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The road to PV competitiveness – PV generation cost in Europe

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ABSTRACT

In recent years solar photovoltaic electricity has shown a steady decrease in cost, thanks to technological improvements and economies of scale. Over the last 20 years the price of PV modules has dropped by more than 20% each time the cumulative volume of PV modules sold has doubled. System prices have fallen accordingly: during the last 5 years a price decrease of 50% has been seen in Europe. This trend will continue in the foreseeable future. System prices are expected to fall in the next 10 years by 36–51%, depending on the segment. Importantly, there is a huge potential for further reductions in generation costs: around 50% by 2020. The cost of PV electricity generation in Europe could decrease from 0.16–0.35€/kWh in 2010 to 0.08–0.18€/kWh in 2020, depending on system size and irradiance level. That decline in cost will continue in the coming years as the PV industry progresses towards becoming competitive with conventional energy sources. Under the right policy and market conditions, PV competitiveness can be achieved in some markets as early as 2013, and then spread across Europe in the different market segments by 2020. This paper summarizes the first part of a newly published EPIA report about PV competing in the energy sector. The report illustrates why PV can become a mainstream player in the energy field before 2020. The study, carried out with the support of the strategic consulting firm A.T. Kearney, shines new light on the evolution of Europe's future energy mix and PV's role in it.

Introduction

The coverage of the study in the EPIA report [1] concerning solar competitiveness is as follows:

- Technologies: the two major categories of commercial PV technologies available on the market are
  - Crystalline silicon
  - Thin film
- Market segments: four categories, out of many, cover a large part of the market, from small-scale residential systems to large ground-mounted installations. The typical installed capacities for these segments are
  - Residential households: 3kW
  - Commercial buildings: 100kW
  - Industrial plants: 500kW
  - Utility-scale plants (ground-mounted): 2.5MW
- Countries: the countries targeted are potentially the five largest electricity markets in Europe, with various combinations of solar irradiance and different country risk and financing conditions. Representing 82% of the European PV market in 2010 [2], they are France, Germany, Italy, Spain and the UK.

Assessing PV's full generation cost

To measure the growing competitiveness of PV, the new study considers the full generation cost of PV electricity generation by using the concept of levelized cost of electricity (LCOE). LCOE represents the cost per kWh and covers all investment and operational costs over the system lifetime, including the fuels consumed and the replacement of equipment. It therefore allows a comparison of the cost of producing a kWh of electricity between various generation technologies.

The LCOE formula used is one that has been developed by the International Energy Agency (IEA) and the Organisation for Economic Co-operation and Development (OECD). This formula, shown in Fig. 1, is widely accepted in the energy domain. For each system the LCOE calculation takes into account:

- The lifetime of the plant
- Capital cost (CAPEX)
- Operational and maintenance costs (OPEX)
- The discount factor, expressed as the weighted average cost of capital (WACC)
- The location of the plant, which for PV is essential for considering differences in solar exposure

$$\text{LCOE} = \frac{\text{CAPEX} + \text{NPV of total OPEX}}{\text{NPV of total EP}}$$

CAPEX: capital expenditure (investment costs)
OPEX: operations and maintenance costs
EP: electricity production (in kWh)
NPV: not present value

Source: IEA/CECO-NEA

Figure 1. The LCOE formula.

PV system price: capital expenditure (CAPEX) as the starting point

The starting base for the LCOE calculation is the total installed PV system price (also referred to as capital expenditure/cost or CAPEX). In practice, the capital cost is usually paid upfront. This represents a significant part of the total investment (around 80–90% depending on the market segment). The CAPEX includes margins taken over the entire value chain and is split into the following elements:

- PV modules
- Inverter (allows connection of the system to the electricity grid)
- Structural components (for mounting and connecting the modules)
- The cost of installation (including the costs relating to project development, administrative processes, grid connection, construction and installation, and all profit margins)

Fig. 2 shows the relative share of the different components in the total PV system price. In 2010 the module price reflected on average around 45–60% of the total installed system price, depending on the segment and the technology. Installation costs were the second most important driver (21–26%), followed by the cost of structural components (10–20%) and the inverter cost (6–14%). The figure additionally provides an insight into how the relative importance of the different cost components will evolve

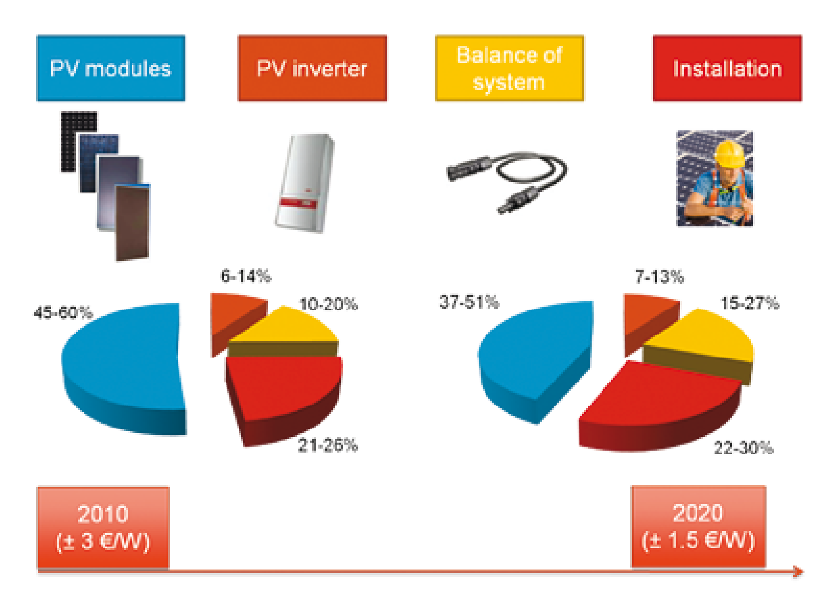

Figure 2. Evolution of the drivers behind the PV system price or CAPEX (industry averages).

through to 2020. The relative share of PV modules in the total system price has already fallen significantly over the years: in 2005 the module price reflected around 51–73% of the total system cost for large ground-mounted installations. Nevertheless, the cost of the modules is expected to remain the most important cost driver during the next decade and could still represent 37–51% of the total installed system price in 2020. The inverter price is expected to follow (more or less) the evolution of the total PV system price.

On the other hand, due to expected higher prices for commodity materials (steel, aluminium, copper, etc.) used in the cables and mounting structures, combined with an increase in labour costs, the relative share of the structural components as well as the installation is expected to increase. However, both the cost of structural components and the cost of the installation are subject to the evolution of module efficiency. Therefore, even though their relative shares will most likely increase, technological innovation in the field of PV module efficiency is an important driver for further system price falls in absolute terms.

> "The cost of the modules is expected to remain the most important cost driver during the next decade."

PV system life cycle cost, including the operational expenses (OPEX)

When calculating the generation cost, the total system life cycle cost has to be considered, including all costs incurred over the entire life cycle of the PV system. Therefore, some additional cost drivers need to be taken into account:

- Costs of operation and maintenance services (includes margins)
- Price of one replacement of each inverter (because the lifetime of inverters is shorter than that of PV modules)

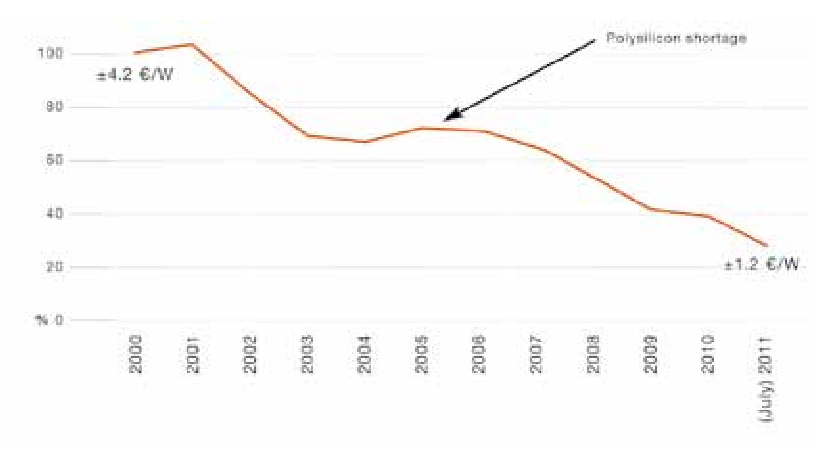

Figure 3. Evolution of the average price of a PV module in Europe.

- Land cost (for large-scale ground-mounted systems only)

- Cost of take-back and recycling of the PV system at the end of its lifetime

As mentioned earlier, the capital cost (between 80 and 90% of the total investment) is usually paid upfront. All other costs highlighted above, however, are paid over the lifetime of the system.

Energy output of a PV system

To calculate the cost per kWh of electricity produced, the total energy output of the PV system has to be determined. This includes the following parameters:

- Solar irradiance: the data on solar irradiance are based on the PV-GIS database of the Joint Research Centre of the European Commission and the SolarGIS database of Geomodel Solar. Extreme values (falling outside of a ±5% band) for each of the countries have been discarded.

- PV module degradation: this affects the performance of the PV system over its lifetime. The assumption is based on the generally accepted guaranteed performance of the PV modules – namely 80% of the initial performance after 25 years. For the purposes of this report, the assumption on the degradation of PV modules is directly tied to the assumption on the lifetime of the PV modules for which the guaranteed lifetime has been used. An increase in lifetime then reflects the improvements in degradation ratios over the years, resulting in a guaranteed lifetime of 80% of the initial performance after 35 years for modules produced in 2020 (see the assumptions on lifetime below).

Critical assumptions

Harmonized cross-European hardware costs

In order to assess the evolution of PV system prices correctly, a harmonized cross-European hardware cost is assumed (modules, inverters, structural components) as well as standard margins for installers. These are based on the German example and therefore reflect the prices in a 'mature market.' The reasoning behind this mature market assumption is that, with further growth of other European and international markets, prices and margins will globally converge.

Lifetime

In order to calculate the generation cost, based on continuous technology developments, a gradual increase in the technical guaranteed lifetime of the PV modules, starting at 25 years and increasing to 35 years in 2020, is assumed. The same reasoning is used for inverters (15 years in 2010 to 25 years in 2020). The technical guaranteed lifetime of the components does not necessarily coincide with the time horizon considered by investors in PV.

Discount rate

All cost and revenue transactions that are not made upfront have to be discounted in order to come up with a present value. The discount factor used is differentiated by market segment and by country. A country-specific risk has been taken into account based on the differences in long-term government bond yields between the five countries assessed. Moreover, a distinction has been made between private PV owners (residential systems) and business investors (all other market segments).

The assessed capital cost in each of the countries does not necessarily reflect the full cost of financing PV systems. While the figures take into account the stability of the financial climate in the different countries, they do not reflect how financing institutions perceive PV technology today and how they will do so in the future: therefore, the current discount factors used by individual and institutional investors are most likely higher. Given that the awareness of financing institutions is rising and that PV is increasingly being perceived as a low-risk investment, the current return demanded by investors in PV could start to decline. From the current levels of 6–8% in the residential segment, the requested return could go down to 4.4–6.1%; in the other segments, a similar decrease from the current 8–12% to 6.5–8.2% could be achieved in the target countries of this study once awareness of the real (technological) risk has widely spread and risks related to the political environment are lifted. If this were to fail to happen, the result would be the LCOE of PV remaining higher than it should be, delaying the competitiveness of PV by on average one year.

Market scenario

Determining PV's generation cost in 2, 5 or 10 years' time requires an assessment of how PV system component prices could go down in the future. Since this depends heavily on market evolution,

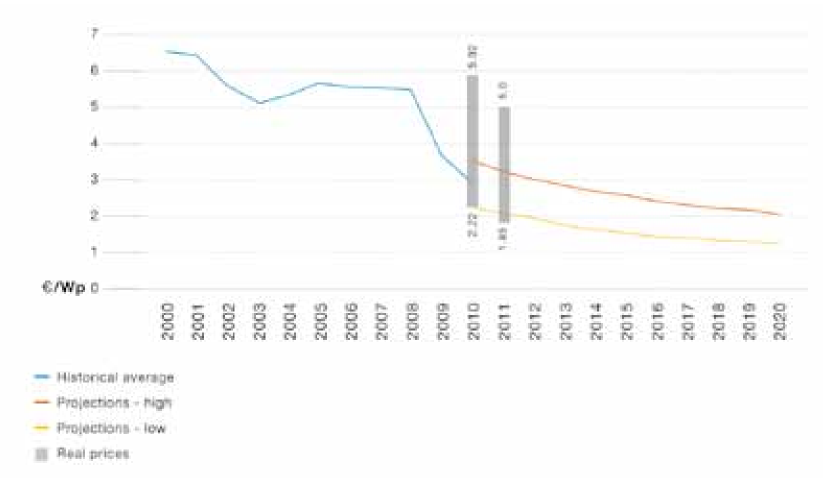

Figure 4. Evolution of the PV system price in Europe.

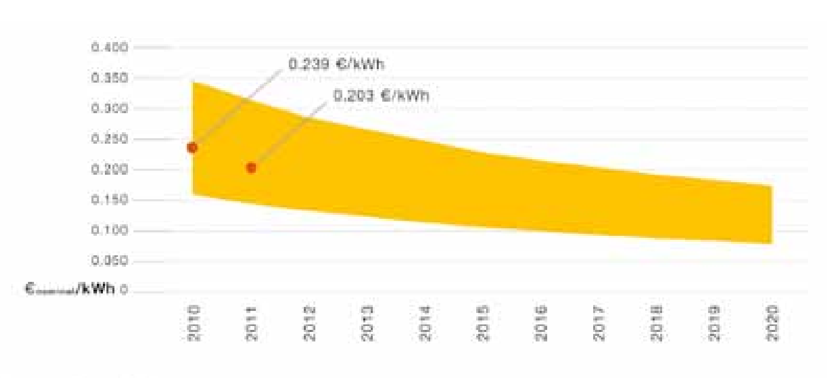

Figure 5. LCOE range projection of European PV for 2010–2020.

an intermediate scenario is chosen: from 2010 to 2015, EPIA's Policy-Driven scenario [2] is taken into consideration. After 2015, EPIA's Accelerated Growth scenario, based on Greenpeace and EPIA's Solar Generation 6 PV market development scenarios [3], is considered. The technology split is based on the Solar Generation 6 report.

Learning rates

All learning factors considered are based on the realized price reductions in the PV industry since the 1980s–1990s:

- PV modules: an initial learning factor of 20% is assumed. For every doubling of the cumulative volume sold, the price will decrease by 20%. Although for thin-film PV modules the learning rate is assumed to remain at 20% until 2020, this rate could decrease to 15% for crystalline silicon modules by 2020.

- Inverters: a learning factor of 20% is assumed for small-scale inverters (used in residential systems) and 10% for large centralized inverters (used in all other market segments).

PV module efficiency roadmap

The evolution of the cost of some components, for example cables and mounting structures, depends on a number of factors, such as the evolution of raw material prices and scale and learning effects. In the evolution of the installation cost, the scale and learning effects are highly relevant as well as the expected increase in labour costs.

In contrast, a significant part of the costs related to the structural components and the installation are influenced by PV module efficiency: the higher the efficiency, the fewer the structural components required. The efficiency evolution of the modules has therefore been taken into account, based on the roadmaps developed by EPIA and the European Photovoltaic Technology Platform [4,5].

Results: a huge potential for cost reduction

The PV module price follows a steady learning curve

The cost of PV systems has been falling for decades and is now approaching competitiveness. Fig. 3 illustrates this remarkable price decline for PV modules: the average price of a PV module in Europe in July 2011 reached around 1.2€/W, which is about 70% lower than 10 years ago. At the time of writing, PV module prices below 1€/W can be found on the market.

> "The cost of PV systems has been falling for decades and is now approaching competitiveness."

The PV system price could decrease by 36–51% by 2020

Fig. 4 indicates that PV system prices (CAPEX) have also declined rapidly: during the last 5 years a price decrease of 50% has occurred in Europe. Moreover, over the next 10 years, system prices could decline by about 0.83–1.59€/Wp – a price decrease of 36–51%, depending on the segment. It is important to acknowledge that significant reductions in the total installed system prices are feasible in all countries and over all market segments.

PV system prices went down sharply during the first half of 2011 – a consequence of a slow market start and a growing global production capacity. However, the observed real market prices in several countries are noticeably different from those in Germany, where the prices are the lowest and the market is more mature. But that gap is narrowing quickly. The lack of maturity of several PV markets in Europe has kept prices in most EU countries higher than in Germany. There is no single, easily remediable reason why PV system prices are higher in some countries than in others. There are many factors that explain the current price variations, such as the lack of competition in smaller markets, political choices that favour only the most expensive PV systems, and administrative rules and grid connection procedures that increase the time to market. All these could have a significant impact on the price level. Moreover, unsustainable support schemes could also artificially slow down the price decrease.

A 50% lower generation cost in 2020 is possible

The study finds a huge potential for the decline in generation cost: a fall of 50% by 2020 (see Fig. 5). Moreover, whereas the spread of the current results for PV's generation cost in Europe is fairly wide, this range will decrease in the future to almost half the width of that in 2010. The wide range reflects the large set of different parameters considered:

- Two different sets of technologies

- National differences among the five countries studied with respect to irradiance levels, financial conditions (including VAT for the residential segment), total installed PV system prices and operation and maintenance costs

- Four different market segments

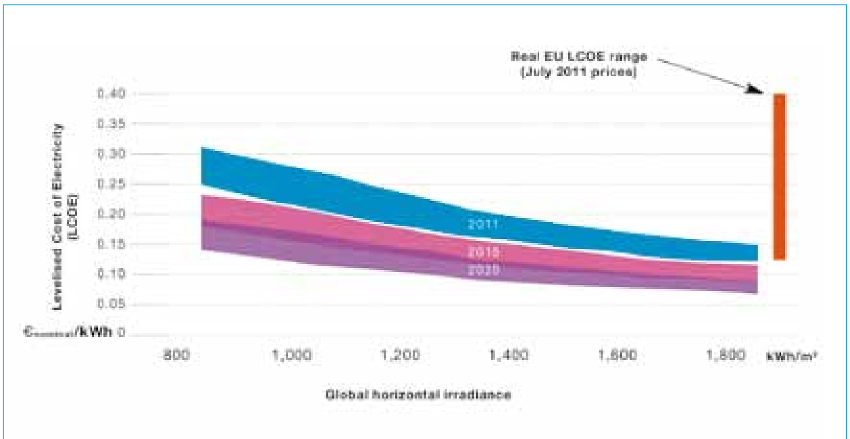

Figure 6. LCOE range projection of European PV for 2011–2020 in relation to irradiance levels.

As mentioned above, the study assumes competitive cross-European hardware prices (modules, inverters, structural components) as well as competitive development prices (including the margins for installers). The range therefore reflects the generation cost assuming mature market prices. Accordingly, the average European LCOEs for 2010 (0.239€/kWh) and for the first half of 2011 (0.203€/kWh) are shown in Fig. 5. This calculation considers the real market volumes and market segmentation in Europe.

"In each of the countries studied, attractive generation costs can be reached within the next 10 years in all market segments considered."

Moreover, the decline in generation cost is relatively stable across all market segments. In each of the countries studied, attractive generation costs can be reached within the next 10 years in all market segments considered.

Fig. 6 indicates the potential range of PV's generation cost in Europe from 2011 to 2020 in relation to the different irradiance levels. Higher irradiance levels are of course a driving factor for lower generation costs. The figure however demonstrates that attractive levels of generation cost could be achieved even in less sunny Northern European regions.

Assessing competitiveness

Finally, PV competitiveness can be assessed. Competitiveness is analysed by comparing PV's generation cost with the PV revenues (dynamic grid parity) and/or directly with the generation cost of other electricity sources (generation value competitiveness).

Competitiveness of PV electricity for final consumers is defined as 'dynamic grid parity' – the moment at which, in a particular market segment in a specific country, the present value of the long-term net earnings (considering revenues, savings, cost and depreciation) of the electricity supply from a PV installation is equal to the long-term cost of receiving traditionally produced and supplied power over the grid.

For large-scale PV installation, 'generation value competitiveness' is assessed: this is the moment at which, in a specific country, adding PV to the generation portfolio becomes equally attractive, from an investor's point of view, to investing in a traditional technology, normally based on fossil fuel.

The EPIA study [1] indicates that competitiveness can be achieved in some markets as early as 2013, and then spread across Europe in the different market segments by 2020.

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