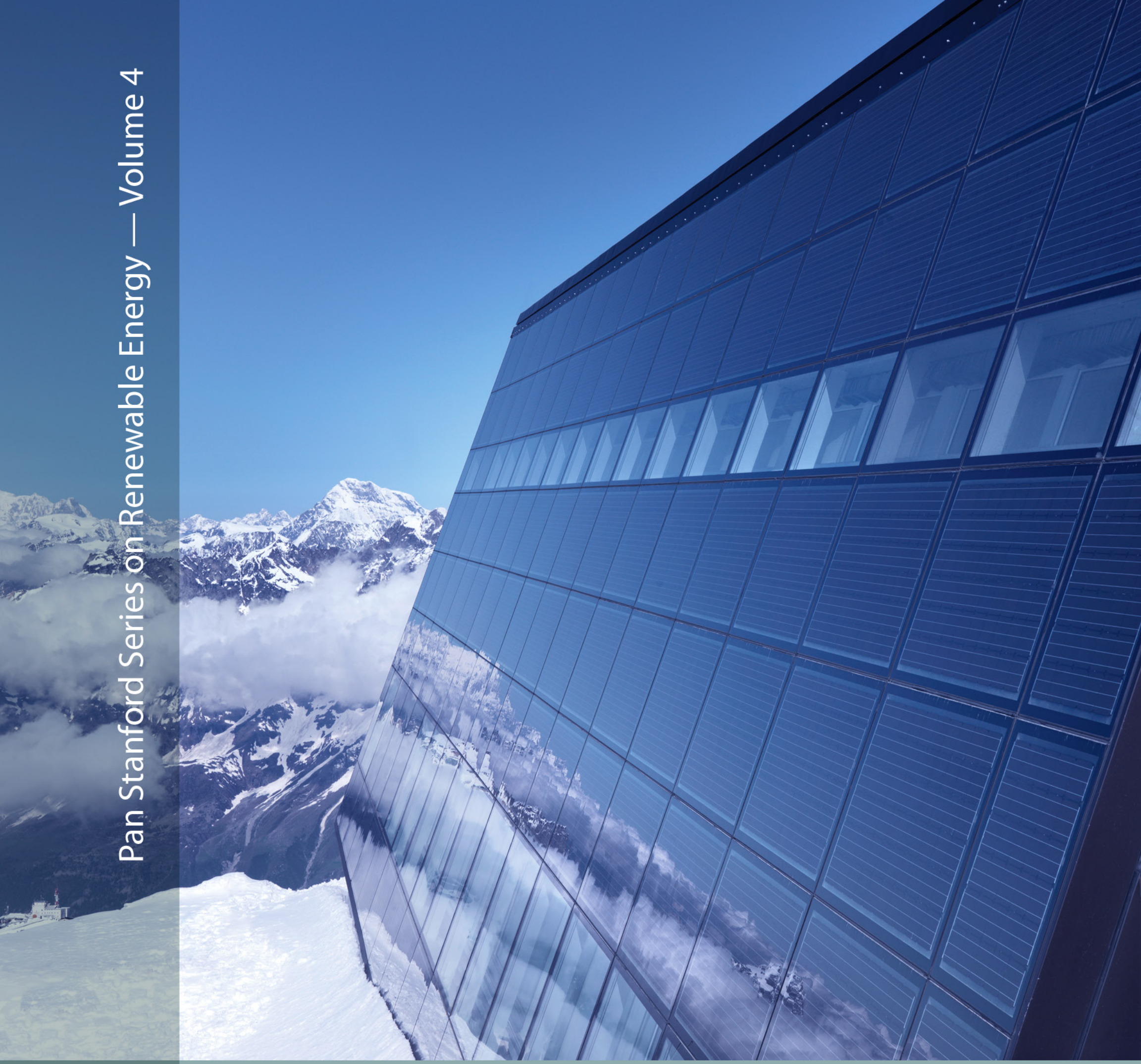
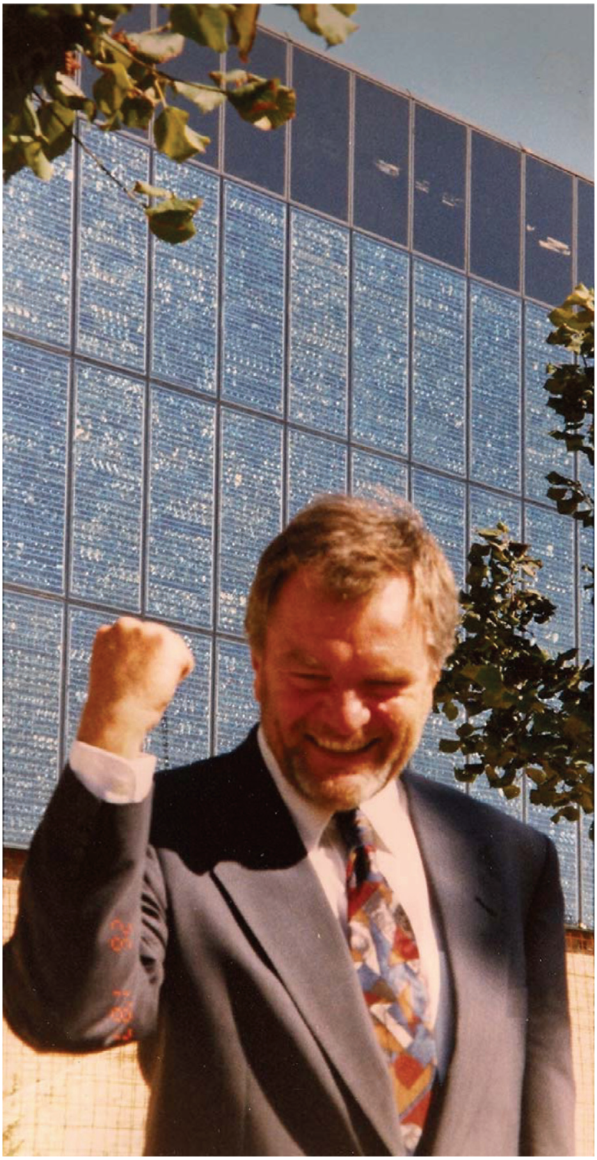


Pan Stanford Series on Renewable Energy — Volume 4

editor
Wolfgang Palz

What You Wanted to Know about Photovoltaics

SOLAR POWER for the World



Wolfgang Palz in front of the PV façade of the public library of Mataró, Spain, in 1992. It was one of the first semitransparent solar façades in Europe, co-financed by an EU programme.

SOLAR POWER
for the World

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SOLAR POWER for the World

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Hymn to the Sun

Your rays feed the fields
You shine and they live
They are abundant for you
You have created the seasons
So that all you have created can be alive
The winter for cooling,
The heat

How numerous are your actions
Mysterious in our eyes!
Only God, you who has no likeness
You have created the Earth as per your heart
When you were alone,
Man, all animals, domestic and wild,
Everything on Earth marching on feet
Everything in the sky flying with wings
The foreign countries, Syria and Nubia
And the land of Egypt

Akhenaton Pharaoh of Egypt 1378–1362 before our time

Nofretete, Echnaton and family, 14th century BC, Neues Museum, Berlin.

Introduction to *Solar Power for the World*

Purpose of This Introduction

The original contributions to the PV book *Power for the World: The Emergence of Electricity from the Sun* were written during 2009 and the beginning of 2010: The book was then available in September 2010.

Four years have elapsed since then, and this period was exactly the time when the global PV took off for a revolutionary market explosion. Obviously, it is now time to summarise the events in this new Introduction. The content of the original book has not been modified in the second edition; just the contributions have been arranged in a more rational order. The original purpose of the book was historical in nature, and the history of PV and its emergence by the commitments of international pioneers was in no way affected by these recent events.

By the end of 2012, the world had installed in total 100 GW, or 100,000 MW or 100 million kW of PV, for electric power generation (all figures in "peak power").

Three quarters of it, or some 75 GW, were installed in the last 3 years, while it took 55 years since the first production of a solar cell at Bell Labs to install just 25 GW, one fourth of what we got today.

By the end of 2012, no less than 80% of the world's global PV capacity was installed in Europe. The driving force for all that had happened since 2004 was Germany, thanks to a courageous decision by its authorities. Today, in early 2013, 32.4 GW, almost a third of global installations, is based in the German territory.

Germany installed 7,634 GW of new PV in 2012, which is a new world record. It was decisive for the global trends when Germany more than doubled in one step from 2009 to 2010 its PV installation up to some 7.5 GW a year. People thought at that time that such high market volumes were unsustainable. Well, in 2011 and 2012, the German people installed again 7.5 GW per year—against the previsions of most experts and even against the wishes of their government. But German people decided otherwise.

By now, Germany alone has invested more than €100 billion ($130 billion) in its PV power production plants, leave alone the heavy investments in its PV manufacturing industry.

I have been active in PV development without interruption for 52 years since my university days in 1961, and I am more than satisfied to see all this happen. Today global PV is like a high-speed train that reached its full speed. Business is tremendous and more and more countries are opening their eyes; now they are getting anxious to jump on and reap the unbelievable benefits. Innovation and clean energy for a better world have nowadays strong supporters everywhere.

People like PV! They like it not only because they can make money this way but also because it gives them a chance to escape the ever-increasing kWh tariffs imposed on them by their traditional electricity providers. The elites in business and art take note as well: In 2012 Warren Buffett, one of America's richest men, started to invest in PV, and so did a member of the Quandt family in Germany, the majority owners of the prestigious BMW car company. In Paris, Karl Lagerfeld, the top fashion designer, presented his models at the "Grand Palais", its ground all covered by wonderful blue PV modules.

In the next few pages, I will shed more light on what solar PV means today for the world.

Importance of PV Today: A Revolution in Society

Since the beginning of the 21st century, we have been more than ever confronted with a new world dominated by modern communication. And most people are unaware that semiconductors are the technology behind all this. Semiconductor diodes and associated integrated circuits (ICs) are at the core of computer technology and all other modern electronics. The Internet, Google, social networks, and cell phones all rely ultimately on the semiconductor technology.

Additionally, we are right in the middle of the conquest of the lighting market by light-emitting diodes (LEDs), which have made their inroads as well into the most recent visual screens of television sets, laptops, mobile phones, iPods and tablets, you name them. Not long ago, television sets had screens that were traditional vacuum tubes; they have been now replaced by the flat screens, of which LED screens have become the latest generation. As almost everybody on the Earth has currently access to modern communication, many billions of semiconductor devices are globally in circulation.

PV is a part of the modern semiconductor world. Solar cells are nothing else than semiconductor diodes. Today over 90% of all solar cells are made from silicon, the same material that serves for the electronic chips, the ICs. Some years ago, global silicon consumption for chips had been already overtaken by that for PV.

PV and LED fit particularly well together. Both are flat, low-voltage DC devices, one generating electricity from the Sun and the other converting electricity into light; light and electricity are common to both.

PV is also the driving force for modern information and communication technology via satellites. All commercial satellites without exception are powered by PV. Today, it is difficult to imagine a world without reliable weather forecasts from space, direct TV reception from satellites, intercontinental communication, GPS and Earth observations, and so on.

Since 2010, PV has started in earnest to become mainstream in global electric power generation and consumption. An example is Germany, one of the world's leading economies, where PV currently provides already over 10% of the electric energy consumed in some southern states. There is no reason for our societies to complain about it; the contrary is true: PV generators are clean and do not affect climate. They are an infinite source of power as the Sun will shine forever! Silicon, which is commonly employed for solar cell manufacturing, is a non-toxic product, just like simple sand from the beach from which it is derived; moreover, silicon is one of the most abundant chemical elements in the Earth's crust.

It is wrong to claim that the exploitation of the Sun's radiation energy makes sense only in the Earth's "solar belts". Germany, the world PV market leader today, has no better solar resource than Alaska. The concept of PV power generation on a large scale makes sense just everywhere, from the equator to the poles. The so-called "Desertec" vision deriving some electricity in Europe from solar generators set up in the deserts of Africa via expensive cables across the Mediterranean Sea does not make any sense. PV is something that has its best place on the roof of our buildings—for local consumption, just anywhere.

We come back later to the question of area availability for production on a large scale. One should just mention here that it has been shown for many countries that the areas available on the existing buildings are more than enough to provide, when equipped with PV, all electricity needed in the country. In conclusion, **as PV power generation makes sense anywhere on the Earth, it provides energy independence for all countries. Nobody has to import it, like oil nowadays. Locally, the solar resources are more than abundant everywhere**.

Like the Sun's radiation, PV power is naturally decentralised. **Today, we have already several millions of independent PV power producers in Japan, the United States, Germany, etc. The dominating role of the conventional energy providers becomes something of the past. Hence, next to national energy independence, PV opens a perspective of energy independence for all**.

PV deployment brings with it an industrial revolution as well. Thousands of new companies came about in a global effort. Overheating led to an industrial "bubble" which is eventually leading to a more rational global PV industry making the leaders more powerful and reliable. Over half a million new jobs have been generated in new companies all around the world, which survived the "bursting of the bubble" in 2011 and 2012. Correspondingly, **PV has become a heavyweight in global finance**. Following Bloomberg in New York, some €100 billion ($130 billion) went into global PV investments in 2011. Further €20 billion of revenues were created by the PV plant operators. Even though the cost of PV generator plants decreased in 2012 thanks to the collapse of global module prices, investment in new plants stayed robust with some $75 billion.

The drive for innovation is unbroken; there is a prosperous effort going on worldwide to improve PV modules and systems. Attendances of scientific PV conferences of which the largest ones are those in Europe that I initiated in the late 1970s go on to attract thousands of delegates.

PV for You and Me: A New Opportunity for Consumers

The collapse of the PV module costs, in particular since 2010, changed dramatically its economic and social attraction for the general consumer. **PV has at last entered the era where it becomes financially accessible to everybody**. In Germany, Italy, Denmark and several other European countries, in some US states, namely Hawaii, and elsewhere, a PV generator installed on the roof of your house produces now the kWh cheaper for your own consumption than that charged by your conventional electricity provider through the net. The phenomenon is usually called "grid parity". In early 2013, the electricity bought by a German consumer from the local provider costs almost 50% more than that produced on your own house with PV. What are you waiting for to go ahead with PV?

PV integration on buildings is an interesting new option in itself. On new constructions, PV is of architectural interest and can easily improve the value of the buildings; PV modules are indeed aesthetically attractive, in particular the polycrystalline blue ones. It is important to note that successful PV integration has become an art. Unfortunately, there are examples around where such integration was not so successful, in particular for retrofit systems on existing houses.

If you don't want to become a building contractor yourselves to set up the solar panels on the roof or façades of your house, just get involved in one of the hundreds of solar community groups that specialise in solar PV investments in the United States, Germany and elsewhere.

As a result of the new competitiveness on purely commercial grounds, PV starts liberating itself from the constraints of being sponsored in one way or the other.

This means also, in particular, gaining the much-sought predictability of market conditions by finance and industry and getting rid of political decisions that are linked to any public support. Remember how decision makers in the renewable energy (RE) scene feel stressed in the United States before eventually knowing at the end of the year if Congress has—or has not—extended the "Investment Tax Credit" or whatever support vehicle.

For the time being, PV investment does not yet provide what you would call "energy autonomy". **At this point, the PV electricity will just allow you to reduce your bill. As solar radiation is an intermittent resource, the PV will at best contribute some 50% of your overall electricity consumption**. It is too early to cut your grid connection completely. For full autonomy from the grid, you need a storage battery and for year-round independence an additional small engine-driven generator. I had proposed a complete hybrid power package combining a PV generator together with a solar heat collector with a gas-driven car engine that is adapted for electricity production. However, for the time being, hybrid systems of this kind are not available; they have been left out of any development so far.

A simple PV generator coupled with a storage battery can well serve as an emergency device for short-term need. This is of interest when a region is hit by a storm or excessive heat or cold, for instance. Then clients in France or elsewhere may be left without electricity for hours or even days. The "Frankenstorm" Sandy, which hit the US east coast end of 2012, reminded us again of such an opportunity for PV emergency systems.

The millions of PV generators that are in place today are not connected with any storage device and could not guarantee an emergency power supply. I have got a small battery attached to the PV generator at my house in Brussels, Belgium. When we have a blackout in the quarter, something that happens once or twice during the year for a few hours, my house is the only around to show proudly its lights on.

The situation may be different in some of the developing countries where daily power cuts are the rule. There, mostly large consumers bridge the blackout through conventional diesel sets. PV combined with some storage could at least alleviate the problem, also for smaller consumers. In these countries, too, in the longer run, PV hybrid systems would be the solution for a sustainable and reliable electricity supply.

General Outlook

As a result of global overcapacity in the PV module manufacturing industry and tough competition in the international markets, virtually all companies were severely hit financially. Since the chronic overinvestment from 2010 onwards, many companies went bankrupt, had to shutter facilities, or saw their stock market value reduced to close to nothing. However, now there is return from the ashes: a few frontrunners such as First Solar have become profitable again in late 2012; likewise, the gross margins of some Chinese companies have returned to the positive territory. **Learning from the recent past, the global PV industry is going to rebound into the future with much more strength and maturity**.

In general, there is little probability for another PV market explosion in the next few years. From the market volume of 33 GW of new installations in 2012, **global PV will continue its yearly market extension at a more regular pace in the lower double-digit growth rate**. The extremely low PV module costs and an increasingly competitive edge with conventional power providers are an enormous driving force. The outlook for PV is very encouraging; global market trends will show upwards all the time. **The minimum we can expect for the next 7 years up to 2020 is a global market going from 100 GW now to over 300 GW. During these 7 years, new investments in PV will exceed €300 billion or some $400 billion**.

Berry Cinnamon wrote in December 2012 in *Renewable Energy World*, "Utilities and other incumbent energy suppliers will intensify their all-out war on solar, deploying every dirty trick in the book. Of course, we all know that "solar is expensive…." I would say, so what?

It is law of physics that every force has a counterforce. There will always be people who oppose.

The national ranking of PV markets will most probably see some changes. Germany was already declared a PV loser many times, but until 2012 it was able to maintain against all odds its position as a global market leader. I believe that **the coming star on the PV markets will be China**. There is talking of a market projection of 10 GW of PV for 2013. It may well happen like it happened in wind power development in the last few years: Less than 10 years ago, Germany was a global leader in wind power development; China was non-existent on that market. Later, the German market started to slow down, whereas the Chinese market went exploding. In 2011, China installed almost 10 times more wind capacity than Germany did.

For PV, the trend is there: In 2010, China had in total 0.8 GW of PV installed against 17 GW for Germany. However, in 2012, it installed 400% more than in 2011. Today PV electricity in China is cheaper than conventional electricity prices in industry and commerce. Unlike Europe, China charges higher kWh rates on industry and the services industry than on residential customers. For the services industry then, PV utilisation becomes particularly competitive. China has a Golden Sun, a Golden Rooftop programme; it has a special fund for Renewable Energy. China encourages PV on school, hospital and public buildings. It encourages building integration—which I really applaud. For building integration, there is a special subsidy for the up-front cost of 88 cents/W. China promotes green energy counties and villages. China plans a total of 40 GW of PV by 2020; I believe it will be a lot more.

Germany has a target of a total of 51 GW of PV to be installed by 2020—a bit less than twice the capacity it has reached end of 2012. A lot of discussion in Germany is under way concerning the vision of a 100% supply of the country with all the different forms of renewable energy on the horizon 2050. In that scenario, PV would occupy a full capacity of 200 GW. Just half of the areas available on existing buildings would suffice to install that power, according to a recent report of the research institute IWES (Fraunhofer). Baden-Württemberg, one of the richest German states, has established a land register to identify all areas suitable for PV panel installation on the 5 million buildings of the state. For further guidance, residential customers will be able to find information on the profitability of PV on the different surfaces of their building according to their orientation to the Sun.

There is strong grassroots movement in Germany in favour of the 100% RE supply concept in regions, towns, and cities (Frankfurt and many others connected in "100% networks").

The European Union has decided a Directive for Renewable Energy implementation by 2020; it is legally binding. It calls for 84.5 GW of PV by that time. There is also the perspective of having all new buildings from 2020 onwards as "Zero-Energy Buildings"; it is an agreement between the EU Institutions, but it is not a directive. Zero-energy buildings and even more so the "Plus–Energy" buildings that consume less energy than they produce need PV integration as an energy input from the Sun. Hence, these building "regulations" are also an encouragement for further PV deployment.

In the United States, California is expected to install in 2013 half of the US PV capacity, followed by Arizona, New Jersey, Nevada, Texas, and others. The California Solar Initiative is part of the "Go Solar California" campaign. The state has the Renewable Portfolio Standards (RPS) installed, which foresee for 2013 the electricity contribution of 20% from RE and by 2016 a share of 25%. California identified PV as part of a "Modern Energy Economy"; it spurs economic growth, as they say. There are many different support mechanisms in the United States in the form of tax rebates, cash incentives or others; details will be reviewed in a later paragraph. The Solar Electric Power Association in the United States came forward with the vision of a 30% PV contribution to the overall electricity consumption of the country by 2031.

For the future, there is a clear tendency that many new nations will become big players in the global markets.

Japan was a market pioneer since ever and has a strong incentive to give PV a bigger role when it will have to reorganise its power supply after the Fukushima nuclear accident. The government has announced in 2012 the "Strategy for the Rebirth of Japan". A generous FIT sponsoring programme was introduced by METI for PV. New arrangements will take time, but in the longer run, Japan will again play a leading role in the world markets.

And there are many newcomers: Australia is looking at a 100% RE future; PV will have to become important in such a country blessed with much sunshine. The United Kingdom is planning to install 22 GW of PV by 2020, enough to provide electricity to 4 million homes. India is keen to develop solar power strongly in the future; it has set up a "National Solar Mission". In particular, it is funding some 60 cities in a "Development of Solar Cities" programme. Ukraine has 9 GW of electricity from RE on its cards. Chile, Mexico and Brazil are getting increasingly active in PV deployment. Many Arab states are declaring their interest, too.

Recent Developments and Achievements of PV Worldwide

Costs and Prices of PV Feedstock, Cells, Modules and Systems

The 150,000 tonnes of **silicon feedstock** that went into the global PV markets in 2012 was produced mainly in Germany, the United States, and China. **Prices collapsed in 2012 to $17/kg from $80/kg in early 2011**. (Note that one needs less than 5 kg of feedstock to manufacture wafers for 1 kW of silicon cells—the better and thinner the cell, the lesser material required.) The so-called "third tier" companies producing this electronic-grade silicon of some lower quality requirements had to fight hard to reduce inventory as they had built up global production capacity to almost 400,000 tonnes/year. Half of the global suppliers were facing bankruptcy in 2012.

Latest figures from end of 2012 for silicon solar cells manufactured in Taiwan, in US$/Watt, range from 0.32 to 0.36. The cost depends on the cell efficiencies, which range in this case from 16.8% to 17.2%; even slightly higher efficiencies are very profitable for lowering costs. In China, 58% of the cells produced in 2012 were polycrystalline, a material that makes solar cells a bit less efficient and hence a bit cheaper than those of mono-crystalline silicon.

Solar cells, and likewise full PV modules, are currently produced everywhere around the world in large automated manufacturing plants of at least 100 MW of output per year. There is a huge global market for this manufacturing equipment, where Germany, the United States and China are the leaders. Not much labour is involved in manufacturing solar cells and modules because of full automation. The Chinese industry employs much German-made equipment, similar to the German cell-manufacturing industry: there is no practical reason why solar cells from China must be cheaper to produce than those in Europe, the United States or elsewhere.

It should be mentioned that equipment manufacturers were hard hit in 2012 as well. Growth rates of world PV markets that used to enjoy a yearly increase of 65% on an average between 2007 and 2011 flattened to just a few percent to the year 2012 and left an overcapacity of 70 GW per year for module manufacturing. As a consequence, "book to bill ratios" were still negative in 2012 for the equipment manufacturing industry; new investments were down over 60%.

Approximately 90% of all solar cells that were sold on the global markets in 2011/2012 were made from crystalline silicon. Thin-film solar cells made from alternative material did not come any cheaper; hence, their share of the global market volume did not increase as had been hoped previously. When prices for both types of material are the same, crystalline silicon solar cells may be preferred as they have a higher efficiency and therefore need less area for their deployment.

The lowest price claimed in China for PV modules of silicon solar cells was €0.46/W ($0.60/W) in December 2012. A year earlier, it was €0.69/W, and at the end of 2010, it was €1.40/W, a reduction by a factor of 3 in just 2 years. Whatever the true cost may be in China and the rest of the world, the average selling price (ASP) in late 2012 was in the range of $0.60/W in China; it was not very much different in Europe, but in the United States, Canada or Japan, it could, in some cases, be up to 50% higher.

Complete systems, i.e. the modules with the balance of system (BOS) (support structures, DC–AC inverters, cabling, etc.), mounting and installation were offered in China in late

2012 at prices between €0.9/W and €1.2/W. Inverter costs came down to just $0.18/W, and as a result of increased competition, market leaders such as the German SMA were hit in the stock market. The average PV system cost in Germany for the whole year of 2012 was €1.76/W. Six years earlier, it had been €5/W. A third of all modules employed in the country that year were German products, and most of the rest came from Asia. In the United Kingdom and France, system prices used to be higher than in Germany in 2012. This was also the case in the United States. There, one had to count at least $4/W for residential and small commercial PV systems; for larger systems of 100 kW and more, it was quoted $3/W or less.

A major part of the price of a completely installed PV power plant is composed of labour cost and a lot of "soft cost" for permissions, regulations, insurance, liability problems, etc. These are local costs that explain the price differences that will be noticed between countries. Only the PV modules and inverters enjoy a global market—making abstraction of the emerging trade war on PV between two sides, the United States, Europe and others on the one side and China on the other—and correspondingly come at lower cost as if they had been produced locally. It is also important to realise that with current system prices, at least outside China, the module cost constitutes only a minor part; it does not impact too much the final investment if the price of the modules differs by a few percent: Why then all this excitement about unfair competition by the Chinese module manufacturers? Could it be that the Chinese are just a bit better than their competitors in marketing their products?

PV Markets

As mentioned earlier, by the end of 2012, the world had installed 100 GW of PV in total. The world's module production passed in 2009 for the first time the 10 GW mark for one single year, but then part of it remained unsold. In 2012, PV markets reached an impressive 33 GW/year, but that one was only an increase of a few percent over the previous year: The market explosion of global PV had come to an end in 2011/2012.

The following list provides facts and figures by country for overall installations by end 2012 (parentheses show the additional capacity installed in 2012; all figures are in GW). The third column shows the electricity generated in 2012 in TWh (1000 GWh or billion kWh):

	GW	GW 2012	TWh in 2012
• Germany	32.4	(7.6)	25
• Italy	17	(3.5)	20
• USA	7.8	(3.5)	10
• China	7	(5.5)	
• Japan	6.5	(2.0)	
• Spain	4.4	(0)	8
• France	4	(1.2)	4
• Belgium	2.6	(0.5)	
• Czech Republic	2.1		
• Australia	2		
• UK	2		
• Greece	1.1		
• India	1		
• Ontario (Canada)	0.6		
• Ukraine	0.5		
• Austria	0.45		
• Switzerland	0.3		
• Denmark	0.25		
• Portugal	0.2		
• Netherlands	0.15		
• Mexico	0.04		
• Morocco	0.02		
• South Africa	0.00		

The PV markets went in the second half of the last decade through a kind of "gold rush" period. This may explain some of the market anomalies that originated during this period. The balance at the end of 2012 had some surprising features. For instance, there was the strong leadership of the German and Italian markets. In reality, the anomaly was not that these two markets stood so high up compared with the others; the anomaly was rather that the markets in the other countries had not, to a larger extent, followed the German and Italian examples. This will no doubt be corrected in the next few years.

A curiosity was in particular that Flanders, a very small region of 6 million inhabitants in Belgium that is not really blessed by the best possible solar resource—visitors of Brussels will know—had twice as much PV installed than the whole of India. Or it was strange to see that Spain used to be a world leader in PV 5 years ago and then gave up completely. Or that Australia was a sleeping solar giant for a long time before all of a sudden it was waking up: between 2009 and 11 Australia multiplied its PV park by a factor of 10.

Solar power stations on utility scale are the fastest growing sector of the global electricity generation market (Philip Wolfe of WIKI Solar). Almost 10% of global PV capacity, i.e. 8.5 GW, came in 2012 in utility scale above 10 MW each; there were some 200 of them in completion. The "Topaz" solar farm in California was one of the biggest with power of 550 MW.

However, by far, **the largest part of global PV capacity was installed as "roof-tops" for residential or commercial use.** Germany, Japan and the United States have each well over a million of such independent but grid-connected systems installed. Australia, the United Kingdom and France had each several hundred thousand of residential systems in place.

The "per capita" installation rate was highest in Germany. It reached 400 W, i.e. 2 large PV modules, on an average for each of the 82 million inhabitants: an impressive figure indeed. The other countries where the per capita rate achieved exceeded 100 W/head were Italy, Belgium and Australia.

During 2012, the installed PV power provided over 5% of overall electricity needs in Germany and Italy. In Spain, the corresponding figure was 3%. Germany's 30 GW or so generated in total 25 TWh of energy, and Italy, which is blessed by a higher solar resource, could generate with its 17 GW an energy of 20 TWh (figures are approximate as the PV power installations changed over the year; in Germany, they went up from 24.8 GW to 32.4 GW). In the United States, PV generated in 2012 some 10 TWh, 0.3% of total demand.

The World's PV Industry

Before 2004, the year in which German politics under the leadership of my friend Hermann Scheer, MP, set on fire the global PV markets, the PV industry around the world was more than modest. In China, the country that achieved in 2012 a global market share of 80% for PV modules, there was hardly any at that time.

But as mentioned in the previous paragraph, the market explosion that followed stopped rather radically on the time horizon of 2011/2012.

It had been like a miracle that by 2011 almost 30 GW could be deployed in one single year; the market had increased again by more than 50% from the previous year. I don't know anybody who would have expected such an incredible boom from 2004 to 2011. Industry was therefore comforted in its belief that this market explosion was going to continue for some more years. But even miracles have limits. Global industry got it wrong and did not stop making huge new investments while the market horizon was already very much darkening. By 2012, the world markets could only slightly exceed the level of 30 GW of the previous year with industry revenues that grew only by 14% from 2011 to 2012: In the preceding years, the industry had achieved over 50% growth per year. Market growth came virtually to a halt. But the global industry was sitting on a manufacturing capacity for PV modules of 70 GW and ended up in doom and gloom.

All module manufacturers around the world were confronted with negative gross margins. Facilities had to be shuttered. It was not rare that companies saw their stock market value plunge by 98%. There is a long list of PV companies that had been closed or were acquired by the end of 2012: ECD, Q-Cells, Konarka, Solarwatt (bought by the Quandts) and Centrotherm, to name a few. Of the 300 module manufacturers, 180—mostly in the United States, Europe, and China—are expected to disappear by 2015 (Greentech Media, October 2012).

Sharp in Japan, one of the world's oldest operators in PV, accumulated a loss of $4.8 billion in just 6 months during 2012. Bosch in Germany, after having bought Ersol and others, had in 2012 an operational loss of €1 billion in their solar business, and SunPower made a loss of $0.35 billion. It has almost become standard in the PV module industry that the companies' debt accumulates to a multiple of their stock market equity. At the end of 2012, LDK, China, had a debt of $3.6 billion, Suntech $2.3 billion and SolarWorld, Germany, €1 billion. Quite a few of these once-prestigious companies would have been bankrupt by normal criteria. Interestingly, even the German PV journal *Photon*, the voice of the global PV industry, had to declare insolvency.

It is important to note that Chinese module manufacturers were as much concerned by this downturn in the industry as those in the rest of the world. But against all logic, SolarWorld was successful in initiating from the United States and Europe a trade war with China followed by retaliation measures by China. There was quite objectively no reason for all this!

These terrible times the world's PV module industry was confronted with have their origin in the chronic overinvestment, and it did not stop when the market explosion came to an end. It is the industry's own fault to have fallen into this disaster hiatus.

But what may be bad for the industry is good for PV, and eventually that is what counts: Without the overenthusiastic commitment of the Chinese module manufacturers, the costs and prices in the world markets would not have come down as fast as they did. Accordingly, PV would not yet be commercially attractive as it is today and markets would not have reached the gigantic dimensions they got nowadays.

Eventually, there came a turnaround for the module industry. By the end of 2012, First Solar, one of the best companies, enjoyed again full capacity utilisation and became once more profitable. Other PV companies in Asia also saw a return of positive margins. **After consolidation, the PV module industry is on its way back, stronger than ever!** There are globally 16,000 companies that are active in PV. We have hundreds of silicon ingot and wafer companies and hundreds of solar cell and module manufacturers (details can be seen on ENF website enfsolar.com).

The hit list of module manufacturers changed again in 2012 as it changed all the years before. This time the market leader was Yingli, with 2.2 GW of modules sold. The following was the 2012 hit list:

- **Yingli Green**
- **Suntech**
- **Trina Solar**
- **Canadian Solar**
- **First Solar**
- **Sharp**
- **JA Solar**
- **Jinko Solar**
- **SunPower**
- **Hanwha Solar (the new owner of Q-Cells)**

It has also to be realised that over 500,000 new jobs have been created in the last few years in PV, 120,000 each in the United States and Germany, and over 300,000 in the European Union. The detrimental effects of the PV industry on employment remained surprisingly limited.

Progress in Solar Cell Efficiencies and Ground-Mounted PV Arrays

In late 2012, a new efficiency record of 44% was announced. It was achieved by Solar Junction in San José, California, on a "multi-junction" cell of III–V compounds (GaAs and others) at a concentration of the light of 947 Suns. The measurement was confirmed by the National Laboratory NREL. This kind of cell has become attractive for the CPV ground-mounted PV plants that employ small mirror or lens concentrators; as they need high light concentration, two-axis tracking of the Sun with high precision is required. CPV plants find currently a lot of new interest. (I am member of the board of the Institute ISFOC in Spain, which is unique in specialising in CPV technologies and has several full-scale plants from around the world installed at its site in Puertollano for testing.)

The efficiency for standard single-junction GaAs solar cells comes, for instance, at 23.5% from Alta Devices. Note that GaAs solar cells are preferred for most satellite applications in space; they are more radiation resistant than silicon cells.

On mono-crystalline silicon cells, optimum efficiencies of up to 24% in production have been reached by SunPower

(Gen3 cells) and Panasonic (HIT cell) for several years. But the technology to produce them is more sophisticated and hence somewhat more expensive than that of standard silicon cells that are manufactured by most other companies. The same is true for the "Pluto" cell of an efficiency of just over 20% that Suntech has in pilot production; it is more complex to make.

Solar cells made from polycrystalline silicon come typically on the market at somewhat lower efficiencies of approximately 17% but with a slight cost advantage.

CdTe solar cells on modules—thin-film cells are produced directly in integrated modules and not like silicon in individual cells—with a record efficiency of 18.7% and 14.4% in their best production line come from First Solar.

The CIGS ($CuInGaSe_2$) thin-film cells come in production at best in efficiencies of approximately 13%. Over 400 MW of them were produced in 2012. The manufacturers claim that such cells are slightly more expensive to make in the co-evaporation process instead of sputtering and subsequent selenisation. On laboratory scale, efficiencies of slightly over 20% have been reached; this shows the high potential of further progress through research.

For ground-mounted solar arrays, tracking the Sun is an option. It is particularly considered in the United States, which has large areas with frequently clear sky. An example is one-axis tracking with an over 30% better energy yield compared with a fixed-plate array. NREL finds that the yearly capacity factor of 17% for a fixed-plate array that corresponds to a yearly harvest of 1500 kWh per kW installed, and tracking might improve that harvest by one third, achieving 2000 kWh in a year. In most parts of Europe, the Sun's radiation energy is mainly received as diffuse radiation; tracking, which is more expensive to implement than the fixed plate, has not received the same attention.

Financing and Support Mechanisms

The two main support schemes for PV system investments are (1) the Feed In Tariff (FIT), which financially supports the kWh fed into the local grid, and (2) the financial support against the up-front cost at the time the system is installed. Germany had implemented first since 2000 a 100,000-roof programme that reduced the up-front cost in the market place. As it was less successful than thought, Germany switched in 2004 to the FIT, called "EEG" in the country. **As it proved to become an efficient driving force for market deployment, the FIT was adopted by many other countries as well.** In addition, German PV investors benefit from special bonus loans from the State Bank KfW.

From 2013 onwards, Germany has imposed on all of its PV systems operators a new "feed-in management". A device must be added to all PV systems in place to allow the local grid operator—there are some 900 of them—to reduce the energy fed into the grid when there is too much of it on offer. This is linked to the fact that there are now millions of these systems connected to the grids. PV owners are alternatively given the option to reduce permanently by 30% the electricity that their systems could at maximum put into the grid. **This is a kind of encouragement of self-consumption of part of the PV electricity they generate.**

As mentioned previously, residential customers of the grid could produce their PV electricity in early 2013 at only 2/3 of the cost they are charged for the electricity from the grid, a tendency that will give PV even further cost advantage in the following years. Why is conventional electricity so expensive in Germany—retail electricity cost €0.27 in early 2013—while in France and the United States, to name just these two, the electricity from the grid costs typically some 12 cents per kWh. The large differences are both due to the greed of the classical electricity generators and utilities and due to the higher taxes imposed on private customers in Germany. The kWh of PV is currently not yet taxed. But taxation on PV electricity could well be introduced as it has been in Spain and France since 2012. This as well encourages the trend towards self-consumption.

Along with the decrease of PV costs when the industry gained strength, the PV tariffs of the FITs could be reduced. However, very often the politics that had to decide on the national tariffs got it all wrong. Until 2011, Germany always experienced strong spikes of system installations at the end of the year. Typically many countries began to put the tariff too high, and when they saw the national market explosion that resulted from it, they put it excessively low and strangled their market. This was, in particular, the case in Spain, where the market for PV definitely came to a complete stop.

Spain has even reduced retroactively the tariffs for the PV plants in place. That raised some eyebrows in the general markets and may legally be incorrect.

Ukraine had some of the highest FIT in place for PV in 2012. **Italy**, too, had a rather generous support system but limited the installation rate by financial ceilings called "Conto Energia". Like some states in America, **Belgium** had a support scheme of tradable certificates; the government fixed a minimum price per kWh fed into the grid. The system was very profitable for investors until the certificate's prices were in 2012 reduced so much that the market started plunging. **The United Kingdom**—which, for many years, pushed for a quota support based on the RPS, the Renewable Portfolio Standards, here called the Renewables Obligation (RO)—eventually switched to the FIT. From early 2013 on, it was 15.5 pence/kWh.

Australia has in place a mix of mandatory targets, the FIT, tradable RE certificates and rebates for installation costs. **China** has, as mentioned earlier, an FIT legislation in place that has recently been joined by a subsidy support programme for reducing the costs of installation.

In terms of certification, it is important to note that in the case of financial support of the up-front installation cost, certification of modules and the other sub-components must be imposed to ensure the quality required for the long-term operation of the plant. The situation is somewhat different for FIT regulation. In this case, it is in the interest of the owner to have a reliable PV system; otherwise they will not be able to generate all the kWh they need to get paid for amortization and profit.

The United States does not employ the FIT; it has a mixture of instruments for support, some federal, some from the respective state. Eventually, the financial support for a PV investor is not really lower than it is in Germany with the FIT. Here is a practical example for Austin, Texas, in 2012:

- System price: $5/W
- 4 kW system: $20,000
- Utility "Austin Energy's" support: $2.5/W = $10,000
- 30% federal tax credit: $3000
- $50 to $60 monthly utility savings

Payback time of 8 years

The US states have the RPS as overall guide for support. It can be implemented in different ways, as rebate programme of public utilities or state agencies, or cash incentives. Apart from these incentives for the up-front cost of a PV system, states may promote PV as part of the RPS Solar Renewable Energy Certificates (SRECS). Those certificates are issued like for the FITs per kWh produced by certified and registered PV systems. They are then sold on a spot market, auctions, or with long-term contracts. The demand is determined by the state's RPS requirements. Moreover, all US states allow net metering.

The federal investment tax credit ITC can raise tax equity or cash payment. There is also a "Federal New Market Tax Credit" for economically depressed regions that allows borrowing at 1% instead of 7%.

In 2009, California started solar rebate programmes for low-income families, the Single Family and the Multi Family Affordable Solar Homes Programs SASH and MASH.

A big issue in the United States is a choice between the alternatives "ownership" or "leasing, i.e. Third Party Owned TPO". The American people made their choice: between 2010 and 2012 the share of leased PV systems increased from 15% to 80%. Solar City, the company that was brought successfully to the stock market in 2012, is one of the largest promoters in the United States offering lease options. The Property Assessed Clean Energy (PACE) is similar to solar leasing. It allows homeowners to mortgage PV and other improvements and pay for the PV benefits only as long as they own the house. In San Diego, the municipality has set up FIGTREE for multiple PACE options; it drops the minimum project size from $50,000 to $5000. Loans are paid with the property taxes over 20 years.

Change of Paradigm: From Feeding the Grid to Self-Consumption

Up to the time horizon of 2012/2013, when PV had to rely on financial support of some kind to qualify for the conventional, commercial power markets, the established scheme was one that was quite illogical. For accounting reasons, the solar electricity had to go in circles. This was in particular true for the PV generated from rooftop systems, the one that is leading the global PV markets—as we have seen previously. Once produced by the PV system that is installed on your own house, all of it is sold to your local grid—only to return when you buy it for your daily needs.

Why not consume directly the PV electricity that is yours? Even though the time profiles of electricity generation and demand do never coincide a 100%, why not replace at least part of what you consume by the PV electricity coming from your roof without letting it go trough the local grids. This option makes sense without having to wait if one day or not storage technology will be available at reasonable cost for achieving full power autonomy. **When grid parity has been reached and the shutters become wide open for cheap PV electricity production without financial promotion, it will be straightforward to utilise yourself the electricity you produce**.

We have seen here above that the new FIT regulations in Germany from 2013 are a first step towards self-consumption. They offer indeed as an option the possibility to consume 30% of your PV power for your own needs**. In northern Germany, the local utility WEMAG, which is owned by towns and villages in the area, started in 2012 marketing PV packages for installation on the buildings that are serviced by this utility**. The offer promotes self-consumption of PV while reducing electricity consumption of the PV residences from the utility's grid by up to 25%.

China has, as mentioned previously, started the promotion of PV self-consumption. The first targets are industry, commerce, administration, and schools. The demand in these buildings and the working and living habits tend to come more in phase with the daily solar availability than that in the residential sector. Further, as the cost of electricity in China's service sector is higher than that in residences, PV can more easily compete there.

Eventually, PV power in its "low-cost habits" that it took on in 2011–2012 has been gaining new interest for ground-mounted PV power plants, as well. In the sunny areas of the United States, Europe and all those countries that are blessed with a generous solar resource, such plants might possibly generate electricity at 10 cents per kWh or even less.

The challenge is particularly high in Spain. As the government has stopped all financial support, PV there has no other choice than to compete eventually in a tough electricity market on purely commercial grounds. But the interest from courageous, innovative companies to go ahead is real there. Power Purchase Agreements (PPA) with the grids were sought in Spain for over 30 GW of new PV capacity. Developers seemed to go for over a hundred PV plants in the multi-MW range for the south of Spain. An example was a 150 MW plant near Toledo. Besides all the declarations and rumours, a total of 1 GW could well come about by 2013/2014.

PV, a New Player in the Mainstream of Global Power Supply

There is not much fun in the conventional markets for oil, gas and atomic electricity anymore. The world's fossil resources are depleting and are getting all the time more expensive to exploit. To contain the exploding costs and market prices to some extent, tremendous subsidies are necessary. Following the influential International Energy Agency (IEA) in Paris, an arm of the OECD, global subsidies for oil and gas are growing all the time. The latest figure they published in late 2012 was $523 billion just for 2011. The figure did not even include the support for atomic power or the military costs for protecting the sites of exploitation and transport.

Consumers are eventually confronted with tremendous price increases for heating and electricity. Millions of Europeans have difficulty in paying their bills for energy and electricity. In "rich"

Germany, 600,000 households got their access to the grid cut for being unable to pay the bill. Many had to adopt candles for lighting—going back to the Stone Age? The coming Solar Age got a competitor there.

The fossil energies keep as well strengthening their grip on the "Western" economies. Europe had to import in 2011 oil and gas for €400 billion, which impacted the national balances of payments more.

However, there is light at the end of the tunnel. The march of the renewable energies in the world's markets is unbroken. The United States installed in 2012 more new wind power than gas plants despite the "shale-gas boom" in the country. The new wind power stood even for twice the new coal power plants—this is significant in a country that relies, like China, so much on coal.

The trend is even more dramatic with respect to nuclear power. **In 2012, new 70 GW of wind and PV power were installed worldwide**, leave alone that from bio-energy and other renewables. Global nuclear energy had, on the contrary, nothing interesting to report: two new plants coming on stream and two old ones shut down.

The conventional power plants are getting older, and not many new ones have come on stream in the last few years. In Europe, approximately half of the park of power plants in place has already passed the medium lifetime of operation. The financial value of all European power plants exceeds well the €1000 billion mark. An increasing number of them will have to be replaced in the foreseeable future, but as the available budgets for new investments in the power sector are tightening as a follow-up to the financial crisis in the major Western economies, the cost for investment and operation of power plant options will be an essential criterion. Leave alone other environmental or even social criteria, the economic trade-off between all the options is becoming the determining factor. The question arises then, **can PV economically compete with nuclear, coal, gas**. . .**?**

The benchmark for PV plants could be the €1000/kW, which was reached in China in 2012. The latest generation of nuclear plants, the French EPR, is being developed in Finland and France. Its cost exceeds €5000/kW, excluding the eventual dismantling cost that will be of the same order. Leave alone the lead times for planning and construction that are in the range of a full decade, the projected kWh cost will be in the range of 11 to 16 cents (World Nuclear Industry Status Report). **Nuclear is not economically competitive with PV**.

Power plants for lignite and coal are cheaper to build, in the range of €2000/kW, but this does not include the cost of the fuel and the annoyances of pollution and CO_2 emissions. Coal plants have no good reputation, not even in the United States and China. People oppose new constructions in their neighbourhood, and governments have also eventually understood that it is better to avoid new constructions as far as possible.

Power plants employing natural gas are cheap and make sense, in particular, as cogeneration plants. But for political reasons, their emerging markets were more limited than previously thought.

PV is improving its position inside the renewable energy family as well. **PV eventually turned out to be much cheaper, in particular, than the concentrating solar power (CSP)**, which employs solar concentration with mirrors. Michael Liebreich, the influential market observer from Bloomberg New Energy Finance, discovered end of 2012 that "the pipeline of projects has narrowed dramatically". It is actually a pity that the technical marvels the CSP community was able to demonstrate in large installations in Spain and the United States make economically no sense. I had this impression seeing the results of the world's first CSP, Eurhelios in Sicily; for that I was a project leader in the 1970s. Consequently, during my time as manager of the R&D programme for the Renewable Energy of the European Union, I made sure that no public money was wasted on CSP, all went on PV—and a few others. One could also mention that **PV continues to strengthen its market position with respect to wind power.** Its share in the global markets has been always increasing compared with the new wind power. Germany, in particular, has installed more PV than wind power for years. The United States is expected to install for the first time more PV than wind power in 2013. However, in terms of actual electricity generation, wind energy will retain its dominating position for quite a while as its capacity factor is more or less twice that of PV.

Annex: Some Facts on PV

- **Thickness**
  The thickness of PV modules is essentially determined by the supporting pane, normally glass. Solar cells are less than 1/3 mm thick when they are made of silicon crystals and not more than 1/1000 mm thick when they are thin film.
- **Areas**
  The area of a PV array of PV modules takes normally less than 10 m^2/kW. It depends on the cell efficiencies and the packing density; 1 MW of PV occupies less than 1 ha (2.5 acres); 1 GW occupies an area of less than 10 km^2 (3.86 square miles).
- **Electricity Production**
  For complete PV systems well oriented south at a fixed inclination corresponding to the latitude of the site, the annual electric energy production is better than 1000 kWh for every kW installed, even at bad or mediocre solar climates. The average for Germany in central Europe is 900 kWh/kW, a capacity factor of 11%. This takes into account that a non-negligible part of the system park is not perfectly oriented south, or that systems have technical flaws. In parts of Germany with a better solar regime, up to 1300 kWh can be produced in a year. In the south of Europe, the yields are higher up to 2000 kWh. The same is true in most of the United States. PV systems employing solar tracking may yield some 15% to 30% more than the corresponding fixed-plate arrays; on the other hand, installation and operation costs are higher: a difficult trade-off.
- **Energy Payback Time for Solar Cells**
  Crystalline silicon cells have a payback time of less than 2 years, i.e. they are operated for less than 2 years at an

average solar regime before the energy invested in cell production is recovered. This is more favourable than the case of nuclear power plants. Thin-film modules have to be operated for only less than half a year to recover the energy invested.

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