reached 100 GW worldwide.

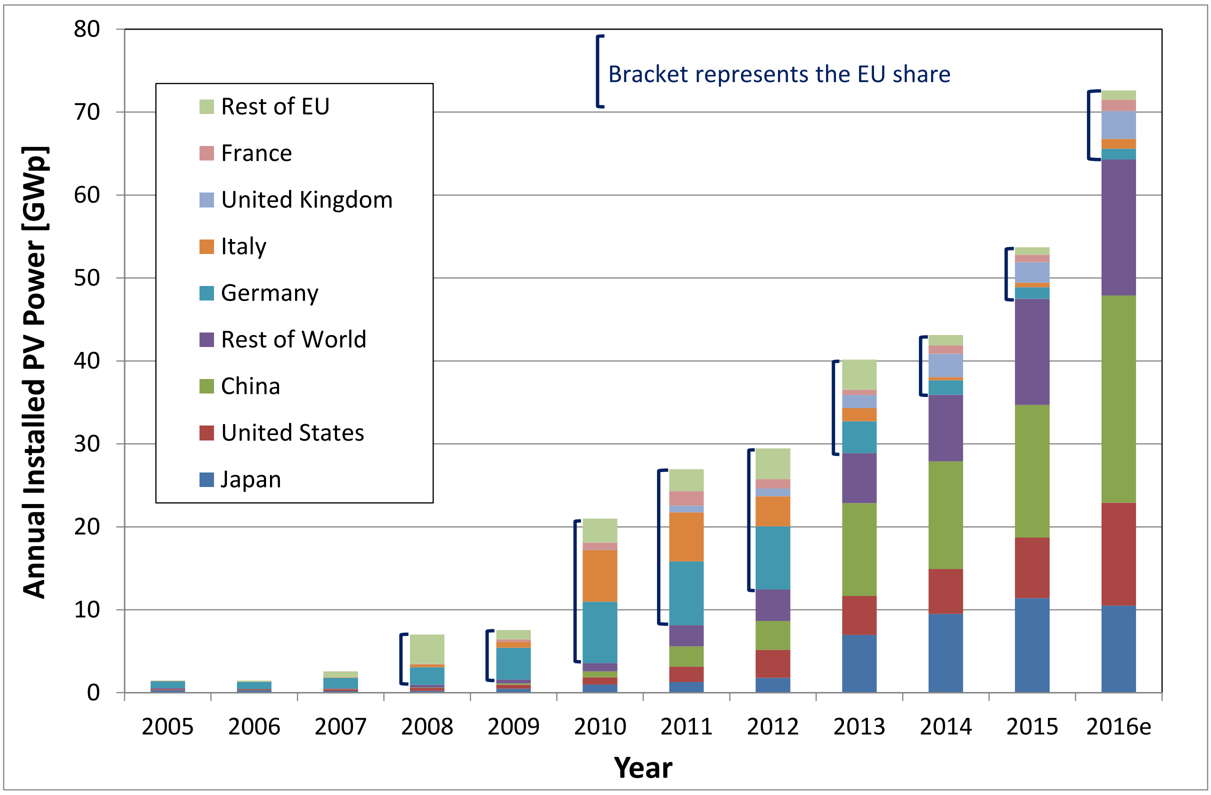

Figure 2: Annual PV system installations from 2005 to 2016
(*data source*: [IEA 2016a, Sol 2016, Sys 2016] and own analysis)

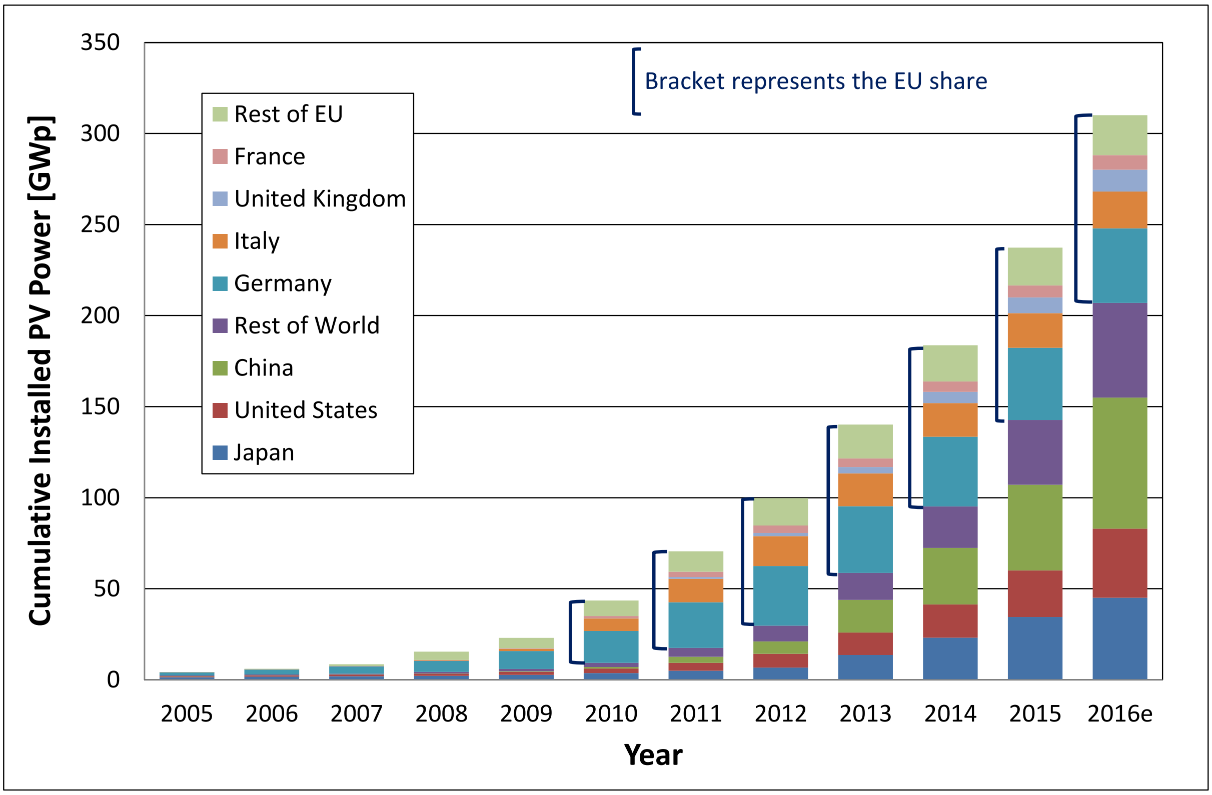

Figure 3: Cumulative PV installations from 2005 to 2016
(*data source*: [IEA 2016a, Sol 2016, Sys 2016] and own analysis)

2.1. Europe and Turkey

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

Looking at the electricity system as a whole, a total of about 27.3 GW of new power generation capacity were installed in the EU last year and 18.2 GW were decommissioned, resulting in 9.1 GW of new net capacity (Fig. 4) [Ewe 2016, Sol 2016, Sys 2016, own analysis]. Renewable energy sources (RES) accounted for 20.6 GW or 75.6 % of all new power generation capacity. PV electricity generation capacity accounted for 6.86 GW, or 25.1 % of the new installed capacity.

In terms of new net capacity, wind power was first with 12.52 GW, followed by solar PV 6.86 GW, solar thermal power plants 370 MW, hydro 239 MW and other sources 127 MW. The net installation capacity for coal-, oil- and gas-fired power plants as well as nuclear and biomass was negative, with a decrease of 3.3 GW, 3.3 GW, 2.4 GW, 1.7 GW and 0.3 GW, respectively.

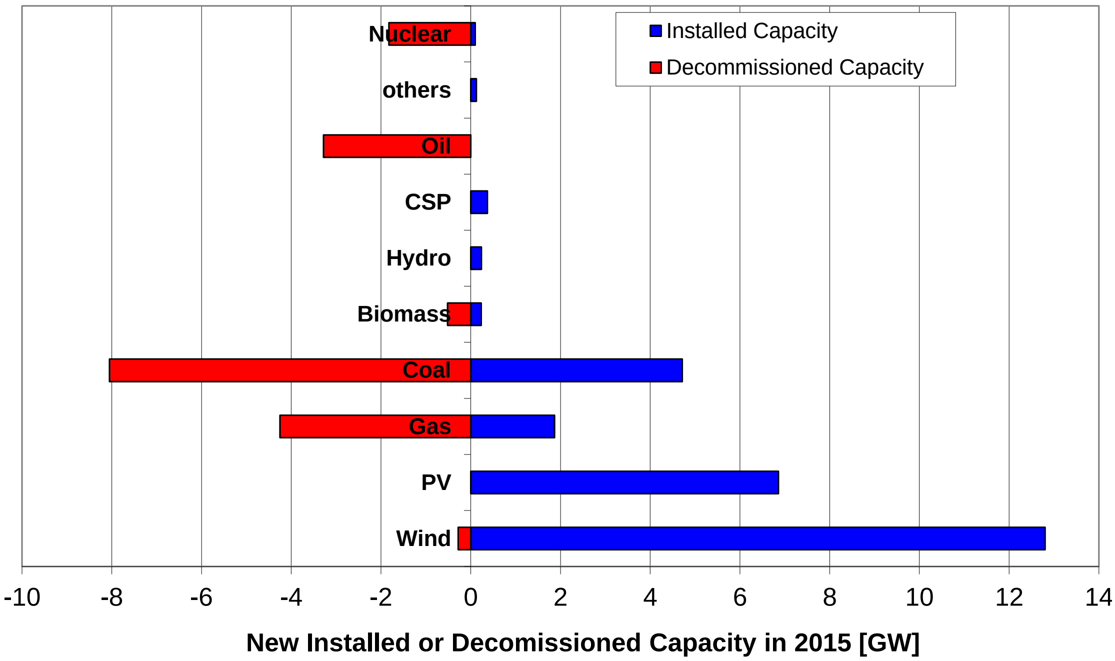

Figure 4: New connected or decommissioned electricity generation capacity in the EU in 2015 (*data source*: [Ewe 2015, Sol 2016, Sys 2016] and own analysis)

Since 2005, solar PV electricity generation capacity has increased from 1.9 GW to 95.4 GW at the end of 2015 (Fig. 5). Already in 2014, the 2020 National Renewable Energy Action Plan (NREAP) target of 83.7 GW was exceeded, reaching about 88.4 GW.

With a cumulative installed capacity of 95.4 GW, the EU is still leading in PV installations with 40.6 % of the global total of 235 GW of solar PV electricity generation capacity at the end of 2015, although this is down from the 66 % recorded at the end of 2012. The installed PV power capacity in the EU at the end of 2015 can generate more than 100 TWh of electricity or almost 4 % of the final electricity demand in the Union.

At first glance, this development appears to be a success. However, by looking at the annual installations, it becomes obvious that Europe's share is not only declining in relation to a growing market worldwide, but also in actual installation figures (Fig. 6). According to the IEA Medium-Term Renewable Energy Market Report 2016, this share will drop below 30 % by 2020 due to a stagnant market of 7 to 8 GW between 2016 and 2020 [IEA 2016].

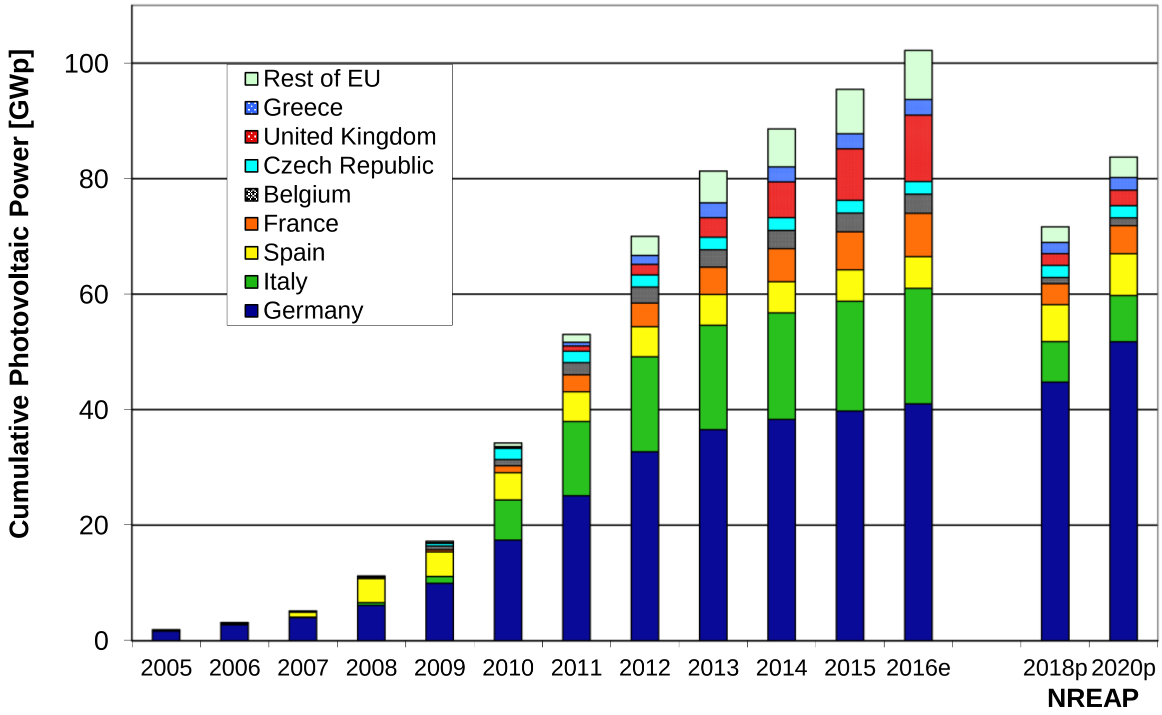

Figure 5: Cumulative installed grid-connected PV capacity in EU + candidate countries compared with the NREAP target for 2020 (*data source*: [Sol 2016, Sys 2016] and own analysis)

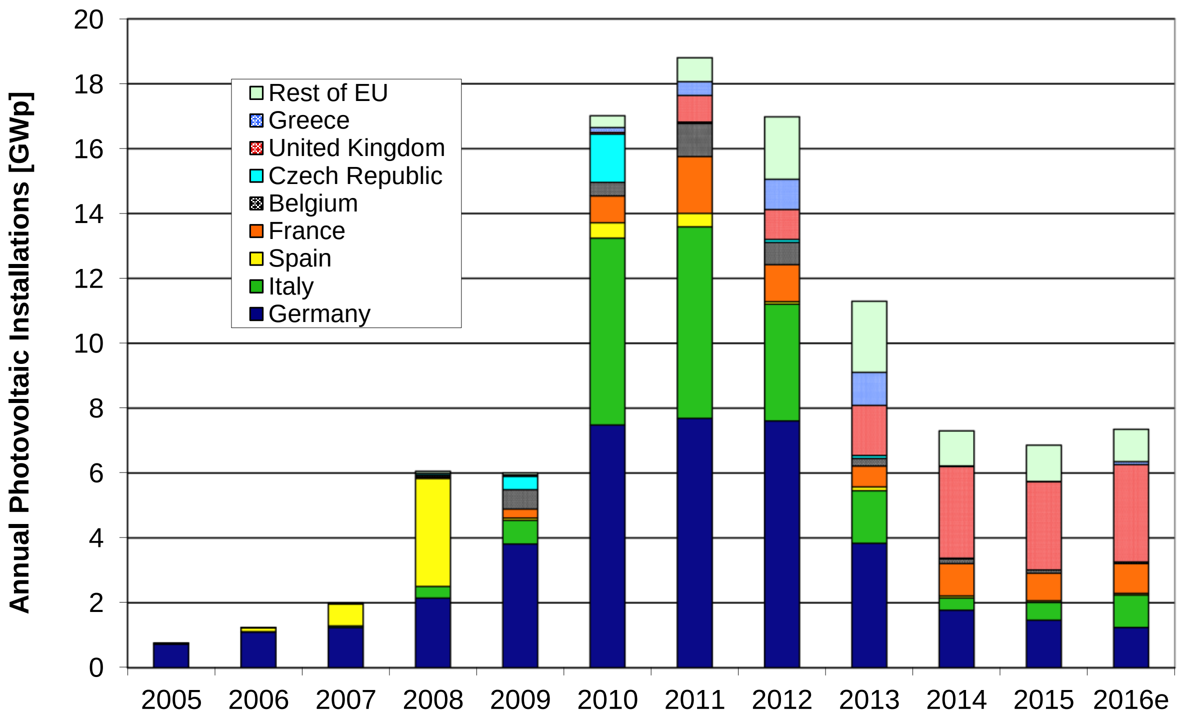

Figure 6: Annual installations in EU and candidate countries (*data source*: [Sol 2016, Sys 2016] and own analysis)

What are the reasons and main consequences of this development?

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

One of the consequences is the effect on local jobs and the local economy: The growth of the PV industry in Europe resulted in the generation of over 260 000 jobs or 38 % of global employment in the PV sector in 2011 [Jäg 2014]. Over 75 % of these 260 000 jobs were in operating and installing solar PV electricity systems. Almost all of them were local European jobs contributing to the European gross domestic product (GDP). The steep drop in new installations from 2011 to 2015 almost halved these local jobs and with them the positive effect on the local European economy [Ire 2016].

The following sections describe market development in some EU Member States, as well as in Switzerland and Turkey. Official and more detailed information about the progress of renewable energy implementation in the EU can be found on the Renewable Energy Mapping and Monitoring in Europe and Africa website of the Joint Research Centre (JRC) and publications listed there (http://iet.jrc.ec.europa.eu/remea) [Ban 2015].

2.1.1. Austria

In 2015, Austria installed about 170 MW of new PV systems and increased the cumulative capacity to 940 MW. 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 a maximum system size of 5 kW and a budget of EUR 8.5 million and an additional programme for farmers and forest enterprises for systems between 5 and 30 kWp with a budget of EUR 6.6 million for 2016. The investment is supported with 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.

2.1.2. Belgium

The three Belgian regions (Brussels, Flanders and Wallonia) have individual support schemes for PV, but one electricity market. Therefore, some regulations are regional and others are national. A common denominator is the fact that all three regions selected an RPS system with quotas for RES. A net-metering scheme exists for systems up to 5 kWp Brussels or 10 kWp (Flanders and Wallonia) as long as the electricity generated does not exceed the consumer's own electricity demand.

Since March 2015, a mechanism called Qualiwatt is used to support residential PV systems up to 10 kWp in Wallonia. For the first 5 years after installation, a fixed sum for the first 3 kWp is paid. The Wallonian Energy Commission (CWaPE) updates this sum for each semester to reflect the decrease of PV system prices. The amount of support is calculated depending on the electricity prices in the different distribution areas, and varied between EUR 473 and 586 for 3 kWp in the second semester of 2016 [CWa 2016].

In the Brussels Capital Region still exists a green certificate scheme for residential PV power. For each MWh the producer is entitled to 2.4 green certificates, which can be sold to energy suppliers or intermediate companies [Bru 2015]. The current price is EUR 81.7 per certificate.

In Wallonia, it was planned to introduce a grid utilization fee in July 2015, but the fee was annulled by the Court of Appeal of Liège before its entry into force on the basis of an appeal of the association 'Touche pas à mes certificats verts'.

In 2011, Belgian installations peaked with over 1 GW of new installations, before starting to decline in 2012. At the end of 2015, cumulative installed capacity was over 3.25 GW [IEA 2016]. Almost 8 % of Belgian households are already generating their own PV electricity, and PV power covered about 3.6 % of the country's total electricity needs in 2015 [Sol 2016a].

2.1.3. Denmark

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

The so called 60/40 programme, which went into effect on 11 June 2013 was suspended with immediate effect on 3 May 2016. Under the scheme PV power systems were eligible for a maximum reimbursement (bonus plus market price) of DKK 0.60/kWh (EUR[5]) 0.080/kWh) during the first 10 years of operation, and DKK 0.40/kWh (EUR 0.054/kWh) being applicable for a further 10 years.

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

It is not clear yet how many PV systems are still eligible for the scheme. At the end of 2015, the installed PV power capacity was about 790 MW [IEA 2016a].

2.1.4. France

In 2015, about 850 MW of new PV systems were installed in France. Total cumulative installed capacity increased to almost 6.6 GW, including about 400 MW in the French Overseas Departments. Electricity production (continental France and Corsica) from PV systems was 7.4 TWh or 1.36 % of the national electricity generation and 1.56 % of the gross consumption [Rte 2016].

In 2015, 895 MW of new solar power capacity was connected in mainland France according to Transmission grid operator RTE. About a quarter of this increase came with the commissioning of the 230 MW Constantin plant in Cestas, in the Gironde department, in September 2015. This facility is connected to the RTE grid and currently the largest solar PV farm in Europe. 565 MW of solar capacity are connected to the RTE grid and another 5 626 MW are connected to the distribution networks of ERDF, LDCs and EDF-SEI in Corsica.

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. The majority of these capacity increases will come from various auctions. In Q3 2016, an auction is foreseen for systems between 100 and 250 kW (150 MW) and one for systems larger than 250 kW (500 MW).

The French tariffs for the purchase of electricity from small solar PV systems for the third quarter 2016 were set as:

Building integrated systems with capacities up to 9 kWp: EUR 0.2429 per kWh

[5] Exchange rate: EUR 1.00 = DKK 7.46

Rooftop systems:

Capacities [kWp]	EUR per kWh
up to 36	0.1272
>36 to 100	0.1213

Ground mounted systems with capacities up to 12 MW: EUR 0.0565 per kWh

The tariffs are adjusted regularly depending on the number and capacity of grid connection requests approved in the previous quarter.

2.1.5. Germany

Since 2013, annual new PV system installations are on the decline. The annual market shrank from 7.5 GW and 7.6 GW in 2011 and 2012 to about 3.3 GW in 2013, 1.8 GW in 2014 and 1.4 GW in 2015 [Bun 2016]. A further decrease is expected for 2016 to about 1 GW, because in the first half of the year PV systems with a capacity of just 450 MW were installed.

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

Since May 2012, the FiT has been adjusted on a monthly basis depending on the actual installation of the previous quarter. The revision of the EEG in 2014 changed the system size for new systems eligible for a feed in tariff and introduced levels of levies on self-consumption [EEG 2014]. So far systems with a capacity of less than 10 kWp are excepted form the levy. For all other systems, the levy on each self-consumed kWh is 35 % of the EEG levy and will increase 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.

Since the beginning of 2016 only systems smaller than 100 kWp are eligible for a feed in tariff. Larger systems have to market their electricity directly or take part in auctions. The feed in tariffs valid from 1 July to 30 September 2016 are:

Systems on residential buildings or sound barriers:

Capacities [kWp]	EUR per kWh
up to 10	0.1231
10 to 40	0.1197
> 40 to 1000	0.1071

Systems on commercial buildings and premises:

Capacities [kWp]	EUR per kWh
up to 100	0.0853

The fact that the tariff for residential PV systems smaller than 10 kWp (September 2016: EUR 0.1231/kWh) is now well below the average variable electricity rate consumers are paying (EUR 0.224- 0.265/kWh) and the fact that they are still exempt from the EEG levy makes self-consumption attractive and is opening up new possibilities for the introduction of local storage. Since 1 May 2013, the Kreditanstalt für Wiederaufbau (KfW) has been offering low interest loans with a single repayment bonus of up to 30 % and a maximum of EUR 600/kW of storage for PV systems up to 30 kWp [KfW 2013]. The maximum repayment bonus was limited to EUR 3 000 per system. A new programme stared on 1 March 2016 [KfW 2016]. Since then the loan is only available if the maximum injected power is 50% or less of the nominal power rating of the PV system. The maximum eligible amount was set as 25% of EUR 2.000 per kWp if the PV system and the battery storage are installed at the same time and EUR 2.200

per kWp of the PV system if the system was installed after 31 December 2012 and more than 6 months have passed before the battery storage is added. However, the maximum eligible amount is reduced by 3% each 6 months starting 1 July 2016. The available funds for 2016 were already allocated at the beginning of October 2016 and new applications are now only accepted from 1 January 2017 on. The programme will be terminated at the end of 2018.

2.1.6. Greece

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

The Hellenic Transmission System Operator SA (HTSO) reported about 2 092 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 May 2016 [Hts 2016]. These figures do not include the installed capacity of non-interconnected Greek islands, which — according to the Hellenic Electricity Distribution Network Operator SA — reached about 136 MW at the end of May 2016 [Hed 2016].

2.1.7. Italy

In 2015, Italy connected 298 MW, increasing cumulative installed capacity to almost 18.9 GW by the end of 2015 according to the annual report of the Gestore dei Servizi Energetici (GSE) [Gse 2016]. After the Quinto Conto Energia (Fifth Energy Bill) ended in July 2013, the only support mechanism is now via the Scambio sul Posto (self-consumption) scheme.

According to the Italian national grid operator TERNA, electricity from PV systems provided 24.68 TWh or 7.8 % of the total electricity sold in 2015 [Ter 2016]. 16.89 TWh or 8.3 % of the total generated during the first eight months of 2016. The highest monthly coverage was in August, when PV electricity provided 11.6 % of the Italian energy supply.

2.1.8. The Netherlands

According to the Dutch Statistical Office, PV systems with a capacity of 437 MW have been installed in 2015 bringing the total installed PV power to 1 485 MW at the end of the year [Cbs 2016]. The total generated solar electricity was 1.1 TWh or 0.9 % of the annual demand.

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 SED+ scheme, for a maximum of 1 000 full load hours per year, which is open for all renewable energy technologies [RVO 2016].

2.1.9. Spain

Spain declined to fifth place in Europe with regard to the total cumulative installed capacity, at 5.4 GW[6]. Most of this capacity was installed in 2008 when the country was the largest market, with over 3.3 GW [IEA 2014]. This was more than twice the expected capacity and was due to an exceptional race to install systems before the autumn of 2008,

[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.

when the Spanish Government introduced a cap of 500 MW on annual installations. A revised decree (Royal Decree 1578/2008) set considerably lower FiTs for new systems and limited the annual market to 500 MW, with the provision that two-thirds are rooftop-mounted and there are no longer any free-field systems [Bol 2008]. These changes resulted in a sharp fall in new installations.

In January 2012, the Spanish Government passed the Royal Decree 1/12 [Bol 2012], which suspended the remuneration pre-assignment procedures for new renewable energy power capacity, affecting about 550 MW of planned solar PV installations. The justification given for this move was that, until then, Spain's energy system had amassed a EUR 24-billion power-tariff deficit; it is also argued that the special regime for renewable energy was the main reason. However, for over a decade, the Spanish Government has prevented utilities from charging consumers the true cost of electricity. Instead of allowing utilities to increase rates every time electricity generation costs increased (due to rising coal or natural gas costs, inflation or to changes in energy or environmental policy, for example), the government allowed them to create a scheme similar to a deferral account, whereby they could recover shortfalls in any individual year from revenues generated in subsequent years.

By January 2007, the European Commission had already opened an in-depth investigation to examine the potential aid to large and medium-sized companies and to electricity distributors in Spain in the form of artificially low regulated industrial tariffs for electricity [EC 2007]. In 2005, these regulated tariffs led to a deficit of EUR 3.8 billion in the Spanish electricity system, and amounted to almost EUR 9 billion in 2007, a time when payments under the special regime for renewable energy were still limited.

Despite the Royal Decree 1/12 and other measures taken in 2012 and 2013, including the increase in electricity prices and introduction of new taxes on electricity generation from the beginning of 2013, the tariff deficit increased further in 2012 and 2013.

Further attempts to end the tariff deficit led to the Electricity Act 24/2013 and the Ministerial Order IET/1045/2014 of 16 June 2014, which implemented and supplemented Royal Decree 413/2014 of 6 June 2014, regulating the production of electricity from RES, cogeneration and waste [Bol 2013, 2014, 2014a]. Together with Royal Decree Act 9/2013 of 12 July 2013 [Bol 2013a], adopting urgent measures to ensure the financial stability of the electricity system, these measures form a complex set of regulations for the remuneration of electricity produced from RES. Amongst other measures, the Electricity Act introduced a levy on the self-consumption of electricity produced by the consumer. After peaking in 2013 with EUR 28.8 billion the deficit has now decreased to EUR 25 billion at the end of 2015 [CNM 2016, Moo 2016].

In 2015, new PV systems were installed with a capacity of 56 MW. In the same year, electricity generated from grid connected PV systems contributed 8.3 TWh or 3.2 % of the Spanish demand.

2.1.10. Switzerland

In 2015, about 300 MW of PV systems were installed in Switzerland, increasing the total capacity to 1.36 GW. After a 40 % price decrease in 2012, prices for turnkey systems fell by a further 12 % in 2013 and a further 5 % until 2015 [Ene 2016]. In 2015, the average kWp price for installed and connected systems was CHF 2459 incl. value added tax (VAT).

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 addition 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).

2.1.11. UK

In 2015, PV systems with a power capacity of about 3.5 GW were connected to the grid increasing the cumulative PV power to 8.9 GW. PV systems generated about 7.6 TWh or 2.25 % of total electricity generation in 2015.

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, but so far only one was held in 2015 where 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. So far only one project was connected to the grid on 30 June 2016 and one project applied for an extension of the connection date.

[7] Exchange rate: EUR 1 = CHF 1.10

The second round planned for October 2015 was cancelled and should now take place at the end of 2016.

The Renewable Obligation Certificate (ROC) scheme introduced in 2012 will end on 31 March 2017. Already in 2014, the maximum size of systems was limited to 5 MW for this scheme, starting from 1 April 2015, but larger systems could apply for a grace period if one of the following criteria were met [Ofg 2015]:

- **'significant investment':** for generating stations where significant investments have been made on or before 13 May 2014;
- **'grid delay':** for generating stations that have been subject to grid connection delays that are not due to a breach by a developer;
- **'preliminary accreditation'**: for generating stations that were granted preliminary accreditation under the ROC scheme on or before 13 May 2014.

In the first quarter of 2016, about 1.5 GW of new solar systems were connected to the grid and the remaining project pipeline for the ROC scheme is estimated at around 3.75 GW. However, industry representatives estimate that only a third of this capacity can actually be realised by the 31 March 2017 deadline.

2.1.12. Other European countries 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), 44.98 MW of PV systems were installed at the end of June 2016. 12 projects with an additional 9.39 MW already have signed contracts but are not yet installed [Hro 2016].

Despite high solar radiation, solar PV system installation in **Portugal** has grown very slowly, reaching a cumulative capacity of 460 MW by the end of 2015.

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 then again to 1 to 2 MW in 2014 and 2015. The total capacity of 591 MW is more than three and a half times the original 160 MW capacity target for 2020, published in the NREAP in 2010.

In March 2010, **Turkey**'s Energy Ministry unveiled the 2010-2014 Strategic Energy Plan. One of the government's priorities is to increase the ratio of renewable energy resources to 30 % of total energy generation by 2023. At the beginning of 2011, the Turkish Parliament passed renewable energy legislation which defines new guidelines for FiTs. The FiT was USD 0.133/kWh (EUR 0.10/kWh) for owners commissioning a PV system before the end of 2015. If 'made in Turkey' components are used, the tariff was increased by up to USD 0.067 (EUR 0.052), depending on the material mix. To take advantage of these local procurement rules, factories have been set up by Anel Enerji, Atsco Solar and China Sunergy to produce PV modules. The first licensing round for a volume of 600 MW, which closed in June 2013, was oversubscribed by about 15 times with close to 9 GW of projects submitted to the Turkish Energy Regulatory Authority. However, no licence for PV installations above 1 MW had been approved by the end of 2013. The market started to take off in 2014 with 40 MW installed and a fivefold increase to 208 MW in 2015 [IEA 2015, 2016a]. Market expectations for 2016 aim at 1 GW of cumulative installed solar PV power at the end of 2016.

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, Japan, 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 2015, more than 34 GW of new PV electricity generation systems were installed in the region, which corresponds to roughly two thirds of the world wide new PV power installed in 2015. The largest market was China with 16 to 18 GW, followed by Japan with about 11 GW and India with over 2 GW. In 2016, a market increase to over 45 GW is possible.

2.2.1. Australia

In 2015, more than 900 MW of new solar PV electricity systems were installed in Australia, bringing the cumulative installed capacity of grid-connected PV systems to over 5 GW. As in the previous years the market was dominated by grid-connected residential systems. In the meantime, more than 1.5 million homes have been equipped with PV systems bringing the national penetration to an average of 16.5 %, and in some areas it even exceeds 30 %. The average PV system price paid by the customer for a grid-connected system fell from AUD 6/Wp (EUR 4.29/Wp[8]) in 2010 to AUD 3.9/Wp (EUR 2.89/Wp[9]) in 2011, AUD 3.0/Wp (EUR 2.4/Wp[10]) in 2012, AUD 2.5/Wp (EUR 1.85/Wp[9]) in 2013, below AUD 2.0/Wp (EUR 1.38/Wp[11]) in the middle of 2014 and AUD 1.62/Wp[12] (EUR 1.08/Wp) at the beginning of August 2016 [Sol 2016b]. As a result, the cost of PV-generated electricity has fallen to, or is even below, the average residential electricity rate of AUD 0.27/kWh (EUR 0.18/kWh).

In 2015, PV electricity systems generated about 5.6 TWh or 2.3 % of Australia's total electricity. The total renewable electricity share was 14.6 % and this should increase to 20 % by 2020. For 2016, the market forecast is about 700 MW.

2.2.2. India

For 2015, market estimates for solar PV systems vary between 2.0 and 2.2 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 2016, the total solar power capacity was 7.8 GW [GoI 2016].

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 (1 GW), 2014 (0.5 GW) and 2015 with market expectations for 2016 and 2017 in the order of 4 to 5 GW and 8 GW respectively.

---

8 Average exchange rate for 2010: EUR 1 = AUD 1.40

9 Average exchange rate for 2011 and 2013: EUR 1 = AUD 1.35

10 Average exchange rate for 2012: EUR 1 = AUD 1.25

11 Average exchange rate for 2014: EUR 1 = AUD 1.45

12 Average exchange rate for first 7 months 2016: EUR 1 = AUD 1.50

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. At the end of 2015, almost 900 MW of cumulative solar PV power were installed and market expectations for 2016 range from 250 to 350 MW.

2.2.4. Japan

In 2015, the Japanese PV market grew by about 11 % to 10.8 GW. Cumulative installed capacity reached 34.2 GW at the end of 2015 [Ikk 2016]. In 2015, solar PV systems generated 34.1 TWh and provided about 3.5 % of the total electricity consumption.

Under the FiT scheme, introduced in July 2012 and amended in the following years [METI 2013], 79.9 GW_{AC}[13] had received approval until the end of FY 2015 (end of March 2016). However, this is down from the 82.6 GW_{AC} approved by the end of FY 2014. Until the end of FY 2015, projects with a total capacity of 27.3 GW_{AC} had been commissioned and are in operation.

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

Until 2010, residential rooftop PV systems represented about 95 % of the Japanese market. Since 2011, due to changes in the permit system, large ground-mounted systems as well as large commercial and industrial rooftop systems started to increased their market share and reached more than 90 % in 2015. Of the 79.9 GW_{AC} approved by the end of March 2016, only 4.6 GW_{AC} or 5.8 % comprised systems smaller than 10 kWp. However, almost 87 % of these systems were actually connected to the grid. PV systems with capacities over 1 MW represented 50 % of the approved capacity, but only 22 % of them had started operation.

For new projects approved after 1 April 2016, the following tariffs apply: for commercial installations (total generated power) larger than 10 kWp, the tariff is now JPY 24/kWh (EUR[14] 0.209/kWh) for 20 years. For residential installations (surplus power) smaller than 10 kWp the FiT is JPY 33/kWh (EUR 0.287/kWh), if the system is equipped with an output control device or JPY 31/kWh (EUR 0.270/kWh) without such a device for 10 years [METI 2016].

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. In July 2012, a METI panel proposed the long-awaited plan to reform the country's power market, and Japan's 4th Strategic Energy Plan was published in April 2014 [METI 2014]. During the COP21, Japan proposed to reduce its greenhouse gas emissions by 26 % by 2030.

On 25 May 2016, the bill for the revision of the Act on Special Measures Concerning Procurement of Electricity from RES by Electricity

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

14 Exchange rate: EUR 1 = JPY 115

Utilities was enacted and will officially be applied from 1 April 2017 onward. The bill itself is not very specific about the new rules to be put in place, but a METI committee released documents in April which could indicate the possible policies to be adopted in the Ministry ordinances when implementing the law. It can be expected that reverse auctions with capacity quotas will be implemented for larger PV plants.

2.2.5. 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. By 2015, about 1 GW must come from RES, according to the Ministry of Energy, Green Technology and Water.

In April 2011, renewable energy FiTs were passed by the Malaysian Parliament with the target of 1.25 GW being installed by 2020. For the period from December 2011 to June 2014, PV had been allocated a total quota of 125 MW. The tariffs are set by the Sustainable Energy Development Authority (SEDA) for each year. For 2016 the tariffs are between MRY 0.416 and 0.829/kWh (EUR 0.091 to 0.181/kWh[15]), depending on the type and system size. In addition, there are small bonuses if the systems are used in buildings or building material as well as for local module or inverter use. According to SEDA, PV systems with more than 264 MW of capacity received the FiT and were operational by the end of August 2016, while another 100.7 MW had already been approved but not yet started operation [Sed 2016].

First Solar (USA), Hanwha Q CELLS (Korea/China/Germany), AOU/SunPower (Taiwan/USA) Jinko Solar (PRC), and TS Solartech have set up silicon solar cell or CdTe-thin film manufacturing plants in Malaysia, amounting to more than 5.6 GW of production capacities. In addition, there are another seven smaller silicon module manufacturing companies.

2.2.6. People's Republic of China

In 2015, the Chinese PV market was not only the largest worldwide, but also took the first place in terms of total cumulative capacity. According to the National Survey Report of IEA PVPS 15.1 GW of solar PV power was connected to the grid in 2015 increasing the total grid connected capacity to slightly over 43 GW [IEA 2016b]. The actual installed capacity could have been 20 to 25 % higher as reported by some consultancy companies, but not all was connected to the grid [Blo 2016c, Hil 2016]. Taking these figures into account, the total cumulative installed capacity could have increased to about 46 to 47 GW at the end of 2015. This assumption is supported by recent reports about the grid connection of 20 to 22 GW in the first half year of 2016 well above NEA's 2016 target of 18.1 GW published in June 2016.

The 2016 International Energy Agency (IEA) Renewable Energy Medium-Term Market Outlook expects an increase of total cumulative installed capacity to over 150 GW in 2021 [IEA 2016].

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

[15] Exchange rate: EUR 1.0 = MRY 4.5677

should be RMB 2.3 trillion (EUR[16] 309 billion) and about RMB 2.6 trillion (EUR 349 billion) are foreseen for the upgrade of the grid infrastructure of which RMB 1.7 trillion are intended for the distribution network [Cai 2015, Wan 2016].

2.2.7. South Korea

In 2015, about 1 GW of new PV systems were connected to the grid in South Korea, bringing the cumulative capacity to a total of almost 3.5 GW [IEA 2016a]. Since January 2012, Korea's RPS has officially replaced the FiTs. Besides the RPS, Korea supports PV installations by the 'One Million Green Homes Programme', a building subsidy programme, a regional development subsidy programme, and the New and Renewable Energy (NRE) Mandatory Use Programme for public buildings.

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

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

2.2.8. 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 2015, a total capacity of about 1 GW was connected to the grid [IEA 2016a].

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 20205. The new planning foresees the installation of over 1.4 GW between July 2016 and July 2018.

At the end of August 2016, the Bureau of Energy under Taiwan's Ministry of Economic Affairs (MOEA) has set tentative FiT rates for PV electricity to be generated in 2017 [Hwa 2016]. The tariffs for the three categories are:

Type of system	TWD (EUR[17]) per kWh
ground-mounted	4.35 (0.123)
mounted on surface of water	4.87 (0.137)
rooftop	6.02 (0.170)

2.2.9. Thailand

Thailand enacted a 15-year Renewable Energy Development Plan in early 2009, with a target to increase the renewable energy share to 20 % of the country's final energy consumption in 2022. Besides a range of tax incentives, solar PV electricity systems were eligible for a feed-in premium or 'Adder' for a period of 10 years. The original THB 8/kWh (EUR[18] 0.190/kWh) Adder (facilities in the three southern provinces and those replacing diesel systems are eligible for an additional THB 1.5/kWh (EUR 0.036/kWh)) was reduced to THB 6.5/kWh (EUR 0.155/kWh) for those

16 Exchange rate September 2016: EUR 1.0 = CNY 7.45

17 Exchange rate: EUR 1 = TWD 35.5

18 Exchange rate: EUR 1 = THB 42

projects not approved before 28 June 2010. The original cap of 500 MW was increased to 2 GW at the beginning of 2012, as the original target had been highly oversubscribed. In addition to the Adder programme, projects were being developed with PPAs.

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

At the end of 2015, grid-connected PV had a capacity of about 1.42 GW, of which 121 MW were connected in that year [IEA 2016a].

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.

2.2.10. 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 2015, more than 4.5 million SHSs (50-60 W) had been installed in Bangladesh [Ire 2016a]. According to the International Renewable Energy Agency (IRENA), over 127 000 people now 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 %). There are also targets for waste-to-energy (40 MW), biomass (7 MW), biogas (7 MW) and hydro (4 MW).

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. 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 is 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. Total installed PV power in Indonesia is estimated around 50 MW at the end of the first half of 2016.

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, PV capacity in Jordan was about 30 MW at the end of 2015 [Mes 2016]. A further 320 MW are under execution, and a further 120 MW are tendered in 2016. Three out of the four winners (50 MW each) of the second solar tender (200 MW) offered power prices of around USD 60 per MWh.

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

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 2015, the total PV capacity was estimated at about 55 MW, and should increase to about 200 MW for the opening of EXPO 2017.

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 first grid connected systems are expected to become operational in the 1st quarter (Q1) 2017.

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. It was estimated that about 1 GW of solar power was installed in Pakistan at the end of 2015 [IEA 2016a].

Market expectations range between 0.5 and 1 GW for 2016. In June 2016, Pakistan's National Electric Power Regulatory Authority (NEPRA) has published its proposal for the revised FiTs for solar energy projects with capacities between 1 and 100 MW. The tariff is paid for 25 years with a higher tariff for the first 13 years and a decreased tariff for the remaining 12 years. According to Mercom, the levelised tariff for the full 25 years duration is PKR 9.923 (EUR[19] 0.086) per kWh for the southern region while PKR 10.507 (EUR 0.091) per kWh for the north [Mer 2016a].

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

In early 2011, the country's Energy Regulator National Renewable Energy Board (NREB) recommended a target of 100 MW of solar installations to be implemented in the country over the next 3 years. It was suggested that a FiT of PHP 17.95/kWh (EUR 0.299/kWh[20]) was to be paid from January 2012 onwards. For 2013 and 2014, an annual digression of 6 % was foreseen. The initial period of the programme is scheduled to end on 31 December 2014.

On 27 July 2012, the Energy Regulatory Commission decided to lower the tariff in view of lower system prices to PHP 9.68/kWh (EUR 0.183/kWh[21]) and confirmed the digression rate. The new FiT for systems installed after 15 March 2016 is expected to be between PHP 7- 8 per kWh (EUR[22] 0.-0.150 per kWh).

The Department of Energy (DoE) reported that, by the end of June 2016, more than 4.4 GW of PV projects had been approved under the Renewable Energy Law and another 2.9 GW were pending [RoP 2016]. Out of the 543 MW of operational PV power only 3.2 MW were for commercial self-consumption.

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, 99.4 MW of grid connected systems were installed at the end of June 2016 [EMA 2016].

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 2016a]. At the end of 2015 about 28 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 MW_{AC}) 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 MW_{AC} 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 MW_{AC} by April 2018,
- 300 MW_{AC} by April 2019 and
- 300 MW_{AC} by April 2020.

19 Exchange rate: EUR 1 = PKR 116
20 Exchange rate for 2011: EUR 1 = PHP 60
21 Exchange rate for 2012: EUR 1 = PHP 53
22 Exchange rate for 2016: EUR 1 = PHP 53.5

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 2016].

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].

At the end of 2015, about 7 MW of PV systems had been installed, mainly in off-grid applications. According to the Electricity Regulatory Authority, two solar farms with about 50 MW were under construction in June 2016.

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. According to the company, it has a production capacity of 200 MW in the first phase. The company is a subsidiary holding company of Powerway Group (PRC).

2.3. Americas

2.3.1. Canada

In 2015, about 600 MW of new PV power were connected to the grid and increased the total cumulative installed PV capacity to 2.5 GW [IEA 2016a]. 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.
- **Net-Metering:** Electricity consumers in Ontario who produce some of their own power from a renewable resource (systems up to 500 kW) can participate in the 'net-metering' initiative.

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

2.3.2. 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 440 MW of PV power was connected to the grid in 2015, increasing the total PV capacity to about 850 MW at the end of 2015 [IEA 2016a].

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.

According to a press report, Chile hat 1.27 GW operating PV power and 1.68 GW under construction at the end of June 2016 [Tai 2016]. In addition, 12 GW have already received environmental qualification resolution status and a further 5.4 GW were under evaluation.

2.3.3. Honduras

In 2007, Honduras enacted a law to promote renewable energy generation, with 20-year income tax breaks and a waiving of import tariffs on renewables components. In 2013, the government introduced a premium tariff for the first 300 MW to be installed until 30 June 2015. The General Electricity Industry Act, which adds a USD 0.03 premium for solar projects not eligible for the premium tariff was enacted in May 2014 [GoH 2014]. So far the Congress has approved 620 MW of solar PV power to be installed until the end of 2016. In November 2015, the National Electric Energy Company reported that 389 MW of solar PV power was connected to the grid in 2015 increasing the total capacity to 455 MW.

2.3.4. 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 2015, about 100 MW of new PV systems were connected increasing the total cumulative PV system capacity to 280 MW [IEA 2016a]. 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[23] 29.24/MWh) and MXN 1 169.78/MWh (EUR 55.70/MWh) [CNC 2016]. The second auction in September 2016 resulted in contracts for 184 MW of additional solar PV power, but in addition more than 4.9 million CELs were given to solar PV projects for a total energy production of 4.84 TWh [CNC 2016a]. All systems have to be operational on 1 January 2019.

2.3.5. Peru

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

On 16 February, 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 with 415 GWh) and 48.50/MWh (40 MW with 108.4 GWh) [Osi 2016]. Start of electricity delivery is December 2018 at the latest.

2.3.6. United States of America

With almost 7.3 GW of newly connected PV power, the United States had reached a cumulative PV capacity of 25.6 GW by the end of 2015 [Gtm 2016a]. In terms of nominal capacity, solar accounted for 29.4 % of new power capacity in 2015, exceeding the one for natural gas for the first time. With 4.15 GW utility PV installations again were the largest segment within 2015. The top ten States — California, North Carolina, Nevada, Massachusetts, New York, Arizona, Utah, Georgia, Texas and New Jersey — accounted for more than 86 % of the US PV market, and California alone had a market share of 45 %. For 2016, more than a doubling of the market is expected, and a set-back in 2017, before it will return to a more stable growth in 2018 to 2021. One of the reasons for this development was the surprising extension of the solar investment tax credit (ITC) of 20 % until 2019, 26 % in 2020, 22 % in 2021 and 10 % from 2022 onwards, at the end of 2015.

PV projects based on PPAs, with a total capacity of 21.5 GW, were under contract in Q3 2016 [Gtm 2016b]. In Q3, 10.1 GW of these projects are under construction and it is estimated that close to 8 GW will be connected to the grid before the end of 2016. If those projects at an earlier development stage are included, the pipeline stands at more than 52 GW.

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

[23] Exchange rate: 1 EUR = 21 MXN

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.

2.3.7. Emerging markets

In 2006, **Argentina** passed its Electric Energy Law which established that 8 % of electricity demand should be generated by renewable sources by 2016 [GoA 2006]. The law also introduced FiTs for wind, biomass, small-scale hydro, tidal, geothermal and solar for a period of 15 years. In July 2010, amongst other RES, the government awarded PPAs to six solar PV projects totalling 20 MW. By the end of 2015, about 50 MW (15 MW off-grid) of PV systems had been installed. The first renewable energy auction received bids for more than six times the assigned 1 GW of power of which 300 MW are assigned to PV projects. The auction received 58 bids for solar projects with more than 2.8 GW capacity. The results should be published by mid-October 2016.

At the end of 2015, it is estimated that **Brazil** had about 60 MW of cumulative installed capacity of PV systems. About half of this capacity is in off-grid systems.
In April 2012, the board of the National Agency of Electric Energy approved new rules to reduce barriers to installing small distributed generation capacity. The rules apply to generators that use subsidised sources of energy (hydro, solar, biomass, co-generation and wind). So far three energy auctions where solar power projects could bid were held.

The auctions secured approximately BRL 12 billion (EUR[24] 3.34 billion) in investments for the next 3 years and attracted a number of domestic and international players into the market, with the following results:

- October 2014 auction (solar-only): over 1 GW was awarded to 31 projects at an average price of BRL 220/MWh (EUR[25]$_{2014}$ 70.97/MWh, EUR$_{2016}$ 61.11/MWh). Start to deliver energy: 1 October 2017
- August 2015 auction (solar-only): over 830 MW were awarded to 30 projects at an average price of BRL 301/MWh (EUR[26]$_{2015}$ 70.82/MWh, EUR$_{2016}$ 83.61/MWh). Start to deliver energy on 1 August 2017.
- November 2015 auction (solar and wind): over 920 GW awarded to 33 solar power projects at an average price of BRL 297/MWh (EUR$_{2015}$ 69.88/MWh, EUR$_{2016}$ 82.50/MWh). Start to deliver energy on 1 November 2018.

As it can be seen, the devaluation of the Brazilian real against the USD and EUR has changed the economics of the solar PPA projects considerably. So far six companies (670 MW), which have won contracts in the first auction applied to alter the delivery start or cancel the contracts. A final decision is still pending.

In December 2015, the 2024 target of the official 10-year energy plan (PDE) was set to 7 GW of utility-scale solar and 1.32 GW of distributed PV installations [MME 2015].

For the next energy auction planned in October 2016, over 390 solar projects with a combined capacity of 12.5 GW have been registered.

As early as 2007, the **Dominican Republic** passed a law promoting the use of renewable energy and set a target of 25 % renewable

24 Exchange rate September 2016: EUR 1 = BRL 3.60
25 Exchange rate 2014: EUR 1 = BRL 3.10
26 Exchange rate 2H 2015: EUR 1 = BRL 4.25

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

In March 2016, the Government of **Panama** approved the National Energy Plan (NEP), 2015-2050 [GoP 2016]. 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 42.7 MW in May 2016 [Ase 2016a]. 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 [Ete 2015].

2.4. Africa

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

Overall, the (documented) capacity of installed PV systems has risen to more than 2.6 GW by the end of 2015, more than forty times the capacity installed in 2008. In 2016, 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. About 300 MW of PV solar power was operational at the end of 2015.

2.4.2. Cape Verde

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

By the end of 2012, two centralised grid-connected PV plants with 7.5 MW had been installed. In addition, there are a number of smaller off-grid and grid-connected systems. At the end of 2015, about 10 MW of PV power was operational [Ire 2016c]. A 2 MW solar/wind hybrid project to provide electricity and fresh water on the Island of Brava has been approved by the IRENA/ADFD Project Facility [Ire 2016c].

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

2.4.3. Egypt

In September 2014, the Ministry of Electricity and Energy and the Regulatory Agency launched a FiT support system for solar PV and wind projects with capacity less than 50 MW. The target of the programme is to install 300 MW from small PV installations below 500 kW, and 2 GW PV plants between 500 kW up to 50 MW. The tariffs vary between EGP 84.8 to 102.5/kWh (EUR[28]0.085 to 0.103/kWh) depending on the size of systems. The tariffs will be adjusted if either the target is achieved or the 2year regulatory period is elapsed, which happens first.

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

It is estimated that 70 MW of PV power was operational at the end of 2015 [Mes 2016]. According to MESIA, about 1.8 GW of solar power are under 'execution', i.e. PPA signing, awarded, construction.

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

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

2.4.5. 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 Inde-

[28] Exchange rate: 1 EUR = 9.95 EGP

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

pendent Power Producer Procurement Programme (IPP) was set up with rolling bidding rounds. Three rounds have already taken place: in 2011 (630 MW), 2012 (420 MW), 2013 (450 MW) and 2014 (415 MW). The overall target is 3.725 GW and that for solar PV is 1.45 GW. Between the first round (closing date: 4 November 2011) and the fourth round (closing date: 18 August 2014) the average bid price fell from ZAR 2.65/kWh (EUR[30] 0.265/kWh) to ZAR 0.79/kWh (EUR[31] 0.056/kWh). In 2015, about 200 MW of solar PV capacity was connected to the grid, increasing total PV power capacity to 1.12 GW [IEA 2016a].

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

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

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

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

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

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

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

At the end of June 2014, SMA Solar Technology AG (SMS) commissioned an inverter factory for local production in Cape Town [Sma 2014]. It consists of a production line, storage facilities and a test centre for central inverters. In September 2016 however, the company announced to relocate its activities to China and Germany.

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

2.4.6. Emerging markets

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

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

2016]. The plants are scheduled to be built in 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 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 the completion has been postponed to 1Q 2017. 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 2008, **Kenya** introduced FiTs for electricity from RES, but solar power was only included in 2010, when the tariffs were revised [GoK 2010]. However, only a little over 560 kW of PV capacity was connected to the grid in 2011; the majority of the 14 MW of PV systems were off-grid installations. In 2011, Ubbink East Africa Ltd., a subsidiary of Ubbink B.V. (Doesburg, the Netherlands) opened a solar PV manufacturing facility in Naivasha with an annual output of 30 000 modules. The plant produces modules for smaller PV systems, such as SHS. Current estimates for Kenya's PV market put average annual sales of home systems at 20 000 to 30 000 and solar lanterns at 80 000. It is estimated that the total capacity of SHS, telecommunication applications, diesel-PV hybrids and the few grid-connected systems will be about 25 to 30 MW at the end of 2016. In March 2016, the Rural Electrification Authority (REA) board approved the construction of a 55 MW Solar Power plant in Garissa [Rea 2016]. It is interesting to note that the solar plant will be financed through concessional funding from the Government of China.

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. However, the tariff scheme was declared illegal by the Federal High Court in Lagos on 13 July 2016 [NER 2016].

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

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

It is estimated that about 20 MW of solar PV power were operational at the end of 2015.

At the end of 2012, **Tanzania's** Ministry of Energy and Minerals (MEM) published its Strategic Plan 2011/12-2015/16, in which the strategic objective to enhance the sustainable development and management of energy resources for national development was formulated [MEM 2012]. As a follow-up, the Scaling-up Renewable Energy Program (SREP) was published in April 2013 [MEM 2013]. The SREP calls for a cumulative installed PV capacity of 60 MW by 2017 and 120 MW by 2020. Cumulative PV capacity is reported with 14 MW at the end of 2015 [Ire 2016b].

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 15 MW at the end of 2015.

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

3. Electricity costs and the economics of PV systems

Over the last four decades, solar module prices have fallen following a price-experience or 'learning' curve with an average learning rate of about 80 %, i.e. the ASP of solar modules fell by 20 % for each doubling of production volume (Fig. 7). This development was driven not only by technological developments but also by market conditions. It is interesting to note that between 2004 and the second half of 2008 the price of PV modules remained fairly constant at roughly USD_{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 the temporary shortage of polysilicon between 2004 and 2009, which limited silicon solar cell production and prevented effective pricing competition, thus providing an opening for thin-film technologies to enter the market. The temporary silicon feedstock shortage and the market entry of companies offering turnkey production lines for thin-film solar cells led to a massive expansion of investments in thin-film capacities between 2005 and 2009. The market share for thin-film modules increased until 2009, when it reached almost 20 %, although it has declined steadily since then.

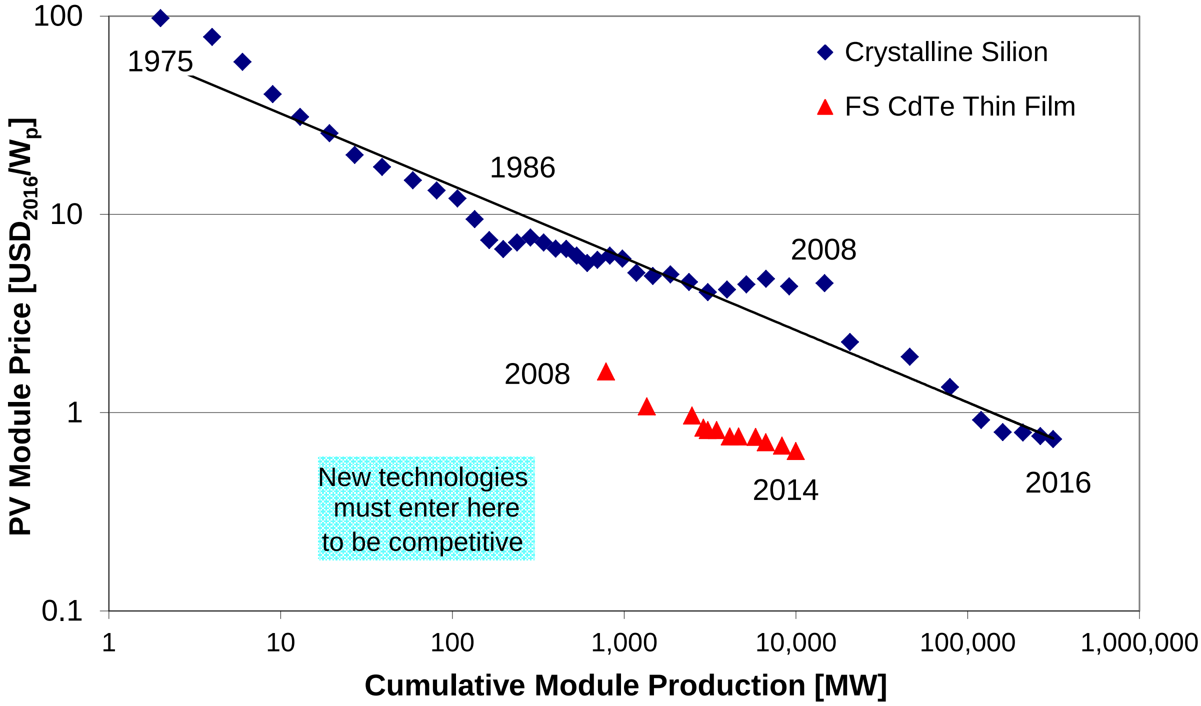

Figure 7: Price-experience curve for solar modules (ASP)
(*data source*: Bloomberg New Energy Finance (BNEF) and PV News)

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.

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

Despite the fact that there is a global market for the hardware components of a PV system, e.g. modules, inverters, cables, etc., and that these prices are very similar worldwide, the prices for installed PV systems still vary significantly [IEA 2016c]. 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].

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

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

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

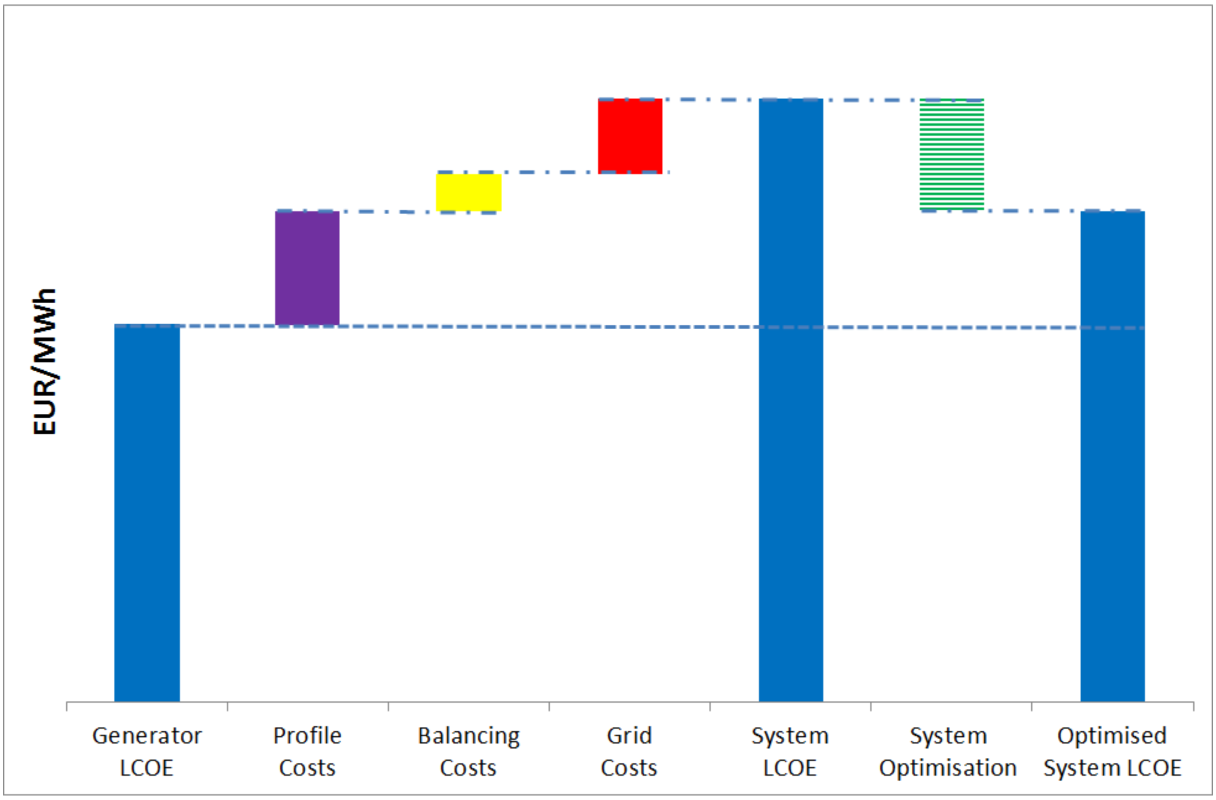

Figure 8: System LCOE

3.2. Influence of financing costs on LCOE

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

The WACC can be calculated as follows:

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

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

As shown above, not only the equity to debt ratio but the corporate tax rate has a significant influence on the WACC. Cost of debt is very much dependent on the economic situation in a given country and the financial stability of the company looking for debt. Therefore, WACC for a given project can vary not only where it is realised, but also by whom.

In this context, it is noteworthy to mention that the latest bids and PPAs in the United Arab Emirates, Chile as well as in Africa have only been able by a combination of excellent solar resource, high debt shares and low debt costs.

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

CAPEX EUR_{2016} 1 000 per kWp, operational expenditure (OPEX) EUR 18 per kW/year, 1 500 kWh/kW per year, financial lifetime of 20 years. Local taxes were not considered.

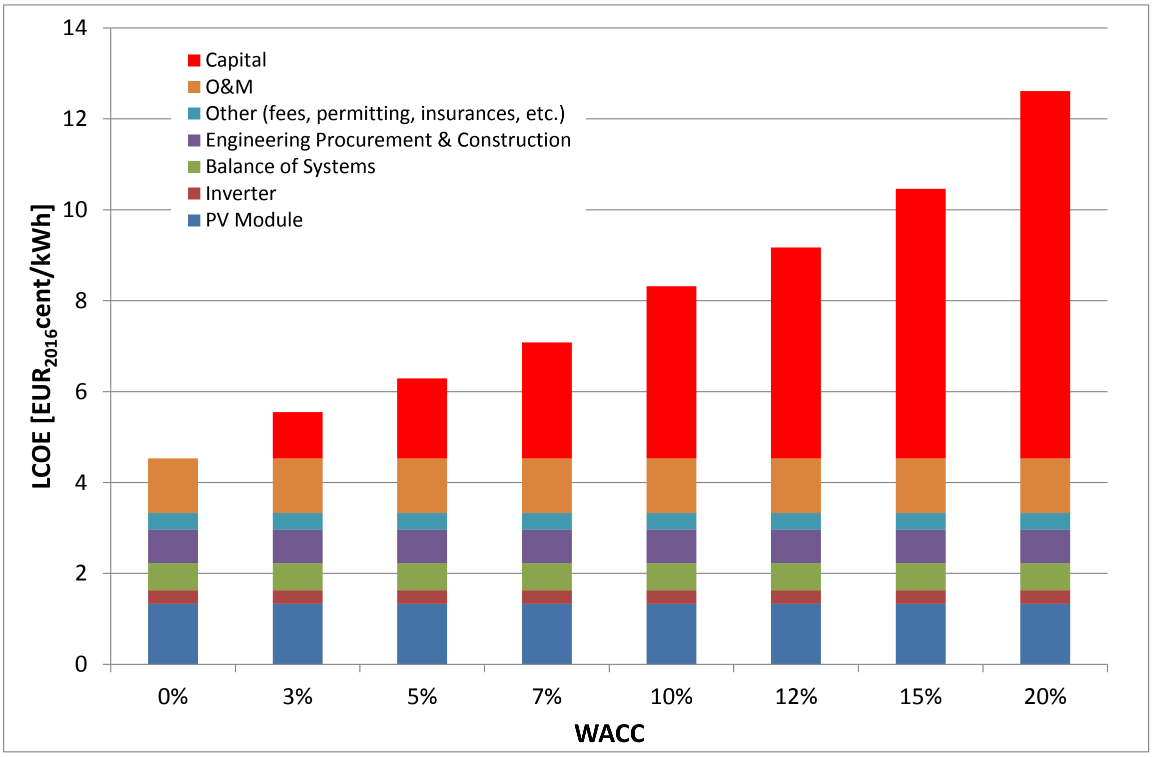

Figure 9: Influence of WACC on LCOE

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

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 9. The increase in PV system prices in Japan, between 2007 and 2010 as well as the increase from 2015 to 2016, are due to changes in exchange rates; in the local currency the prices fell further.

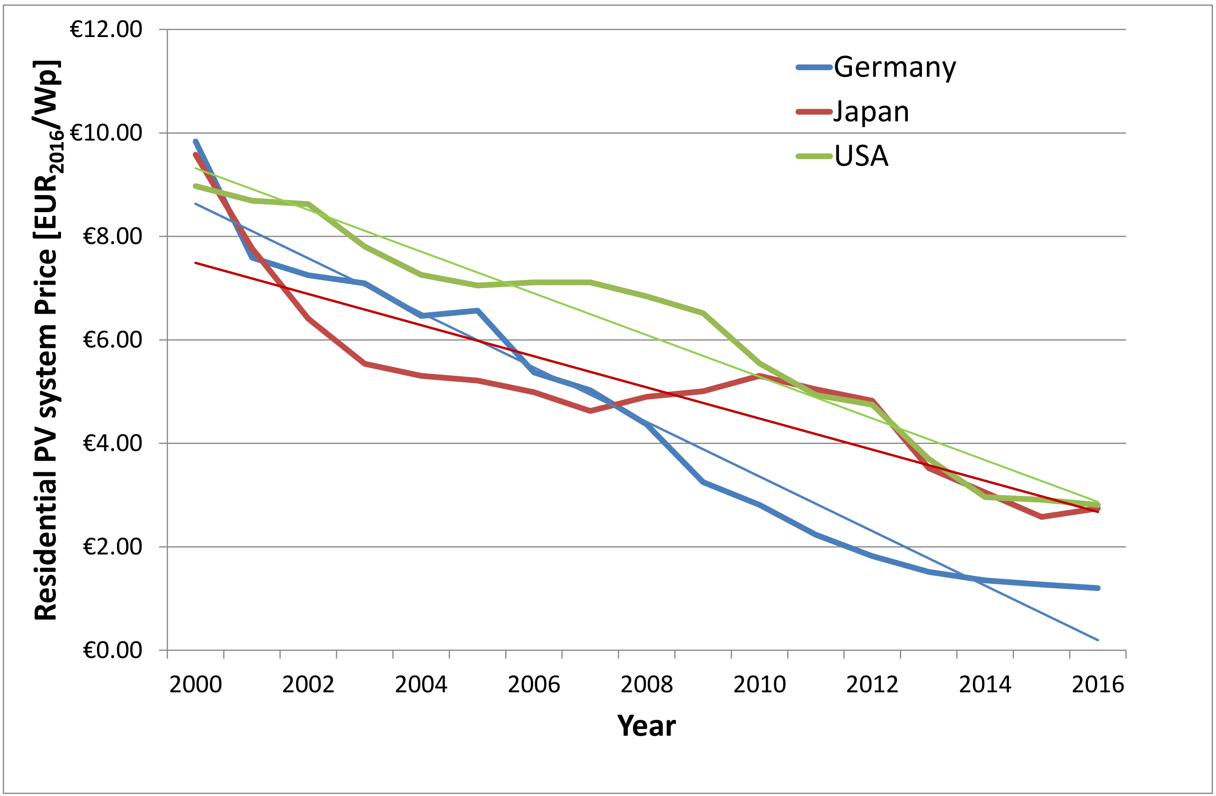

Figure 10: Residential PV system price development over the last decade (*data sources*: IEA PVPS, BSW, DoE SunShot Initiative, Eurostat, OECD key economic data)

In September 2016, the worldwide average price of a residential system without tax was given as USD 1.67/Wp (EUR 1.49/Wp) about 25 % higher than in Europe with EUR 1.21/Wp or Australia [Pvi 2016, Sol 2016]. Taking the European price and adding a surcharge of EUR 0.14/Wp for fees, permits, insurance, etc., an installed PV system costs EUR 1 350/kWp without financing and VAT. The influence of the European VAT rates on investment costs and LCOE are shown in the European Cost Maps [Hul 2014].

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

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

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.

For the benchmark calculation of residential systems operation, maintenance and repair (O&M) costs of 2 % was used, which is 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 the second or third largest cost factor. 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.

Depending on the actual radiation level, the 2 % O&M costs are a main cost factor besides 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 2.7 EUR cent /kWh results in an electricity price of 2.9 to 3.5 EUR cent/kWh after the 20-year financial payback period, depending on the actual solar radiation.

Table 1: LCOE of PV-generated electricity for residential systems with a system price of EUR 1 350/kWp (excluding VAT, because the differences in the various countries are too large), 2 % O&M cost, an annual generation of 1 000 kWh/kWp/year and financial lifetimes of 20 years

	Price [EUR/kWp]	LCOE Product	LCOE Capital			LCOE O&M	LCOE Total		
WACC		0 %	3 %	5 %	10 %		3 %	5 %	10 %
		[EURct/kWh]							
Hardware	910	4.55	1.39	2.40	5.17	1.82	7.76	8.77	11.54
Eng. and installation	300	1.50	0.46	0.79	1.70	0.60	2.56	2.89	3.80
Other (fees, permits, insurances...)	140	0.70	0.21	0.37	0.79	0.28	1.19	1.35	1.77
Total	1 350	6.75	2.06	3.56	7.66	2.70	11.51	13.02	17.12

Table 2: LCOE of PV-generated electricity for residential systems with a system price of EUR 1 350 kWp (excluding VAT, because the differences in the various countries are too large), 2 % O&M costs, an annual generation of 1 300 kWh/kWp/year and a financial lifetime of 20 years

	Price [EUR/kWp]	LCOE Product	LCOE Capital			LCOE O&M	LCOE Total		
WACC		0 %	3 %	5 %	10 %		3 %	5 %	10 %
		[EURct/kWh]							
Hardware	910	3.50	1.07	1.85	3.97	1.40	5.97	6.75	8.87
Eng. and installation	300	1.15	0.36	0.61	1.31	0.47	1.97	2.23	2.93
Other (fees, permits, insurances…)	140	0.54	0.16	0.28	0.61	0.22	0.92	1.04	1.37
Total	1 350	5.19	1.59	2.75	5.90	2.08	8.85	10.01	13.17

In 2016, the average residential electricity rate, excluding the daily connection charge, in Australia is about AUD 0.25/kWh (EUR[33]) 0.171/kWh), but for customers with peak tariffs this can increase to AUD 0.39/kWh (EUR 0.267/kWh) between 14.00 and 20.00, which is a good match with PV electricity generation. The average European residential electricity price given by Eurostat for the second semester of 2015 was EUR 0.211/kWh, including fixed charges [Est 2016]. Fixed charges vary widely between EUR 20 and 170, depending on the respective Member State and electricity provider. The same holds true for the variable part of the electricity price, which can vary between EUR 0.075 and 0.26 per kWh. Nevertheless, PV-generated electricity for the lower ROI financing options, which are more realistic for private consumers, is already cheaper for a large number of European Union citizens. Cyprus, Denmark and Germany had the highest prices with EUR 0.294/kWh, EUR 0.292/kWh and EUR 0.248/kWh, respectively. In September 2016, the kWh based prices of Japan's largest utility Tokyo Electric Power Company (TEPCO) were JPY 19.52/kWh (EUR[34] 0.170/kWh) for the first 120 kWh per month, JPY 26.00/kWh (EUR 0.226/kWh) for everything above 120 kWh and below 300 kWh per month, and JPY 30.02/kWh (EUR 0.261/kWh) for every kWh above 300 kWh per month [Tep 2016]. In addition, customers pay a demand charge between JPY 280.80 (EUR 2.04) per month for 1 kW and up to JPY 1 684.80 (EUR 12.21) for a 6 kW connection. The Renewable Energy Power Promotion Surcharge in FY 2016 is JPY 2.25/kWh [METI 2016a].

Without support, the profitability of a solar PV system depends primarily on the owner's self-consumption, as less energy has to be purchased from the utility. In the case of a PV system size that generates as much electricity as the customer uses over a year, the actual consumption during the time of generation is in general only around 30 % if no de-

33 Exchange rate: EUR 1 = AUD 1.46

34 Exchange rate: EUR 1 = JPY 115

mand shifting or local storage is applied. Therefore, 70 % of the generated electricity has to be sold to the grid. The question is what kind of pricing should be used — contract, wholesale or day-ahead prices.

The first option for improving profitability is to increase self-consumption by demand shifting and using electrical appliances like the washing machine, dishwasher, electric hot water heaters or heat pumps during the day when the sun shines. Another option is to use the difference between the PV electricity generation costs and the household retail price to invest in local storage options, be they residential or community-owned. The current investment costs for a residential battery storage system are roughly equally divided between the batteries and the electronic control components. In the future, it is very likely that the solar inverter will include large parts of the necessary electronics, thereby lowering the costs significantly.

As an indication of storage costs, according to BNEF prices for battery packs for electric vehicles have declined from about USD 1 000/kWh in 2010 to USD 350/kWh in H2 2015 and could reach USD 200/kWh by 2020 [Blo 2015]. 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 0.07/kWh (EUR 0.063/kWh) and should fall to USD 0.04/kWh (EUR 0.036/kWh) by 2020. However, these costs do not yet include the investment for the power and control electronics needed to combine it with a PV system.

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

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

3.4. Residential and commercial electricity storage models

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

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

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

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

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

3.5. LCOE of utility-scale PV systems

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

Due to the plant size, which is currently up to 850 MW[35], the cost structure and LCOE is quite different from that of residential PV systems. Figure 11 shows an average cost breakdown in competitive markets. The actual cost breakdown differs from project to project.

[35] Longyangxia Dam Solar Park, PRC

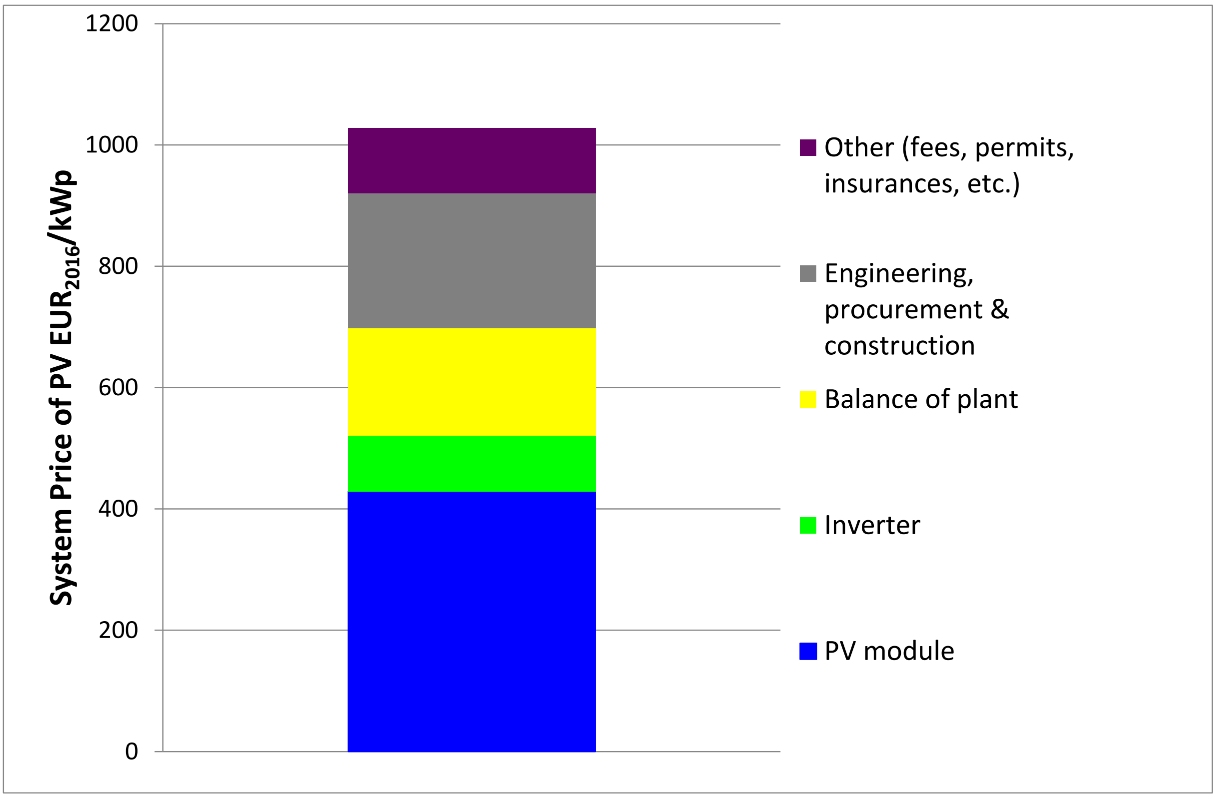

Figure 11: Price breakdown of utility-scale PV system

Already in 2010, Ken Zweibel published an analysis of how discount rates influence the competitiveness of solar PV electricity generation [Zwe 2010]. He calculated that with a market size of 40 GW per year system costs of USD_{2010} 2.00/Wp (EUR_{2010} 1.54/Wp) should be possible. The 2014 market was already above this, with utility system prices around EUR 1 100_{2014}/kWp (USD 1 554_{2010}/kWp[36]).

In 2016, a number of record breaking PPA contracts and bids below USD 30/MWh have been reported reaching a new low with the USD 24.2/MWh bid by JinkoSolar (China) and

[36] United States inflation — see: http://www.usinflationcalculator.com/inflation/historical-inflation-rates/

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 latest solar auction in Germany in August ended with contracts awarded to projects for prices between EUR 68.90/MWh and EUR 77.70/MWh [BNA 2016]. Other examples are:

- Auction results in Zambia: 45 MW (USD 60.02/MWh (EUR 53.12) and 34 MW (28 MWAC) for USD 78.40/MWh (EUR 69.38) where the World Bank's 'Scaling Solar' programme provide risk management and credit enhancement products to lower financing costs for the projects. Duration of the PPAs are 25 years, paid in USD.
- In Nigeria, NBET 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. Duration of the PPAs are 20 years, paid in USD.
- The first two clean energy auctions were held in Mexico in 2016. The scheme is more complicated as the energy contracts were for 15 years, whereas the additional Clean Energy Certificates (CEL) are for 20 years. After the 15th year, the projects have to sell their electricity at the wholesale market.
  After the first auction in March 2016, the winning solar projects with a capacity of 1 595 MW signed energy contracts between MXN 614.14/MWh (EUR[37] 29.24/MWh) and MXN 1 169.78/MWh (EUR 55.70/MWh). The average CELs were priced at MXN 444/MWh (EUR 21.14/MWh).
  The second auction in September 2016 resulted in contracts for 184 MW of additional solar PV power, but in addition more than 4.9 million CELs were given to solar PV projects for a total energy production of 4.84 TWh [CNC 2016]. The average CELs were priced at MXN 375/MWh (EUR 17.86/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 %.

[37] Exchange rate: 1 EUR = 21 MXN

4. The PV industry

The PV industry consists of a long value chain from raw materials to PV system installation and maintenance. So far, the main focus has been on the solar-cell and module manufacturers, but 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 and meteorological forecasts. The main focus in this report, however, is still on solar-cell, module and polysilicon manufacturers.

In 2015, the PV world market grew by roughly 20 % in terms of solar cell production to about 57 GW. The market for installed systems also grew about 20 %, and values between 50 and 56 GW were reported by various consultancies and institutions. This mainly represents the grid-connected PV market since, to what extent the off-grid and consumer-product markets are included remains unclear.

In addition, the fact that some companies report shipment figures, some sales figures and others production figures adds to the uncertainty. An additional source of error stems from the fact that some companies produce fewer solar cells than solar modules, but the reporting does not always differentiate between the two and there is a risk that cell production is counted twice — first at the cell manufacturer and then again at the 'integrated' cell/module manufacturer. The difficult economic conditions contributed to the lowering in willingness 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. However, the slight increase in profit margins as well as the rapid expansion of some markets immediately led to an increase of new entrants in the field, notably large semiconductor or energy-related companies. In 2013, no significant capacity increase was reported, but since the beginning of 2014 the announcements of new capacity expansions have significantly increased totalling about 6.6 GW of thin film and 34 GW of c-Si solar cell capacity to be realised within the next 18 to 24 months. Not all of these announcements were realised, but the capacity increases along the value chain were large enough to increase the overcapacity to levels accelerating the price pressure. 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 2015, their market share was over 90 % and they continue to be the main technology. Commercial module efficiencies range widely from 12 % to 22 %, with monocrystalline modules from 16 % to 22 %, and polycrystalline modules from 12 % to 18 %. The massive increases in manufacturing capacity for both technologies were followed by the capacity expansions needed for polysilicon raw materials.

In 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 slowly as the ramp-up of new production lines has not followed that of wafer-based silicon.

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 of the last 5 years. Within CPV, there is a differentiation according to concentration factors[38] 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.

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.

---

[38] High concentration > 300 suns (HCPV), medium concentration $5 < x < 300$ suns (MCPV), low concentration < 5 suns (LCPV).

4.2. Polysilicon supply

Since 2000, the rapid growth of the PV industry 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, 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 August 2014, prices were in the USD 14 to 16/kg (EUR 12 to 14/kg) range.

Projected silicon production capacities for 2016 vary between 415 000 tonnes [Blo 2016c] and 470 000 tonnes [Ikk 2016]. It is estimated that about 27 000 to 30 000 tonnes will be used by the electronics industry. In addition, possible solar cell production will depend on the material used per Wp. The current average worldwide is about 4.5 g/Wp for mono- and 5.0 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 trichlorosilane, with the help of the hydrogen, decomposes to elemental silicon and deposits as a thin-layer film on to the filaments. Hydrogen chloride is formed as a by-product.

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

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

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

4.3. Polysilicon manufacturers

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

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

GCL-Poly (http://www.gcl-poly.com.hk) was founded in March 2006 and started the construction of its Xuzhou polysilicon plant (Jiangsu Zhongneng Polysilicon Technology Development Co. Ltd.) in July 2006. Phase I had a designated annual production capacity of 1 500 tonnes and the first shipments were made in October 2007. Full capacity was reached in March 2008. At the end of 2015, polysilicon production capacity had reached 70 000 tonnes and 14 GW of wafers. The wafer capacity was further increased to 17 GW at the end of 1H 2016. The company reported production of 74 358 tonnes of polysilicon with sales of 18 023 tonnes of polysilicon and 15.2 GW of wafers for 2015.

The company also invested in the downstream 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 2.3 GW at the end of 2015.

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 is ramped up in 2016 and once operational, the company plans to have a capacity of 80 000 tonnes by the end of 2016. For 2015, a production of 51 051 tonnes was estimated [Ros 2016].

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. Further capacity expansions, P4 (20 000 tonnes) and P5 (24 000 tonnes), had been put on hold due to the rapid decline in the price of polysilicon. Instead, the company finished an additional de-bottlenecking of the existing plants and increased the capacity by 10 000 tonnes in 2015. For 2015, a production of 44 209 tonnes was estimated [Ros 2016].

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

4.3.4. 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 2015, a production capacity of 36 000 tonnes and actual production of 26 000 tonnes was estimated [Ros 2016].

4.3.5. TBEA Silicon Co. Ltd. (China)

TBEA Silicon Co. Ltd. (http://www.tbea.com.cn/) was established at the State Hi-Tech Development Zone in Urumqi, Xinjiang, China by Tebian Electric Apparatus Stock Co. Ltd. (TBEA) and East Electric EMei Semiconductor Institute. TBEA is a major manufacturer of power transmission and transformation equipment including inverters for renewable energy applications. TBEA Silicon is active in the field of polysilicon manufacturing as well as gird-connected and mini-grid power plants. For 2015, a production capacity of 23 000 tonnes and actual production of 19 205 tonnes was estimated [Ros 2016].

4.3.6. REC Silicon ASA (Norway/USA)

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

Production capacity at the end of 2015 was about 2 000 tonnes and, according to the company, a total of 16 882 tonnes of polysilicon, of which 14 098 tonnes were FBR and, 2 784 tonnes of Siemens solar grade, were produced in 2015.

4.3.7. Tokuyama Corporation (Japan)

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

A production capacity of 23 000 tonnes was reported for FY 2016 [Ikk 2016]. For 2015, an actual production of 16 344 tonnes was estimated [Ros 2016].

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 more than 10 000 tonnes at the end of 2015. For 2015, a production of 10 091 tonnes was estimated [Ros 2016].

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. SunEdison Inc. (USA)

SunEdison (http://sunedisonsilicon.com), formerly MEMC Electronic Materials Inc., has its headquarters in St Peters (Missouri), USA. It started operations in 1959 producing semiconductor-grade wafers, granular polysilicon, ultra-high-purity silane, trichlorosilane, silicon tetraflouride and sodium aluminium tetraflouride. In February 2011, the company and Samsung entered into a 50/50 equity joint venture to build a polysilicon plant in Korea with an initial capacity of 10 000 tonnes in 2013. At the end of 2011, the company closed its 6 000-tonne factory in Merano, Italy, and in 2012 it reduced its capacity in Portland (Oregon), USA. For 2015, a production capacity of 21 100 tonnes and actual production of 10 055 tonnes was estimated [Ros 2016].

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

4.3.10. Daqo New Energy Co. Ltd. (China)

Daqo New Energy (http://www.dqsolar.com/) is a subsidiary of the Daqo Group and was founded by Mega Stand International Ltd. in January 2008. Initially, the company built a high-purity polysilicon factory in Wanzhou, China, with an annual output of 3 300 tonnes in the first phase. The first polysilicon production line, with an annual output of 1 500 tonnes, started operating in July 2008. Production capacity in 2009 was 3 300 tonnes and had reached more than 4 300 tonnes by the end of 2011. According to the company, production capacity at the end of 2013 was 6 150 tonnes and an expansion of the capacity to 12 150 was achieved at the end of September 2015. A further expansion of the capacity to 18 000 tonnes should be finished at the end of 2016 and start production in 1Q 2017. In addition, the company manufactures wafers and had a capacity of 87 million at the end of 2015. The company reported sales of 8 234 tonnes of polysilicon and 61.1 million of own wafers and 15.3 million OEM wafers for 2015.

4.4. Solar-cell production companies

In 2016, more than 100 companies still produce solar cells[39] 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 given with 90 GW for Q1 2016 and could increase to 109 GW at the end of 2016 [Blo 2016c].

The following section gives a short description of the 20 largest companies, in terms of actual production/shipments in 2015. 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. Trina Solar Ltd. (China)

Trina Solar (http://www.trinasolar.com/) was founded in 1997 and went public in December 2006. The company has integrated product lines, from ingots to wafers and modules. In December 2005, a 30 MW monocrystalline silicon wafer product line went into operation. In February 2016, Trina completed the acquisition of all the assets from Solland Solar, with approximately 200 MW solar cell manufacturing capacity located in Heerlen, the Netherlands [Tri 2016].

According to the company's annual report, the production capacity at the end of 2015 was 1.8 GW for wafers, 2.3 GW for ingots and 3.5 GW for cells, and 5 GW for modules, with a planned increase to 5 GW for cells and 6 GW for modules in 2016. Module and system deliveries of 5.7 GW were reported for 2015. A solar cell production of 3.5 to 3.6 GW was estimated for 2015.

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

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

JingAo Solar Co. Ltd. (http://www.jasolar.com) was established in May 2005 by the Hebei Jinglong Industry and Commerce Group Co. Ltd., the Australia Solar Energy Development Pty Ltd. and the Australia PV Science and Engineering Company. Commercial operations started in April 2006 and the company went public on 7 February 2007. According to the annual report of the company, the production capacity was 4.4 GW for cells, 3.9 GW for modules and 1.5 GW for wafers at the end of 2015. For 2016, an increase of the cell and module manufacturing capacity to 5 GW each is foreseen. Total shipments for 2015 were reported with 3.9 GW (about 3.5 GW modules and 400 MW cells). It is estimated, that about 3.5 to 3.6 GW of solar cells were produced in 2015.

4.4.3. Hanwha (China/Germany/ Malaysia/South Korea)

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 pro-

39 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.

duces 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, it acquired Q CELLS (Germany/Malaysia), which had filed for insolvency in April 2012. Hanwha, with its two brands Hanwha Q CELLS and Hanwha SolarOne, had a combined production capacity of 3.7 GW of solar cells (2.1 GW in China, 1.6 GW in Malaysia) and 4.3 GW for solar modules (2.3 GW in China, 0.5 GW in Korea and 1.5 GW in Malaysia) at the end of 2015. In the first half of 2016, the module manufacturing capacity in Korea was expanded to 1.4 GW. In addition, Hanwha SolarOne has 1.4 GW of ingot and 900 MW of wafer production capacity. After the closure of the manufacturing facilities in Germany in March 2015, a 60 MW cell production line remained as a R & D facility. For 2015, Hanwha a solar cell production of 3.5 to 3.6 GW and 3.3 GW solar modules is estimated from the annual report. The company reported a PV power project pipeline of 946 MW in March 2016.

4.4.4. Canadian Solar Inc. (CSI) (China/Canada)

CSI (http://www.canadiansolar.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 2015 it had 400 MW of wafer capacity, 2.7 GW cell capacity and 4.3 GW module manufacturing capacity (3.8 GW in China and 500 MW in Ontario, Canada). In 2016, the solar cell manufacturing capacity should be increased to 3 GW and the module manufacturing capacity to 5.8 GW. For 2015, the company reported shipments of 4.7 GW of modules. In terms of sales, the company reported 4.1 GW of modules and 298 MW of systems. The solar cell production was estimated at 2.5 GW. In September 2016, the company reported operation and ownership of PV power plants with 470 MW and a contracted project with 2.4 GW.

4.4.5. First Solar LLC (USA/Germany/Malaysia)

First Solar LLC (http://www.firstsolar.com) is one of the few companies worldwide to produce CdTe thin-film modules. It currently has two manufacturing sites — in Perrysburg (United States) and Kulim (Malaysia) — which, at the end of 2015, had a combined capacity of 2.8 GW. In Q2 2016, the company reported an average module efficiency of 16.2 %. In March 2016, the company reported that it had PV power plants with more than 5 GW under O&M contracts [Fir 2016].

For 2015, the company reported a production of 2.52 GW and shipments of 2.9 GW.

4.4.6. JinkoSolar Holding Co. Ltd. (China)

JinkoSolar (http://www.jinkosolar.com/) was founded by Hongkong Paker Technology Ltd. in 2006. Starting from the upstream business, in 2009, the company expanded its operations across the solar value chain, including recoverable silicon materials, silicon ingots and wafers, solar cells and modules. In May 2010, it went public and was listed on the New York Stock Exchange. According to the company, it had manufacturing capacities of 3 GW for wafers and 3.5 GW for solar cells (3.1 GW in China, 400 MW in Malaysia) and 4.3 GW for solar modules at the end of 2015. A capacity increase to 3.5 GW for wafers and cells and 6.3 GW for modules is planned in 2016. For 2015, the company reported module shipments of 4.5 GW. It is estimated that 2.4 to 2.5 GW of solar cells were manufactured in 2015.

4.4.7. 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 2013 annual report, it reported that, by the end of 2015, it had a production capacity of 3 GW for ingots and wafers, 3.2 GW for solar cells and 4 GW for solar modules. Total reported shipments of solar modules for 2015 were 2.4 GW. Solar-cell production is estimated at 2.3- 2.4 GW for 2015.

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.

4.4.8. 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 2015 was reported as 3.2 GW (1.06 GW China and 2.14 GW Taiwan), and total shipment of 2.45 GW was reported.

4.4.9. Neo Solar Power Corporation (Taiwan)

Neo (http://www.neosolarpower.com/) Solar Power was founded in 2005 by Powerchip Semiconductor, Taiwan's largest DRAM company, and went public in October 2007. The company manufactures mono- and multicrystalline silicon solar cells. In 2013, it merged with DelSolar to become the largest Taiwanese cell producer. Since the end of 2014, total installed manufacturing capacity was 2.2 GW for silicon solar cells (400 MW in China, 1.8 GW in Taiwan) and 480 MW for modules. In 2016, the company plans to expand its capacities to 2.5 GW of solar cells and 0.8 to 1 GW of modules. According to the company, shipments in 2015 exceeded 2 GW.

4.4.10. Tongwei Solar (Hefei) Co., Ltd. (PRC)

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.

Tongwei Solar, has an annual production capacity of 2 GW afor solar cells and 500 MW for solar modules. Furthermore, the group's subsidiary Sichuan Yongxiang Polysilicon has now a polysilicon production capacity of 15 000 tonnes. It is estimated that the company had a solar cell production of 1.6 GW in 2015.

4.4.11. Shunfeng International Clean Energy Ltd. (China)

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

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

100 % ownership: Jiangsu Shunfeng Photovoltaic 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 2015, the annual production capacity of solar modules and solar cells, was approximately 2.4 GW and 2.51 GW respectively. The solar power generation business had a grid-connected annual designed installed capacity, of 1 780 MW. For 2015, a total shipment of 2.28 GW solar modules was announced with 1.30 GW being shipped to external customers. Solar cell production was estimated at 1.4 GW.

4.4.12. Gintech Energy Corporation (Taiwan)

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]. In 2015, solar cell production of about 1.3 to 1.4 GW was estimated.

4.4.13. Zhongli Talesun Solar Co. Ltd. (China)

Talesun Solar (http://www.talesun-eu.com/) was established in 2010 as a wholly owned subsidiary of Zhongli Sci-tech Group. According to the company, it currently has an annual capacity of 2 GW of solar cells and 3 GW of modules. 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]. According to the company, the factory is designed for a capacity of 800 MW each to be reached in 2017. Total shipments were reported with 1.5 GW for 2015. In house solar cell production is estimated at 1.2 to 1.3 GW.

4.4.14. Risen Energy Co., Ltd. (China)

Risen Energy (http://www.risenenergy.com/en/) was founded in 1986, and is located in Ninghai, Zhejiang. The company went public on the Shenzhen Stock Exchange on 2 September 2010. According to the company, it had a manufacturing capacity of solar cells and modules of 2.6 GW each at the end of 2015. A further expansion of 500 W each is foreseen in 2016. It is estimated that about 1.2 to 1.3 GW of solar cells and modules were produced in 2015.

4.4.15. SunPower Corporation (USA/Philippines/Malaysia)

SunPower (http://us.sunpowercorp.com/) was founded in 1988 to commercialise proprietary high-efficiency silicon solar-cell technology. It went public in November 2005. The company designs and manufactures high-performance silicon solar cells based on an interdigitated rear-contact design for commercial use. The initial products, introduced in 1992, were high-concentration solar cells with an efficiency of 26 %. SunPower also manufactures solar cells with an efficiency of 22 %, called Pegasus, which is designed for non-concentrating applications.

The company's main R & D activity is conducted in Sunnyvale (California), United

States, and has its cell-manufacturing plants in the Philippines and Malaysia. Since2013, SunPower had two cell-manufacturing plants, one in the Philippines with 700 MW capacity and a joint venture (AUOSP) with AU Optronics Corporation in Malaysia with over 800 MW. The 350 MW capacity expansion in the Philippines started commercial operation in 2016. The company has three solar module factories in the Philippines, Mexico and France. Modules are also assembled for SunPower by third-party contract manufacturers in China and California. Total cell production in 2015 was estimated at about 1.2 GW.

4.4.16. Kyocera Corporation (Japan, Czech Republic, Mexico)

Kyocera (http://global.kyocera.com) started with research into solar cells in 1975, The Shiga Yohkaichi factory was established in 1980, and R & D and manufacturing of solar cells and products started with the mass production of multicrystalline silicon solar cells in 1982. In 1993, it became the first Japanese company to sell home PV generation systems.

Besides solar-cell manufacturing plants in Japan, Kyocera has module manufacturing plants in China (joint venture with the Tianjin Yiqing Group [10 % share] in Tianjin since 2003), Tijuana in Mexico (since 2004) and in Kadaň in the Czech Republic (since 2005).

The company is also marketing systems that both generate electricity through solar cells and exploit heat from the sun for other purposes, such as heating water. The Sakura factory, Chiba Prefecture, is involved in everything from R & D and system planning to construction and servicing, and the Shiga factory in the Shiga Prefecture, is active in R & D as well as the manufacturing of solar cells, modules, equipment parts, and devices which exploit heat. In 2015, solar cell production is estimated at 1 to 1.1 GW.

4.4.17. 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 production capacity was about 1.2 GW at the end of 2015. A solar cell production of 980 MW was estimated for 2015

4.4.18. Hareon Solar Technology Co. Ltd. (China)

Hareon Solar (http://www.hareonsolar.com) was set up as the Jiangyin Hareon Technology Co. Ltd in 2004 and changed its name to the Hareon Solar Technology Co. Ltd. in 2008. It has five manufacturing facilities in both Jiangsu and Anhui province, including Jiangyin Hareon Power Co. Ltd., Altusvia Energy (Taicang) Co. Ltd., Hefei Hareon Solar Technology Co. Ltd., Jiangyin Xinhui Solar Energy Co. Ltd. and Schott Solar Hareon Co. Ltd. Solar-cell production started in 2009, with an initial capacity of 70 MW. According to the company, the current production capacity is 2 GW annually for ingot casting, wafers, cells, and modules. For 2015, a solar cell production of 950 MW was estimated.

4.4.19. Solartech Energy Corp. (Taiwan)

Solartech Energy Corp. (http://en.solartech-energy.com/) was established in Taiwan in 2005. The first solar cells production line was inaugurated in April 2006. In June 2016, the company reached a solar cell production capacity of 1.04 GW. The company has expansion plans to 1.6 GW without a date specified. For 2015, a solar cell production of 950 MW is estimated.

4.4.20. Solar Frontier (Japan)

Solar Frontier (http://www.solar-frontier.com) is a 100 % subsidiary of Showa Shell Sekiyu KK. In 1986, Showa Shell Sekiyu started to import small modules for traffic signals, and began module production in Japan, cooperatively with Siemens (now Solar World). The company developed CIS solar cells and, in October 2006, completed the construction of its first factory with 20 MW capacity in the Miyazaki Prefecture. Commercial production started in the 2007 financial year. The second Miyazaki factory (MP2), with a production capacity of 60 MW, began manufacturing in 2009. In July 2008, the company announced it would open a research centre 'to strengthen research on CIS solar-powered cell technology, and to start collaborative research on mass production technology of the solar modules with Ulvac Inc.' The aim of this project was to start a new plant in 2011 with a capacity of 900 MW. The ramp-up started in February 2011 and at the end of that year overall capacity was 980 MW. In 2011, the company changed its name to Solar Frontier. In early 2013, the company reported that the Kunitomi plant (MP3) was operating at full capacity. Production at MP2 was halted at the end of 2012 to make adjustments for the production of new differentiated products. The plant resumed production in July 2013, and in January 2014 the company announced it would build a new factory with a capacity of 150 MW in Ohiramura, Miyagi prefecture. The new plant started commercial operation in June 2016. A production of about 900 MW is estimated for 2015.

5. Conclusions and outlook

After a worldwide 2-year decrease (2012 and 2013) in new investments in clean energy, the investment volume started to increase again in 2014 and reached a new high of USD 286 billion in 2015 [FSU 2016]. Even more impressive is the fact that almost 54 % of all new power generating capacity connected came from renewable energy excluding large hydro. This record installation of 135 GW of new renewable power capacity was made possible by the significant reductions in renewable energy system prices, especially solar PV. The total of renewable power capacity (excluding large hydro) at the end of 2015 stood at 785 GW (1 849 GW including large hydro) and generated 1 700 TWh of electricity (5 680 TWh including large hydro) worldwide.

For the 6th year in a row, solar power attracted the largest amount of new investments in renewable energies in 2015. It attracted 56 % of all new renewable energy investments or USD 161 billion (EUR 142.5 billion) a 12 % increase compared to 2014 [FSU 2016]. Over 90 % of this investment went into asset financing USD 148 billion (EUR 131 billion) out of which small distributed PV capacity investments accounted for USD 67 billion (EUR 59.3 billion).

In 2015, for the first time, investments in developing economies for renewable energies were larger than the investments in developed ones. Investments in developing economies grew by 18 % to USD 156 billion (EUR 138 billion), whereas the decreased in developed countries by 8 % to USD 130 billion (EUR 115 billion).

In contrast to Europe, where new investments in renewable energy declined by 27 %, new investments increased almost everywhere else [FSU 2016]. According to the current market trends, as well as the IEA's Medium-Term Renewable Energy Market Report 2016, this development will continue if no new policies are introduced in Europe [IEA 2016]. The top country for new renewable energy investment was China with USD 102.9 billion (EUR 91.1 billion), followed by the USA at USD 44.1 billion (EUR 39.0 billion) and Japan with USD 36.2 billion (EUR 32.0 billion).

Europe as a whole saw investments of USD 48.8 billion (EUR 43.2 billion), mainly in the UK (EUR 19.6 billion), and Germany (EUR 7.5 billion). South Africa recorded the biggest change in 2015 with a 329 % increase compared to 2014.

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 2015, only one had solar cell production facilities in Europe, namely Trina due to the takeover of Solland Solar (China, Thailand, The Netherlands). If Europe wants to regain a double digit market share of the solar cell manufacturing industry, a major industry policy effort is needed to revitalise the European PV manufacturing industry. Europe still has an excellent PV R & D infrastructure along the value chain, but it will only be possible to maintain this in the long run if industry players along this value chain, including PV manufacturing, are operating in Europe.

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

In 1990, implementation of the 100 000 roofs programme in Germany, and the Japanese long-term strategy set in 1994, with a 2010 horizon, marked the beginning of extraordinary growth in the PV market. Before the start of the Japanese market implementation programme in 1997, annual growth rates were about 10 % in PV markets, driven mainly by communication, industrial and stand-alone systems. Since 1990, PV production has increased by three orders of magnitudes, from 46 MW to over 60 GW in 2015. This corresponds to a CAGR of a little more than 33 % over the last 25 years. In 2015, statistically documented cumulative installations worldwide accounted for 235 GW.

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

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

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

This view is shared by an increasing number of financial institutions, which are turning to renewables as a sustainable and stable long-term investment. Increasing demand for energy is pushing the prices of fossil energy resources higher. Already in 2007, a number of analysts were predicting that oil prices could hit USD 100/bbl by the end of that year or early in 2008 [IHT 2007]. After the spike in oil prices in July 2008, when they were close to USD 150/bbl, prices fell due to the global financial crisis, reaching a low around USD 37/bbl in December 2008. Since then, the oil price has been on a rollercoaster ride reflecting the economic and political uncertainties with a new low of USD 26.21/bbl in February 2016. Since then the price has rebound to about USD 45 to 50/bbl driven by political uncertainties in the Middle East and a decision by OPEC to curb production.

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 2013] and about 10 times the amount the IEA presents in the World Energy Outlook 2015 as direct subsidies for fossil fuels (USD 493 billion in 2014) [IEA 2015a].

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

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

The 2013 energy subsidies of USD 4.9 trillion, would have been sufficient to install 1 270 GW of PV systems at 2013 PV system prices able to generate 1 500 TWh of electricity or 6.6 % of the global electricity demand. For 2015, the figures are even more breath-taking as system prices have decreased significantly. With the assumption of a 60:40 % split between utility scale and residential PV plants the energy subsidies of USD 5.3 trillion could have been used to install 2 120 GW of utility PV plants and 900 GW of residential PV systems in 2015. Together these PV systems would be able to generate about 3 300 TWh of electricity or about 15 % of global electricity demand. Compared to this, actual PV installations stood at 235 GW at the end of 2015.

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 2016, the average system price for residential systems was about EUR 1.50/Wp (USD 1.70/Wp) in Germany, but between USD 2.90 and 3.60/Wp (EUR 2.57 and 3.18/Wp) in California and Japan [Blo 2016c]. 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. Already on 9 June 2014, there was about 23 GW of solar power on the German grid, covering more than 50 % of the total electricity demand at noon. To handle these high shares of renewable electricity effectively, new technical and regulatory solutions have to be implemented to avoid running into the problem of curtailing large parts of this electricity. Besides conventional pumped storage options, electrical batteries are becoming increasingly interesting, especially for small-scale storage solutions in the low-voltage distribution grid. According to BNEF, prices for battery packs for electric vehicles have declined from about USD 1 000/kWh in 2010 to USD 350/kWh in H2 2015 and could reach USD 200/kWh by 2020 [Blo 2015]. 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 0.07/kWh (EUR 0.063/kWh) and should fall to USD 0.04/kWh (EUR 0.036/kWh) by 2020.

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

With LCOE from PV systems reaching USD 0.05 to 0.15/kWh (EUR 0.044 to 0.133/kWh) in the second quarter of 2016 [Blo 2016d], the additional storage costs already make sense in markets with high peak costs in the evening, where a shift of only a few hours is required. As early as February 2012, BYD (Build your Dreams) and the State Grid Corporation of China (SGCC) finished the construction of a large-scale utility project located in Zhangbei, Hebei Province, which combines 100 MW of wind power, 40 MW of solar PV electricity system, and 36 MWh of lithium-ion energy storage. It is interesting to note that the batteries used in this system are lithium-ion car batteries, which were used before in the BYD 36 taxi for about 4 000 cycles [Che 2014].

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

It is of interest to note that within a year the IEA scenarios in the 2016 WEO have increased the cumulative installed capacity by 17 to 23 % for 2020 and 24 to 36 % by 2030 compared to the figures given in the WEO 2015. With forecasts for new PV system installations between 223 and 241 GW from 2016 to 2018, even the high value scenarios are not unlikely to be reached [Blo 2016c].

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.

Table 6: Evolution of the cumulative solar electrical capacities until 2050 [Blo 2016b, Gre 2015, IEA 2014, 2015a, 2016d]

Year	2015 [GW]	2020 [GW]	2025 [GW]	2030 [GW]	2040 [GW]
Actual installations	**235**				
Greenpeace (reference scenario)		332	413	494	635
Greenpeace ([r]evolution scenario)		732	1 603	2 839	4 988
BNEF New Energy Outlook 2016	251	578	1 046	1 831	3 917
IEA PV Technology Roadmap (1) (hi-Ren Scenario)		450	790	1 721	4 130
IEA 2015 Current Policy Scenario		361	420	569	773
IEA 2015 New Policy Scenario		397	560	728	1 066
IEA 2015 450 ppm Scenario		420	605	938	1 519
IEA 2016 Current Policy Scenario		424	592	708	991
IEA 2016 New Policy Scenario		481	715	949	1 405
IEA 2016 450 ppm Scenario		517	833	1 278	2 108

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

The IEA's 2014 Energy Technology Perspectives (ETP) state that the total investment costs between 2011 and 2050 for achieving a low-carbon energy sector (2 °C scenario, 2DS) would be an additional UDS_{2012} 44 trillion (EUR 33.8 trillion) compared to the business-as-usual scenario (6DS) with investment needs of UDS_{2012} 118.4 trillion (EUR 91.1 trillion) [IEA 2014a].

However, the estimated fuel savings in the low-carbon scenario are between USD_{2012} 115 trillion (EUR 88.5 trillion) and USD_{2012} 162 trillion (EUR 125 trillion) or 2.9 to 4.1 times the additional investment needed. This clearly indicates the huge societal benefit of a more aggressive climate change approach.

The power sector would require USD_{2012} 39.6 trillion (EUR 30.5 trillion) for the 2DS and USD_{2012} 30.5 trillion (EUR 23.5 trillion) for the 6DS scenario. The additional investments for the 2DS scenario compared to the business as usual would be USD 200 million (EUR 154 million) per year, which is less than the current investment in the renewable energy sector.

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. As mentioned above, the ETP 2014 shows that fuel savings are on average more than three times higher than the additional investment in a low-carbon power supply.

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.

6. 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 China, India, Japan, 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.

7. References

[Acw 2015] ACWA Power, Press Release, 15 July 2015, ACWA Power led consortium achieves financial close for the landmark Shuaa Energy 1-260 MWp Solar PV IPP transaction (Phase II of Dubai Electricity and Water Authority's Mohammed bin Rashid Solar Park in Dubai).

[ADB 2014] Asia Development Bank, Scoping off-grid renewable energy opportunities in Myanmar, March 2014.

[Art 2013] Art Solar, Press Release, 23 May 2013, http://artsolar.net/content/dr-wosley-barnard-officially-opens-artsolars-productionline-thursday-23-may-2013

[Ase 2016] Autoridad Nacional de los Servicios Públicos (ASEP), Press Release, 15 April 2016, ASEP considera ampliar capacidad de instalación de energía solar en hogares y comercios del país.

[Ase 2016a] Autoridad Nacional de los Servicios Públicos (ASEP), datos relevantes del mercado eléctrico panameño mayo de 2016.

[Ban 2015] Banja, M., Monforti-Ferrario, F., Scarlat, N., Dallemand, J.-F., Ossenbrink, H., Motola, V., *Snapshot of renewable energy development in the EU-28*, Vol. 2, Publications Office of the European Union, 2015, ISBN 978-92-79-47234-3.

[Bau 2012] Baumgartner, F., presentation at University Erlangen i-MEE, Germany, 11 May 2012, www.ahaw.ch/~bauf/

[Bau 2016] Baumgartner, F., presentation EUPVSEC 32, Munich, Germany, 22 June 2016, www.ahaw.ch/~bauf/

[BBC 2014] BBC, Rockefellers to switch investments to 'clean energy', 23 September 2014, http://www.bbc.com/news/world-us-canada-29310475

[Bis 2014] BISOL, Press Release, 29 January 2014.

[Blo 2013] BNEF, Scaling up financing to expand the renewables portfolio, Presentation given by Michael Liebreich (CEO) at the IEA Renewable Energy Working Party, Paris 9 April 2013.

[Blo 2015] BNEF, 1 December 2015, H2 2015 Electric Vehicle Battery Price Survey.

[Blo 2016] BNEF, February 2016 PV spot price and shipment index, 29 February 2016.

[Blo 2016a] BNEF, Analyst reaction, Suntech is up for sale again, 8 June 2016.

[Blo 2016b] BNEF, New energy outlook, solar, June 2016.

[Blo 2016c] BNEF, Q3 2016 Global PV market outlook, 1 September 2016.

[Blo 2016d] BNEF, H1 2016 PV LCOE outlook, 12 April 2016.

[BNA 2016] Bundesnetzagentur, Öffentliche Bekanntgabe der Zuschläge des Verfahrens nach § 12 Absätze 1 und 2 FFAV für den Gebotstermin 1. August 2016, 29 August 2016.

[Bol 2008] Real Decreto 1578/2008, de 26 de septiembre, Boletín Oficial del Estado: sábado 27 de septiembre de 2008, Núm. 234, http://www.boe.es/boe/dias/2008/09/27/pdfs/A39117-39125.pdf

[Bol 2012] Real Decreto-ley 1/2012, de 27 de enero, Boletín Oficial del Estado: sábado 28 de enero de 2012, Núm. 24, http://www.boe.es/boe/dias/2012/01/28/pdfs/BOE-A-2012-1310.pdf

[Bol 2013] Ley 24/2013, de 26 de diciembre, Boletín Oficial del Estado: viernes 27 de diciembre de 2013, Núm. 310, http://www.boe.es/boe/dias/2013/12/27/pdfs/BOE-A-2013-13645.pdf

[Bol 2013a] Real Decreto-ley 9/2013, de 12 de julio, Boletín Oficial del Estado: sábado 13 de julio de 2013, Núm. 167, http://www.boe.es/boe/dias/2013/07/13/pdfs/BOE-A-2013-7705.pdf

[Bol 2014] Real Decreto 413/2014, de 6 de junio, Boletín Oficial del Estado: martes 10 de junio de 2014, Núm. 140, http://www.boe.es/boe/dias/2014/06/10/pdfs/BOE-A-2014-6123.pdf

[Bol 2014a] Ministerio de Industria, Energía y Turismo, IET/1045/2014, Boletín Oficial del Estado: viernes 20 de junio de 2014, Núm. 150, http://www.boe.es/boe/dias/2014/06/20/pdfs/BOE-A-2014-6495.pdf

[Bru 2015] Commission de régulation de l'énergie en région de Bruxelles-capitale, proposition, (Brugel-Proposition 20151030-16), Relative au coefficient multiplicateur appliqué au photovoltaïque — Analyse des paramètres économiques, 30 octobre 2015.

[Bun 2016] German Federal Network Agency (Bundesnetzagentur), Installierte EE-Leistung 2015 (vorläufig — Stand 27.07.2016).

[Bxc 2016] BXC Ghana Limited (BXC), http://bxcghana.com/

[Cai 2015] Caixin, 1 September 2015, 5年再造个国家电网，2万亿配网投资你真看懂了吗？ ,http://www.wusuobuneng.com/archives/23118

[Cbs 2016] Centraal Bureau voor de Statistiek, Hernieuwbare elektriciteit; productie en vermogen, 30 June 2016, http://statline.cbs.nl

[Che 2014] Robert Chen, BYD Motors, PRC, private communication.

[CNC 2016] Centro Nacional de Control de Energía, Comunicado conclusión 1ª Subasta Eléctrica de Largo Plazo, 30 March 2016.

[CNC 2016a] Centro Nacional de Control de Energía, Inversión de 4 mil millones de dólares al concluir el proceso de la Segunda Subasta Eléctrica, 28 September 2016.

[CNM 2016] Comisión Nacional de los Mercados y la Competencia, Notas de Prensa, 7 de marzo de 2016, La deuda del sistema eléctrico se ha reducido en 1.890 millones en 2015.

[CWa 2016] Commission wallonne pour l'énergie, communication, CD-16c23-CWaPE-0002 sur le 'montant des primes Qualiwatt pour les installations photovoltaïques d'une puissance inférieure ou égale à 10 kW mises en service entre le 1er juillet et le 31 décembre 2016', 23 March 2016.

[EC 2007] European Commission, C 3/2007 — Tarifs réglementés de l'électricité en Espagne, Official Journal of the European Communities, C 43/50, 27 February 2007.

[Ecr 2016] ECREE, ECOWAS observatory for renewable energy and energy efficiency, Project: Oyandze.

[EEG 2000] Gesetz über den Vorrang erneuerbaren Energien (Erneuerbare-Energien-Gesetz — EEG), Bundesgesetzblatt Jahrgang 2000, Teil I, No 13, p. 305, 29 March 2000.

[EEG 2014] Gesetz für den Ausbau erneuerbarer Energien (Erneuerbare-Energien-Gesetz — EEG 2014) Bundesgesetzblatt Jahrgang 2014, Teil I, No 33, 24 July 2014, p. 1066.

[EMA 2016] Government of Singapore, Energy Market Authority, Installed capacity of grid-connected solar photovoltaic (PV) systems, 11 August 2016.

[Ena 2016] Ethiopian News Agency, 28 August 2016, EEP to transfer solar energy projects to private developers.

[Ene 2016] Energie Zukunft Schweiz, Juni 2016, PV-Preisumfrage 2015.

[Est 2016] EUROSTAT, Electricity price statistics, May 2016 http://ec.europa.eu/eurostat/statistics-explained/images/f/f2/Half-yearly_electricity_prices_%28EUR%29_V2.png

[Ete 2015] ETESA, Resolución No GC-01-2015, 28 January 2015.

[Eth 2015] *The Ethiopian Herald*, 24 September 2015, Ethiopia: solar panel factory due to begin production.

[Ewe 2016] European Wind Association, Wind in power — 2015 European statistics, February 2016.

[Ewg 2010] Energy Watch Group, March 2010, Abschätzung der jährlichen weltweiten Ausgaben für Energieversorgung, http://www.energywatchgroup.org

[FiT 2010] *Financial Times*, IEA counts $ 550 billion energy support bill, 6 June 2010.

[Fir 2016] First Solar, Press Release, 10 March 2016, First Solar reaches 5 GW of O&M assets.

[FSU 2016] Frankfurt School — UNEP Centre/BNEF 2016, Global trends in renewable energy investment 2016, http://www.fs-unep-centre.org

[Gcl 2016] GCL-Poly energy holdings limited, discloseable transaction, 28 August 2016, http://gcl-poly.todayir.com/attachment/2016082818170200002600333_en.pdf

[Gin 2015] Gintech Energy, Press Release, 20 July 2015, Gintech Energy and Tongwei Group reach a strategic partnership and private placement agreement.

[GoA 2006] Ley 26.190 — Ley de Energía Eléctrica (2006), Boletín Oficial de la República de Argentina, Núm. 31.064, http://www.diputados-catamarca.gov.ar/ley/BO020107.PDF

[GoC 2015] Government of Chile, Ministry of Energy, Energy 2050 — Chile's energy policy, http://www.energia2050.cl/uploads/libros/energy2050.pdf

[GoD 2007] Ley No 57-07 sobre Incentivo al Desarrollo de Fuentes Renovables de Energía y de sus Regímenes Especiales (Dominican Republic).

[GoD 2012] Klima-, Energi- og Bygningsministeriet, Bekendtgørelse om nettoafregning for egenproducenter af elektricitet, Lovtidende A, BEK nr 1068 af 16/11/2012, https://www.lovtidende.dk/Forms/L0700.aspx?s31=10&s19=1068+&s20=2012

[GoH 2014] Decreta No 404-2013: Ley general de la industria eléctrica, La Gazeta, Martes 20 de mayo del 2014, Num. 33 431.

[GoI 2015] Gazette of India, Extraordinary, Part I, Section 1, No 222, 25 August 2015, MNRE (NSM Coord. Group), Resolution, Scaling up of grid connected solar power projects from 20 000 MW by the year 2021-2022, to 100 000 MW by the year 2021-2022 under national solar mission.

[GoI 2016] Government of India, Press Information Bureau, Press Release, 4 August 2016, More than 44 235 MW accumulative capacity of renewable energy installed in the country.

[GoJ 2012] Government of Jordan, Law No 13 of 2012, Renewable Energy and Energy Efficiency Law, 16 April 2012, http://www.memr.gov.jo/EchoBusV3.0/SystemAssets/PDFs/EN/Laws/CleanVersionFinalRenewableEnergyEnergyEfficiencyLaw.pdf

[GoK 2010] Ministry of Energy, Kenya, Feed-in-tariffs policy for wind, biomass, small hydros, geothermal, biogas and solar, 1st revision, January 2010, http://www.erc.go.ke/erc/fitpolicy.pdf

[GoK 2013] Government of Kazakhstan, Press Release, 5 February 2013.

[GoM 2008] Decreto por el que se expide la Ley para el Aprovechamiento de Energías Renovables y el Financiamiento de la Transición Energética, *Diario Oficial* (Primera Sección) 88 (Mexico), 28 November 2008, http://www.diputados.gob.mx/LeyesBiblio/ref/laerfte/LAERFTE_orig_28nov08.pdf

[GoM 2012] Se Expide la Ley General de Cambio Climático, *Diario Oficial* (Segunda Sección) 1 (Mexico), 6 June 2012, http://www.diputados.gob.mx/LeyesBiblio/ref/lgcc/LGCC_orig_06jun12.pdf

[Goo 2011] Goodrich, A., James, T. and Woodhouse, M., Solar PV manufacturing cost analysis: U.S. competitiveness in a global industry, 2011, NREL/PR-6A20-53938.

[GoP 2006] Government of Pakistan, Policy for development of renewable energy for power generation, December 2006.

[GoP 2016] Government of Panama, Press Release, 29 March 2016, Government approves NEP, 2015-2050, to guarantee energy security.

[GoS 2008] Act No 34 of 2008: National Energy Act, *Government Gazette*, Republic of South Africa, Vol. 521, No 31638, 24 November 2008, http://www.info.gov.za/view/DownloadFileAction?id=92826

[GoS 2012] Government of Singapore, Energy Conservation Act 2012, *Government Gazette*, Acts Supplement, 2012, No 12, Friday 1 June 2012.

[GoS 2014] Schweizer Eidgenossenschaft, 2014. Revision der Energieverordnung per 1. April 2014, https://www.news.admin.ch/message/index.html?lang=de&msg-id=52243

[Gre 2015] Greenpeace International, Global wind energy Council, solarPowereurope, Energy [r]evolution, 5th edition 2015 world energy scenario, September 2015.

[GUK 2016] https://www.gov.uk/feed-in-tariffs/overview

[Gse 2016] Gestore dei Servizi Energetici, Pubblicato il rapporto statistico 2015 sul solare fotovoltaico, 10 August 2016.

[Gtm 2016] gtm research, April 2016, Q2 Global Solar demand monitor.

[Gtm 2016a] gtm research and Solar Industry Association, U.S. solar market insight, Executive summary, 2015 Year in Review, March 2016.

[Gtm 2016b] gtm research and Solar Industry Association, U.S. solar market insight, Executive summary, Q3 2016.

[Hed 2016] Issuance of power generation informative report for the non-interconnected islands, May 2016 http://www.deddie.gr

[Hil 2016] Hill, J., Clean Technica, 7 July 2016, *China installed 18.6 GW of solar PV in 2015, but was all of it connected?*

[Hir 2013] Hirth, L., 'The market value of variable renewables', *Energy Economics*, Vol. 38, 2013, pp. 218-236.

[Hro 2016] HROTE, Data on RES and HE-CHP feed-in support system, June 2016, http://files.hrote.hr/files/PDFen/OIEIK/Monthly_Report_06_2016.pdf

[Hts 2016] HTSO SA, RES & CHP monthly statistics, May 2016, http://www.lagie.gr/fileadmin/groups/EDRETH/RES/2016_05_RES.pdf

[Hul 2014] Huld, T., Jäger Waldau, A., Ossenbrink, H., Szabo, S., Dunlop, E. and Taylor, N., Cost maps for unsubsidised photovoltaic electricity, JRC 91937.

[Hul 2014a] Huld, T., Ruf, H., Heilscher, G., Self-consumption of electricty by households, Effects of PV system size and battery storage, Proceedings of the 29th EUPVSC, Amsterdam, 2014.

[Hwa 2016] Hwang, A., Digitimes, 31 August 2016, MOEA sets tentative 2017 feed-in tariffs for renewable energy.

[IEA 2014] IEA, PVPS, Trends 2014 in photovoltaic applications, Report IEA-PVPS T1-25:2014.

[IEA 2014a] IEA, Energy Technology Perspectives, 2014, 376 p., ISBN: 978-92-64-20800-1

[IEA 2014b] IEA, Technology Roadmap – Solar Photovoltaic Energy, 2014 edition, 55 pages

[IEA 2015] IEA, PVPS, 2014 snapshots of global PV markets, Report IEA PVPS T1-29:2016, ISBN 978-3-906042-32-9

[IEA 2015a] IEA, November 2015, World Energy Outlook 2015, ISBN 978-92-64-243668

[IEA 2016] International Energy Agency, Medium-Term Renewable Energy Market Report 2016 - Market Trends and Projections to 2021, 278 pages, ISBN 978-92-64-26497-7

[IEA 2016a] IEA PVPS, 2015 Snapshots of global PV markets, Report IEA PVPS T1-29:2016, ISBN 978-3-906042-42-8.

[IEA 2016b] IEA PVPS, National survey report of PV power applications in China 2015.

[IEA 2016c] IEA PVPS, 2016, Trends in photovoltaic applications — survey report of selected IEA countries between 1992 and 2015.

[IEA 2016d] IEA, November 2016, World Energy Outlook 2015, ISBN 978-92-64-26495-3

[IHT 2007] *International Herald Tribune*, 24 July 2007.

[Ikk 2016] Osamu I., *PV Activities in Japan*, Vol. 22, 2016.

[IMF 2013] International Monetary Fund, *Energy subsidy reform: lessons and implications*, 28 January 2013.

[IMF 2015] International Monetary Fund, Coady, D., Parry, I., Sears, L. and Shang, B., 'How large are global energy subsidies?', *IMF Working Paper*, WP/15/105, May 2015.

[Ire 2015] IRENA, 'Renewable energy prospects: United Arab Emirates', *REmap 2030 analysis,* March 2015.

[Ire 2016] IRENA, 'Renewable energy and jobs', *Annual Review*, 2016.

[Ire 2016a] IRENA, IRENA Quarterly, Q3 2016, Letting in the Light.

[Ire 2016b] IRENA, Renewable capacity statistics, 2016.

[Ire 2016c] IRENA/ADFE, 17 January 2016, http://adfd.irena.org/contentimages/Cape %20Verde %20summary.pdf

[Jäg 2013] Jäger-Waldau, A., PV status report 2013, Publications Office of the European Union, 2013, ISBN 978-92-79-32718-6 (pdf)

[Jäg 2014] Jäger-Waldau, A., 'European photovoltaic market contracts in a rapid expanding global market', *European energy innovation*, Autumn 2014, pp. 52- 56.

[Jäg 2014a] Jäger-Waldau, A., PV status report 2014, Publications Office of the European Union, 2014, ISBN 978-92-79-44621-4 (pdf)

[Jas 2014] JA Solar, Press Release, 22 January 2014 http://investors.jasolar.com/phoenix.zhtml?c=208005&p=irol-newsArticle&ID=1892516&highlight=

[Jet 2016] Jet Contractors, Press Release, 23 May 2016, Partenariat tripartite Jet Contractors — Haeron Solar — SIE.

[Jin 2014] Jinko Solar, Press Release, 11 August 2014 http://www.jinkosolar.com/press_detail_969.html

[JvG 2014] JvG Thoma, Press Release, 18 February 2014, http://www.jvg-thoma.de/en/start/news/!/page/2/

[Kaz 2011] Kaz Silicon, Project file, http://www.kazsilicon.kz/en/node/16

[Kaz 2014] Kazatomprom, News: Astana Solar will discuss the construction of solar power stations, 12 September 2014, http://kazatomprom.kz/en/#!/article/3091

[KfW 2013] Kreditanstalt für Wiederaufbau, KfW-Programm Erneuerbare Energien 'Speicher', Programmnummer 275 (Version 1)

[KfW 2016] Kreditanstalt für Wiederaufbau, KfW-Programm Erneuerbare Energien 'Speicher', Programmnummer 275 (Version 2) https://www.kfw.de/inlandsfoerderung/Unternehmen/Energie-Umwelt/F%C3%B6rderprodukte/Erneuerbare-Energien-%E2%80%93-Speicher-%28275%29/#2

[MEE 2016] *Ministre de l'Environnement, de l'Énergie et de la Mer,* Les objectifs pour le développement des énergies renouvelables, 25 April 2016, http://www.developpement-durable.gouv.fr/IMG/pdf/2016-04-25_Obj-_Dvp-_Energies_Renouvelables.pdf

[MEM 2012] Ministry of Energy and Minerals Tanzania, Strategic plan 2011/12-2015/16, November 2012.

[MEM 2013] Ministry of Energy and Minerals Tanzania, Scaling-up renewable energy programme, April 2013, http://www.mem.go.tz/Portals/0/EasyDNNNewsDocuments/1033/0039_08052013-SREP_Tanzania %20IP_Final_Draft.pdf

[MEM 2016] Ministry of Energy and Mineral Resources, Indonesia, Regulation No 19 of 2016 on Purchase of power by PLN from solar photovoltaic.

[Mer 2016] Mercom Capital Group, Solar market update, April 2016.

[Mer 2016a] Mercom Capital Group, Market intelligence report solar, 20 June 2016.

[Mes 2016] Middle East Solar Industry Association, Middle East solar outlook for 2016.

[METI 2013] Japanese Ministry of Trade and Industry, Agency for Natural Resources and Energy; Announcement regarding the present status of introduction of facilities generating renewable energy as of 31 May 2013, http://www.meti.go.jp/english/press/2013/0820_01.html

[METI 2014] Japanese Ministry of Trade and Industry, 4th Strategic energy plan, April 2014.

[METI 2016] Japanese Ministry of Trade and Industry, Agency for Natural Resources and Energy; Settlement of FY2016 purchase prices and FY2016 surcharge rates under the feed-in tariff scheme for renewable energy, March 2016.

[METI 2016a] Japanese METI, General Energy and Natural Resources Investigation Committee and Renewable Energy Support System Reform Committee, 1 April 2016 meeting material: http://www.meti.go.jp/committee/sougouenergy/kihonseisaku/saisei_kanou/008_haifu.html.

[MII 2012] Ministry of Industry and Information Technology, 太阳能光伏产业"十二五"发展规划 (issuance of the solar photovoltaic industry, 'second five' development plan), 24 February 2012, http://www.miit.gov.cn/n11293472/n11293832/n12771663/14473764.html

[MME 2015] Ministério de Minas e Energia, Secretaria de Planejamento e Desenvolvimento Energético, Plano decenal de expansão de energia 2024, Dezembro 2015.

[MoE 2015] Ministry of Energy Thailand, Alternative energy development plan: AEDP 2015.

[Moo 2016] Moody's, 14 March 2016, Spanish electricity system heads toward sustainability, as electricity tariff deficit debt falls.

[Mos 2015] Moshövel, J., Kairies, K.-P., Magnor, D., Leuthold, M., Bost, M., Gährs, S., Szczechowicz, E., Cramer, M. and Sauer, D. U., 'Analysis of the maximal possible grid relief from PV-peak-power impacts by using storage systems for increased self-consumption', *Applied Energy*, Vol. 137, 1 January 2015, pp. 567-575

[Mot 2014] Motech, Press Release, 26 December 2014, Motech and Topcell announced the signing of merger agreement.

[Mot 2015] Motech, Press Release, 25 September 2015, Motech (Suzhou) Renewable Energy Co., Ltd and Jiansu Aide Solar Energy Technology Co., Ltd reach a strategic cooperation and capital increase agreement.

[Mub 2016] Mubadala, Press Release, 27 June 2016, DEWA announces the selected bidder for the 800 MW third phase of the Mohammed bin Rashid Al Maktoum Solar Park.

[Nat 2016] The National, Marubeni-Jinko submit world-record low bid for 350 MW Sweihan solar project in Abu Dhabi, 20 September 2016.

[Nat 2016a] The National, UAE eyes new clean energy generation target by 2030, 20 January 2016.

[NER 2016] Nigerian Energy Regulatory Commission, Press Briefing on Reversal of Existing Electricity Tariff Regime, 14 July 2016.

[Oci 2016] OCI, Press Release, 28 September 2016, OCI will acquire new shares of Tokuyama's Malaysian subsidiary for polysilicon production.

[Ofg 2015] Ofgem, Guidance, 13 April 2015, Renewables Obligation: closure of the scheme to large-scale solar PV.

[One 2015] Office National de l'Electricité et de l'Eau Potable (ONEE), Branche Electricité, 18 February 2015, Programme solaire photovoltaïque de 400 MWc de l'Office national de l'électricité et de l'eau potable — Branche Electricité.

[Osi 2016] Osinergmin, Press Release, 16 February 2016, Otorgan buena pro a 13 proyectos de energía renovable.

[Pho 2012] Photon International, March 2012.

[PMV 2016] Prime Minister of Viet Nam, Decision No 428/QĐ-TTG dated 18 March 2016, The approval of revisions to the national power development plan from 2011 to 2020 with visions extended to 2030.

[Pow 2014] Powerway, Press Release, 13 March 2014 http://www.pvpowerway.com/news/1075.html

[Pow 2015] Powell, D. M., Fu, R., Horowitz, K., Basore, P. A., Woodhouse, M. and Buonassisi, T., 'The capital intensity of photovoltaics manufacturing: barrier to scale and opportunity for innovation', *Energy and Environmental Science,* Vol. 8, 2015, p. 3395.

[Pvi 2016] *PVinsights*, September 2016, http://pvinsights.com/SolarSystem/SolarSystemPrice.php

[Pvn 2015] *PV News*, published by The Prometheus Institute, ISSN 0739-4829 (until 2015).

[Pvt 2014] pv-tech, 24 February 2014 http://www.pv-tech.org/news/nigerias_first_module_plant_operational

[Rea 2016] REA, 31 March 2016, Construction of a 55 MW solar power plant in Garissa, http://www.rea.co.ke/index.php?option=com_content&view=category&layout=blog&id=89&Itemid=511

[RoG 2011] Parliament of Ghana, Renewable energy bill, http://www.parliament.gh/assets/file/Bills/Renewable %20Energy %20Bill %202011.pdf

[RoI 2014] Regulation of the Government of the Republic of Indonesia, No 79/2014 concerning The National Energy Policy.

[RoK 2009] Law of the Republic of Kazakhstan, from 4 July 2009 of No 165-IV ZRK, about support of usage of renewable energy sources, http://cis-legislation.com/document.fwx?rgn=28433

[RoP 2016] Republic of the Philippines, DoE, Awarded solar projects as of June 30, 2016.

[Ros 2016] Roselund, C., *pv magazine* 04/2016, 2015 Poly and wafer rankings.

[Rte 2016] RTE Réseau de transport d'électricité, 2016, Annual Electricity Report 2015 edition, http://www.rte-france.com/sites/default/files/2015_annual_electricity_report.pdf

[RVO 2016] Rijksdienst voor Ondernemend Nederland, Stimulering duurzame energieproductie (SDE+), (http://www.rvo.nl/)

[Sea 2014] Sustainable Energy Association of Singapore, A case for sustainability: Accelerating the case for renewable energy in Singapore, 20 January 2014.

[Sed 2016] Sustainable Energy Development Authority, SEDA Portal accessed on 2 September 2016.

[Sin 2014] Singulus, Press Release, 3 February 2014 http://www.singulus.com/en/press-news/press-releases/press-release/article/a-long-standing-cooperation-partner-of-singulus-technologies-ptip-officially-launces-its-cigs-phot/7.html

[Sma 2014] SMA Solar Technology AG, Press Release, 5 August 2014, http://www.sma.de/en/newsroom/current-news/news-details/news/5288-suedafrika-lokale-produktion-von-sma-zentral-wechselrichtern-gestartet-und-zweites-megawatt-ph.html

[Sol 2013] Solarbuzz, Marketbuzz 2013, Press Release, 11 March 2013.

[Sol 2016] Solar Power Europe, Global market outlook for solar power 2016-2020, June 2016.

[Sol 2016a] Solar Power Europe, Solar market report, 2016 Edition.

[Sol 2016b] Solar Choice, PV price index http://www.solarchoice.net.au

[Ste 2013] Société Tunisienne de l'Electricité et du Gaz, Prosol Elec, 2013.

[Sys 2016] *Systèmes Solaires, le journal du photovoltaique*, Photovoltaic energy barometer, ISSN 0295-5873.

[Tai 2016] *Taiyang News*, 18 July 2016, PV additions Chile June 2016, South America's largest PV market reaches 1 267 MW total solar power by end of H1/2016 http://taiyangnews.info/markets/pv-additions-chile-june-2016/

[Tal 2015] Talesun Energy, Press Release, 2 December 2015, Talesun begins production in Thailand.

[Tep 2016] Tokyo Electric Power Company (TEPCO), Customer communication, rate calculation, http://www.tepco.co.jp/en/customer/guide/ratecalc-e.html

[Ter 2016] TERNA, Rapporto mensile sul sistema elettrico, Consuntivo Giulio 2016.

[Tri 2016] Trina Solar, Press Release, 23 February 2016, Trina Solar acquires a solar cell factory in the Netherlands.

[Uec 2013] Ueckerdt, F., Hirth, L., Luderer, G. and Edenhofer, O., *System LCOE: What are the costs of variable renewables?* Social Science Research Network, SSRN-id2200572, 14 January 2013, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2200572

[UNEP 2008] Reforming energy subsidies — opportunities to contribute to the climate change agenda United Nations, United Nations Environment Programme, 2008.

[UNFC 2016] United Nations Framework Convention on Climate Change, 5 October 2016, Paris Agreement — status of ratification, http://unfccc.int/paris_agreement/items/9444.php

[Ven 2013] Ventures Africa, Ethiopia Awards 300 MW solar contract to US firms, 25 November 2013, http://www.ventures-africa.com/2013/11/ethiopia-awards-300mw-solar-contract-to-us-firms/

[Wac 2016] Wacker AG, Press release, 18 April 2016, Wacker officially opens new production site in the USA.

[Wan 2016] Wang, L., *Economic Information Daily*, 29 January 2016, '十三五"可再生能源五年新投2.3万亿

[Wes 2015] Wesoff, E., Greentech Media, 1 December 2015, The mercifully short list of fallen solar companies — 2015 edition http://www.greentechmedia.com/articles/read/The-Mercifully-Short-List-of-Fallen-Solar-Companies-2015-Edition

European Commission

EUR 28159 EN – Joint Research Centre – Directorate C: Energy Transport and Climate

Title: PV Status Report 2016

Author(s): Arnulf Jäger-Waldau

Luxembourg: Office for Official Publications of the European Communities

2016 – 84 pp. – 21 x 29.7 cm

EUR – Scientific analysis or review

ISSN 1018-5593 (print)
ISSN 1831-9424 (online)

ISBN 978-92-79-63054-5 (print)
ISBN 978-92-79-63055-2 (PDF)

Abstract

PV 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.

The unique format of the PV Status Report combines up-to-date international information on PV. These data are collected on a regular basis from public and commercial studies and cross-checked with personal communications. Regular fact-finding missions involving company visits, as well as meetings with officials from funding organisations and policymakers, complete the picture.

Growth in the solar PV sector has been robust. The CAGR over the last 15 years was over 40 %, thus making PV 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.

LD-NA-28159-EN-N

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

doi:10.2790/682995

ISBN 978-92-79-63055-2