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EXPERIENCE CURVE APPROACH FOR MORE EFFECTIVE POLICY INSTRUMENTS

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ABSTRACT

The price evolution of PV systems in Europe shows that a significant reduction is achieved for modules and the BOS of small rooftop grid connected systems. The learning rate is 20%, consistent with other studies. The module price has stabilised the last years, as market conditions had a large effect. It is expected that recently built and planned module production facilities will give an increased cost reduction. For rooftop systems the market that has been created in the last decade will lead to more standardisation and integration in the building sector, leading to lower prices, but also more application.

1. INTRODUCTION

For large-scale application of PV it is essential that it is cost-effective in the longer term. Public and private money is invested in the development of PV, because it is thought to have a high potential to become low-cost. For the ultimate success of PV it is important to follow a route that is consistently supported, based on realistic confidence of the potential of solar energy. A crucial element in this process is monitoring the price evolution. A systematic method to evaluate the results is the learning curve approach.

The preliminary results of the European research project PHOTEX are presented here [1]. Experience (learning) curves for PV are developed in close co-operation with the International Energy Agency (IEA). IEA has established a network called EXCETP (EXperience Curves for Energy Technology Policy) to provide experience curve data base and methodologies, which together with insights from case studies will support policy making for energy technology [2,3].

An experience curve is based on the empirical observation that many technologies show a linear decline of the price with the cumulative sales when plotted double-logarithmically. The slope of this line is the progress ratio, PR, defined as the price ratio after a doubling of the cumulative sales. In figure 1 and 2 can be seen that for PV modules a progress ratio of about 0.8 is observed, or a learning rate, LR, of 0.2, using the relation:

$$LR = 1 - PR \quad (1)$$

LR is the relative price reduction after one doubling in sales, due to "learning".

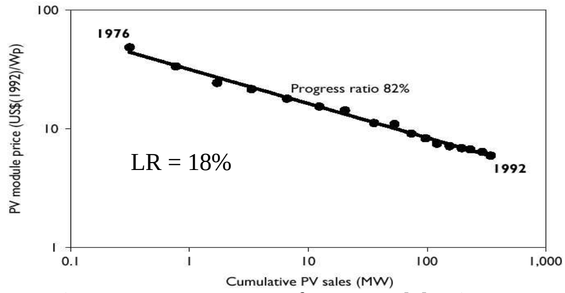

Fig. 1 Experience curve for PV modules (1976-1992) according to Williams and Terzian [4]

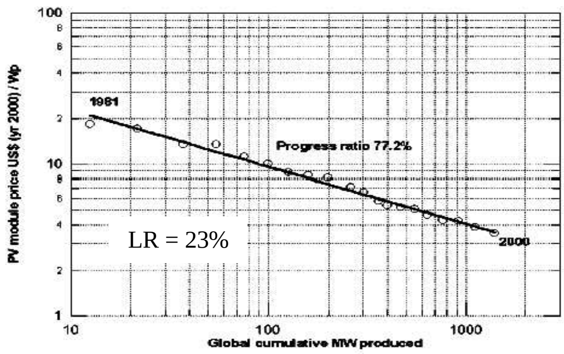

Fig. 2 Experience curve for PV modules (1981-2000) according to Parente et al. [5]

2. LEARNING RATE REQUIRED

As can be seen in figure 1 and 2 the price evolution of modules indeed follows the linear relation in a double-logarithmic plot. The learning rate is 20% over the past 25 years.

Suppose a constant LR will occur in the coming decades, what will be the related price reduction and will this be consistent with the expectations?

In figure 3 a price projection of PV systems is depicted as calculated using the data from table 1.

Table 1 Status of PV sales, installed capacity and price

Cumulative Capacity end 2002 [6]	2.35 GWp
Shipments 2002 [6]	0.5 GWp
System Price 2002	6 €/Wp
Module Price 2002	4 €/Wp

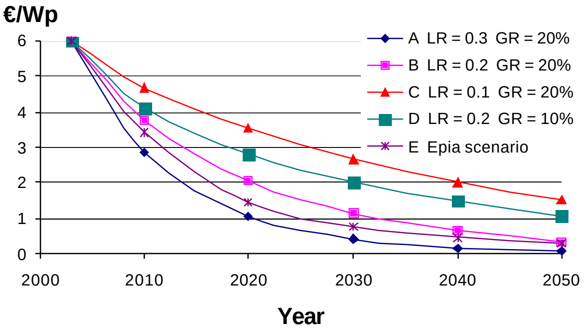

Fig. 3 Price of PV Systems as a function of Learning and Growth Rate (PHOTEX calculations)

As can be seen in figure 3, when an average growth rate of the annual shipments of 20% (common in the last decade) is used, a learning rate of 10% is too low to obtain low-cost PV in a reasonable time. Even with an LR of 20% the price decrease is slower than projected, unless a very ambitious implementation scheme is followed. EPIA and Greenpeace [7] extrapolated the more than 30% rates of the last five years until 2020 and could conclude that even ambitious targets are within reach. For 2020 until 2040 a 20% rate was used; still high as with an increasing penetration the growth rate usually decreases.

Table 2 Price projections of PV for 2010

Scenario	Price €/Wp	LR
GR = 20%	3.8 System	20%
EC White Paper [8] GR = 28%	2.5 System	29%
GR = 20%	2.5 Module	20%
Greenpeace EPIA GR = 27%	1.6 Module	31%
5% annual price reduction	2.6 Module	19%

Growth rate is 20% unless indicated differently
The EU has a target of 3 GWp in 2010 resulting in a GR of 28%

In table 2 can be seen that the EU and EPIA/Greenpeace are very ambitious, as a learning rate of 30% is needed. A 5% annual price reduction is in line with the historic trend. Of course the LR depends on the price assumed for 2002. For a system 6 €/Wp and for modules 4 €/Wp are perhaps conservative estimates, but quite realistic as can be seen in the following. If a module price of 3 €/Wp is used, a LR of 23% is sufficient to attain the Greenpeace EPIA target.

Another way of looking at the needed learning rate is to calculate the cost before a competitive technology is obtained. It is obvious that cost-effectiveness depends on the market segments and on their future cost and price developments. As a first approximation it is calculated what investment is needed before the price of a system is below 1 €/Wp. Depending on the insolation and interest rate this results in an electricity price of 0.05 to 0.10 €/kWh. This is attractive for private consumers and peak shaving, especially if external costs are taken into account. In table 3 the total "learning" investment is shown: the price difference with 1 €/Wp is multiplied with the volume installed that year and added until the breakeven year is reached. Not taken into account in this figure is the moment of investment. The appreciation of an investment further in the future is often more positive i.e. cost should be discounted.

Table 3 Learning Investment

Scenario	Total Cost ($x10^9$ €)	Breakeven Year
LR = 30% GR = 20%	55	2021
LR = 20% GR = 20%	270	2032
LR = 10% GR = 20%	> 10,000	2066
LR = 20% GR = 10%	270	2053
Greenpeace EPIA	270	2024

Learning investments depend on the LR, in fact it is the surface area under the learning curve, see figures 1 and 2, and between the line of competitive technologies, assumed here at a level of 1 €/Wp.

It can be seen clearly that a learning rate of 10%, under the given assumptions, will not make PV competitive. So, at the given starting point of 2002 the cost reduction of PV should follow a learning curve with a rate of 20% or better.

Of course the growth rate has an impact on the investment rate; on the period when the investment is maximal and on the annual amount. It also has an impact on the price in a given year. So, from the policy point of view, the relevant questions are: at what time, what contribution of PV is needed and at what cost. Not shown here, obviously the learning rate may depend on the growth rate in a given time window.

3. PV PRICES IN THE EUROPEAN UNION

In the frame of the PHOTEX project price data have been collected for modules, system components and complete grid connected systems. In total 3400 data records are available, being a representative sample, more then one third of the installed capacity, for Germany, Italy, the Netherlands and France. The original price data, in local currency, were converted to Euro of the year 2000. Most of the data are end user prices of typical roof top systems, BRD and NL, and large PV installations, Italy.

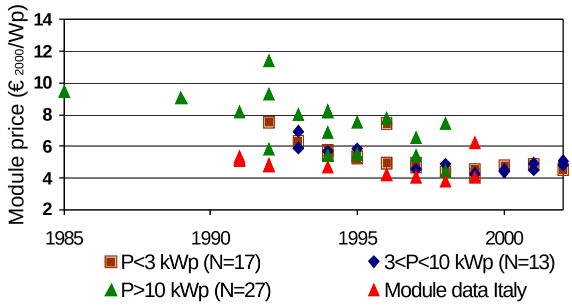

Fig. 4 Module Prices in the EU

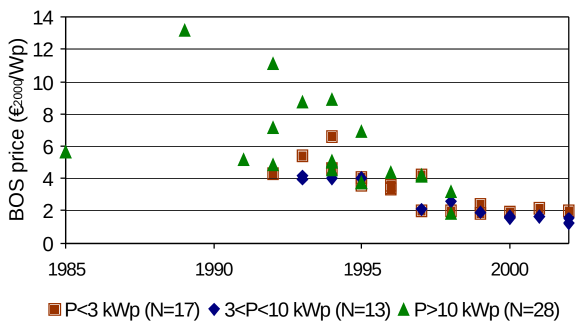

Fig. 5 BOS Prices in the EU

Figure 4 and 5 present first results for systems in Germany and Italy. It can be seen that a considerable price reduction is achieved for modules, consistent with the learning curves presented in figures 1 and 2. A closer look shows that since 1999 the module prices went up. This does not mean that the cost has increased, but is merely an indication that the market conditions changed. The growth in European shipments was 10% in 1998, 20% (1999) and increased to 50% in 2000, 40% (2001) and 30% (2002) [6]. The price increase is confirmed by IEA-data [9].

In figure 5 can be seen that a significant reduction is achieved for the BOS. Clearly a small rooftop system can not be compared with a large PV plant directly. However in both cases the experience gained in the first demonstration projects resulted in more standardised approaches in recent years.

As an example the system cost of some typical German rooftop systems is shown in figure 6.

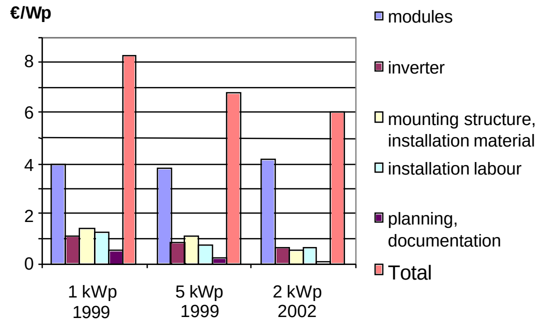

Fig. 6 Typical Cost Structure of German Grid Connected Rooftop PV Systems

It can be seen clearly in figure 6 that the BOS cost is only minor compared to the price of the module. This is due to standardisation. The size of the German market and the perspective made it attractive for actors in the building sector, suppliers and installers, to invest in standard systems. Because of the critical mass that was achieved the cost of planning even became negligible.

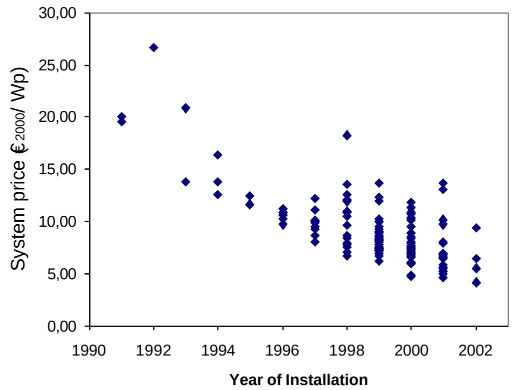

Fig. 7 Prices of rooftop PV systems in the Netherlands

A similar trend as in Germany can be observed in the Netherlands, figure 7, where also a high implementation rate in the nineties and demonstration programs "caused" a price reduction from 20 $€_{2000}$/Wp in 1991 to even 5 $€_{2000}$/Wp in 2000. A cost breakdown of these systems could not be obtained, but with a module cost between 3.5 and 4 €/Wp, the BOS cost is between 1.5 and 2 €/Wp, hence very low for roof–integrated systems.

4. LEARNING CURVE FOR ROOF TOP SYSTEMS IN GERMANY

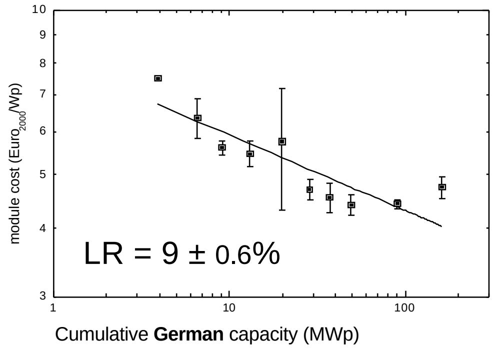

Fig. 8 Learning curve for modules used in German rooftop PV systems

Based on the data of figure 4 a learning curve was constructed using the cumulative capacity installed in Germany. It turned out that for the last decade the PV module learning rate was only 9%. At first glance one could say that it is caused by the recent stagnation in the price development. A second more detailed analysis learns that module manufacturing and sales are not a local activity. There is an intensive interaction between the R&D community and manufacturers world-wide. Thus, the learning will not be determined locally, apart from maybe the German distribution chain, but globally. If as x-axis the global cumulative capacity is used a better description of the actual learning is obtained.

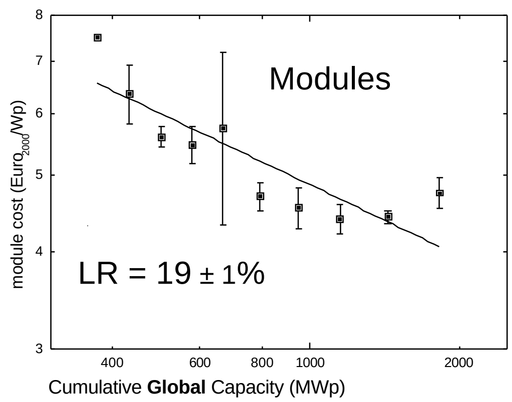

Fig. 9 Learning curve assuming global learning for modules used in German rooftop PV systems

The learning rate for modules that we find then is 19%, a value consistent with earlier work. Although the ambitious implementation programmes in Germany could not enhance local learning to lower module prices, it can well be that German manufacturers are able to produce at lower cost in the future due to this market stimulation.

In figure 10 the learning curve for BOS is shown. Using weighing, an LR of 22% is obtained. Installed capacity in Germany is used for the x-axis, as it is reasonable to assume local learning for BOS. This is certainly valid for the building sector. For inverters this also holds because of national grid regulations.

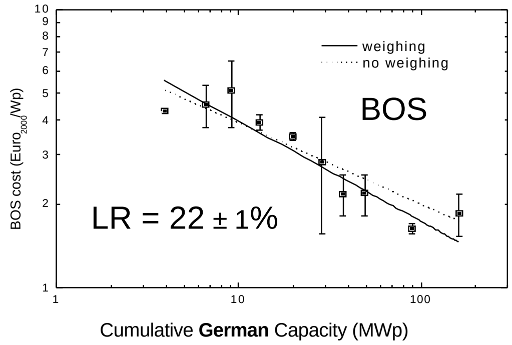

Fig. 10 Learning curve assuming local learning for BOS of German rooftop PV systems

To analyse the learning curve, a mix of global and local learning must be considered for the total price of PV systems. Plotting the price evolution against the cumulative German capacity gives an LR of 14%. On the other hand, if global learning is assumed for systems an LR of 20% is obtained.

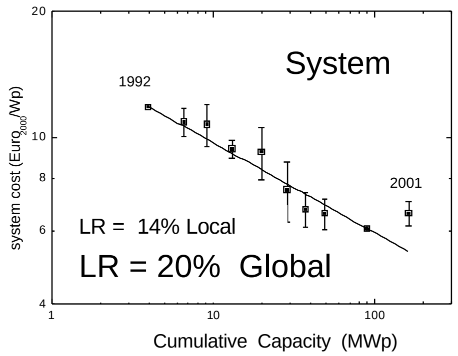

Fig. 11 Learning curve German rooftop PV systems

5. DISCUSSION

In the PHOTEX project the price evolution of PV is studied. Usually this reflects the cost, as the price equals the cost plus a profit. In a normal competitive market this gives a saw-tooth curve, as to be seen in figure 12, above the cost curve; straight for an ideal learning curve. In case of PV, it may well happen that a large gap between the cost and price lines exists. Many PV companies are part of a large company, so large relative losses may be obscured as the absolute loss can be well accommodated. This can give a large uncertainty in the learning rate if the time (capacity) interval small.

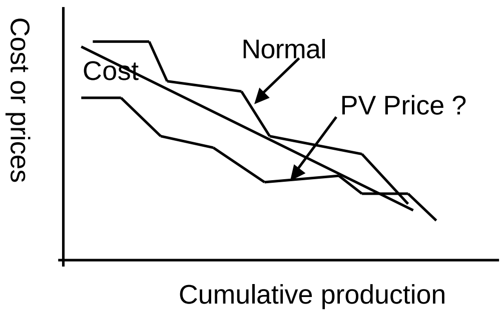

Fig. 12 Relation between price and cost

6. CONCLUSIONS

A representative evaluation of the price developments in Europe shows that the learning rate is still on the right track. This means that price projections using LR = 20% are consistent with the recent past. An increase in the growth rate can result in a temporarily higher price due to market effects. Though this needs not to result in a permanent change of the learning rate, it could give a signal to the policy makers to reduce market support. A stop-and-go support influences the learning community probably very negatively. Consistent policy and a related predictable market are needed to maintain a high learning rate for PV.

As prices of the different components in a PV system are evaluated, it can be concluded that the learning rate of modules and BOS are quite similar, if considered in the correct context. As a consequence and in contrast to earlier predictions, modules are still the major cost factor.

Not considered in this paper, but an important subject in PHOTEX, is the potential for cost reduction. The learning rate is not an autonomous number, there must be underlying reasons and mechanisms to make lower cost possible. Though it is difficult to quantify the cost potential of solar modules, the route to 1 €/Wp is clear: up-scaling, less use of materials (silicon), higher efficiencies and higher yield (thin-films) [10,11]. For further progress most probably new concepts are needed such as (organic) polymer solar modules.

In the learning evaluation, system price is the parameter considered. It would be more appropriate to take the cost and price of a kWh. This also comprises the output of a system, the lifetime and maintenance costs. However data on this subject are quite scarce. If such an analysis was done, the increasing reliability of inverters and improved maintenance schemes, important in case of high feed-in tariffs, would probably show an even better learning rate for BOS. So, though difficult to quantify, increased reliability, lower maintenance cost are important factors for BOS.

7. ACKNOWLEDGEMENT

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