Summary of study findings

The True Value of Photovoltaics for Germany

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0. Preface on the background and objectives of the study

The installation of photovoltaic (PV) systems has been promoted in Germany through the German Renewable Energy Act (EEG) since 2000. Operators of these systems can feed the electricity they generate into the national grid and be paid a statutory feed-in tariff for each kilowatt-hour (kWh) over a period of 20 years. The meanwhile very high level of interest in this distributed form of power generation – particularly among private individuals and commercial businesses – has led to a boom in the industry. The cost levy that electricity customers cover through the price of their electricity has risen. This much-cited "rise in differential cost" is partly based on the decline in one of the parameters used to calculate the differential cost, namely the prices quoted on the European Power Exchange (EPEX) in Leipzig. These prices depend not only on changes in power demand due to economic business cycles, but also on the trading strategies of energy traders and the success of renewables themselves: the greater the volume of EEG electricity traded on the EPEX, the lower the price (a phenomenon known as the merit-order effect) and the higher the EEG levy billed to electricity customers as a result. The complexity of this mechanism is difficult to get across in the public debate and is usually not properly understood.

Studies have demonstrated that electricity customers are generally prepared to pay more to support renewable energies.[1] But the total burden is the subject of increasing discussion. Public debate is marked by a mix of factual argument and analysis as well as half-truths and statements moulded by the specific interests of the respective stakeholders.

This summary of the analysis of "the true value of photovoltaics for Germany" aims to make an informed contribution to the debate on the position of photovoltaics in the energy mix and in society. The analysis looked at the costs incurred as a result of the EEG and system integration and the benefit to society of the targeted expansion of distributed power generation with photovoltaics. The findings aim to demonstrate the true value of photovoltaics.

The study first analysed the differential cost of photovoltaics and verified the validity of statements on the extent of this cost. For the first time, the costs and benefits of photovoltaics in the electricity system were analysed over a period that corresponds to the expected lifetime of photovoltaic systems. All systems installed under the scope of EEG since 2000 were taken into account. The analysis included both the electricity revenues after the end of EEG support and the impact on the grid and system costs that go into balancing and backing up of the variable power fed into the grid from photovoltaic systems.

Building on the above analysis of effects in the electricity system, the contribution of photovoltaics to saving on carbon dioxide (CO_2) and to boosting tax revenues from investments in photovoltaic systems was quantified. This resulted in a comprehensive and quantified cost-benefit analysis of society's investment in photovoltaics in Germany.

[1] TNS Emnid on behalf of the German Solar Industry Association (BSW). BSW press release dated 13 October 2010, which states that 75% of Germans are prepared to pay up to 2 €c/kWh to support solar power.

These study findings will be presented to politicians, energy experts in companies, institutes and associations, as well as other interested parties. The findings will thus be deepened and developed further in consultation with these stakeholders. As such, the study is an invitation to engage in dialogue. It is intended to provide the momentum for bringing a sense of objectivity to an emotional debate in which, the authors hope, forward-looking and integrated perspectives will eventually prevail.

Phoenix Solar AG, a photovoltaic systems integrator operating in the German market since 1999, commissioned A.T. Kearney, a strategic management consultancy firm experienced in the energy industry, to conduct the study.

1. *Summary of key statements and conclusions*

Subject: The value of photovoltaics

Issue for analysis: Verifying the validity of the calculation of photovoltaics' share in the differential cost and analysing the impact of the new rules for EEG electricity marketing on the European Power Exchange (EPEX) in Leipzig, which have been in place since 1 January 2010.

Findings: The current method of calculating the differential cost does not adequately reflect the true value of photovoltaic electricity. With proper valuation, the levy for photovoltaic electricity could turn out to be significantly lower and would amount to approximately 1.38 EURc/kWh instead of 1.67 EURc/kWh in 2011.

- The marketing of all EEG electricity volumes on the wholesale market brings down market prices, which increases the differential cost passed onto electricity customers in accordance with the EEG. Although an above average share of revenues is rightly assigned to photovoltaic electricity on the grounds of its nature as a provider of peak and medium load capacity, it is inappropriate to base its fundamental value on the wholesale price alone.
- The resulting market prices in this system are consequently not a suitable benchmark for measuring the value of photovoltaic electricity. It would be better to compare it with the full cost of new peak and medium load power plants, since PV is ultimately a substitute for new capacity additions in such plants. In this case, the 2011 PV levy could turn out to be 18 percent lower than that calculated under the current system. In 2010, the levy would be 12 percent lower than it actually is.

➔ **Key action required:** The marketing mechanism should be corrected or supplemented to ensure the adequate valuation of the quality of electricity delivered. Consequently, the EEG levy for end consumers could fall significantly and an meaningful comparison with conventional energy sources could be enabled.

Issue for analysis: Calculating the costs and benefit of PV investments to Germany in 2010 and since the EEG came into force.

Findings: *New capacity additions of photovoltaic systems* in Germany will reach breakeven in 2010, in other words, photovoltaic systems newly installed in 2010 are economically viable for Germany. If capacity additions continue, the *entire portfolio of photovoltaic systems installed in Germany since 2000* can break even at the end of 2011.

- Starting in 2010, the quantified benefit of *additional* photovoltaic capacity outweighs the cost: the cost-benefit equation is positive. This is true for both of the "reference" and "higher" fuel cost scenario (gas and coal) put forward by the International Energy Agency (IEA). The situation will improve further, in other words the economic benefit will rise, for each additional year in which new PV capacities are added.

- The cumulative cost of the entire portfolio of systems installed since 2000 and supported under the German Renewable Energies Act (EEG) can be expected to break even in 2011. In a high fuel price scenario, the return on tariff payments under the EEG amounts to about four percent. Assuming a moderate rise in fuel costs, break-even point is likely to be achieved from 2012 onwards, depending on how much capacity is added.

- This positive effect is greatly influenced by the fact that the installed PV systems are considered over the whole of their anticipated lifetime of 30-35 years. This is substantially longer than the 20/21-year period of feed-in-tariff support. Furthermore, the avoidance of CO_2 damage costs, and the tax revenues resulting from the investments in photovoltaic systems, are also taken into account. The expected extra cost of integrating the variable electricity generation from photovoltaics in the energy system is deducted.

➔ **Key action required**: The overall effect of integrating photovoltaic electricity in the power grid (e.g. the cost of keeping back-up power plants, the reduction in grid losses thanks to distributed feed-in, etc.) is small in relation to the total benefit of photovoltaics and is no impediment to further expansion. The costs should be allocated to PV in line with where they are incurred, just as the costs of CO_2 damage should be allocated to conventional means of power generation under the polluter-pays principle.

Subject: The competitiveness of photovoltaics

Issue for analysis: Examining the long-term price development for PV electricity under the prevailing insolation conditions in Germany and comparing it with that of electricity from (hard) coal or gas-fired power plants.

Findings: Photovoltaics will be able to supply electricity competitively in Germany within the next five to eight years.

- Taking into account the cost of CO_2 damage caused by conventional power plants as well as the cost of keeping back-up power plants, photovoltaic electricity can attain the price level of conventional medium or peak load generation at the low and medium-voltage level (gas and coal) sometime between 2015 and 2018. Based on the higher fuel price scenario, PV attains this level in about 2015, whereas assuming the IEA's reference scenario, this would be happening in about 2018. Having achieved the competitiveness defined in these terms, photovoltaic electricity can be taxed and have grid costs added, just like conventionally generated electricity. Photovoltaic electricity therefore contributes to grid maintenance in the future and to funding the state and municipal authorities to the same extent as conventionally generated electricity does.

- **Key action required:** Only by considering the CO_2 damage costs of conventional energy sources and the system integration costs of photovoltaics on a costs-by-cause basis is it possible to compare electricity prices in any realistic way. Standard methods of calculating these costs according to where they are incurred should be agreed upon between the industry players and the ministries.

- Even considering the pure costs of power generation alone, photovoltaics in Germany can be more economical than conventional gas and coal-fired power plants in the long term. This confirms that the future of photovoltaics lies not only in the earth's sunbelt, but in Germany too. In order for the necessary cost reductions to be achievable, the world-wide photovoltaic capacity additions will need to continue at a high level. The photovoltaic industry must also make substantial additional efforts towards fully exploiting the potential for reducing the lifecycle cost of photovoltaic systems.

Subject: Photovoltaics' contribution to structural change

Issue for analysis: Overview of the role of photovoltaics in bringing about structural change in the energy system and as an element in Germany's industrial landscape.

Findings: PV accelerates the structural transition to an efficient, smart energy world with a high proportion of distributed power generation.

- Photovoltaics accelerates the trend towards a distributed power system and drives investment in smart grid solutions in which power generation is effectively reconciled with electricity consumption. PV thereby enables households, individual investors and municipal authorities to play an active role in this structural transition.

- Photovoltaics is an important element in integrated energy systems and future application possibilities. The strong role of the domestic photovoltaics industry therefore helps Germany to keep its leading role in the innovation and export of high-end systems and applications.

- Photovoltaics offers clear advantages for Germany as a home to industry, which go beyond the effects of the quantified benefits analysed here. And photovoltaics offers an added benefit in terms of modifying existing structures in the energy sector, providing an additional argument in favour of the continued expansion of photovoltaics on a significant scale in Germany.

Key assumptions in brief:

- The development of gas and coal prices was based on the International Energy Agency's assumptions from 2009 ("reference scenario" and "higher price scenario").
- Assumptions on the cost of CO_2 certificates and CO_2 damage were taken from the German federal government's energy concept as compiled by EWI, GWS and Prognos and data from the Federal Ministry for the Environment (BMU).
- The cost-reduction potential, lifetime and degradation of photovoltaic systems were modelled based on the expertise of Phoenix Solar, A. T. Kearney and various external interviewees.
- Assumptions on financing terms, interest rates and inflation were estimated conservatively on the basis of historical values and extrapolated where necessary.

2. Key findings of the analysis

2.1 The value of photovoltaics

The current method of calculating the differential cost does not adequately reflect the true value of photovoltaic electricity. With proper valuation, the levy for photovoltaic electricity could be significantly lower and would amount to approx. 1.38 EURc/kWh instead of 1.67 EURc/kWh in 2011.

The marketing of all EEG electricity on the wholesale market brings down market prices, which increases the differential cost passed onto electricity customers in accordance with the EEG. Although an above average share of revenues – 120 percent of the average – are rightly assigned to photovoltaic electricity on the grounds of its nature as a provider of peak and medium load power, we believe it is inappropriate to base its fundamental value on the wholesale price alone: new investments in photovoltaic systems are 100 percent marketed through the wholesale market. Electricity generated from conventional capacities, on the other hand, is usually marketed via a portfolio of short, medium and long-term contracts and only partly sold at market price, depending on the market circumstances. As a result, the wholesale market price is only a part of the price that end customers actually pay for power generation.

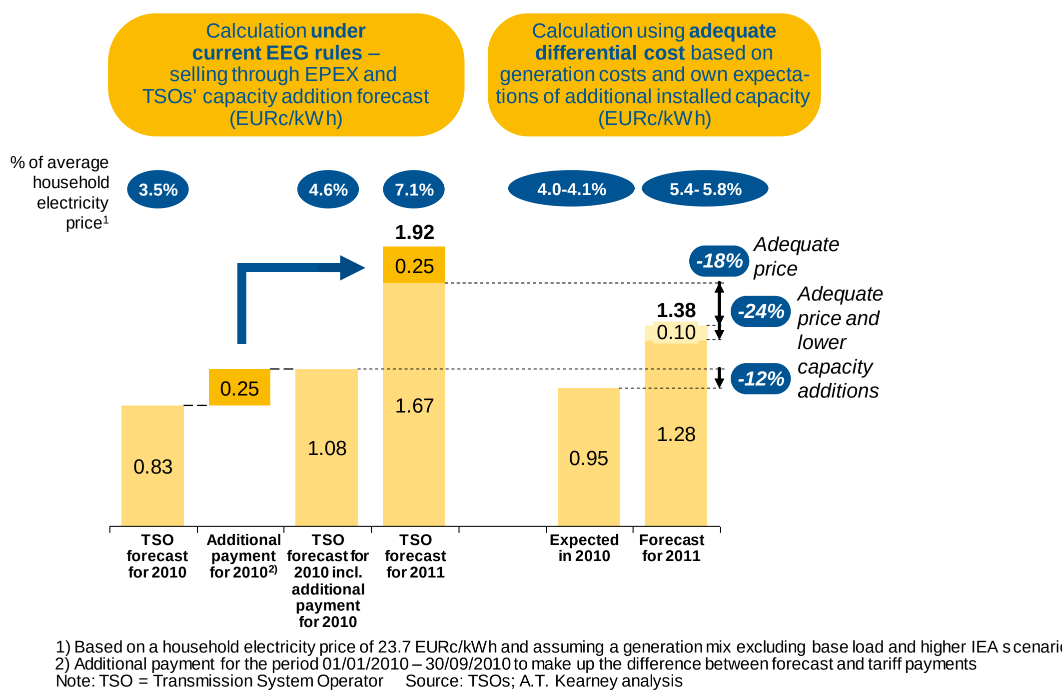


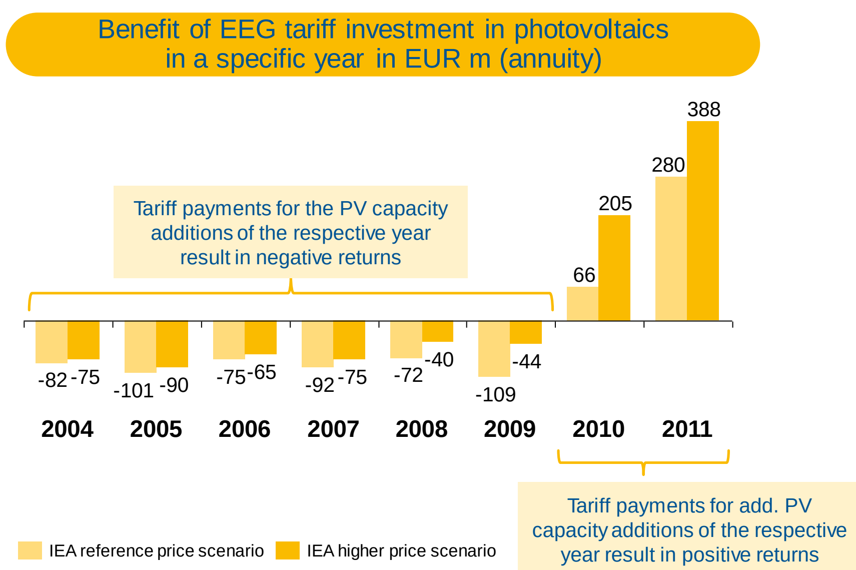
Figure 1: Possible impact of adequate valuation of PV's share in the EEG levy

The market prices ascertained under this system are consequently not a suitable benchmark for valuing photovoltaic electricity. It would be more appropriate to compare it with the full cost of new peak and medium load power plants, since PV is ultimately an alternative to new capacity additions in such plants. In this case, the 2011 PV levy could be up to 18 percent lower than that calculated under the current system. If we also accept the assumption made in this study, that capacity additions in 2010 and 2011 will be 8 GW and 6 GW, respectively, there is an additional difference of six percentage points compared with the Transmission System Operators’ forecast of 9.5GW in 2010 and 2011, respectively. The levy would then amount to 1.28 EURc/kWh, a total of 24 percent lower than in the current official forecast.

Figure 1 illustrates this correlation by contrasting the levy calculation under current EEG rules (left) with the calculation based on a mixed electricity price originating from new gas and coal-fired power plants delivering peak and medium-load capacity. The high sum of 1.92 EURc/kWh calculated for 2011 stems from the need to make up for the major underestimation of photovoltaic capacity additions in the official forecast of 2009, necessitating a retroactive surcharge of 0.25 EURc/kWh.

New capacity additions of photovoltaic systems **in Germany will reach breakeven in 2010, in other words, photovoltaic systems newly installed in 2010 are economically viable for Germany.**

The net return on additional photovoltaic capacity begins to be positive for society in 2010. Over the entire period considered here, the return amounts to EUR 66 million or EUR 205 million p.a., depending on which scenario for the development of coal and gas prices is applied (Figure 2). The net return on additional photovoltaic capacity rises to EUR 280 million or EUR 388 million p.a. in 2011.



Note: Based on an annuity of EEG payments and benefits in EUR m. Discount rate: 2.0%. PV investments from 2000 to end of 2011, module lifetime vintage 2000-2007: 30 years, module lifetime in 2008-2011: 35 years. Reference price: Average LV/MV generation price at consumer level assuming a conventional generation mix excluding base load capacity.
Capacity additions in 2010: 8 GW, capacity additions in 2011: 6 GW
Source: A.T. Kearney analysis

Figure 2: Annual return on PV investments in a given year

This calculation is based on the assumption that there will be 8 gigawatts (GW) of newly installed capacity in 2010. This is substantially more than the expected figure published at mid-year, which indicated a total of 6 GW[2], but is justified by the fact that 5.4 GW worth of PV systems were already registered in the market by the end of September 2010.[3] Should the installed capacity exceed 8 GW, the return for 2010 will be even greater, given that systems installed in the final quarter of the year will be included in the calculation at the substantially lower tariffs in force from 1 October 2010.

A market volume of 6 GW and the scheduled 13 percent reduction in feed-in tariffs on 1 January 2011 were assumed to apply to figures for 2011. As Figure 2 shows, photovoltaic systems installed in 2011 thereby make a substantial positive contribution to the German economy. Beyond 2011, newly added PV capacity will make an even bigger contribution, given declining tariff payments and otherwise identical assumptions. Thus, in 2010, the economy starts to benefit from the return on its investment in the market launch of photovoltaics from 2000 onwards, which it financed through feed-in tariffs.

If capacity additions continue, the *entire portfolio of photovoltaic systems installed in Germany since 2000* can break even at the end of 2011.

Figure 3 shows a positive, 4 percent return on the sum of all EEG payments. This calculation is based on the IEA's scenario[4] of high gas and coal prices. The positive figure means that the returns obtained in 2010 and 2011 already outweigh the investments made between 2000 and 2009 – albeit only just.

This result is primarily a consequence of the anticipated high rate of capacity additions totalling 8 GW or 6 GW p.a. in 2010 and 2011, respectively. Lower tariffs will be paid for these volumes compared with the almost 10 GW that had been cumulatively installed by the end of 2009. The positive effects for 2010 and 2011 already illustrated in Figure 2 therefore represent heavily weighted components of the overall result for the period 2000 to 2011. In the event of lower price rises for gas and coal (IEA reference price scenario of moderate gas and coal prices), the net effect is slightly negative, at minus five percent, but – depending on the amount of capacity added – the overall result is expected to be positive from 2012 onwards.

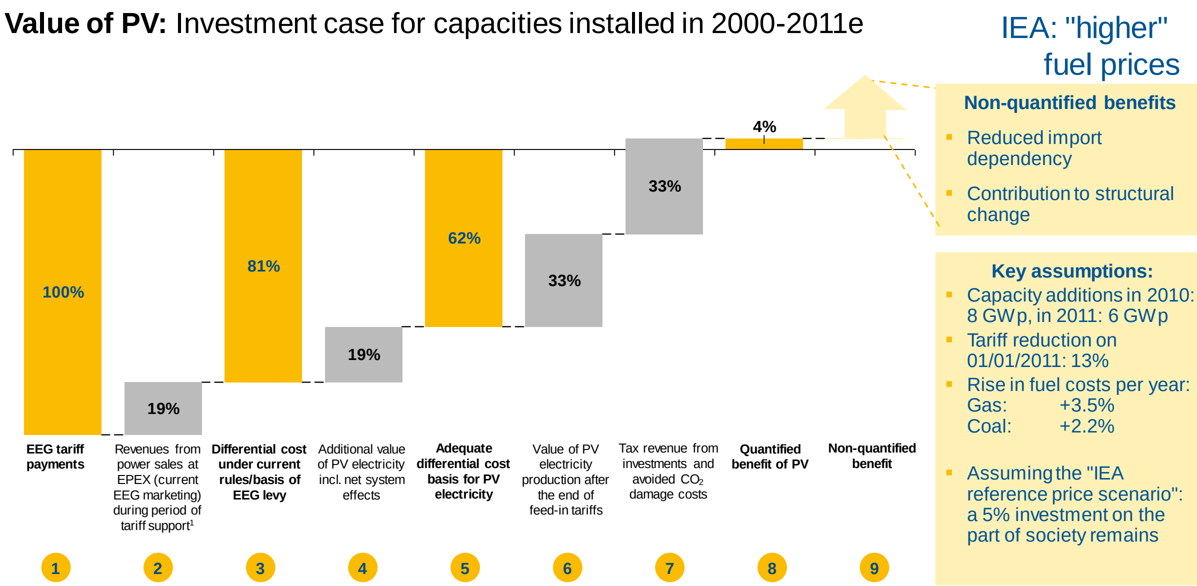
These findings are in stark contrast to the thrust of the current debate on the support for photovoltaics in Germany. So far, the focus has been mainly on the pure cost of PV, which is usually considered to equal the differential cost as defined under the EEG. This cost is set against the quantities of electricity generated and priced at market levels in the 20-year period in which support is forthcoming. The value of the CO_2 reduction is generally expressed in terms of certificate prices.[5]

[2] See Wenzel and Nitsch: Long-term scenarios and strategies for the expansion of renewable energies in Germany. June 2010.

[3] Registered systems according to data notified to BNetzA as per 29 October 2010. www.bundesnetzagentur.de

[4] International Energy Agency: World Energy Outlook 2009. Paris 2009.

[5] See, for instance, the publications on PV from Frondel et al. in RWI (2009): Economic Impacts from the Promotion of Renewable Energy Technologies; Bode and Groscurth, Arrhenius Institute, August 2010: The Impact of PV on the German Power Market; the Federation of German Consumer Organisations, 22 April 2010: "Support for solar



Note: Based on an annuity of EEG payments and benefits in EUR m. Discount rate: 2.0%. PV investments from 2000 to 2011, module lifetime from 2000-2007: 30 years, module lifetime in 2008-2011: 35 years. Reference price: Average LV/MV generation price at consumer level assuming a conventional generation mix excluding base load capacity; based on the IEA's "higher price sensitivity" scenario
1) Including value of peak load generation, taking into account the marketing costs for PV under EEG
Source: A.T. Kearney analysis

Figure 3: Overall calculation of the value of the PV capacity installed in Germany by the end of 2011

The calculation presented for discussion here differs in a number of fundamental assumptions and is explained below with reference to the individual effects illustrated in Figure 3.

1. The calculation is based on the sum total of all tariff payments in accordance with the applicable feed-in tariffs for systems installed in each year between 2000 and 2011 (tariff investment). This takes into account the period of support granted to each system, i.e. 20 years plus the year of installation, in other words, all tariffs paid between 2000 and 2031. A certain amount of degradation is assumed to occur to the photovoltaic systems, resulting in a decline in absolute power output as well as tariff payments over time.

2. In line with the current EEG marketing mechanism, the PV-specific revenues from the sale of EEG electricity on the European Power Exchange (EPEX) are offset by the Transmission System Operators. This marketing of all photovoltaic electricity at EPEX prices gives PV electricity a low value, which is, for the most part, below the full cost of generating peak and medium-load electricity from new gas or coal-fired power plants. **Consequently PV electricity is sold on the**

power inflates electricity prices", or Schulz in Spiegel Online, 22 July 2010: "Record summer inflates electricity costs"

EPEX "below value".[6] Since PV electricity supplies predominantly peak and medium load capacity at the medium and low-voltage level, this study compares it with a mix of coal-based medium load and peak load capacity from new gas-fired power plants that is identified as adequate for the voltage level concerned.

3 The sum of the tariff payments made to power plant operators for EEG electricity less the proceeds of the sale of EEG electricity on the EPEX wholesale market represents the differential cost. This differential cost is currently passed onto electricity consumers through the EEG levy. The differential cost is at the centre of the political debate. **Selling PV electricity below value inflates the cost.** Moreover, this method of calculation leads to the paradoxical situation whereby a high level of solar irradiation and the resulting increase in the amount of photovoltaic electricity produced causes wholesale market prices to fall in the short term and the differential cost to rise as a result (merit-order effect). **Ultimately, through the EEG levy the electricity consumers therefore foot the bill for the diminished prices achieved by energy buyers on the wholesale market.**

4 The additional value of PV electricity that EPEX prices do not remunerate is the difference between the relevant full costs of electricity production for medium/peak load and the market prices realised. **In order to arrive at an adequate valuation of photovoltaics in power trading, this value would need to be added to the EPEX revenues.**

5 The level of the new – adequate – differential cost that results from the above assumptions would make it possible to reduce the levy on households. Furthermore, direct calculation on the basis of the adequate reference prices for coal and gas would prevent fluctuating market prices and the merit-order effect from influencing the value of photovoltaics and other renewable energy sources. A specific recommendation on how to design such mechanisms was beyond the scope of this study and is a matter for further analysis.

6 When support in the form of feed-in tariffs expires, photovoltaic systems will not necessarily be taken off the grid. In fact, it is anticipated that PV systems will produce marketable electricity throughout their 30-35-year technical lifetime. There will therefore be substantial long-term returns from the continued operation of amortised photovoltaic systems in the future.

7 Tax revenues and avoided CO_2 damage represent returns that flow back to the government and to society at large. This study looks only at the tax revenues accrued as a result of the initial investment in systems and their installation, in other words immediately or with a slight time lag. The avoided CO_2 damage costs represent the difference between the CO_2 certificate prices included in the price of conventional power generation and the Federal Environment Ministry's best estimate of the cost of CO_2 damage, which is 70 euros per ton.[7]

[6] A similar result was already concluded by Braun et al.: "The value of PV electricity", ISET 2008; and the Association of Energy Consumers' Response to the EEG Progress Report dated 27 September 2010

[7] BMU 2010: Renewable Energies in Figures, p. 33.

8 The overall result is summed up in the quantified benefit of photovoltaics resulting from the above assumptions. The total value of the modelled returns is slightly higher than the value of tariff investment in the course of the first 20 years here. Demonstrating a benefit of just under four percent over the entire duration of the period under consideration, which can amount to as many as 46 years, with all of the associated uncertainties, is not an exact forecast. But what it does express is the fact that a thorough and long-term perspective reveals that society is not only burdened with the differential cost under EEG, it can also expect to receive returns on a considerable scale. If the additions to photovoltaic capacity continue after 2011 at declining tariffs as before, and assuming a moderate fuel cost scenario, Germany is very likely to see a positive overall return on its investment in photovoltaics in 2012.

From an economic standpoint it should, however, be noted that this perspective does not consider the matter of distribution. What this means is that political decisions still need to be made on which group in society should benefit from the evident benefit potential of photovoltaics and on what scale. This applies particularly to the substantial returns from the continued operation of amortised photovoltaic systems until the end of their lifetime.

9 The effects expressed in monetary terms are not the only ones. Photovoltaics have other positive effects on the economy which are not quantified here. For example, the higher the share of photovoltaic power, the lower Germany's dependency on gas and coal imports and the lower the nation's long-term susceptibility to political risks in the respective countries of origin. At the same time, Germany's innovation capability is strengthened, since a strong photovoltaics market also contributes to the development of innovative, integrated approaches in photovoltaics, and to the reinforcement of Germany's position as a centre for research. This secures export opportunities in the global photovoltaics market for companies based in Germany. Another important aspect in the political debate is the structural change taking place in the field of energy supply. Declared political goals see Germany moving in the direction of more distributed supply and smarter approaches on the consumer and the grid side. Being very versatile in terms of application possibilities, ranging from large-scale solar power plants to household rooftop systems, photovoltaics can assume the role of enabler. This statement is given further credence in section 2.3.

2.2 The competitiveness of photovoltaics

Photovoltaic systems in Germany will be able to supply electricity competitive with power generated from gas and coal within the next five to eight years. As illustrated in Figure 4, photovoltaics will be able to attain the same price level as that of conventionally generated medium or peak load electricity at the low and medium-voltage level sometime between 2015 and 2018. This holds true if the cost of CO_2 damage caused by conventional power plants and the net costs of system integration (e.g. the provision of back-up power plants to balance out the variability inherent in photovoltaic electricity) are considered in tandem.

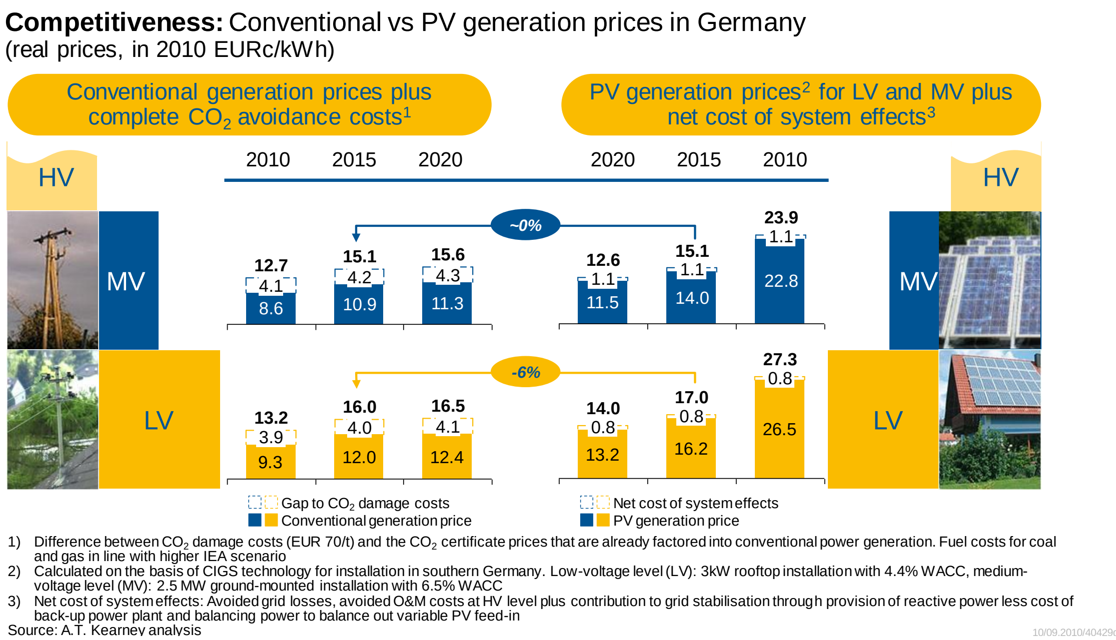


Figure 4: Comparison of conventional power generation prices and PV power generation prices

The debate on the competitiveness of photovoltaics has long been shaped by the concept of grid parity. Under this concept, the costs of generating power from photovoltaics are compared with the average gross electricity prices paid by end consumers. So with grid parity, the cost of electricity from your own rooftop would be the same as the consumer price. Achieving grid parity is certainly an important milestone on the way to achieving competitiveness for photovoltaics. From an energy-industry perspective, however, there are still questions on how the grid infrastructure will be financed and what contribution will be made to tax revenues to fund other social issues.

This study takes a different approach for that reason. **The competitiveness of photovoltaics is defined in relation to the cost of power generation.** The claims made therefore apply before taxes and fixed grid costs. **Once competitiveness as described in these terms is achieved, photovoltaics can be taxed and have grid costs added, just like conventional power generation.**

To deliver a realistic view, new photovoltaic systems and new conventional power plants were compared throughout their entire lifetime. Since PV electricity supplies predominantly peak and medium load capacity at the medium and low-voltage level, it is compared with a mix of coal-based medium load and peak load capacity from gas-fired power plants that is adequate for the respective voltage level concerned.

Besides the generation cost from a business perspective, the respective technologies are shown including extra system or environmental costs caused by the respective technologies. Thus, the conventional power side of Figure 4 (left) incorporates both the CO_2 certificate costs implicit in the price of power generation and the gap between that figure and the 70 EUR/t cost of damage caused by CO_2 emissions. The Federal Ministry of the Environment also arrived at this figure for damage costs and applies it in its evaluations. The photovoltaic side (right) encompasses the net effect of various system effects such as the grid loss avoided through distributed feed-in, the provision of grid services and the necessary investments in back-up power plants to balance out the variability inherent in photovoltaic electricity. The respective assumptions correspond to those presented in section 2.1 for determining the value contribution of photovoltaics and are specified in more detail in the Appendix.

2.3 Photovoltaics’ contribution to structural change

In addition to the quantified effects of photovoltaics on which this study focusses, the promotion of photovoltaics also contributes to a structural transition in the German system of power supply that is desired by politicians and society alike.[8] The contribution of photovoltaics has an impact in three distinct areas, as depicted in Figure 5.

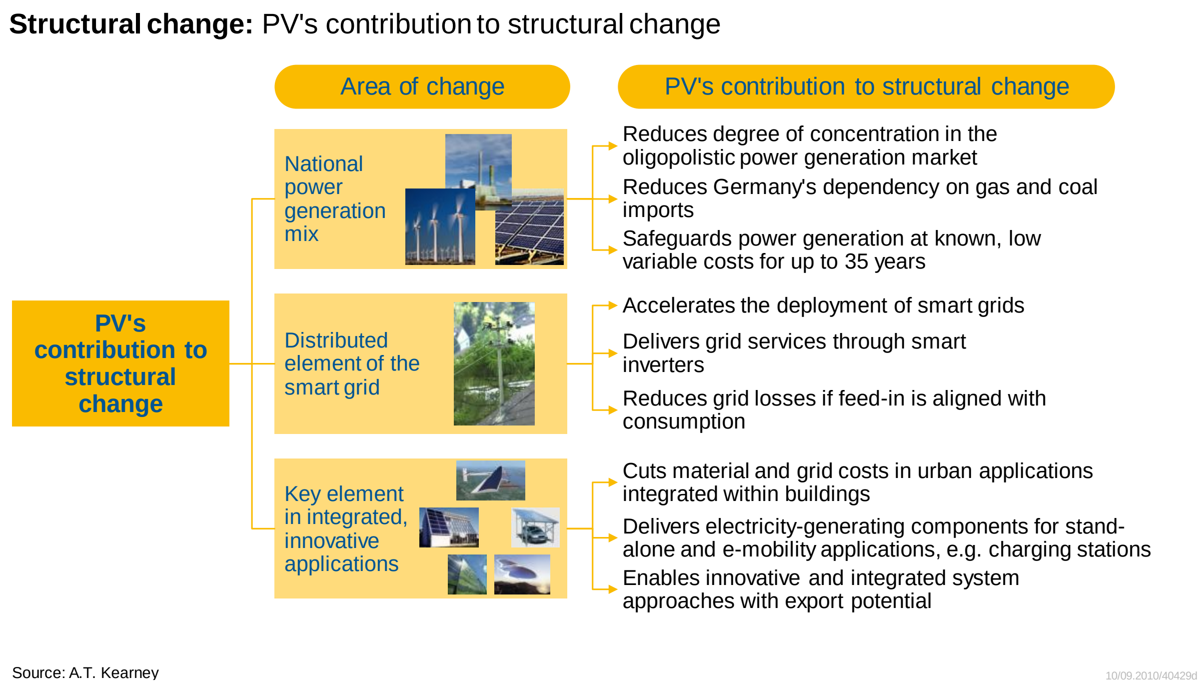


Figure 5: Photovoltaics’ contribution to structural change

In the context of the ***German power generation mix***, photovoltaics contributes directly to reducing market consolidation. No other technology for generating power has lower entry barriers. The spectrum of new electricity providers ranges from private households to commercial businesses, financial investors and municipal utility companies. Electricity generated from photovoltaics also reduces Germany’s dependency on coal and gas imports. The effect of this is still fairly limited. But it has the potential to

[8] See, for example, the German federal government’s Integrated Climate and Environment Programme dated December 2007; the German federal government’s National Development Plan for Electro-Mobility dated August 2009; report on Deutsche Welle dated 6 September 2010: Federal Government Presses for Smart Grids; Federal Ministry of Economics and Technology press release, 13 September 2010: Brüderle Banks on Future-proof Energy Systems; Environment Minister Norbert Röttgen in Frankfurter Allgemeine Zeitung on 2 December 2009: “Germany is a technology leader in renewable energies and energy efficiency. Our clear commitment to climate protection increases our chances in international competition, [and] lends momentum to the structural change we urgently need in the energy industry […].”

increase markedly with the rapid expansion of photovoltaics. Another advantage, albeit one that is difficult to quantify, is the well established low variable cost of producing electricity from photovoltaics. Once installed, a photovoltaic power plant is very cost effective to run. Photovoltaics therefore provides lasting protection against the sometimes dramatically varying cost of coal and gas that needs to be imported.

As a ***distributed element in the smart grid***, photovoltaics is a key driver of the expansion of local grids controlled by smart technology. As such, photovoltaics is helping to drive the transition that will ultimately benefit more than just the technology itself. It is also putting some of the prerequisites in place for the politically desired development of distributed power generation and energy management by consumers, for instance under the scope of e-mobility initiatives. The photovoltaic inverter, an essential part of a PV system, is assuming a key role in this respect as a control centre or data centre. With functionalities that are now mandatory, such as the provision of reactive power, inverters can contribute some of the “intelligence” to smart grids. By generating electricity close to its place of consumption, photovoltaics can ultimately reduce the amount of transmission and therefore help avoid grid losses. This is not automatically the case, though. For it to work, **photovoltaic power generation needs to be spread more evenly across the country and throughout the day as far as possible. Also, consumption profiles need to be adjusted, which can be achieved by incentivicing changes in consumer’s behaviour and by implementing distributed storage, for instance.**

Besides its role in the power generation landscape, photovoltaics is also a ***key element in integrated, innovative applications*** for numerous products and systems in Germany. In building technologies, for example, integrated PV applications are a crucial element in the development of positive-energy buildings – buildings that generate more energy than they consume. In the field of mobility too, photovoltaic systems in car ports and car parks generate power for electric vehicle charging stations. Miniaturised applications on parking ticket machines and LED light fittings above street signs and such like are already standard. These applications operate independently of the power grid. They serve to illustrate that photovoltaics is not only important as a power plant technology but as an innovative component in numerous products with which Germany enjoys global success as an innovation and export leader as well.

3. *Action required*

None of the positive developments illustrated above will happen without targeted action on the part of the players involved. In order for the potential of photovoltaics in Germany to be exploited to the full, a paradigm shift will actively need to be effected in several areas.[9]

Figure 6 presents the main action required in respect of the topics discussed in the study, differentiated by principal actor. The explanations that follow also touch upon areas in which action is needed that go beyond the scope of the analytical findings presented in this summary. These are intended as an additional contribution to the debate.

	Political / legal framework	Energy market	PV industry
Value of PV	• Adjust marketing mechanism to reflect adequate valuation in differential cost • Continued support to warrant significant capacity additions	• Ensure flexibility of conventional power generation portfolio to balance/ backup PV	• Further develop PV systems to become intelligent nodes for energy management and grid service
Competitiveness of PV	• Decrease feed-in tariffs in line with cost reduction of total system cost • Adjust incentives to foster improved geographic and temporal distribution of feed-in	• Reflect actual cost inflicted by conventional power (CO2 damage) as well as PV (system integration cost)	• Focus all efforts on PV system cost reduction
Contribution to structural change	• Switch to time-of-use tariffs • Support market introduction of integrated PV applications	• Accelerate systematic smart grid introduction incl. e-mobility applications	• Improve cross-industry sector collaboration for integrating PV in innovative system applications

Figure 6: Summary of action required

In terms of the ***political and legal framework*** governing the role of photovoltaics in Germany's domestic energy mix, an appropriate correction needs to be made to the current marketing mechanism. The current rules do not reflect an adequate valuation of photovoltaics. Consequently, the debate on the amount of differential cost takes place on a misleading basis. As this study has found, the cost of photovoltaics and other renewable energies is depicted as higher than it actually is.

A further significant addition to photovoltaic capacity in Germany is crucial if the federal government's objectives for 2020 as laid down in the National Action Plan for Renewable Energies[10] are to be met. To

[9] See also EPIA 2009: "Set for 2020" report.

realise the scenario for expanding photovoltaics to around 52 GW in 2020 as described in the action plan, further capacity additions totalling 28 GW are required for the years 2012 to 2020 if, as this study assumes, 8 GW and 6 GW of capacity are added in 2010 and 2011, respectively. As demonstrated, additional amounts of installed capacity on tariffs that continue to be scaled back continuously increase the benefit to society. This study points out that the benefit has been positive since 2010.

Sound judgement should be applied to the further digression in feed-in tariffs to keep it in line with the actual development of costs. This will avoid either too much or too little support being injected into the photovoltaic value chain. Whereas affordable returns are still expected in 2011, which can stimulate further capacity additions, this appears unlikely in 2012 according to the current situation in relation to costs and tariffs. Since cost reduction is primarily a function of numbers rather than of time, the development of PV prices depicted here has a causal relationship with the size of the global market. The greater the volume of globally installed capacity, the more likely it is that costs will come down.

Furthermore, the incentive provided by feed-in tariffs should be reconfigured in order to get power fed into the grid on a wider scale in terms of both time and place. Introducing tariffs that increase or decrease according to the intensity of the solar irradiation or offering specific support for PV power generated on east or west-facing rooftops are two ways of achieving this.

From a structural perspective, the political framework should set the course for the transition to a new, "smart energy" world. This would involve, for instance, the widespread availability of electricity tariffs that vary depending on the time of day and that reward energy-saving behaviour such as using appliances at times of low load. Such transparency would provide a clear basis for deliberate optimisation on the part of consumers. Providing specific support for integrated approaches like e-mobility in combination with renewable energies or changing building energy regulations to move on from the low-energy or passive house and promote the positive-energy house are other political levers that can be used to accelerate structural change in the energy industry.

The players in the ***energy market*** – electricity suppliers, grid operators, energy traders and the regulator too – all have crucial roles to play in integrating photovoltaics into the German electricity mix. The further expansion of photovoltaics in Germany necessitates greater flexibility in the power plant portfolio. New storage facilities need to be built to balance out the variable nature of the photovoltaic power fed into the grid. If the merit-order effect and the significant uncertainties concerning nuclear phase-out and long-term gas prices put an end to profitable investment in gas-fired power plants and the like, the issue of paying for the capacities made available by back-up power plants should ultimately be considered as well.

The cost of providing back-up power plants and the additional balancing power required should be allocated to renewable energies on a costs-by-cause basis. At the same time, conventional power plants should be burdened with the full extent of the anticipated cost of CO_2-induced climate change damage. No statements on competitiveness can be made in the absence of a comparison of the full costs of each

[10] Federal Republic of Germany: National Action Plan for Renewable Energy in accordance with Directive 2009/28/EC to promote the use of energy from renewable sources, dated 4 August 2010.

form of power generation. Comparing photovoltaic costs with the market price or the electricity price paid by household customers, including taxes and grid costs, is inaccurate and distorts the issue.

When it comes to grid integration, photovoltaics can assume the role of a driver of structural change.[11] More systematic efforts should be made to increase the intelligence of the grid at the low and medium-voltage level with a view to additional applications of the future such as electromobility and the concept of home power plants dubbed “SchwarmStrom”[12] – a network of distributed combined heat and power plants that also feed distributed powerinto the grid. But to achieve this, electricity suppliers need the regulator’s support, and the regulator ought to reward these pioneering investments appropriately.

The ***photovoltaic industry*** too has a responsibility to justify society’s investment in the technology by realising the benefit of photovoltaics to the greatest extent possible. This means, amongst other things, taking the opportunities that are available to improve PV systems’ support of the grid. Beyond adhering to grid guidelines, the photovoltaic industry must play an active role in shaping the issue of grid integration. Working closely with grid operators and the regulator, it can bring the potential of distributed feed-in close to the point of consumption and intelligent photovoltaic inverters fully to bear.

The efforts that have been made to cut costs in recent years need to be redoubled. Besides module costs, the focus should be more squarely placed on the other system costs throughout the entire lifetime of a PV plant. The possibility of halving photovoltaic production costs in Germany by 2020, as demonstrated in this study, will not happen automatically – the entire value chain will need to direct its full attention to the issue of cost reduction.

The focus on achieving growth and expanding production that has prevailed to date should now be reinforced with targeted research cooperation and the injection of greater investments by the photovoltaic industry. Specific efforts should be made to address industry-spanning initiatives to build on Germany’s strengths as a business location with its well networked and rich industrial “ecosystem”. Integrated and intelligent system applications from the field of photovoltaics could thereby lead to sustainable exports of technologies “Made in Germany”, even if mass production figures for some of the individual components are falling.

[11] See also Bode and Groscurth (2010), p. 27.

[12] See, for example, the cooperation between Lichtblick and Volkswagen to link up 100,000 “home power plants”, www.lichtblick.de

4. Appendix detailing the model assumptions

Assumptions on the price of generating power from conventional energy sources

Model components	Description	Sources
Fuel costs	▪ Coal: Reference case (2010: USD/t 65.9, 2050: 119.0), higher price sensitivity case (2010: USD/t 65.9, 2050: 156.2) ▪ Gas: Reference case (2010: USD/Mbtu 6.0, 2050: 18.5); higher price sensitivity case (2010: USD/Mbtu 6.0, 2050: 24.1)	▪ International Energy Agency (World Energy Outlook 2009)
Cost of capital	▪ Investment costs in EURc/kWh: hydro (5.1), lignite (1.3), nuclear (2.0), hard coal (1.4), gas (1.68), pumped storage (3.6) ▪ All kept constant over time (2010 to 2050)	▪ A.T. Kearney analysis based on EWI, IER
Generation margin	▪ The assumption is that as renewable energies' share in electricity generation rises margins for conventional generation will decline over time ▪ Low voltage (2010: 35%; 2050: 15%), medium voltage (2010: 25%; 2050: 15%)	▪ A.T. Kearney estimate based on annual reports
CO_2 certificate prices	▪ CO_2 certificate price: EUR/t 22.0 (2010), 18.2 (2020), 38.4 (2030), 58.5 (2040), 75.2 (2050) ▪ CO_2 damage costs: EUR/t 70.0 (2010-2050) ▪ CO_2 emissions: lignite (1,150 g/kWh), hard coal (950 g/kWh), gas (400 g/kWh). Lifetime emissions from photovoltaics (48.5 g/kWh) were subtracted in each case	▪ Energy scenarios for an energy concept by the German government, 2010 (ewi/gew/Prognos) ▪ DLR/ISI "External costs of electricity generation from renewable energies compared with electricity generation from fossil fuels", 2006 ▪ IEA – System's Values Beyond Energy, 2008
Base, medium, peak load share	▪ Low voltage: 35% (base), 50% (medium), 15% (peak) ▪ Medium voltage: 70% (base), 25% (medium), 5% (peak) ▪ Percentages kept constant over time (2010 to 2050)	▪ Standard load profile, BDEW low voltage ▪ Assumptions based on client examples, medium voltage

Power plant mix and cost assumptions

Model components	Description	Sources
Development of the conventional power plant mix and costs	▪ Current power plant mix: hydro (3.5%), lignite (27.7%), nuclear (28.8%), hard coal (21.6%), gas (13.7%), pumped storage (1.2%) (data from 2008) ▪ As PV is being compared with an alternative conventional reference technology, the model is not dependent on the developed power generation mix	▪ BNetzA 2009 monitoring report ▪ Assumption
Efficiency	▪ Development of efficiency of hard coal and gas-fired power plants ▪ Gas efficiency rises to 62% by 2019, up from 57.4 in 2010 ▪ Coal efficiency rises to 50% by 2038, up from 44.6 in 2010	▪ A.T. Kearney estimate

Financial assumptions

Inflation	▪ Inflation (2%) drives the nominal development of electricity prices	▪ Assumption based on historical inflation figures (Economist Intelligence Unit) ▪ DLR/IWES/IFNE "Long-term scenarios and strategies for the expansion of renewable energies in Germany, taking account of developments in Europe and across the world", 2010
Discount rate	▪ To calculate the net present value and the annuity, a discount rate equal to the assumed inflation (2%) has been chosen	▪ Assumption

Assumptions on installed PV systems in Germany 2000-2011

Model components	Description	Sources
Irradiation/ insolation	900 kWh/kWp	I-suppli 2010, ISET "Value of PV energy in Germany", 2008
Degradation	An average degradation of 0.5% p.a. is assumed for the installed base across all technologies	Osterwald et al.(2006) "Comparison of degradation rates of individual modules held at maximum power", Phoenix Solar
System lifetime	Installations from 2000-2007: 30 years Installations from 2008-2011: 35 years	Phoenix Solar estimate Expert interviews
Capacity additions	8 GW addition in 2010 6 GW addition in 2011	2010: Expectation Phoenix Solar and A.T. Kearney DLR/IWES/ifne "Langfristszenarien und Strategien für den Ausbau der Erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global", 2010
Tariff digression	13% digression January 1st 2011	Report of the regulatory agency according to §20 EEG

PV Value model assumptions

Model components	Description	Sources
Grid losses	Avoided grid losses mid voltage (2.2%) Avoided grid losses low voltage (4.4%)	A.T. Kearney analysis based on data from the federal statistical office
Balancing cost	EURc 0.1/kWh until 2015, afterwards EURc 0.2/kWh	ISET "Value of PV energy in Germany", 2008
Backup cost	EURc 1.0/kWh	Based on IER (2010) calculation, A.T. Kearney analysis
Tax effects	Total tax effects of EUR 4.4 bn for capacity additions 2010 (indirect tax volume: EUR 2.1 bn)	EuPD research (2010)

Assumptions on PV cost development – new installations between 2010 and 2020

Model components	Description	Sources
Module efficiency	▪ Continuous increase in solar conversion efficiency; rising to 18.4% for c-Si modules (multi-crystalline); rising to 17.4% for CIGS modules	▪ EU PhotoVoltaic Technology Platform, 2010 ▪ Photovoltaics ▪ A.T. Kearney & Phoenix Solar analysis
Module price	▪ Reduction in processing costs due to economies of scale and learning curve effects ▪ Continuous but levelling improvements in polysilicon consumption ▪ Polysilicon price to stabilise at USD 35-40/kg ▪ Price rises for other raw materials (glass, aluminium, etc.) of between 3% and 5% p.a ▪ Declining gross margins (down to 7-15% in some cases); however, to isolate the margin effects, a constant standard margin of 20% was assumed for a cost-plus scenario	▪ A.T. Kearney cost model ▪ Various analyst forecasts ▪ EU PhotoVoltaic Technology Platform, Solar Europe industry initiative – implementation plan 2010-2012, 2010
Balance of system costs (non-module costs)	▪ Rising unit prices for mounting systems, cables, etc. (caused by the rise in raw material prices) are offset by reduced material needs per W_p ▪ Significant reduction in the price of inverters is assumed	▪ A.T. Kearney cost model ▪ Company data ▪ Expert interviews
Installation costs	▪ Labour cost increases of 2.2-2.6% p.a. (depending on the job) will be almost completely balanced out by process efficiencies ▪ Margins are expected to fall significantly	▪ A.T. Kearney cost model ▪ Company data ▪ Federal Statistical Office
Operation & maintenance costs	▪ Labour cost increases of 2.2-2.6% p.a. (depending on the job) will be almost completely balanced out by process efficiencies ▪ Margins are expected to fall	▪ A.T. Kearney cost model ▪ Company data ▪ Expert interviews ▪ Federal Statistical Office

Assumptions on PV cost development – new installations between 2010 and 2020

Model components	Description	Sources

Financing costs & discount rate	▪ The model incorporates financing costs by discounting future cash flows with a WACC
	▪ The following WACC were assumed (constant until 2020):
	  ▪ **Residential rooftop systems: 4.4%**
	  ▪ **Ground-mounted systems: 6.5%**
		▪ Based on cost model assumptions regarding the share of borrowed capital and actual expected interest rates and returns

Solar irradiation/ insolation	▪ The model assumes mean irradiation for southern Germany of **1,200 kWh/m²** ▪ For the whole of Germany the assumed average is: **1,087 kWh/m²** ▪ Irradiation is assumed to be constant. Note, however, that some scientists consider an increase of 4 kWh/m² per decade to be a realistic scenario for Germany	▪ German Meteorological Service (DWD) ▪ Remund, J., 2009, Development of global irradiation over time in the period 1950-2099

Performance ratio	▪ PV system's initial performance ratio (before degradation):
	  ▪ Ground-mounted system: c-Si/CIGS: 80%
	  ▪ Rooftop system: c-Si/CIGS: 75%
		▪ Expert interviews with companies that install large numbers of systems

Lifetime	▪ Economic lifetime of 35 years for the complete PV system, with replacement of the inverter in year 20	▪ King et al., 2000, Photovoltaic Module Performance and Durability Following Long-Term Field Exposure

Degradation	▪ Degradation assumptions for new installations:
	  ▪ c-Si: initial degradation 2%, annual degradation: 0.25%
	  ▪ CIGS: initial degradation 1%, annual degradation: 0.20%
		▪ DGS Compendium

Abbreviations used in the study

AR = Anti-reflecting
BNetzA = Bundesnetzagentur, the German regulatory office
BOS = Balance of systems
CAGR = Compound average growth rate
CdTe = Cadmium telluride
CIGS = Copper-indium/gallium-diselenide/ disulphide
EEG = German Renewable Energies Act
EPEX = European Power Exchange (Leipzig)
FiT = Feed-in tariff
HV = High voltage
IEA = International Energy Agency
kVArh = Kilovolt ampere reactive hour
KWKG = German Heat and Power Co-generation Act
LCOE = Levelised cost of energy
LID = Light-induced degradation
LV = Low voltage
MT = Megaton
MTBF = Mean time between failure
MV = Medium voltage
O&M = Operation & maintenance
PD&I = Project development & installation
PV = Photovoltaics
SG&A = Sales, general management and administration expenses
TCO = Transparent conductive oxide
TSO = Transmission System Operator
WACC = Weighted average cost of capital
W_p = Watt peak