PV in Urban Policies- Strategic and Comprehensive Approach for Long-term Expansion

WP5- Deliverable 5.3: Study on "Global context, environmental costs and energy portfolio analysis for urban PV"

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PV Upscale: Urban Scale Photovoltaic Systems

PV UP-SCALE, is a European founded project related to the large-scale implementation of photovoltaic (PV) in European cities Intelligent Energy for Europe programme.

Its objective is to bring the stakeholders in the urban planning process to attention the economical drivers, bottlenecks like grid issues, the do and don'ts within the PV-urban planning process. To reach the urban decision makers workshops will be organised and a quality handbook will be written using gained experience with PV-Urban projects in the Netherlands, Germany, France, Spain and the United Kingdom. The project suits the activities that are executed in the IEA PVPS implementing agreement, in particular IEA PVPS Task 10. It takes information from Task 7 (building integrated PV), which ended in 2001 and Task 5 (grid issues), ended in 2003.

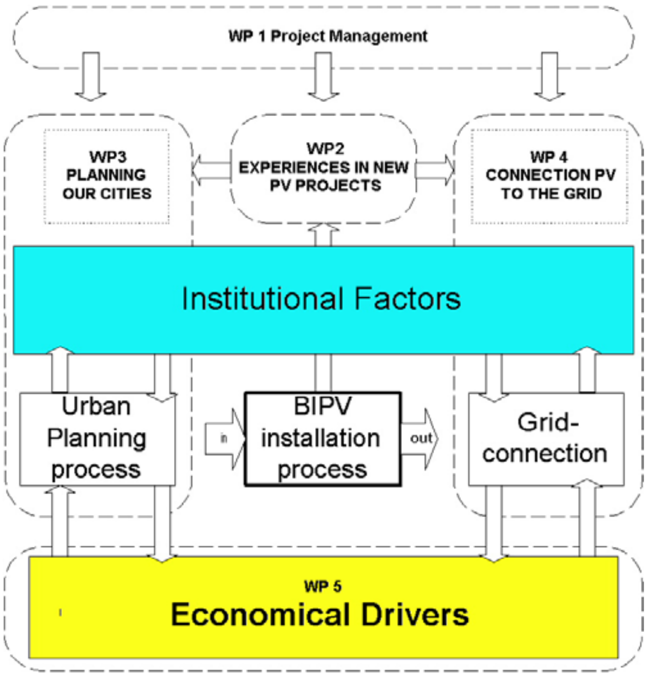

Figure 1: Structure of Project PV upscale

Work package (WP) 5 of the project, to which this report contributes to, analyses economic and non-economic institutional drivers and barriers for an increase of the market penetration of Building-integrated PV on an urban scale. This task involves the following steps:

1. Survey on value analyses;
2. Identification of the most important stakeholders (PV system owners, manufacturers, utilities, local politicians...) in the market penetration process;
3. Analysis of the impact parameter in the decision making process of these stakeholders;
4. Investigation of the economic and financing aspects;
5. Discussion of successful policy strategies.

The project PV Upscale

Year of implementation:	01-2006 – 06-2008
Client:	European Commission, DG TREN; EIE Programme Contract No. EIE/05/171/SI2.420208
Partners:	ECN- Energieonderzoek Centrum Nederland, Research Institute, Netherlands (Projekt co- ordinator) HORISUN- Consulting, Netherlands Fh ISI- Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung eV Research Institute Germany EEG-Vienna University of Technology, Energy Economics Group, Austria HESPUL- Consulting, France Halcrow- Halcrow Group Ltd, Consulting, United Kingdom Universidad Politecnica de Madrid, Spain Ecofys- Ecofys Energieberatung und Handelsgesellschaft mbH, Consulting, Germany Continuon Netbeheer NV, Utility, Netherlands MVV- MVV Energie AG, Utility, Germany
Web:	www.pvupscale.org

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1 INTRODUCTION

1.1 Core Objective

In this study attention will be given to the recent developments of the PV market at the global scale, focussing on both emerging economies such as China or India and industrialised countries outside Europe as e.g. Japan or the USA. In this context an overview of the present PV world-wide market will be presented both from the point of view of the capacities installed (demand side view) and of cell and modules production (supply side view). The role of PV in the set of different national energy policies will be analyzed. Moreover the impact of global PV developments on Europe will be discussed – e.g. the resulting cost reductions due to increased deployment and competition as well as the impact on the European industry. Besides also attention will be given to the effect of high oil prices and the new insights and views on environmental costs and the reduction of financial risks of Energy Mix Portfolio's including renewable energies in general and PV in particular.

1.2 Introduction- Global Context

Like other economic sectors also the European PV market is influenced by globalization. This effect is mainly seen in the increasing development of worldwide production markets. While most of the worldwide installed PV capacity is concentrated on industrialised countries, essentially Europe (basically Germany), Japan and USA, the industry moves more and more to other zones with diverse impacts on Europe. Two effects can be stated from the viewpoint of the European economy:

- The positive effect of industrial development in poor countries[1] and also a diminution of general costs for the consumer of industrialized countries (since the national products are usually more expensive than those produced in developing and emerging markets). This last point also forces the local industry to improve its production chain and quality in order to maintain its competitiveness.
- The negative effect of competitive pressure from abroad forcing the domestic local industry to undertake actions like "outsourcing" with the corresponding loss of well-being for the affected country (i.e. job losses). Another derived effect can be the diminution of quality of offered products.

[1] This analysis is actually much reduced since the subject of the globalization is very ample and complicated. The industrial development of developing and emerging countries due to cheap production conditions in comparison with industrially developed countries also entails an increase of the difference between rich and poor in poor countries.

2 REVIEW OF THE WORLDWIDE MARKET DEVELOPMENT

2.1 Installed Capacity

According to a study recently published by Solarbuzz (Marketbuzz, 07) the global yearly installed PV capacity reached 1744 MW in 2006 which represents an increase of 19% compared to the previous year. Germany was again world leader, comprising 55% of the worldwide installations – where almost solely grid connected PV systems have been added. Below a graphical depiction is given in Figure 2, indicating a regional breakdown of the global PV market in 2006 by means of installed capacities.

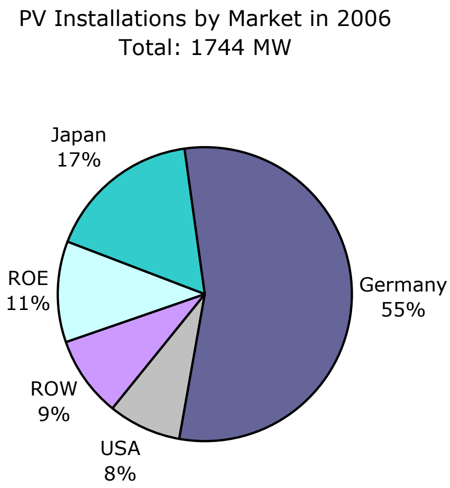

Figure 2: PV Installation by market 2006

Source: (Marketbuzz, 07)

Note: ROW: Rest of World, ROE: Rest of Europe

Figure 3 indicates the global annual PV installations according to cell use[2] by applications (Bradford and Maycock, 2007). Off grid rural applications don't play a significant role in comparison with the grid connected applications. As PV represents a currently expensive technological option to generate electricity the use of this technology occurred mostly in industrialised countries as grid connected applications, driven by support as offered in several national energy policy strategies. Although currently the grid connected applications dominate, representing about 76% of the global market (see Figure 3), it can be expected that this share will decline in favour of off-grid applications due to need for electricity in the rural areas and the huge potential of emerging economies like China and India where also PV cell production takes place.

[2] Please keep in mind that the used sources for these analyses indicate the used cells in order to show market applications. In this respect the used modules and cells in MW differs as cells get converted into useful modules and products, which are installed finally in order to generate electricity (Bradford and Maycock, 07).

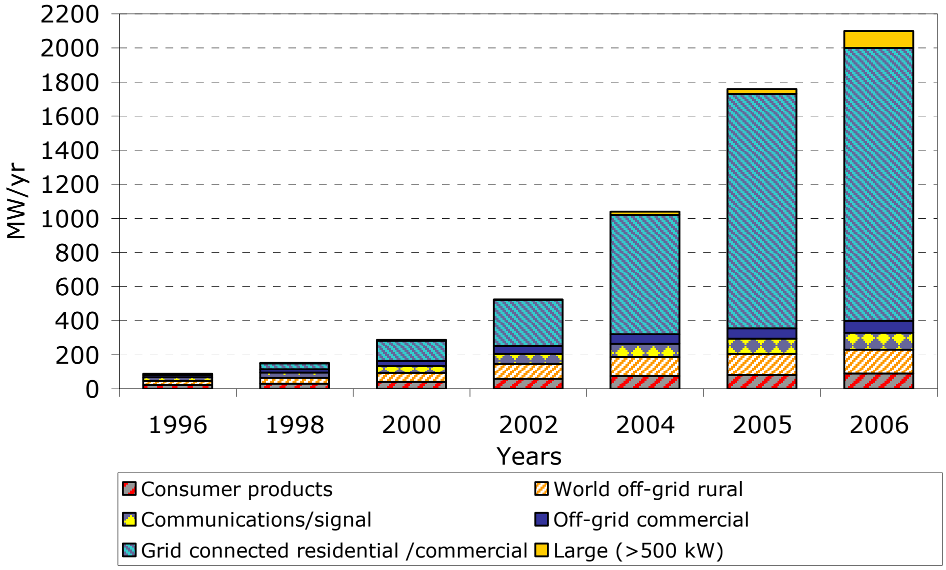

Figure 3: Global annual PV cell use by application

Source: (Bradford and Maycock, 2007)

2.2 Global Produced Cells and Modules

In 2006, global cell production grew by 41% and reached 2520 MW (Bradford and Maycock, 2007). Figure 4: shows the cell production growth from 2000 until 2006, broken down into important regions and countries. The most important countries in terms of PV cell production are Japan, USA and Germany in Europe. Although Japan is still the largest producer in the global market, the relative growth slowed down, whilst the production in the rest of the world grew stronger due to the attendance of new Chinese and Taiwanese companies in the global PV market. This trend is getting also apparent from Figure 5, which indicates the regional shipment shares in terms of cell production for 2005 and 2006.

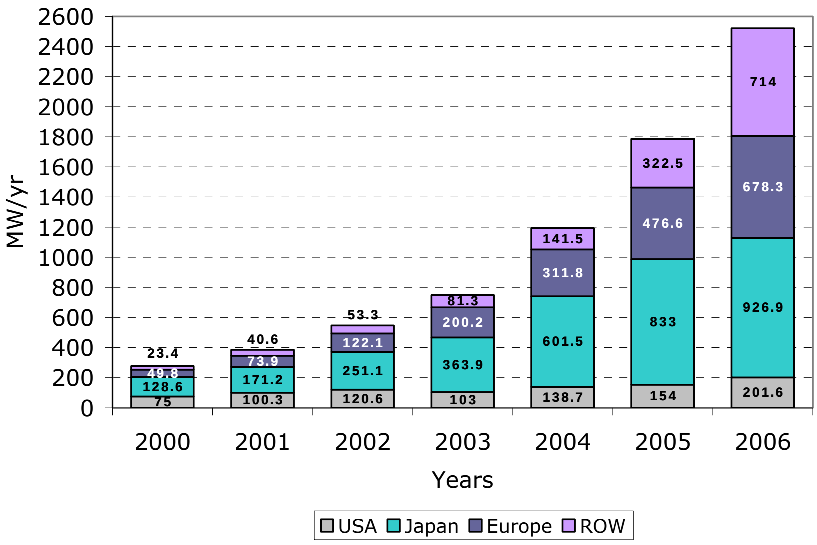

Figure 4: Global cell production until 2006 (MW DC)

Source: (Bradford and Maycock, 2007)

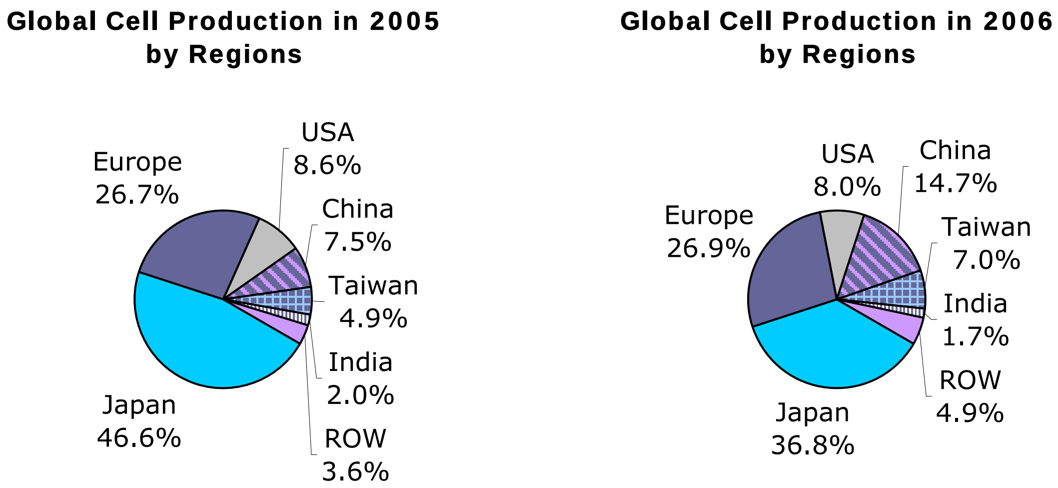

Figure 5: Global cell production shipment by regions in 2005 and 2006

Source: (Bradford and Maycock, 2007)

Figure 6 depicts the cell production in China, Taiwan and India from 2000 to 2006. Chinese producers nearly tripled their cell production to 369.5 while Taiwanese producers doubled their production from 2005 to 2006 (Bradford and Maycock, 07)

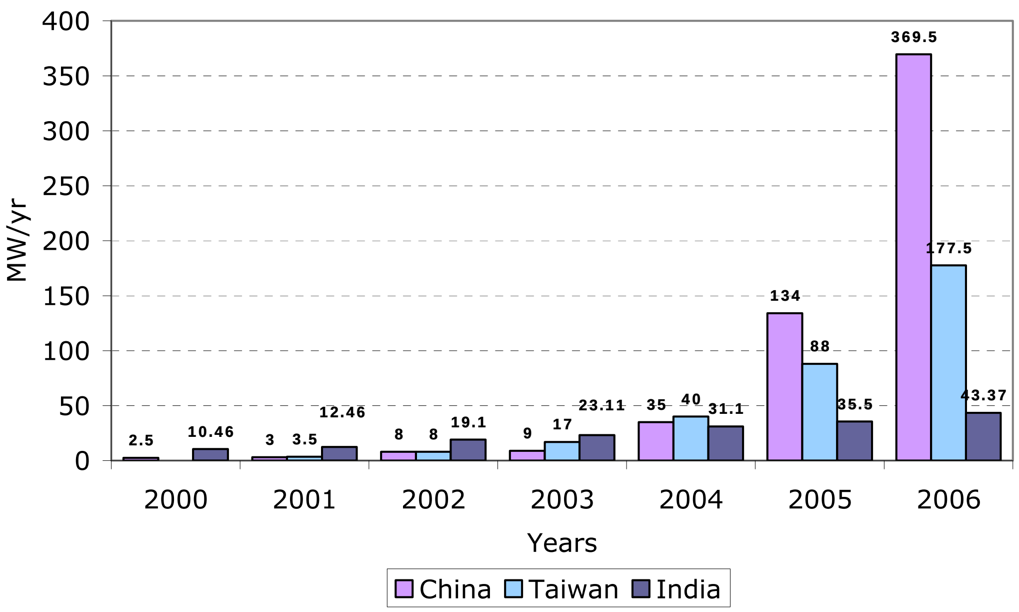

Figure 6: Cell production in China, Taiwan and India

Source: (Bradford and Maycock, 07)

Table 1: Global Cell Production from 2000-2006 by Companies and by Regions in MW

Source: (Bradford and Maycock, 2007)

	2000	2001	2002	2003	2004	2005	2006	06 vs. 05 - Growth in [%]
US PV Cell Production								
First Solar				3	6	20	60	200 %
Solarworld CA (Shell Solar)	28	39	46.5	52	62	42	35	-17%
U.S. OVONICS	3	3.8	4	7	14	22	28	27%
BP Solar	20.5	25.2	31	13.4	14.2	22.6	25.6	13%
GE (Astropower)	18	26	29.7	17	25	18	22	22%
Evergreen Solar			1.9	2.8	6	14	13	-7%
Schott Solar	4	5	5	4	10	13	13	0%
Global Solar				2	1	1	2.5	150%
Other	1.5	1.3	2.5	1.8	0.5	0.5	2.5	400%
USA -Total	**75**	**100.3**	**120.6**	**103**	**138.7**	**153.1**	**201.6**	**32%**
Japanese PV Cell Production								
Sharp	50.4	75	123.1	197.9	324	428	434	1%
Kyocera	42	54	60	72	105	142	180	275%
Sanyo	17	19	35	35	65	125	155	24%
Mitsubishi	12	14	24	42	75	100	111	11%
Kaneka	5	8	7.5	13.5	20	21	30	43%
Mitsubishi HEL				2	10	12	12	0%
Hitachi						5	5	0%
Other	2.2	1.2	1.5	1.5	2.5		0.5	
Japan-Total	**128.6**	**171.2**	**251.1**	**363.9**	**601.5**	**833**	**927.5**	**11%**
European PV Cell Production								
Q-Cells (DE)			8	28	75	166	253.1	52%
Schott Solar (DE)	10	16	24.5	38	53	82	83	1%
Isofoton (ES)	9.5	18	27.4	35.2	53.3	53	61	15%
Deutsche Solar Shell (DE)	3.3	7.5	9	42	38	55	51	-7%
Ersol (DE)			9	9	16	20	40	100%
Sunways (DE)			4.5	4.5	11	16	30	88%
Scancell (NO)					5	10	27.5	175%
Photowatt (FR)	14	14	17	20	22	24	24	0%
Photovoltech (BE)						12	20	67%
Ever-Q (DE)							15	
BP Solar (DE)	9.2	12.2	16.7	16.5	23.5	16.8	12.3	-27%
Solterra (CH)							12	
Solarwatt (DE)							8	
Antec (DE)					7	8	8	0%
Helios (IT)	1.5	2.2	3	3.5	4	5	5	0%
Würth Solar (DE)							2.4	
Other	13.2	16.5	16	13.7	11.6	14	15	7%
Europe- Total	**49.8**	**73.9**	**122.1**	**200.2**	**311.8**	**472.8**	**657.3**	**39%**
ROW (Rest of World) PV Cell Production								
Suntech (CN)					28	82	157.5	92%
Motech (TW)		3.5	8	17	35	60	110	83%
SunPower (PH)						23	62.7	173%
CEEG Nanjing PV (CN)						7	60	757%
Baoding Yingli (CN)						10	35	250%
BP Solar (AU)	5.8	7	8.4	26.2	34	35.2	33.4	-5%
E-TON (TW)					5	28	32.5	16%
JA Solar (CN)							25	
Solarfun (CN)							25	
DelSolar (TW)							20	
Microsol Intl. (UAE)					1.4	6.8	15	121%
Gintech (TW)							15	
Shenzhen Topray (CN)						5	15	200%
Solar (CN)								
BP Solar (IN)	6.5	8.1	13.1	14.1	141.1	13.4	14.4	7%
Kyungdong (SK)							12.5	
PV Energy (SK)								
Other China	2.5	3	8	9	7	30	52	73%
Other India	4	4.4	6	9	17	22.1	29	31%
Other	4.7	14.7	9.8	6				
ROW- Total	**23.4**	**40.6**	**53.3**	**81.3**	**141.5**	**322.5**	**714**	**121%**
China- Total	**2.5**	**3**	**8**	**9**	**35**	**134**	**369.5**	176%
Taiwan- Total		**3.5**	**8**	**17**	**40**	**88**	**177.5**	102%
India- Total	**10.46**	**12.46**	**19.1**	**23.11**	**31.1**	**35.5**	**43.37**	22%

Table 1 provides a list of worldwide most evident solar cell companies and their production trend from 2000 to 2006. Shipments from the total of ROW region, which also comprise the fastest growing companies of the latest years like Chinese Suntech, Taiwanese Motech or Sunpower from the Philippines, grew by approx. 121% in 2006 (compared to 2005) while the European shipments accounted for a growth of 39%.

The company First Solar is the driver of U.S. production. Its cell production in 2006 has exploded threefold to 60 MW (see Table 1) with its cadmium telluride product onto glass which was cheaper than its silicon based cells (Bradford and Maycock, 2007)

There are many thin films and crystalline technology production facilities in start up in the USA but as most of these companies are in an early stage their future productivity can not be assessed. Many U.S. companies after their initial commercialisation are choosing to expand capacity in other areas of the world in order to be closer to the market or due to lower material and manufacturing costs (Mints et al., 2007).

Producers	Ranking in 2004	Ranking in 2005	Ranking in 2006
Sharp	1	1	1
Q-Cells	4	2	2
Kyocera	2	3	3
Suntech	9	8	4
Sanyo	6	4	5
Mitsubishi	4	5	6
Motech	8	9	7
Schott Solar	7	6	8
BP Solar	3	7	9
Shell Solar	5	10	10

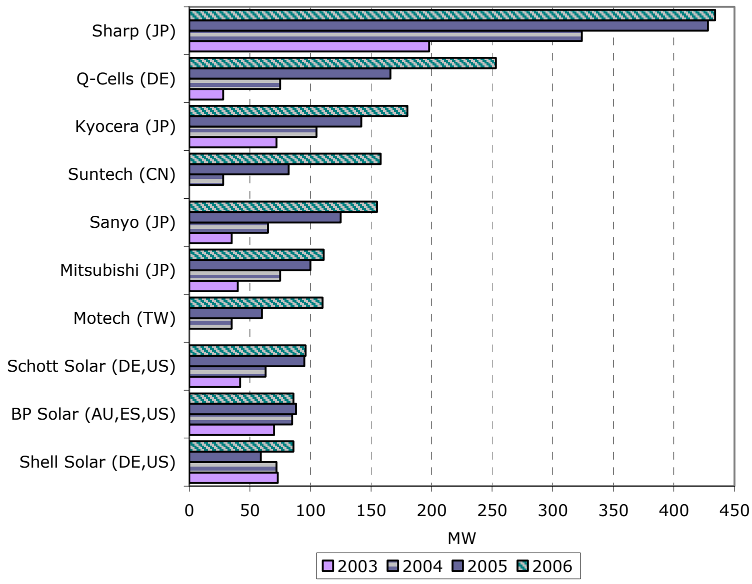

Figure 7: Worlds top 10 solar producers from 2003 until 2006 and their rankings

Source: (Maycock and Bradford, 06) and (Bradford and Maycock, 2007).

Figure 7 indicates the top 10 PV cell producers at global scale, from which some trends can be observed: While Suntech from China was number eight by 2005, this company climbed to the fourth place within one year (2006). Motech of Taiwan has achieved a rise from the ninth place in 2005 to the seventh as of 2006. Other Chinese and Taiwanese companies aim to enter the top ranking also in the near future where e.g. in the case of China existing as well as new manufacturers plan to expand their production capacity tremendously. It is expected that within the next few year manufacturing capacity in China will reach about 2 GW which almost equals to the yearly cell production in the world today (Sicheng, 2006). According to a recent survey as presented in Photon (7/2007) the 30 largest Chinese module manufacturers plan to achieve a capacity of 1146 MW already in 2007, which means a growth of 290 % in comparison to 2006 – of course, it appears questionable if they can realise their aims.

Against this the German module manufacturers achieved a doubling of their production in the same period – from 341 to 656 MW.

2.2.1 PV Cells Technology

The PV Market is dominated by solar cell modules based on the use of crystalline and poly crystalline silicon wafers. Although this type of solar cells represents a robust and reliable technology and still offers a potential for future cost reduction, thin film technologies indicate promising future perspectives because of their character which eliminates the use of comparatively expensive and material intensive silicon wafers (Green, 2007).

Thin film technologies increased their share on total production from about 6.3% in 2005 to approx. 7.5 % in 2006. Figure 8 gives an overview on the applied cell technologies from 1999 to 2006. Within the set of different thin film technologies, cadmium telluride (CdTe), amorphous silicon (a-Si) and Copper Indium Selenid (CIS) hold a noticeable share on the market. Thereby, a-Si cells took the largest share with 4.7% in 2006. The share of CdTe increased due to the expansion of the U.S. Company First Solar. From 1999 to 2006 shipments of other thin films beside amorphous silicon increased by a compound annual growth rate of 80% per year, whilst the average annual growth rate of the period 2004 to 2006 was at 147% (Mints et al, 2007).

The reasons for the trends of thin film technology can be classified as follows.

- Especially the temporary shortage of silicon in the previous years has played an important driver for accelerated research and development of the thin film technology.
- The thin film technology is still developing slowly - however, the technology is now ready to go into mass production. The efficiency factor approximates to the 10% or exceed.
- The market development of thin film is at the beginning stage; hence, each company has equal possibilities to achieve a significant share in this market. (Sonne, Wind&Wärme, 11/2006).
- This technology needs also low material consumption, a better temperature coefficient (constant power output at rising temperature) as well as shorter energy payback time, as production is less energy intensive (Sarasin, 06).

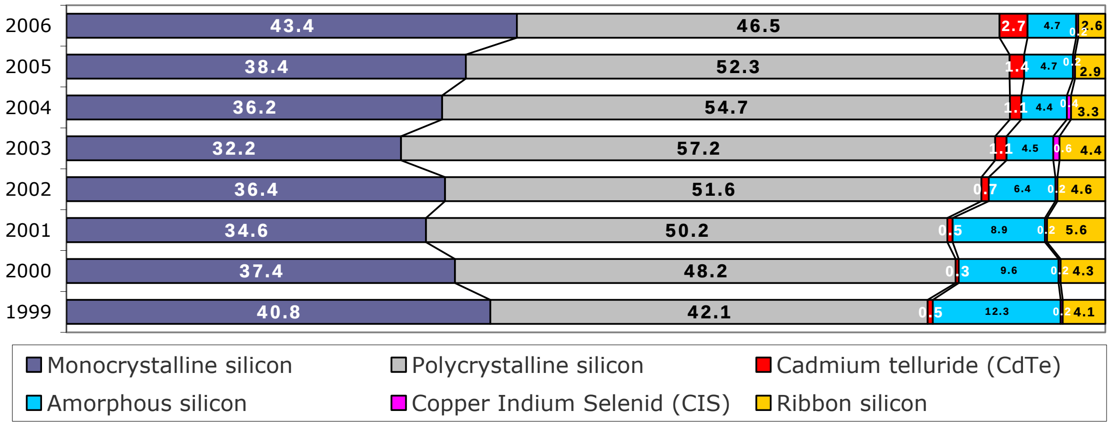

Figure 8: Breakdown of produced PV cells by technology on global scale for the period 1999 to 2005

Source: (Photon, 4/2007)

Figure 8 shows that polycrystalline silicon dominates among produced PV cell technologies although its share is decreasing continuously since 2003. Despite the shortage of polycrystalline, crystalline silicon technologies still comprise about 93% of the market in 2006 (compared to 94% in the previous year). Currently there is strong interest in the higher conversion efficiency as achievable with monocrystalline products (Mints et al, 2007). Consequently, in 2006 the market share of monocrystalline technologies has increased while polycrystalline technologies decreased by about 6% - due to a lack of access to polysilicon the ranking of some traditional market players like the manufacturers Schott or BP and Shell has decreased as well (Bradford and Maycock, 2007).

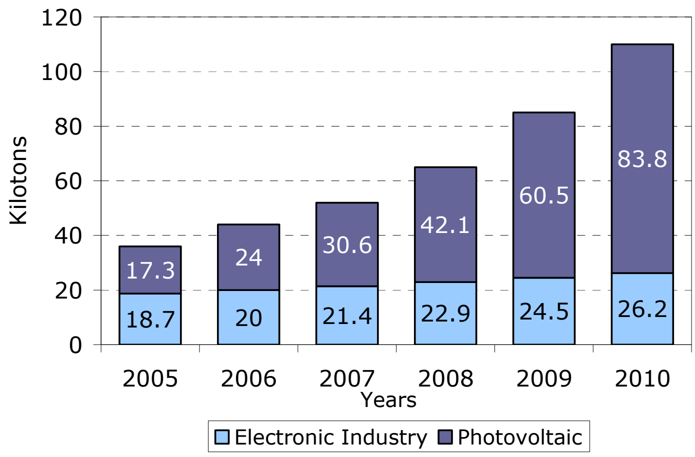

Figure 9: Forecast of silicon production until 2010

Source: (Photon, 2/2007)

Figure 9 shows according to a forecast of Photon consulting (Photon, 2/2007) that silicon production will achieve about 110 kilotons in 2010, of which approx. 84 kilotons are dedicated to the PV sector. The comparison of this silicon production with PV expansion plans indicates that there will again appear a shortage on the market – where supply cannot follow demand.

3 GLOBAL PV MARKET INTERACTIONS

In this section we present an analysis of interactions and impacts arising from global developments on the PV market from contrary perspectives - on the one hand from the demand side's viewpoint and, on the other hand, from the perspective of the supply side.

3.1 Demand side perspective

With regard to the demand side two aspects are in focus: Firstly, the effects of globalization on the quality of products and confidentiality for consumers and, secondly, the reduction of PV system prices for consumers.

3.1.1 Quality implications

The global movements on the market for PV cells and systems awoke the fear of a loss of quality, implying some sort of suspicion and prejudice on quality standards in emerging economies. In fact, at present some small Chinese manufactures offer PV systems at lower prices but with reduced efficiency and guarantee.

Table 2 provides a comparison of conversion efficiencies of various solar cells as measured in laboratories in China and at global scale. The lower cell efficiencies in China compared to the rest of the world under laboratory conditions can be explained by the fact that China invested so far less in R&D, and also PV market deployment lacks behind in comparison with other PV manufacturing countries. Nevertheless, the need for a functioning domestic solar market is increasing also in China.

Table 2: Best conversion efficiency of various solar cells developed in laboratories in China and in the World

Source: (Marigo, 2006b) based on for China (REDP, 04) and For World (Green et al., 06)

Category	**China**		**World**	
	Efficiency (%)	Area (cm²)	Efficiency (%)	Area (cm²)
Silicon				
Mono- Si cell	20.4	4	24.7± 0.5	4
Poly- Si cell	16	4	20.3 ± 0.5	1.002
Si (thin film)	13.6	1	16.6 ± 0.4	4.017
III-V Cells				
GaAs (crystalline)	21.9	1	25.1 ± 0.8	3.91
Thin film				
CIGS (cell)	12.1 (CIS cells)	1	18.4 ± 0.5	1.04
CdTe (cell)	13.36	0,5	16.5 ± 0.5	1.032
Amorphous Si				
Si (amorphous)	8.6	100	9.5 ± 0.3	1.07

However, as indicated in Table 3 on the commercial side cell and module efficiencies have improved and no differences are applicable between China and the rest of the world. Considering that Chinese PV exports represent 80% at present (Marigoa, 2006a), it is possible to affirm that a big part of the industry tries to satisfy the overseas exigencies of the market (Marigo, 2006b). Companies are increasing the quality in terms of cell and module efficiencies in order to obtain international quality certifications as required by European countries and the USA (Marigo, 2006a).

Table 3: Commercial solar PV module efficiency in China and in the World

Source: (Marigo, 2006b)

Category	China		World	
	Efficiency (%)	Module (model & dimension)	Efficiency (%)	Module (model & dimension)
Mono-Si module	14	Suntech STP175S-24/Ab 1580 x 808 x 50 mm	14,2	Sharp NT-185-U1 1575 x 826 x 46 mm
Poly-Si-module	13	Suntech STP060-12/Nb 995 x 453 x 30 mm	12,6	Sharp ND-167-U1 1328 x 1004 x 46 mm
a - Si	5	Soltech PVS 60-24 1549 x 787 mm	5	RWE Schott Solar 1000 x 600 mm

The PV installers and PV owners consider besides system prices also solar energy yields as arising over the at least 20 years of the system's lifetime. A difference of just 10 kWh per kW_p justifies a 1% difference in PV system prices which also indicates the quality. In this context, a certificate as issued by the IEC (International Electrotechnical Commission) assures certain minimum quality standards for PV systems. According to a survey from Photon (7/2007) every second PV installer in Germany is ready to test solar modules from China that posses ICE-Certificates.

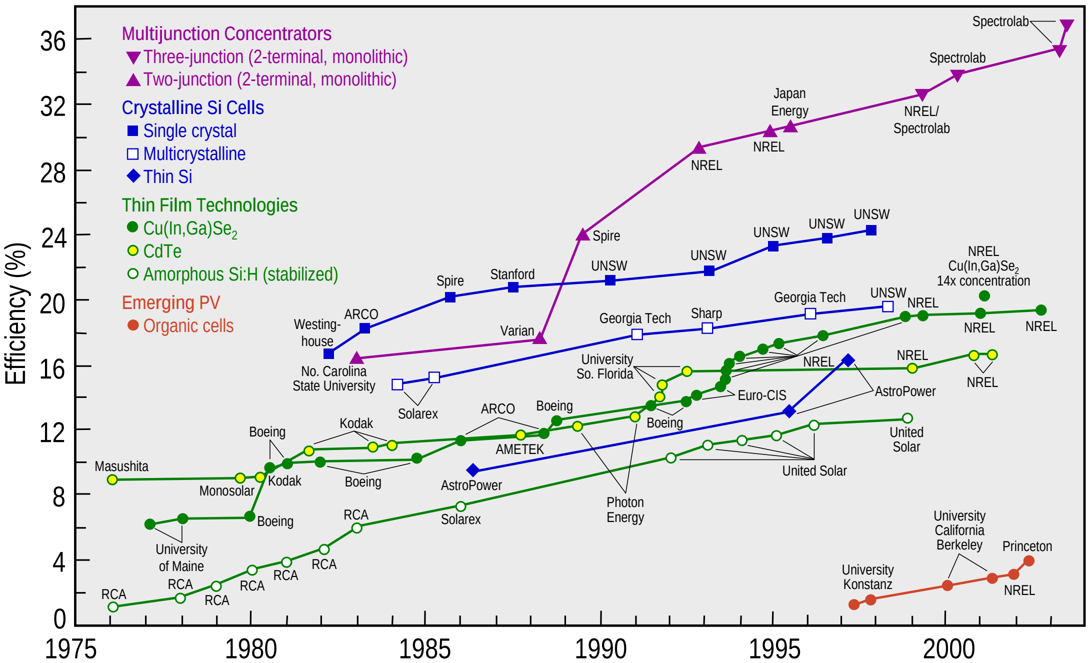

Figure 10: Best research cell efficiencies

Source: NREL

Figure 10 shows the development efficiencies of different solar cells under laboratory conditions from 1975 to 2003, indicating a continuous increase over the whole period. As expected by EPIA & Greenpeace (2007) this trend will continue in the future – see Figure 11.

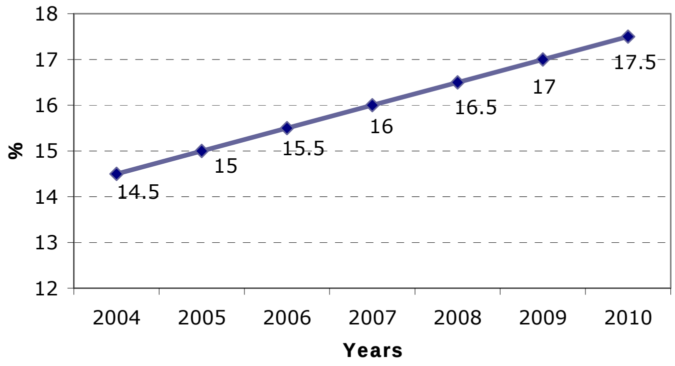

Figure 11: Development of average cell efficiency for crystalline cells

Source: (EPIA & Greenpeace, 2007)

3.1.2 PV system price reductions

In terms of price reductions two components have to be considered: Global and local components – whereas the module prices are determined essentially by global developments, whilst the installation cost are determined by local conditions.

Figure 12 indicates a comparison of module and non-module costs for Germany, Japan and Spain. The latter represents an emerging market where typically non-module costs (e.g. installation) are higher in comparison to already matured countries. Nevertheless, in Spain a fast reduction of other costs can be observed within the short period of one year (i.e. from 2004 to 2005).

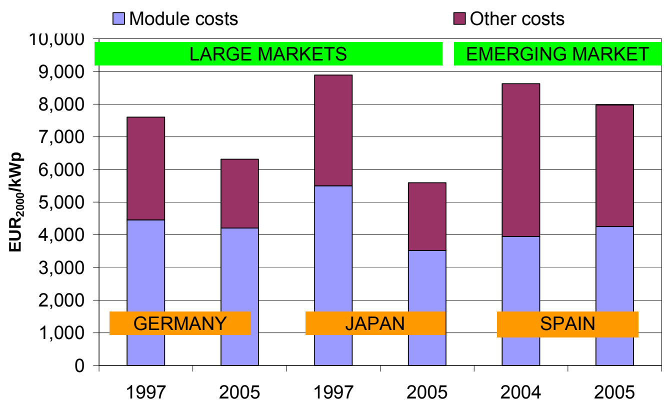

Figure 12: Comparison of module costs and non module costs for two large markets (Germany and Japan) and one emerging market (Spain)

Source: (Lopez-Polo et al., 2007)

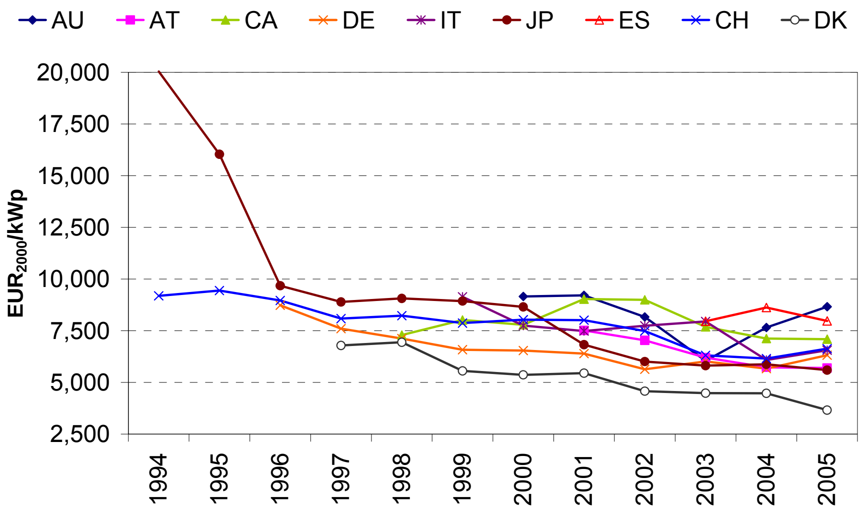

Figure 13: PV System Cost reduction over time

Source: (Lopez-Polo et al., 2007)

Figure 13 shows in detail the cost evolution in different countries for the period 1994 to 2005, referring to PV systems as installed in the residential sector. Despite the decrease of system costs over the whole period from 1994 to 2003, most depicted countries experienced an increase in the last years stipulated by the rising demand especially in Germany.

3.2 Supply side perspective

The supply side of PV is facing new challenges with ongoing globalisation. The impact of new market entrepreneurs in emerging economies is exemplified for the fast growing manufacturing market in China in the following sub-section. We then conclude this chapter by application of the learning curve approach in order to briefly describe the historically achieved and the expected future technological progress in terms of cost reductions with regard to PV cells and systems.

3.2.1 Impact of new markets - the case of China

The main obstacle for the European industry represents the increased competition arising from the cost effectiveness of Chinese products (see Table 4).

Table 4: Chinese module prices vs. German and Japanese due to diverse companies

Source: (Photon, 7/2007)

Country	**Company**	**€ / W**
Germany	Solar Fabrik, Solarworld, Aleo, Solon or Solara	3.30-3.68
Japan	Sharp, Kyocera	3.11-3.29
	Sanyo	from 3.50
China	Suntech Power	2.98-3.06
	Yingli	2.84
	Trina and Solarfun	2.91-2.99
	Sunlink PV oder ET Solar	2.78-2.84

The Chinese solar modules are about 10% to 20% favourable in terms of cost compared to European or Japanese products (Photon, 7/2007). Thereby, the role of low labour cost plays a minor role than expected. The major reasons are diverse savings referring to the low price of production equipment and consumables. The Chinese manufacturers have a higher flexibility due to the higher share of handcraft, consequently, they can easily adapt to the improvements than automated European enterprises (Photon, 7/2007).

Against these advantages Chinese manufacturers have to pay high silicon prices due to a lack of long term contracts with raw material producers. Therefore, they meet a large part of the requested silicon on the spot market (Photon, 7/2007). On the long-term market 1 kg silicon costs about 50 EUR and the production has been already sold for the forthcoming years, whilst the price on the spot market is currently on a level of 150 EUR (Photon, 2/2007). Contrary to China, European manufacturers have assured their silicon supply until 2010 which can be seen as a reducing factor for the risk arising from the increased competition with ongoing globalisation. Furthermore, it is also expected that European manufacturers reduce their costs about 25% until 2010 (Photon, 7/2007).

Besides the aspects discussed above, cost reductions in more high tech manufacturing activities are becoming more and more relevant – also for China. Since the political support for a development of PV is limited in the domestic market most of Chinese producers will continue their export activities especially to Germany as currently worldwide mainly Germany is implementing a PV support without introducing a cap in terms of qualified installations.

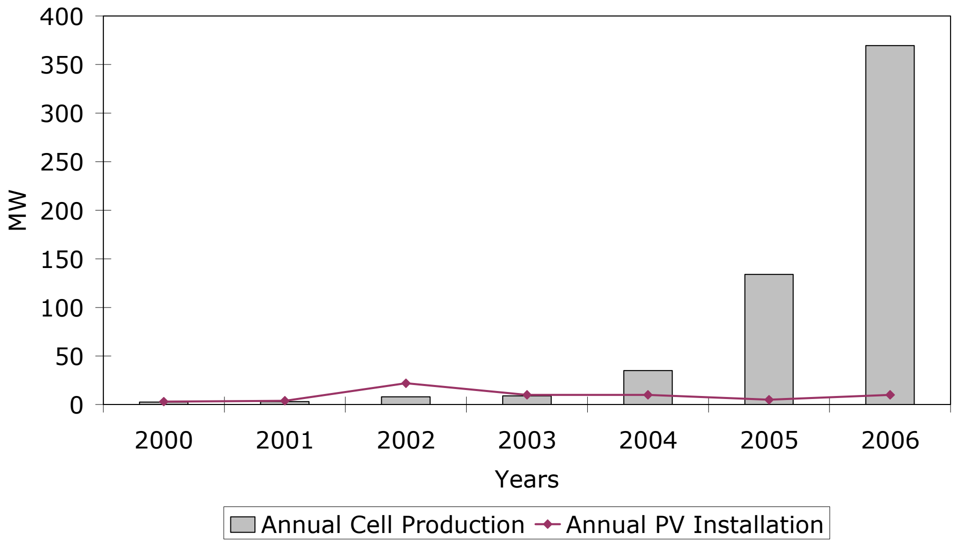

Figure 14: Annual PV installation vs. annual produced cell in China

Source: (Bradford and Maycock, 2007) and (ter Horst et al., 2006)

The dominance of exports for Chinese PV manufacturers is also illustrated in Figure 14, indicating the yearly PV production in comparison to domestic installations. While the cell production in China achieved about 370 MW in 2006, the yearly installed capacity in this year was just 10 MW. It is getting apparent that Chinese PV industry is dependent on the support policies as provided in other countries worldwide. Accordingly, any changes on these policies could cause troubles for the Chinese PV industry (Sicheng, 2006).

There is a close relationship between price and quality in China. However, the general prejudice that Chinese modules have comparatively poor quality cannot be confirmed. As mentioned in section 3.1.1 similar standards have to be met worldwide to achieve certification as often preconditioned for receiving policy support.

3.3 Technological Learning of PV cells and systems

Photovoltaic is currently a costly technology which, besides niche markets and under special conditions, requires support to deploy on the power market. However, this technology represents a promising future option with a high potential for future cost reductions. This can be argued with the so called "learning (experience) curve"[3], indicating how costs decline with increased deployment. For a broad set of commodities the empirical evidence has been derived that costs decline by a constant percentage with each doubling of the units produced or installed, respectively.

In the case of PV it is useful to differentiate between PV modules and BOS (Balance of Systems). The latter generally comprises the PV system components except the modules, including installation cost. Module costs are related specifically to experiences gained with the PV technology globally, whilst BOS components benefit from spill over knowledge as gained also in other sectors. Cost reductions in BOS typically also comprise a high share of local learning.

As indicated in Figure 15, according to a study of Photex (2004), the progress ratio for PV modules is in size of 80±0.4%, equivalent to learning rate (LR) of 20±0.4%. Furthermore, this analysis shows that the learning rate for PV modules has improved from 20% to 23±1.5%. This study also indicates a progress ratio of about 78% for BOS in Germany and 81% in the Netherlands over the period 1992-2001 for residential systems. These values are close to the PR value of modules (Photex, 2004).

---

[3] In general, an experience curve is expressed as follows:

$$C_{CUM} = C_0 * CUM^b$$

where:

CCUM	Costs per unit as a function of output
C0	Costs of the first unit produced or installed
CUM	Cumulative production over time
b	Experience index

Thereby, the experience index (b) is used to describe the relative cost reduction – i.e. (1-2b) – for each doubling of the cumulative production. The value (2b) is called the progress ratio (PR) of cost reduction. Progress ratios or their pendant, the learning rates (LR) – i.e. LR=1-PR – are used to express the progress of cost reduction for different technologies. Hence, a progress ratio of 85% means that costs per unit are reduced by 15% for each time cumulative production is doubled.

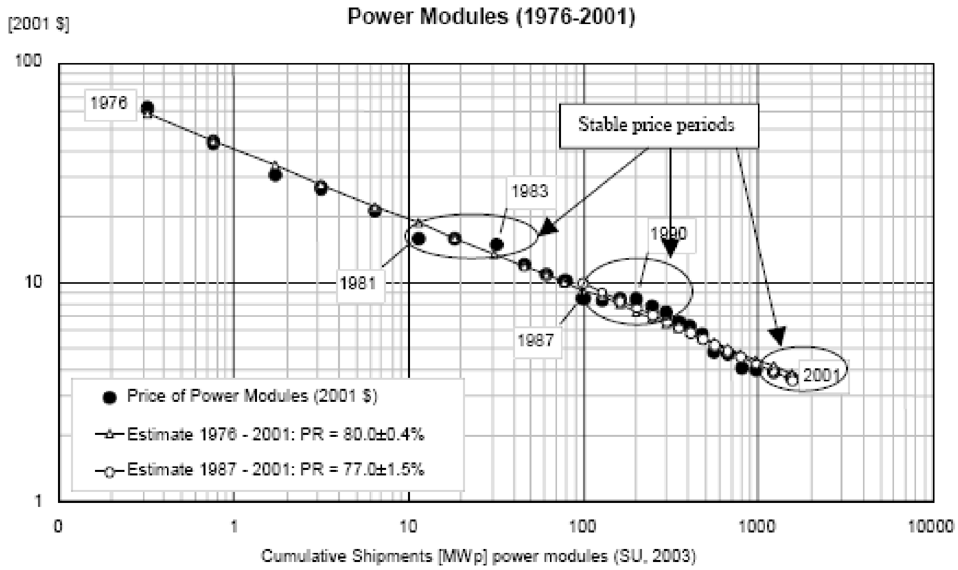

Figure 15: Experience curve for module prices (GlobaL Average selling Price)

Source: (Photex, 2004) original data from (SU, 2003)

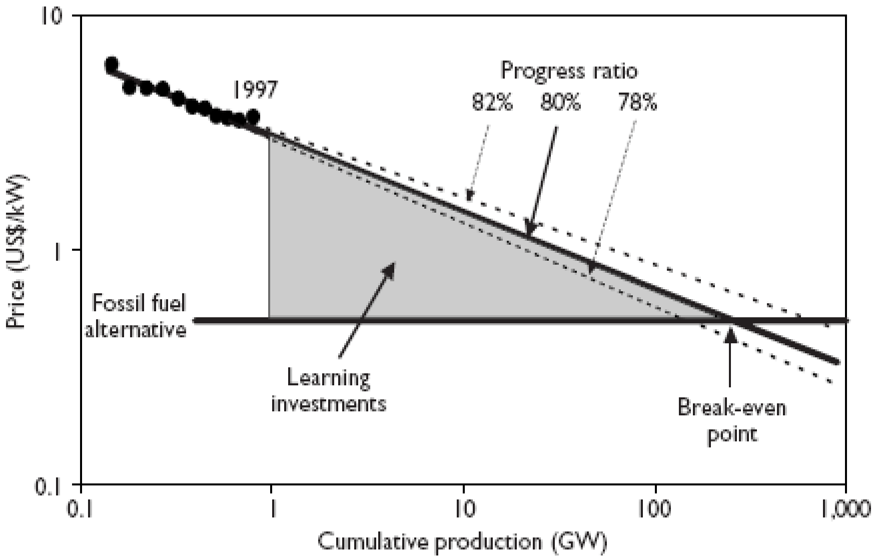

Figure 16: Break-even point and learning investments for photovoltaic modules with a progress ratio of 80%.

Source: (IEA, 2000)

“The experience curve shows the investment necessary to make a technology, such as PV, competitive, but it does not forecast when the technology will break-even. The time of break even depends on deployment rates, which the decision-maker can influence through policy. With historical annual growth rates of 15%, photovoltaic modules will reach break-even point around the year 2025. Doubling the rate of growth will move the break-even point 10 years ahead to 2015” (IEA, 2000).

Obviously, in the case of PV impressive additional investments are needed to reach the break-even point, i.e. the production cost level as observed at present on the market, set by currently mature technologies (fossil power generation). The required additional investment costs are referred in IEA (2000) as "learning investments", indicated for the case of PV by the shaded triangle in Figure 16. This figure also shows how changes in the assumed future progress ratio (i.e. by expressing besides the default value of 80% also a range from 78% to 82%) affect the achievement of the break-even point. "*The sum of all future learning investments needed to bring module technology to the breakeven point indicated in the figure is 60 billion US$. This is a substantial investment in learning, considering the learning investments of 3-4 billion US$ made in PV modules until 1998*" (IEA, 2000).

4 FUTURE PROSPECTS

The PV industry has made impressive progress in the last years. This effect is evidenced by the achieved price reduction, by the increase of the conversion efficiencies of solar cells, by the development of new technologies and by a strongly improved system reliability and energy yield.

4.1 Worldwide Expectations

According to the advanced scenario taken from Epia & Greenpeace (2007)`s Solar Generation scenarios, the annual PV installation will achieve 5,6 GW_p by 2010, continue to increase to 44 GW_p in 2020, and account for impressive 179 GW_p by 2030. The corresponding cumulative PV capacity in 2030 is in size of almost 1300 GW_p. The moderate scenario from the same study predicts for the yearly PV installation in 2010 4.2 GW_p, 28 GW_p in 2020 and 84 GW_p in 2030 (see Figure 17) corresponding then to a cumulative capacity in size of more than 700 GW_p. This "moderate" view for the near future is confirmed by estimates from Sarasin (2007), predicting an increase of yearly PV installations from currently (2006) 1.7 GW_p to 4.1 GW_p in 2010.

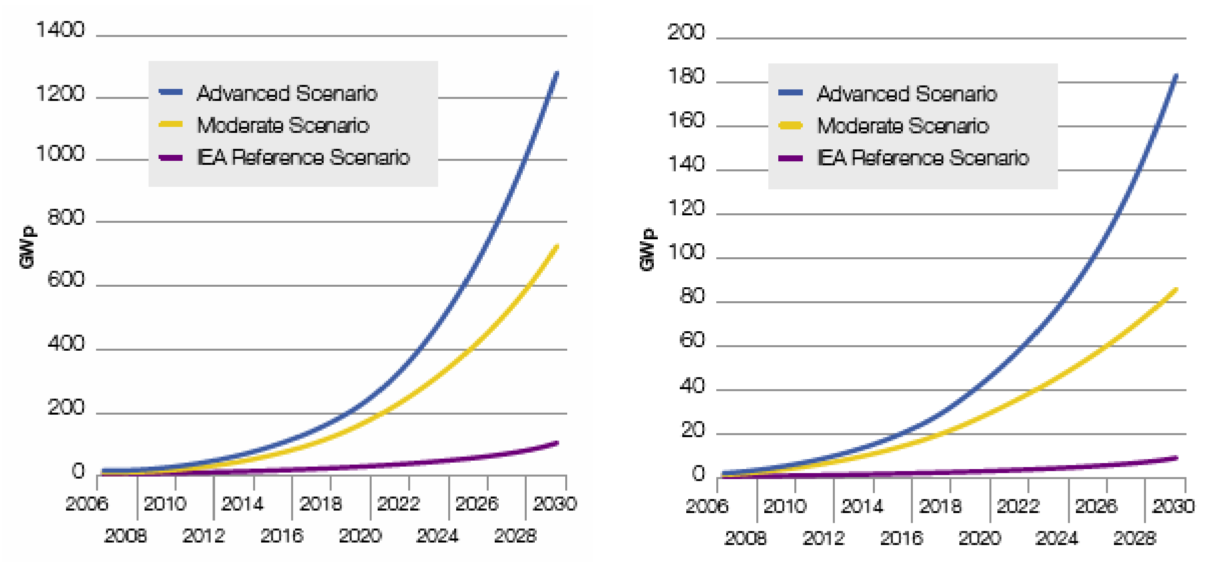

Figure 17: Global PV cumulative capacity (left) and global annual PV capacity (right) up to 2030

Source: (Epia & Greenpeace, 2007)

Table 5 shows the regional breakdown of annual and cumulative PV installations of Epia & Greenpeace's scenarios discussed above. In both cases industrialised countries dominate the market - Europe followed by the OECD pacific and North America. However, many studies and assessments as observed in literature foresee that especially China and also Africa will make a significant contribution to the global PV market in the future.

Table 5: Solar Generation scenarios break down in terms of regions of the world

Source: (Epia & Greenpeace, 2007)

	Annual PV installation by regional share			Cumulative PV installation by regional share		
	2006	**2020**	**2030**	**2006**	**2020**	**2030**
OECD Europe	60%	32.3%	10%	43.7%	39.9%	22%
OECD North America	8.3%	14.9%	13%	10%	15.4%	14%
OECD Pasific	23.4%	13.6%	6%	27.5%	17.3%	10%
Central and South America	1.3%	5.6%	11%	4.6%	3.8%	8%
East Asia	1.5%	4.2%	8%	2.3%	2.9%	6%
China	0.3%	10.4%	18%	1.2%	7.7%	14%
South Asia	0.9%	9.1%	15%	3.8%	6.9%	12%
Middle East	0.5%	1.6%	3%	2.1%	1.1%	2%
Africa	1.5%	6.1%	12%	3.9%	4.1%	9%
Economies in Transition	0.5%	2%	4%	0.4%	1.3%	3%
Consumer Goods	1.8%	0.3%	0%			

For the near future up to 2010 a study recently published by the bank institution Sarasin (Sarasin, 2006) predicts in its scenario the yearly new installed PV capacities based on an intensive market survey. It is stated therein that Germany and Japan will become less important – i.e. Germany's share on the global market will drop from 55% in 2005 to 22% in 2010, and Japan's from 23% to 13%. Other European markets such as Spain, Portugal and Italy are expected to become more important in the near future. The estimates for Asia point to China, India, South Korea, Taiwan and Thailand as they act well on their way from emerging to globally important PV markets (Sarasin, 2006).

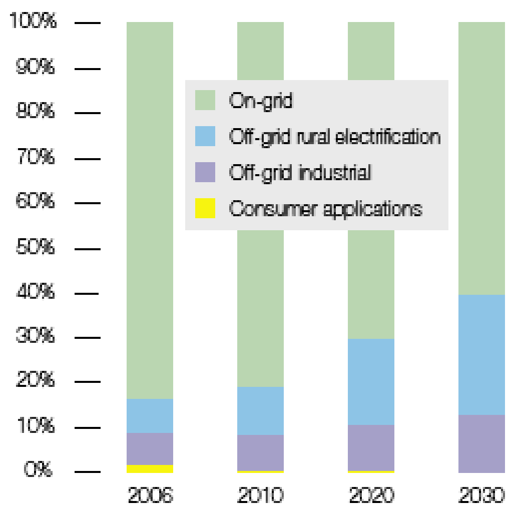

Figure 18: Annual PV installation by applications

Source: (Epia & Greenpeace, 2007)

It is a fact that today in developing and emerging economies about two billion people have no access to electricity, mainly within the rural areas. Hence, it is expected that the importance of rural electrification will increase. This development is currently dominated by grid systems, but it is expected that this will lose share in favour of off-grid rural applications. Epia & Greenpeace (2007)'s view in this respect is illustrated in Figure 18 – where off-grid system refer to about 40% of the yearly new installations by 2030.

Table 6: Expected PV generation costs for roof-top systems at different locations in €

Source: (Epia & Greenpeace, 2007)

	Sunshine hours	2006	2010	2020	2030
Berlin	900	0.45	0.35	0.20	0.13
Paris	1000	0.40	0.31	0.18	0.12
Washington	1200	0.34	0.26	0.15	0.10
Hong Kong	1300	0.31	0.24	0.14	0.09
Sydney/Buenos Aires/ Bombay/Madrid	1400	0.29	0.22	0.13	0.08
Bangkok	1600	0.25	0.20	0.11	0.07
Los Angeles/Dubai	1800	0.22	0.17	0.10	0.07

Table 6 indicates the current levels and future expectations on PV generation costs for small-scale distributed systems in selected major cities worldwide. As indicated therein, Epia & Greenpeace expect that by 2020 the PV generation cost will have halved compared to the status quo (Epia & Greenpeace, 2007).

4.2 Future Plans of selected countries

In this section the future plans of selected countries outside of Europe are illustrated. A geographical focus was put on Asia, selecting relevant countries with regard to the demand (customer market) and / or the supply (manufacturing) for PV. The (former) market leader Japan as well as emerging countries like China, India, Taiwan and Korea will be discussed briefly below.

4.2.1 Japan

Japan is an important market player with respect to both the global supply, i.e. its domestic PV industry, and the demand for PV, i.e. its strong domestic market. This country was the worldwide market leader until the end of 2004 and after this year changed its first place in favour of Germany. The total installed PV power at the end of 2006 was about 1708.5 MW_p (IEA-PVPS, 2007) and total shipment was about 928 MW_p with a business value of 4 billion USD. In 2006 total shipment has not increased as large as compared with 2005 (see Table 1) due to a shortage of the required raw material silicon (Honda, 2007).

Japan’s roadmap for PV assumes that about 50% of residential electricity demand, corresponding to about 10% of the total domestic electricity demand, can be met by electricity from PV systems by 2030. This would imply to achieve a cumulative capacity of approx. 100 GW_p (III-Vs Review, 2005). In the Japanese Roadmap, the generating costs are indicated for 2010 to reach a level of 23 JPY/kWh, 14 JPY/kWh in 2020, and 7 JPY/kWh by 2030. In this context, Table 7 summarises the targets with regard to deployment and cost of PV roadmap.

According to the revised JPEA road map to 2030 (JPEA, June-2006), in 2030 PV industry business scale will become to 20,000 million USD and job creation 300,000. From the viewpoint of the Japanese industry, there will be a sharp increase in export up to 2010, triggered by favourable markets in Europe and the USA (Honda, 2007).

Table 7: Japanese PV Roadmap 2030

Source: (Honda, 2007) based on (NEDO, 2003-2004)

Targeted by	PV electricity cost (Equivalent to the tariff for)	Module Cost	Target efficiency % of cell Module				
			Cry-Si	TF-Si	CIS	III-V	Dye-
2010	23 JPY/kWh (residential use)	100 JPY/W	20 / 16	15 / 12	19 / 13	40 / 28	10 / 6
2020	14 JPY/kWh (Business use)	75 JPY/W	25 / 19	18 / 14	25 / 18	45 / 35	15 / 10
2030	7 JPY/kWh (generating use)	< 50 JPY/W	25 / 22	20 / 18	25 / 22	50 / 40	18 / 15

The goal of the current Japanese national PV programme is to achieve a cumulative PV capacity of 4820 MW_p already by 2010. However, even optimistic prognoses despair that this target can be achieved (Photon, 12/2006).

4.2.2 China

By the end of 2006, China's installed capacity of PV systems is about 80 MW, of which approximately 50% is used to supply electricity in remote rural areas without grid connection. The future potential is seen as enormous and most areas within China comprise also a high solar irradiation. Of course, the dominant hindrance at present and in the near future is the high cost. Consequently, in the near term the major utilization of solar PV will still be to provide power in remote areas and for industrial use, whilst grid-connected PV will remain in its demonstration stage (see Table 8).

About 67% of Chinese primary energy demand is met by coal. This causes huge environmental effects and there is need to develop renewable energies (III-Vs Review, 2005). It is expected that by the year 2010, the total installed PV capacity will reach 400 MW_p and the approx. 2 GW_p by the year of 2020 and 100 GW_p by 2050 which will correspond to approx. 5 % of total power supply. If Chinese Renewable Energy Law (REL) – which came into force at the beginning 2006 – is fully implemented and effective also at the provincial level, it is seen as not too difficult to reach this target (Sicheng, 2006).

Table 8: Future prediction of PV Market by applications

Source: (Sicheng, 2006)

	2004		**2010**		**2020**	
Market Sector	**Installed PV (MW_p)**	**Market Share (%)**	**Installed PV (MW_p)**	**Market Share (%)**	**Installed PV (MW_p)**	**Market Share (%)**
Rural Electrification	30	46.2	250	62.4	500	28
Communication & Industry	24	36.9	47	11.8	400	22
PV Products	8	12.3	30	7.6	100	6
BIPV	2.8	4.3	53	13.2	600	33
VLS-PV	0.2	0.3	20	5	200	11
Total	65	100	400	100	1800	100

Note: PV Products: calculators, garden lights, torches etc. and VLS-PV (Very large scale PV systems)

4.2.3 India

With respect to PV, India has an expanding domestic industry sector: Recent figures indicate 9 solar cell manufactures, 22 PV module manufactures, and 50 PV systems manufacturers.

Due to its location between the Tropic of Cancer and the Equator, India offers a huge solar potential. The sunniest areas are situated in the south/east coast, from Calcutta to Madras. As stated for China, the predominant current barrier to a mass deployment is the high cost.

In India there are 120,000 villages which don't have access to electricity and about 20,000 of them remote for which PV electricity would offer a suitable solution (Photon 6/2006).

The PV roadmap in India plans a new annual installation of 1500 MW in 2020 and 3000 MW in the year 2027. During 2005-2006, India introduced two new initiatives, the National Electricity Policy and the "Rajiv Gandhi Gramin Vidyutikaran Yojana (RGGVY)", both giving important implications for rural electrification. In particular, RGGVY is targeting electricity access to all households by 2012, with the exception of homes in certain remote villages (IEA-PVPS, 2007).

A study from he Indian Ministry of Non-Conventional Energy Sources (MNES) named "New and renewable energy policy 2005" offers the following expectations: In 2021 the grid-connected PV energy should be competitive and a scenario projects that in 2100 about 42% of the Indian energy mix comes from solar energy. This value includes also solar thermal power plants. (Photon 6/2006)

During the last several years the Indian PV industry has been growing steadily at 20-25% only with c-Si based PV modules despite shortage of silicon feed stock. In addition thin film modules will make very significant contribution (Barua, 2007). Table 9 shows the growth projections of PV modules in India until 2020.

Table 9: Projections of PV modules production in India upto 2022

Source: (Barua, 2007)

Year	Production MWp		Total Production MWp
	c-Si	Thin Film	
2006	65	-	65
2007	80	-	80
2012	200	150	650
2017	500	300	800
2020	1500	1500	3000

4.2.4 Korea

In 2006 in Korea the total installed PV capacity increased dramatically to 34.7 MW_p. The majority of this increase came from the financial support as offered by the feed in tariff system for 3 kW_p residential roof top applications under the "100,000 solar roof program" launched by the Korean Ministry of Commerce in 2002.

Under Koreas new national PV Plan the goal has been set to 100,000 PV roofs and 70,000 buildings with PV providing a total capacity of 1.3 GW in 2012 which indicate an expectation of an explosive market growth between 2006 and 2012 (IEA-PVPS, 2007).

In 2003 the Korea Energy Management Corporation (KEMCO) set up the R&D Center for Photovoltaics to further coordinate PV related R&D between academia and industry. Apart from improving manufacturing technology, universities and national laboratories are working on a wide range of materials research. Korea Advanced Institute of Science and Technology (KAIST) focuses on high efficiency a-Si (thin film solar cells) for low cost, large area modules. Korea Institute of Energy Research (KIER) is studying CIGS and polycrystalline Si thin films. Dye sensitised cells are also being investigated by other groups (III-Vs Review, 2005).

Korea has also several projects of multi-scale in the planning stage involving local governments and local utilities as well as foreign companies (IEA-PVPS, 2007).

4.2.5 Taiwan

Taiwan is becoming an important global player with regard to the manufacturing industry of PV. In 2006 177.5 MW_p, corresponding to a share of 7% on the total global solar cell production came from this country. The ministry of Economy of Taiwan hopes, that in five or six years the PV-companies in Taiwan will be competitive to the manufacturers in Germany and Japan. These hopes appear optimistic as currently almost no domestic PV market exists and the industry is heavily dependent on exports. A renewable energy law is waiting since six years to be adopted by the parliament (Photon 9/2006).

The largest Taiwanese solar cell company Motech improved its ranking in the global record from 9 to 7 within one year (2005 to 2006), corresponding to a production volume of 110 MW_p in 2006 (see Table 1).

5 THE CONTRIBUTION OF PV TO THE REDUCTION OF ENVIRONMENTAL COSTS

Emissions caused by energy generation damage a wide range of receptors, such as human health, natural ecosystems and the built environment – specified as the external effects of energy supply. These effects cause also cost to the whole society as they are typically not paid by the polluter itself (Re-Xpansion, 2005).

In this context, the contribution of renewable energy in reducing greenhouse gas (GHG) emissions and air pollutants, and accordingly avoiding external costs is well known. However, also renewable energies cause (minor) emissions, mainly referring to manufacturing - i.e. in the case of PV during manufacturing of the solar cells. If we compare PV technologies[4] with other energy technologies we see that PV manufacturing cause considerably lower GHG emissions than all comparative fossil technologies (see Figure 19).

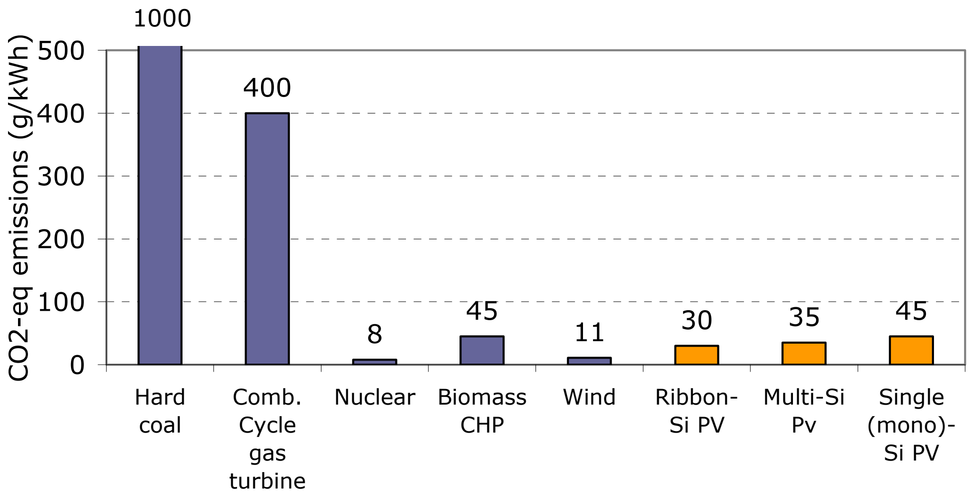

Figure 19: GHG emissions of PV systems based on three silicon technologies, compared to a number of other energy technologies

Source: (Alsema et al., 2006a)

More recent studies indicate that energy pay back time (EPBT) and related greenhouse gas emissions of PV systems are declining due to achieved technological progress in the manufacturing processes. Alsema et al. (2006b) has shown that there are good prospects for further reduction of GHG emissions, down to a comparatively low value of 15 g/kWh.

According to Krewitt et al. (2006), evaluating several external cost studies, the recommended valuation for loss expenses for GHG emissions are as follows;

15 €/t CO_2 → Low Valuation
70 €/t CO_2 → Median Valuation
280 €/t CO_2 → High Valuation

[4] The PV systems are installed on a roof top in South Europe where is irradiation 1700 kWh/m²/yr and have 30 years life time

The quantifiable loss expenses of several air pollutants and recommended external cost for GHG emissions, expressed in €/t, are listed in Table 10. Next, Table 11 shows the life cycle emission factors for different electricity generation technologies – from renewable energy to fossil technologies.

Table 10: Quantifiable Loss expenses of several air pollutants and greenhouse gas emissions (€/t)

Source: (Krewitt et al., 2006) based on (ExternE), (EcoSenseLE, 2006)

	CO_2	SO_2	NO_X	PM_{10}	NMVOC
Climate Change	70				
Health Damage		3060	3120	12000	230
Crop losses		-10	130		640
Material Damage		230	70		
Total	70	3280	3320	12000	870

Table 11: Life cycle emissions of different electricity generation technologies from renewables and fossil fuels

Source: (Krewitt et al., 2006) based on (Nitsch et al. 2004; Marheineke 2002)

	CO_2 g/kWh	SO_2 mg/kWh	NO_X mg/kWh	PM_{10} mg/kWh	NMVOC mg/kWh
Renewable Energies					
PV, Polycrystalline silicon (2000)	99	288	340	119 [1)]	20
PV (2030)	54	182	214	65 [1)]	13
Run of river (300kW)	13	28	49	31 [1)]	11
Wind onshore (1.5 MW)	10	40	31	42 [1)]	26
Wind offshore (2.5 MW)	9	35	21	11 [1)]	2
Geothermal	38	62	189	35 [1)]	n.a.
Concentrating solar thermal power plant (80 MW)	13	47	73	40 [1)]	2
Fossil Fuels					
Lignite-Steam power plants (η=40%)	1054	402	830	94	n.a.
Lignite-CCGT (η=48%)	873	235	354	79	n.a.
Hard Coal-Steam power plants	838	351	696	40	n.a.
Hard Coal-CCGT (η=46%)	780	287	435	34	n.a.
Gas-CCGT (η=58%)	386	125	351	21	n.a.

n.a. = not available; [1)] total particle emissions

Multiplying the monetary expression of loss expenses as illustrated in Table 10 with specific life-cycle emissions as expressed in Table 11, the external costs caused by the assessed energy technologies are derived, see Figure 20. In order to derive a net balance with regard to the avoidance of external cost for the case of PV, one has to subtract from the figure referring to the replaced fuel the amount of external cost referring to PV generation. For instance if we could replace 1 kWh electricity produced in a lignite steam power plant by PV electricity we can avoid 6.9 EUR-cent external costs.

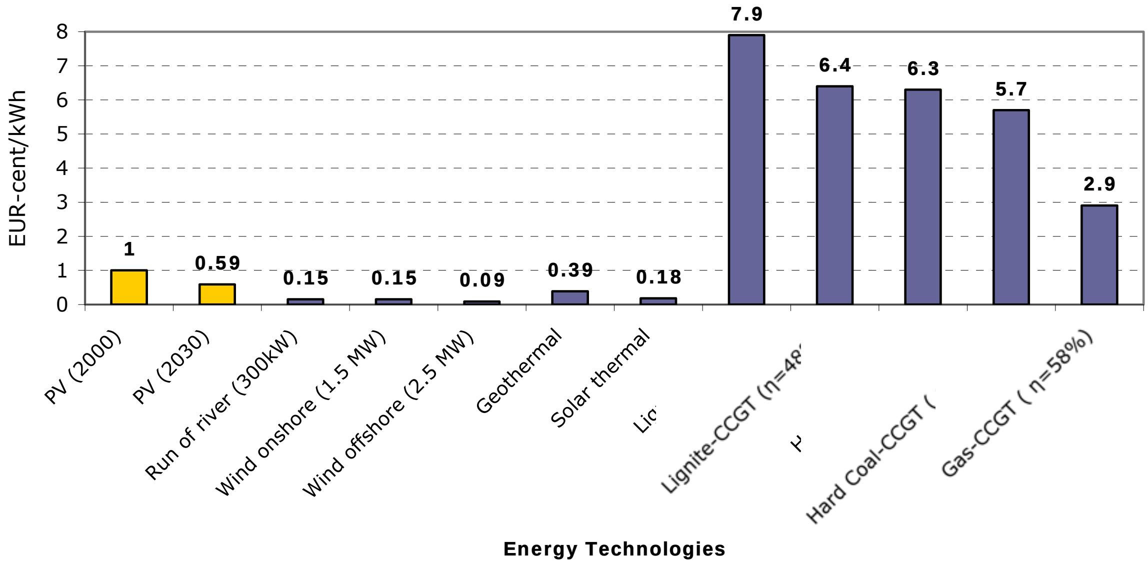

Figure 20: External cost of different energy technologies in EUR-cent / kWh (GHG emissions are valuated as 70 € / t CO_2 (median valuation))

This theoretical consideration of external cost arising from energy supply has also entered the political scene, and started to affect the utilities' investment decisions: Within the European Union the *Emission Trading Scheme (ETS)* – a cap and trade system which represents a cornerstone of the European Climate Change Programme – aims to result in an internalisation of external costs for green house gas emissions caused by the use of fossil fuels. As the ETS captures the energy sector, the implementation of the Kyoto Protocol leads to a change in electricity prices. In this context, a utility also has to pay the CO_2 certificate prices for emissions caused by generating electricity from fossil fuels. This represents an additional monetary burden from the utilities point of view which can be reduced by generating PV electricity. Taking into account the currently observed certificate price levels, we can express – similar to the theoretical example above – monetary savings for the utilities for alternatively generated PV electricity. With CO_2 prices on a level of 18 EUR on average (as observed from 2005 to October 2006), a utility can reduce its cost burden by about 1.7 EUR-Cent for each kWh generated PV electricity, assuming that it replaces with this electricity as otherwise generated in a lignite steam power plant.

6 THE CONTRIBUTION OF PV TO SUPPLY SECURITY

6.1 High oil and gas prices – Facing the energy crisis of today

One key argument for an accelerated deployment of renewable energies in general and PV in particular is besides environmental benefits the avoided risk of disruption in fossil fuel supply and of the associated price instability. Therefore renewable energies have a significant contribution towards supply security. Rising oil prices and both existing as well as (un)expected forthcoming crisis between countries associated with the fossil fuel supply, which is currently focussed on oil and gas, underpin the importance of forming diversified energy profiles largely based on clean and indigenous energy sources. Figure 21 depicts that fossil fuel prices and accordingly also electricity prices have continuously increased in the near past.

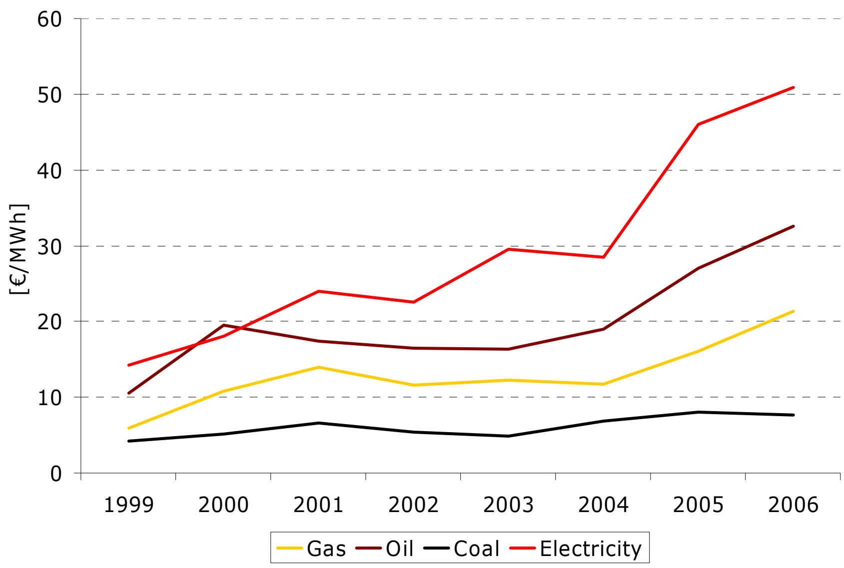

Figure 21: The price development of fossil fuels and electricity from 1999 until 2006

Source: EEX and BAFA

Although PV is one of the most prominent renewable energy technologies and dependent on a worldwide abundant fuel source – the sun, the currently comparatively high level of cost of this technology is still a huge barrier for an accelerated deployment. However, as described briefly in chapter 3.3, the PV technologies comprise also a large potential for promise cost reduction while the fossil fuel prices are increasing. In this respect in following the role of photovoltaic in energy portfolio will be analysed according to the some relevant literature briefly.

6.2 The Role of PV in the energy portfolio analysis

In finance a widely accepted approach to control risk is the Mean-Variance Portfolio Analysis. Recently, this was recognised also by the energy community. The IEA (2003) describes the role of the portfolio theory as follows: "*Portfolio-based techniques can suggest ways to develop diversified generating portfolios with known risk levels that are commensurate with their expected overall electricity generation costs. Simply put, the underlying insight is that efficient generating portfolio's can minimise society's energy price risk.*"

The volatility of fossil fuel prices perceives an important factor in the energy portfolio analysis. The change of input price can reduce the financial return of conventional generating technologies. The addition of renewable energy production capacity can reduce the total portfolio risk without a significant reduction of profitability. This fact should be considered by the energy planners. Consequently, they should try to reduce or minimise the risk by adding no-risk or neutral-risk technologies to their portfolios as illustrated schematically in

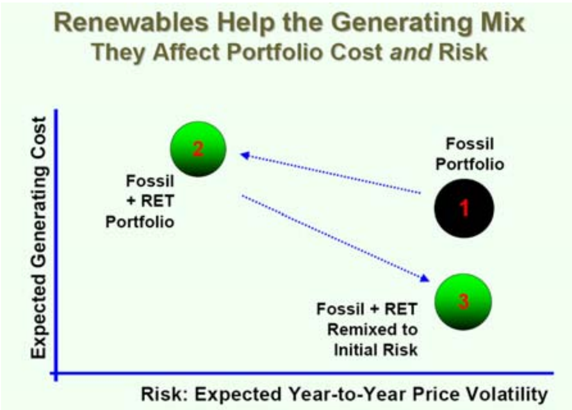

Figure 22: Schematic impact of the inclusion of renewable energy technologies (RET) into the generation portfolio

Source: (Albrecht, 2007)

According to Albrecht (2007), there are two reasons why renewable energies can be classified as risk-less technologies:

- ► Firstly, besides biomass, renewable energy technologies involve no price volatility with respect to the inputs – i.e. the fuel sources – from the point of installation[5].
- ► Secondly, investors also face no risks for future environmental restrictions by using renewable technologies.

The first point is facing increasing interest in combination with the depletion of fossil fuel reserves. It is a certainty, that fossil fuels are not unlimited available. The second point refers to the steady increase of greenhouse gas. The current use of oil and coal will gradually evolve into an environmental and also a social risk.

However, renewable energy technologies cannot be considered as a riskless technology. If we add to the fuel price volatility also the maintenance and operation cost risks, renewable technologies are no longer risk-free but bear some degree of market risk. In consideration of

[5] Of course, this cannot be stated for PV manufacturers as they face price volatility risks for the used materials – as e.g. the recent of scarcity of silicon. However, by focussing on the utility's and investor's viewpoint, this statement goes beyond the scope and can be neglected.

these aspects the portfolio analysis will be improved. But relevant data about these cost risks are hard to find or do not exist at present. However, the results from the new analysis confirm the conclusions of the analysis with only fuel price risk. This result is not surprising since the fuel risk dominates all the other market risks for the electricity sector.

There are two crucial questions in the future: Could we assume the low production costs of fossil power plant and how should the future energy and electricity infrastructure look like? If we add renewable energy technologies into an energy portfolio the risk will be reduced but also the revenue. After addition of RET and a clever remix of the fossil contingent we possibly reach the same risk level by reduction of the production costs as illustrated in Figure 22 above.

Focussing on PV, the disadvantage of the current PV costs and according to this fact the low financial return often reduces the share of PV in portfolios. Thereby, financial support as offered by energy policy strategies in several countries in Europe and at global scale aims to solve this deficit and, consequently, largely improves the competitiveness and role of PV. However, cost competitiveness represents a key criterion today and also for the future role of PV in electricity production and also for its relevance in energy portfolios.

7 SUMMARY AND CONCLUSIONS

PV technology and industry have made impressive progress in the last years. Yet, currently PV is still an expensive technology in comparison to other electricity generation technologies and its development is dependent on promotional drivers. According to the expectations of different studies, PV systems will become cost-competitive between 2015 and 2040. Some studies estimate that solar electricity generation options could, under favourable political circumstances, supply more than 25% of the worlds primary energy consumptions by 2050 and 64% by 2100 (WBGU, 2003).

The future expectations also show that the share of grid connected PV systems is expected to decline in favour of off-grid applications due to the need for electricity in the rural areas and the huge potential of emerging economies like China and India where also PV industry is becoming stronger.

From the historical viewpoint countries like Japan, Germany and USA have recognized the future potential of this technology and support this novel power generation option. The current and future perspectives of PV as also analysed in this study can be summarised generally as follows;

- PV industry offers a new businesses opportunity and export possibility and creates new jobs.
- The PV industry has achieved a considerable price reduction; the market observations in the period 1987 to 2001 indicate that a reduction of module costs (per kWp) by approx. 23% has been achieved with each doubling of cumulative production.
- The conversion efficiencies of solar cells and the overall reliability of PV systems are increasing.
- PV contributes to reducing greenhouse gas emissions and air pollutants as well as environmental costs, respectively.

The PV Market is dominated by solar cell modules based on the use of crystalline silicon wafers. Although this type of solar cells represents a robust and reliable technology, the share of thin film technologies is increasing because of their character which eliminates the use of comparatively expensive and material intensive silicon wafers. Especially the temporary shortage of silicon in the previous years has also played an important driver for accelerated research and development of thin film technology.

Like in almost all economic sectors also in the PV sector global rules are in force. PV markets and industries of industrialised countries and the recent developments of emerging economies like China, Taiwan, India, etc. interact with each other from different viewpoints. The manufacturing industry moves from Germany, Japan and the USA more and more to other zones - considerably to China - with diverse impacts on Europe.

The mutual effects of these developments can be summarised as follows:

- PV module costs got favourable in emerging economies - e.g. in China by 10% to 20% compared to the rest of the world. The increased competition was on of the key drivers for recently achieved cost reductions. Obviously, it also represents a new challenge for in particular European PV manufacturers which, on the one hand, have to assure their technological leadership also for the future by fostering R&D activities related to novel technological PV options, and, on the other hand, have to reduce their own manufacturing cost.
- The emerging economies which have entered the market for PV manufacturers are dependent on the support policies in other countries as they export most of their production to abroad. Any changes on these policies could cause troubles for them. This growing risk represents an important driver for the establishment of reasonable support incentives in order to build up their own domestic PV markets.
- Another positive effect of export activities of emerging economies is that such companies are forced to increase their product quality in order to meet the standards as set by European countries or the USA.

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