Socio-Economic Aspects
of
Photovoltaic Energy Technology

C. de Keizer
E.A. Alsema
W. van Sark

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Department of Science, Technology and Society
Copernicus Institute
Utrecht University

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Contents

1 Introduction

In this study we will review several socio-economic aspects of photovoltaic technology and photovoltaic energy generation. The study was conducted within the framework of the Integrated Project CrystalClear, which focuses at crystalline silicon technology for photovoltaic energy generation. In this study we consider mostly photovoltaic technology in general because the distinction between c-Si and other solar cell technologies is less relevant in our present context.
Most of the results and discussions are based on existing literature sources supplemented with some own research.

In chapter 2 we will first look into the current socio-economic impacts of PV technology, among production and market volumes, RD&D budgets, market subsidies and the amount of jobs created in the PV sector.
Subsequently, in chapter 3 we will investigate historic trends with regard to photovoltaic RD&D spending, technology development and production cost. One of the questions we will address in this chapter is how we can measure the effects of RD&D spending in the past. Also we address in chapter 3 the experience curves for PV modules and for PV systems.
Chapter 4 deals more with the future of PV technology. First we look at the break-even costs of grid-connected PV in Europe and secondly we review a number scenario studies that include PV generation.
In chapter 5, finally, we give a summary of the main findings and we draw some conclusions.

2 Current socio-economic impacts of PV technology

2.1 Introduction

In this chapter we will give an overview of the current economic position of PV technology in terms of market volumes, expenditures for newly installed systems, as well as the (public) spending for Research, Development and Demonstration activities. Also we will discuss market stimulation programmes and the number of jobs that has been created by the investments in PV technology.

2.2 Production and market volume

The volume of cell production increased from 1.3 MWp in 2004 to 1.8 GWp in 2005. The largest share of this, more than 1 GWp, was produced in Asia as can be seen in Figure 2-1. 28 % of the solar cells (515 MWp) were produced in Europe. Of these more than two thirds were produced in Germany. Next in the line is Spain with a production of circa 14 % of the European solar cells, followed by France with over 6 %, Norway with almost 4 % and Belgium, Italy and Switzerland with about 2 %. [Hirshman and Schmela, 2006]

As in previous years Sharp was the largest producer of solar cells, with a production of 428 MWp (24 %). In Europe the largest producer of solar cells was the German company Q-Cells with a production of 166 MWp. [Hirshman and Schmela, 2006]

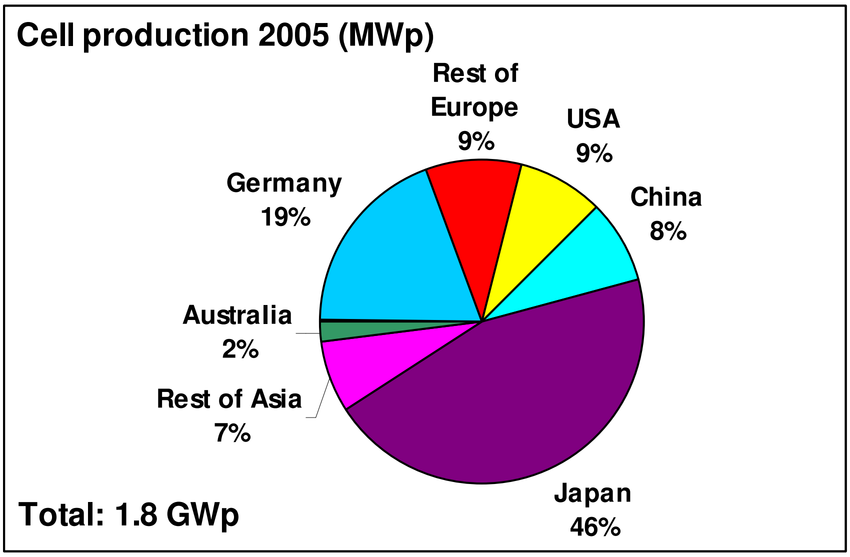


Figure 2-1 Cell production in 2005 [Hirshman and Schmela, 2006]

According to the photovoltaic energy barometer nearly 645 MWp of PV was installed in European Union countries in 2005. This is an increase of 18 % compared to the previous years. In Germany there is a dispute on the figures of installation between the industry organisation and the magazine Photon International. The barometer follows the German solar industry association BSW, who published a figure of 600 MWp installed power for 2005. A survey by the journal Photon of German inverter manufacturers led to a figure of 870 MWp for 2005 in Germany. Also for 2004 there was a dispute between the installation figures for Germany.

The runner up in PV system installations is Spain with 20 MWp PV installed in 2005, followed by France with more than 6 MWp and Italy with 5 MWp. In the United Kingdom, Austria and the Netherlands more than 2 MWp was installed in 2005.

The cumulative installed capacity in the European Union is 1.8 GWp, according to the photovoltaic barometer [Observ'ER, 2006].

Figure 2-2 shows the fuel shares of the total world primary energy supply in 2003. Although solar and wind energy constitute only a very small part of the total primary energy supply, they are part of the strongest growing sectors.

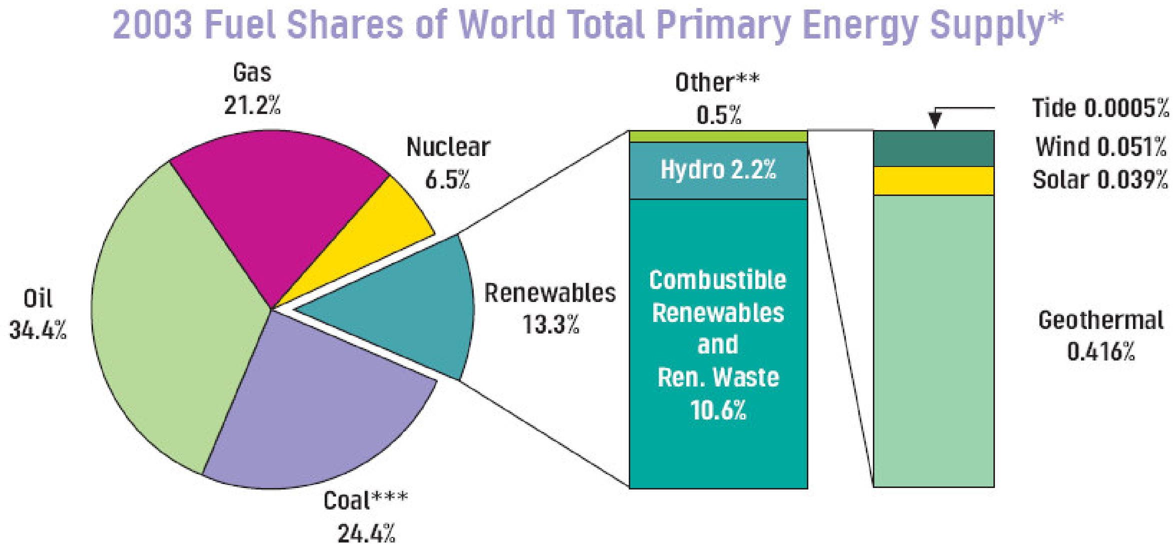


Figure 2-2 Fuel shares of world total primary energy supply [International Energy Agency, 2006]

2.3 Annual expenditures

Due to the growing market for solar energy the annual expenditures in the solar energy market have increased over the last years. The total net revenue increased from 8.3 billion US$ in 2004 to an expected 11.1 billion US$ in 2005 according to the Sun Screen II report by Credit Lyonnais Securities Asia (CLSA). This revenue is based on sale figures for 2004 and 2005 of respectively 1.15 GW and 1.5 GW and installed system prices of respectively 7.25 and 7.45 $/Wp. [Rogol and Fisher, 2005]

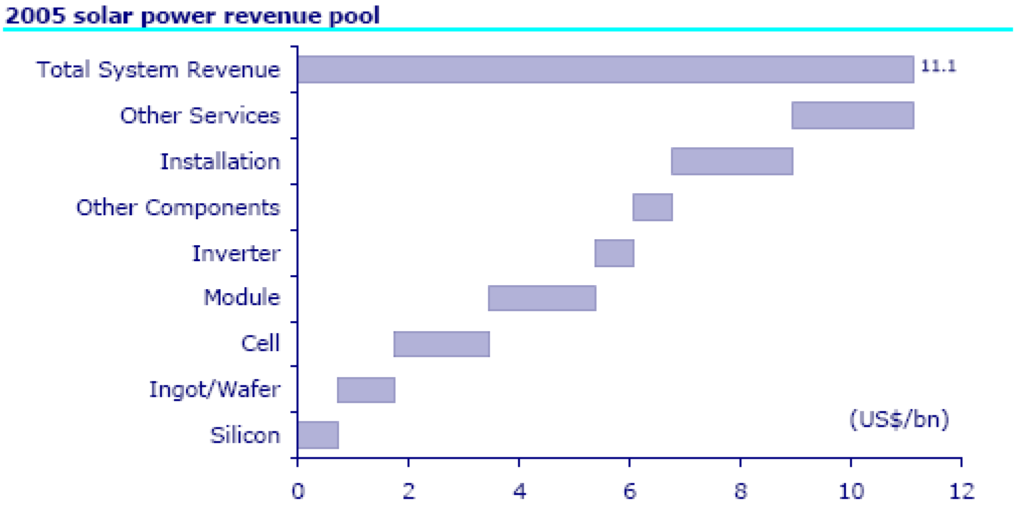
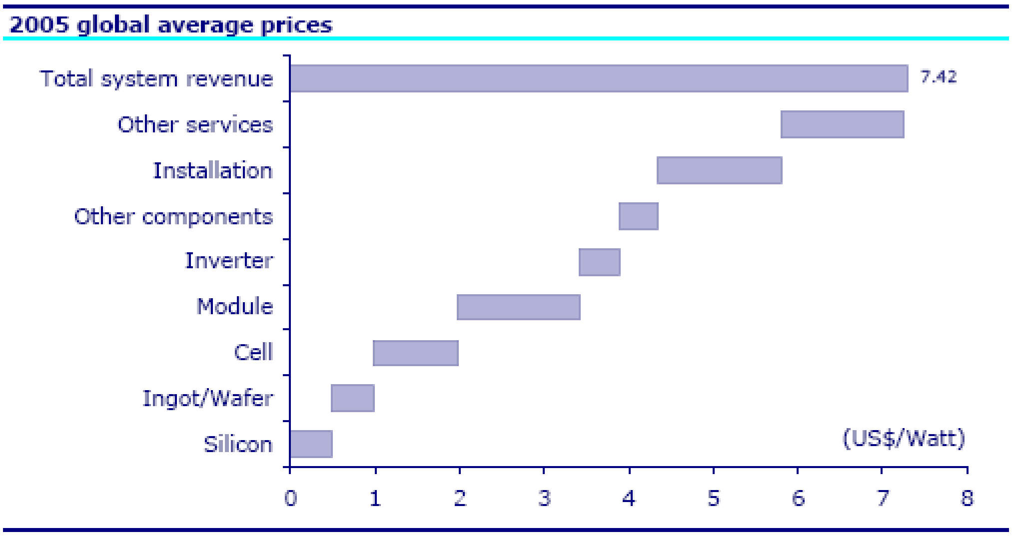


Figure 2-3 The solar power revenue pool [Rogol and Fisher, 2005]



Note: rough estimates. Source: CLSA Asia-Pacific Markets

Figure 2-4 The global average prices of a solar system [EPIA and Greenpeace, 2004, Rogol and Fisher, 2005]

The revenue for the different sections of the supply chain is shown in Figure 2-3, while the price used in the Sun Screen II study for the final product, an installed solar system, is depicted with its breakdown over different sectors in Figure 2-4. Relatively large added value is generated in the sectors "installation" and "other services".

The pre-tax profits for 2004 and 2005 were expected to be respectively 1.2 and 2.2 billion US$. This means that the profit has increased from 15 % in 2004 to 21 % in 2005 (Figure 2-5). The pre-tax margins differ between the different sections of the supply chain. For 2005 the pre-tax margin on silicon was the highest with 35 % and expected to increase further, because of the tight situation on the silicon supply market. The wafer pre-tax margin was 10 %, and so was the module pre-tax margin. The pre-tax margins for cells, inverters and installation were respectively 15, 30 and 20 %. The profit was expected to increase further in 2006 and 2007 because prices in the solar power sector are currently not decreasing. The reason for this is that feedstock availability is currently very tight, so this is the chief competitive factor instead of price. At the same time demand is staying very high, while the costs of production are decreasing. [Rogol and Fisher, 2005]

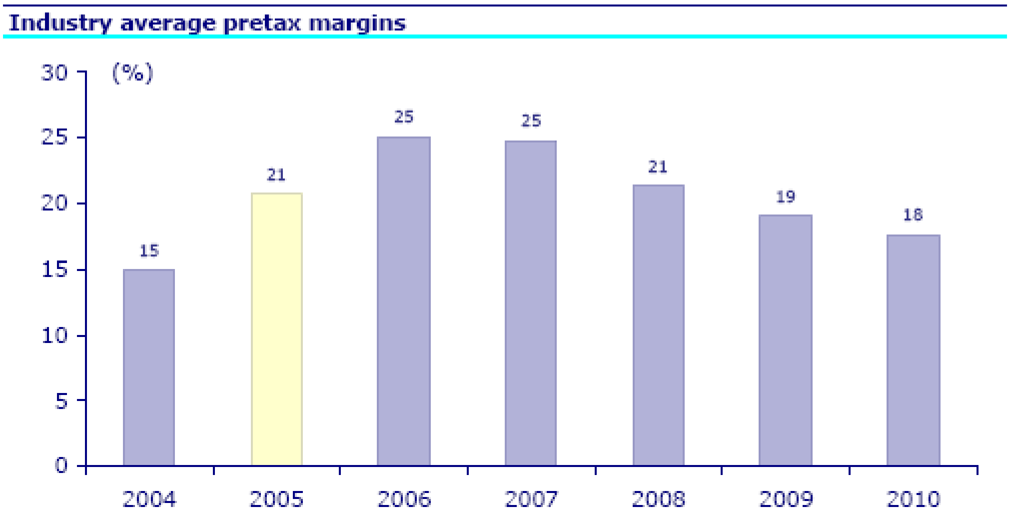


Figure 2-5: Pretax profit margins in PV industry. Figures for 2006 and beyond are predicted values [Rogol and Fisher, 2005]

2.4 RD&D budgets

Public Research, Development & Demonstration (RD & D) budgets for photovoltaic solar energy are reported for participating countries in the IEA PVPS reports [IEA PVPS, 2005]. Separately the IEA statistics database gives R&D budgets for the whole energy sector, according to IEA the budgets for demonstration activities should also be included in these data [International Energy Agency, 2005]. Several countries do no participate in IEA and consequently no data is reported for example for China, India and Thailand. However, the budget for R&D in those countries will be small compared to that in the reported countries. The budgets reported in the IEA database differ slightly from the budgets in the PVPS report. The total photovoltaic RD&D including demonstration projects in the IEA database was 303 million Euros, while PVPS reports 319 million Euros. The cause for this could be a difference in included countries, but it also possible that not all countries correctly include the budgets from demonstration projects in the IEA database.

In 2004 about 203 million Euros were spent on national public R&D for solar energy in IEA countries, excluding demonstration activities. Of this budget 35 percent was spent in Europe, compared to 37 % in the United States and 25 % in Japan. The distribution over the different countries is shown in Figure 2-6.

The budget for demonstration projects and field trials was 116 mln Euros according to IEA PVPS (Figure 2-7). The PVPS data suggest that Japan had by far the largest budget for demonstration, but note that the same country is reported to have spent relatively little on market stimulation (section 2.5). Therefore the observed differences may be distorted by reporting differences between the countries.

Several trends are observed by the IEA PVPS. Compared to previous years the total budget increased in about half the countries, if we include spending on market stimulation. Over the past decade the public spending on solar energy has nearly doubled, but the spending on market stimulation increased at the expense of R&D until 2004. [IEA PVPS, 2005, International Energy Agency, 2005]

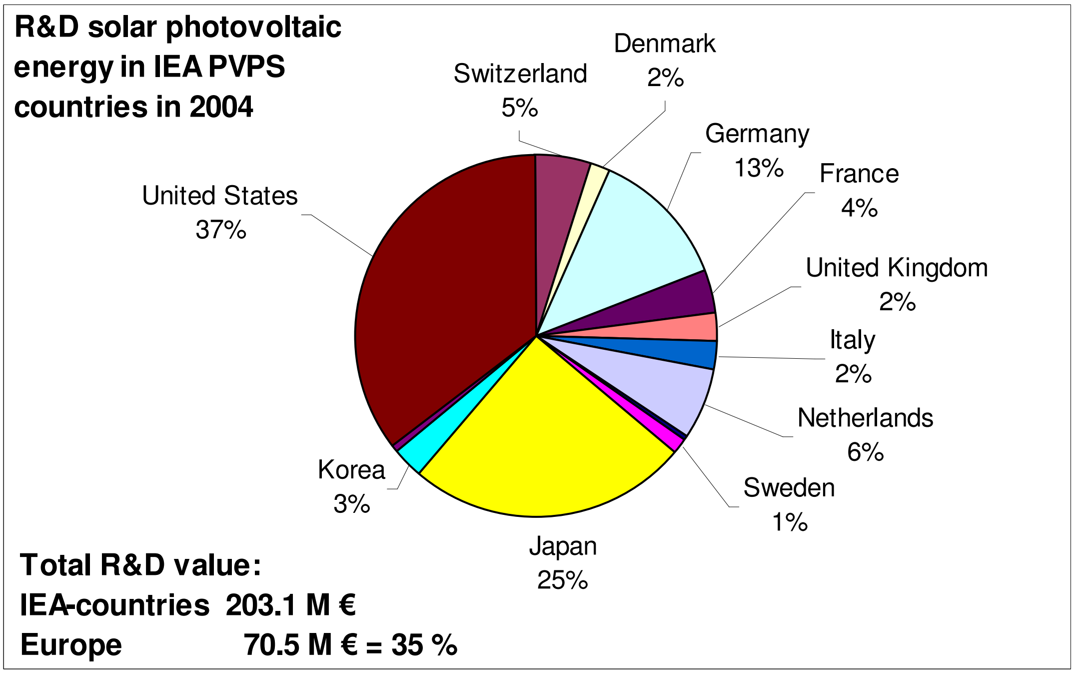


Figure 2-6 R&D solar photovoltaic energy in IEA PVPS countries in 2004, data from [IEA PVPS, 2005]

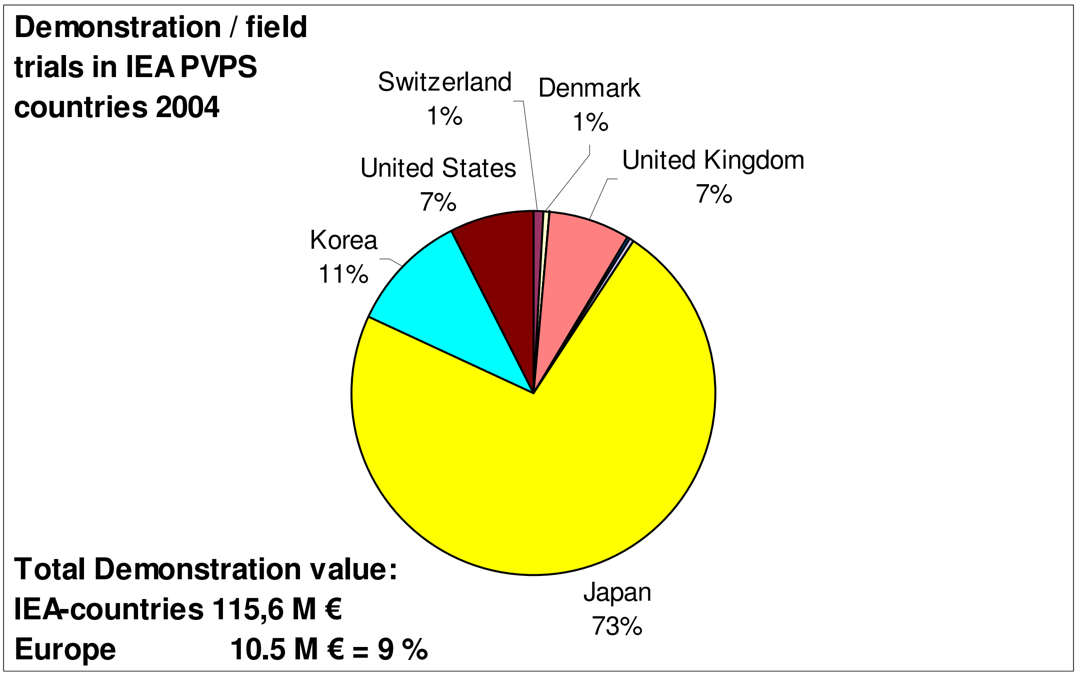


Figure 2-7 Public budget for demonstration and field trials in IEA PVPS countries in 2004 [IEA PVPS, 2005]

Besides the public spending by individual countries also the European Commission of the European Union supports a number of PV projects. On average the EU support was 18 M €/year for photovoltaic RD&D projects, which is about 20% of the national budgets in

Europe. The funding for the different program periods over the years is depicted in Figure 2-8. [Östrom, 2006]

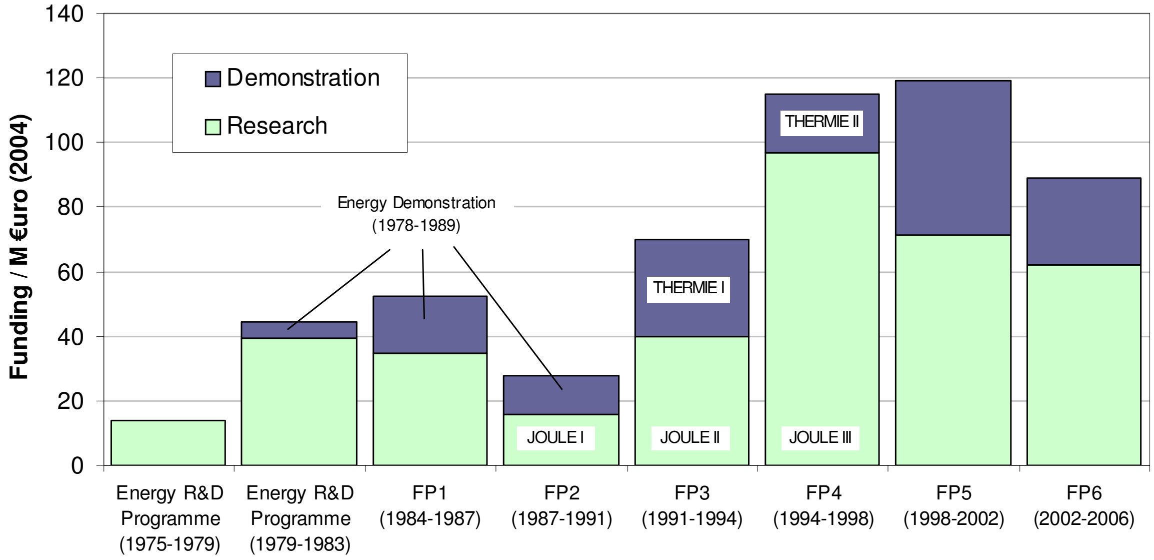


Figure 2-8 Funding of the European Commission for photovoltaic projects between 1975 and 2006 [Östrom, 2006]

What is the budget for photovoltaic RD&D in relation to that for *all* energy R&D? According to the IEA database the total Energy RD&D budget in 2004 was 7.7 billion Euros[1]. Figure2.9 shows the distribution of money spent on energy research, development and demonstration across sectors (left) and countries (right). The majority of the budget was spent in Japan (41 %) and in the United States (29 %); 24 % was spent by European countries (including Switzerland and the UK). Most of the money was spent on nuclear fission and fusion (42 %). Two of the total three billion Euros for this sector was spent by Japan on RD&D on nuclear fission. 11 % of the budget was spent on renewable energies. The majority of the energy RD&D money in Europe was spent by France (417 M € 2002), Germany (371 M €), Italy (285 M €), The Netherlands (131 M €), Sweden (105 M €) and Switzerland (121 M €), as is shown in Figure 2.10.

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[1] For Australia, Austria, Belgium, France, Finland, Greece and Korea, the 2004 budgets were not available. Therefore the data for the last available year was used. This was usually for the year 2002 or 2003, but for Belgium it was 1999.

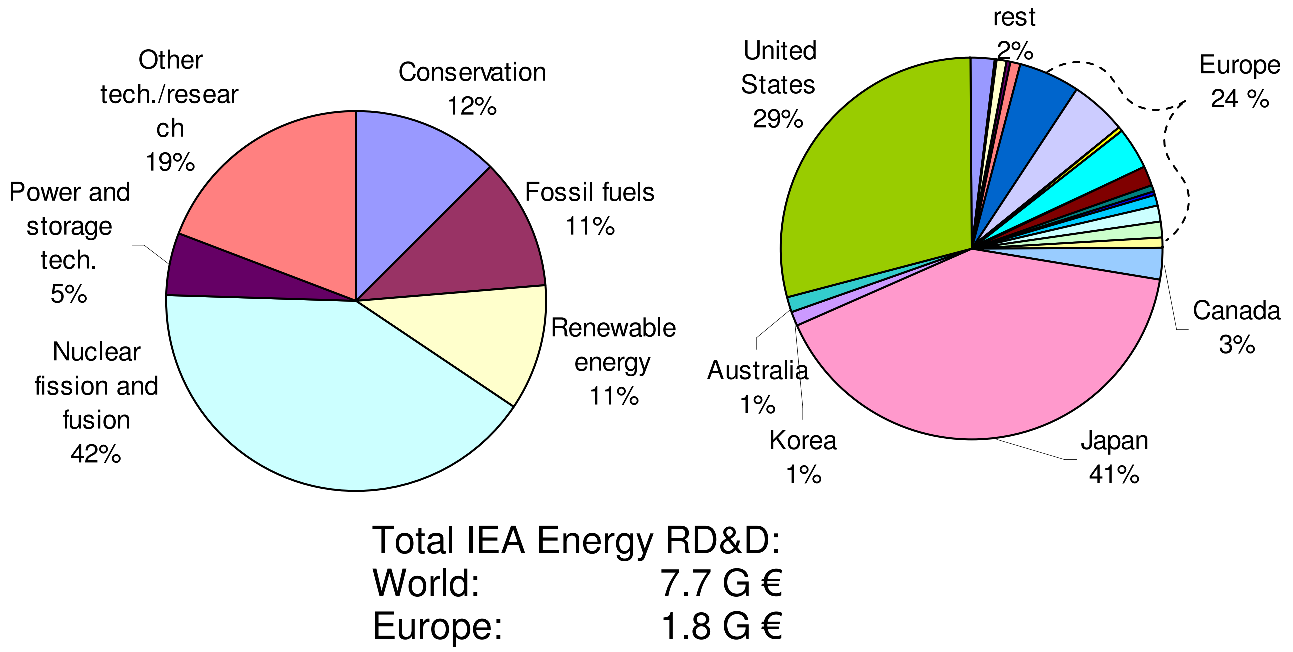

Figure 2-9 Energy RD & D budget for the world; data from [International Energy Agency, 2005]

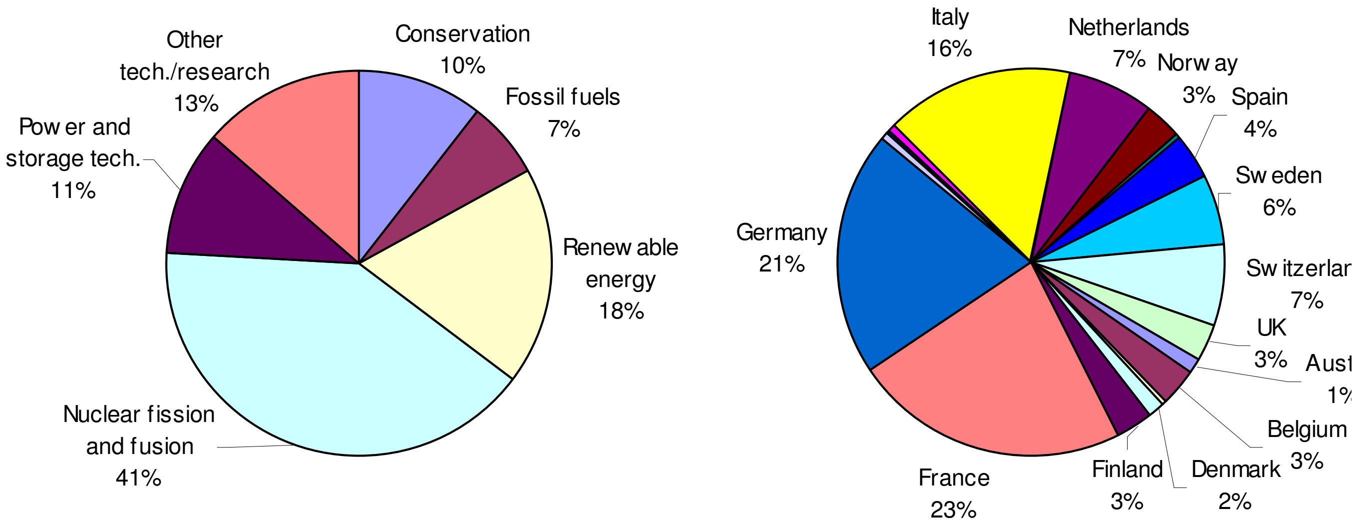

Figure 2-10 Energy RD & D budget for Europe; data from [International Energy Agency, 2005]

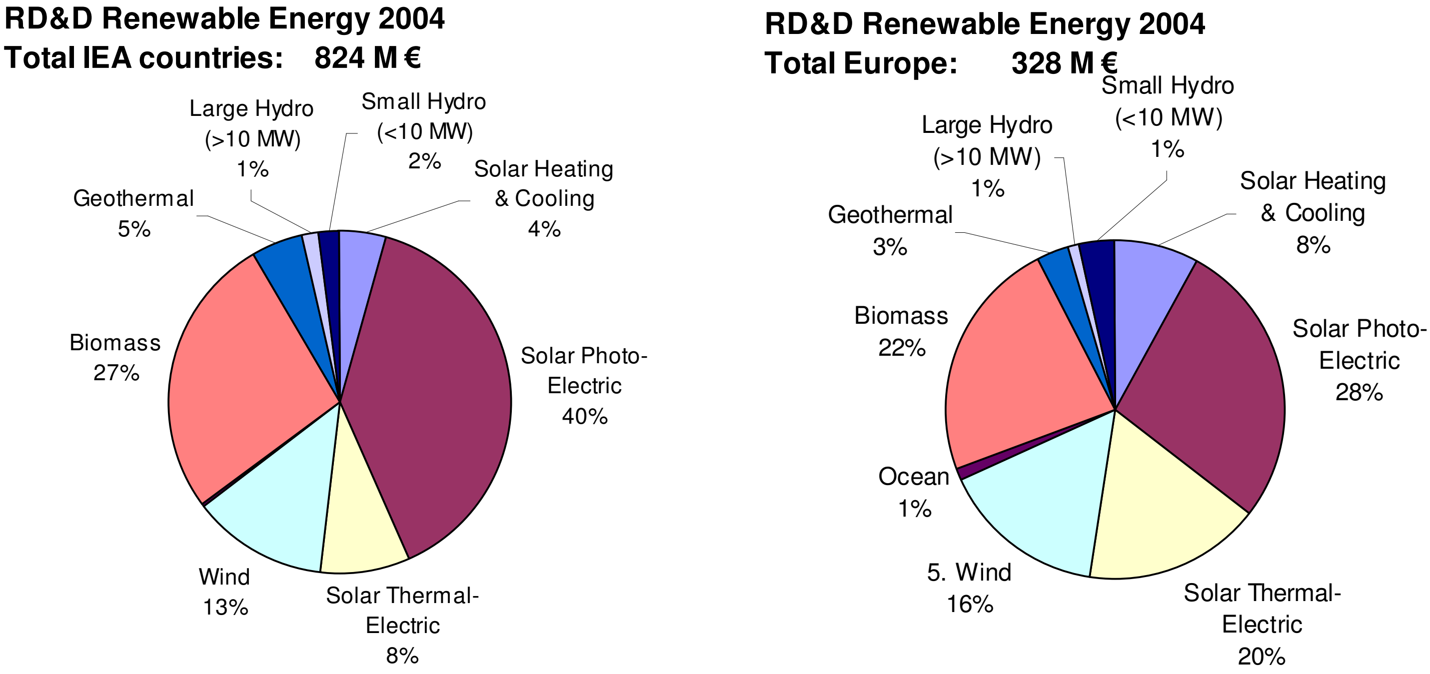

Figure 2-11 RD&D budgets in the world (left) and in Europe (right); data source [International Energy Agency, 2005]

Europe spends relatively more of its energy research budget on renewables than the rest of the world. The distribution of RD&D money over different sources is shown in Figure 2.11. About 28 % of the budget in Europe is spent on solar photovoltaic energy, 22 % on biomass and 20 % on solar thermal electric energy. On the other hand the European spending on PV seems relatively low (28% of Renewables budget) in comparison with the worldwide spending (40% for PV).

This impression is confirmed if we analyse the per capita R&D budgets for PV in Europe, USA and Japan.

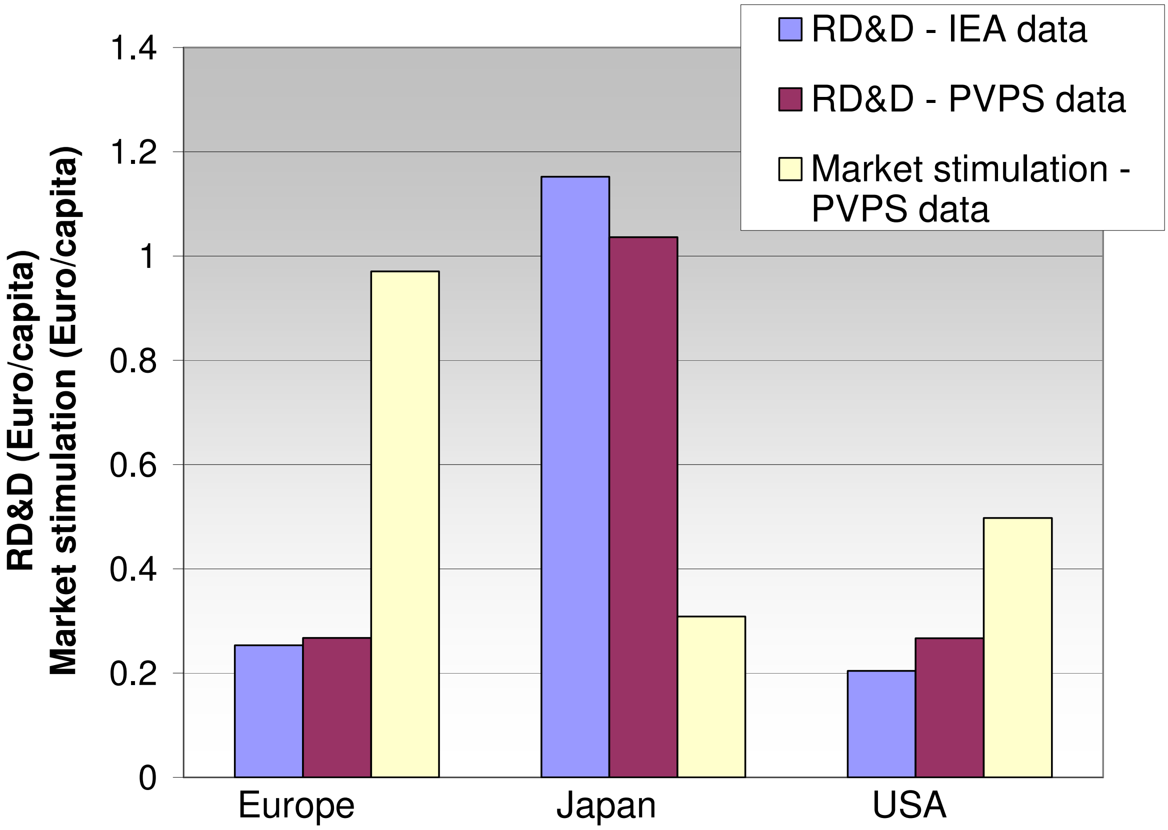

Figure 2-12: Comparison of RD&D and market stimulation budgets per capita for three regions. N.B.: Data for Europe are restricted to Denmark, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland and UK, as these are the only European countries for which IEA PVPS reports gives all budget data. Population data are for the same set of countries (=about 75% of EU -15) [IEA PVPS, 2005, International Energy Agency, 2005]

2.5 Market subsidies

In EU-countries government support for renewable electricity may take three forms. First of all the government may support RD&D as discussed in the previous section. Secondly governments may wish to support market uptake of renewable electricity. Currently four major market support systems are present in EU countries: feed-in tariffs or feed-in premiums systems (FIT or FIP), renewable portfolio standards (RPS), investment subsidies and tendering systems. Thirdly governments may wish to empower consumers to influence the market. [Jansen *et al.*, 2005].

Here we will focus on the market support systems currently present inside the different EU-countries and outside these countries. Feed-in tariffs are preferential, technology-specific tariffs feeding renewable electricity into the grid, as mandated by the regulator and guaranteed for a specified period of up to 20 years. The German feed-in tariff has over the past years been very successful in stimulating wind, PV and other renewables.

An RPS, on the other hand, is a requirement for consumers or for the electricity supplier to get a minimum percentage of the electricity supply from eligible renewable-based energy. This system has been introduced in i.e. Australia, Japan, UK, Italy, Sweden, Belgium and more than 18 American states.

Forms of investment subsidies have been around for a long time. Although they can take different forms, the subsidy is usually related to the installed (peak) power.

Under a tendering system, finally, the government issues power purchase contracts for a certain volume of eligible renewable electricity. The project developers who submit the lowest kWh asking price are offered a long-term purchase agreement. Currently this system is being used in Ireland and France. [Jansen *et al.*, 2005].

In many cases the market support is limited by a “cap”: a maximum budget that may be spent within a specific year.

The IEA PVPS reports figures for market stimulation of PV. These are presented in Figure 2-13. Also it notes that the border between R&D, demonstration and market stimulation may be different in different countries. It can be seen that half of the total budget for market stimulation (including the feed-in-tariff) is spent in Germany.

A caveat in this comparison is however that the definitions of the categories “demonstration” and “market stimulation” seem to differ between nations. While Japan reports to spend only a small amount of the money on market stimulation, it does spend a lot on demonstration projects. Germany, on the other hand, does not spend any money on demonstration projects (in the PVPS statistics), but it does spend a lot on market stimulation.

If we add both categories together, 41 % of the demonstration and market stimulation budget is spent by Germany, 25 % by the United States and 20 % in Japan.

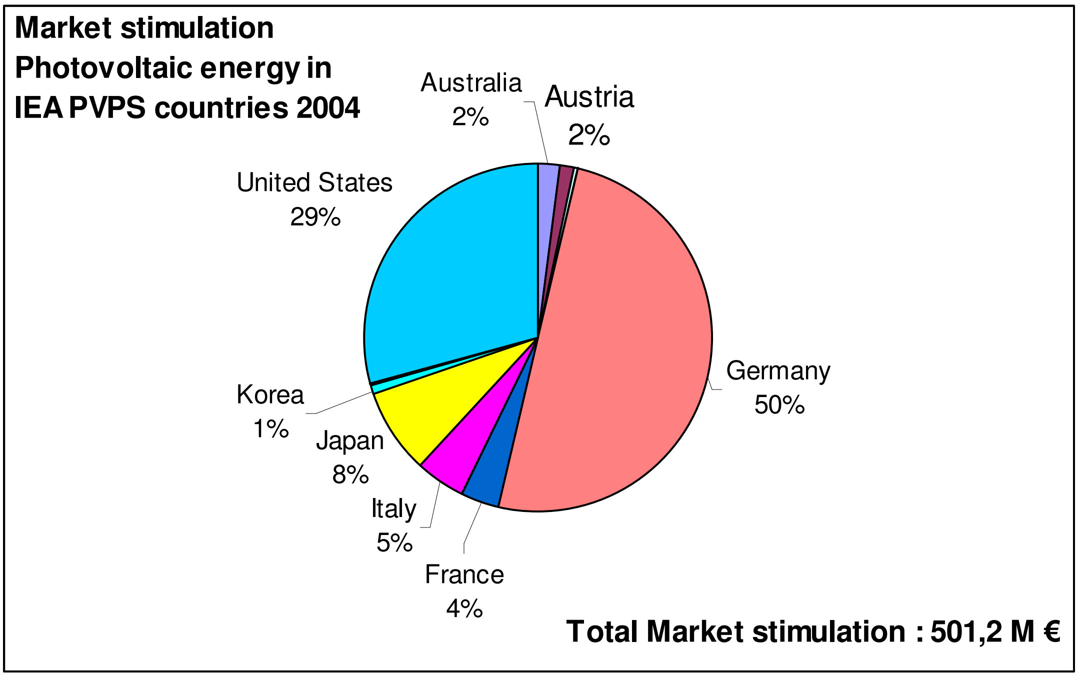

Figure 2-13 Market stimulation of PV in IEA PVPS countries (source: [IEA PVPS, 2005])

An overview of the market subsidies used in European countries is presented in Table 3. Already 16 out of the 25 member states of the EU have introduced a feed-in tariff. The efficiency of this measure depends on whether the tariff covers the expenses, the period of guaranteed increased tariff, the size of the cap and the administrative requirements [Jäger-Waldau, 2005]

In the United States most of the incentives supporting PV are governed at a state level. Among those are tax exemptions, buy down programs, loan programs and grants and industrial recruitment incentives. Furthermore the RPS in Colorado has a specific target for solar electricity. In Japan there are subsidies offered per kWp installation. [Jäger-Waldau, 2005]

Table 2.1 Overview of market subsidies in EU countries [Jäger-Waldau, 2005, , 2006]

Austria	According to the Austrian Eco Electricity Law (2006) electricity from PV will be supported

	with € 1.7 million per year for the next 10 years, the same amount will be added by the Federal States. Some of the Federal States have investment support schemes
Belgium	Green Certificates (with guaranteed minimum price): 0.15 €/kWh Flanders from 1 January 2006: 0.45 €/kWh for 20 years
Cyprus	Feed-in tariff: 0.12 – 0.26 €/kWh and investment subsidies up to 55% for private investors and up to 40% for companies.
Czech Republic	New Law on the Promotion of Production of Electricity from Renewable Energy Sources went into effect on 1 August 2005. Producers of electricity can choose from two support schemes: • Fixed feed in tariffs (for 2006 0.466 €/kWh for systems commissioned after 1-1-06, 0.222 €/kWh before 1-1-06) • Green Bonus (for 2006 0.445 €/kWh for systems commissioned after 1-1-06, 0.200 €/kWh before 1-1-06) In addition, the annual price decrease for new installations should be 5% max.
Denmark	No specific PV programme, but settlement price for green electricity.
Estonia	No specific PV programme but Renewable Portfolio Standard and tax relief. Feed-in tariff for electricity produced out of RES is 5.1 ct/kWh.
Finland	Investment subsidy up to 40%.and tax/production subsidy for electricity from renewable energy sources (6.9 €/MWh)
France	New feed-in tariff since July 2006 (only for new installations): 0.30 €/kWh (0.40 €/kWh for Overseas Departments and Corsica) for 20 years For BIPV a supplement of 0.25 €/kWh 50 % of investment costs are tax deductible. Lower VAT
Germany	Feed-in tariff for 20 years with built-in annual decrease of 5% from 2005 onward. For plants, neither on buildings nor sound barriers, the decrease will rise to 6.5% from 2006 onward. Tariffs for new installations in **2006**: Freestanding systems 40.6 ct/kWh minimum; on buildings and sound barriers 51.8 ct/kWh < 30 kWp, 49.3 ct/kWh > 30 kWp and 48.7 ct/kWh > 100 kWp, for façade integration there is an additional bonus of 5 ct/kWh.
Greece	New feed-in tariff since June 2006. 0.45 €/kWh (0.50 €/kWh on islands) for systems < 100 kWp and 0.40 €/kWh (0.45 €/kWh on islands) for systems > 100 kWp guaranteed for 20 years Commercial installations are eligible to grants (30 to 55 % of total system costs), while small domestic systems are eligible for a 20 % tax deduction capped at €500 per system Target for 2020 is 700 MWp
Hungary	Ministerial Decree 56/2002: Guaranteed feed in tariff (on indefinite term), beginning in January 2003, all energy generated from renewable energy resources must be purchased between 6.3 and 10 ct/kWh, not technology specific. Subsidies for renewable energy projects.

Ireland	Renewable Energy Feed in Tariff (no targets for PV).
Italy	Feed-in tariff: guaranteed for 20 years. The tariffs for 2005 and 2006 are listed below, after that there is a 2% decrease for new systems each year, but tariffs will be corrected according to inflation (ISTAT) 1) up to 20 kW: 44.5ct/kWh (1 and 2 together have a cap of 360 MW) 2) between 20 kW and 50 kW: 46 ct/kWh 3) between 50 kW and 1 MW: 49 ct/kWh (cap of 140 MW) Annual installation limited to 85 MWp[2]
Latvia	Feed-in tariff: Licensed before 01.06.2001: double the average sales price (~ 10.1 ct/kWh) for eight years, then reduction to normal sales price. Licensed after 01.06.2001: Regulator sets the price A national investment programme for RES has been running since 2002.
Lithuania	No specific PV support
Luxembourg	Feed-in tariff of €0.56/kWh for 20 years (not legally binding), grants up to 15 % are available
Malta	Net metering for electricity from PV systems: 0.126 €/kWh Surplus exported to the grid: 0.063 €/kWh – but there is a one time charge of € 46 for the extra metre. 20 % grant for roof-top PV installations
Netherlands	Net metering up to 3000 kWh/year
Poland	Tax incentives: no customs duty on PV and reduced VAT (7%) for complete PV systems, but 22% for modules and components. Some soft loans and subsidies. A new law was passed in April 2004 that tariffs for all renewable energies have to be approved by the regulator (until now only for projects larger than 5 MW).
Portugal	Feed-in tariff: 45 ct/kWh < 5 kWp and 0.28 ct/kWh > 5 kWp with a cap of 150 MW (2010) The tariff is guaranteed for the first 15 years or 21 GWh/MW. In addition investment subsidies up to 40 % are available under the PRIME programme (2000-2006) and also tax deductions are available
Slovakia	Feed-in tariff set by regulator €0.206/kWh for 2006. Tax deduction on income earned. RES feed-in tariff ~ 3 ct/kWh
Slovenia	Feed-in tariff: either fixed price or electricity price (8 SIT/kWh)+ premium Uniform annual price: 37.5 ct/kWh Uniform annual premium: 34.6 ct/kWh
Spain	Feed-in tariff with cap of 150 MW: 0.44 €/kWh < 100 kWp for 20 years, > 100 kWp 0.23 €/kWh.
Sweden	70% tax deduction on investment and installation cost for systems on public buildings proposed as from beginning of 2005 and for 36 months onwards. Electricity certificates for wind, solar, biomass, geothermal and small hydro. Energy tax exemption.
Switzerland	Net metering with feed-in tariff of min. 0.15 CHF/kWh (10 ct/kWh); investment subsidies in

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[2] [Hirshman, 2006]

	some cantons; promotion of voluntary measures (solar stock exchanges, green power marketing).
United Kingdom	Investment subsidies in the framework of a PV demonstration programme. Reduced VAT.

In Figure 2-14 the feed-in-tariffs of the different countries in Europe have been compared. The feed-in-tariffs are depicted for two different system sizes, of 2 and 500 kWp. Furthermore each tariff (in €/kWh) is multiplied by the average daily irradiation for the considered country and subsequently normalized to the highest relative feed-in-tariff for a 2 kWp system (Portugal). For the four countries where the feed-in tariff was *lower* than the electricity price for households, we have assumed that net metering would be allowed for small systems, so that the actual tariff was equal to the household electricity price.

Note that several countries have a cap on the feed-in tariff scheme. There are several factors that limit the effectiveness of motivating tariffs. Firstly a too early fulfilled cap. Secondly a too short period of validity for a guaranteed tariff and lastly too complicated administrative requirements [Jäger-Waldau, 2006].

From the figure we can see that for smaller systems there is a beneficial feed-in-tariff in Spain, Italy, Portugal, Germany and Slovenia. For larger systems the FIT is high in Italy and a bit less in Germany.

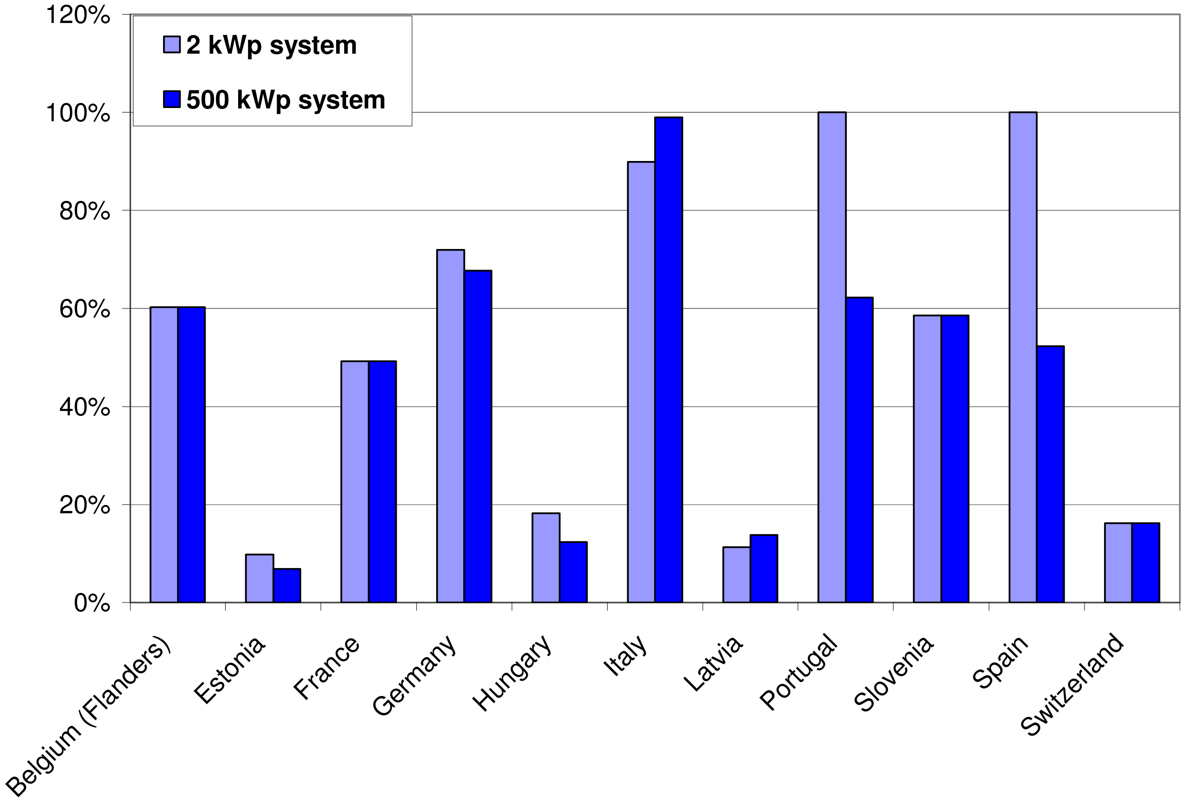

Figure 2-14 Comparison of the height of feed-in tariffs, taking into account average irradiation. For each country the feed-in tariff is multiplied with average daily irradiation in the approximate middle of the country and normalized to the highest value for a 2 kWp system (Spain) (Status 2006)

2.6 Job creation

The PV industry provides numerous jobs in different fields where different skills are required. At manufacturers of solar cells, modules, inverters and other parts employment is generated. But also locally where the PV system is installed, jobs are created for installation, construction, sales and maintenance.

There are several methods to estimate the number of jobs in the strongly growing solar industry. Several studies present figures for the direct employment, this information is mostly gathered by interviews or surveys. In addition to that other studies also calculate the indirect employment, e.g. the jobs needed to produce the machines, via an economic input-output analysis[3]. Some other studies make use of macro-economic models to include the macro-economic effects of applicable subsidy schemes. We will first focus on the studies on direct employment and subsequently consider the input-output analyses and the results of macro-economic models. Finally we will compare the number of jobs generated by solar power, versus the employment generated by other energy producing technologies.

An overview of several studies on direct employment is given in Table 4. The total estimate for the amount of jobs per produced and installed MWp of PV capacity varies between 37 and 55 for the situation after the year 2000. A large uncertainty is due to the uncertainty in the volume of installed PV in Germany, which for the year 2004 varies from 363 MWp to 770 MWp (see section 1.1). The division of jobs over the different section of the supply chain is very different between the different studies. This might partly be caused by using different system boundaries.

The information from the Renewable Energy Policy Project is based on interviews with 10 firms engaged in one or more of the listed activities. These all operated in the United States. The survey examined the labour requirements for 1 MWp PV of 2 kWp residential systems [Singh and Fehrs, 2001]. The figures in the report are in hours, the average European working year of 1740 hours was used to convert this data to person years. The EPIA and Greenpeace data are based on information provided by the industry [EPIA and Greenpeace, 2004]. The figures in [Hille *et al.*, 1997] are partly derived from a large European study. The figures for PV module production from Europressedienst originate from a survey by the German Solar Industry Association (BSI). Their figures for installation are derived from their own surveys of 200 out of approximately 4000 PV installation companies and 47 out of approximately 100 wholesalers [Europressedienst, 2005]. They present the number of jobs for installation and wholesale in Germany.

Table 2.2 Overview of direct employed persons (in persons per MWp) in respective sectors of the PV industry. Sources: REPP [Singh and Fehrs, 2001] for United States, GP/EPIA [EPIA and Greenpeace, 2004], [Hille *et al.*, 1997] for Germany, [Europressedienst, 2005] for Germany

REPP	GP/EPIA	Hille	Hille	Europressedienst
2 kWp		2 kWp	projection	

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[3] In economic Input-Output analysis the effect of spending money in a certain economic sector on the activities in other sectors is analysed.

	USA		Germany		Germany
	2001.0	2004	1997	2004	2004
Glass	0.1	17	26	11	
Plastics	0.2				
Silicon	3.2				
Cell Manufacturer	1.8				23.8
Module Assembler	12.0				
Inverters	2.7		19	15	
Wires	1.1				
Mounting frame	0.9				
Systems integration	6.8	30			
Distributor					
Contractor	2.3		6	5	4.4
Installer	6.0		17	11	34
Total	**37**	**47**	**68**	**42**	**62**

The number of jobs per MWp production varies from 17 from the EPIA report to 26 for the projection by Hille et al. The projection of Hille for the production of wires, inverters and the mounting of the frame seems very high. Likewise the 23 jobs/MWp production from the Europressedienst for Germany and the company information might be on the high side, because of the quickly growing industry. It is questionable if this will change in the future though; the expectations are that the market will keep on growing.

All-in-all an amount of 20 jobs per MWp for module production and another 25-30 jobs/MWp for BOS and installation seems a reasonable estimate for the present and for the next few years to come.

On the longer run, however, the labour intensity will of course decrease due to process automation, production up-scaling and higher module efficiency. Without such a decrease the significant cost reductions that are foreseen in most studies would be possible.

In the future also a part of the jobs in module and BOS production will be transferred from Europe to countries with low wages. Several companies already have opened module assembly factories in China. but the activities with respect to retail, wholesaling, installation and maintenance, on the other hand, are not easily transferable so these will continue to provide local employment.

Besides the jobs for production and installation, there is also a small amount of labour needed for maintenance. EPIA/Greenpeace estimate this at 1 job per installed MWp, the REPP report gives an estimate of 0.29 job, while Hille estimates it at 2 jobs per installed MWp.
Apart from the direct jobs estimated above PV production and installation will also generate a number of indirect jobs in e.g. construction, material production and the construction of machines. Such indirect employment effects can be estimated by means of IO analyses, and we will discuss one below.

On basis of evaluations as given above, it is often argued that the increase of renewable energy sources will always generate a net employment increase. The reasons are that renewable energy production is more labour-intensive than conventional energy production and that renewable energy systems rely less on imported goods and services. On the other hand market stimulation programmes that presently are necessary need to be financed, somehow, and this implies that less money will be available to spend in other economic sectors resulting in a certain employment loss [Uyterlinde *et al.*, 2005].

The latter effect is regarded in a study by the Bremer Energie Institut (BEI), which investigated the German situation, with inclusion of the feed-in tariff system. This study distinguishes several employment effects such as: the investment effect, the operation effect, the budget effect, the dynamic effect and the trade effect [Pfaffenberger *et al.*, 2003].
For the investment effect the direct and indirect jobs by adopting renewable energy were calculated via an input-output analysis. Because of an investment an employment effect is created at e.g. the producers and their suppliers. The employment effect of investments is only large while the 'plant' is being built and installed, after that it returns to zero. The investment effect of 1 MWp of 3 kWp-sized PV systems is calculated to be 77 person years. The operation effect deals with the employment created by operation and maintenance of the PV plant, on the one hand, and the decrease of employment in the conventional electricity supply sector, on the other hand. In the considered study this operation effect is calculated at 10,6 jobs per installed MWp over 20 years, or 0,53 job per year per MWp PV.
The budget effect results from the assumption that investments in renewable energy result in costs. This will via several mechanisms result in higher prices for the consumers of energy. This in turn will result in higher spending for consumers on energy and therefore less spending on other goods. Therefore the employment effect for these non-PV goods will decrease. The budget effect will be small when the costs of renewable energy sources are

similar to those of displaced electricity supply. The analysis for the budget effect in the BEI study is based on the costs of the German feed-in tariff, which is 48 cents/kWh for a period of 20 years. According to the BEI this results in a budget effect for PV of -109,3 jobs per installed MWp.

The dynamic effect considers changes in the market and like the appearance of new markets and new products. The dynamic effect on the employment is difficult to oversee and has therefore not been quantified by the BEI. The trade effect, finally, can only be analysed in a global economic model and was therefore also not included.

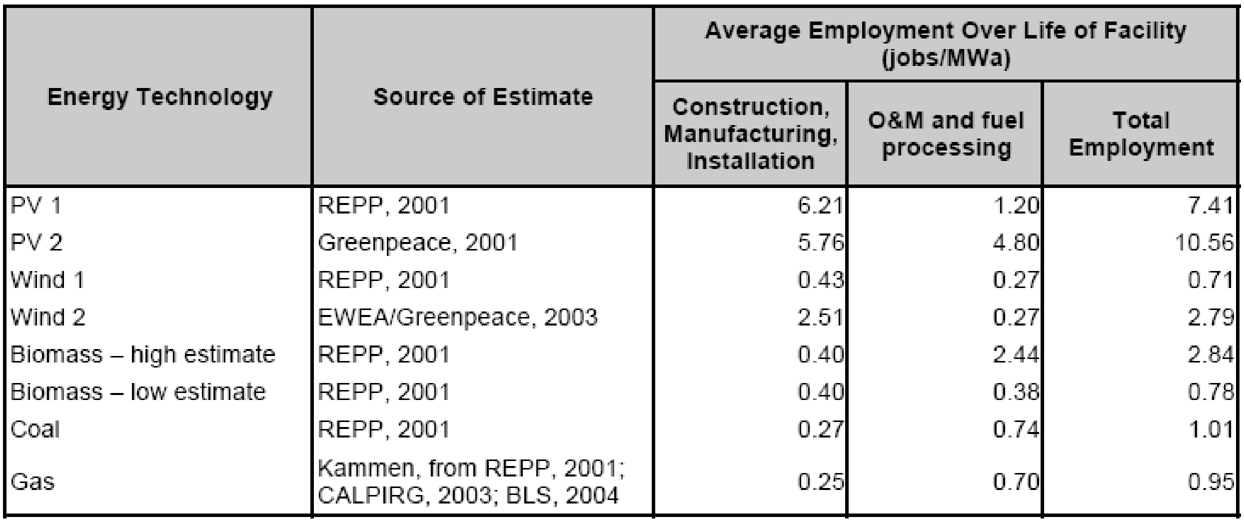
One point of criticism with respect to the BEI study is that especially the budget effect for future years is very much dependent on the difference in price between renewables and conventional energy sources. In the BEI-study it was assumed that the prices of both energy sources remain constant, which is quite unlikely. More likely the prices for renewables will decrease, while those for conventional fuels may increase.

The BEI further remarks that the investment in renewables can also be seen as an insurance for the future when energy prices of conventional fuels rise above renewable energy prices, in which case the budget effect will become positive.

Adding up all employment effects the BEI calculates a *loss* of 21.7 jobs per MWp of installed PV. As explained this negative employment effect is caused by the negative budget effect, which is largely based on the expenses for the German feed-in tariff [Pfaffenberger *et al.*, 2003].

The worldwide, direct employment in the PV solar industry in the year 2005 can be estimated at about 80 thousand, assuming 45 jobs/MWp and a production of 1,8 GWp and. Another 2 thousand people would be employed in maintenance.

A comparison between the jobs that different type of energy industries generate is made in [Kammen *et al.*, 2004]; see table 1.3 . This study expresses the employment in jobs per MW-average (MWa), which is the amount of installed megawatts de-rated by the capacity factor of the technology. The used capacity factor for PV is 21 % for the Californian situation. This is much higher than e.g. for Germany (~9%). This means that for PV in Germany the employment per MWa is higher than for California. For wind energy it is also likely to differ a little bit. From several studies on one renewable technology it is clear that the employment impact of most energy technologies is rather uncertain, but still PV-energy is generally found to generates more jobs than other technologies, provided that budget effects are not included



Energy Technology	Source of Estimate	Average Employment Over Life of Facility (jobs/MWa)		
		Construction, Manufacturing, Installation	O&M and fuel processing	Total Employment
PV 1	REPP, 2001	6.21	1.20	7.41
PV 2	Greenpeace, 2001	5.76	4.80	10.56
Wind 1	REPP, 2001	0.43	0.27	0.71
Wind 2	EWEA/Greenpeace, 2003	2.51	0.27	2.79
Biomass – high estimate	REPP, 2001	0.40	2.44	2.84
Biomass – low estimate	REPP, 2001	0.40	0.38	0.78
Coal	REPP, 2001	0.27	0.74	1.01
Gas	Kammen, from REPP, 2001; CALPIRG, 2003; BLS, 2004	0.25	0.70	0.95

Table 2.3 Comparison of average employment effects between energy technologies [Kammen *et al.*, 2004]
Note: the Greenpeace mark for PV 2 is not correctly divided over the job categories

Also in the BEI-study a comparison between the employment effects of different renewable energy sources is made, based on a production of 2 GWh electricity. By the investment plus the operation effect 218 jobs are created for PV. This is followed by 48 jobs for small hydro plants, 36 for biomass, 33 for biogas, 25 for wind, 19 for small geothermic plants, 18 for large hydro plants and 12 for large geothermic plants.

So also from this study it can be concluded that PV presently generates the largest employment in the renewable energy sector. Partly this employment will be in sectors like installation and less skilled production work. But also a lot of engineers, researchers and more educated personnel are employed by the photovoltaic industry.

3 Historic trends in PV RD&D, technology development and production cost

In this chapter we will examine some historic trends with regard to photovoltaic technology to see what lessons can be learned from the past and to investigate how effective public RD&D expenditures and market stimulation programmes have been to improve the competitive position of PV technology.

3.1 Analysis of historic RD&D budgets and their impact on technology development

3.1.1 Indicators for the effectiveness of R&D

One of the aims of investing money in research, development and demonstration (RD&D) projects to advance new technologies to a point where they may be implemented into the existing economic system without special support. One of the key factors to achieve this is often to increase the cost-effectiveness of the technology. A second important objective of public RD&D spending is to place the national industry in a good competitive position for promising new markets.

Also for renewable energy technologies, the success is dependent on investments in RD&D to realize cost reductions. Up to now photovoltaic energy is still one of the more expensive sources of renewable energy. But it has high learning rates and a large future potential. The RD&D goals for photovoltaic energy over the past decades have been focussed mostly on reducing costs and increasing cell and system efficiencies. [Ragwitz and Miola, 2005].

In this section we will look into historic RD&D budgets for PV technology and we will try to investigate what the effects of these expenditures have been. As a first indicator for the effectiveness of RD&D activities we will consider the improvements in solar cell efficiency as a measure of technological progress[4]. Secondly we will look at the development of module price in relation to R&D. Finally patent applications will be considered as an indicator of the level industrial activity and industrial interest. The correlation between R&D budgets and these two indicators will be investigated to gain insight into the question how effective

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[4] Other interesting indicators of technological progress may be thought of: e.g. the system efficiency or Performance Ratio. However, insufficient historic data exist on these parameters for our purpose.

photovoltaic R&D has been in the past. But we will start with an historic overview of R&D budgets in a number of countries.

3.1.2 Historic budgets for photovoltaic RD&D

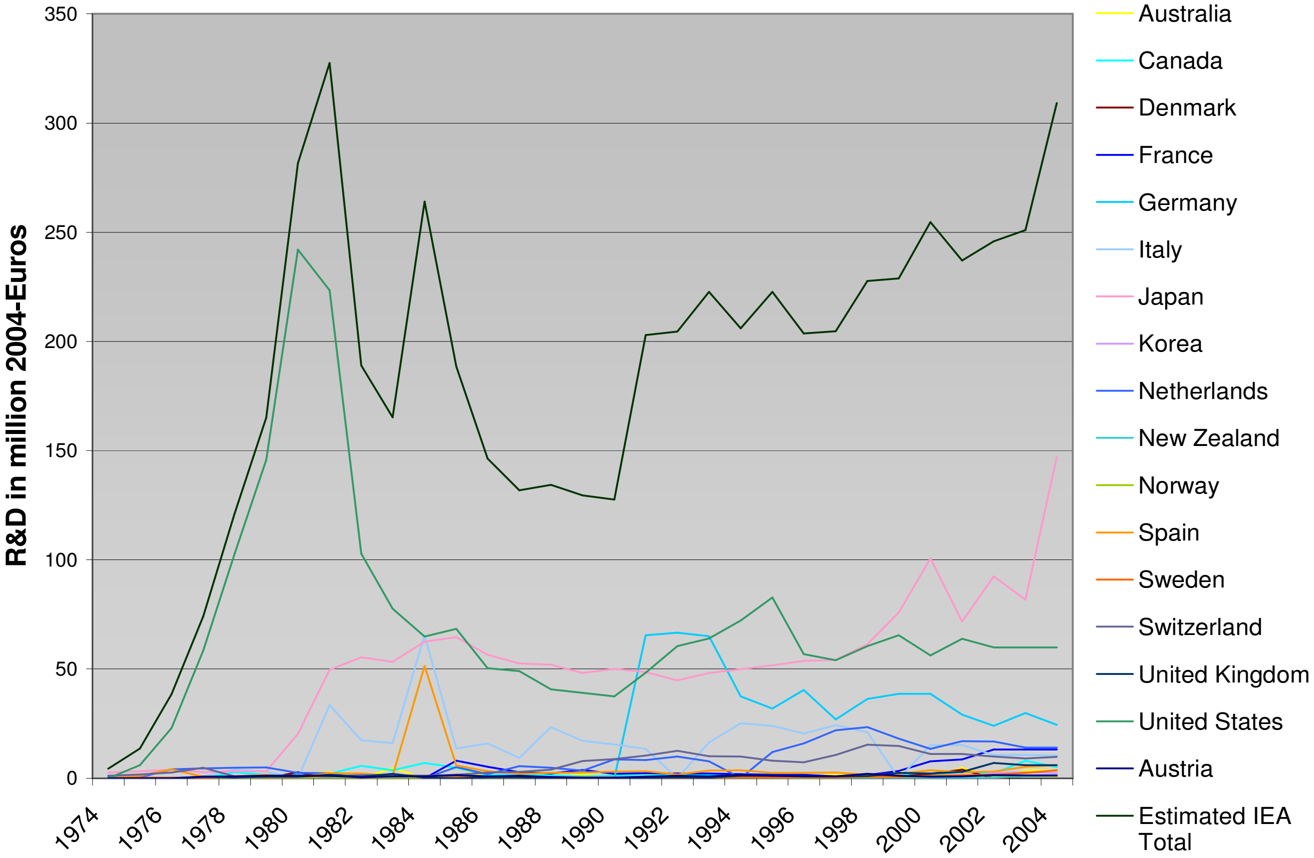

Figure 3-1 Public RD&D budgets for solar photovoltaic energy from 1975 to 2004 [International Energy Agency, 2005]

In Figure 3-1 the historic public RD&D budgets for PV technology from 1976 to 2004 are shown for a number of countries, based on IEA statistical information. Unfortunately not all these data seem to be entirely correct and partly they are incomplete. For example Germany only reports PV RD&D from 1990 onwards. Also the peaks in the budgets of Spain and Italy in 1984 look odd, but it is impossible to check the real status of these historic budgets. For a number of countries data are missing for several years, e.g. for 2003 and 2004 for the USA[5]. Also, the RD&D data published in the IEA database are quite different from the one published by the IEA PVPS.

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[5] The R&D budgets are assumed to be stable in case of missing data as for the US and France in 2003 and 2004 and in Austria and Australia in 2004.

Between 1976 and 1980 a large increase in the RD&D budget can be observed, of which the largest share is spent by the USA. In the 70's the USA started specific programmes to develop cheap solar energy for terrestrial applications. Before that time most PV research was aimed at extraterrestrial applications. After the oil crisis in 1973 and '74 solar energy was for the first time seen as an alternative for the dependency on fossil fuel. After Reagan got into power in 1981, budgets for PV R&D were largely reduced and several PV organisations were dismantled.

Japan on the other hand started a lot of solar activity in the early 80's. [Poppen, 2003] The total RD&D budget seems to increase again from ca. 1990, but this mainly is caused by the inclusion of Germany in the database. It is not known what the budgets in Germany were before that time. In the early 90's Germany, the USA and Japan were the major funders of public RD&D. In the last few years the budget of Germany is seen to be declining, while the budget of Japan increases.

3.1.3 Solar Cell Efficiency in relation to RD&D spending

One of the main targets of research and development of photovoltaic energy is to increase the conversion efficiency of solar cells, because this is one of the most important ways to improve their cost-effectiveness. The development of the efficiency for different type of photovoltaic cells over time is shown in Figure 3-2. We see that over the past 30 years large improvements in cell efficiency have been realized and that new types of solar cells have been introduced.

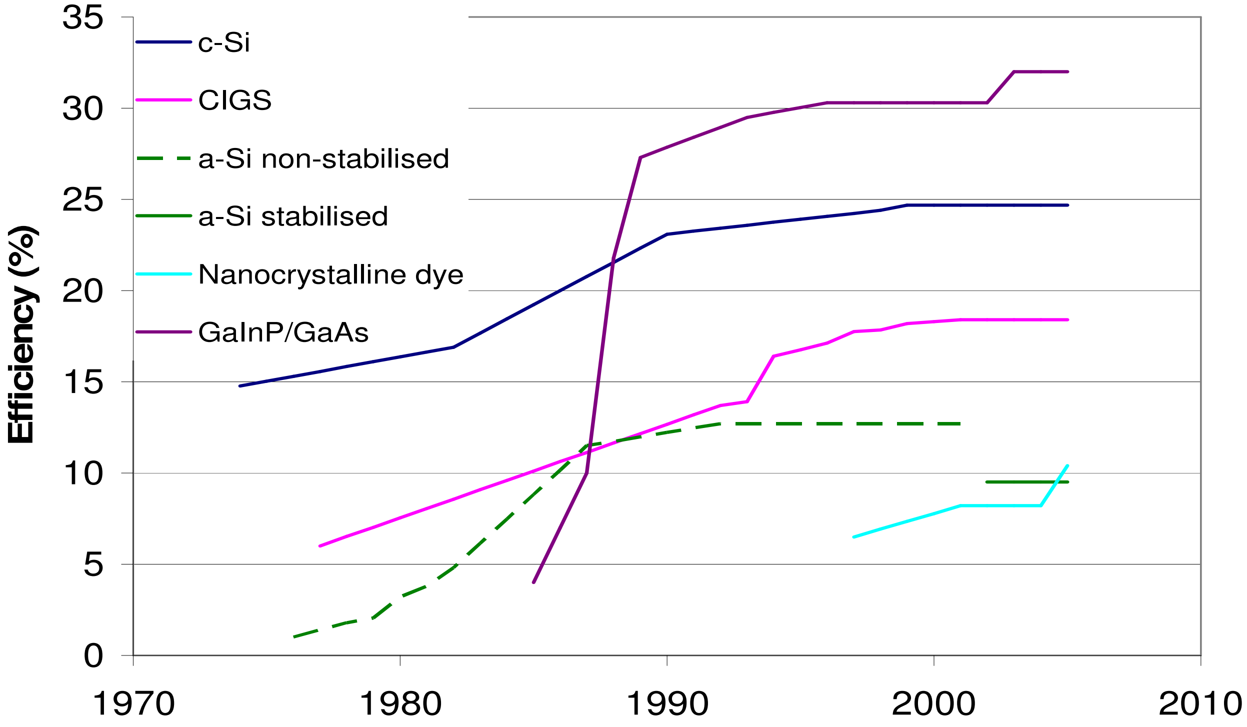

Figure 3-2: Historic overview of solar cell efficiencies for different cell types (small area efficiency) (Sources: *NREL, IEEE PV Spec. Conf., 1973-2000;[Green, 1993-2006].*). N.B.: the graph for a-Si shows *unstabilized* efficiency data before 2000, stabilized efficiencies after 2000.

In order to have one single indicator for solar cell efficiency which may be correlated with the R&D input, an aggregated Solar Cell Efficiency Index has been defined as follows:

$$SCEI = \frac{\sum_{n}^{1} \frac{\eta_t}{\eta_{\max}}}{n}$$

SCEI = index

n = cell technology indicator, five technologies were considered: c-Si, a-Si, CIGS, nanocrystalline, dye-sensitized and GaAs/GaInP

η_t = highest realized efficiency (small area) of solar cell type n in year t

$\eta_{\max}$ = theoretical efficiency limit of technology n

In Figure 2.6 the historic trend in SCEI is displayed next to the cumulative RD&D investments[6]. Although the SCEI as an indicator has its limitations it is clear that an increasing cumulative budget goes along with increasing SECI. Also we see that the rate of increase in SECI differs with time, but partly this has to do with the definition of SECI[7].

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[6] The SCEI is in a way also a cumulative value, namely of technological progress.

[7] Introduction of a new cell type at a certain time (e.g. 1998) results in a jump in SCEI.

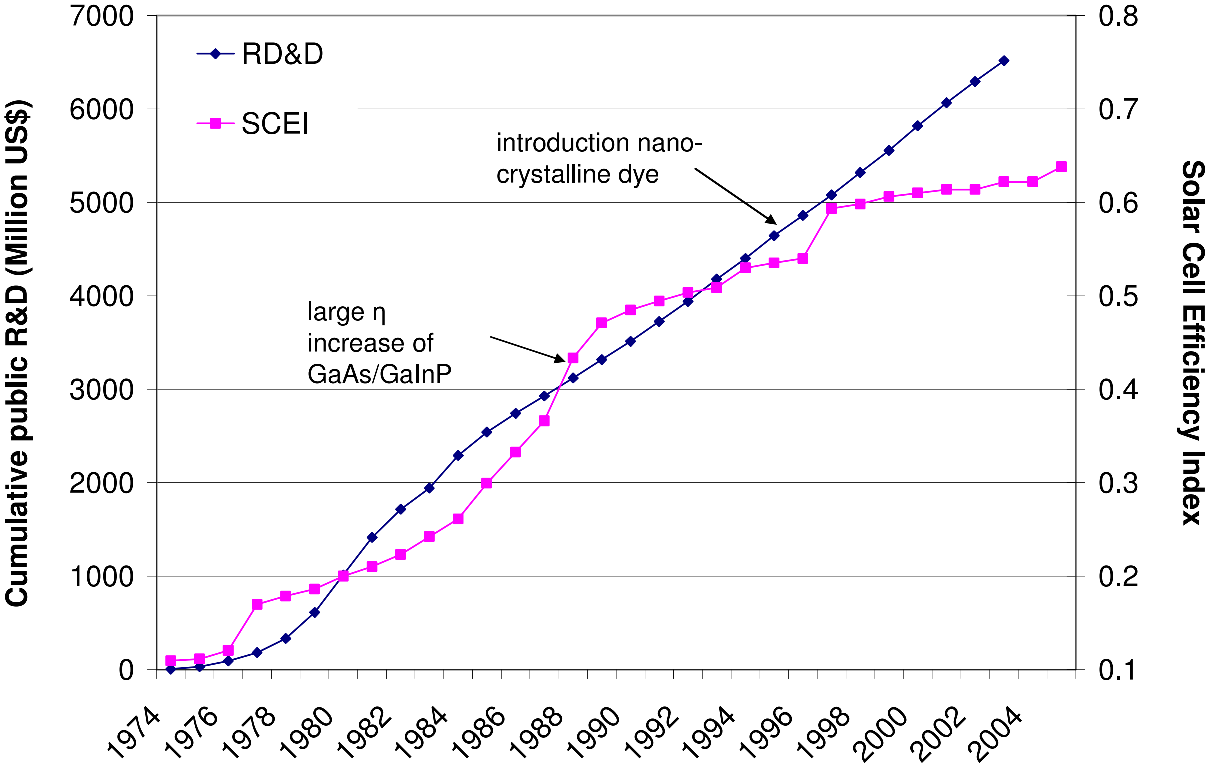

Figure 3-3: The historic development of the Solar Cell Efficiency Index and of the cumulative global R&D spending Note: a-Si unstabilized efficiency is used

3.1.4 Module Production Cost in relation to RD&D spending

Nemet has analysed the cost changes of PV modules in the period 1975 to 2001 [Nemet, 2006]. He used a cost model that simulates the effect of changes in each of seven factors on manufacturing cost in each year. The seven factors considered are module efficiency, plant size, yield, poly-crystalline share, silicon cost, silicon consumption and wafer size. E.g. if module efficiency doubles cost will be half in the model. According to Nemet these seven factors explain 95 % of the cost trend between 1980 and 2001 (Figure 3-4). He claims that 43 % of the decrease of the cost of PV is caused by increasing plant size, while the increase of efficiency accounted for a 30 % decrease of the cost. During this period the highest laboratory efficiencies increased 16-fold. Six of these breakthroughs were made by companies, while most were accomplished by universities. The rapid rise in lab efficiencies was preceded by an enormous R&D investment.

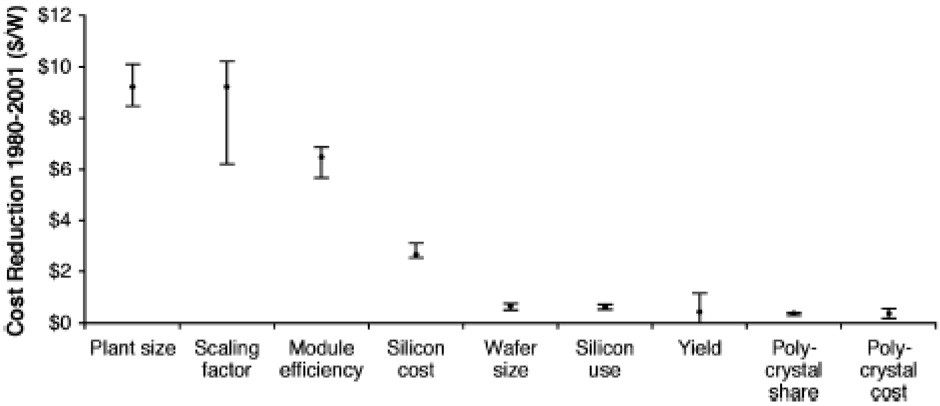

Figure 3-4 Cost reduction for module production between 1980 and 2001 [Nemet, 2006]

3.1.5 Patenting activity in relation to RD&D spending

The relation between RD&D investments and the number of patents has been investigated for the United States, Japan and Germany. Since the patent data for the USA and the other countries are not comparable and also since the RD&D budgets might have been reported differently no correlation was made for the three regions together.

In the USA (Figure 3-5) a clear correlation is seen between the number of US patents granted to US inventors (excluding foreign patents) and the public RD&D budget [Nemet and Kammen, 2007]. The number of patent applications increased considerably between 1975 and 1980; it might be that research in the previous period was partly listed under a [Nemet and Kammen, 2007]different name (space/physics?). A peak in patenting can be observed in the early 80’s with some years of time lag after the peak in investments from the late 70’s, after that patenting declines as does the R&D budget.

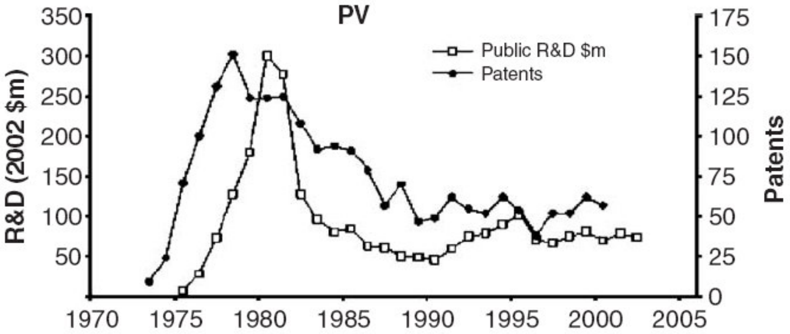

Figure 3-5 Public R&D versus patents [Nemet and Kammen, 2007].

The first filing patents for Japan and the RD&D for Japan are shown in Figure 3-6. Note that these data look at first filing patents, and not granted patents. Compared to Figure 3-5 and Figure 3-7, it is clear that the number of patents filed per dollar R&D investment in Japan is much higher than in other countries. To some extent this appears to be a difference in patenting "culture". The relevance of filing a patent in Japan is reported to be of increasing relevance; the number of new patents are even used as a leading annual target [Incerti, 2005]. Like in the US data, a quite close correspondence can be observed between R&D budgets and patenting activity.

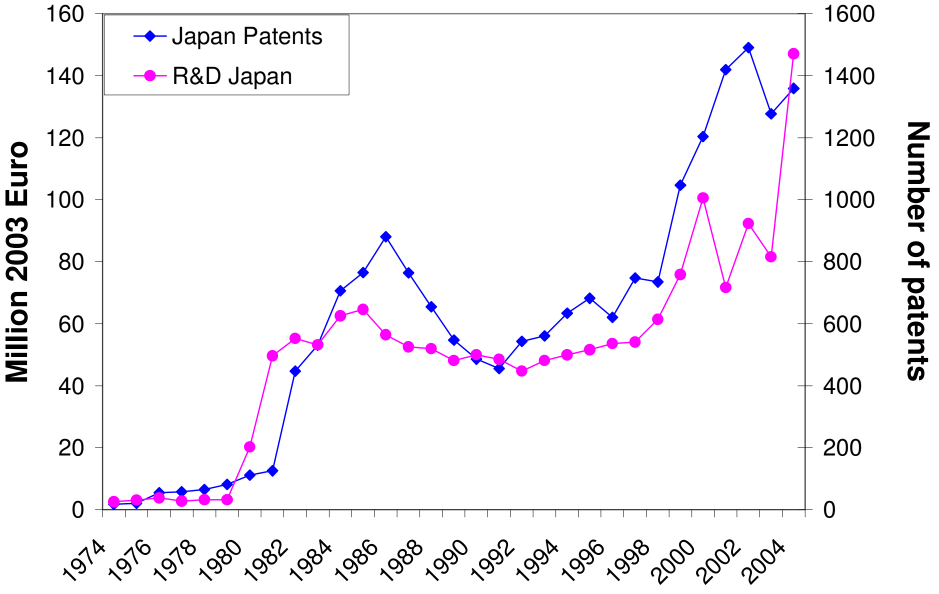

Figure 3-6: RD&D budgets and the number of first filing patents in Japan 1974-2004 [Incerti, 2005].

When we turn to the patenting and RD&D budget data from Germany, however, we can observe that the public RD&D budgets have declined between 1990 and 2004, while the number of patents has increased over the same period. So there seems to be an inverse relationship. One factor to take into account is that only the public RD&D budget is considered here[8], while it may be expected that the private RD&D funding has increased significantly in the same period because of the rapidly growing PV market in Germany. Also it is possible that there is an underreporting of public RD&D expenditures. Finally note that for Germany we have data over a much shorter time period (1990-2004) than for the USA and Japan (1974-2004).

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[8] To our knowledge there are no reliable estimates for private R&D funding in PV.

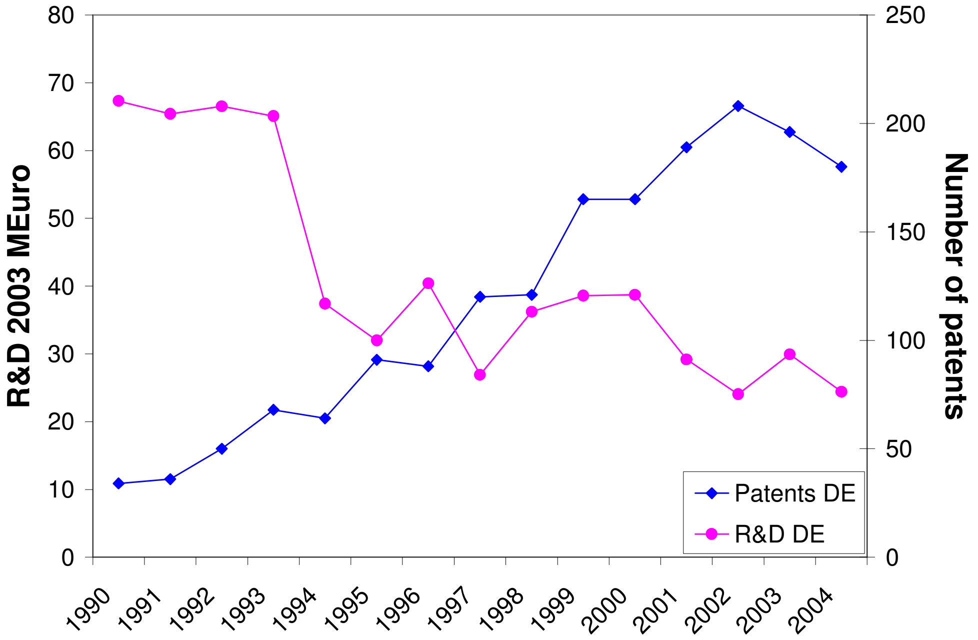

Figure 3-7: Historic patent and RD&D budget data for Germany [Incerti, 2005]

In conclusion we can say that historic data show a clear correlation between the level of (public) RD&D spending on the one hand and technological progress for solar cells on the other hand. With regard to the correlation between industrial activity, as measured by patents, and RD&D spending the results are less conclusive, but a positive correlation seems to exist here too, especially when we consider longer time periods. Of course historic trends provide no guarantee for future success, but at least it is highly unlikely that future public expenditures would not give a similar result.

3.2 Market stimulation policies

The last decade has proven that the right type of market support is very important for the growth of the PV sector. In section 2.5 existing market stimulation policies were described. In this section we will look at historic trends with regard to market stimulation.
The budget data used in this section were derived from the annual 'Trends in Photovoltaic Application' reports of the IEA PVPS [IEA PVPS, 2005]. These reports warn that the division line between demonstration programs and market subsidies are often vague and that it may differ between countries.

In general the argument for market subsidies is that increased adoption of photovoltaic energy will lead to lower costs, because of technological learning and economy of scale. Besides these economic reasons market stimulation of PV also creates institutional benefits, since it increases institutional learning and increases political power of PV advocacy groups against lobby groups promoting the vested energy interests. [Sanden, 2005].

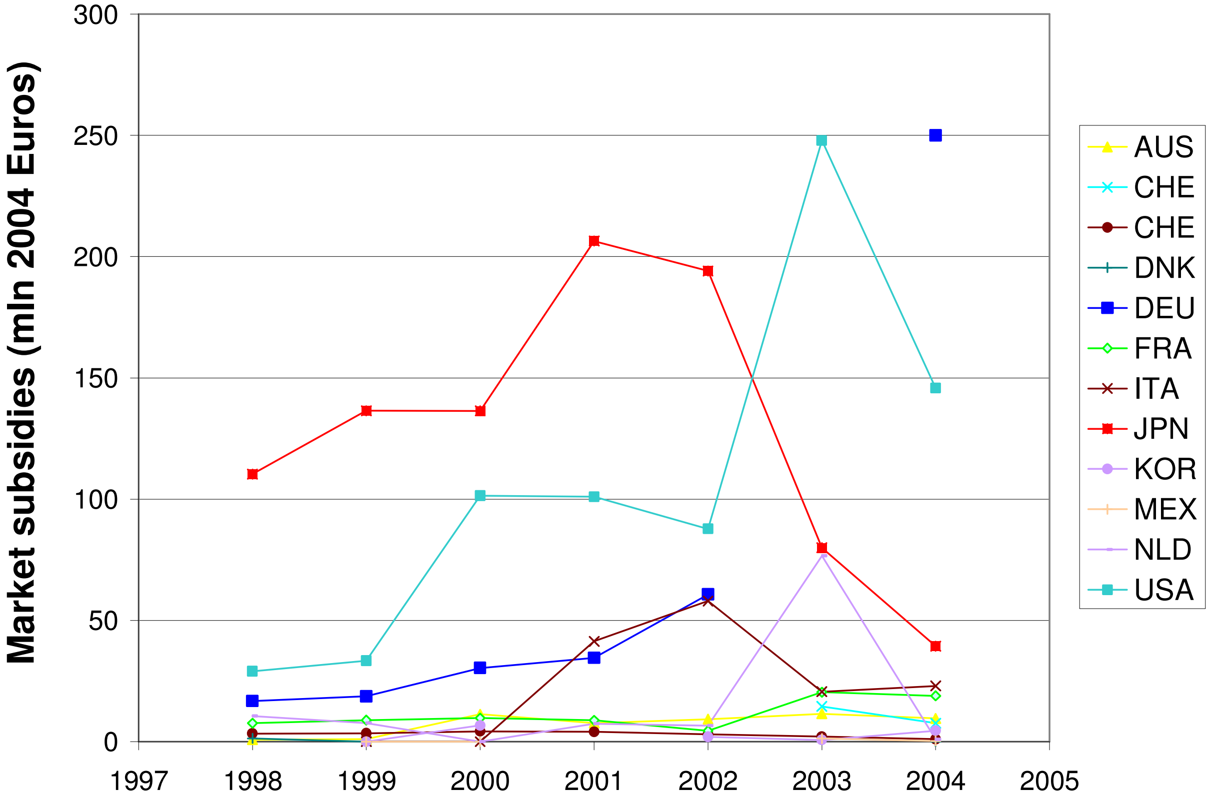

Figure 3-8 Market subsidies in million 2004 Euros (IEA PVPS reports 1998 to 2005)

The market subsidies for several IEA countries are plotted in Figure 3-8 for the period 1998 to 2004. For several countries the support budget increased and than decreased again. For Germany the loans are not included in the amount, but the budgets from feed-in tariffs are included.

One measure of the effectiveness of market subsidies could be to compare the yearly (public) expenditures with the annual installed capacity. In such a comparison errors will be introduced since subsidy and installation can fall in a different year. Also both of these data sets are known to have large uncertainties. Unfortunately it thus appears that the data quality is generally insufficient to make a quantitative analysis of the effectiveness of PV market subsidies.

The effectiveness of market subsidies have been analyzed on the basis of historic analysis in [Ragwitz *et al.*, 2005]. The authors found that the best progress towards a higher renewable energy share was achieved in countries with a stable support system and low overall barriers. Furthermore feed-in tariffs were found to be the most effective for the promotion of innovative technologies. Quota systems were found to be expensive, but with low growth rates.

3.3 Analysis of experience curves for PV modules and systems

In the Photex project technological learning with respect to PV technology was analysed extensively on the basis of historic data from 1976 up to 2001 [Schaeffer et al., 2004]. The concept of technological learning explains the observation that the cost per unit product decrease because of increasing experience. In an experience curve (or "learning curve") historic cost data are plotted as a function of the cumulative production volume. Because data on production *costs* are not easily available, market *prices* are generally used as a proxy of production costs.

In the Photex project the well-known Progress Ratio of 80% for modules, which implies that a doubling of cumulative module production results in a cost reduction of 20%, was again confirmed (Figure 3-9). For the last 4 years of the analyzed period (1987-2001)a steeper experience curve (PR=77%) was observed. Of course, after 2002 module prices in the market have increased instead of decreased, due to silicon supply shortages and the high demand for modules in Germany and Japan. However it is quite likely that the underlying production cost have decreased, also after 2001. Only when production capacities for silicon feedstock, wafers and cells have been ramped up to levels exceeding the demand we will be able to see again how the experience curve has progressed since 2001.

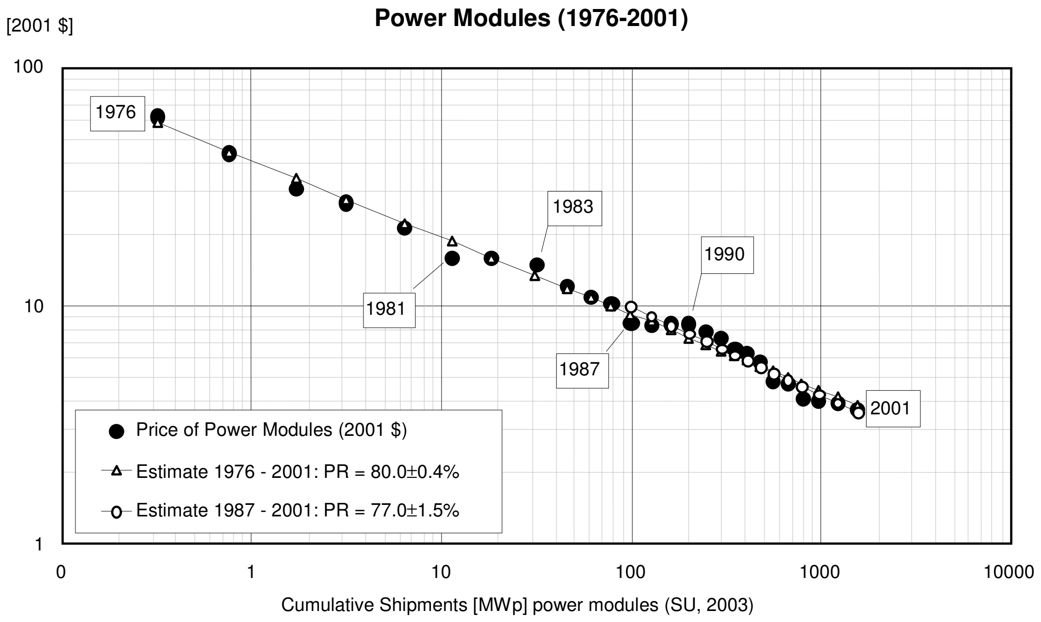

Figure 3-9: Experience curve for PV modules between 1976 and 2001 as analyzed in the Photex project [Schaeffer et al., 2004]

An analysis of prices for the Balance-of-System was also performed for residential (rooftop) PV systems in Germany and the Netherlands. In the Photex project it was observed that technological learning for these BOS components should be considered primarily on a national scale9, whereas module technology may be considered as global system of technological learning. When analysing experience curves the cumulative volume (on the X-axis) should be based on data for the same geographical market.

Although the available data for BOS prices spanned a shorter time period than in the case of modules, again a Progress Ratio of about 80% could be observed (Figure 3-10 and Figure 3-11). This result was somewhat surprising as it was believed previously that BOS components may have less potential for cost reductions.

For other types of PV system not enough consistent BOS price data were available to make a proper experience curve.

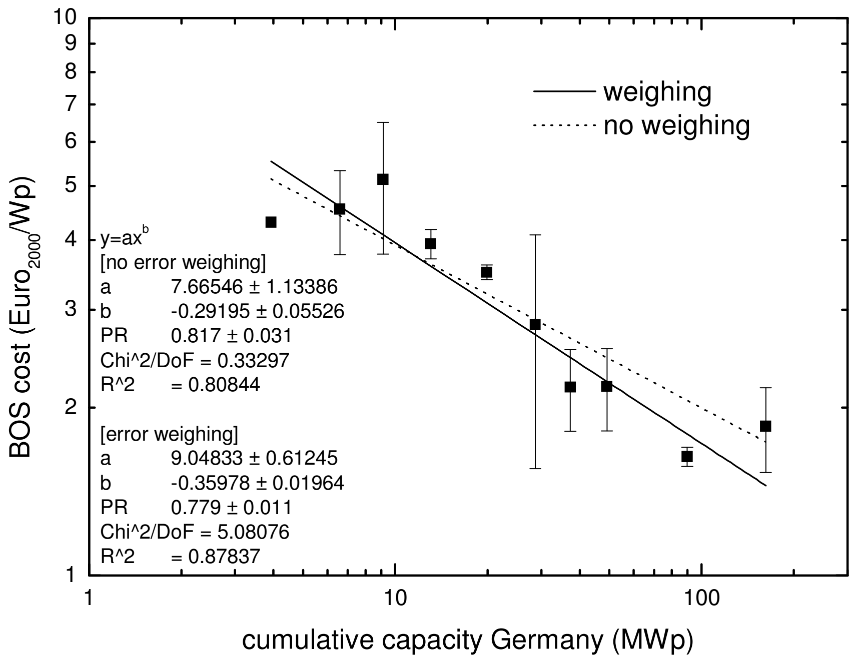

Figure 3-10: Experience curve for balance of system prices of residential systems in Germany[Schaeffer et al., 2004].

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[9] Especially for building integration components this holds true. In recent years the market for BOS components is becoming more and more a European market.

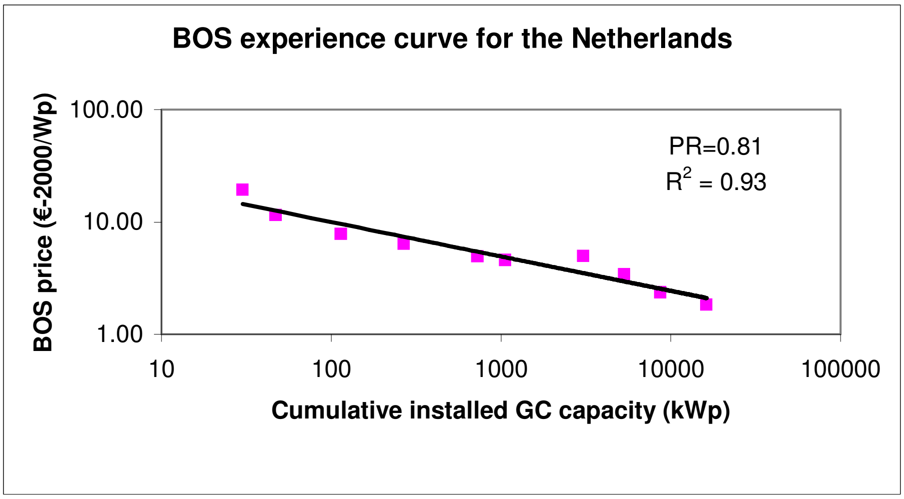

Figure 3-11: Experience curve for balance of system prices of residential systems in the Netherlands [Schaeffer et al., 2004].

Of course these results give no absolute certainty about future developments of the module and BOS prices as a function of installed volume. Moreover it seems likely that the rate of technological learning effect is also dependent on external conditions like RD&D funding. Although so-called two-factor learning curves (i.e. with cumulative RD&D budget as the second factor) have been proposed and modelled [Kouvaritakis et al., 2000, Miketa and Schrattenholzer, 2004] it remains quite difficult to obtain generate scientific evidence for such a model.

In conclusion we can say that is the historical price development for PV modules has consistently shown a Progress Ratio of 80% and that a similar PR is observed for the BOS part of residential PV systems. For the future it seems likely the PR values will also be in the 75-85% range, where a lower PR (i.e. stronger price reductions) is more likely if the conditions for technological learning are optimal because adequate levels of RD&D funding are available.

4 Break-even costs and scenarios for PV deployment

4.1 Introduction

In this chapter we will investigate when PV systems may become competitive in the European market and which development the penetration of PV supply might undergo, according to a number of published scenario studies.

4.2 Break-even costs for grid-connected PV systems in Europe

For the analysis of break-even costs we focus on grid-connected systems in Europe. Stand-alone applications of PV generally have a higher break-even price level than grid-connected but the corresponding market segments – in Europe at last- are relatively small. Of course important markets for stand-alone PV exist outside Europe which are often competitive already at today's prices. An interesting exercise with respect to break-even cost was presented by Sinke for the European PV Technology Platform [Sinke, 2006].

For the purpose of this analysis the price development for PV systems as published in the document "A Vision for Photovoltaic Energy "[Sinke *et al.*, 2005] were assumed (Figure 4-1).

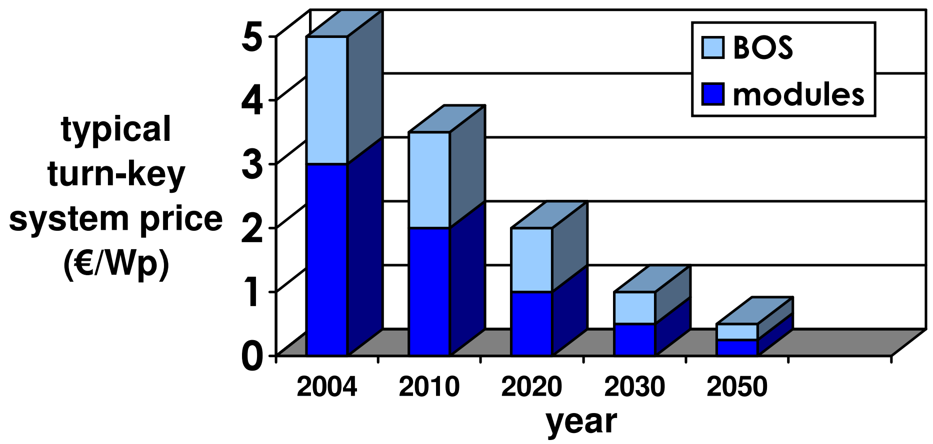

Figure 4-1: Assumed PV price development up to 2050 (prices excluding VAT). After: [Sinke *et al.*, 2005])

If we assume a depreciation over 25 years system life, a real interest rate of 4%, O&M cost of 1%/yr, and a PV system Performance Ratio 0.75 we can calculate levelized electricity costs for the PV system at a certain installed system price and given yearly irradiation.

For the year 2005 the resulting PV electricity costs are depicted in Figure 4-2 as coloured bands on the (irradiation) map of Europe. Irradiation values (in kWh/m2/yr) are specified on the right-hand side in the figure, while the corresponding PV price levels are displayed on the left-hand side.

For our break-even analysis we take the viewpoint of the private electricity consumer who has to pay electricity prices at the level of 0.10-0.22 €/kWh in the various European countries (Eurostat data; numbers in grey). Parity between PV electricity prices and consumer electricity prices is only attained in a small, high-irradiation zone at the bottom of the figure.

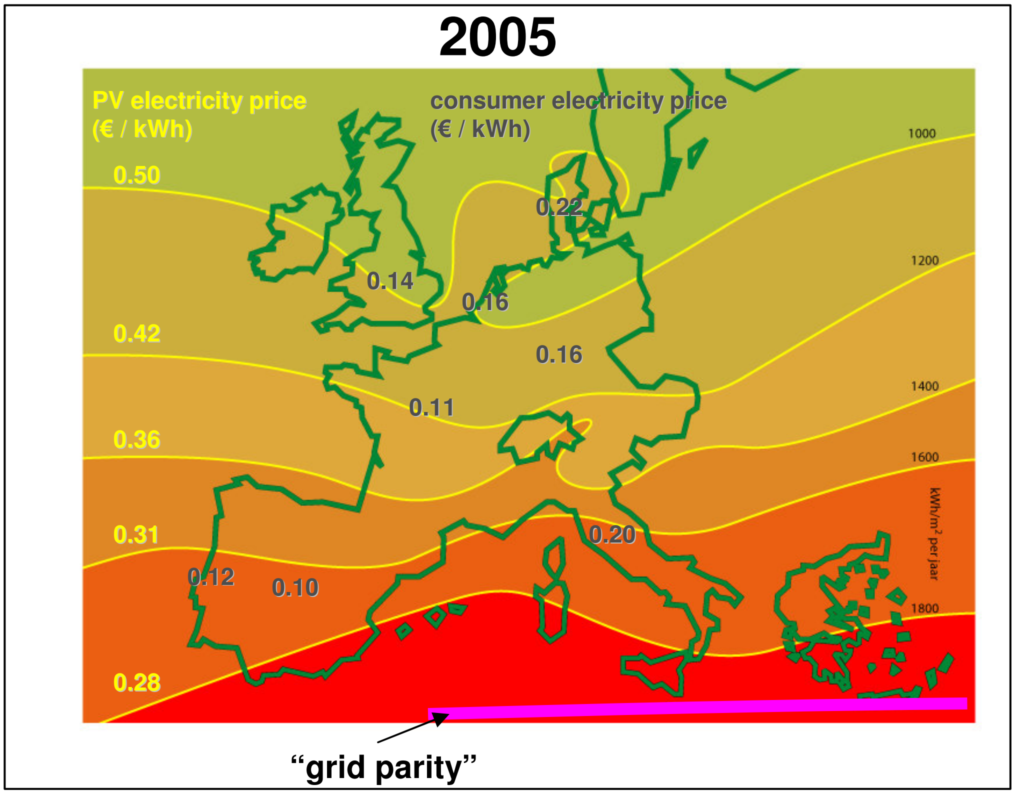

Figure 4-2: Break-even analysis for grid-connected PV system in Europe (status 2005). The coloured zones on the map indicate typical prices of PV electricity (yellow numbers,left), depending on the yearly irradiation (black numbers, right). These PV price levels can be compared with typical electricity prices paid by small consumers in different countries (grey numbers). Grid parity is possible in areas with a very high irradiation, shown as a narrow purple band at the bottom of the figure. After [Sinke, 2006].

If we apply the same analysis to the situation in 2010, with installed PV system prices of 3.5 €/Wp, and at consumer electricity prices which have increased by 1% per year, we obtain the results of figure Figure 4-3 where we can observe that in large parts of Italy grid parity has been attained.

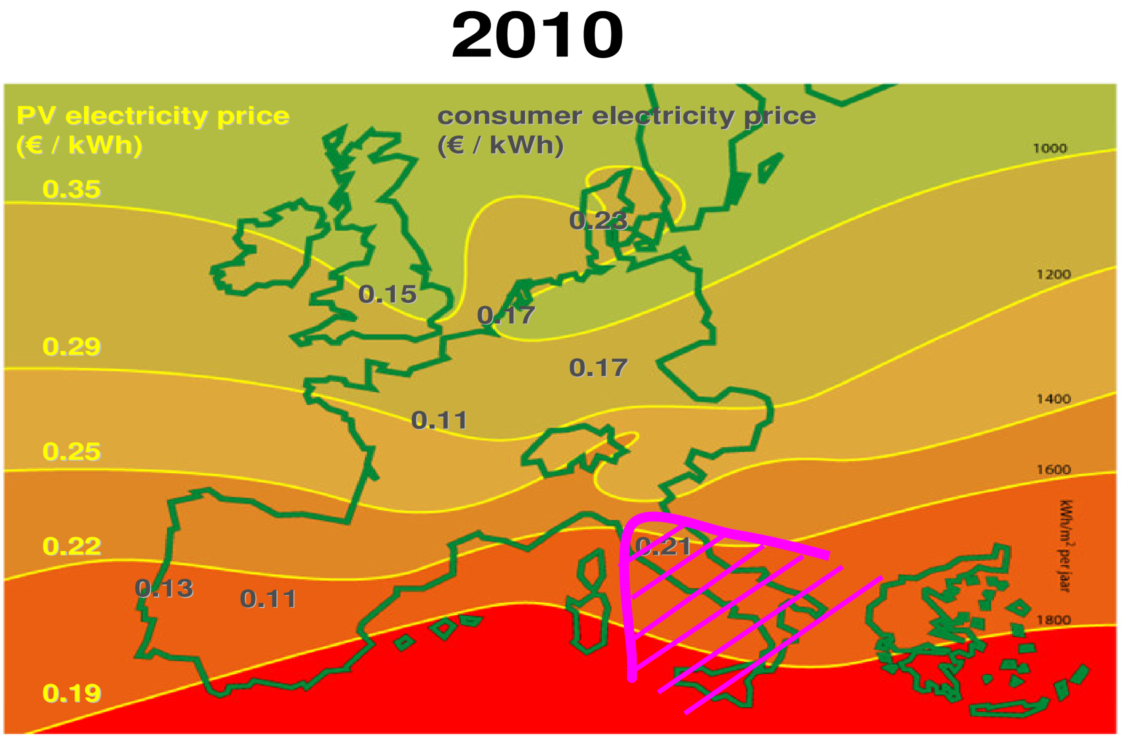

Figure 4-3: Break-even analysis for grid-connected PV, projection for 2010. Grid parity is achieved in large parts of Italy (purple hashed zone). Installed PV price 3.5 €/Wp, consumer electricity price is assumed to have increased by 1% year since 2005. After [Sinke, 2006].

In figure 4-4 to 4-5 the projected situation for respectively 2015 and 2020 are shown and we can see that – under the given assumptions – grid parity will be attained in large parts of Europe by 2020. Of course care is needed in the interpretation of these results.

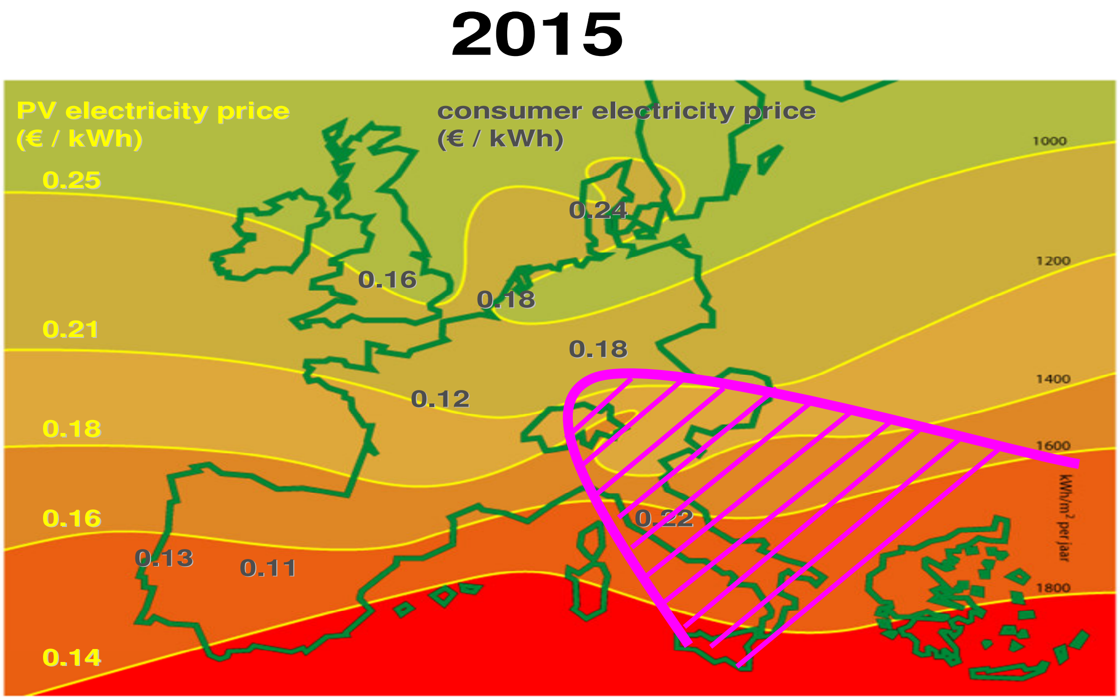

Figure 4-4: Same analysis as figure 4.3, projection for 2015. Grid parity in large parts of South-East Europe. Installed PV price 2.5 €/Wp, consumer electricity price is assumed to have increased by 1% year since 2005. After [Sinke, 2006].

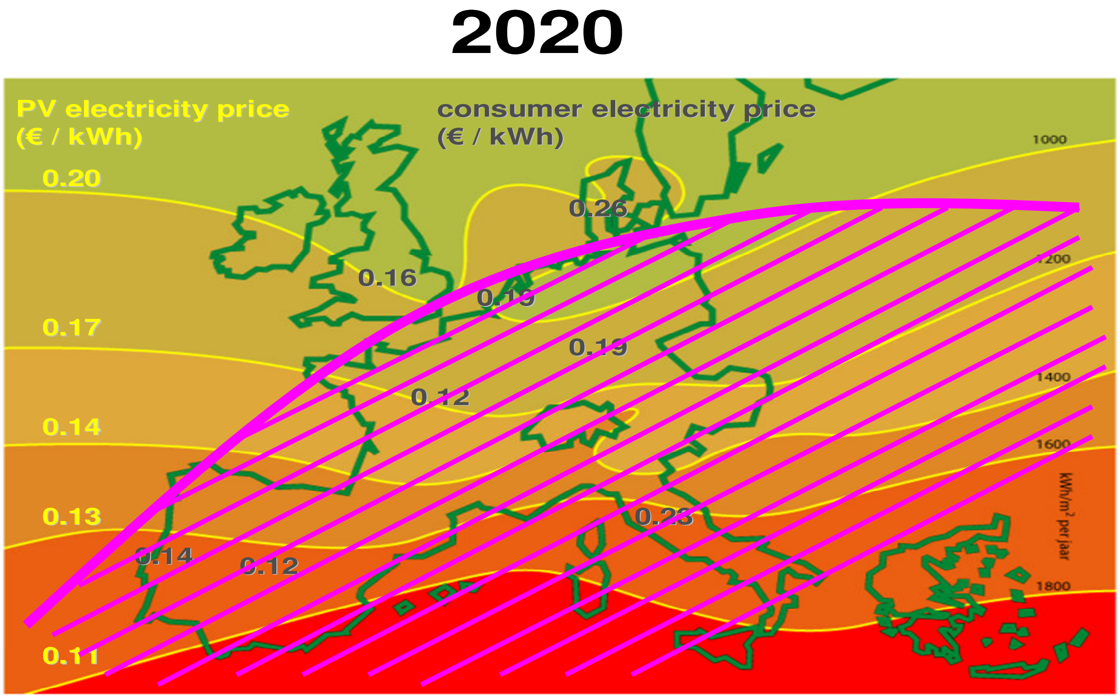

Figure 4-5: Same analysis as figure 4.3, projection for 2020. Grid parity in large parts of Europe. Installed PV price 2 €/Wp, consumer electricity price is assumed to have increased by 1% year since 2005. After [Sinke, 2006].

One point to note is that we assumed that electricity generated by PV may valued at the level of the consumer electricity price. This consumer electricity price is actually composed of different components, i.e. fuel costs, capacity costs and distribution costs. In the Netherlands for example the distribution costs are about 0.07 €/kWh. Because the costs of the distribution network still have to be covered when part of the electricity is generated by distributed PV there will be a point where the network operator may no longer allow PV to be fed in at a tariff that includes the distribution costs. In other words when the penetration of PV in the electricity supply network increases the question which costs are actually avoided by PV generation will be asked and these avoided costs will most probably be lower than electricity prices paid by the small consumer. Nonetheless the analysis above shows that there is a very interesting potential for PV deployment in Europe when installed PV system price decrease to a price level of 2-2.5 €/Wp.
In the next section we will discuss some scenario studies that try to quantify this deploymentof PV capacity.

4.3 Existing energy supply scenarios and the role for PV generation

4.3.1 Introduction

Several scenarios for a (sustainable) future energy supply have been published. In this chapter three selected scenarios will be discussed and compared. All scenarios discuss the world energy supply.

The first scenario is the ‘Solar Generation’ scenario developed by the European Photovoltaic Industry Association (EPIA) and Greenpeace, which has been published in 2004 [\EPIA and Greenpeace, 2006]. This report aimed at providing an analysis on the market potential of photovoltaics and shows that with realistic assumptions solar can play a significant role in the future energy supply. In this scenario 1.1 % of the world electricity supply in 2020 is supplied by solar.

The second scenario was developed by the German Advisory Council on Global Change [WBGU, 2004]. This comprehensive report proposes a pathway for a transformation to a sustainable energy system for the world in the 21st century. It includes a roadmap with concrete goals and policy options.

The last scenario has been developed by the European Renewable Energy Council and runs up to 2040 [EREC, 2004]. It aims to show that 50 % renewable energy by 2040 is feasible. Therefore it provides two growth scenarios. In the first ‘Advanced international policies scenario (AIP)’ ambitious growth rates for renewables are assumed, that require additional support measures. The ‘Dynamic current policies scenario (DCP)’ is based on less international cooperation, the demand for total energy is higher than in the AIP-scenario.

In section 4.1.5 these scenarios are compared with respect to energy production by PV and the share of energy provided by PV of the total energy supply.

4.3.2 Solar Generation by EPIA and Greenpeace

This scenario only concerns photovoltaic power. The scenario for 2020 with an extended projection up to 2040 is based on several inputs [\EPIA and Greenpeace, 2006]:

- PV market development over recent years both globally and in specific regions
- National and regional market support programs
- National targets for PV installations and manufacturing capacity
- Potential of PV in terms of solar irradiation, suitable roof space and demand in off-grid areas

The scenario assumes an average annual growth rate of 35 % per year from 2005 to 2009 and a growth rate of 26 % between 2010 and 2015. Between 2016 and 2020 market growth rates are remaining high at 19 % and drop to 11 % between 2020 and 2025. This leads to a global solar electricity output of 276 TWh in 2020 and 589 TWh in 2025. This translates to 1.3 % of the global electricity demand in 2020 and 2.5 % in 2025. In 2040 they expect a solar electricity output of 4890 TWh or 16 % of the global electricity demand.

4.3.3 WGBU scenario

This scenario is developed by the German Advisory Council on Global Change (WGBU) and is presented in the book “World in transition; towards sustainable energy systems” [WBGU, 2004]. The scenario gives a possible path for a transition towards a sustainable energy system in the 21st century.

The authors of this scenario study find it essential to turn towards sustainable development of the energy system for a couple of reasons. Firstly the use of fossil energy sources endangers natural life-support systems by releasing emissions, which cause air pollution, climatic change and human disease. Furthermore currently 2 billion people lack access to modern forms of energy. In developing countries biomass and coal are frequently used as a fuel indoors, causing 1.6 million deaths every year.

The paths for sustainable transformation of the WGBU are bounded by 'guard rails', which should not be crossed. Ecological guard rails include climate protection, sustainable land use, protection of rivers and their catchment areas, protection of marine ecosystems and prevention of atmospheric air pollution. The socio-economic guard rails comprise of access to advanced energy for all, meeting individual minimum energy requirement, limiting the proportion of income expended for energy, minimum macroeconomic development, keeping risks within a normal range and preventing disease caused by energy use.

The WGBU developed an exemplary path, which contains four key components:

1. major reduction in use of fossil energy sources
2. phase-out of the use of nuclear energy
3. Substantial development and expansion of new renewable energy sources: notably solar
4. improvement of energy productivity far beyond historical rates

The sustainable transformation path is depicted in Figure 3.1.

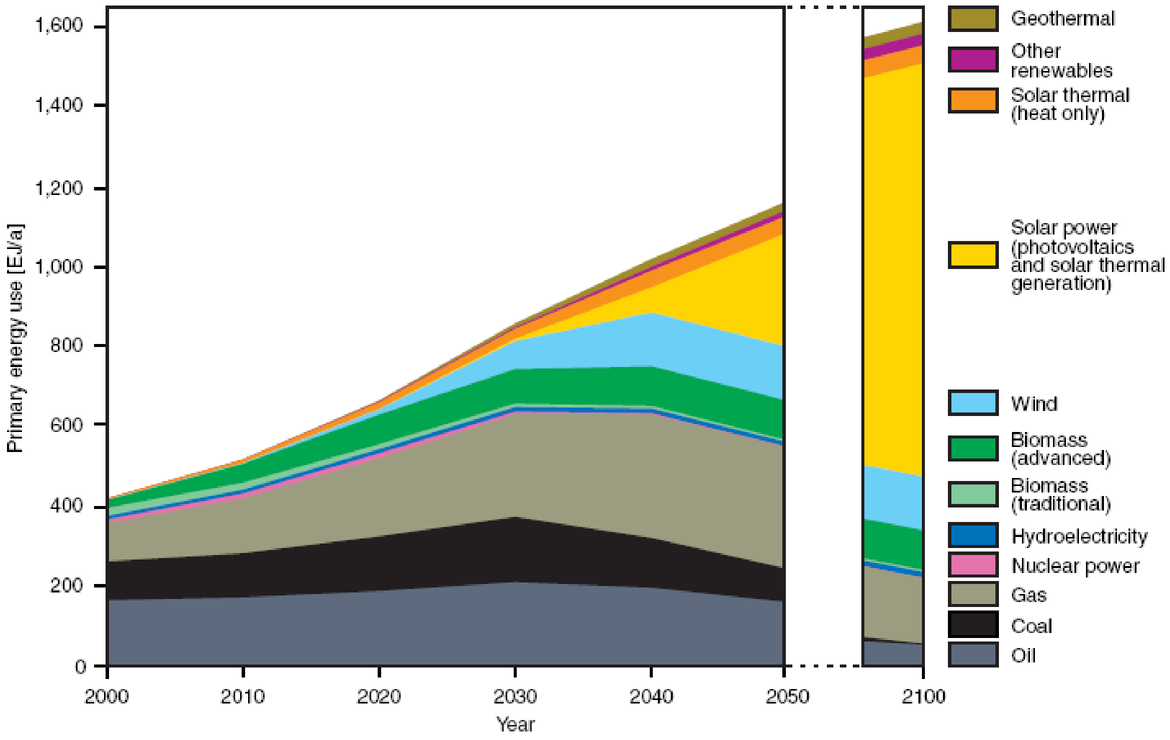

Figure 4-6 **Energy supply scenario of WBGU**

The share of solar energy increases slowly from 0,002 % in 2000 to 6 % of the total energy use in 2040 and than via 25 % in 2050 to 64 % in 2100. In the developed scenario the amount of solar power increases slower than in the scenario the WGBU derived this scenario from, since they found the original growth curve unreasonably high. Solar-based power generation grows tenfold each decade until 2040. This means a yearly increase of installed power by 26 %. After 2040 the growth is lower. In this scenario the solar-based power consists of distributed photovoltaics and photovoltaic and solar thermal power generation.

4.3.4 EREC Scenario

The European Renewable Energy Council (EREC) developed two scenarios to show that renewables will be able to play a significant role in the future world wide energy supply [EREC, 2004]. According to them a share of 50 % renewables in 2040 is possible as can be seen in the AIP-scenario.

The ‘Advanced international policies scenario (AIP)’ assumes ambitious growth rates for renewable energy, higher prices for conventional energy sources and growing support for electrification of the less and least developed countries. It also assumes unprecedented progressive international cooperation focused on environmental protection and international equity, including substantial resource transfer from industrialized to developing countries. Nuclear power is phased out in the 21st century. The assumptions for total energy consumption are based on a scenario from IIASA.

The ‘Dynamic current policies scenario (DCP)’ is less ambitious than the AIP scenario, but more ambitious as a business as usual scenario. Less international cooperation is assumed, but ambitious policy measures on national levels are expected at least in the industrialized part of the world. The figures for energy consumption are higher than in the AIP scenario.

In the AIP-scenario the share of PV in the energy supply increases via 0.21 % in 2020 to 5.89 % in 2040. The energy generation increases from 279 TWh in 2020 to 9118 TWh in 2040. In the DCP-scenario the energy generation increases from 174 TWh in 2020 to 5175 TWh in 2040.

4.3.5 Comparison of scenarios

Since several scenarios start in 2000, the growth rates up to 2005 of the scenarios have been adapted to the real growth rates (Maycock data). After 2005 the growth rates indicated in the scenarios are used. This makes a difference, especially for the EPIA-scenario, where annual market growth rates were assumed.

The resulting energy yield of the scenarios is shown up to 2040 in Figure 3-3, while Figure 3-2 shows the developments up to 2020 in more detail. The EPIA/Greenpeace scenario results in the fastest increase in PV energy supply[10]. It can be seen that the WGBU scenario starts a bit more pessimistic, but grows more quickly between 2030 and 2040.

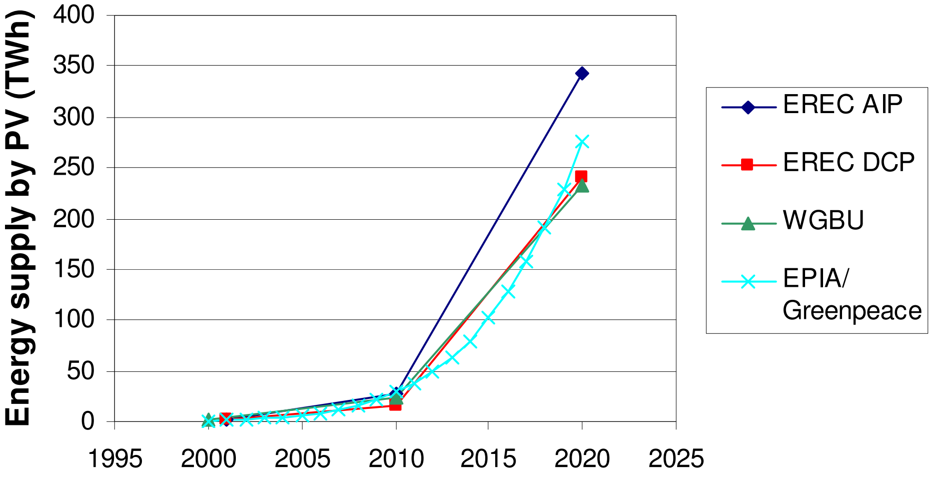

Figure 4-7 Energy supply by PV in a number of scenarios, up to 2020 (data corrected for actual growth figures 2000-2005)

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[10] The 2040 value of the EPIA-scenario is a single value and therefore it was not adapted to the higher growth rates that occurred in the period 2000-2005. Furthermore a yearly energy yield of 1220 kWh/kWp was assumed.

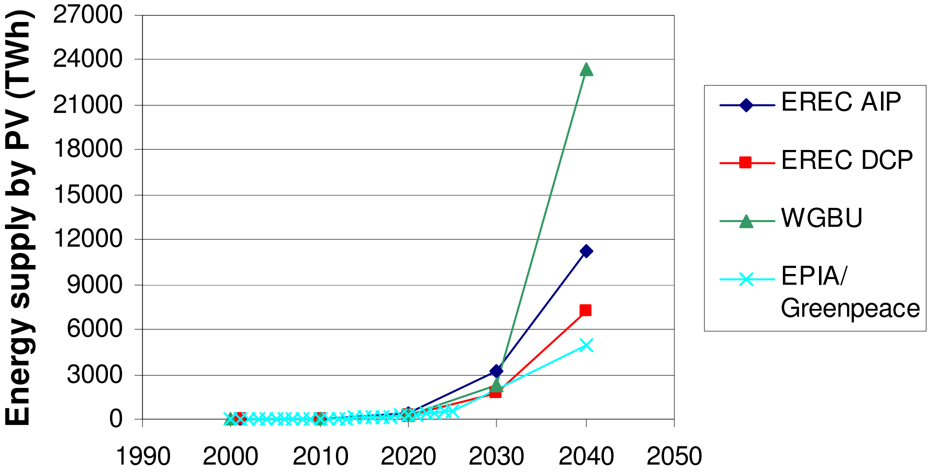

Figure 4-8 **Energy supply by PV in different scenarios, up to 2040 (data corrected for actual growth figures 2000-2005)**

The total energy demand that was assumed in the EREC and WBGU scenarios is shown in Figure 3-4, while Figure 3-5 displays the relative share of PV in each scenario. Because assumptions on demand growth vary between scenarios, the comparison of relative PV shares gives a different picture as the absolute PV generation data. The more optimistic scenarios expect that in 2040 around 8 % of the energy use will be supplied by PV.

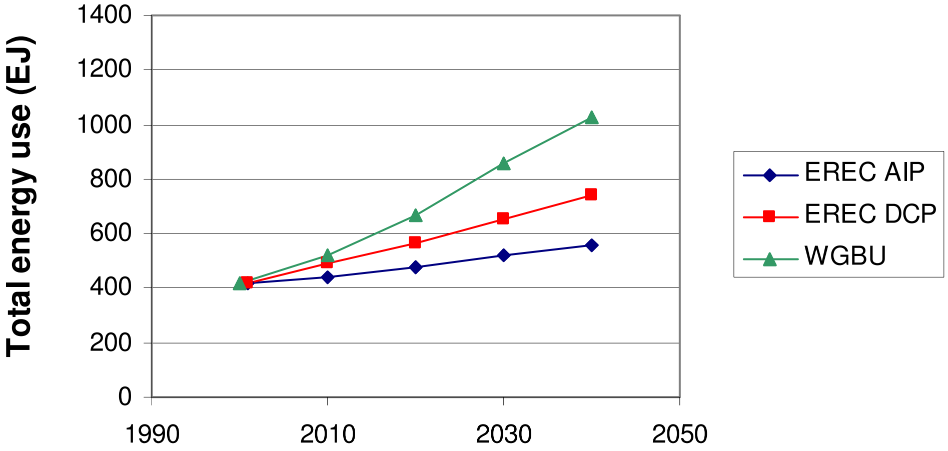

Figure 4-9 **Global energy demand assumed in the EREC and WGBU scenarios**

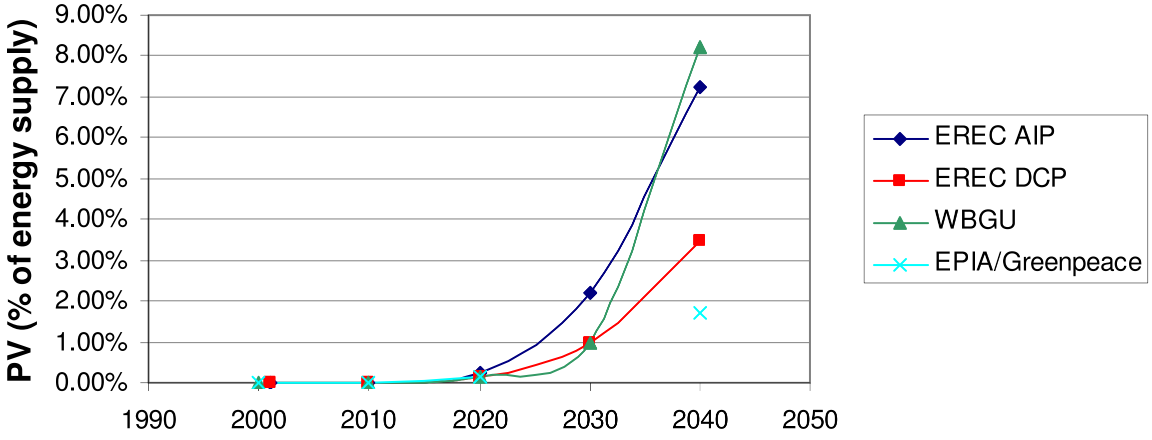

Figure 4-10 **PV share in the global energy supply for the EREC and WGBU scenarios, EPIA on basis of WGBU energy demand**

5 Summary and Conclusions

In this study we have reviewed several socio-economic aspects of photovoltaic energy technology. Attention was given RD&D budgets and market stimulation instruments in different countries. We have seen that in 2004 about 203 million Euros were spent on national public R&D for solar energy in IEA countries, excluding demonstration activities. Of this budget 35 percent was spent in Europe, compared to 37 % in the United States and 25 % in Japan. Over the past decade the public spending on solar energy has nearly doubled, but the spending on market stimulation increased at the expense of R&D until 2004. The EU support was on average about 20% of the national budgets in Europe.

European countries spent relatively more of its energy research budget on renewables than the rest of the world but on the other hand the share of PV in renewables budget seems relatively low in Europe (28%) in comparison with worldwide spending (40% for PV). If we compare the total budget for RD&D and market stimulation between Europe, Japan and the USA on a per capita basis, the budgets are highest in Japan (ca. 1.3 €/cap) , with Europe closely behind (ca. 1.2 €/cap) and lowest in the USA ca. 0.75 €/cap).

The exact effects of RD&D spending are not easy to determine but examination of historical data (1974-2005) for RD&D spending on the one hand and technological progress on the other hand suggests that there is a positive correlation between available RD&D budgets and technological progress, as measured by solar cell efficiency or by module production cost.

A historic analysis (1974-2004) of patenting activity in the USA, Japan and Germany indicated that the number of patent applications in Japan and the USA correlated quite well with the size of RD&D budgets, of course with a time lag of some years. For Germany no positive correlation could not be observed (it seemed even negatively correlated), but here we had data for a period of last 15 years.

Studies on job creation by the PV industry indicate that roughly 20 jobs are created per MWp of module production and another 25-30 jobs/MWp for BOS and installation activities. Of course the labour intensity in the PV industry will decrease in the future, due to process automation, production up-scaling and higher module efficiency. The estimates given above only include *direct* jobs, that is jobs that are directly related to PV technology. If we would include also indirect jobs in sectors supplying materials or services to the PV sector then the number wiil increase by roughly about 30 jobs per MWp, bringing the total effect to 70-80 jobs per MWp installed. On the other hand, an economic study which did also include the effects of the market stimulation subsidies in Germany (i.e. the feed-in tariff) found a negative effect on job creation because of the reduced spending in other economic sectors ("budget effect"). According to this study the negative effect on jobs would outweigh the positive effect.

One can conclude that PV technology is presently relatively labour-intensive sector and therefore it creates a relatively high number of jobs per euro invested. The downside of this characteristic is that PV needs specific stimulation budgets in order to attract investments. When PV becomes more competitive with other energy technologies the number of jobs will probably also reduce. Also we can conclude that the market stimulation of PV technology should not be done with the argument of job creation, but rather for the sake of energy and climate policy.

The analysis of historic experience curves has shown that for PV module technology a progress Ratio of 0.80 can be observed, meaning that the price is reduced by 20% at each doubling of cumulative production volume. With respect to BOS costs a similar Progress Ratio was observed for residential PV systems in Germany and the Netherlands. Because the latter learning effect has taken place primarily on national scale, it was argued that the experience curve analysis must be done within the corresponding geographical boundaries (i.e. by looking at *national* market volumes). For PV modules on the hand the technological leaning system has a global scope.

At present in Europe PV electricity can not compete with end-user electricity prices yet. But if turnkey PV system prices decrease to roughly 2.0-2.5 €/Wp and if grid electricity prices continue to increase with 1% per year, PV electricity may reach the break-even point for small electricity consumers in large parts of South- and even Middle-Europe. This break-even situation would open the way for large-scale introduction of PV energy in European electricity markets. However careful analysis is still needed of the *actual* costs avoided by PV generation in relation to the structure of the electricity supply system in different regions because PV feed-in tariffs at a level equal to end-user price levels will not be economically acceptable once PV penetration reaches significant levels in a utility system.

Several scenarios for a (sustainable) future energy supply have been published and all include a significant share of PV generation. In three scenarios analysed here from EREC, WGBU and EPIA/Greenpeace global energy supply by PV reaches levels of 250-350 TWh/yr in 2020,and grows up to 23000 TWH/yr in 2040. In the most optimistic scenario (WGBU) PV would supply about 8% of the global electricity demand in 2040.

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