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LEARNING IN PV TRENDS AND FUTURE PROSPECTS

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ABSTRACT: For large scale application of PV cost reduction is essential. It is shown in this study that the price evolution is on track and even accelerating the last 15 years. Using an experience curve approach a learning rate of little over 20% was found consistent with other studies. As data were collected for small rooftop grid connected systems, it could be shown that this learning rate is not only found for modules, but also for BOS in Germany as well as in the Netherlands. Projections of the future price of PV systems show that a learning rate of at least 20% is needed to make introduction of PV affordable. It is very effective to invest in learning, thus increasing the learning rate, as well as developing market segments were the value of PV is higher, such as residential PV systems in southern Europe.

Keywords: Strategy, Marketing, Economic Analysis

1 INTRODUCTION

For large-scale implementation of PV, cost is the essential success factor. A systematic method to evaluate the progress made in reducing the costs is the experience curve approach [1,2]. It is based on the empirical observation that for many technologies for every doubling of cumulative produced capacity of a product or technology, the cost for making it declines with a fixed percentage: the learning rate. More often progress ratio, PR, is used, defined as the price ratio after a doubling of the cumulative sales.

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

The cost reductions in the experience curve refer to total costs and changes in production (process innovations, learning effects, and scaling effects), products (product innovations, product redesign, and product standardisation), and input prices of the raw materials. Gaining experience is a long-term process, which represents the combined effect of a large number of parameters, which may undergo fluctuations over short periods. Only after many doublings of cumulative shipments can the underlying pattern or trend be distinguished.

For PV modules a learning rate of about 0.2 is observed in several studies [3,4]. This rate is remarkable constant over more than three decades: 1976-2000. As the cost of solar electricity is determined by the total system and the BOS (all costs apart from the modules), was expected to become dominant, it is necessary to evaluate the costs of the different systems components. The rapid deployment of PV in Europe raised the question whether a mature industry could be able to maintain this relatively high learning rate of 20%.

The European project Photex [5] was initiated to collect recent data for European PV systems and to further explore the experience curve approach. The theory of learning was studied, experience curve analyses were combined with bottom-up engineering studies, indicating routes and possibilities for cost reduction and lessons for PV policy were deduced.

2 LEARNING RATE FOR BOS AND MODULES

The basis for a good experience curve analysis is the availability of firm and reliable data. As cost data are proprietary information of manufacturers price data are collected in the PHOTEX project. PV systems including installation and their cost break down into modules and BOS were evaluated. In total 3600 data records are available, being a representative sample for Germany, Italy, the Netherlands and France. 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.

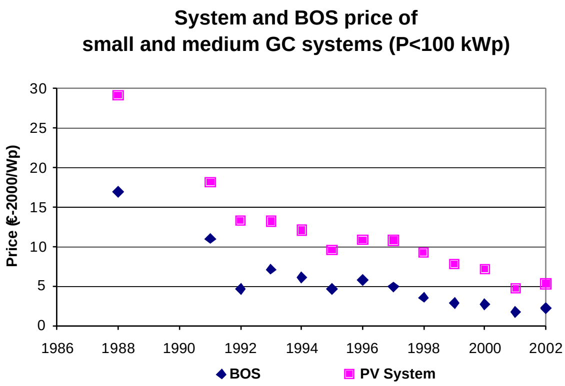

Figure 1: Price development of small grid-connected PV systems in Europe.

As discussed in a previous paper [6] it makes no sense to deduce a learning rate for a PV system, as the module prices are determined globally, whereas BOS “learn” locally. As can be seen in Figure 1 a significant price reduction can be observed, with periods of stagnation due to market effects.

In constructing the Photex-database, it was experienced that the cost breakdown of installed systems into components is often unavailable. Therefore the BOS cost is partly calculated subtracting module data, that are rather constant, from system prices. In Figure 2 can be seen that the resulting learning rate for

BOS of systems installed in Europe and represented in the Photex database (i.e. mainly from Germany and the Netherlands) is 21%. It is also visible that the BOS prices are developing with the same rate as the total system cost. They remain a rather constant one third of the total investment. A further breakdown has been presented already indicating that there is no dominant cost factor once the installation process is standardised [6].

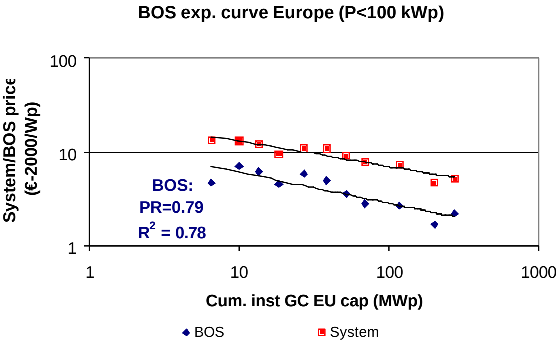

Figure 2: Experience curve for BOS of small and medium-size systems in Europe

Since modules are part of a global market, the historical learning rate of modules has been assessed by using the average module selling price data that have been purchased from Strategies Unlimited (see Figure 3)

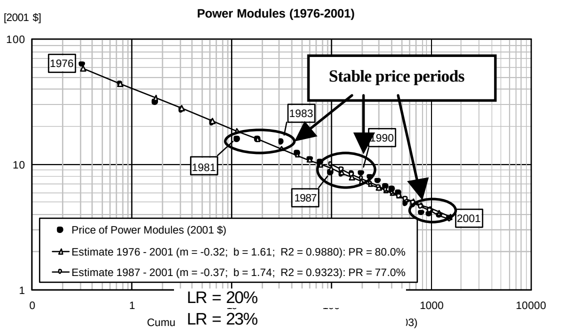

Figure 3: Experience curve for modules Strategies Unlimited data (1988-2001) [7]

The graph shows some interesting aspects of experience curves. First, it can be seen that prices do not decline at a constant percentage, but that periods of stable prices are followed by periods of relatively sharp declining prices. When assessing learning rates this is an aspect that should be considered. If the period, on which the determination of the learning rate is based, is not representing both kinds of periods, the result might be either far too optimistic, or far too pessimistic.

Another issue that can be seen is that a learning rate can change over time. In standard experience curve theory it is often assumed that learning rates do not change over time, and if they do, they will always become less favourable, because the technology is going to a more 'mature' phase. Analyses in the Photex-project contradict this assumption.

Figure 4, depicting moving averages of learning rates over 10 years, shows that after a period in which the learning rate has been for quite some period around 20%, during the 1990s it started to increase to 25%-30%. The high value of the 1990-1999 period coincides with a period that does not include a stable price period, so this value might be overoptimistic. As the period 1999-2001 was a stable price period, the value of 23-25% can be seen as a good estimate of the learning rate of the past 10 to 15 years.

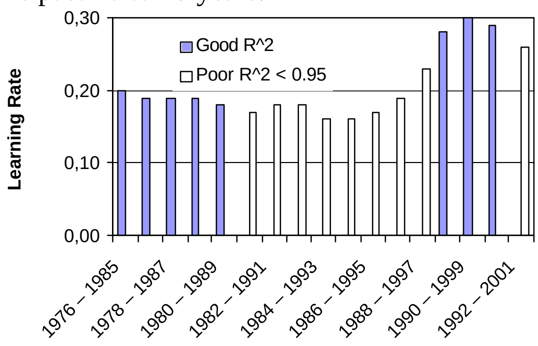

Figure 4: Moving average analysis for the Learning Rate (based on data from Strategies Unlimited)

The improvement of the learning rate in the 1990s coincides with a time of relatively more R&D-support to PV in the early 1990s and a relatively lower market growth rate [8]. Both factors, more R&D and a temporisation in market growth, have been a result of policy decisions. This indicates that policy measures can influence learning rates of technologies, and that it is not an intrinsic property of a technology.

As the Figure above suggest, there might be a relationship between growth rate and learning rate. However this relationship is not straightforward. If there is no market growth at all, there is no learning-by-experience. A certain critical mass in market growth is needed to initiate and continue learning cycles. For PV modules, history suggests that growth rates around 15% to 20% combined with enhanced R&D-efforts yield good learning rate results. If, however, we look at BOS-costs, the German support policies (feed-in tariffs and loans with special conditions) have resulted in an extremely strong market pull (from about 70 MW in 1999 to 260 MW in 2002). This market-pull strategy has not led to a decline in PV module prices, but instead has led to an enormous decline in BOS-prices [6]. This shows that for different components of systems the relationship between growth rate and learning rate can be different.

3 PRICE PROJECTIONS

One of the possible uses of the experience curve approach is to forecast costs of a technology over time. Extrapolating the learning rate into the future can give relevant information about future cost developments and will also give information how much 'learning money' will be needed to get to the break-even point.

A factor needed to forecast a price as a function of time is the market growth. As a first approximation this can be taken constant, with the EU and Japanese targets for 2010, 3 and 4.5 MWp as first milestones. This gives a growth rate of 25% as used in the EPIA scenario [10]. As a first approximation in Figure 5 constant learning and growth rates of shipments are used. Scenario B is the business as usual scenario, the others represent variations around that line. By using scenarios the future price development can be assessed on the basis of market growth data and can be adjusted if price data, covering a long enough time period, indicate that the learning rate has changed. A spreadsheet is available [5] to calculate the price using different scenarios.

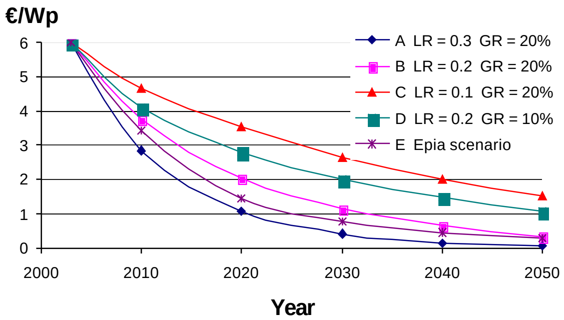

Figure 5: Possible price developments of PV

In Figure 5 can be seen that a system price of 3 to 4 €/Wp is expected in 2010; a price below 1 €/Wp is earliest achieved between 2020-2030; and 0.5 €/Wp, a level probably required for large-scale bulk electricity generation is reached around 2040, if learning and growth rates in the 20% range can be maintained. These prices are higher than generally assumed.

4 LEARNING INVESTMENTS

An experience curve approach cannot only be used to make price projection scenarios, but also to make an assessment of the learning investment needed to achieve a cost-competitive technology.

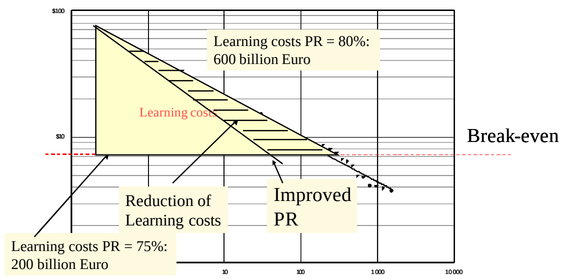

Figure 6: Illustration of the concept of learning investments (derived from [1])

In Figure 6 the projected cost decline follows an expected learning curve. Knowing the break-even price, the total learning investment is reflected by the size of the shaded area. The point at the x-axis at which the break-even line is reached shows the installed capacity that will be needed before market break-even is reached. Filling in the market growth results in an estimate of the year when the technology is cost-competitive. Note that break-even prices depend on the specific market segment, that competitive technologies might also have learning effects and that cost is only one factor in an investment decision.

Table I *Break-even years, learning investments Bulk electricity market in Southern Europe*
0.7 €/Wp systems price at break-even

	GR=0.1	GR=0.15	GR=0.2	GR=0.25	GR=0.3	Cost 10^9 €
LR=0,1	2152	2104	2080	2066	2056	3,3 * 10^6
LR=0,15	2099	2068	2053	2044	2037	5193
LR=0,2	2073	2050	**2039**	2032	2028	**634**
LR=0,25	2057	2039	2031	2025	2022	193
LR=0,3	2046	2032	2025	2021	2018	89

Table I shows that an electricity price of 0.05 €/kWh (0.7 €/Wp, 8% interest rate, depreciation 15 years, common for commercial investments, capacity factor 0.19) can be reached in 2039. With an investment of 634 10^9 €, 3000 TWh will be produced then, equal to 22% of the present annual world electricity production.

It is evident from table I that for a learning rate less than 20% it is too costly to introduce PV on a market that is only willing to pay 0.05 €/kWh. Also it can be seen that an improvement of the learning rate from 20% to 25% will enormously reduce the learning investments needed: from about 600 billion to 200 billion €.

This raises two questions:
- how can learning be influenced
- are there significant markets allowing higher prices

4.1 Learning mechanisms

Experience curves reflect outcomes of underlying learning processes. The concept of learning as discussed in theories of technical change is taken very broad and is more or less equal to innovation. Currently four types of primary learning are normally distinguished [9]:

- Learning-by-searching *know-why*
  R&D at universities, public and industrial research labs
- Learning-by-doing *know-how*
  Experience in manufacturing
- Learning-by-using *know-what*
  Expertise that market parties gain in how they can benefit from the new technology
- Learning-by-interacting *know-who*
  Coming to a division of tasks

In addition one can define:

- Learning-by-learning [10]
  By analysing the learning processes in a specific community knowing how to improve it.
- Learning-by-expanding
  A rapidly expanding market attracts by it (may-be only perceived) potential, new actors that wants to benefit.
  If a certain critical mass has been achieved, the technology becomes imbedded in other business sectors and the interests merge.

5 HIGH-VALUE MARKETS

A second way of reducing the learning investments is exploring markets with a high-value break-even point (see Figure 7) [11]. Added value for PV can be found in several ways: in building integration as functions can be combined, by competing on the retail market (in-house) where end-user prices can be relatively high and markets, where the demand is low considering the distance to the grid.

It is important to identify these markets, determine their potential and developing effective marketing instruments as well as adequate products [12,13].

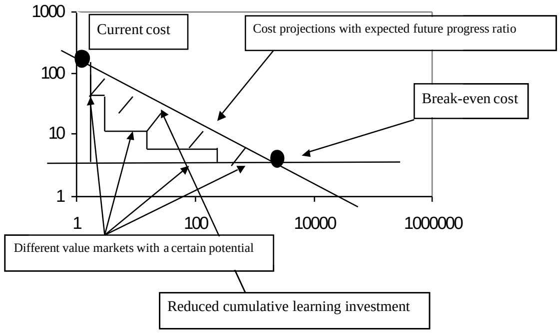

Figure 7: Reducing learning investments by exploiting high-value markets

As an example it was calculated what the effect is of such a high-value market. A small roof-top system in Italy (Palermo) that substitutes electricity purchases from the electricity supplier, with a retail price of 0.20 €/kWh, and purchases as part of a new-built home with a (mortgage) interest rate of 5% and a depreciation period of 25 years (private investor).

***Table II** Break-even years, learning investments*
Residential electricity market in Southern Italy
4 €/Wp systems price at break-even

	GR=0,1	GR=0,15	GR=0,2	GR=0,25	GR=0,3	Cost 10^9 €
LR=0,1	2031	2021	2017	2014	2013	19
LR=0,15	2022	2015	2012	2010	2009	8
LR=0,2	2016	2011	2009	2008	2007	5
LR=0,25	2013	2009	2008	2007	2006	3
LR=0,3	2011	2008	2006	2006	2005	2

In the business-as-usual case a break-even market in the Palermo region will be reached before the end of this decade. At the end of 2002 the cumulative global installed capacity was about 2.4 GW. If the remainder of the learning capacity were installed in the residential electricity sector in Southern Italy, the learning investment would be only 2 to 5 billion Euro (LR>20%).

The learning capacity needed to come to break-even is about 5 GW in the business as usual case. This is larger than this market segment. However, still an enormous reduction of learning investments could be reached by aiming at these kind of high-value markets first.

6 CONCLUSIONS

The cost reduction of PV systems is right on track and is probably even benefiting from the R&D and market introduction support in Japan and Europe.

To be able to support the implementation of PV effectively is important to monitor the price. However, drawing conclusions in terms of more technology funding or market stimulation is dangerous as short-term market effects easily dominate over long-term cost reduction.

It is very effective to stimulate learning as that reduces the learning investment considerably. However, learning is more than only R&D. The whole community from researchers, to industrial engineers, marketers, as well as other sectors, like equipment suppliers, building companies, utilities, financial institutes and private customers should be addressed.

To implement PV cost-effectively it is crucial to address high-value markets, that are able to absorb high volumes, such as:

- BIPV
- PV in remote areas, ranging from SHS's via mini-grids to GW-scale power plants in deserts
- Peak shaving

For PV to fulfil its high potential a learning and market growth rate both in the 20% range is needed to have it available as a large-scale source of electricity in the middle of this century. This requires a long-term vision and consistent support in the field of technology, market, as well as the courage to remove institutional barriers, in the electricity, building and financial sector.

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