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STUDY

LEVELIZED COST OF ELECTRICITY RENEWABLE ENERGIES

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SUMMARY

This study analyses the current levelized cost of electricity (LCOE) using technology-specific system designs and system prices for the second quarter of 2012, for the following renewable energy technologies: photovoltaics, concentrating solar power plants (CSP, also called solar thermal power plants) and wind power plants. The different cost trends for these technologies are also compared.

The LCOE allow a comparison of energy generation technologies on the basis of weighted average costs. Different technologies can be compared and do not have to be equated with the level of the feed-in tariff. The true value of energy is defined by the daily fluctuations in supply and demand and cannot be captured in the LCOE.

This updated version (2012) of the study on the "Levelized costs of electricity - renewable energies" from December 2010 incorporates current cost trends from the last two years (Kost and Schlegl, 2010). The standard financing costs and risk premiums for the market are covered in more detail in this version and are calculated individually for each technology and country. This allows for a realistic comparison of power plant locations, technology risks and cost trends. The level of financing costs has a considerable influence on the LCOE and on the competitive capacity of a technology. This has to be taken into account when comparing the 2010 study with the current version. The LCOE have been recalculated using current, specific investments. The study models future cost trends based on market growth and observed learning curves, thus allowing conclusions to be drawn regarding the competitive capacity of the individual technologies.

The following energy generation technologies will be investigated and evaluated in terms of the current level of LCOE for a variety of different size layouts and under the conditions pertaining at locations in Europe (Germany, France, Spain) and North Africa:

Photovoltaic installations – multicrystalline silicon (PV)

- Small installations installed on the roof (up to 10 kWp) – PVSmall
- Large installations installed on the roof (up to 1000 kWp) – PVLarge
- Ground-mounted installations (larger than 1000 kWp) – PVGround

For the PV installations, locations in Germany were investigated with 1100 to 1300 kWh/m² per year of horizontal solar irradiance in relation to a PV module in optimum orientation. Locations in France with 1700 kWh/m², in Spain with 2000 kWh/m² and in North Africa with 2500 kWh/m² per year were also analysed.

Large Concentrating Solar Power Plants (CSP)

- Parabolic trough power plants (100 MW) with and without heat storage tank - Parabolic
- Power plants with Fresnel technology (100 MW) - Fresnel
- Tower power plants (100 MW) with heat storage tank - Tower

As CSP power plants can only be used to generate energy if there is a high level of direct radiation, the analysis focuses on the locations in Spain (2000 kWh/m²year) and North Africa (2500 kWh/m²year).

Wind Power plants

- Onshore (2 - 3 MW)
- Offshore (3 - 5 MW)

The operation of onshore wind power plants in central Europe with 1300 to 2700 full-load hours per year and offshore wind power plants in the North Sea with 2800 to 4000 full-load hours per year are considered.

Current LCOE, May 2012

Figure 1 shows a comparison of the current LCOE in the first half of 2012 for new installations using the renewable energies under consideration and for conventional energy generation using fossil fuels. **For all technologies, the project-specific location conditions are a key factor in determining the level of LCOE.**

At locations with 1300 kWh/m²year of solar irradiance (typical irradiance on a PV installation with optimum orientation in southern Germany), the LCOE are between 0.14 and 0.16 euro/kWh for small PV installations and between 0.13 and 0.14 euro/kWh for ground-mounted PV installations. Depending on the structure, size and location of the installation, the LCOE for PV installations reach 0.10 euro/kWh for ground-mounted PV installations with 2000 kWh/m²year of irradiance. **The LCOE using PV therefore fall below the end customer energy price (0.253 euro/kWh, BMWi 2012) not only in regions with very high levels of irradiance, but also in Germany.**

At locations with good wind conditions, wind power plants are competitive compared to conventional power plants. The LCOE for onshore wind power plants are currently between 0.06 and 0.08 euro/kWh and are therefore within the range of conventional power plants (hard coal, lignite, nuclear power).

Despite higher full-load hours of 3200 to 4000 hours annually, the LCOE for offshore wind power plants, at almost 0.11 to 0.16 euro/kWh, are higher than onshore power plants. The reasons for this are that offshore power plants are more expensive to install and have higher operating and financing costs.

The LCOE for solar thermal power plants (Concentrating Solar Power – CSP) at locations with an annual direct normal irradiance (DNI) of 2000 kWh/m²year are between 0.18 and 0.24 euro/kWh. A considerable reduction in costs in recent years has given PV installations a cost advantage over CSP plants at the same location.

The advantage of being able to store and regulate the energy produced by CSP plants has not been considered. The advantages for wind power plants in terms of a higher number of full-load hours, particularly for offshore power plants, are also not captured in the LCOE. **However, the ability to store energy and the full-load hours do play an important role in the long-term development of energy systems.**

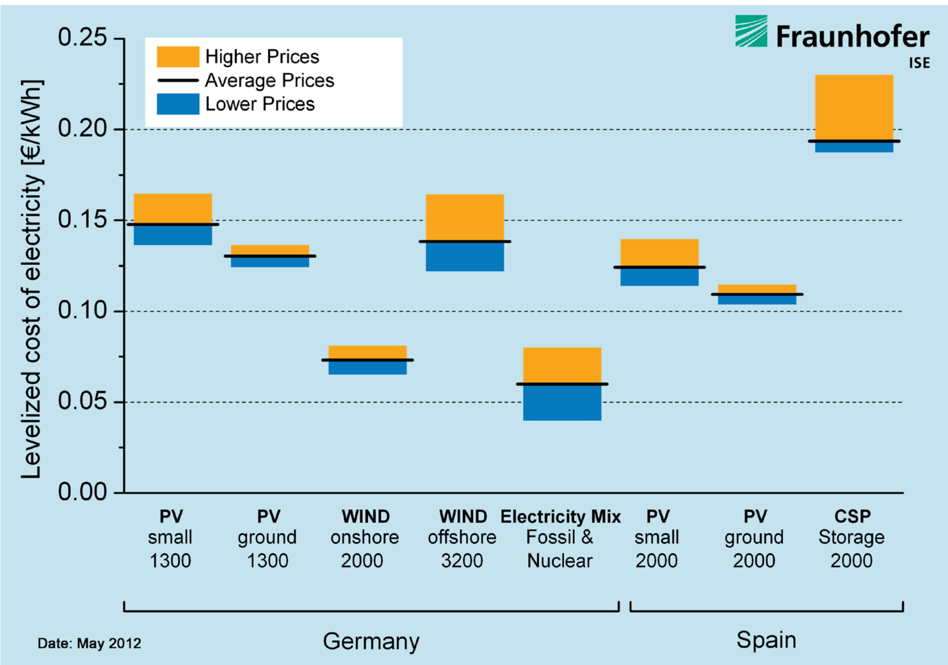

Figure 1: The LCOE for PV, CSP and wind power at locations in Germany and Spain. The value underneath the technology refers to the solar irradiance in kWh/m²year (optimum angle of inclination for PV and DNI for CSP have been taken into account); for wind power it refers to the number of full-load hours per year.

LCOE forecast up to 2030

For the purpose of the market forecast, three global market scenarios for the years 2012 to 2030 are investigated and presented for each of the renewable energy technologies (PV, CSP, wind). These reference scenarios help to assess the future market and cost trends of each of the technologies, taking into consideration further reductions in costs. Reductions in costs can be achieved throughout the entire value added chain, such as during the production of system components, when constructing or installing the system and by increasing the level of efficiency.

Provided the learning rates of PV systems and PV modules remain the same in future (15-20% if the installed system capacity doubles, which corresponds to a progress ratio of 80-85%), the LCOE of future installations will decrease disproportionately in comparison to CSP power plants and wind power plants (Figure 2 and 3). As early as 2022, ground-mounted PV installations in Germany will therefore be able to reach similar cost levels as conventional, fossil fuel power plants, as the latter will increase to an average of 0.08 euro/kWh in this period, according to data from the 2011 BMU Leitstudie (BMU 2012) (Figure 3).

As a comparison, Figure 2 shows the cost forecast for the solar technologies in Spain, as an example of a location with significantly higher irradiance than Germany. Despite higher irradiance (based on mixed-source energy in Germany) PV installations do not reach the same level as conventional power plants earlier due to the current financing conditions in Spain.

CSP power plants achieve significantly smaller cost decreases due to their weak market growth and lower learning rates.

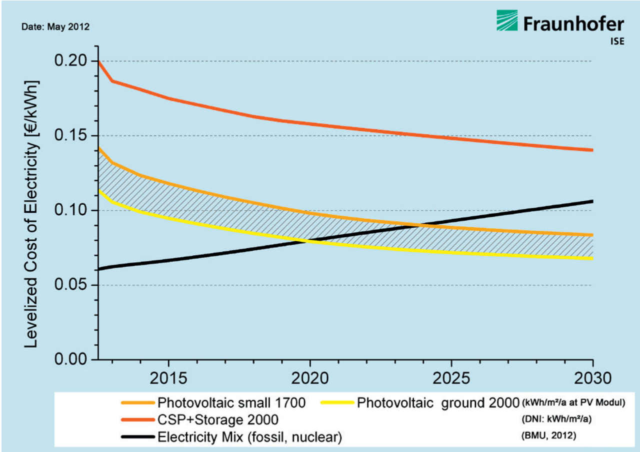

Figure 2: LCOE forecast of renewable energies in Spain to 2030, based on learning curves.

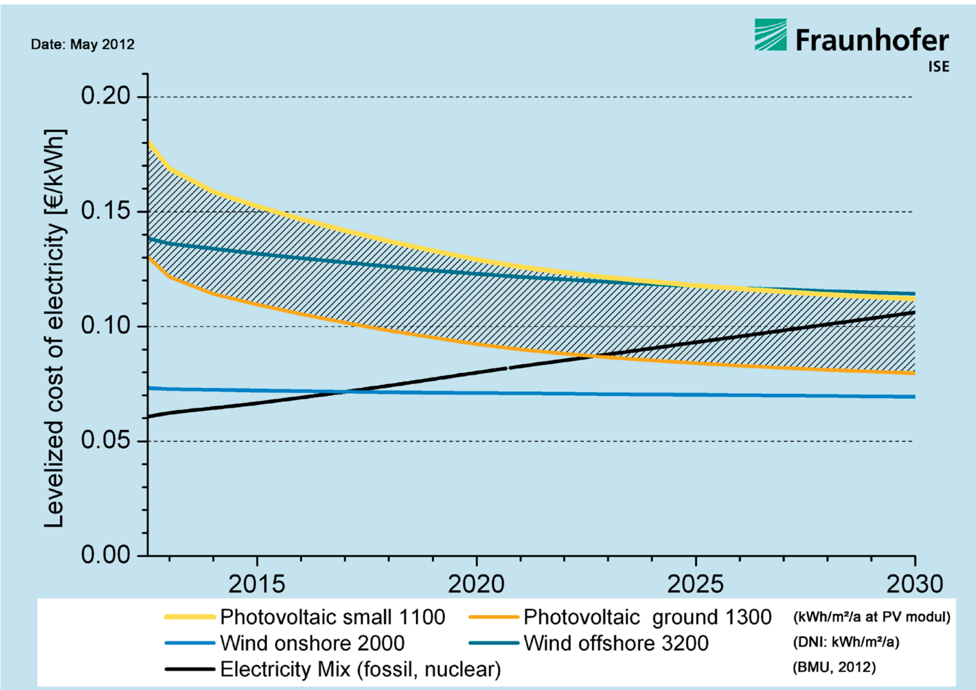

Figure 3: LCOE forecast of renewable energies in Germany to 2030, based on learning curves.

1. OBJECTIVE OF THE ANALYSIS

As opposed to the increasing fossil fuel and nuclear energy prices, the levelized cost of electricity (LCOE) of renewable energies is continuously decreasing. This is due to innovative technological development, more efficient materials, less material consumption, more efficient production processes, increase in efficiencies and mass production caused by a worldwide market growth. Only the increase in raw material prices and bad site selection can increase the LCOE.

Main content of the study:

1. Analysis of the status quo and the renewable energy market development Photovoltaic (PV), concentrated solar power (CSP) and wind energy parks (WEA) according to researched costs and market scenarios.

2. Economic modeling of the technology specific LCOE (2. quarter of 2012 for different plant types and locations e.g. irradiance and wind speeds) according to market financing costs.

3. Evaluation of the different technology and financing parameters with sensitivity analysis for the individual technologies.

4. Future outlook for the LCOE for renewable energies until 2030 based on different market scenarios and learning curves.

The technologies are evaluated and compared based on documented learning curves and market financing costs. An economic profitability of new plants based on researched market prices for investments in euros per installed capacity (with upper and lower price range) facilitates a fair evaluation of the results for the LCOE. It is important to consider that the market prices are sometimes geared by the available FiT and are therefore not always oriented by the free market. Characteristics of individual technologies that are not reflected in the LCOE like for example advantages of storage, number of full load hours decentralized electricity generation and daytime availability dependency are also not considered.
The level of the LCOE of renewable energy technologies is very dependent on the following:

- **Specific purchase investments**
  For the construction and installation of the plant with upper and lower limits, ascertained from current plant and market data.

- **Location conditions**
  With typical irradiation and wind speeds for different plant locations

- **Operation and maintenance costs**
  During the usage of the plant

- **Lifetime of the plant**

- **Financing conditions**
  Return of investment, based on technology specific risk charges and country specific financing conditions are determined by the financial market, while considering the amount of foreign and local investments.

2. MARKET FOR RENEWABLE ENERGIES

In the last ten years, the global market for renewable energies has experienced very strong growth (see Figure 4). Particularly in recent years, the ability to compete with conventional power plants has given the market for renewable energies an extra push which, previously, was predominantly carried by state subsidy programmes.

The wide implementation of clear regulations for renewable energies and the creation of legal conditions and funding programmes (feed-in tariffs, fixed quotas or certificate trading) created a stable climate for investment in many countries. The legislatures in these countries therefore reacted to the foreseeable shortage of fossil fuels and to the challenge of climate change, and attempted to profit economically from developing a national industry for renewable energies at an early stage. At the same time, more and more technology applications have been and are being developed, where renewable energies are competitive even without the funding support of investment.

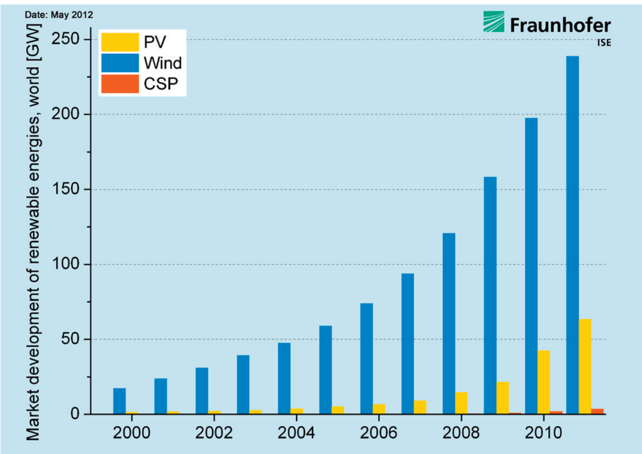

Figure 4: 2000-2011 global cumulative installed capacity of PV, CSP and wind power plants according to Fraunhofer ISE, GWEC 2009, Sarasin 2011.

The strong market growth and investments in technologies for renewable energies led to intensified research efforts, which contributed to improved system solutions with higher levels of efficiency and lower costs whilst the system is operational. Combined with increasing mass production, it was possible for the specific investments and the LCOE for the technologies analysed here to be significantly reduced. With the costs for producing energy continuing to fall, this market volume will significantly increase further and contribute to the dynamic development of the renewable energies market.

With a total installed caapcity of almost 400 GW by the end of 2011 and annual investments in new systems of up to 211 billion US$ in 2010 (figures from REN21 2011): 312 GW renewable energies in 2010 and other large water power plants with approx. 1000 GW), the scope of the global expansion of renewable energy power plant capacities is clear. In comparison, the global installed capacity of nuclear power plants is 366 GW.

Due to differing cost and market structures as well as subsidy measures, the markets for the individual technologies have developed very differently. Hence the market for wind power plants achieved competitive market prices at an early stage, and thus found markets in a number of countries without market incentive programmes, where the installed capacity currently totals almost 240 GW (GWEC 2012).

Wind power therefore has by far the largest market of the renewable energy technologies. Compared to conventional energy generation technologies, the truly competitive LCOE using wind power plants at onshore locations with good wind conditions has allowed wind power to be established in a number of markets, including some developing and emerging markets.

Despite forecasts of high growth rates, the proportion for offshore wind power plants of the total capacity of all installed wind power plants is currently less than 1.5%. The high prioritisation of offshore wind energy in many national energy strategies came up against unexpected complications and additional costs during the first projects in past years, which often led to project delays.

After the supply bottleneck due to silicon shortages, the photovoltaics market transitioned from a seller's to a buyer's market in the years 2007 to 2009. The steep rise in production capacities since 2009 led to high levels of competition within the PV industry and overcapacities in the market. Both led to significant price reductions and partially unexpected market dynamics in 2011 in particular.

In sunny areas, CSP plants in some countries have been rediscovered since the first system installations in the 1980s in the USA, meaning that 2000 MW have since been installed (Sarasin 2012). In the sunny MENA countries (Middle East and North Africa) in particular, the concept of CSP plants is currently being keenly pursued by political decision makers, due to the advantages of being able to store energy and the possibility of a high degree of local value added.

To forecast the LCOE up to 2030, this study uses learning curve models for estimating future trends. Constant learning rates for wind technology and crystalline silicon PV in particular have been observed over the last 20 years (Albrecht 2007, Neij 2008). For CSP, a stable learning curve over a number of years has not yet been established, meaning evaluation of the CSP learning curves is riddled with uncertainty. Market scenarios form the basis of the learning curve models, which have been taken from reference scenarios with various authors (Table 3 in appendix).

The technology-specific market scenarios produce a development horizon for each technology, which will be influenced by numerous decision variables relating to technology, energy politics and the economy, over the next twenty years.

For each technology there is considerable uncertainty regarding the actual market development up to the year 2030, as this is highly dependent on the level of specific investment, the usable full-load hours taking into account the integration of storage possibilities, the regulatory environment of different markets and, not least, the price development of conventional fuels. The actual market development for each technology is, however, a decisive factor in the time it takes for costs to decrease. The developments in the LCOE presented here are therefore potential development paths based on various reference scenarios and current market trends.

3. METHOD OF LCOE

Approach

The calculation of LCOE of new projects is carried out with the net present value method which calculates the expenses for investment and operation during the lifetime of the plant and incomes by discounting to the same reference point. Therefore, all present values of the expenses are divided by the present values of the electricity output. The total costs over the lifetime consist of the investment expenses and the operation costs over the lifetime of the plant.

The following formula is for the calculation of LCOE for new projects in the year of installation (Konstantin 2009):

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}}$$

LCOE : Levelized costs of electricity in Euro/kWh
I_0: investment in Euro
A_t: annual total costs
M_e: electricity output in yeat t in kWh
i: interest rate (discount rate)
n: economic lifetime in years
t: year of operation (1, 2,…n)

The annual total costs contain the fixed and variable operation and costs for the projects, maintenance, service replacements, and insurance. The share of debt and equity influences the discount rate by using the WACC (weighted average cost of capital) method. It depends on the volume of equity, return of equity, costs for debt and the share of debt.

Therefore, the formula for the annual total costs is in the calculation of levelized costs of electricity:

Annual total costs =

fixed operation costs +
variable operation costs +
(residual value, dismantling of system)

Comparability of results is ensured by discounting the expenses and the electricity output over the lifetime on the same reference point.

The exchange of inverter is considered for small PV systems after the half of the lifetime; large PV systems include costs for an exchange of inverters and costs for maintenance in the operation costs. Residual value and costs for dismantling or deconstruction of a plant are expected as balancing effect and are therefore neglected in the analysis here (exemption: an residual value of 10% of the investment for PV systems).

The LCOE method can compare different technologies on a cost basis but it is not a calculation of feed-in tariffs. They can only be defined by additional input parameters. Self-consumption, tax laws and realized incomes for the owner make it more difficult to calculate a feed-in tariff from the results of levelized costs of electricity. Furthermore, the calculation of levelized costs does not consider the value of generated electricity within an energy system in a certain hour of a year.

Technology and financing parameters

Table 4 of the appendix gives the investment volumes in Euro/kW of the technologies PV, CSP and wind determined by a market analysis of current power plant installations. Within each technology the system costs can be differentiated by size and layout of the plant. An average value as well as upper and lower limits for the costs is defined for each technology on the basis of the data analysis. The typical market values for installation and operation of the plants range between these limits. Investment volumes for all countries are standardized.

For PV, average values and upper/lower limits can be assumed for different system sizes: small systems by 10 kWp, large system by 1000 kWp and ground mounted systems. For these classes, the levelized costs of electricity can be calculated. The lifetime of PV systems are assumed to 25 years which is in contrast to the study of 2010.

The differentiation of CSP plants is determined by parabolic trough plants with and without thermal storage (1010 MWh_{th}) up to a size of 100 MW, by solar tower plants and Fresnel systems of which exemplary cost projections also have been included. Data of reference plants such as site specific irradiance, share of used natural gas for hybrid operation (<10%) and plant specific output are the basis for the calculation of LCOE of solar thermal plants.

Data of current onshore and offshore wind energy systems are assumed according to Windguard (2011) and EWEA (2009) as well the wind offshore projects Baltic 1 and Borkum West2. In those studies, average values and upper/lower limits can be found for the investment per installed capacity (in kW) (see table 4 in the appendix).

The parameter determined below are used in the calculation of LCOE for the 2. Quarter of 2010 (table 1). The financing parameters have been analyzed in detail since the study of 2010 and adapted according to the risk and investor structure of each technology as the selected discount rate influences the final value of the calculated LCOE considerably.

This aspect is not analyzed in many studies sufficiently as identical discount rates often are assumed for all technologies and all analyzed sites. This leads to large deviation to the real achieved values. The discount rates are defined technology specific in this study by using weighted average costs of capital for each investment which incorporates debt rate and return of equity. Large power plants constructed and operated by utilities and large financial investors require higher WACC due to the expectations of the investors than smaller and medium-sized plants which are constructed by private investors or local utilities.

A second factor influencing the return of equity is the project related risk: The higher the default risk the higher the required return of equity by investors. To lower capital cost of an investment, a high share of cheap debt is preferred. However, this

	Germany				Spain		
	PV Small	PV Large/Ground	Wind Onshore	Wind Offshore	PV Small	PV Large/Ground	CSP
Lifetime	**25 Years**	**25 Years**	**20 Years**	**20 Years**	**25 Years**	**25 Years**	**25 Years**
Share of equity	20,0%	20,0%	30,0%	40,0%	20,0%	20,0%	30,0%
Share of debt	80,0%	80,0%	70,0%	60,0%	80,0%	80,0%	70,0%
Return on equity	6,0%	7,5%	9,0%	14,0%	9,0%	10,5%	12,0%
Debt rate	4,0%	4,5%	4,5%	7,0%	7,0%	7,5%	9,0%
WACC (Weighted Average Cost of Capital)	**4,4%**	**5,1%**	**5,9%**	**9,8%**	**7,4%**	**8,1%**	**9,9%**
Annual operation costs	**30 €/kWp**	**30 €/kWp**	**0,015 €/kWh**	**0,030 €/kWh**	**30 €/kWp**	**30 €/kWp**	**0,025 €/kWh**
Annual increase of operation costs	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%
Annual degredation of electricity output	0,20%	0,20%	0,00%	0,00%	0,20%	0,20%	0,20%

Table 1: Input parameter for economic evaluation

share is limited by the project related risk: a higher default risk restricts banks in providing debt.
For offshore wind parks, banks assume the project related risk as high. That leads to a limited provision of debt by requiring large securities. Therefore, these projects currently are carried out by large companies only, which have access to debt by their company indirectly or are liable due to their company value. The typical market interest rate is at about 7% for renewable energy projects. If special promotion credits are used, e.g. by the KfW-Bankengruppe, an interest rate of about 4% could be achieved depending on the technology.

It has to be considered that financing condition could be changed in country analysis besides differences of resource factors such as irradiance and wind. Country specific risk caused by a default in payment due to potential country bankrupt has to be taken into account for renewable energy projects as they are financed by subsidies in terms of feed-in tariffs. Another factor is the availability of promotion credits. Especially Germany offers very good framework conditions for the investments in renewable energy projects. Locations in Spain or North Africa profit by the good solar irradiance, but for a comparison based on LCOE method less profitable financing conditions reduce this advantage.

Learning curve models

Based on the results and the market projections until 2020 and 2030, learning curves with a projection on future developments of the LCOEs can be developed. The concept of a learning curve portrays the relationship between the cumulated produced amount (market size) and the decreasing unit cost (production costs). If the amount is doubled and the cost is decreased by 20% it is called a learning rate of 20%. The relationship between the produced amount x at the time t , the cost C(xt) and the learning parameter b can be presented as follows:

$$C(x_t) = C(x_0)(\frac{x_t}{x_0})^{-b}$$

For the learning rate it is imperative::

$$LR = 1 - 2^{-b}$$

Compare Ferielli (2009), Wright (1936).

It is possible to assign the cumulative market size, in relation with the market scenarios for the coming 20 years, with respective years to attain a time-dependent prediction. Any change in the financing conditions due to different macroeconomic boundary conditions, are difficult to predict and therefore not included in this study. This afflicts the development of the prediction of the LCOE with an additional non technology specific uncertainty. In a sensitivity analysis different parameters, like specific investments, life of the system, Weighted Average Cost of Capital (WACC), full load hours and operation and maintenance expenditures can be analyzed according to their influence on the LCOE. (see chapter 4)

Analyzed site specific conditions

Irradiance – Full load hours

Another important parameter with a significant influence on the LCOE of renewable energies is the amount of irradiance on location of the solar plant (PV or CSP) and the full load hours respectively the wind speeds and availability at the chosen location (WEA). For that reason showcase locations with full load hours and specific outputs from irradiation are investigated (see table 2).

Typical locations in Germany have an irradiation of 1100 and 1300 kWh/m² and results in an output electricity of 1100kWh/kWp. Solar thermal power plants only convert direct radiation, through reflection into a focal point, to heat. Therefore in the following only locations in southern Spain and North Africa with Direct Normal Irradiation (DNI) of 2000 and 2500 kWh/m²year are considered.

The wind potential is also depends a lot on the location. In locations with lower wind speeds, average full load hours are around 1300 hours a year. This value can reach 2700 hours in coast areas. The average value for all onshore wind parks in Germany for 2006-2011, ranges between 1500 and 1800 full load hours.

Many offshore plants reach 2800 full load hours if close the coast and till 3600 hours a year if further away from the coast as in the Atlantic in front of the UK (EWEA 2009, IWES 2009). Also in the North Sea offshore locations with over 4000 full load hours have been identified (Gerdes 2006).

PV standard module	Solar horizontal irradiance at PV module with optimum angle of inclination	Electricity output per 1 MW
Germany (North)	1100 kWh/m²year	900 MWh/Year
Germany (Middle and East)	1200 kWh/m²year	1000 MWh/Year
Germany (South)	1300 kWh/m²year	1100 MWh/Year
France (South)	1700 kWh/m²year	1400 MWh/Year
Spain (South)	2000 kWh/m²year	1600 MWh/Year
North Africa	2500 kWh/m²year	2000 MWh/Year
CSP plant 100MW	**Direct normal irradiance for CSP**	**Electricity output per 1 MW**
Parabolic with storage (South of Spain)	2000 kWh/m²year	3300 MWh/Year
Parabolic with storage (North Africa)	2500 kWh/m²year	4050 MWh/Year
Fresnel (South of Spain)	2000 kWh/m²year	1850 MWh/Year
Fresnel (North Africa)	2500 kWh/m²year	2267 MWh/Year
Solar tower with storage (South of Spain)	2000 kWh/m²year	3240 MWh/Year
Solar tower with storage (North Africa)	2500 kWh/m²year	3980 MWh/Year
Wind power plants 2 - 5 MW	**Wind full load hours**	**Electricity output per 1 MW**
Onshore: Middle and South of Germany	1300 Hours/Year	1300 MWh/Year
Onshore: Coastal area in Germany	2000 Hours/Year	2000 MWh/Year
Onshore: Atlantic coast (UK)	2700 Hours/Year	2700 MWh/Year
Offshore: Small distance to coast	2800 Hours/Year	2800 MWh/Year
Offshore: Medium distance to coast	3200 Hours/Year	3200 MWh/Year
Offshore: High distance to coast	3600 Hours/Year	3600 MWh/Year
Offshore: Very good locations	4000 Hours/Year	4000 MWh/Year

Table 2: Annual output at typical locations of PV, CSP und wind (source: Fraunhofer ISE).

4. RESULTS

In the comparison of technologies carried out here, the LCOE for the renewable energy technologies of PV, CSP and wind power plants have been calculated using market data for specific investments, operating costs and other parameters. The price of electricity in the 2011 BMU Leitstudie of 0.06 - 0.07 euro/kWh for a pure mix of fossil and nuclear energy in Germany (BMU, 2012), together with the energy price development outlined in the Leitstudie, is used as a comparative value (Figure 5). With average investments of 1400 euro/kW, wind power plants at onshore locations with 2000 full-load hours annually feature the lowest average costs for producing energy of 0.073 euro/kWh. The costs vary in one area between 0.065 euro/kWh and 0.081 euro/kWh, depending on the specific investments and the number of full-load hours (see Table 2 and 4). Compared to the 2010 study, the costs shown here are higher since, on the basis of current project data, higher system prices have to be taken into account. In comparison, at 0.105 euro/kWh up to 0.164 euro/kWh, the costs for offshore wind power plants are significantly higher, despite higher full-load hours of 3200 to 4000 annually. Here too there is a cost increase, which is due to the total investment being revised upwards for current projects in construction. This rise is also reflected in the increased feed-in tariffs for offshore wind power plants as laid down in the German Renewable Energies Act (EEG). The EEG feed-in tariffs for onshore wind power plants are in keeping with these values, with 0.089 euro/kWh for the first five years and a basic tariff of 0.049 euro/kWh. For offshore wind power plants, the legislator has fixed a long-term, stable feed-in tariff of 0.15 euro/kWh up to 2015 for new installations over a duration of twelve years of operation (from 2013: 0.13 euro/kWh with an annual decrease of 5%). The considerably more expensive connection to the grid for the grid operator has not been taken into account in the LCOE.

When purely comparing the costs of PV systems with CSP power plants at locations with high irradiance (2000 kWh/m² per year), the considerable advantages of PV compared to CSP are evident in the LCOE since the last calculation. Due to lower market growth, compared to PV, the average costs of CSP power plants with integrated heat storage tanks (full-load hours up to 3600 h) are 0.194 euro/kWh, whereas ground-mounted PV installations with the same irradiance achieve an average cost of producing energy of 0.109 euro/kWh. At locations in Germany with irradiance values of 1300 kWh/m²year (1100 kWh/m²year) the LCOE for small PV installations are between 0.137 and 0.165 euro/kWh (0.167 - 0.203 euro/kWh), depending on the level of specific investments, which were estimated at between 1700 euro/kWh and 2200 euro/kWh. Ground-mounted installations already achieve values between 0.107 and 0.129 euro/kWh (0.152 - 0.167 euro/kWh). At 0.253 euro/kWh in 2011 (BMWi 2012), the LCOE for all types of PV installation in Germany are therefore below the average energy costs for households. The LCOE do not reflect the changing value of the electricity generated. For example, the energy generated by the individual technologies varies substantially depending on the specific season and day. Differences in the achieved market sales price of energy, due to the use of storage tank capacities which allow energy to be produced at times when prices on the electricity exchange are highest, are therefore not taken into account.
By integrating a thermal salt storage tank, solar thermal power plants can store energy, and therefore export energy to the grid regardless of the current weather conditions or time of day. This integrated storage option is the principle difference between CSP and wind power plants and PV systems.

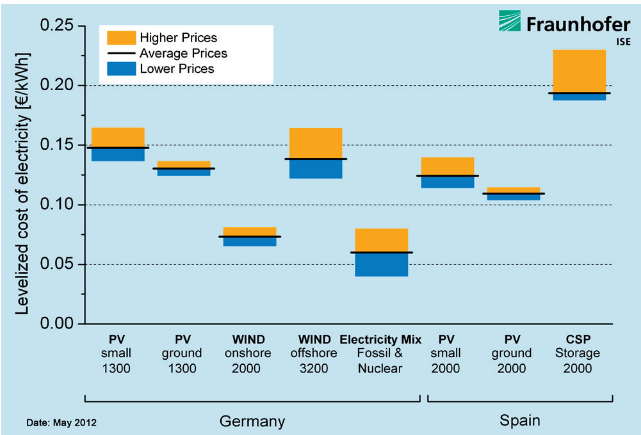

Figure 5: The LCOE for PV, CSP and wind power at locations in Germany and Spain.

Photovoltaics

Market development and forecast

The global PV market recorded high growth rates again in 2011. In Germany, the record in 2010 (7.4 GWp) was marginally exceeded in 2011 with 7.5 GWp. However, it lost its leading position as the largest sales market to Italy, where 9.0 GWp were newly installed in 2011. China, USA, France and Japan also contributed to the global growth, each with more than 1 GWp. Many other countries have also begun increasing their PV capacity. The global PV market is no longer dictated by a few countries alone; rapidly growing markets are beginning to establish themselves on all continents (EPIA, 2012).

The high rate of growth in sales at the end of 2011 is, however, complemented by the significantly greater production capacity of PV modules of approximately 50 GWp (Sarasin 2011). At the same time, improvements in production materials and fabrication technologies led to a significant decrease in cost of manufacturing silicon-based PV modules. Overcapacities and technological developments, in conjunction with falling feed-in tariffs, put pressure on prices and margins within the industry, resulting in a fall in prices for PV modules of over 40% during 2011 (pvXchange 2012). These developments introduced a phase of global consolidation in the solar industry. Consolidation pressures led to company take-overs and mergers, and companies with unfavourable cost structures had to reduce staff numbers or declare themselves insolvent. This market rationalisation will continue in 2012 until the remaining module manufacturers are able to produce cost-effectively again at the established market prices.

The market for production equipment for manufacturing silicon, wafers, PV cells and modules, which is dominated by German mechanical engineers, will also have to endure a period of overcapacity. At the same time, Asian manufacturers will try to catch up with the technological leadership of the European and North American mechanical engineers, in order to be a competitive alternative for the renewed increase in demand.

According to the studies examined here, the global market demand for PV will continue to grow strongly in the coming years. The market forecast by Sarasin (2011) anticipates an average annual global growth in demand of 19% to 116 GWp of newly installed PV capacity in 2020. It estimates that demand will increase in sunny markets outside of Europe in particular, and that the PV demand will be distributed more equally on a global level.
Figure 6 shows the market forecasts up to 2030 extrapolated by EPIA (up to 2015) and Sarasin (up to 2020). Bhandari and Stadler (2009) are somewhat more reserved and forecast 750 GWp of installed capacity for 2030.

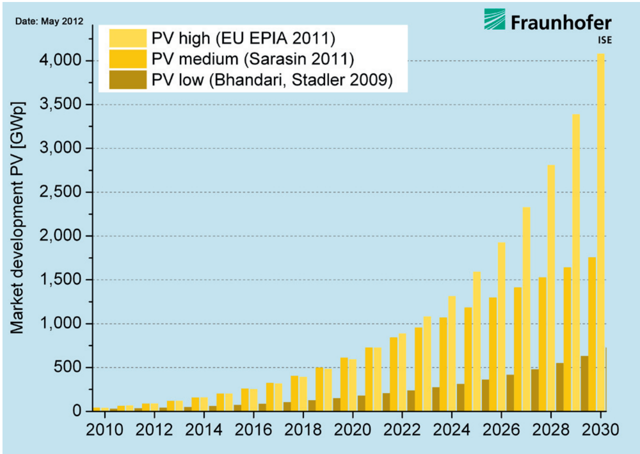

Figure 6: Market forecast of cumulative power plant capacity for PV 2010-2030 according to Sarasin (2011), EPIA (2011), Bhandari (2009).

Price and cost development

During 2011, the wholesale prices for crystalline PV modules from Germany fell by 37% from 1.71 euro/Wp (Jan 2011) to 1.07 euro/Wp (Jan 2012). During this period, the prices for crystalline modules from China fell by 46% from 1.47 euro/Wp to 0.79 euro/Wp. This situation is the subject of fierce debate in the international PV industry, as the Chinese manufacturers, supported by the Chinese government, have been accused of price dumping in order to achieve a dominant position in the market in the period after the market consolidation. Prices for thin-film modules (CdTe) falling by 46% from 1.25 euro/Wp to 0.68 euro/Wp (pvXchange 2012) are also exerting a cost pressure. Given the enormous price and margin pressures, it must be assumed that currently only very few cell and module manufacturers can sell their products with positive margins. Almost all large PV manufacturers were in the red for Q4/2011 and Q1/2012.

The sharp fall in the price of solar modules also led to a reduction in the prices of PV systems. However, the costs for inverters and BOS (Balance of System) components, such as mounting systems and cables, and the costs for the installation of these did not decrease at the same rate. In 2005, the cost proportion for solar modules was almost 75% of the system costs, whereas today, this is almost 60% and for small PV systems, only 50%. This also means that the proportion of value added in the target market is increasing. In fact, 50-55% of the total value added of a PV installation is currently created close to the end market, with the largest proportion in Germany and the EU (EPIA 2011).

Current rates of investment for different size categories of PV installation are listed in the appendix. Currently, the costs for a small PV installation (< 10 kWp) are approximately 1900 euro/kWp (average value). For larger PV installations of over 100 kWp or over 1000 kWp, the current costs are approximately 1700/1600 euro/kWp or lower. These values include all the costs for the components and installation of the PV system. Therefore, the costs for PV systems have decreased by an average of 35% since our previous study in December 2010, irrespective of the size of the system.

The values for the current LCOE for PV installations are shown in Figure 7 for the installation sizes and costs (average value) listed in Table 4 in the appendix for different irradiance values (in accordance with Table 2).
The annual irradiance values of 1100 kWh/m² therefore correspond to the average horizontal solar irradiance on the module surfaces of a PV installation in optimum orientation in northern Germany. 1300 kWh/m²year reach a PV installation at a location in southern Germany, and 1700 kWh/m²year of solar radiation fall on a PV installation in southern France.

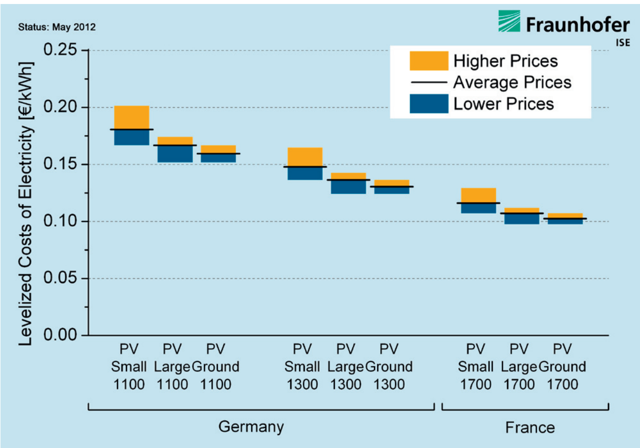

Figure 7: LCOE for PV installations in Germany and southern France by installation type and irradiance at an optimum angle of inclination, in kWh/m2/year.

The sharp price decrease with regard to system investment has a substantial influence on the development of the costs for producing energy using PV. Even in northern Germany, LCOE of under 0.20 euro/kWh can be achieved. At 0.253 euro/kWh in 2011 (BMWi 2012), the costs for energy generated by photovoltaics using all types of PV system throughout Germany therefore fall below the average energy costs for households. At locations in southern Germany, even small PV installations achieve LCOE of less than 0.15 euro/kWh.

In areas with higher annual solar irradiance, such as southern France, the LCOE are between 0.10 and 0.13 euro/kWh.
Due to the preceding massive price decrease and the current market situation, further considerable reductions in the LCOE using PV are unlikely to occur in 2012. However, as all PV technologies still possess significant potential for cost reduction, further decreases in the LCOE can be expected in the medium and long-term. We are therefore on the threshold of it being more cost-effective for German industrial companies, which consume between 500 and 2000 MWh, to use PV energy they have generated themselves, than to obtain energy from the grid at a price of 0.125 euro/kWh (BMWi 2012).

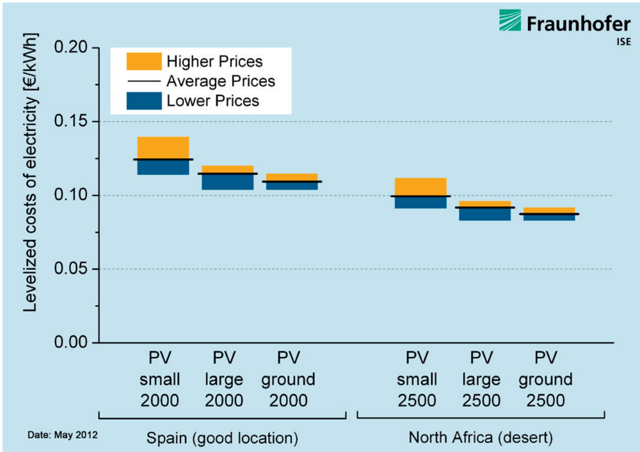

Figure 8: LCOE for PV installations in Spain and North Africa by installation type and irradiance at an optimum angle of inclination, in kWh/m2/year.

At locations with higher irradiance of 2000 kWh/m²year, such as in southern Spain, or 2500 kWh/m²year, such as in North Africa, the LCOE have fallen from 0.14 to 0.08 euro/kWh (Figure 8). However, greater financing costs at a location in Spain or North Africa raise the LCOE which, in part, results in the advantage of higher levels of irradiance being lost.

A sensitivity analysis for a small PV installation in Germany shows that the LCOE are heavily dependent on irradiance and specific investments (see Figure 9). This explains the sharp fall in LCOE in recent years resulting from lower module prices. One influence on the LCOE that must not be ignored is the weighted average cost of capital (WACC). The slight change in operating costs has less of an influence on the LCOE, as these constitute only a minor proportion of the total costs. The service life of the system has a significant impact on costs insofar as, with longer service lives, even amortised installations continue to produce energy at very low operating costs.

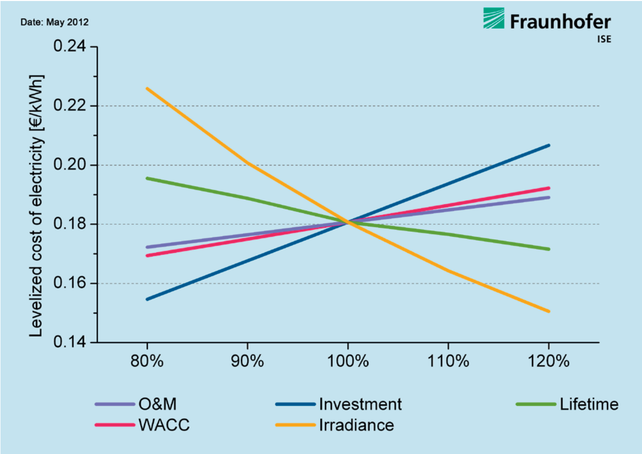

Figure 9: Sensitivity analysis for small PV installations with irradiance of 1100 kWh/m² per year, 100% corresponds to the average value for PVSmall from Figure 7.

Solar thermal power plants

Triggered by attractive government subsidies in the USA and Spain, CSP power plant technology has experienced a recent upturn in the last five years, after the construction of nine power plants in California between 1980 and 1990 with a total capacity of 354 MW had no effect on growth. Countries with very strong direct normal irradiance (DNI) in particular are currently preparing comprehensive expansion plans for CSP power plant projects (CSP Today, 2011), often in sunny desert areas. For this reason, Greenpeace (2009) Trieb (2009) and Sarasin (2011) forecast considerable market growth for CSP power plants (see Figure 10), which can, however, only be operated effectively in sunny areas with annual DNI of over 2000 kWh/m²year due to their technical properties.

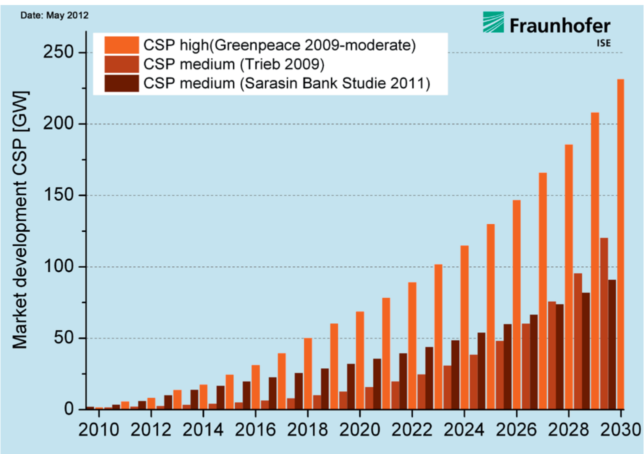

Figure 10: Market forecast of the cumulative capacity for CSP plants from 2010-2030, Sarasin (2009), Trieb (2009), Greenpeace (2009).

In mid 2012, the total installed capacity of CSP power plants worldwide was 2000 MW. The scope of all planned power plant projects, including those currently in construction, totals approximately 5 GW, with commissioning of these due to take place by 2014/2015.

The analysis of the LCOE for CSP power plants is based in particular on the data of completed power plant projects with parabolic trough and tower technology in Spain and the USA, taking as a basis the power plant parameters and investment data of parabolic trough power plant projects with an capacity of 50 MW, such as Andasol1-3 (CSP power plant with 8 h storage tank) or Shams1 with 100 MW in Abu Dhabi. These power plant projects are compared to the LCOE for the Gemasolar tower in Spain, which has a capacity of 20 MW and a 15 h storage tank. The size of the storage tank indicates the number of hours the turbines can be supplied with energy if the storage tank is full and there is no solar irradiance.

A new 30 MW Fresnel power plant in Spain has allowed Fresnel technology to be taken into account in the analysis for the first time. Therefore, only individual projects can be drawn upon as a reference for solar thermal power plants. A broad market analysis of a number of projects is currently not possible, as many power plant projects are at the development stage.

The LCOE for the CSP power plants with storage tanks analysed here are between 0.187 euro/kWh and 0.230 euro/kWh, at a DNI of 2000 kWh/ m²year (Figure 11). These therefore perform better than parabolic trough power plants without storage tanks (0.265 euro/kWh), as a larger heliostat array with combined salt storage tank units permits higher power plant turbine utilization and therefore provides a higher number of full-load hours.

Compared to tower power plants and power plants with Fresnel technology – each at 0.230 euro/kWh – parabolic trough power plants do slightly better. In regions with higher solar irradiance of up to 2500 kWh/m²year, such as North Africa or the Californian deserts, LCOE of 0.163 euro/kWh can be achieved.

In contrast with the first reference power plants, reductions in costs are anticipated for CSP technology over the next few years due to increased automation, project experience, the use of improved materials and components, and through further large commercial projects (Fraunhofer and Ernst&Young, 2011).

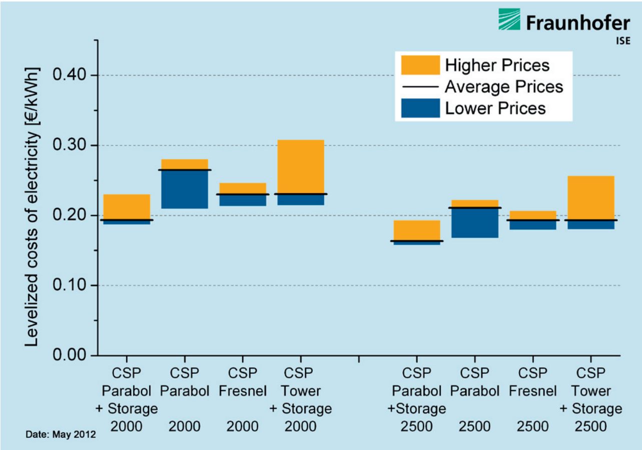

Figure 11: LCOE for CSP by installation type and irradiance (DNI in kWh/m2/year).

The sensitivity analysis shows that investments that are 20% lower than the reference case will lead to LCOE of 0.16 euro/kWh (see Figure 12). At the same time, a higher DNI also has very positive effects on the LCOE.

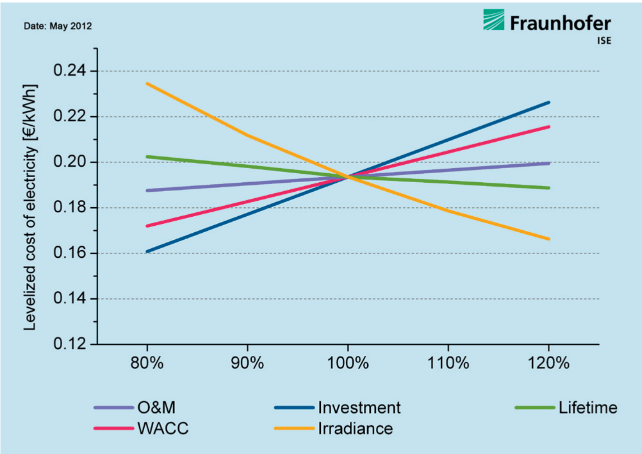

Figure 12: Sensitivity analysis for CSP (100 MW with storage tank) with annual irradiance of 2000 kWh/m²year, 100% corresponds to the average value for Parabolic with storage tank from Figure 11.

Wind power plants

Wind power currently enjoys the deepest level of global market penetration of all the renewable energies, due to its highly competitive capacity compared to conventional energy generation. Taking markets such as Denmark and Germany as a basis, extremely strong growth has been recorded in Spain, the UK, the USA, China and India in recent years. In addition to these mass markets, wind power projects and wind farms with several hundred MW are being developed in a number of industrial countries, as well as in some emerging and developing countries (Zervos 2009).

By the end of 2011, the total capacity of all installed wind power plants had increased to a volume of 238 GW (GWEC 2012), with offshore wind power plants accounting for 2.9 GW (EWEA 2012). In future, however, much more expansion of offshore wind power plants is expected (Krohn 2009), see Figure 13.

In the past, the market has demonstrated sustained growth of 15% on average, and therefore falls below the growth rates of photovoltaics in recent years. Various studies forecast an increase in the future market volume (see Figure 13) to a total capacity of approximately 1400 to 2330 GW in 2030. Of this total, offshore wind power plants are expected to account for 54 GW by 2020 and 218 GW by 2030.

At the same time, the LCOE for onshore wind power plants at economical locations are competitive compared with conventional energy generation technologies such as coal, natural gas and nuclear power. In Germany in 2011, wind power represented a proportion of up to 7.7% of the total energy generation. This figure is also likely to increase sharply in future due to the expansion of offshore wind power capacities (BMU 2011). In terms of renewable electricity, at 36.5% in 2011, wind power represents the highest proportion by far – much higher than all other renewable energy technologies (BMU 2011).

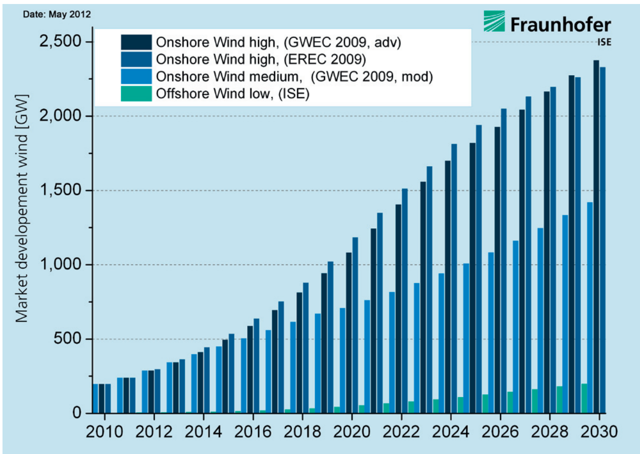

Figure 13: Market forecasts of cumulative wind power from 2010-2030 according to GWEC (2009) and EREC (2009).

The LCOE for wind power plants are heavily dependent on the conditions of the location for both on and offshore power plants, and also due to the attainable full-load hours. As shown in Figure 14, the LCOE for onshore wind power plants at locations near the coast with 2700 full-load hours are 0.059 euro/kWh with an average investment of 1400 euro/kW. Locations with less favourable wind conditions reach prices of 0.090 to 0.115 euro/kWh depending on the specific investments. With a price range of 0.065 to 0.081 euro/kWh, average locations with 2000 full-load hours are only slightly above the stated energy reference price of 0.06 euro/kWh for fossil fuel power plants. The average number of full-load hours for all wind power plants operated in Germany currently fluctuates between 1500 and 1800 hours annually.

In contrast, the analysis of current offshore wind power plants shows that even locations with higher full-load hours (up to 4000 full-load hours), have higher LCOE than onshore wind power plants. This is due to the necessary use of more robust, higher priced materials, costly anchoring in the ocean bed, system components with more expensive installation and logistics, and a higher level of maintenance. In addition, projects that are currently in construction have demonstrated that previous cost estimates for offshore wind power plants have had to be revised upwards again. In future, however, a reduction in system costs can be expected due to learning effects.

Offshore wind power plants in locations with very good conditions currently achieve LCOE of 0.105 to 0.150 euro/kWh (Figure 14). The disadvantage of these locations, which are often far from the coast, is that the connection to the grid is more time and cost-intensive, and the obstacle of the sheer depth of the sea must be overcome. Locations with a lower number of full-load hours achieve LCOE of 0.122 to 0.183 euro/kWh. The LCOE for offshore wind power plants at all locations are therefore higher than those for onshore wind power plants.

The current installation and connection of larger wind farms to direct current connections (e.g. OWP BARD offshore 1, Transpower 2009) reduces the specific costs for individual wind farms and also provides the possibility of transporting energy over a distance of 100 to 200 km with minimal losses.

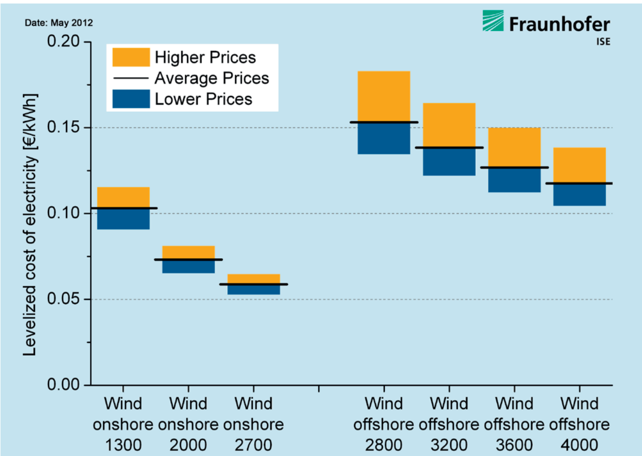

Figure 14: LCOE for wind power plants by location and full-load hours.

There are, however, regulatory weaknesses that significantly delay the connection of current offshore projects to the grid. These technology-specific risks lead to higher capital costs and safety requirements on the part of the outside creditor, resulting in higher WACC for offshore projects compared to onshore wind farms.

For offshore wind power plants, the margin for cost reductions is limited due to the higher installation and maintenance costs. Therefore, the possibility of achieving a level comparable with onshore wind power plants currently seems difficult. In future, however, cost reduction effects can be expected due to intensified market growth, as the extensive installation of offshore wind power plants in a number of other countries, such as the North Sea states, will begin in the next few years.

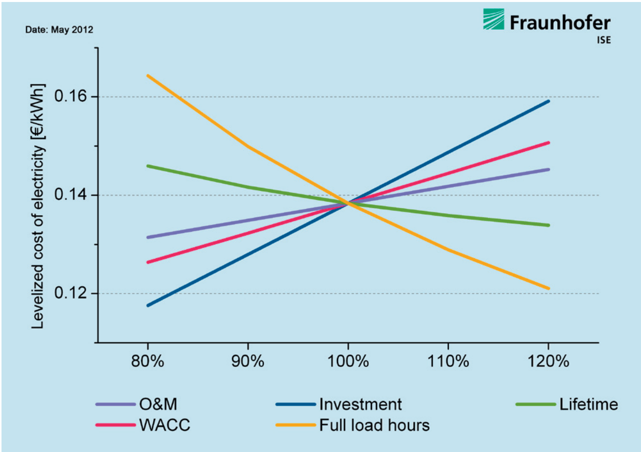

Figure 15: Sensitivity analysis of offshore wind power plants with 3200 full-load hours, specific investment of 3200 euro/kW.

The sensitivity analysis identifies the installation of the systems as the primary area with the potential for future cost reductions. As with the PV and CSP technologies that have already been investigated, the sensitivity analysis displayed the strongest reaction to this parameter.

The offshore power plants are distinguished by the advantage of a higher number of full-load hours, a minimal amount of noise pollution and acceptance among the public, if the minimum requirements for the distance to the coast and for environmental protection are upheld.

Forecast of the LCOE up to 2020 and 2030

Cost forecasts for each of the technologies considered (PV, CSP, wind power plants) can be created using observed learning curves, the temporal progression of which is used as a basis for the different market forecasts for the time period up to 2020 and 2030. Over the last 20 years, a very constant learning rate or progress ratio (PR = 1 - learning rate) has been identified for both photovoltaic and wind technology (see Bhandari, 2009). Investments per watt for PV modules decreased as a consequence of a PR of 80%. Bhandari and Stadler suggest that the PR for PV installations will reduce to 85% from 2015.

In contrast, the costs for wind power plants have followed a PR of 97% in recent years whereas, previously, this was 87 - 92% (ISET, 2009). Due to the minimal market volume of offshore wind power plants, calculation of a stable PR has not yet been possible. As, on the one hand, the current offshore projects must resort to using technologies developed for onshore systems but, on the other hand, developments specific to offshore systems can be expected in future, this study has set a PR of 95% for offshore wind power plants.

Current studies by the German Aerospace Center (DLR) differentiate between the individual components of CSP power plants (solar array, thermal storage tank, power block) with PRs between 88% and 98% (Viebahn 2008, Trieb 2009). The average PR of 92.5% used here refers to the entire power plant. The 2009 Sarasin study used a higher PR for the years after 2015 (92% / 96%), whereas the Greenpeace study is based on a PR of 90%. The varying PRs are used below for the different market forecasts. Table 5 (in appendix) displays the PRs used to model future LCOE for the individual technologies.

The modelling of the LCOE shows a different development dynamic for the individual technologies depending on the parameters discussed above, the financing conditions (WACC), the market launch and development of the technologies (PR), the current volume of investment (euro/kWh) and the conditions at the location (Figure 16). Today, newly installed PV systems in Germany can generate energy for 0.18 euro/kWh. At an annual irradiance level of 1100 kWh/m², the costs in 2015 fall below the 0.15 euro/kWh mark, even for smaller on-roof installations. Larger ground-mounted installations generate energy for less than 0.11 euro/kWh at an annual irradiance level of 1300 kWh/m². From 2020, the LCOE for both types of system fall below 0.13 / 0.10 euro/kWh.

As early as 2022, larger ground-mounted PV installations will generate energy in southern Germany more cheaply than the conventional mixed-source energy, the costs of which have been taken from the 2011 BMU Leitstudie.

Onshore wind power plants are the most cost-effective form of renewable energy generation, with costs in Germany currently less than 0.08 euro/kWh at 2000 full-load hours per year. These will remain the most cost-effective throughout the time period considered, even if the LCOE only decrease very slowly to almost 0.07 euro/kWh in 2030. However, even in 2016, energy can be produced by these onshore wind power plants at a cheaper rate than by the conventional mixed-source energy. With a lower progress ratio of 95%, offshore wind power plants have greater potential for cost reduction, to be able to compete with the conventional mixed-source energy. The expected reduction in the LCOE from 0.14 euro/kWh to 0.11 euro/kWh in 2030 will be bolstered by a decrease of only 5% in the feed-in tariff specified in the German Renewable Energies Act (EEG) from 2015.

As the learning rate for PV is significantly greater than for wind power plants, from 2025, the LCOE will be lower even for small PV on-roof installations in northern Germany than for offshore wind power plants. With onshore wind power plants, however, it will be possible to achieve the lowest LCOE of 0.069 euro/kWh in 2030, according to the specified learning curves.

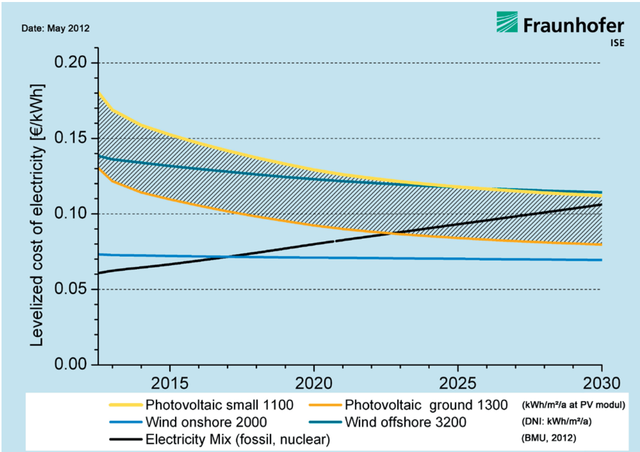

Figure 16: Forecast for the development of the LCOE for renewable energies compared to the conventional mixed-source energy in Germany up to 2030.

At locations with very good irradiance conditions (approx. 2000 kWh/m²year) and market growth of 1400 GW of cumulative installed capacity, PV can achieve similar LCOE in 2025 as onshore wind power plants, as demonstrated in Figure 17 for Spain.

Solar thermal power plants generate energy at 0.15 euro/kWh and are therefore 0.05 euro/kWh more expensive than PV installations under the same conditions, but also offer the possibility of storing energy. Over the next five years, increased market growth should provoke a particularly sharp decrease in the LCOE for CSP power plants, as by then the market will have surpassed a critical mass. In the long-term, however, the LCOE for PV power plants will be higher than the costs of the other technologies. As a result of a weaker learning rate compared to PV semiconductor technology, the difference in cost between both technologies will become greater.

In the long-term, PV installations at locations with intensive irradiance and wind power plants at onshore locations with good wind conditions will generate energy at the lowest costs. The developments in technology and costs in recent years have significantly improved the competitive capacity of wind power plants and PV. For PV in particular, costs were reduced so sharply that it is no longer generally the most expensive renewable energy technology in Germany. According to the analysis of the LCOE for the second quarter of 2012, it has been possible to significantly improve on the forecasts for PV in the last study (2010) due to the strong market growth and the substantial reductions in price for PV systems. This shows that the forecast for the LCOE using learning curves is liable to uncertainty (Ferioli 2009). In future, how far will the learning curve be continued or even improved upon by innovative developments and new production technologies? How will the markets develop in future or how will the financing costs develop within a national or global economic environment? For these reasons, sensitivity analyses of the learning curves using different progress ratios have been introduced (see Figure 18-21).

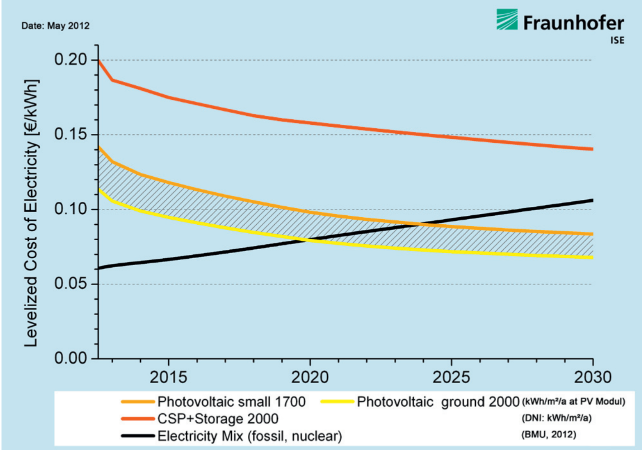

Figure 17: Forecast for the LCOE for renewable energies using learning curves and compared to the conventional mixed-source energy in Spain up to 2030.

Sensitivity analyses of the learning curves used

The final five graphs show the range of LCOE for CSP, PV and wind power, for a varied combination of progress ratios and market scenarios. Based on current costs, the values demonstrate fluctuations from 10 to 20% depending on the parameters used. This reflects the uncertainty surrounding the level of future cost reductions that can actually be realised for each of the technologies.
For small photovoltaic installations at locations with energy outputs of 900 kWh/kWp, LCOE between 0.14 euro/kWh and 0.22 euro/kWh have been identified. A higher level of irradiance at locations with 2000 kWh/kWp allows photovoltaic installations to reach 0.06 to 0.11 euro/kWh.
According to calculations using different learning curves, in 2020, solar thermal power plants will produce energy for 0.11 euro/kWh to 0.15 euro/kWh. Due to the current low level of the LCOE for onshore wind power (0.06 – 0.068 euro/kWh), only minimal reductions in these costs are expected in future. Fluctuations in the price of raw materials (as with steel in 2008) will have a much stronger influence on these LCOE. For offshore wind power plants, the LCOE might reach the level of between 0.100 euro/kWh and 0.115 euro/kWh in 2020.

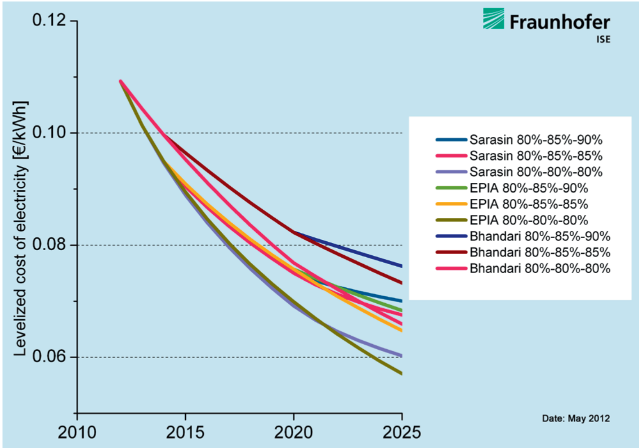

Figure 19: Sensitivity analysis for the forecast of the LCOE for ground-mounted PV installations using learning curves.

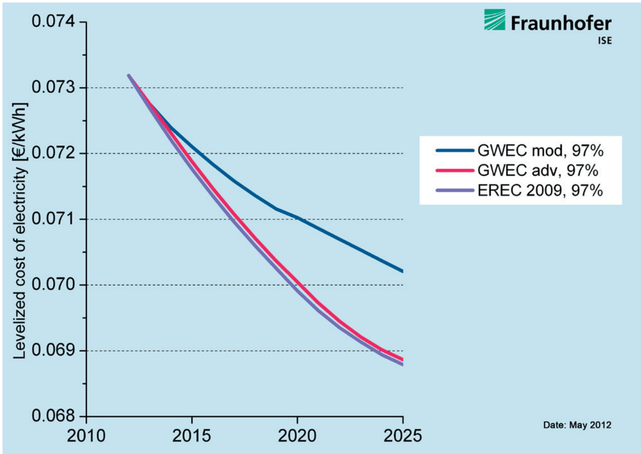

Figure 20: Sensitivity analysis for the forecast of the LCOE for CSP power plants using learning curves.

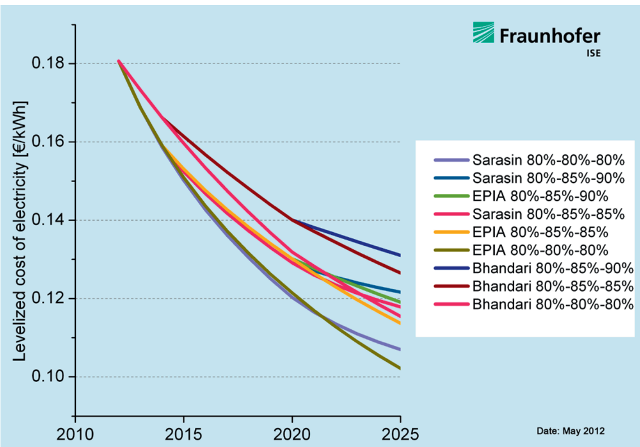

Figure 18: Sensitivity analysis for the forecast of LCOE for small PV installations using learning curves.

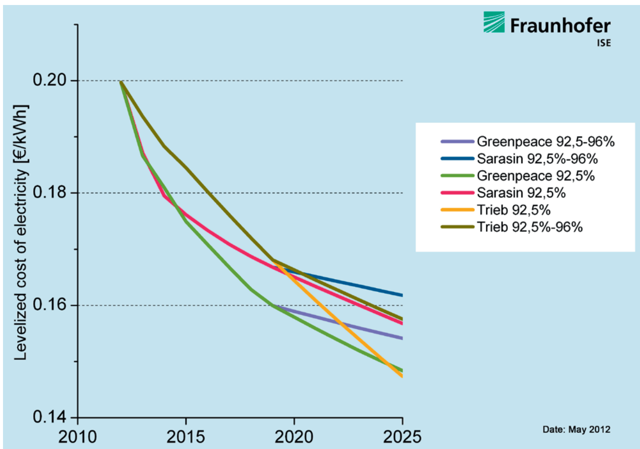

Figure 21: Sensitivity analysis for the forecast of the LCOE for onshore wind power plants using learning curves.

Technological outlook

Production technologies for crystalline solar modules

In recent years, great advances in production technologies for crystalline solar modules have been achieved in terms of the efficiency and costs of production of PV silicon, solar cells and PV modules. This has been brought about by the application of developments in research to industrial methods of production throughout the entire value chain. The German research institutes and engineering companies in particular have made a decisive contribution to this development. In 2011, the global market for PV production equipment reached a sales volume of 12.8 billion US dollars (IMS Research 2011), with German engineering accounting for a proportion of almost 50% (VDMA 2012). Innovative PV production technologies will also drive down PV production costs in future. Manufacturers and engineers throughout the entire PV value added chain are working towards further improving established production processes and materials in terms of their cost-effectiveness. This includes increasing the throughput of production plants, decreasing the rate of breakages and failure, and reducing the production materials used. For example, the amount of silicon or silver, which is currently used as the contact material on most solar cells, can be further reduced. In addition to optimising the established production processes, new, more cost-effective production technologies, or ones which increase efficiency, will replace the technologies that are currently in use. One approach is to use alternative contact materials; copper has a similar electric conductivity to silver, but is one hundred times cheaper. The use of plasma-enhanced texturing technologies could also replace established wet chemical processes and substantially reduce the costs of the processing materials and their disposal. Another example is provided by the development of so-called quasi-mono silicon wafers. These are produced using an enhanced version of the crystallisation process for manufacturing multicrystalline wafers, thereby achieving the high quality of multicrystalline wafers combined with lower production costs. In addition to substituting current production technologies, new innovative production technologies will enable new cell concepts to be transferred from the laboratory to industrial production. Highly efficient solar cell structures, the industrial manufacture of which was previously not economically viable, may have a cost advantage over the established solar cell designs in future, due to innovative and cost-effective production technologies. Laser technologies promise great potential for this; they can be used for the structuring, alloy and connection processes, and all at very low production costs. New technologies for connecting the solar cells within the PV modules will also allow the cost-effective implementation of highly efficient rear contact solar cells, and will further increase the efficiency of the solar modules.

Innovative PV production technologies allow new cost-effective module designs and solar cell structures to be produced, and therefore have the potential to further reduce the costs of generating energy using photovoltaics.

Optimising large PV power plants

In recent years, a trend towards large PV power plants in the multi-megawatt range has emerged, which will be further strengthened by the exploitation of new market opportunities in sunny regions outside of Europe. In principle, these large projects offer cost advantages compared to small systems, which are brought about due to synergy effects in planning and procurement, simplified installation and the use of more cost-effective central inverters. However, this potential has not yet been completely exhausted, as neither the installation nor the system technology have been optimised for the specific requirements of large PV power plants. The sharp decrease in costs for solar modules, coupled with an increase in the price of metal raw materials such as copper, iron and aluminium has, however, led to the system technology in particular (solar inverters, cabling, transformers, mounting etc.) playing an increasingly important role in the total costs of the power plant. Work is therefore being done to create new concepts for the system technology, which address the requirements of large PV power plants and have the potential to considerably reduce the number of components, the amount of material used, and the time and cost of installation. An initial step, for example, is to increase the voltage levels on both the DC and AC sides, which will allow savings to be made in terms of the power plant wiring. Concepts using significantly higher system voltages in the medium voltage range are also being investigated. These have far-reaching consequences for the entire system technology and promise significant savings in terms of BOS costs. The implementation of these new concepts requires the close cooperation of research establishments and industry partners who, through this, will be able to secure a clear competitive advantage in the area of large PV power plants. This is an attractive possibility considering the context; due to falling prices for solar modules, large PV power plants can already be built without state subsidies in sunny locations in southern Europe, the USA, South America, Africa and Asia, and the costs will be further reduced due to new concepts in the system technology.

5. APPENDIX

Technology	Study	Market Scenarios	Additional Assumptions
PV	Sarasin (2011)	2012-2015: Projected values, until 2020 increase of expension by 116MW	After 2020: Constant market growth until 2030 with projected values from 2020
PV	EPIA (2009)	2012-2015: Projected values	After 2016: Market growth 20% until 2030
PV	Bhandari und Stadler (2009)	Untill 2020: Market growth of 20% After 2020: Market growth of 15%	
CSP	Sarasin (2010)	2012-2020: Projected values	After 2020: Constant market growth
CSP	Greenpeace (2009) *moderate*	2011-2015: Market growth from 17% to 27% 2015-2020: Increase of 27% After 2020: Increase of 7%	
CSP	Trieb (2009)	Target value of 15 GW in 2020 Target value of 150 GW in 2030	
Wind onshore	GWEC (2009) *moderate*	Target value of 709 GW in 2020 Target value of 1420 GW in 2030	
Wind onshore	GWEC (2009) *advanced*	Target value of 1081 GW in 2020 Target value of 2375 GW in 2030	
Wind onshore	EREC (2009)	Until 2020: Market growth 20% From 2020: Market growth 7%	
Wind offshore	Fraunhofer ISE (2012), EWEA (2011), Market Research (2011)	EWEA: Projection for EU until 2030 Projection (World) until 2025	Consolidation of projection until 2030

Table 3: Overview of market scenarios for PV, CSP und wind power.

Investment in Euro/KW in 2012					
Technologies	Installations	Average Value	Lower Bound	Upper Bound	Sources
Photovoltaics	Small installations <10 kWp	1900	1700	2200	*BSW Preimonitor (2012), Fraunhofer ISE (SCost-System)*
	Large installations <1000 kWp	1700	1500	1800	
	Ground-mounted >1000kWp	1600	1500	1700	
CSP	Parabolic 100 MW without storage	4700	3600	5000	*Nevada One, Acciona (Majadas de Tietar)*
	Parabolic 100 MW with 8h storage	5400	5200	6600	*Andasol1-3 (ES)*
	Fresnel 100 MW without storage	3700	3400	4000	*PE2 power station (ES)*
	Tower 100 MW with 8h storage	6500	6000	9000	*Crescent Dunes (US), Abengoa (RSA)*
Wind	Onshore (1,5 – 2 MW)	1200	1000	1350	*EWEA (2009)*
	Onshore (2 – 3 MW)	1400	1200	1600	*Windguard (2011)*
	Offshore (3 – 5 MW)	3200	2700	4000	*EWEA (2009), Gerdes (2006), Krewitt (2009), Projekte: Borkum West 2, Baltic1*

Table 4: Investment in Euro/kW with current power plant installations.

Learning Curve	2012	2015	2020	Market Forcast
PV PR 1	80%	80%	80%	B/S (2009), Sarasin (2009), EPIA (2011)
PV PR 2	80%	85%	85%	B/S (2009), **Sarasin (2009)**, EPIA (2011)
PV PR 3	80%	85%	90%	B/S (2009), Sarasin (2009), EPIA (2011)
CSP PR 1	90%	92%	96%	Sarasin (2009), Greenpeace (2009), Trieb (2009)
CSP PR 2	92,5%	92,5%	92,5%	Sarasin (2009), **Greenpeace (2009)**, Trieb (2009)
Onshore-WEA PR 1	97%	97%	97%	**GWEC (2009)** *moderate* und *advanced*, EREC (2009)
Offshore-WEA PR 1	97%	97%	97%	GWEC (2009) *moderate* und *advanced*, EREC (2009)
Offshore-WEA PR 2	95%	95%	95%	**GWEC (2009)** *moderate* und *advanced*, EREC (2009)

Table 5: Progress ratio (PR) for learning curve modelling (marked values were used in figure 2,3 as well as 16,17).

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