Fraunhofer ISE

Recent facts about photovoltaics in Germany

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1. What purpose does this guide serve?

Germany is leaving the fossil-nuclear age behind, paving the way for photovoltaics (PV) to play a significant role in a future shaped by sustainable energy production. This compilation of the most up-to-date facts, figures and findings is regularly updated and aims to help create a comprehensive assessment of the expansion of PV in Germany.

2. Does PV contribute significantly to the electric power supply?

Yes.
As estimated on the basis of figures from [BDEW3] and [BDEW4], PV generated **28 TWh** [BDEW4] of power in 2012, covering approximately **5.3 percent** of Germany's net power consumption (compare section 20.8). Taken as a whole, renewable energy (RE) accounted for around **25.8 percent** of net power consumption, while the proportion of Germany's gross power consumption covered by PV and RE stood at **4.7 percent** and **23 percent** respectively.
On sunny days, PV power can cover at times **30 - 40 percent** of the current power consumption. According to the German Federal Network Agency, PV modules with a rated power of **32.4 GW** had been installed across a total of around **1.3 million** plants in Germany by the end of 2012, meaning the installed capacity of PV has exceeded that of all other types of power plants in Germany. See Figure 1.

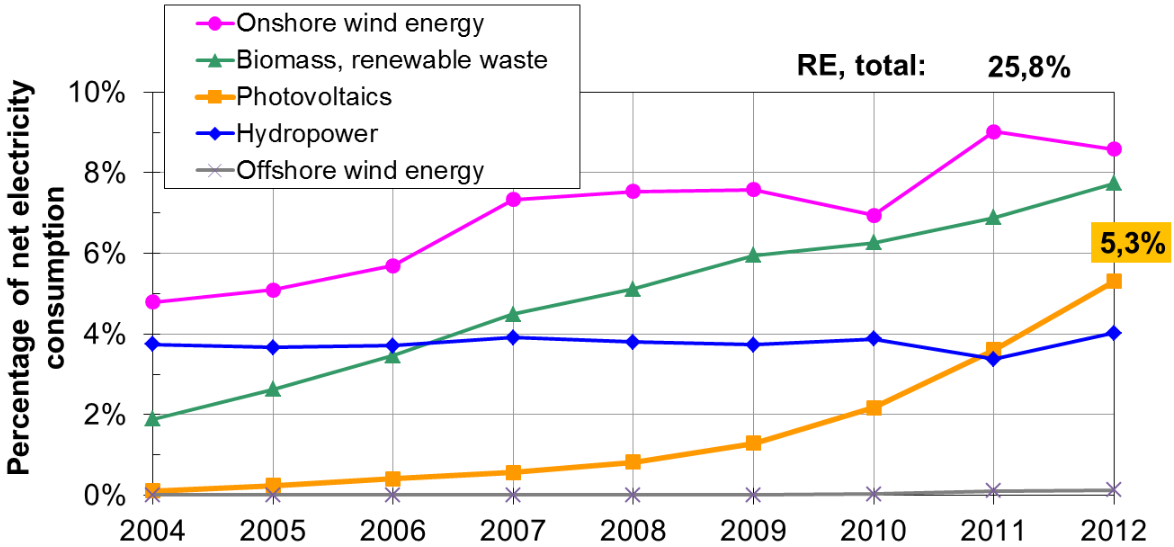


Figure 1: Development of the percentage of renewable energy in net power consumption (final energy) in Germany, data from [BMWi1], [BDEW3] and [BDEW4], [BMU4].

The fact that the German government's minimum targets for the amount of power to be generated using RE by 2020 remain achievable is down to the high level of momentum with which new PV capacity is being installed (Figure 2). PV not only contributes significantly to the power supply, but also to the transformation of Germany's energy supply to renewable energy. The installation of offshore wind, the transmission link to the mainland and the expansion of the power lines are behind schedule. In the meanwhile, the German federal government's goal of 10 GW offshore wind by 2020 appears to be reachable only with a great amount of effort (Handelsblatt, 16.5.2013).

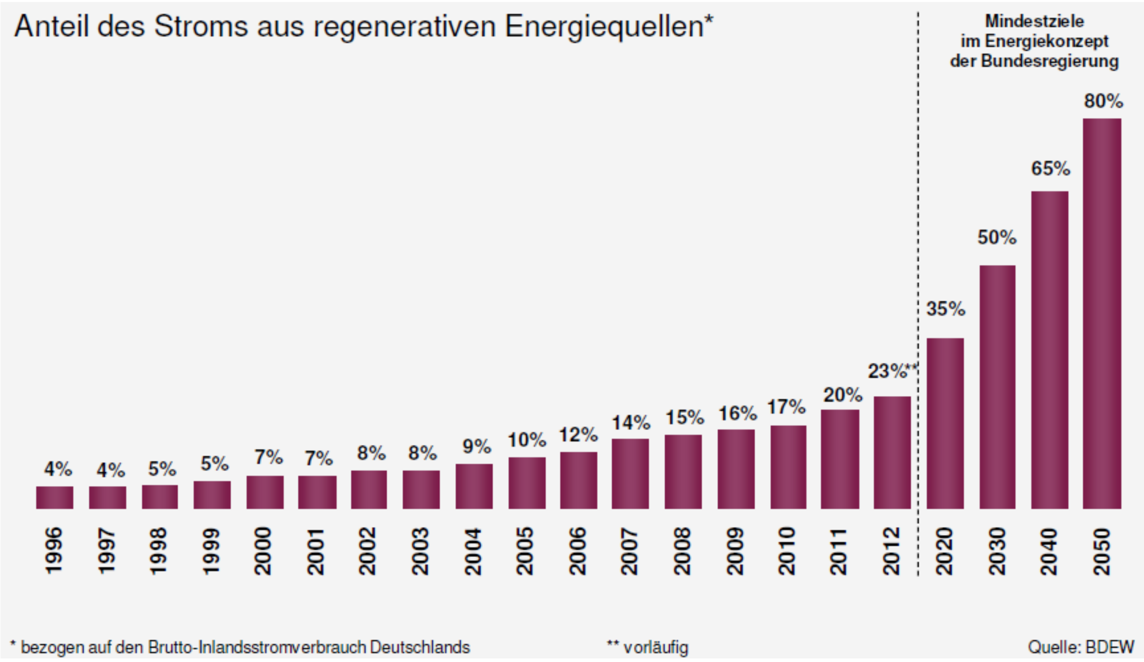


Figure 2: Percentage of RE in gross power consumption in Germany and minimum targets set by the German government [BDEW4].

3. Is PV power too expensive?

It depends on how you look at it.
In Germany, it is currently more expensive to generate PV electricity than electricity from conventional power plants. As an important mainstay of the energy transition, PV power is therefore being backed by the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG), enabling plant operators to run their installations profitably and investments to be generated. The additional costs of producing energy from renewable sources are calculated on the basis of the electricity prices on the national energy stock exchange, placing high consumers of electricity in a more favorable position (see section 4.3). The EEG also aims to continuously reduce the levelized cost of electricity. (see learning curve in section 3.1). Additionally, considering the external costs of conventional energy in real terms when calculating electricity prices will contribute significantly to achieving sustainable and emission-free power generation (see section 20.9, [DLR],

[FÖS1]), which is one of the aims of emissions trading, for example. To date, however, emission trading has not brought about any noteworthy increase in the price of conventional energy, leaving renewable energy with an insufficient level of competitiveness for the time being (see section 4.3 on the influence of government policies on electricity prices).

3.1 Levelized cost of electricity

The levelized cost of electricity produced by PV power plants is calculated according to the relationship between the plant's total costs (€) and total electrical energy production (kWh), both of which are worked out in terms of the plant's economic lifetime. The levelized cost of electricity generated by PV power plants [ISE1] is predominantly calculated on the basis of:

1. purchase investments for constructing and installing plants
2. financing conditions, plant lifetime and return on investment
3. operating costs over the lifetime of the plant
4. amount of irradiance
5. lifetime of the plant

Thanks to technological progress and economies of scale, investment costs, which represent the greatest proportion of outlay for PV power plants, have in the past fallen by around **15 percent** annually. Figure 3 shows the price development over recent years of rooftop installations with rated outputs of up to 10 kW_p.
The price of PV modules is responsible for more than half of a PV power plant's investment costs. The price development of PV modules follows a so-called price learning curve, in which doubling the total capacity installed causes prices to always fall by the same factor. Provided that significant efforts continue to be made to develop products and manufacturing processes in the future, prices are expected to continue to fall in accordance with this rule.

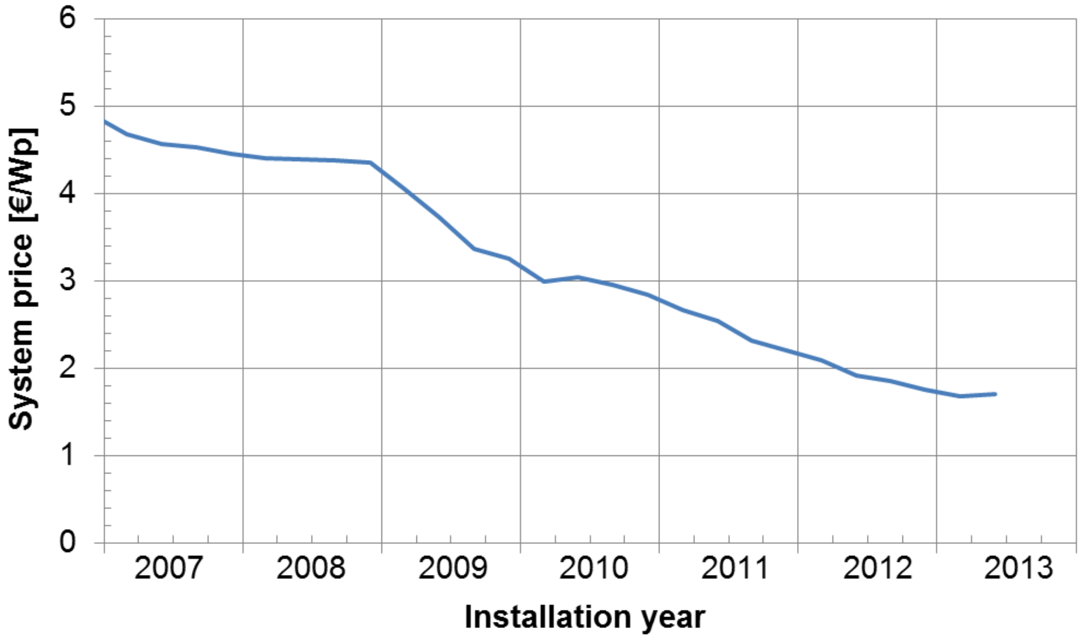


Figure 3: Average end customer price (net system price) for installed rooftop plants with rated power of up to 10 kWp, data from [BSW].

According to current estimates by the German Solar Industry Association (BSW), approximately **100 GW** of PV capacity was installed worldwide by the end of 2012. Figure 4 shows the prices adjusted for inflation and calculated in euros in line with the 2012 exchange rate.

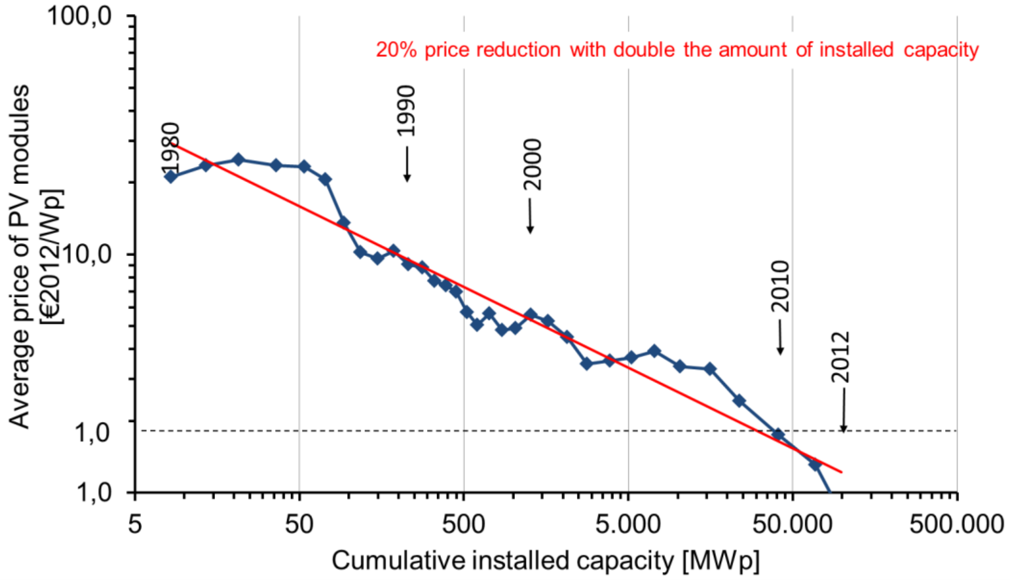


Figure 4: Historical price development of PV modules (PSE AG/Fraunhofer ISE, data from: Strategies Unlimited/Navigant Consulting, estimated in 2012). The straight line shows the price development trend.

The average prices were calculated by Strategies Unlimited and Navigant Consulting and comprise all market-relevant technologies, i.e. crystalline silicon and thin-film technology. The trend indicates that doubling the cumulative installed capacity results in a 20 percent reduction in price.

3.2 Feed-in tariffs

Since at today's prices (see section 3.7) neither a multi-megawatt PV power plant let alone a small rooftop PV installation are able to compete with fossil fuel and nuclear power plants in terms of their levelized cost of electricity, PV power plant operators in Germany receive a fixed feed-in tariff for a period of 20 years. Following the end of the amortization period, power from PV power plants is less expensive than that from any other source thanks to low operating costs and the absence of fuel costs ("marginal costs"). On the other hand, fossil fuel and nuclear power plants must continue to purchase fuel and dispose of the waste produced from burning this fuel in order to generate electricity even once the investment has fully amortized.

The EEG [EEG1, EEG2] stipulates the rate of remuneration and grants priority to the feeding in of solar power. The aim of this remuneration is to give investors a reasonable return on investment and for the gradual degression to stimulate a further drop in the levelized cost of electricity generated by PV plants (Figure 5). Depending on their size and type, plants commissioned, for example, in **July 2013**, receive between **10.44** and **15.07 Euro cents / kWh** for a period of 20 years. In comparison, power generated by offshore wind farms has received up to 19 Euro cents / kWh (initial tariff incl. bonuses) since 2012. Further costs and risks arise from the rule on the liability for the connection of offshore wind farms.

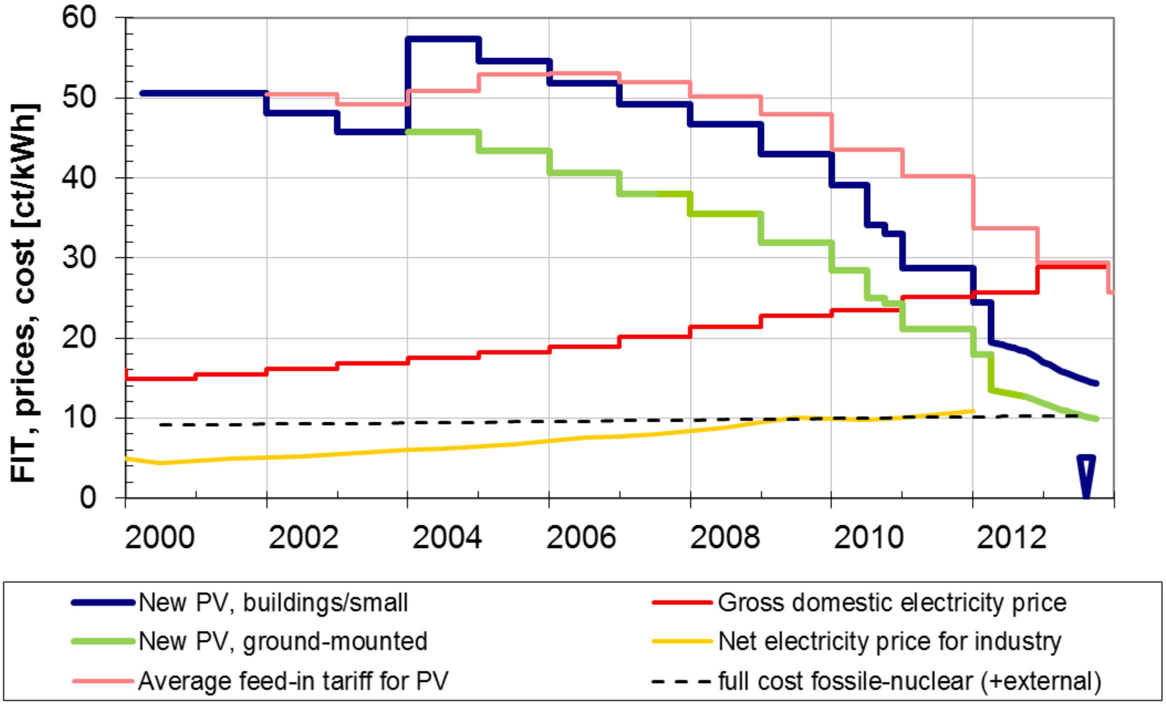


Figure 5: Remuneration for PV power according to the date on which the plant was commissioned in line with the EEG, average remuneration for PV power for existing installations from [BDEW4], [R2B], electricity prices [BMWi1]; estimated full costs for the fossil-nuclear power generation [IFNE]

The feed-in tariff for PV power decreases more rapidly than that for any other renewable energy source. Newly installed, large-scale plants had already achieved grid parity for residential consumers by 2011, meaning that since that time remuneration has been lower than the gross domestic electricity price. Newly installed, small rooftop installations had also achieved grid parity by the beginning of 2012. The grid parity of these installations marks a crucial milestone that was almost utopian just ten years ago, but it should not suggest any comparison of the levelized cost of electricity. Assuming a constant development of electricity price and remuneration, grid party will also be achieved in 2013 for many industry electricity customers. July 1, 2013 is an important date for grid parity. On this day, the remuneration for the electricity generated from newly installed free-standing PV systems in open spaces shall reach a level close to the estimated full costs for fossil-nuclear electricity [IFNE].

In 2013 the average EEG tariff for PV power is about **29 Euro cents/kWh**. This value gives the actual payables and includes the higher remuneration rates of older installations. The currently valid remuneration rate, which applies to new installations, is the relevant figure for determining the future expansion of PV installations.
After 2020, the oldest plants will gradually no longer receive EEG remuneration, as their 20-year payment periods will begin to expire. However, they will continue to supply power at levelized costs that undercut those of all other fossil fuel and renewable ener-

gy sources. Old installations are currently making the average rate of remuneration higher, and are likely to cause a drop in prices from 2020.
Remuneration for new installations initially fell moderately by five percent per year over the course of several years, before this downward trend accelerated to a reduction of between 30 and 34 percent in 2012. This virtually put an end to the increase in the amount of new capacity installed, which in 2011 stood at 7.5 GW of expansion (previous year: 7.4 GW of expansion). Lowering remuneration too quickly runs the risk of investors no longer seeing opportunities for making returns in Germany. In fact, in 2012, many manufacturers, including those from Asia, had to sell their PV modules for less than the cost of production.
Up to April 2012, the decrease in the remuneration was carried out in large, irregular jumps. As a result, this led to a similarly irregular increase in installed capacity and made the expansion difficult to predict. This problem was solved with the initiation of adjustments on a monthly basis.
Important facts in brief:

- The only relevant factor for the economic viability of the further PV capacity is the current rate of remuneration.
- As of midyear 2013, the remuneration for electricity produced by new, large PV systems will be less than the electricity price paid by some of the major industrial enterprises.
- As of midyear 2013, the remuneration for electricity produced by small PV systems will be less than half of the gross electricity price paid by households.
- As of midyear 2013, the remuneration for electricity produced by new, large area systems in open spaces will have reached the estimated full costs for fossil-nuclear power.
-

3.3 Total Remuneration

With the already radical reduction in feed-in rates, the further degression agreed upon and the remuneration phase-out for new PV systems above a threshold of 52 GW, it can be ensured that the total EEG remunerations for PV are limited to 10-11 billion € per year [R2B].

Figure 6 shows clearly that any further expansion in PV installations after 2013 would increase the total remuneration only moderately. There is little room to reduce the total sum of remunerations any further through additional cuts in the EEG. Capping the yearly expansion could limit the annual increase in the EEG-levy related to PV systems. This measure, however, would send a fatal signal to all market participants indicating that future efforts – also for cost reduction – would not be worthwhile.
Important facts in brief:

- Any additional cuts in the EEG levy can hardly affect the total remuneration; however, it can drastically limit the capacity increase of cost-effective PV systems.

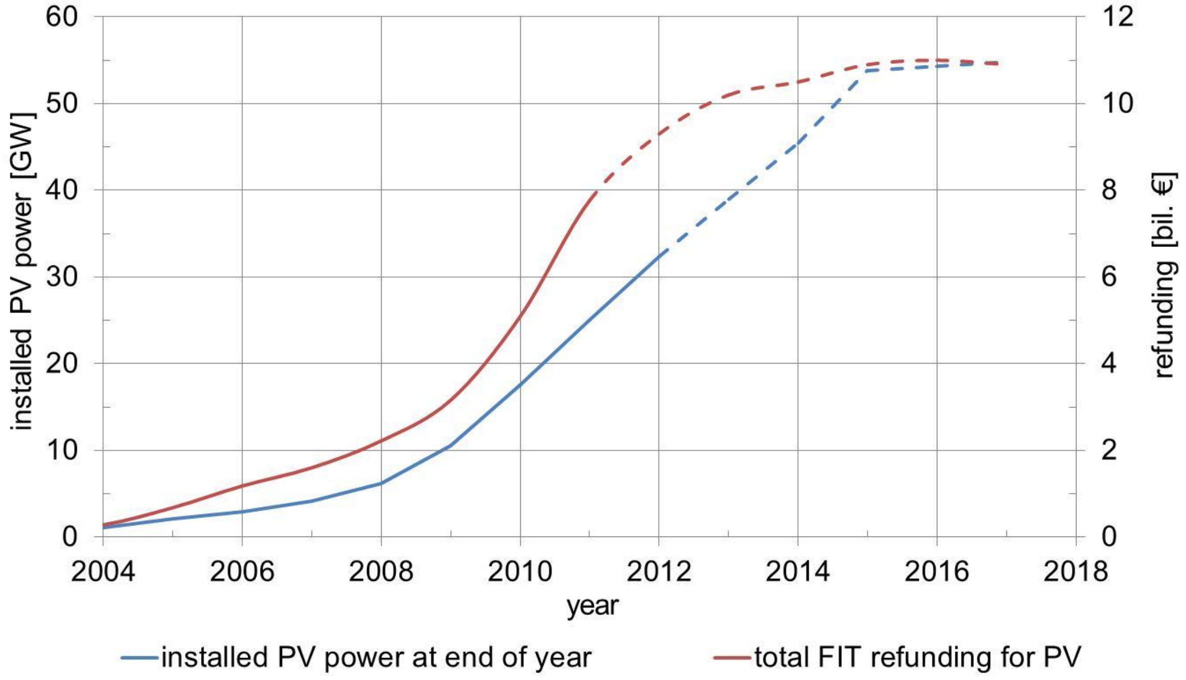


Figure 6: PV expansion and total remuneration, data from [BDEW4, R2B]

3.4 Pricing on the energy exchange and the merit order effect

Prices on the European Energy Exchange AG (EEX) in Leipzig are determined by the merit order principle. The sales prices offered by power generators for specific quantities of power, which are generally defined by their respective marginal costs, are ranked in ascending price order (Figure 7), while the purchase offers of power consumers are arranged in descending order. The point of intersection of the two curves shows the energy exchange price of the entire quantity traded. The most expensive offer made therefore influences the somewhat substantial profit margins of the more cost efficient suppliers, i.e. providers of power generated from nuclear and coal-fired power plants.

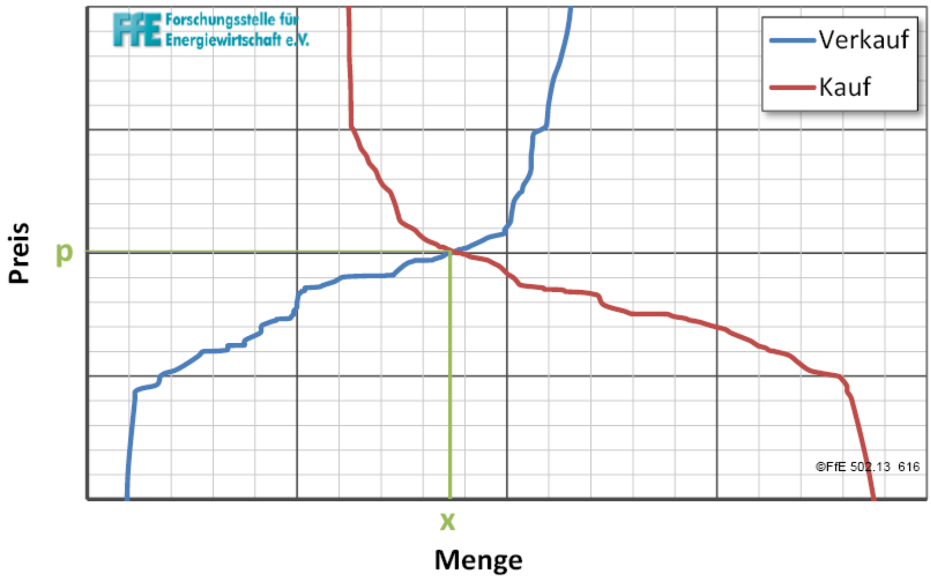


Figure 7: Pricing on the EEX [Roon].

The feed-in of PV power has legal priority, meaning that it is found at the start of the price scale of power being offered. With fictitious marginal costs of zero, PV power is always sold when available. It is, however, predominantly generated during the middle of the day when power consumption experiences its midday peak and during these periods, it displaces mainly electricity from expensive power plants (especially gas-fired and pumped-storage power plants). This displacement lowers the overall electricity price and, in turn, the profits made by utilities generating power from fossil fuel and nuclear sources (Figure 8). It also lowers the utilization and profitability of traditional peak-load power plants.

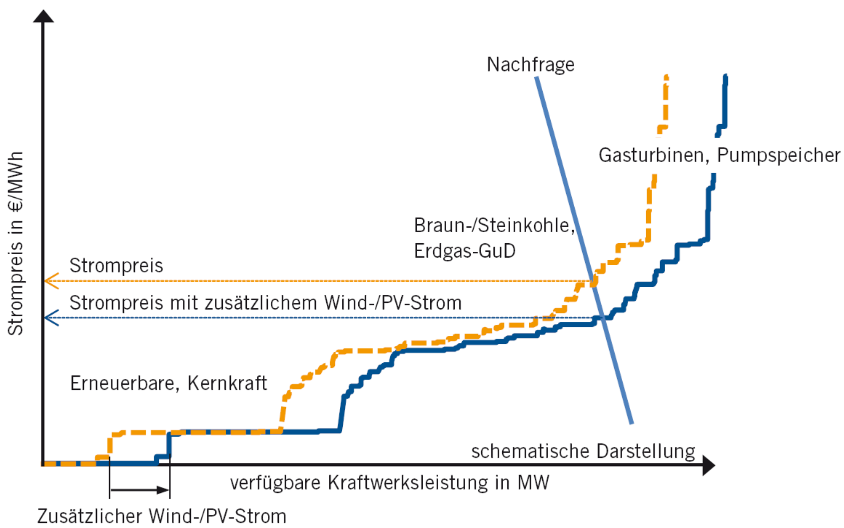


Figure 8: Influence of RE on pricing on the energy exchange [WEC].

As an example, Figure 9 depicts the merit order in 2008 and the influence of residual load on EEX prices, i.e. the difference between the electricity demand and the amount of privileged feed in of power produced by wind energy, PV, hydropower and CHP plants.

"As shown by Figure 9, the electricity price correlates positively with the residual load. An increased level of feed-in from renewable energy sources reduces the residual load, leading to a lower electricity price. This is known as the merit order effect." [Roon] In 2011, an additional one gigawatt feed-in of PV power led to an average spot price decrease of 82 Euro cents/MWh [BDEW4].

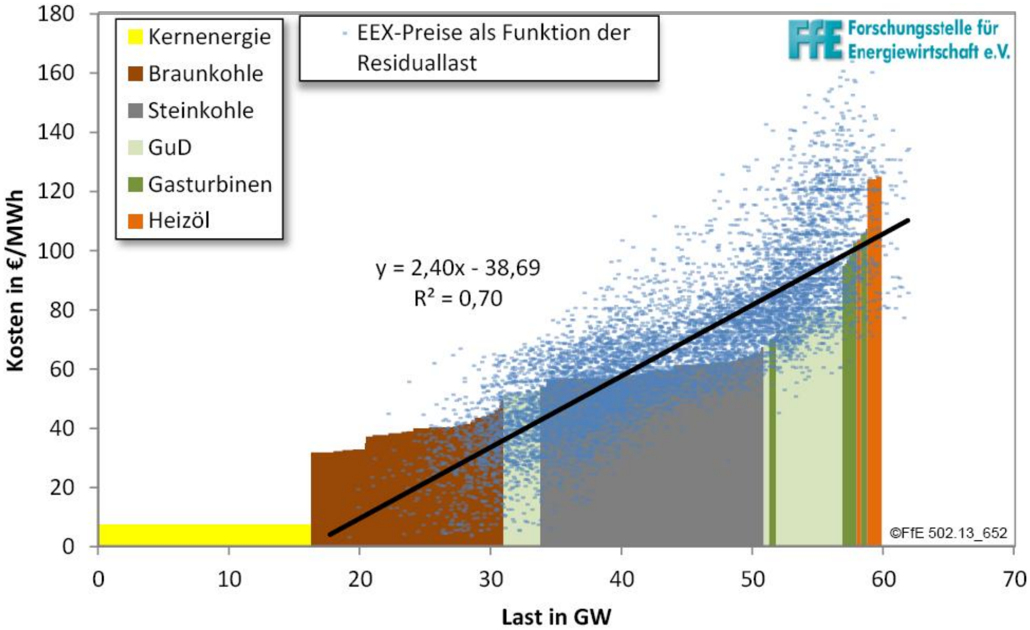


Figure 9: The merit order effect in 2008 and EEX prices [Roon].

In 2011, the amount of power traded on the energy exchange corresponded to around a third of all the power generated in Germany. It is, however, to be assumed that the pricing on the energy exchange also has a similar influence on over-the-counter prices on the futures market [IZES]. Figure 10 shows the merit order effect in 2011.

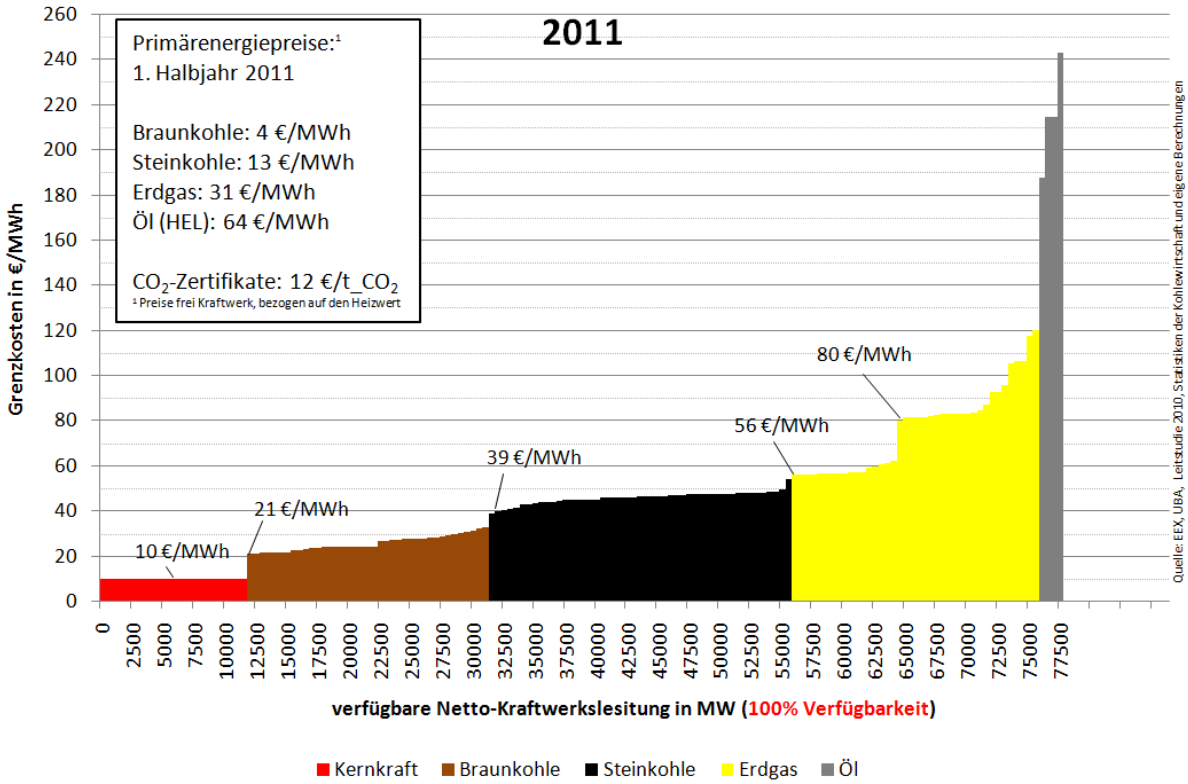


Figure 10: The merit order of conventional power plants in 2011 [IZES]; the data on primary energy prices refers to calorific values, while the marginal costs refer to electrical energy.

3.5 Determining the Differential Costs

The differential costs shall cover the gap between the payments received according to the EEG promotion and the sales revenues from PV electricity.

The sales revenues of PV electricity are estimated based on an average price of electricty on the national market. Following a peak of almost 7 Euro cents/kWh in 2009, the market value of power has since fallen to a differential cost of 5 Euro cents/kWh. This price drop is accounted for, on the one hand, by the growing feed-in of renewable energy electricity, and on the other hand, by the decrease in coal prices and the added capacity of coal power plants which consequently resulted in power surpluses and massive exports.

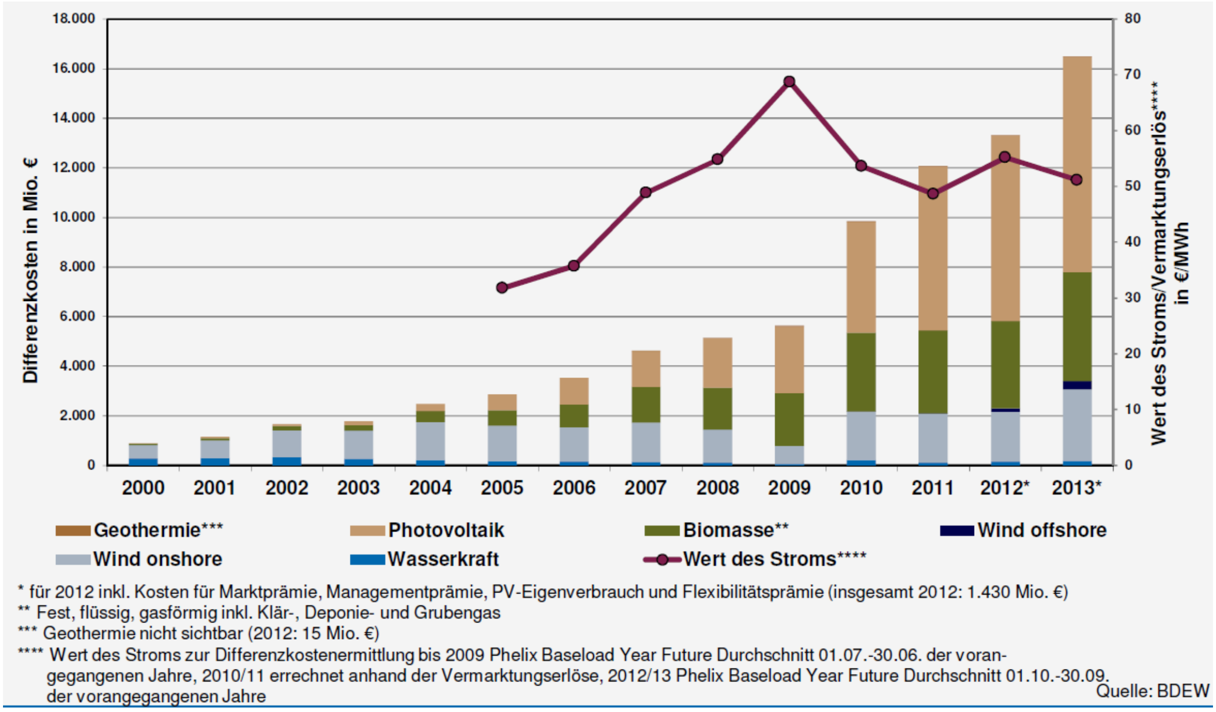


Figure 11: Development of the market value of power and differential costs [BDEW4].

The problematic aspects of the calculation method in brief:

- The feed-in of PV electricity reduces the stock market price through the merit order effect and paradoxically increases the calculated differential costs. According to this method, the more PV that is installed, the more expensive the kWh price of PV appears to be.
- The price drops of coal and of the CO2 certificates reduce the stock market price and thus increase the calculated differential costs.

3.6 EEG levy

The difference between remuneration payments and revenue generated by power produced from renewable sources, supplemented by other items, is compensated for by the EEG levy.
The cost of the levy is borne by those power consumers, who do not apply for an exemption from the levy. The EEG levy has been set at **5.27 Euro cents/kWh** for **2013**, with end customers paying turnover tax on top of this.
Amounting to just 2.29 Euro cents/kWh, the actual incentive for RE is less than half this amount (Figure 13).

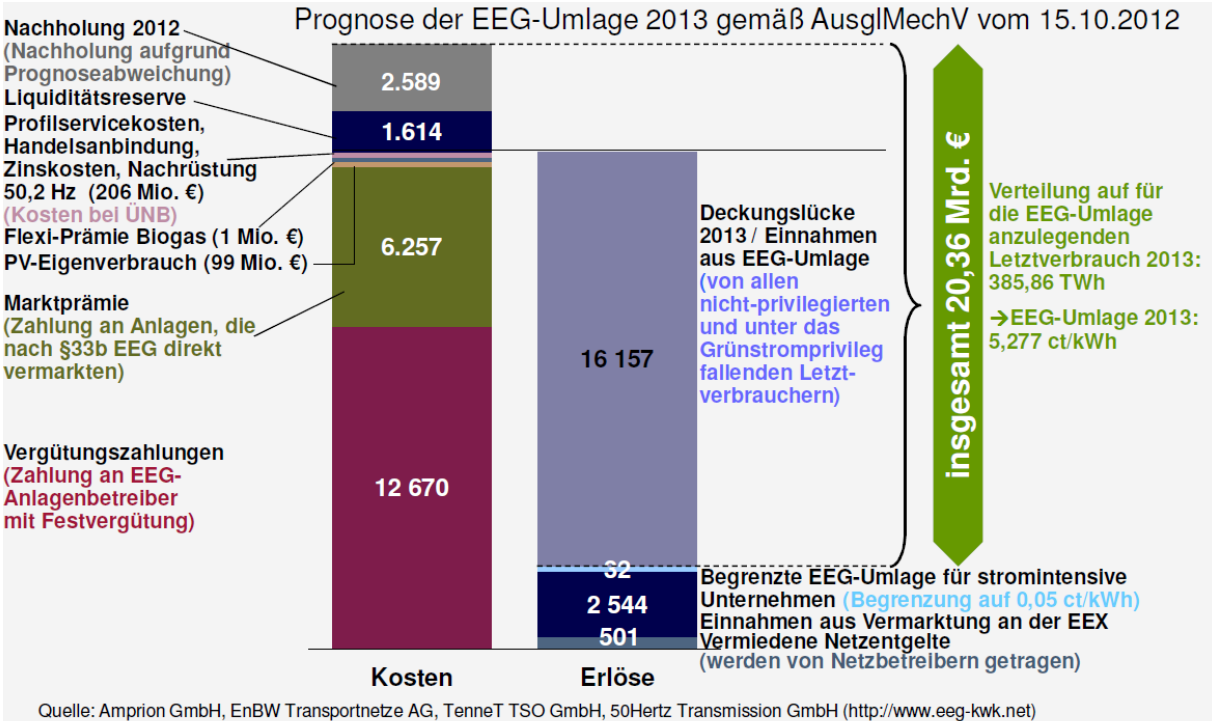


Figure 12: Principles used to calculate the EEG levy in 2013 [BDEW4].

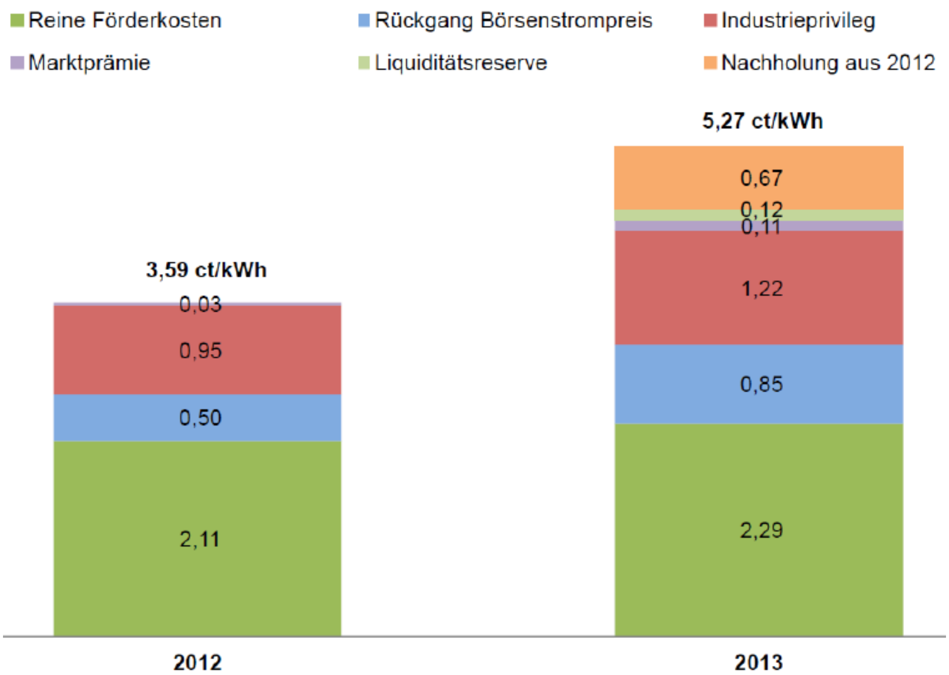


Figure 13: Composition of the EEG levy in 2012 and 2013 [BEE1].

Excluding external costs, the proportion of the EEG levy forecasted to be allocated to PV power generation amounts to around **60 percent** in **2013** (Figure 14), i.e. **1.38 Euro cents/kWh**. As PV is only expected to account for around **26 percent** of the energy covered by the EEG in 2013 [ÜNB], it is receiving preferential support. This is neither surprising nor unintentional. The over-proportional support granted to PV is a direct consequence of the fact that during the initial years of the EEG, the levelized cost of PV electricity and its feed-in tariff were many times greater than those of other RE sources, e.g. approximately seven times greater than those of wind power. The preferential treatment was also intentional due to PV being expected to have the greatest cost reduction potential. In reality, developments greatly exceeded all expectations, with power from newly installed PV plants already receiving significantly less remuneration than wind power from new offshore installations (initial tariff incl. bonuses).

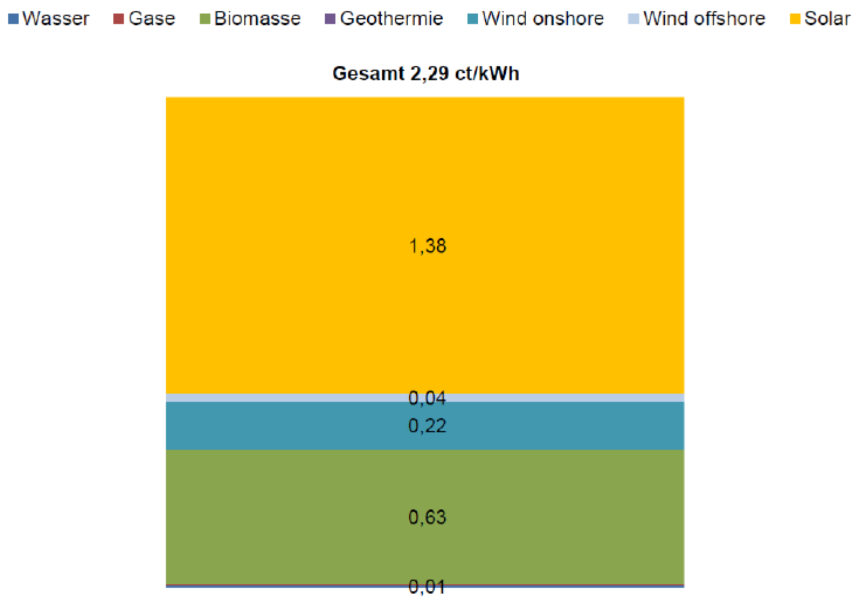


Figure 14: Component parts of the EEG levy in 2013 excluding external costs [BEE1].

According to the calculations of the German Renewable Energy Federation (Bundesverband Erneuerbare Energie BEE), the EEG levy will increase in 2014 from today's level of 5.27 cents / kWh to presumably 6.42 cents / kWh electricity. (…) The actual production costs for the expansion of renewable energies, however, increases only from 2.39 to 2.54 cents / kWh electricity (…). [BEE2]

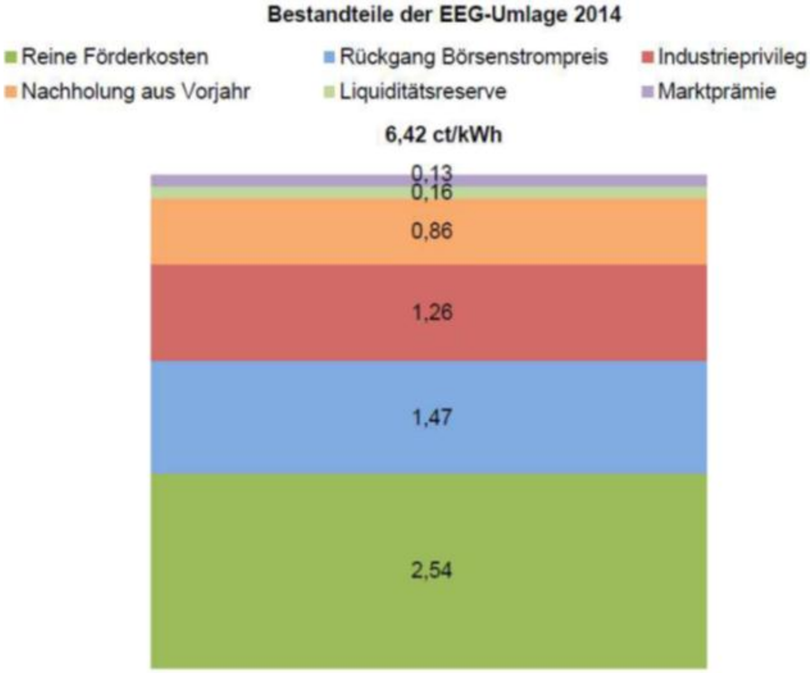


Figure 15 : Projected values for the components of the EEG levy 2014 [BEE2]

According to definition, the EEG levy is increased due to the following factors:

1. Decreasing spot electricity prices
   The cheaper the electricity price becomes on the Leipzig European Energy Exchange (EEX), the more the EEG levy increases and thus the more expensive electricity becomes for private households and small consumers.
2. increasing quantities of power used by privileged consumers
   In 2012, around 18 percent of power generated was consumed by energy-intensive industrial enterprises which are virtually exempt from contributing to the levy. The resulting additional costs of 2.5 billion euros are borne by smaller-sized consumers, such as householders and small industrial and commercial consumers [BNA]
3. increasing production of electricity from RE, without on-site consumption (own consumption)
   While the increase in power generated from renewable sources is desired in itself, it nevertheless increases the levy at least in the short term. This happens both directly due to more remuneration being paid for feed in, and indirectly due to the dramatic drop in prices for emission allowances, which leads to fossil fuel power plant operators being able to offer electricity at lower prices.
4. merit order effect
   The feed-in of PV power during periods of the day when the price of electricity on the energy exchange used to be high effectively lowers electricity prices, but simultaneously increases the difference between the feed-in tariff and the market price, which forms the basis for calculating the EEG-levy.
5. dropping electricity consumption

Initiatives to reduce power consumption lower the amount of power remaining in the grid, thereby increasing the levy per kWh

6. the management premium as an element of the market premium
   The current market premium model adds additional costs amounting to hundreds of millions.

3.7 Is PV power subsidized?

No. The support is provided through a levy.
It is power that is generated from fossil fuel and nuclear sources that is subsidized.
PV power generation is not supported with public funds. Whilst fragmentary reports often quote figures relating to past and future PV power feed-in tariff payments that amount to hundreds of billions and term these "subsidies", a true subsidy is provided by public funds. The EEG, on the other hand, makes provisions for a levy in which energy consumers make a compulsory contribution towards transforming the energy system. This interpretation is also supported by the European Commission. Instead of being equal to the total level of remuneration, the levy corresponds to the differential costs, i.e. the difference between costs (remuneration) and benefits. (see section 3.5)
On the costs side, the cumulative amount paid for PV power fed into the grid up to and including **2012** amounted to **around 32 billion euros**.

To calculate the EEG levy, the financial benefits of PV power are determined according to the energy exchange price. With this method, the benefits of PV power are systematically underestimated. For one, PV power has long been having the desired effect on this market price, namely that of driving it downwards (see section 3.4). Second, the market price leaves out the heavy external costs of fossil fuel and nuclear power production (section 3.8). Considering total costs of fossil fuel and nuclear power production of ca. 10 Euro cents/kWh, the additional costs of the PV feed-in tariff decline so quickly that the first intersection point occurs already in 2013 (Figure 5). Future decisions impact new PV installations. New PV systems installed in open spaces must produce cheaper electricity than the existing fossil and nuclear power plants, when total costs are considered. The marginal costs decrease to zero and thereafter are negative.

As it is expected that the external costs of fossil fuels and nuclear power shall soon become impossible to bear, the increase in RE shall ensure that electricity remains available at sustainable prices in the long term. Our industrial sector needs better future prospects for a secure energy supply, as do householders.

The electricity policy can learn from the bitter lessons experienced in housing construction policy. Because comprehensive measures to renovate the existing building stock have not been undertaken to date, many low-income households must apply for social funds to be able to pay for their heating fuel. These funds flow, in part, then to foreign suppliers of gas and oil. A study commissioned by the BMU analyzes the costs and benefits of the RE electricity production in depth [ISI]. On the cost side, there are the EEG differential costs, that is, the additional acquisition costs rising from the EEG for electricity producers. Also the costs for balancing and controlling the energy from fluctuating renewable sources are incurred.

2011	*Provisional data*			
Impact categories	Area of Analysis	**Power (in bn. €)**	**Heat (in bn. €)**	**Total RE (in bn. €)**
System-analytical impacts	Direct differential costs	9.3	1.4	10.6
	Costs for balancing energy	0.16		0.2
	Costs for grid expansion	0.13		0.1
	Transaction costs*	0.03		0.03
	Total differential costs	**9.6**	**1.4**	**10.9**
	Avoided environmental damage	8.0	2.1	10.1
Distribution impacts	EEG differential costs, single additional costs	13.5	1.2	14.7
	cumulated support - MAP systems	-	0.2	
	Special compensation regulations	2.2		2.2
	Merit Order Effect	2.8		2.8
	Government subsidies			0.6
	Market subsidies			0.3
	R&D subsidies			0.3
	Taxation of RE Electricity**	1.6		1.6
Macroeconomic impacts	Reduced imports***	2.9	3.4	6.02
	Investments (in power and heat plants)	20.0	2.9	22.9
	Revenue (manufacturers of systems and components)			24.9
	Total Employment (in persons)			381,600
Other, not quantified impacts	Security of supply, technological development, risk of a nuclear accident, spill-over of R&D, trend of policy and public opinion			n.a.
*Estimates from 2010, **Average value, ***Sum of heat and power with consideration to increased biogenic fuel import				
All prices are current values (2011), except for environmental damage (price basis: 2010)				

Figure 16: Comprehensive cost-benefit analysis of power generated from RE [ISI].

What would be the price to pay if the energy transition fails? Without knowing this figure, it is difficult to make a statement as to the costs of the transition.

3.8 Are the fossil fuel and nuclear energy production subsidized?

Yes.

A study from the Forum Green Budget Germany [FÖS2] states: "For decades, the conventional energy sources of nuclear, hard coal and brown coal have profited on a large scale from government subsidies in the form of financial assistance, tax concessions and other beneficial boundary conditions. In contrast to the renewable energies, a large portion of these costs is not accounted and paid for in a transparent manner. Rather, funds are appropriated from the national budget. If these costs were also to be added to the electricity price as a "conventional energy tariff," they would amount to 10.2 ct/kWh, which is almost three times the value of the Renewable Energy Tariff in 2012. Up to now subsidies for the renewable energies have amounted to 54 billion euro. To compare, from 1970 to 2012 subsidies for hard coal amounted to 177 billion euro, for brown coal at 65 billion euro and for nuclear energy at 187 billion euro respectively."

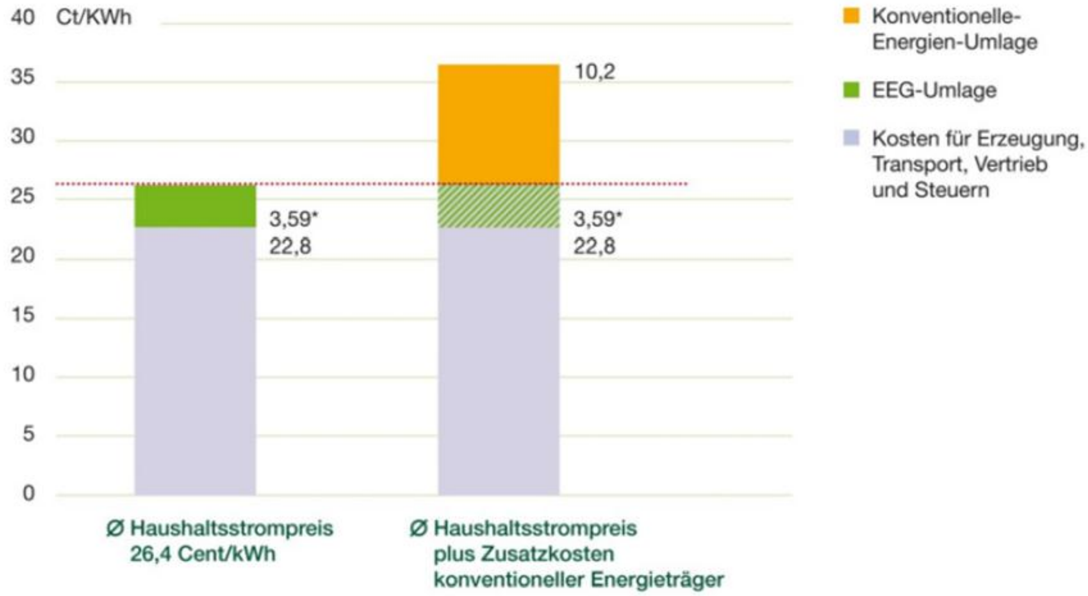


Figure 17: Estimate of a "conventional energy tariff" using the additional costs of conventional energy sources 2012 as a basis [FÖS2]

Contrary to initial plans, and with costs of less than 5 euros per metric ton of CO_2, CO_2 emission allowances only have a minor effect on the costs of generating power from fossil fuels. In terms of figures, this equates to a subsidy of more than 20 billion euros per year for fossil fuel power plants if compared to the estimated, realistic price of 70 euros per metric ton [DLR].
It is currently impossible to pinpoint the actual costs and risks of generating power from fossil fuel and nuclear sources, as the majority of these shall only emerge in the future (CO_2-induced climate-related catastrophes, nuclear disasters, the permanent storage of nuclear waste, nuclear terrorism, permanently contaminated sites), making a comparison difficult. The risks of nuclear power predicted by experts are so severe, however, that insurance and reinsurance companies the world over are not willing to offer policies for plants generating energy of this kind. A study conducted by the Versicherungsforen Leipzig sets the limit of liability for the risk of the most serious type of nuclear meltdown at 6 trillion euros, which, depending on the time period over which this sum is built up, would increase the electricity price per kilowatt hour to between 0.14 and 67.30 euros [VFL]. As a result, it is essentially the tax payers who act as the nuclear industry's insur-

ers. This is essentially forced upon them both against their wishes, since the majority of Germans have been opposed to nuclear energy for many years, and in an unspecified amount, because no fixed price has been established to date for damage settlements. This is a subsidy whose burden on the future cannot be predicted.

According to estimates by the IEA, power generated by fossil fuels received more than 400 billion dollars of subsidies worldwide in 2010.

4. Does PV power generation make electricity more expensive for householders?

Yes.
However, pricing is in the hands of the major electricity generators, energy supply companies (ESC) and policy makers. Policy makers set the principles for calculating and distributing the EEG levy, taxes and fees, the effects of which are currently detrimental to householders, while ESCs ultimately determine domestic electricity prices.

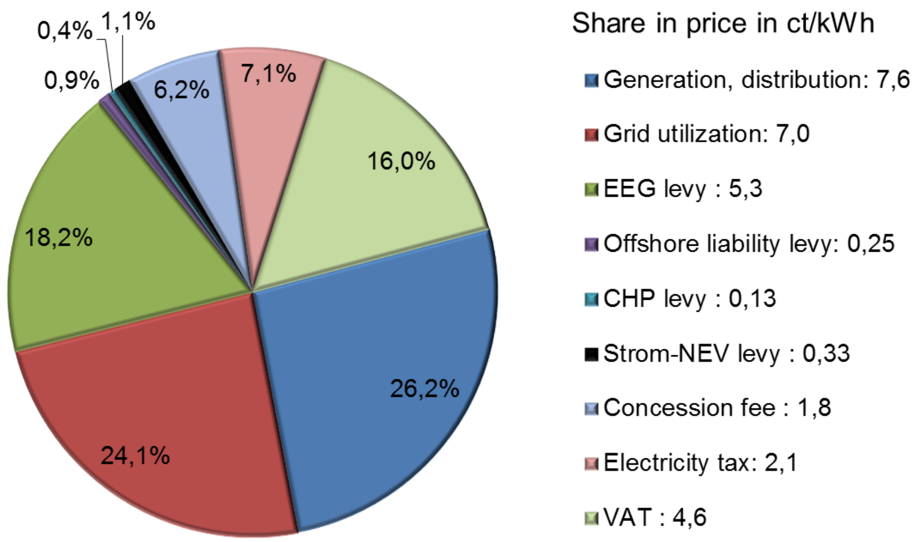


Figure 18: An example of the elements making up the domestic electricity price of 29 Euro cents / kWh in 2013 (CHP: German Combined Heat and Power Act; German Electricity Grid Access Ordinance (Strom-NEV): easing the burden on energy-intensive industrial enterprises; concession fee: fee for using public transmission lines).

A standard household with three people and an annual power consumption of 3,500 kWh paid roughly **25.7 Euro cents / kWh** in 2012 [BDEW2]. According to current forecasts, this amount is set to rise to around **28 - 29 Euro cents / kWh** in 2013. Figure 18 shows an example of the elements making up this total price.

4.1 Influence of large-scale power generators on electricity prices

Despite the forced closure of nuclear power plants and falling prices on the energy exchange, large-scale power plant operators recorded handsome profits in 2012. The earning achieved by major utility RWE alone, which amounted to 6.4 billion euros, covers around half of the entire remuneration expected to be paid to plant operators for power generated from RE in 2013 (12.6 billion euros). Despite this, RWE have announced plans to lower the annual amount they invest in RE from 1 billion to 0.5 billion euros. Such profits are thus driving up electricity prices without making a significant contribution towards transforming our energy system.

4.2 Influence of ESCs on electricity prices

Some ESCs have used the increase in the EEG levy to justify raising domestic electricity prices (Renewable Energy Sources Act, provisionally planned advance payment, see section 20.1). While the gross domestic electricity price rose by around **14 Euro cents / kWh** between **2000 and 2013**, the EEG levy increased to a mere **5.3 Euro cents / kWh** net (Figure 20), corresponding to a gross amount of **6.3 Euro cents / kWh**. The EEG levy can therefore simply not be used to justify the majority of price increases.
The costs ESCs incur for purchasing power are mainly determined by long-term supply agreements, with the spot market prices on the European Energy Exchange in Leipzig having a minor effect. On the energy exchange, ESCs benefit from the fact that feeding in PV power lowers prices as a result of the merit order effect (see section 3.4).
When the weather is sunny in spring and summer, the current amount of PV capacity installed in Germany (more than **30 GW**) means that solar power already covers a majority of the peak load during the day (see Figure 48). In 2011, the price of electricity during the day on the EEX spot market fell below that of electricity consumed at night for the first time (2.5 Euro cents / kWh). PV power displaces expensive electricity from power plants in the merit order (see section 3.4). If the use of PV is increased further, experts predict the market prices during the day to fall below those of power consumed at night more and more frequently and for increasingly longer periods during the summer months. This effect of PV is currently not being adequately taken into consideration when calculating costs and the EEG levy, and to date, many ESCs have not allowed their end customers to benefit from the price reductions brought about by feeding in PV.

4.3 Influence of government policies on electricity prices

Policy makers determine who finances the transition to renewable energy. They have decided to release the majority of energy-intensive industrial enterprises which spend a high proportion of their costs on electricity from the EEG levy, and are planning to extend this level of exemption in the future. It has been estimated that more than half of the power consumed by industry shall be largely freed from the levy in 2013 (Figure 19) with the level of exemption totaling 6.7 billion euros. This increases the burden on other electricity customers and in particular householders who account for almost 30 percent of the overall amount of power consumed.

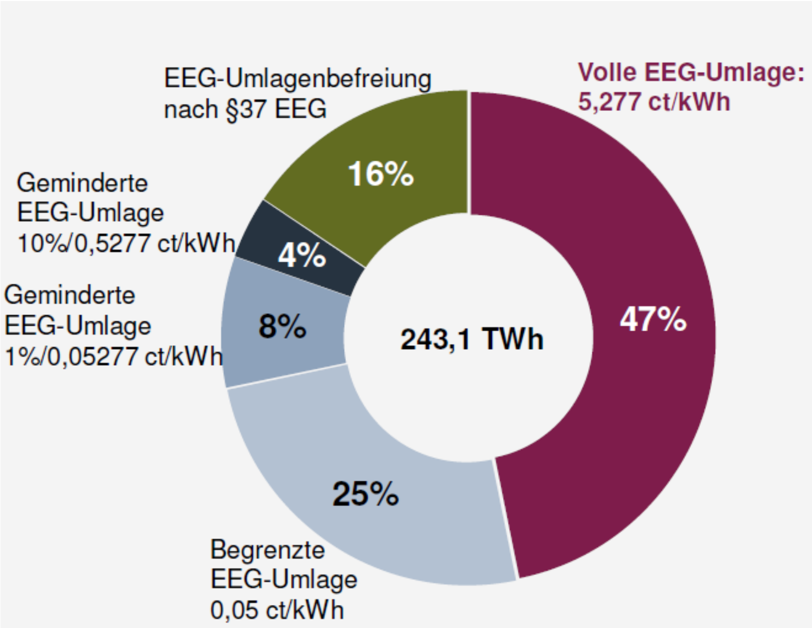


Figure 19: EEG levy payments according to quantities of power consumed (industry only, [BDEW4])

This political decision has resulted in electricity prices falling for energy-intensive industrial enterprises in recent years. On the other hand, the EEG levy per kilowatt hour has risen (Figure 20), while energy-intensive industrial enterprises clearly benefit from the fact that PV power lowers prices on the energy exchange during peak times, with a part of the PV levy indirectly ending up in the pockets of these energy-intensive industrial enterprises: "Energy-intensive companies, which are largely either exempt from the EEG levy or only pay a reduced rate of 0.05 Euro cents / kWh, benefit the most from the merit order effect. For these companies, the lower prices brought about by the merit order effect overcompensate by far for the costs incurred as a result of the EEG levy." [IZES] Energy-intensive industrial enterprises therefore benefit from the energy transition without making a noteworthy contribution.

Policy makers use the difference between the price of electricity on the energy exchange and EEG remuneration as a basis for calculating the EEG levy. By delivering valuable power during periods of peak load around midday, PV lowers the market price for the benefit of large-scale consumers but paradoxically increases the EEG levy to the detriment of householders.

Policy makers also influence the price of electricity generated by fossil fuel and nuclear power plants. Political decisions determine the price of CO_2 emission allowances, conditions for filtering smoke and, where necessary, for the permanent storage of CO_2 (carbon capture and storage, CCS), the taxation of nuclear power as well as insurance and safety requirements for nuclear power plants. For example, the current price of CO_2

emission allowances of less than 10 euros per metric ton has been kept so low by policy makers that it virtually has no influence on the levelized cost of electricity of fossil fuel power plants. A study conducted in 2006 recommends that emission allowances cost 70 euros per metric ton, corresponding to the "best possible estimated value" of the damage caused by CO_2 emissions [DLR].
This means that policy makers decide to what extent today's power consumers must bear responsibility for the elusive risks and burden of producing energy from fossil fuel and nuclear sources. By increasingly considering these costs more rigorously, it is likely that PV power will make the power mix less expensive, while the overall electricity generation price will be noticeably higher. Until this happens, fossil fuel and nuclear power will be sold at prices that conceal their external costs (see section 20.9, [DLR], [FÖS1]) and pass the burden on to future generations.

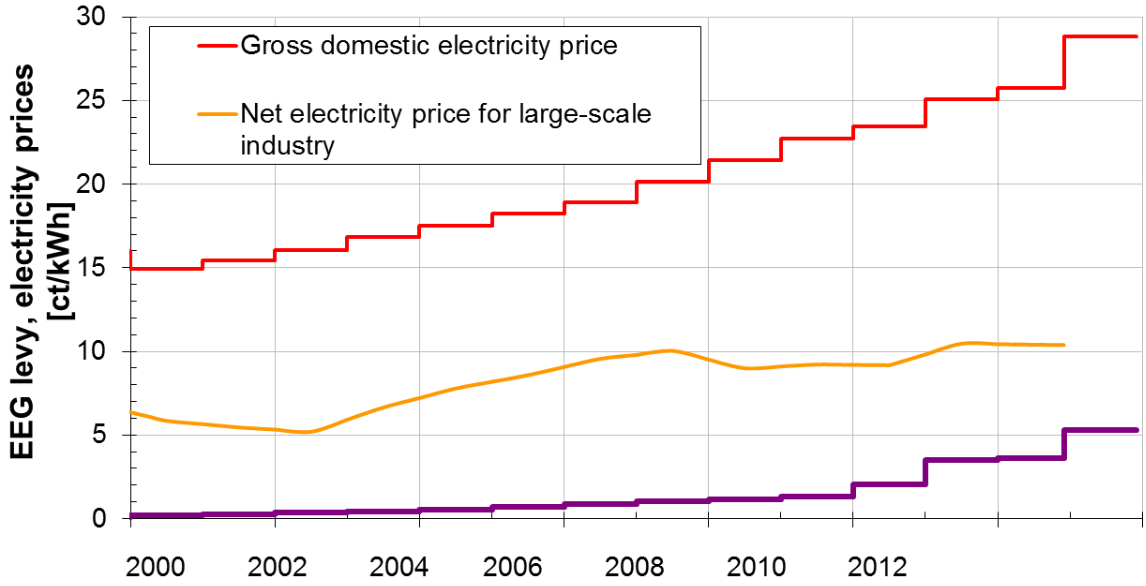


Figure 20: Development of gross domestic electricity prices, net electricity prices for large-scale industrial consumers [BMWi1] and the EEG levy; half of the gross domestic electricity prices are made up of taxes and fees.

Electricity tax (Figure 18) was finally introduced in 1999 on the grounds that the higher rate of taxation would make energy more expensive. The majority of revenue generated enters the pension fund. Many politicians are now calling for the expansion of renewable energy to slow down in order to stop domestic electricity prices rising further.

4.4 Are tenants subsidizing wealthy home owners?

No.
This notion, which makes a popular headline and in this instance is taken from the "Die Zeit" newspaper published on December 8, 2011, is a distorted image of reality. Except

for the politically willed exception granted to energy-intensive industrial enterprises, the costs of switching our energy system to RE are being borne by all power consumers according to the cost-by-cause principle. Consumers include all households and thereby home owners and tenants. In addition to funding PV, these costs contribute to wind energy and other RE sources. The power consumption of all electricity customers can be influenced by their selection and use of devices, with many municipalities offering free energy saving advice and grants to help pay for new, more efficient devices. Electricity tariffs that increase with consumption would be a suitable means to reduce the burden on low-income households and simultaneously to reward energy efficiency.
PV systems installed by home owners are usually in the power range under 10 kWp. The sum of all systems in this power range makes up less than 15% of the total installed PV power in Germany, while large systems in the power range above 500 kWp contribute about 30 %. The larger systems are often financed with citizen participation or funds, in which tenants can also participate.

5. Are we exporting large amounts of PV power to other European nations?

No, the increased export surplus comes primarily from new coal power plants. After a casual glance, the expansion of RE is often cited as the cause for the increased electricity export, which amounted to 16 billion kWh alone in the first quarter of 2013. Is PV electricity remunerated at an average of ca. 29 Euro cents / kWh and then sold for 5-8 Euro cents / kWh? That is not the case. The PV power production still lies clearly below the residual load, Electricity is exported during the day, because it is hard to throttle back coal-fired plants (lignite) due to their inertia or because it is simply lucrative to produce power in Germany and to sell it in other countries (bituminous coal). In countries other than Germany, gas-fired plants also became unprofitable. The statistics convey a clear message: Compared to the first quarter 2012, electricity exports in the first quarter 2013 increased by ca. 7 billion kWh. During the same period, the electricity production from RE (Figure 21:) decreased by 2 billion because of weather conditions [ISE4].

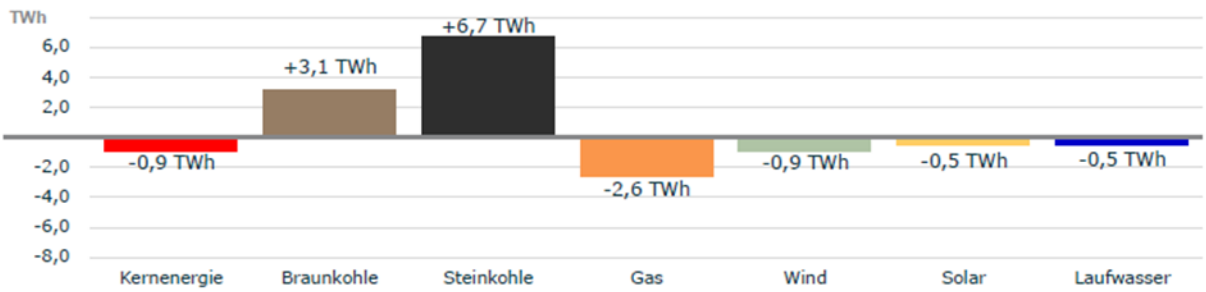


Figure 21: Difference in electricity production in the first quarter 2013 as compared to 2012. Nearly all of the surplus electricity production from lignite and bituminous coal was exported [ISE4]

6. Do PV plants create reasonable rates of return?

Yes.
Given current plant prices and the feed-in tariff, it is possible to make good rates of return when generating solar power across Germany. The rate of return in sunny regions is somewhat higher than that in areas with a lower level of irradiance. However, regional differences in irradiance do not have a 1:1 effect on the specific yield (section 20.4). This is due, for example, to differences in snow cover or the fact that increased wind results in lower module operating temperatures which in turn improves yield.

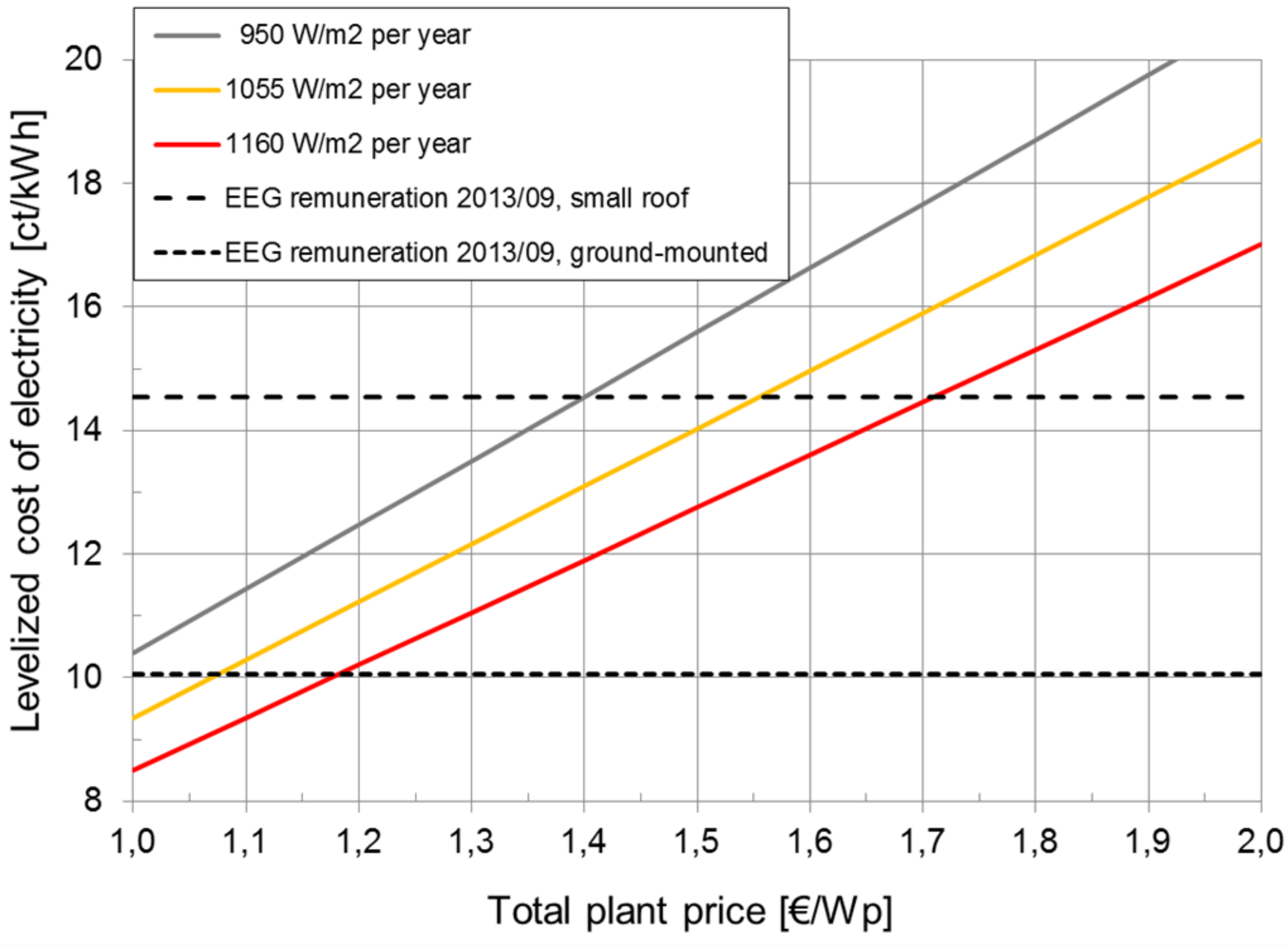


Figure 22: Rough estimate of levelized cost of electricity generated by PV power plants with varying irradiance conditions.

To gain a rough estimate of the discounted levelized cost of electricity (not adjusted for inflation) (See Figure 22), the following assumptions were used:

- optimal orientation of module (approximately 30° south)

- performance ratio (section 20.6) of 85 percent
- annual yield degradation of 0.5 percent
- lifetime of 20 years
- annual operating costs of 1 percent (of plant price)
- inflation rate of 2 percent
- nominal imputed interest rate of 5 percent

In Germany, the annual sum of average global irradiance on a horizontal surface is 1055 kWh / m² per year [DWD].

The levelized cost of electricity (LCOE) is estimated using the net present value method, according to which the running costs and LCOE are discounted by the interest rate given to the time at which the plant was commissioned. The running costs for insurance and maintenance, for example, are adjusted for inflation. The figures concerning the LCOE are not adjusted for inflation to make it easier to compare them with the feed-in tariff which is constant in nominal terms but declines in real terms.
In the event of a 100 percent equity investment, for example, an average rate of return which corresponds to at least the imputed interest rate may be obtained, provided the feed in or on-site consumption of power is worth more than the levelized cost of electricity. In this case, the imputed interest is equivalent to the rate of return. To compare, the Federal Network Agency (Bundesnetzagentur) set the return on equity at 9.05 percent (before corporate tax) for both new and further investments in the electricity and gas networks [BNA2].

It is currently not possible to calculate the exploitation of power beyond the 21st year of operation. It is, however, likely that many plants will continue to generate significant quantities of power at low running costs but the future ability to consume power on site and the future pricing and remuneration structure of ESCs are needed to calculate this specifically. The rate of return of a PV plant is also not guaranteed during the period of remuneration set by the EEG. Neither manufacturer guarantees nor plant insurance policies are able to remove the risk to the investor entirely.

7. Does installing PV only create jobs in Asia?

No, however over the last few years Germany lost many jobs in the PV industry.
In 2012, the PV industry employed approximately **88,000** people in Germany [BMU2] and achieved an export quota of around **60 percent** [BSW].
Businesses from the following sectors contribute to the German PV industry:

1. manufacture of materials (silicon, wafers, metal pastes, plastic films, solar glass)
2. manufacture of intermediate and final products, including cells, modules, inverters, supporting structures, cables and coated glass
3. construction of manufacturing plants

4. installation (especially trade)

The global market share of all German PV suppliers (component, machinery and plant manufacturers) stood at **46 percent** in 2011 and boasted an export quota of **87 percent** [VDMA].
With a production volume of 2 GW, Germany was a net importer of solar cells and modules in 2012 (Photon 2013-01). However, in other sectors of the PV industry, the country is a clear net exporter and is even regarded as an international market leader in certain areas (e.g. inverters with a total production volume of around 12 GW and manufacturing plants). Many jobs were lost in Germany in the last two years as a result of company closures and insolvencies, which also affected cell and module manufacturers as well as the mechanical engineering industry. In 2007, the plan that the combination of EEG, investment grants in the (new) eastern states of Germany and research support would be sufficient to establish Germany as a worldwide leading production site for PV cells and modules appeared to work, as a German company led in the international rankings in production volume. Since then, the market share of German manufactures has dramatically decreased due to the industrial policy in the Asian region and the huge investments in production capacity generated there. The labor costs play a subordinate role in this development because PV production today is highly automated. An important aspect, however, is the low complexity associated with PV production as compared, for example, to the automobile or microelectronic industry. Since several years, turn-key production lines that produce very good quality PV modules can be bought off-the-shelf, which enables fast technology transfer.

Effective laws for feed-in tariffs in Germany and Europe have spurned on massive investments in PV power plants. Alone in Germany, these amounted to estimated investments of 70 billion euros through to 2012. In these countries, however, the economic-political framework is missing for generating investments in production capacity within a competitive format (today in GW). Rather China and other Asian countries have succeeded through the creation of attractive conditions for investments and credit to mobilize four billion euro investment capital from national and international sources for the construction of large-scale production lines. According to press releases appearing over the past months, even large, highly-indebted PV manufacturers received new credits during the present crisis. The EU commission imposed a provisional punitive duties on PV modules imported from China.

In spite of the high import quota of PV modules, a large part of the value chain for PV power plants remains within Germany. If it is assumed that around 80 percent of PV modules installed in Germany come from Asia, that these modules comprise roughly 60 percent of the total cost of a PV power plant (remainder predominantly made up of inverter and installation costs) and that power plant costs make up around 60 percent of the levelized cost of electricity (remainder: cost of capital), only just under 30 percent of the feed-in tariff is used to import modules from Asia. Furthermore, the fact that around

half of Asian PV products are used in plants originating from Germany must also be taken into account.
In the long term, the falling cost of manufacturing PV modules coupled with increasing freight costs and long delivery times shall increasingly improve the competitive position of companies manufacturing modules in Germany.

8. Are the operators of large-scale power plants refusing to install PV systems?

To date, they have shown little interest in PV power production in Germany.
In 2010, the majority of Germany's installed PV capacity belonged to private individuals and farmers, while the remainder was divided between commercial enterprises, project planners and investment funds. The power plant operators EnBW, Eon, RWE and Vattenfall (the "big four" in Figure 23) owned a mere 0.2 percent. From where does their aversion to PV power stem?
PV power plants deliver power during the day at times when demand is at a peak (Figure 48). This means that expensive peak load power plants are required less often and to a smaller extent, lowering the electricity price on the energy exchange which, in accordance with energy exchange rules, affects all power plants generating energy at that time (section 3.4). Previously, the big four power plant operators were able to sell inexpensive base load power very lucratively during the middle part of the day. By 2011, however, PV had led to a drop in energy exchange prices and dramatic slumps in profit. In addition to affecting the energy exchange price, this drop in prices shall also influence long-term supply agreements in the future. Added to this, PV's increasing ability to cover peak loads during the day in spring and summer decreases the utilization of fossil fuel power plants, thereby increasing their costs. With the expansion of PV and increase in load management, inexpensive power from coal-fired power plants whose costs have been amortized shall be used less and less in spring and summer. While large-scale power plant operators have to date shown little interest in PV installations, large wind projects and in particular offshore systems are much better suited to their business models.
In a F.A.Z. interview appearing on April 2, 2013, the EU commissioner Günther Oettinger gives his opinion on this issue: "The expansion of photovoltaic systems in Germany is getting out hand and we must put a limit on it. In general, we need to impose a speed limit for the expansion of renewable energies, until we have developed sufficient storage capacities and energy grids to intelligently distribute the electricity. (…) Actually, for the long term it is much more meaningful to construct wind farms on the open sea because there more many more wind-hours per year there. They need a start-up financing which the EEG can guarantee because the feed-in remuneration for each energy source is fixed – not, however, the quote model."

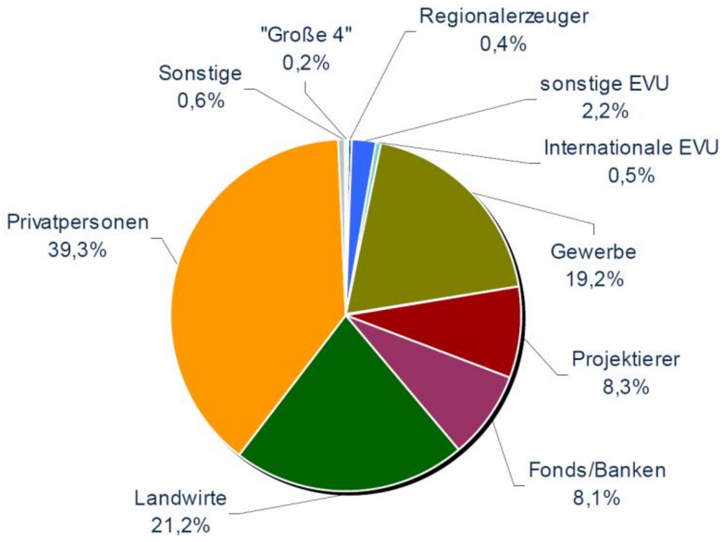


Figure 23: Division of ownership of the total installed capacity of PV plants at the end of 2010 [trend:research].

Many of the approximately 1000 municipal power suppliers in Germany have understood the demands of the energy transformation and react with new products and integral concepts, e.g. "virtual power plants" (Figure 24).

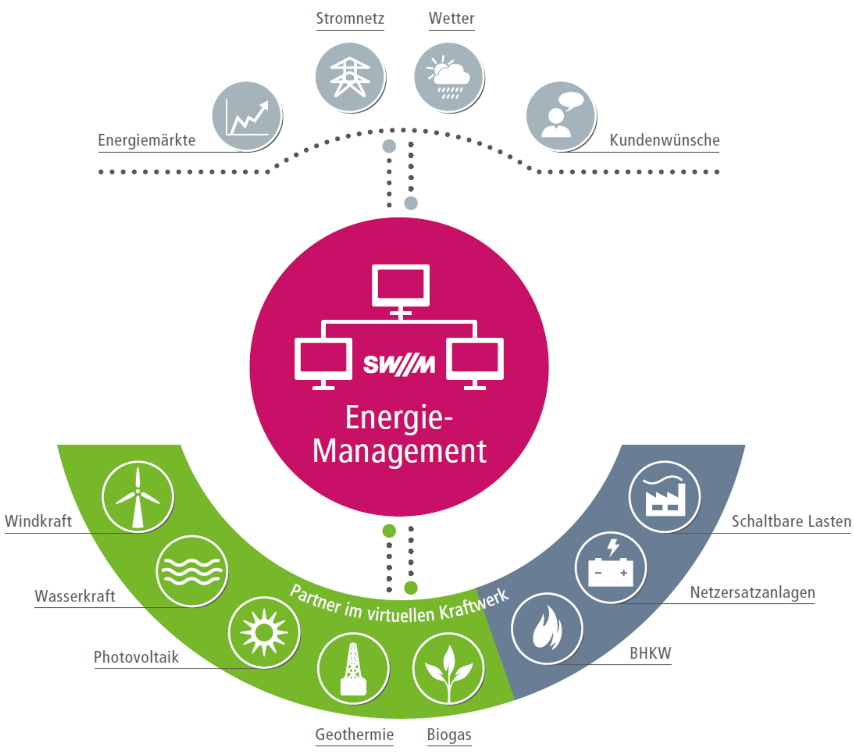


Figure 24: Concept for a virtual power plant of the Stadtwerke München (Munich municipal works) [SWM]

9. Are PV research costs taking up high levels of funding?

Looking back at previous numbers, Figure 25 shows that it took time for renewable energy and energy efficiency to become a focal point of energy research. Figure 26 illustrates the funding granted by the BMU for PV research.

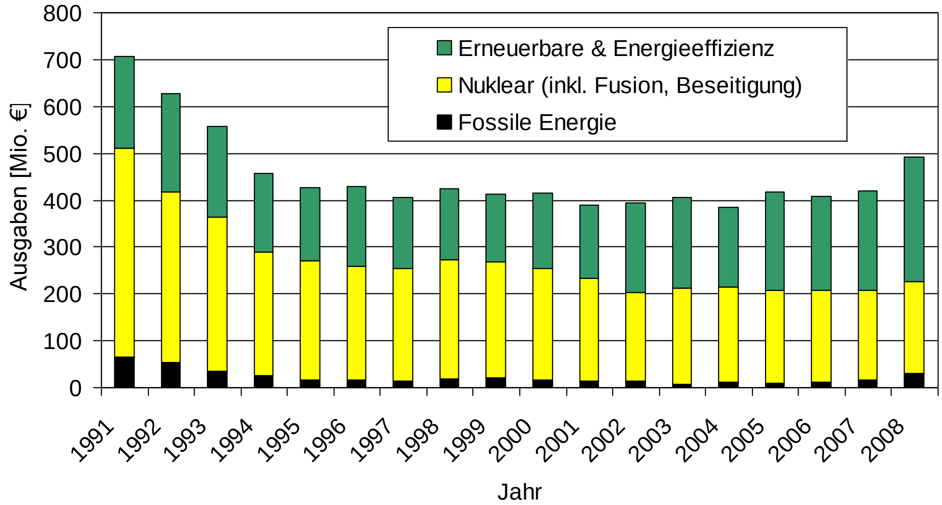


Figure 25: Germany's expenditure on energy research [BMWi1]

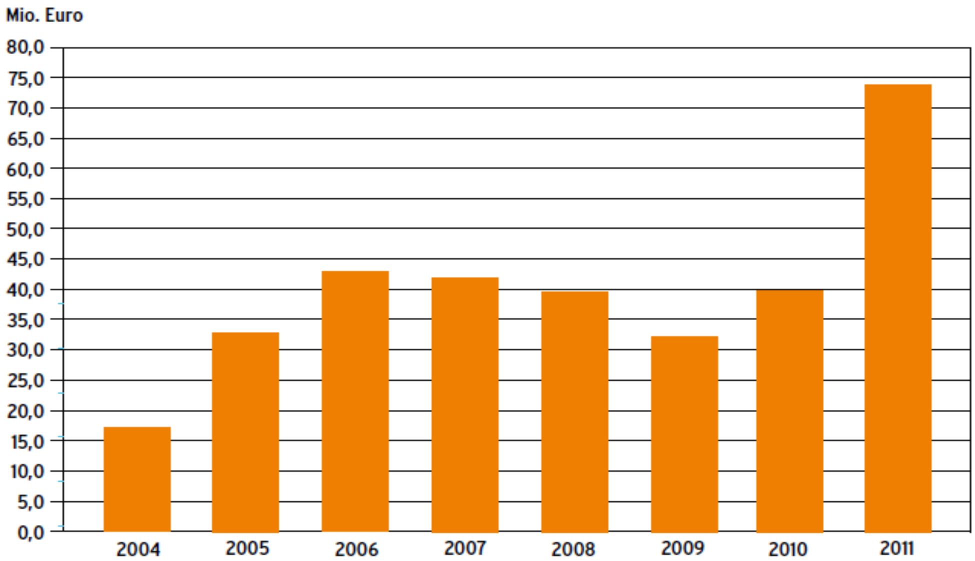


Figure 26: New funding volumes approved for PV research, in 2011 including funding for the "Innovation Alliance" ("Innovationsallianz") program [BMU3].

10. Does PV power overload the grid?

Generally speaking, no. Problems that do arise are of local nature.

10.1 Solar power is fed in decentrally

Over 98 percent of Germany's more than one million solar power plants are connected to the decentralized low-voltage grid and generate solar power in close proximity to consumers [BSW]. PV power plants with an output of over 1 MW only account for 15 percent of the PV capacity installed in Germany.
A high density of power plants in a low-voltage section of the power grid may result in power generation exceeding consumption in this section of the grid on sunny days. In this event, transformers feed power back into the medium-voltage grid and in sections with high plant densities, this may push transformer stations to their limits. An equal distribution of PV installations across all of the grid sections reduces the need to expand the grid.

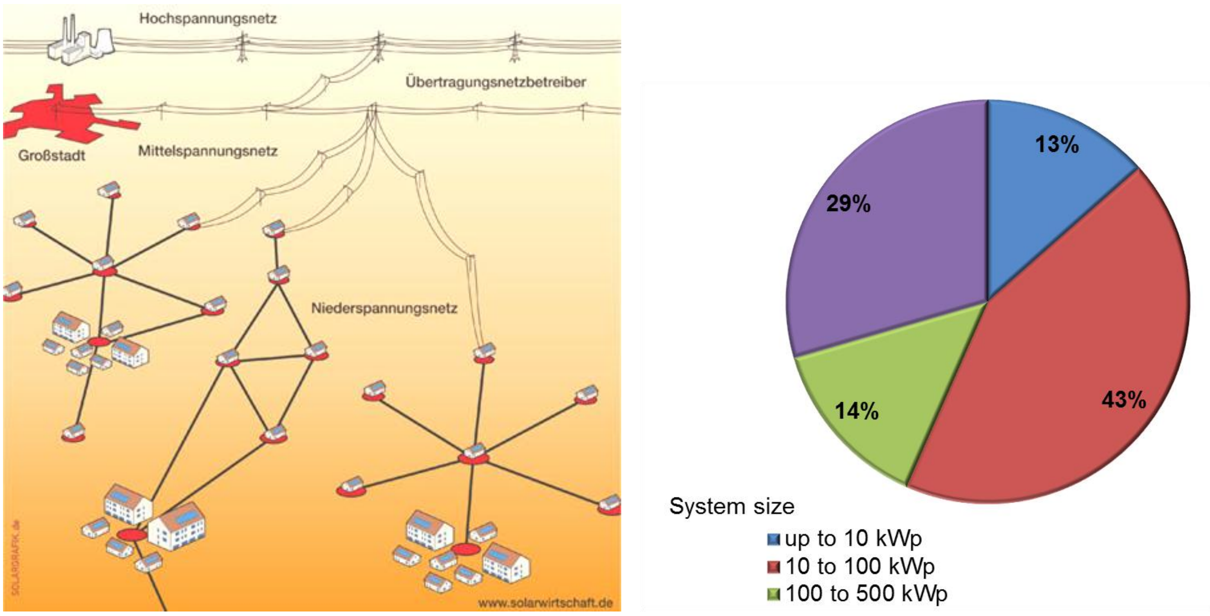


Figure 27: Left: Feed-in of PV power [BSW], Right: Installed PV power categorized by system size; status as of Dec. 2012 (Data source: up to 2008 transmission system operators (TSO), from 2009 Bundesnetzagentur (German Federal Network Agency); Data compiled by PSE/Fraunhofer ISE 2013.

10.2 Solar power production is predictable

Reliable national weather forecasts mean that the generation of solar power can now accurately be predicted (Figure 28). As a result of the decentralized generation of PV power, it is usually not possible for changes in cloud cover to cause serious fluctuations in the PV power production throughout Germany.

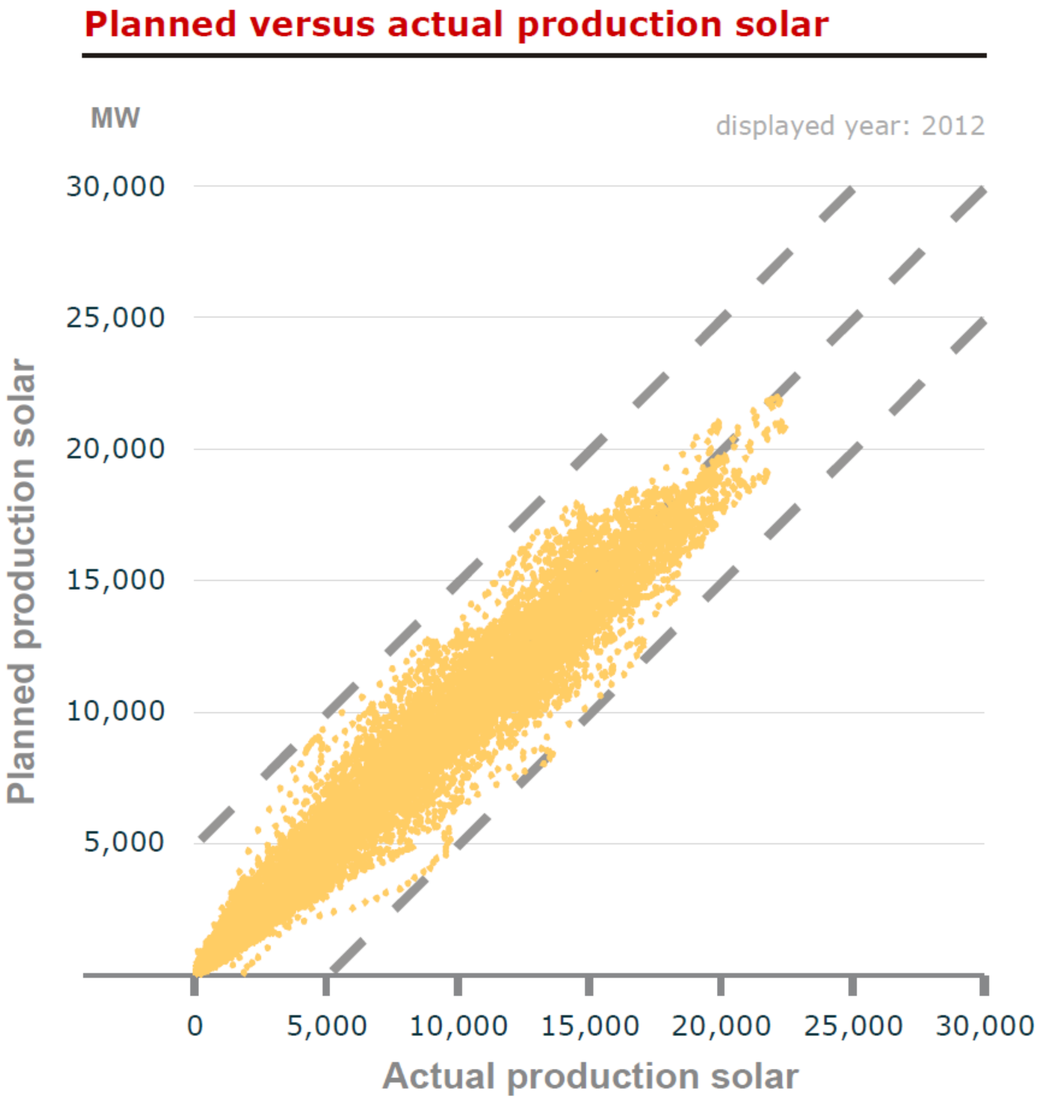


Figure 28: Actual and predicted hourly generation of power in 2012 [ISE4].

10.3 Peak production is significantly lower than installed capacity

Losses caused by technical reasons (performance ratio, PR <= 90 percent, see section 20.6) and changeable weather conditions mean that actual power generation greater than 70 percent of the installed rated power (see section 2) can only be expected across the whole of Germany on a few days of the year.
Restricting or limiting ("feed-in management") individual plants to 70 percent of their rated power leads to an estimated loss of revenue of between 2 and 5 percent [Photon International 2011-07, p. 58]. A statutory regulation that actually enforces this limit for small plants came into force in 2012 (see section 10.5).

10.4 Solar and wind energy complement each other

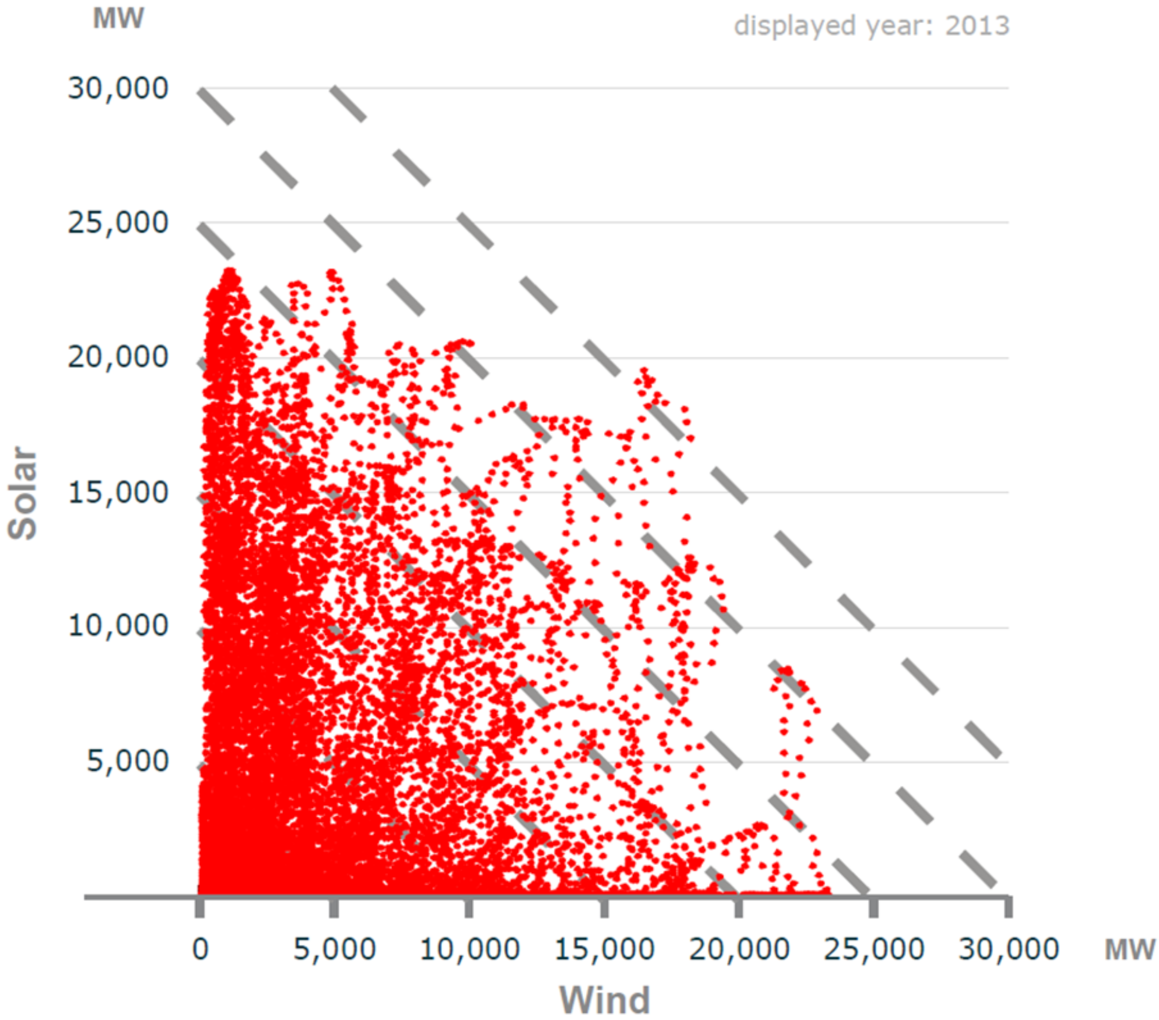


Figure 29: Average hourly amount of solar and wind energy fed into the grid in 2012 [ISE4].

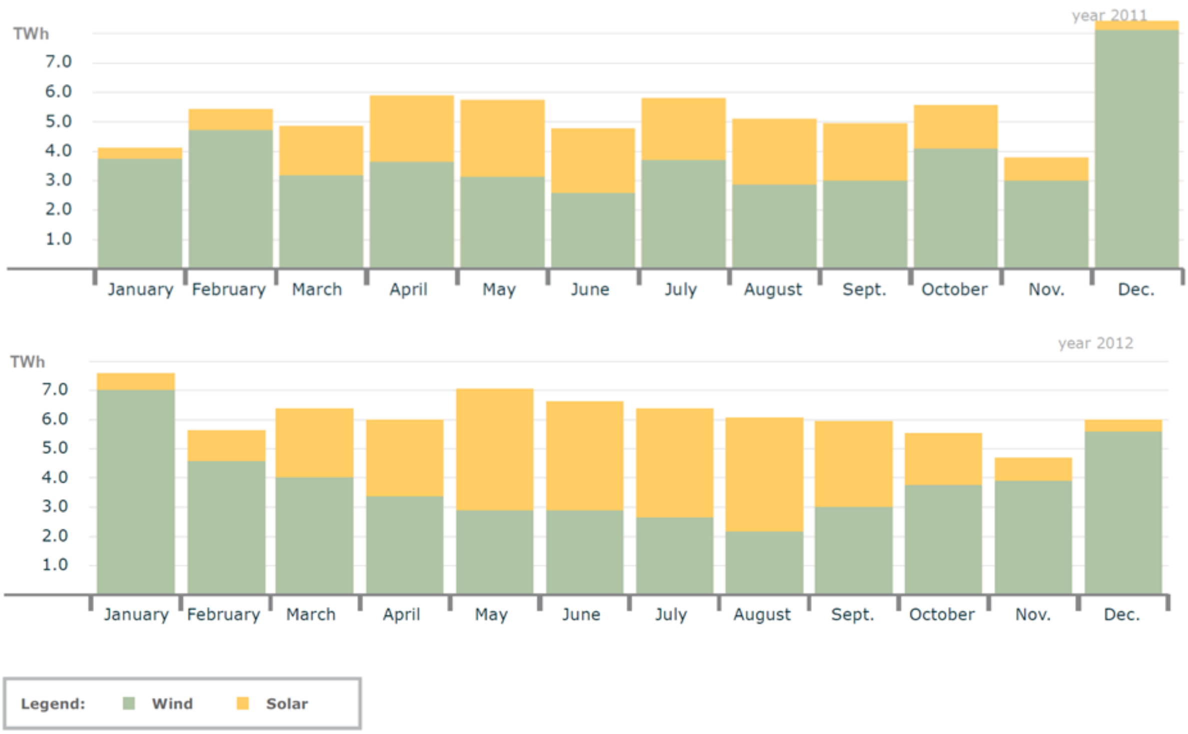


Figure 30: Monthly production of PV and wind power in 2011 and 2012 [ISE4].

Due to the country's climate, high solar irradiance and high wind strength have a negative correlation in Germany. With an installed capacity of 30 GW of PV and around 30 GW of wind power in 2012, the amount of solar and wind power fed into the grid by September 30 of that year rarely exceeded the 30 GW mark (Figure 29:). Therefore, limiting feed-in from solar and wind at a threshold value of nearly half the sum of their nominal powers does not lead to substantial losses. A balanced mix of solar and wind power generation capacities is markedly superior to the one-sided expansion that would be brought about through the introduction of a competitive incentive model (e.g. the quota model).

10.5 How much PV power is our grid currently able to take?

The decentralized way in which PV generates power over an extensive area fits in well with the fact that it is absorbed and distributed by the existing power grid. Large-scale PV power plants or local accumulations of smaller plants in thinly populated areas require the distribution grid and transformer stations to be strengthened in some places. In order to make distributing solar power easier, future PV expansion should be based more on consumption. Bavaria and Brandenburg have installed three to four times more PV capacity per inhabitant than the Saarland, North Rhine-Westphalia, Saxony and Hesse.

With an ever greater capacity, PV is increasingly fulfilling its role as a stabilizing variable. The amended EEG dated January 1, 2012 stipulates that feed-in management in the form of remote control via the grid operator or an automatic cut off at 70 percent of real power is also performed to regulate plants connected to the low-voltage grid. In accordance with the Low Voltage Directive VDE AR-N-4105, which has been in force since January 1, 2012, inverters must perform functions that support the grid.
"...the predominantly decentralized way in which PV is fed into the distribution grid in close proximity to consumers reduces grid operating costs and in particular those relating to the transmission grid. A further advantage of feeding in PV is that in addition to feeding in real power, PV plants are in principle able to offer extra grid services (e.g. local voltage regulation) at cost-effective prices. They are particularly suitable for integration in subordinate grid management systems and may contribute towards improving grid stability and quality." [ISET2]
The PV power generation profile fits so well with the power grid's load profile that the entire electricity demand, which lies within a range of 40–80 GW, shall exceed the amount of PV available at all times, even in the event of PV capacity expanding further over the coming years. However, conflicts with slow power plants are increasing (especially nuclear power and lignite-fired power plants). Due to technical and economic reasons, these plants react to fluctuating residual loads only to a very limited extent.
During past heat waves, the rivers used as cooling reservoirs for fossil fuel and nuclear power plants became critically warm. The PV installations in Germany were able to help relax this problem and can also help to reduce this problem in neighboring countries such as France. Especially during summer, the installed PV in Germany categorically reduces the load on the fossil fuel and nuclear power plants.

10.6 Does the expansion of PV have to wait for more storage?

No.
Although the EU commissioner Guenther Oettinger in an interview with the newspaper FAZ (2 April 2013) said: "We must limit the escalating PV capacity in Germany. In the first place, we need to set a tempo limit for renewable energy expansion until we have sufficient storage capacity and an energy grid that can intelligently distribute the electricity."
In fact, the situation is the opposite. Investing in storage is first profitable when large price differences for electricity frequently occur, either on the electricity exchange market EEX or on the consumer level. Currently investments in storage, specifically pumped storage, are even being deferred because cost-effective operation is not possible.
First, a continued, further expansion in PV and wind capacity will cause prices on the electricity exchange EEX to sink more often and more drastically. On the other side, the reduced amount of nuclear electricity due to the planned phase out and more expensive electricity from coal-fired plants due to CO_2-certificates or taxes will cause price increases on the EEX at other times. This price spread creates the basis for a profitable storage

operation. If the price difference is passed on to the final customer through a tariff structure, then storage also becomes an interesting alternative for them.

A study from the German Institute for Economic Research (DIW) comes to the conclusion that surpluses from renewable energies are a problem that can be solved [DIW]. By making the electricity system more flexible, especially by eliminating the "must-run" basis of conventional power plants which is presently at ca. 20 GW and establishing a more flexible system of biomass generated electricity, the electricity surplus from wind and solar energy can be reduced to less than 2 % by 2032. The DIW takes the grid development plan 2013 as its basis [NEP] with an installed PV capacity of 65 GW, onshore wind capacity of 66 GW and offshore wind of 25 GW respectively.

11. Does the manufacture of PV modules take up a lot of energy?

No.
A solar plant's energy payback time depends on the technology used and the plant's location. For an annual global horizontal irradiance of 1055 kWh / m² (average in Germany), this takes approximately two years [EPIA]. The lifetime of solar modules is between 20 and 30 years, meaning that a solar plant constructed today would generate at least ten times as much energy during its lifetime as is used to manufacture it. What's more, energy-saving manufacturing processes mean that this value shall improve in the future.

12. Is the installation of new PV capacity competing with food production?

No.
The large-scale construction of PV systems on arable land has not been supported by the EEG since July 2010, resulting in the installation of such systems grounding to a halt and new ground-mounted systems only being constructed on specific redeveloped brownfield sites or in the close vicinity of highways and railway lines.
Furthermore, expansion scenarios do not envisage a noteworthy installation of PV systems on arable land. Given the EU's current plans to abandon the use of seven percent of arable land, corresponding to 600,000 hectares in Germany, any public discussion on this issue seems even more bizarre.
There are various methods being investigated under the heading "Agro-PV" which allow land to be used for both agricultural purposes and PV [Beck]. Reduced irradiance has not been found to stunt the growth of many crops, with some even benefiting from it.

13. Are PV plants in Germany efficient?

The nominal efficiency (see section 20.2) of commercial wafer-based PV modules (i.e. modules with solar cells composed of silicon wafers) has risen in recent years by an annual rate of around 0.3 percentage points to an average of **14–15 percent** and a peak performance of **20 percent**. Each square-meter module has a rated power of 140–150 W, while premium modules generate up to 200 W under rated operating conditions. The nominal efficiency of thin-film modules stands at between **6 and 11 percent**, with a peak performance of **12–13 percent**.

Since additional losses occur during operation, PV plants are unable to operate at nominal module efficiency. These effects are combined in the performance ratio (PR). A well designed PV plant installed today achieves a total PR of 80–90 percent throughout the year. This takes into account all losses incurred as a result of the actual operating temperature, varying irradiance conditions, dirt on the solar modules, line resistance and conversion losses in the inverter. Inverters convert the direct current (DC) generated by the modules to make it suitable for feeding into the grid (AC). Regardless of the module technology at play, the efficiency of new PV inverters currently stands close to 98 percent.

Depending on irradiance and PR, specific yields of around 900 kWh / kWp are generated in Germany and in sunny regions, this amount exceeds 1000 kWh / kWp. This corresponds to around 130 kWh per square-meter module or around 180 kWh per premium module. An average 4-person household consumes around 4400 kWh of power per year, corresponding to the annual yield generated by 34 m^2 of standard modules. The roof of a detached family home is expansive enough to accommodate a PV plant capable of generating a family's annual power needs. Modules are tilted on flat roofs and open land to increase their yields. South-facing modules positioned at suitable distance from one another cover approximately 2.5 times their own surface area.

In comparison, when converting energy crops into electricity, the efficiency value calculated on the basis of irradiance is significantly less than one percent. This amount falls further when organic fossil fuels such as coal, oil or natural gas are converted into electricity. The combustion-based power plants used for this task generally determine their efficiency data according to the conversion of the chemical energy already found in fossil fuels. Based on this method of calculation, Germany's coal-fired power plants report an average efficiency value of 38 percent, for example.

Burning biofuels in vehicles also only results in mediocre levels of efficiency when these are determined on the basis of the irradiated energy and surface area used. Figure 31: compares the total driving distances of vehicles that burn various biofuels with that of an electric vehicle (plug-in hybrid drive), whose required electric driving energy is provided by a PV array of an equal size to the field of energy crops.

If one considers the driving range per tank filling or charging, electric-powered vehicles have a lower range than vehicles with combustion engines. Mass-produced plug-in hybrid vehicles are capable of running between 20 and 50 kilometers on the electrical energy provided by a fully charged battery alone, while purely electric vehicles are able to run for up to 200 kilometers (e.g. 199 km standard drive range of the Nissan Leaf, which is equipped with a storage capacity of 24 kWh and a combined consumption of 17.3 kWh / 100 km).

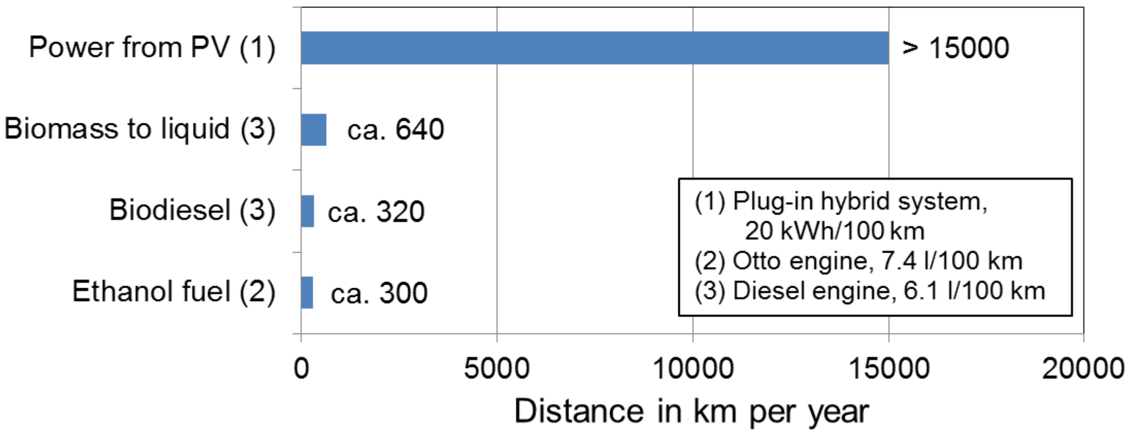


Figure 31: Vehicle running distances for the annual yield of 1 a = 100 m² of energy crops (2,3) or 40 m² of elevated PV modules constructed on 100 m² of flat open ground, Sources: Photon, April 2007 (1) and Fachagentur Nachwachsende Rohstoffe (2), (3).

While southern Spain and North Africa are able to produce specific yields of up to 1600 kWh/kWp, transmitting this power all the way to Germany would result in significant energy losses and additional charges. Depending on the voltage level, transmission losses are between 0.5 and 5 percent per 100 kilometers. Not taking conversion losses into account, high-voltage direct current (HVDC) transmission lines reduce transportation losses to just under 0.3 percent per 100 kilometers. Based on this, an HVDC transmission line of 5000 kilometers in length would present transmission losses of around 14 percent.

13.1 Do PV plants degrade?

Yes, albeit very slowly.
Wafer-based PV modules age so slowly that calculating their output losses at all poses a challenge to scientists.
A study examining 14 plants in Germany fitted with poly and monocrystalline modules showed an average degradation of a 0.1 percent relative drop in efficiency per year across the entire plant, including the modules [ISE2]. In this context, the common assumption that plants experience annual output losses of 0.5 percent seems conservative.
The above figures do not take into account any losses arising as a result of manufacturing faults. Comprehensive tests conducted by Fraunhofer ISE have shown that light-induced degradation of between one and two percent occurs during the first few days of operation depending on the material used in the solar cells. The indicated rated power of modules normally refers to output following this initial degradation.
Long-term data has not been collected for many thin-film modules. Depending on the module type, degradation during the first few months of operation and seasonal fluctuations are observed.

13.2 Can PV modules become soiled?

Yes, but any dirt that accumulates on the vast majority of plants in Germany is generally washed away the next time that it rains, meaning that it leads to virtually no yield losses. Problems only arise in modules installed at extremely shallow angles or those that are located in the vicinity of deciduous trees or sources of dust.

13.3 Do PV plants often operate at full capacity?

No. The performance indicator "full-load hours" is the quotient of the actual energy generated by a power plant in the space of a year and its rated power (see section 20.3). Irradiance conditions mean that PV plants work for fewer than half of the 8760 hours of the year and even when they are are working, they generally only operate at partial load. The trend scenario for the years 2013–2017 found in the study "Jahresprognose 2013 und Mittelfristprognose bis 2017 zur deutschlandweiten Stromerzeugung aus EEG geförderten Kraftwerken" ("Annual forecast for 2013 and mid-term projection up until the year 2017 for the generation of electricity by power plants supported by the EEG across Germany") [R2B] predicts that PV plants in Germany that operate the whole year round shall work at full load for an average of roughly 970 hours per year. Figure 32: shows the full overview of the forecasts made for RE.

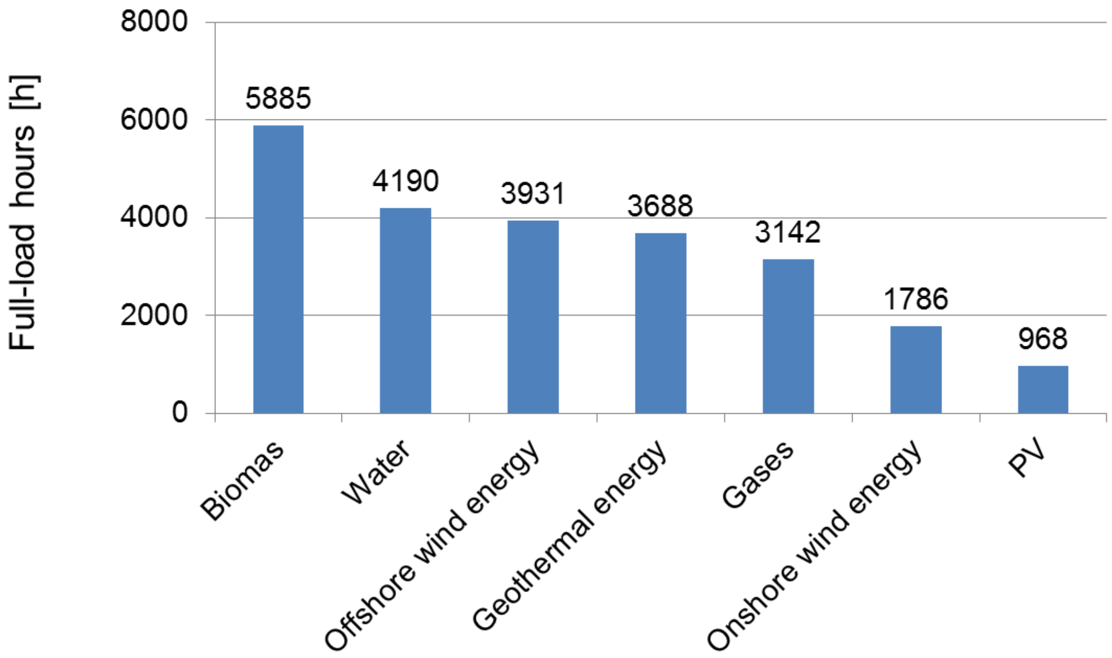


Figure 32: Forecasted hours of full-load operation for plants that run the whole year round, average annual values between 2012 and 2016, data from [R2B].

The average total amount of irradiance on a horizontal surface in Germany between 1981 and 2010 stands at 1055 kWh/m^2 per year and fluctuates according to location between approximately 951 and 1257 kWh/m^2 per year [DWD]. Figure 33 shows levels of irradiance across Germany. In order to maximize yields, PV modules are oriented towards the south and are installed with an inclination to the horizontal surface of around 30–40°. This increases the total irradiance reaching the modules calculated on the basis of irradiance on a horizontal surface by around 15 percent, resulting in an average of roughly 1200 kWh/m^2 per year throughout Germany.

A performance ratio PR (see section 20.6) of 85 percent and ideal orientation would result in a geographical average across Germany of more than 1030 full-load hours. Since some plants are not ideally oriented and many still have a PR of less than 85 percent, the actual average number of full-load hours is, however, somewhat lower. Tracking systems significantly increase the number of hours at which PV modules run at full capacity (section 16.3.1).

Technical improvements in the module and installation can increase the performance ratio PR, the yield and thus the number of full-load hours of a PV system. Included in this are the temperature coefficient of the solar cells, the reduction in the operating temperature of the modules, improvements in the module performance under low and oblique light or the reduction of losses due to snow cover or dirt.

In wind power plants, the greater the hub height, the greater the number of full-load hours. When required, nuclear, coal and gas-fired power plants are capable of working almost continuously (one year = 8760 hours) at their rated power. In reality, according to [BDEW1], brown coal-fired power plants reached 6640 full-load hours in 2007, while hard coal-fired power plants achieved 3550 hours.

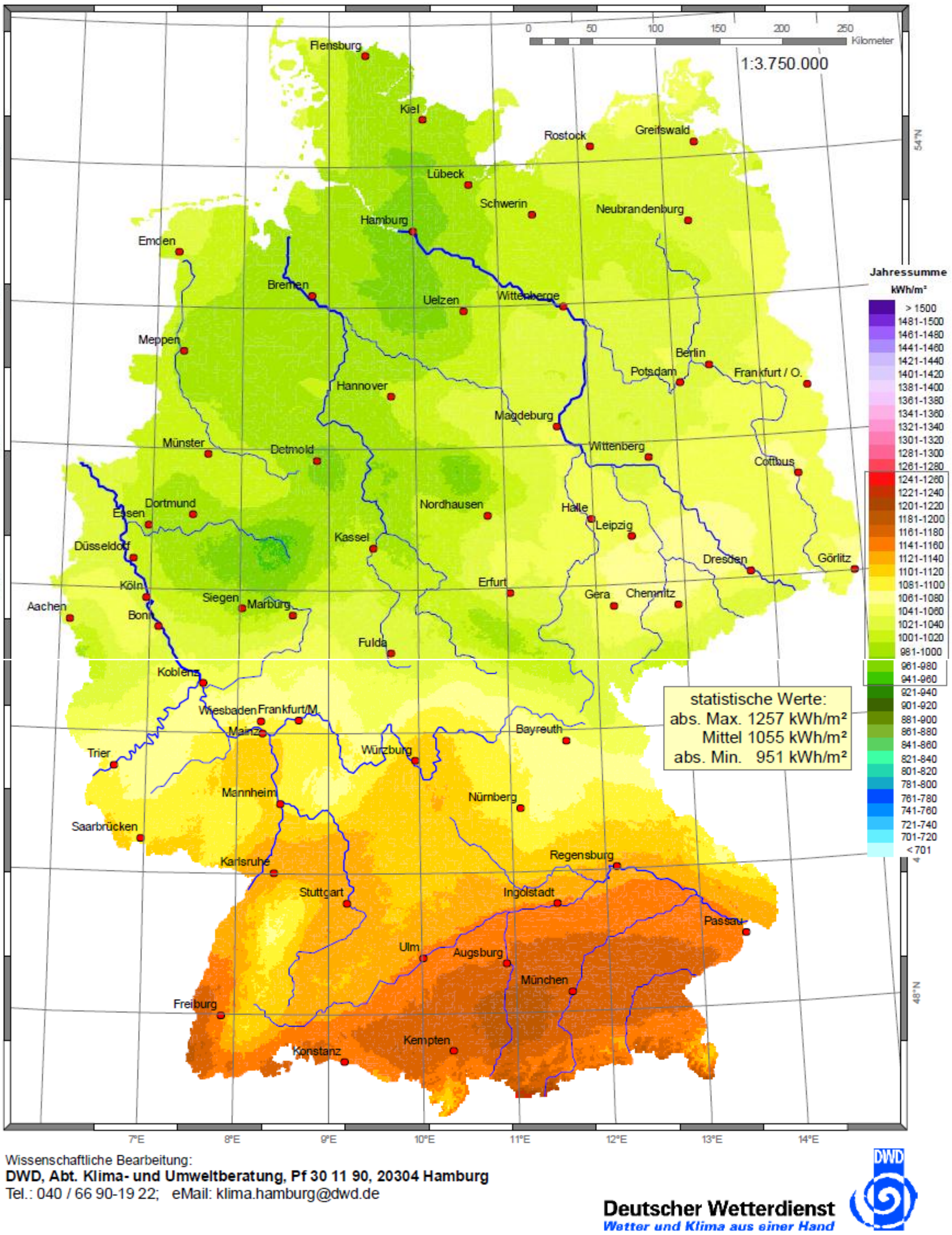


Figure 33: Global annual solar irradiance on a horizontal surface in Germany between 1981 and 2010 [DWD].

14. Does PV make relevant contributions to climate protection?

14.1 Do anthropogenic CO_2 emissions danger the climate?

Yes. The large majority of experts see a substantial risk. In May 2013, the atmospheric CO2 concentration reached 400 ppm for the first time in ca. 5 million years. Compared to the preindustrial era, the mean global temperature has risen by 0.8°C [IEA]. The vast majority in the scientific community hold the opinion that with a high degree of certainty anthropogenic greenhouse gas emissions are the main cause for the rising concentration of greenhouse gases in the atmosphere as well as for the increasing mean global temperature. Figure 34 and Figure 35 show the development through today of the atmospheric CO_2 concentration and the global, or rather Antarctic, temperature.

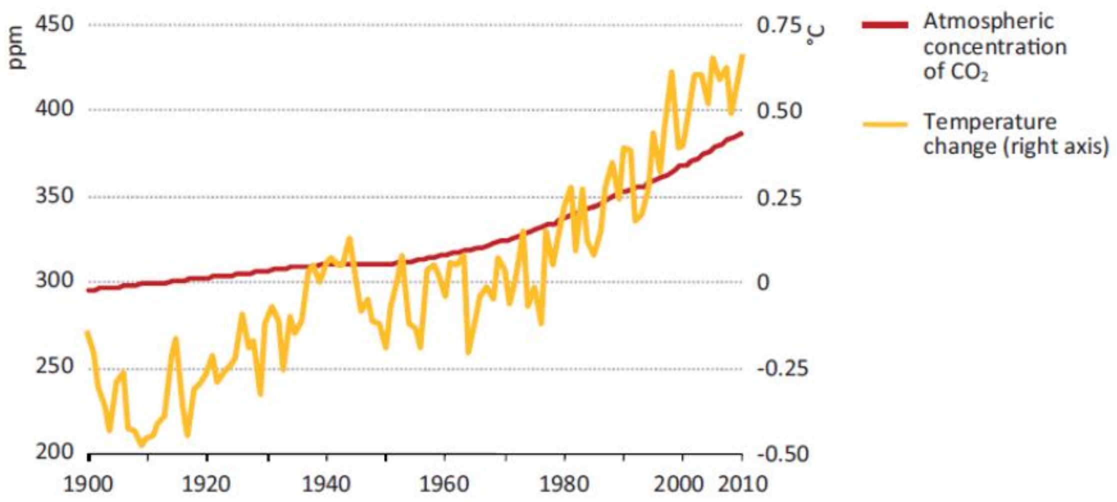


Figure 34: Development of the atmospheric CO_2 concentration and the mean global temperature change based on the NASA Global Land-Ocean Temperature Index [IEA2].

A faster increase in the global temperature dangers the stability of the global climate system to an extent that is not fully understood today. The temperature increase has far-reaching effects on the global food security, coastal settlements, diversity of species and various habitats.

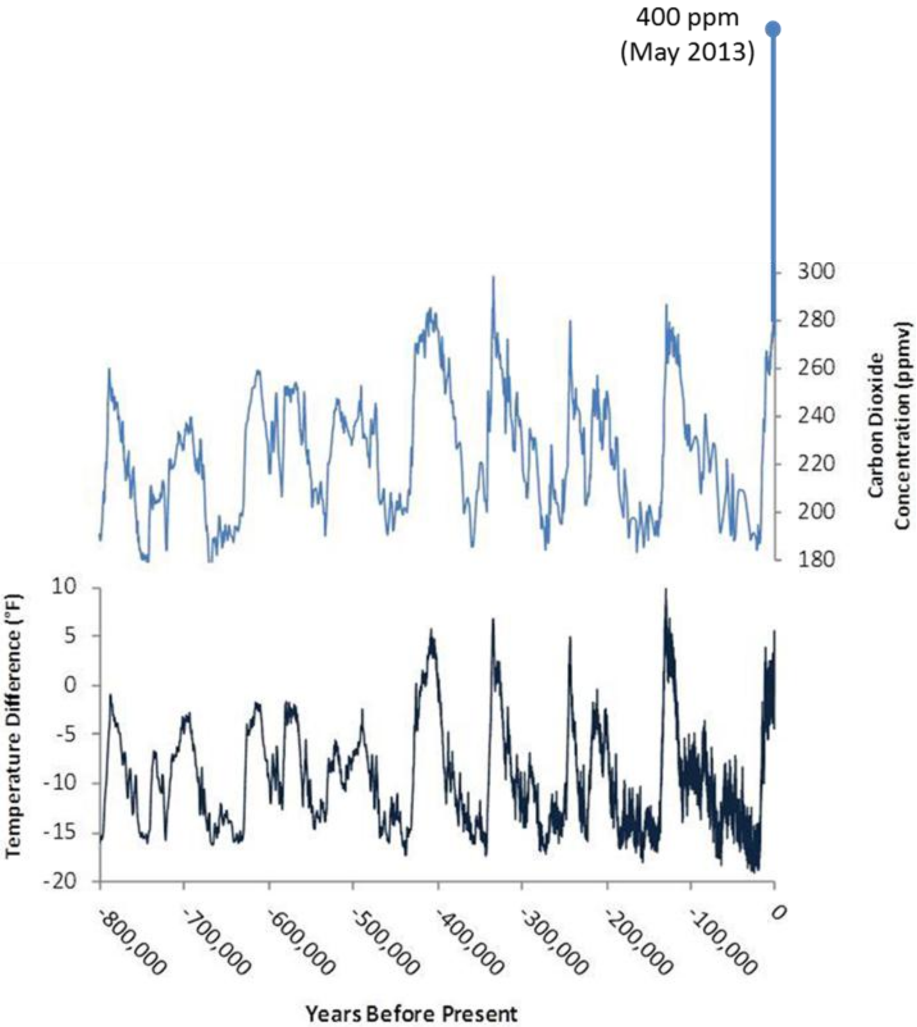


Figure 35: Estimate of the atmospheric CO_2 concentration and the temperature in Antarctica based on ice core data [EPA], CO_2 concentration for 2013 is included

14.2 Does PV make a significant contribution to reducing the CO_2 emissions?

Yes.

The low efficiency of generating power from coal means that each kWh of PV power and wind power saves approximately 2.3 kWh and 2.6 kWh of primary energy respectively (Figure 36). The cumulative amount of primary energy saved by PV by the end of 2011 stood at more than 100 TWh of primary energy, with 50 TWh of solar power production. Power generated from natural gas is more expensive than that generated from coal, and the power generation from gas is more flexible. For these reasons, the amount of power generated from natural gas in recent years has dropped in favor of coal with the expansion of RE.

Strom	kWh_{prim}/kWh_{el}
Braunkohle	2,68
Steinkohle	2,64
Erdgas	2,04
Mineralöl	2,48
Wasserkraft	0,01
Windenergie	0,04
Photovoltaik	0,31
Feste Biomasse (HKW)	0,06
Flüssige Biomasse (BHKW)	0,26
Biogas (BHKW)	0,37
Klär-/Deponiegas (BHKW)	0,00
Biogener Anteil des Abfalls	0,03
Geothermie	0,47

Figure 36: Amount of primary energy required to generate power from various energy sources [EEBW].

The level of emissions avoided by PV power equates to 700 g CO_2e/kWh [BMU1]. This factor is the quotient of the emissions avoided and the amount of electricity generated and takes into account both greenhouse gases and other air pollutants. Thus, with the use of **28 TWh** PV electricity in 2012, greenhouse gases on the order of **19.7 Mio. tons** of CO_2 equivalent were avoided. Hard coal-fired power plants emit roughly 949 g CO_2/kWh of electricity, while lignite-fired power plants emit approximately 1153 g CO_2/kWh of electricity.
Germany's energy policy is also influential on an international scale. Although Germany only accounted for around three percent of global power consumption in 2008 and this proportion is on a downward spiral, German policy makers are leading the way in terms of developing incentive programs for RE, the EEG being the best example of this. The EEG has been and continues to be closely observed around the world and has been used by many countries as a model for similar regulations. The International Energy Agency (IEA) commends the EEG in their report "Deutschland 2013" as a very effective instrument for expansion, which has drastically reduced the costs for renewable energy production in the last years [IEA3]. Meanwhile, Germany's break with nuclear energy has also caught people's attention worldwide.
In terms of avoiding CO_2 emissions, the EEG achieved the highest impact due to a side effect: Through the creation of the largest and most secure sales market for PV lasting over many years, it markedly accelerated the global expansion, technology development and price reduction. In 2013, the worldwide PV installations will increase to more than six-fold that of the German market, with increasing trend. PV is reducing worldwide the use of fossil fuels for electricity production.

The German EEG has made PV power more quickly affordable for many people in developing countries. In this context, the EEG is "possibly the most successful development program of all time when it comes to energy supply" (Bodo Hombach in the "Handelsblatt” newspaper on January 11, 2013), also helping developing countries to save significant amounts of CO_2.

14.3 Are environmentally harmful gases released during the production of PV?

Yes, in the case of some thin film technologies.
During the production of thin-film PV and flat screens, nitrogen trifluoride (NF3) is still used, in part, to clean the coating systems. Residues of this gas can thereby escape into the atmosphere. NF3 is more than 17,000 times as harmful to the environment as carbon dioxide. Current emission quantities are not known. As of 2013, however, NF3 emissions are to be determined in 37 countries according to the revised Kyoto Protocol.

15. Are PV systems capable of replacing fossil fuel and nuclear power plants?

No, at least not in the near future.
PV and wind power may currently be capable of reducing the use of fossil fuels, imported energy consumption and CO_2 emissions but until considerable storage capacities for storing electric energy in the form of electric energy are available in the grid, they are not capable of replacing the capacities generated by fossil fuel and nuclear power stations. Calm, dull winter days when power consumption is at a maximum and no solar or wind power is available present the critical test.
Despite this, PV and wind power are increasingly colliding with inert conventional power plants (nuclear power, lignite). These power plants, which are almost only capable of covering the base load, must be replaced by flexible power plants as quick as possible. The preferred power plant choice is CHP plants which are laid out to cover the electricity demand but are also fitted with thermal storage systems (section 16.3.2).

16. Are we capable of covering a significant proportion of our energy needs with PV power?

Yes, depending on the extent to which we are able to adapt our energy system and the facilities that make up our energy industry to meet new requirements [FVEE2]. Given current conditions, the following steps provide a brief overview of what needs to be done to achieve this aim. More detailed explanations can be found in the following sections of this chapter.

Time frame by 2020. Focus on **"Creating flexibility"**

1. The installed PV capacity needs to be increased to at least 52 GW, close to the site of consumption; to achieve more constant production levels, plants must also be constructed with an east/west orientation or be fitted with a tracking system; inverter functions need to support the grid. This is necessary to ensure that at least 50 TWh of solar power per year is generated in 2020 with peak power capacities of up to 36 GW.
2. The energy efficiency of electrical consumers in households and the industry needs to increase, with special focus on the night consumption
3. Demand needs to be managed (via control signals from local PV plants or from the grid, tariffs, switchable loads in the industry) to ensure that certain proportions of our power consumption are in line with PV power (and wind power) availability; Thermal storage solutions need to be added to cooling applications
4. Power plants using storable renewable energy sources (run-of-the-river hydroelectricity, biomass) need to be adapted to allow them to run complementary (pondage, storage). In accordance with current plans, the performance and capacity of pumped-storage power plants needs to be increased by between 30 and 40 percent
5. Multi-functional power plants for flexible power production need to be built, having CHP and substantial heat storage which also can be electrically charged with a heat pump and heating rod. The power plant scale ranges from large plants for district heating supply down to micro CHP systems for single family homes.
6. PV systems need to be equipped with grid-connected battery systems.
7. Existing coal-fired plants need to be optimized to enable flexible complementary operation. Nuclear and older lignite-fired plants need to be progressively decommissioned.
8. Power grid connections with our neighboring countries need to be strengthened

In order to avoid costly mistakes and to carry out the above measures in a timely manner, proper incentives are necessary: a stable EEG, investment incentives for energy efficient measures, multi-functional power plants and pumped storage, price and investment incentives for supply side power availability, remuneration for demand side electricity feed-in and lowering the implicit subvention for coal-fired plants by reducing the CO_2 certificates or a national CO_2 tax.

Time frame by 2040–2050. Focus on **"Storage"**

1. to enable around 190 TWh of solar power to be generated per year, installed PV capacity needs to be gradually increased to approximately 200 GW
2. heating supply systems need to be completely switched to RE and the energy efficiency of buildings must be improved
3. all modes of transportation need to run completely using electricity/renewable gas
4. the conversion and storage of RE (in particular electric energy in the form of electric energy) via renewable gas and batteries needs to increase substantially
5. the energetic use of fossil fuels needs to stop completely

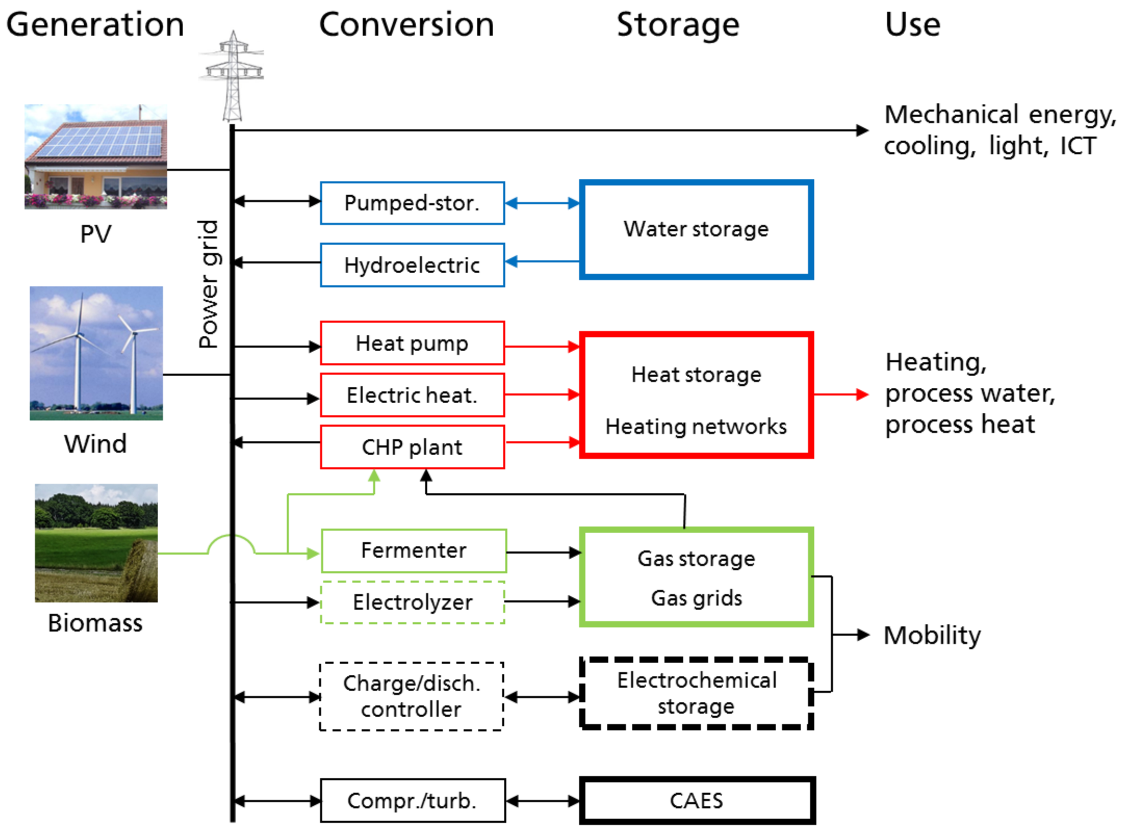


Figure 37: Simplified diagram of a renewable energy system with the most important grid-connected components for the generation, conversion, storage and consumption of energy; ICT: information and communications technology; dotted lines: very low outputs/capacities currently available.

It is already possible to envisage the technical and economic aspects of an energy system based on 100 percent RE. Figure 37 shows the most important grid-connected elements ranging from energy generation to energy consumption.

16.1 Energy scenarios

Energy scenarios provide neither facts nor forecasts. A few scenarios are considered below to provide a context for the assessment of the technical and economic potential of possible future energy systems.
Our current energy system, which is based on generating power from fossil fuel and nuclear sources, cannot survive in the long term. A variety of energy scenarios have been created for the coming decades, and they are increasingly incorporating the use of RE. The rapid expansion of PV witnessed in Germany, alongside the speed with which its costs have fallen, have already exceeded many of these studies' expectations.
The long-term scenarios and strategies for increasing RE in Germany drawn up on behalf of the BMU [IFNE] are based on the assumption that around 53 GW of PV capacity shall be installed in the country by the end of 2020 (Figure 38:). Assuming that these PV power plants work at full capacity for 950 hours, 50 TWh of solar power shall be generated in 2020.

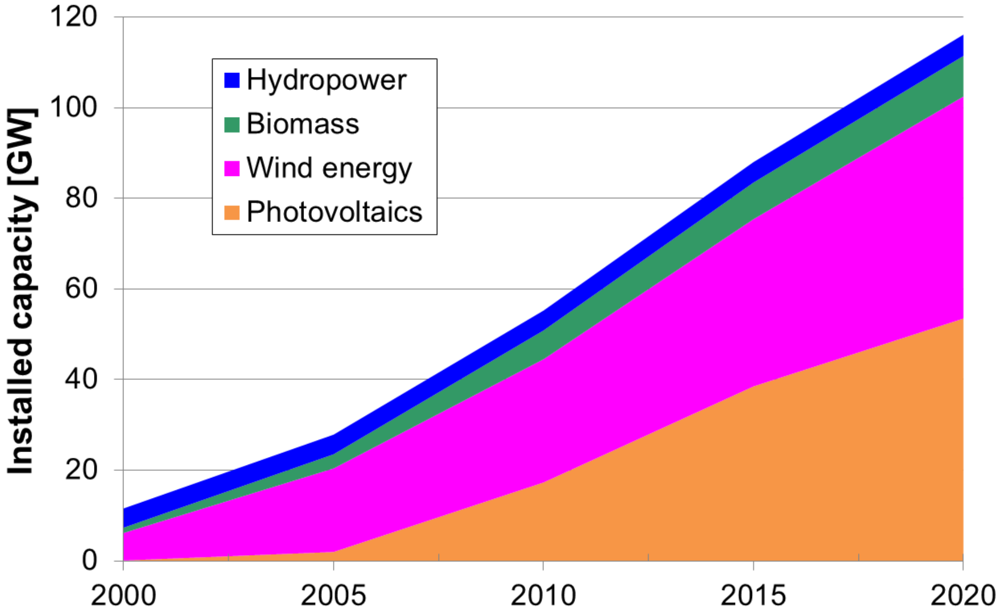


Figure 38: Scenario "2011 A" for the expansion of RE capacity, data from [IFNE].

A study commissioned by the Federal Environment Agency has concluded that it shall be technically possible to generate all power renewably and in an environmentally friendly manner by 2050 [UBA1]. While this study works on the assumption of a total installed PV capacity of 120 GW in 2050, conservative estimates suggest that this milestone shall only be reached with an installed capacity of 275 GW. Figure 39 outlines a conversion and storage concept for the power and heating sector.

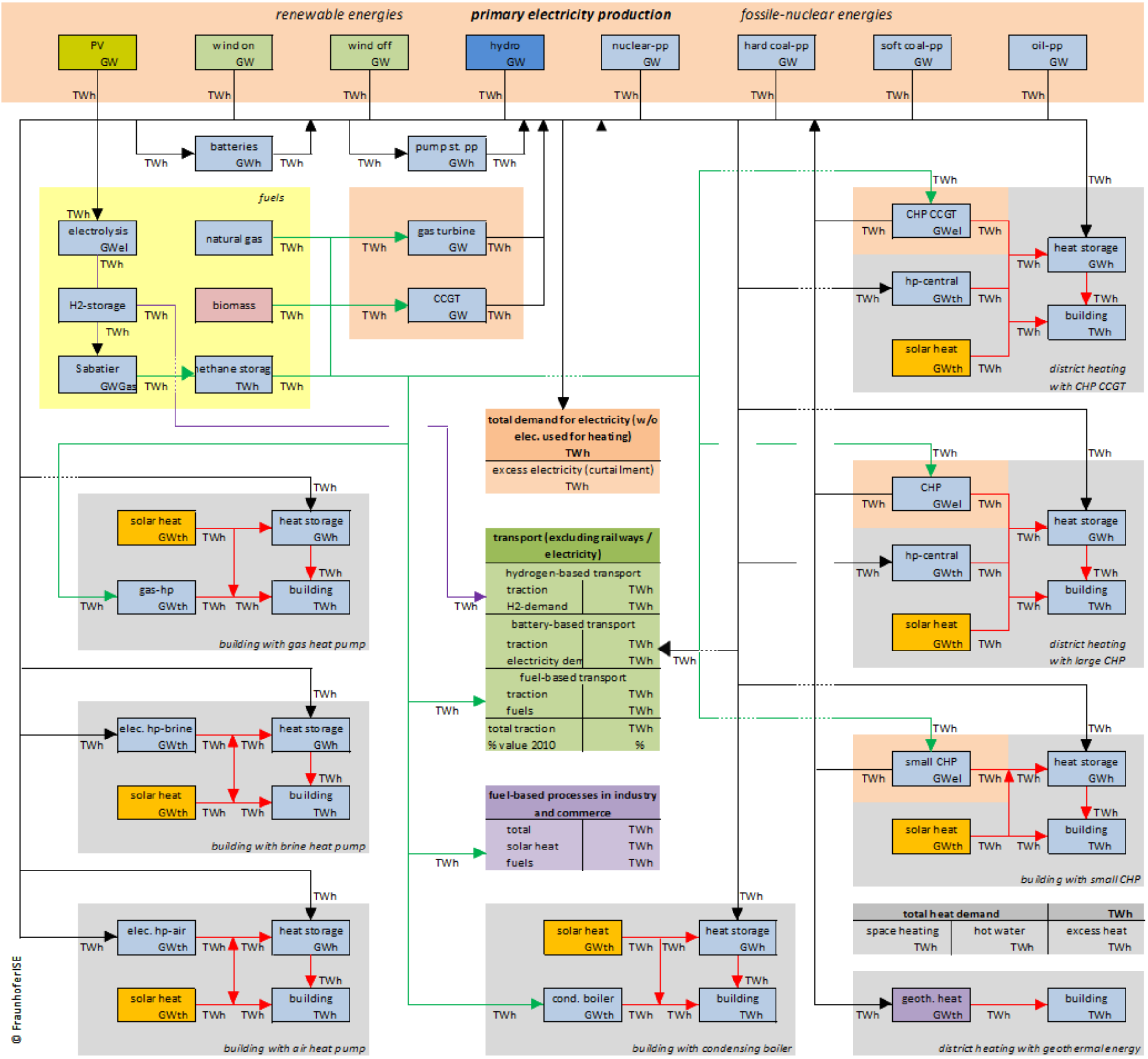
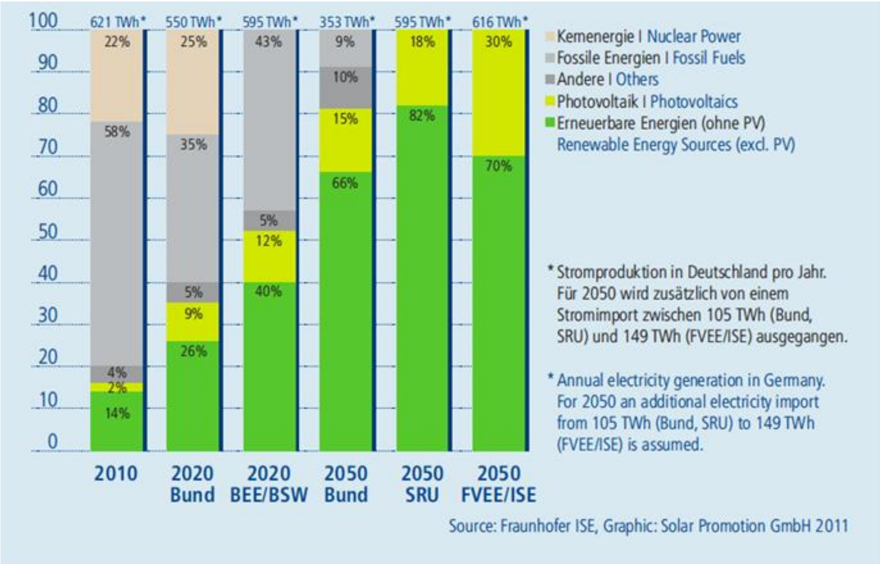


Figure 39: Scenario for Germany's energy system, diagram of the system's structure [ISE5].

Taking the energy concept developed by the German Research Association for Renewable Energy [FVEE] as a basis, Fraunhofer ISE has created a scenario that envisages PV power accounting for 30 percent of energy production by 2050. Figure 40 compares several scenarios for the supply of electricity in 2020 and 2050 emerging from this study.

A study conducted by the magazine Photon believes that the optimum solution in economic terms is a power generation mix comprising about 170 GW of installed PV power [PHOTON] in an expansion scenario that sees power being generated solely by wind and solar plants by 2030.

Researchers from Fraunhofer ISE have studied a conceivable German energy system by simulating it over a period of time split into hourly intervals. The system works solely on the basis of renewable energy and incorporates the heating sector's potential for storage and low energy renovation. PV must contribute an installed capacity of 200 GW in order to ensure an economically optimal power generation mix [ISE5].



Quellen I Sources:
2020 Bund, 2050 Bund: Szenario IIA mit 52 GW PV I energy scenario IIA with 52 GW PV, ewi/gws/prognos, 8/2010
2050 SRU: Gutachten 100 % erneuerbare Stromversorgung I Report 100 % renewable electricity supply, Sachverständigenrat für Umweltfragen, 1/2011
2050 ISE: ISE-Szenario auf Basis des FVEE-Energiekonzepts 2050 I ISE-Scenario based on the FVEE-energy concept 2050, Fraunhofer ISE, 5/2011

Figure 40: Scenarios for the share of various energy sources in power production in Germany [ISE3].

A quick look at global energy scenarios reveals a study conducted by Royal Dutch Shell entitled "New Lens Scenarios" [Shell], which describes a dynamic "Oceans" scenario that envisages a global installed PV capacity of 500 GW before 2020 and predicts that PV will grow into the most important primary energy source by 2060 (Figure 41). The International Energy Agency (IEA) predicts that RE in 2016 will overtake the energy production from natural gas and will produce double the amount of that from nuclear power plants worldwide [IEA1].

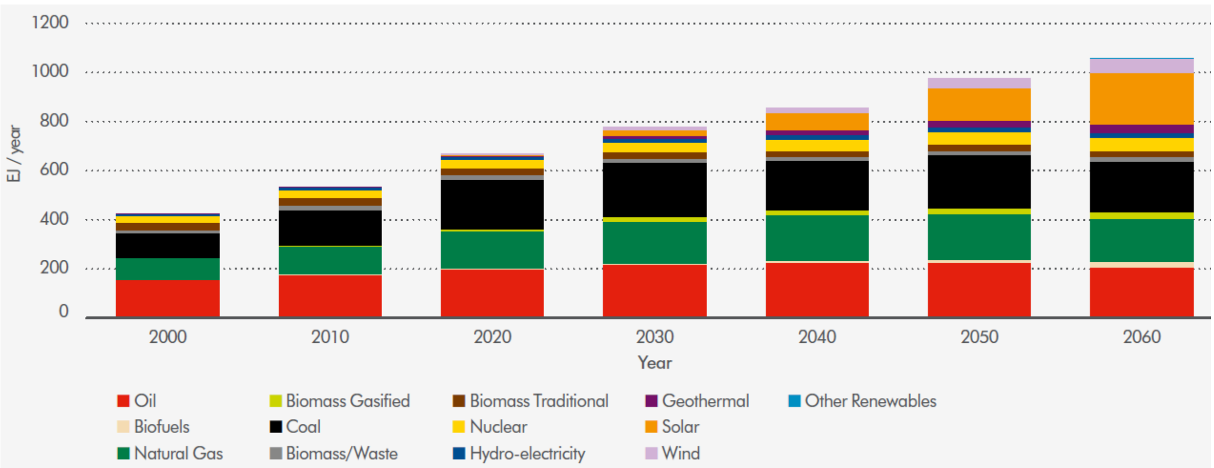


Figure 41: Primary energy consumption of various sources of power [Shell].

16.2 Energy demand and supply

The traditional energy industry promotes fossil and nuclear energy sources (primary energy), converts them and prepares them for end users. The energy flow diagram in Figure 42 shows how heavily Germany depends on energy imports.

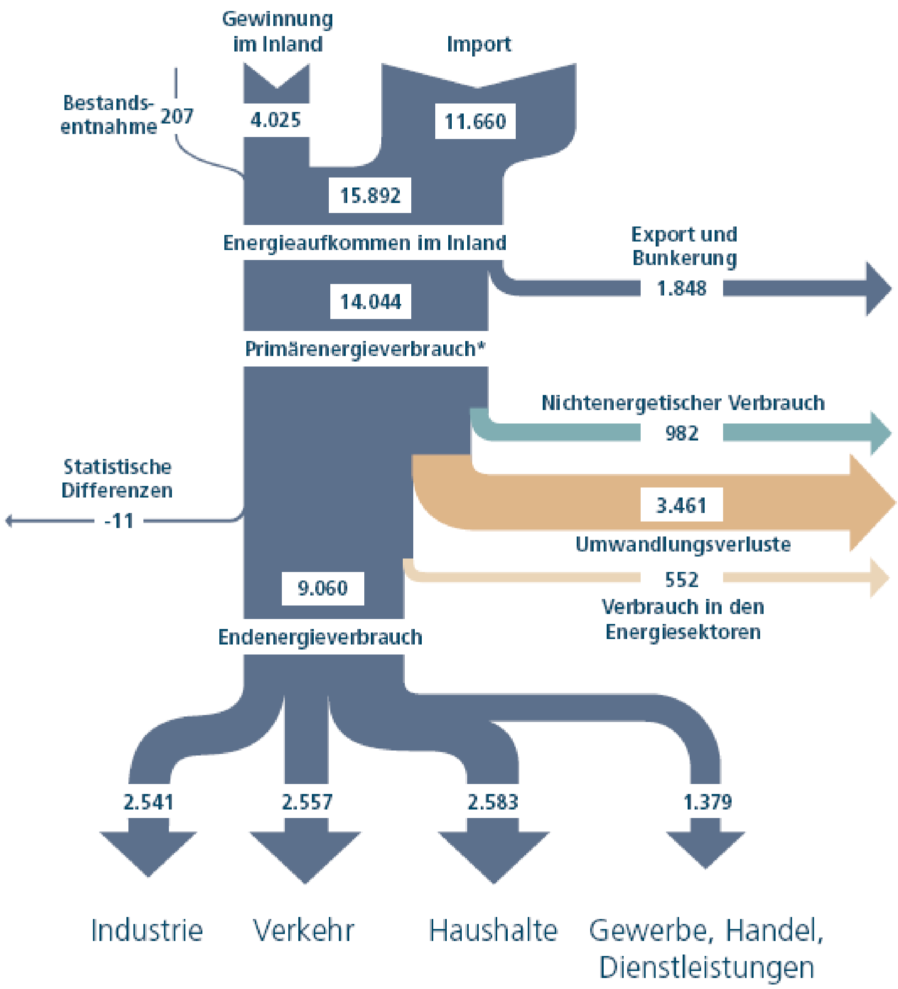


Figure 42: 2010 energy flow diagram for the Federal Republic of Germany in petajoules [AGEB2].

Energy conversion and consumption is extremely inefficient. For example, the final energy consumed by vehicles is predominantly converted into waste heat via their combustion engines, with even a considerable part of the energy used to drive a vehicle being irreversibly converted into heat when applying the brakes. Householders, who use around 75 percent of the final energy they consume for heating, could half this level of consumption by introducing simple heat recovery measures. These examples clearly illustrate that no comparison can be made between current and future energy demands in terms of both quantities and energy sources.

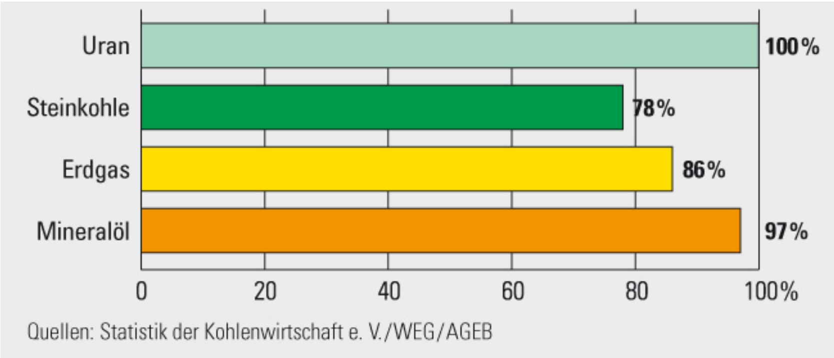


Figure 43: Germany's dependence on the import of raw energy materials 2011

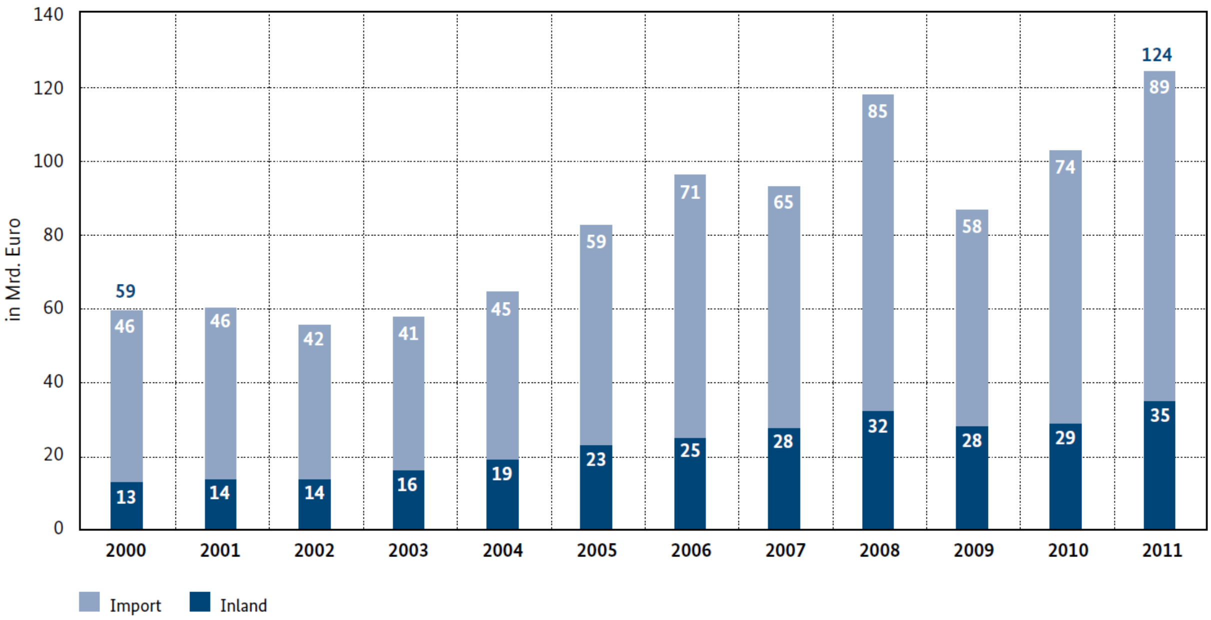


Figure 44: Cost development for the provision of primary energy in Germany [BMWi2]

Fehler! Verweisquelle konnte nicht gefunden werden. shows the increasing costs of the energy imports, which are estimated have reached 100 billion euros in 2012.

Figure 45 shows the different proportion of the various energy sources making up Germany's primary energy consumption. The severe lack of efficiency in the way in which all power generated from fossil fuel and nuclear sources is used results in between 50 and 75 percent of the primary energy produced being lost. In turn, this is partly responsible for the significant proportion of these energy sources found in the primary energy mix. Nuclear power plants, for example, work at an efficiency of about 33 percent [EEBW], while fossil-fuel plants, which are mostly run on coal, have an efficiency of roughly 40 percent. Meanwhile, mineral oil products are used to heat poorly insulated buildings or fuel inefficient vehicle drive mechanisms.

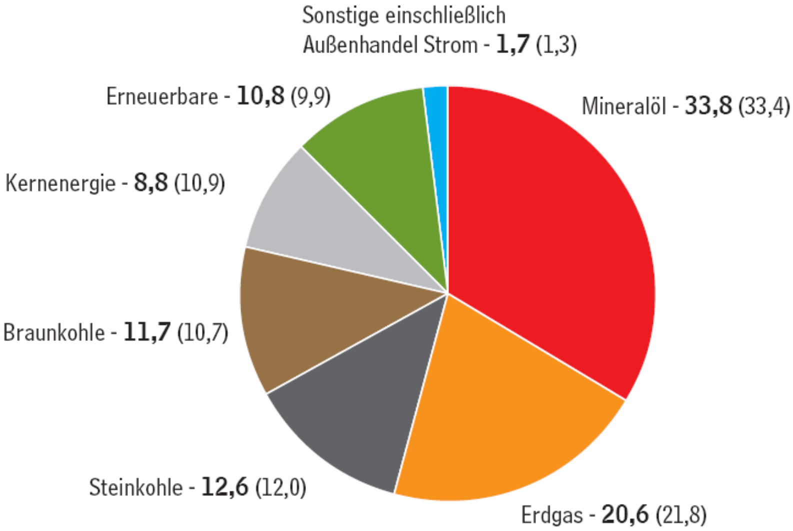


Figure 45: Composition of primary energy consumption in Germany in 2011, figures given as percentages (data for previous year in brackets), totaling 13,411 petajoules or 457.6 million metric tons of coal equivalent [AGEB3].

The majority of final energy (36 percent) is used to generate mechanical energy (force) for vehicles and stationary engines (Figure 46), whereby the combustion engines used in road vehicles are affected by significant conversion losses.

Space heating accounts for the second largest use of final energy (31 percent) and is accompanied by significant thermal losses due to poor heat recovery. Cooling is also generated indirectly via the production of mechanical energy, and electrically operated heat pumps can be used to generate space heating and hot water.

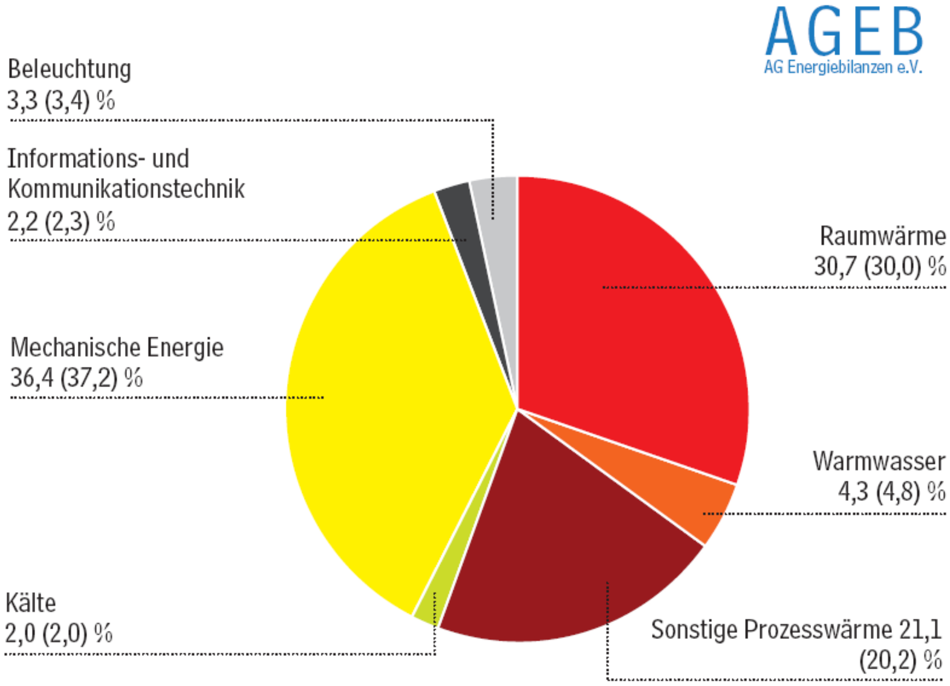


Figure 46: Different proportions of the various energy types making up Germany's final energy consumption in 2010 (data for previous year in brackets) [AGEB4].

Figure 46Figure 47 provides an example of how energy demand is distributed throughout the course of the year. The energy consumption of road transport vehicles is characterized by a certain base load. The total amount of power and energy required to generate hot water only drops slightly in summer, while heating requirements correlate negatively with global irradiance, with the highest point of intersection being found in spring.

The monthly distribution of solar and wind power generation is also shown. While around 69 percent of the PV power generated throughout the year is produced in spring and summer (April–September), 62 percent of wind power is generated in autumn and winter.

Figure 47 clearly shows that even without seasonal storage systems, solar power has the potential to cover significant amounts of the electricity, road transport and hot water requirements, provided that complementary energy sources hold the fort in autumn and winter. The potential for covering heating requirements is much lower, however, with spring being the only time of year where this is likely. Furthermore, a combination of solar and wind power may allow power to be generated using renewable sources throughout the year because the amount of wind energy produced falls significantly in spring and summer.

In addition to the generally regular seasonal fluctuations in PV power generation, irradiance changes significantly over the course of hours, days and weeks. On a local level, significant changes are seen as much as every minute or even second but these fluctuations do not have a bearing on Germany's power grid as a whole.

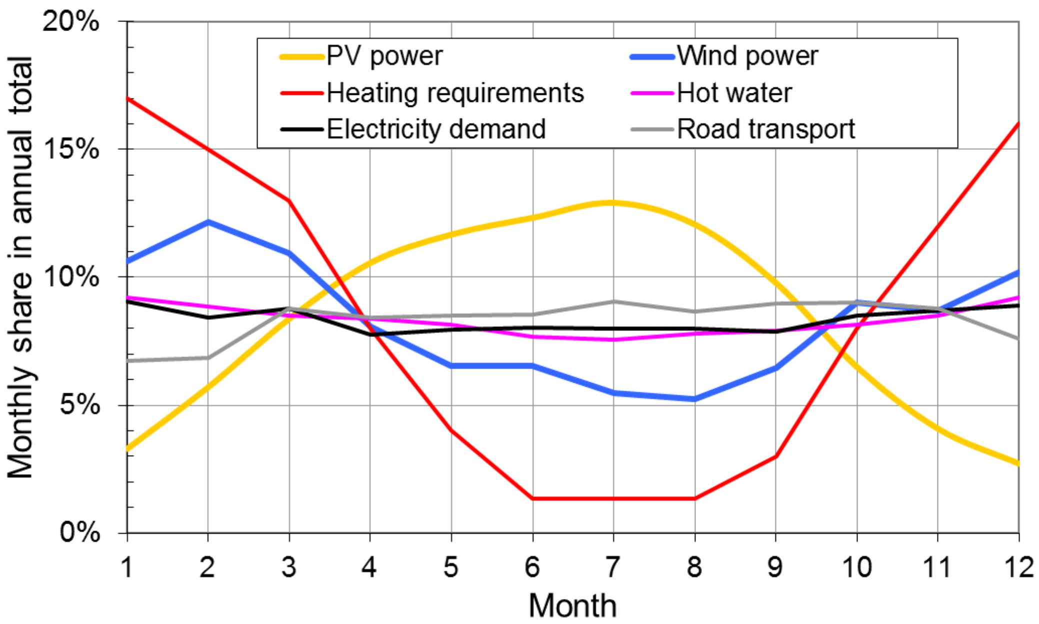
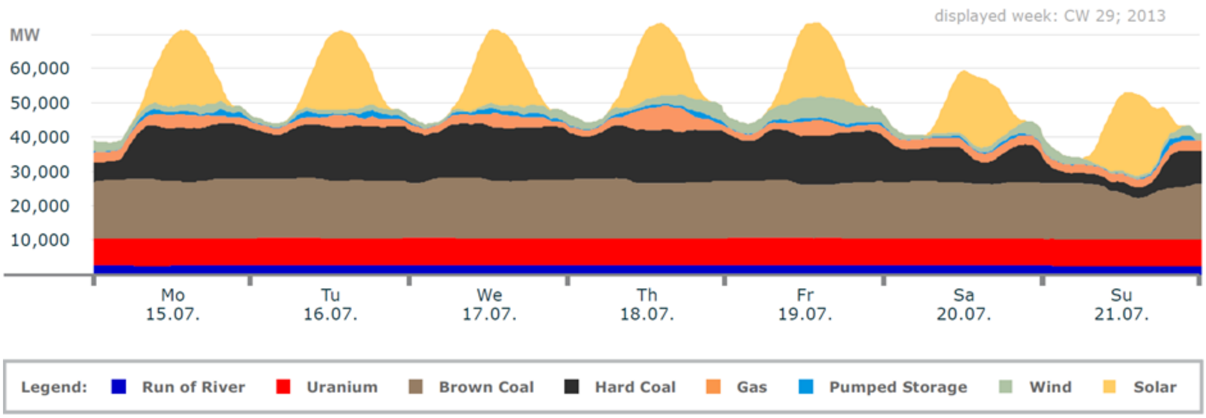


Figure 47: Rough estimate of the monthly distribution (annual total = 100 percent) of solar power (calculated in Freiburg [PVGIS]), wind power [DEWI], heating requirements according to heating degree days (VDI Guideline 2067 and DIN 4713), energy requirements for domestic hot water production, electricity demand [AGEB1] and fuel requirements [MWV].

The power load also fluctuates during the course of the day, with more power being required during the day than at night, and more being needed on working days than over the weekend or on bank holidays. When considering load profiles, utilities distinguish between base, intermediate or peak load demands (see section 20.7). Base load corresponds to a power demand of 30–40 GW that remains virtually constant over a 24-hour period. Intermediate load fluctuates slowly and mainly in a periodic manner, while peak load comprises sudden, highly changeable spikes in demand that are greater than the base and intermediate loads.

When it is sunny, PV power is already capable of covering most of the peak load seen around midday. In spring and summer, the generation rates of PV plants correlate well with the level of power consumption during the day, meaning that the amount of capacity currently installed is sufficient to cover the majority of the peak load on sunny days. Further expansion shall result in a greater proportion of the peak load experienced around midday being covered even on less sunny days, while the power generated during the middle part of sunny days, especially over the weekend, shall cut into the base load.



	RoR	Uran	BC	HC	Gas	PSt	Wind	Solar
min. power (GW)	2.4	7.4	12.1	2.7	1.5	0	0.2	0
max. power (GW)	2.8	7.9	17.5	16.1	6.9	2.2	6.7	24
weekly energy (TWh)	0.4	1.3	2.8	2.1	0.5	0.1	0.3	1.3

Figure 48 : Power production in 29th week of 2013, showing the current record value of 24 GW PV power generated on Sunday, July 21 with total nominal power of c. 34.5 GW (Chart: B. Burger, Fraunhofer ISE; Data: European Energy Exchange in Leipzig, EEX)

When solar power is available, the energy demand is generally high. At high demand, the electricity price on the energy exchange used to be at its most expensive. Continuing to install new PV capacity over the coming years shall not lead to a surplus of PV power, provided that other energy sources are not increased at the same time. Today’s conditions can result in the residual base load being reduced.

Figure 50 shows what a generating profile may look like for an expanded PV capacity of 50 GW. By selecting the week that boasted the year’s highest amount of solar power production, the graph is able to illustrate the greatest possible impact that PV power could have. The maximum amount of power that can be generated with an installed capacity of 50 GW is around 35 GW. The residual intermediate load (see section 20.7) only comes into play in the afternoon, with peak load occurring in the evening. With increasing expansion of RE, the residual base load disappears.

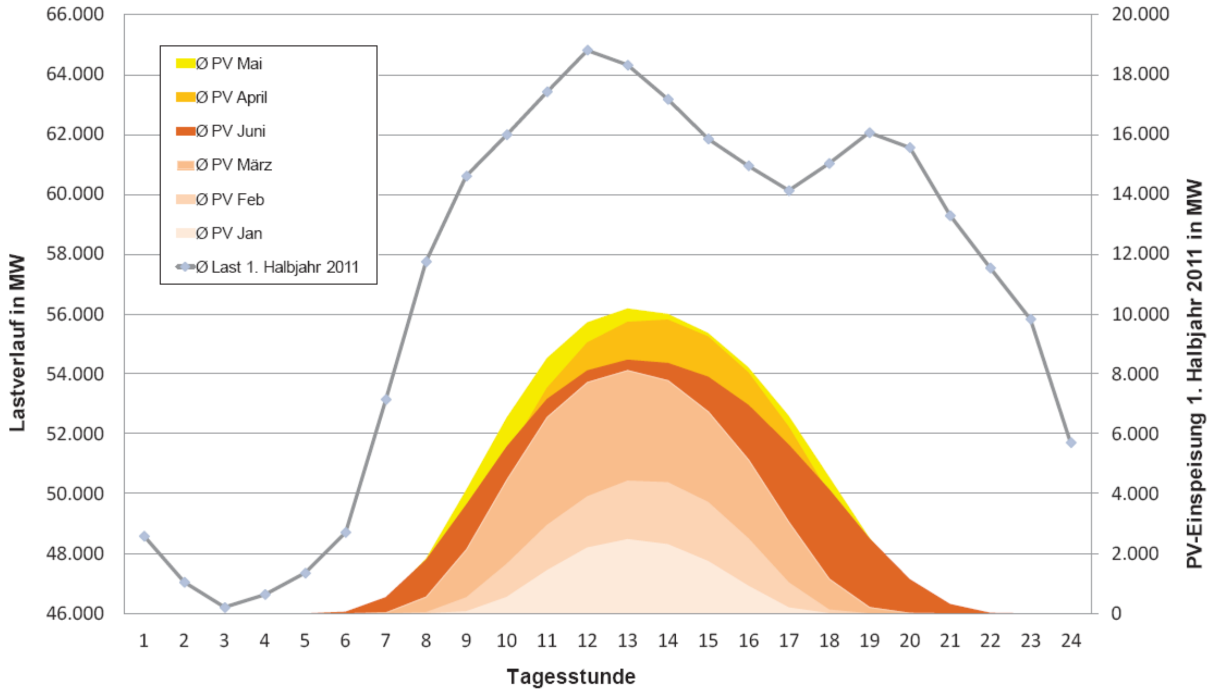


Figure 49: Average load profile and average monthly PV feed-in profiles in the first half of 2011 [IZES].

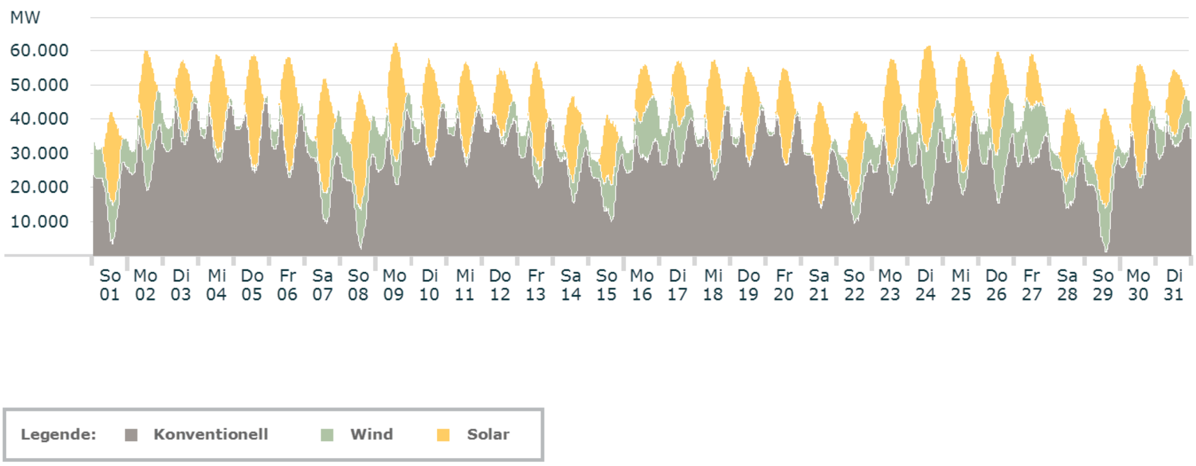


Figure 50: Simulated load profile and energy generation profile based on weather data for a sunny week in May for installed capacities of 50 GW PV and 40 GW wind. Peak powers of 35 GW PV and 21 GW wind are generated respectively. (B. Burger, Fraunhofer ISE)

16.3 Compensatory measures

Despite there being no hard and fast rules for integrating volatile PV power into our energy system on a large scale and in an economically as well as technologically feasible manner, a plethora of complementary measures exist that are suitable for this very purpose. The following sections examine the most important aspects of this in detail.

16.3.1 Keeping PV power generation constant

How can the amount of PV power available in the grid be kept at a constant level? One of the simplest approaches is to increase the installation of roof- and ground-mounted PV modules with east/west orientation. Although in comparison to south orientation this results in lower annual yields per module, daily peaks in PV feed in across Germany last for longer, meaning that complementary power plants do not need to be used until the late afternoon (compare Figure 50). Even more effective in achieving this aim are single and dual-axis tracking systems that in addition to making power production more constant throughout the day, increase the annual yield by between around 15 and 30 percent.

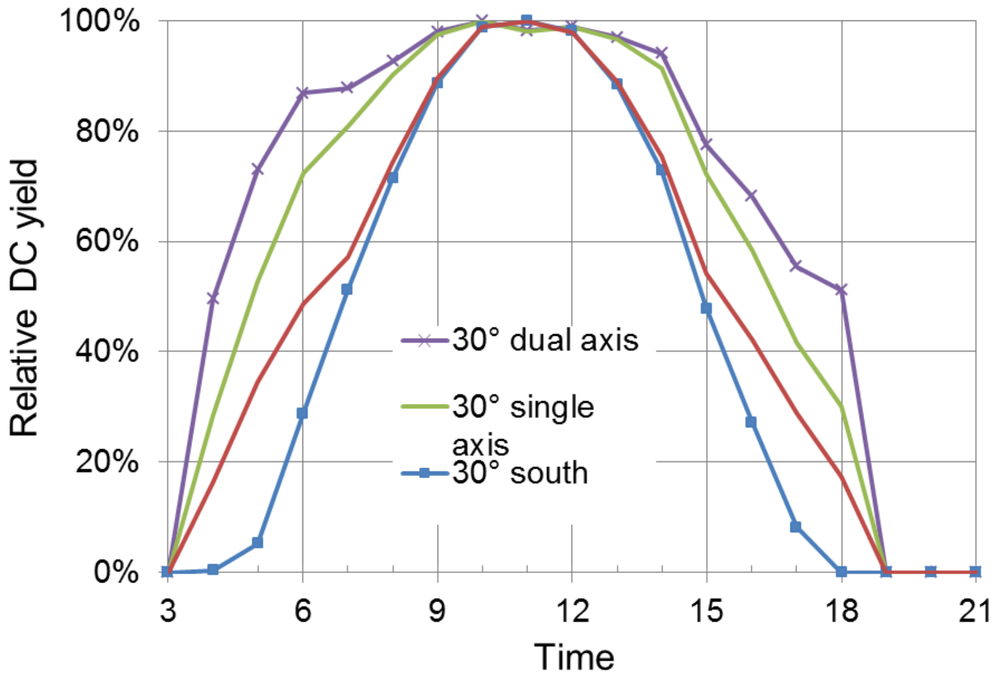


Figure 51: Yield development throughout the course of a day of PV plants installed in a variety of different ways, calculated using the software PVsol on a predominantly clear July day in Freiburg.

Increased on-site consumption and the associated savings as a result of having to purchase less electricity mean that accepting the somewhat higher levelized costs of electricity of the various methods of installing PV modules mentioned above pays off already, especially when the plants are installed for commercial users. The measures to increase the number of full-load hours, which are given in section 13.3., also contribute to the stable supply of electricity from PV.

16.3.2 Complementary operation of adjustable power plants

It is technically possible to operate, design or retrofit many fossil fuel power plants in such a way so as they are able to serve both base and intermediate load requirements (compare Figure 52).
Operating at partial load and any retrofitting that may be necessary for this increases power production costs. Gas-fired power plants in particular are highly suitable for fluctuating loads. However, since PV power is already noticeably reducing price peaks on the energy exchange during the middle part of the day and reduce utilization rates of gas fired power plants, these plants do not currently constitute a worthwhile investment.
Nuclear and old brown coal-fired power plants find it the most difficult to operate flexibly, and the expansion of RE means that they will not survive in the long term. The sooner they make way for flexible power plants, the quicker the switch to PV and wind power shall succeed.

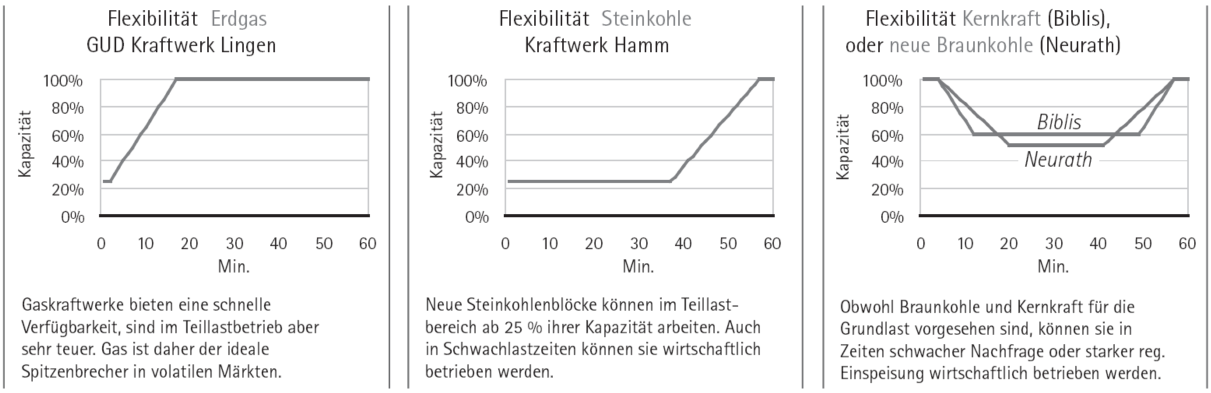


Figure 52: Power plant availability [VGB].

Existing hydroelectric power plants (see section 16.3.8 for information on pumped storage) may make adjustable contributions to the energy supply when operating complementarily to PV power. However, in doing so, they must consider the interests of the shipping industry and the need to protect the environment. While they contributed around 4.5 GW of rated power and roughly 20 GWh of production in 2011 [BMWi1], there is little scope for these levels to be improved on in the future.

	AT	CH	DE	NO	SE
Kapazität von Wasserkraftwerken [MW]	**12.919**	**13.728**	**9.790**	**31.004**	**16.735**
- Speicherwasserkraftwerke	3.744	8.078	335	23.405	10.802
- Pumpspeicherkraftwerke	3.781	1.839	6.521	1.344	108
- Laufwasserkraftwerke	5.395	3.810	2.934	6.255	5.825

Figure 53: Total capacity of hydroelectric power plants in selected countries as of 2010 [Prognos]; the way in which the capacities have been classified into the different power plant types varies according to the data source used.

Norway has about 30 GW of hydroelectric capacity at its disposal [Prognos] with the potential to expand this further. A 600-kilometer underwater cable with a transmission efficiency of 1.4 GW that creates a direct link to the German power grid shall be constructed by 2018. Meanwhile, Switzerland and Austria have 12 and 9 GW of hydroelectric capacity respectively.

Provided their operators provide the required storage systems, biomass power plants (5.3 GW of rated power, 32 GWh of generation, [BMWi1]) also have the potential to operate complementarily to PV power plants.
CHP plants ranging from micro systems built for detached houses (micro combined heat and power) to large-scale plants for district heating networks are excellently suited to complementary operation alongside PV, provided that those managing these CHP plants take both heating and electricity demands into consideration. Around 20 GW of CHP power was connected to the grid in Germany in 2010 [Gores]. Using combustion or Stirling engines to generate mechanical power, even micro CHP plants are capable of achieving electrical efficiencies of up to 25 percent and overall efficiencies of up to 90 percent [LICHTBLICK].
While large-scale thermal storage systems are essential for ensuring that CHP plants are able to operate in a way that is oriented towards electricity demand, these are missing from most existing plants to date. At times when high amounts of power are generated from renewable sources, such storage systems are generally able to be charged via electric heat pumps and during rare peaks in power, they may also be charged via less efficient heat rods. Finally, it is also technically possible to operate gas-fired CHP plants using renewable gas. As a result, CHP plants equipped with storage systems play a key role in switching our energy system to one based on RE.

16.3.3 Increasing the energy efficiency

Measures for improving the energy efficiency in households and in the industry are among the most cost-effective for reducing the residual load. The Stiftung Warentest found, for example, that a house equipped completely with older appliances uses twice as much electricity as a comparable house with energy saving devices [TEST]. Especially effective are measures that reduce the nighttime electricity consumption. In the nighttime solar electricity is available only through storage systems which are, in comparison, costly and less efficient than direct use.

16.3.4 Adapting consumption habits and increasing self-consumption

Raising consumer awareness, the use of timers and, in the future, control signals emitted by transmission lines providing information on the power supply as well as cooling devices with increased thermal mass will change electricity consumption habits in such a way that a significantly greater amount of PV power (also wind by grid control) can be consumed on site (Figure 54). In order to make this possible, some domestic appliances must be capable of communicating with the PV plant on the roof. For self-produced electricity, this can increase the self-consumption by a large amount.

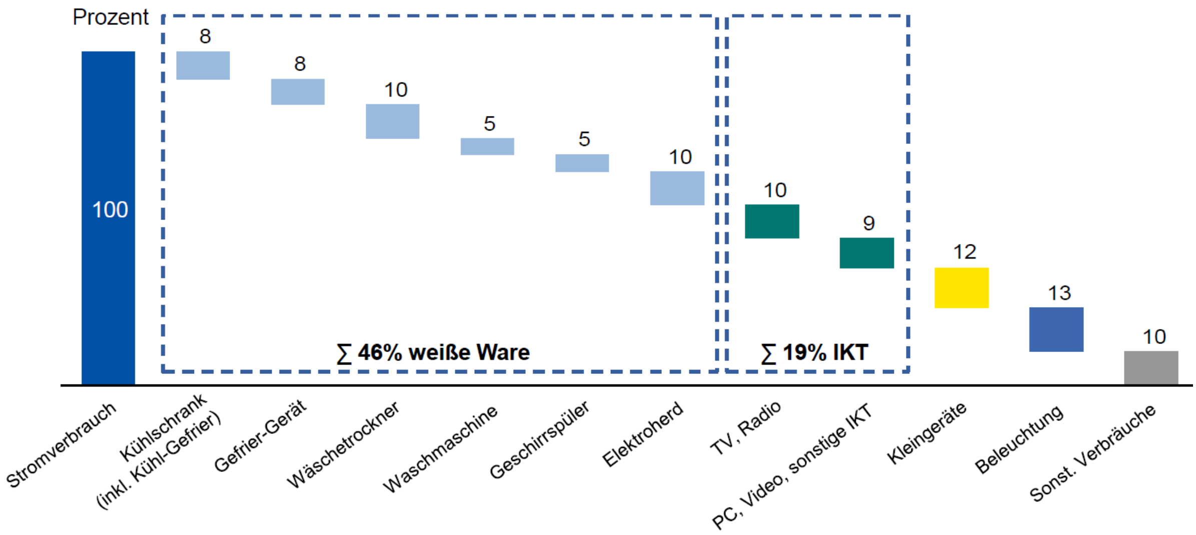


Figure 54: Power consumption of an average household not including hot water production, from [RWE].

On working days, many commercial users are able to achieve a high fraction of self-consumption that can be increased further by employing PV modules fitted with tracking systems.

Regardless of whether solar power is generated on consumers' own roofs, a special solar power tariff applicable during midday would encourage consumers to shift their power consumption into this period. Appliance manufacturers would soon respond to this and develop corresponding programming options for washing machines, tumble dryers and heat pumps.

There are also opportunities to adapt the consumption habits of energy-intensive industrial enterprises. These will only be introduced, however, once the much cheaper power

during the day is more often available, i.e. when the installed PV capacity increases further. Often investments are necessary in order to enlarge the capacity of energy intensive process steps, by decreasing capacity, and in order to increase the amount of interim storage.
The same applies to cold stores and air-conditioning units, for example, whose thermal mass means that they are already equipped with a certain level of storage capacity and the addition of further storage space is cost effective in comparison.
Self-consumption (or captive use) is advantageous because it reduces the need for electricity transport and respectively for balancing the electric grid. Since the PV electricity produced by private and commercial consumers themselves costs much less than the electricity from the grid, this serves as a natural incentive to match one's consumption to the PV production.

16.3.5 Balanced expansion of PV and wind power capacities

In Germany, weather conditions cause a negative correlation between the amount of PV and onshore wind energy generated on scales ranging from hourly to monthly. In terms of hourly fluctuations, the overall amount of actual PV and onshore wind power generated only very rarely exceeds 50 percent of the total rated power, while in terms of monthly changes, the total amount of power produced by both sources is distributed more evenly than the individual amounts generated by each source.
Storage demands shall drop if the combined amount of installed PV and onshore wind power capacities continues to remain at a similar proportion.

16.3.6 Grid expansion

Studies conducted by the Fraunhofer Institute for Wind Energy and Energy System Technology IWES and Ecofys on behalf of BSW have shown that increasing the installed PV capacity to 70 GW by 2020 shall incur costs of approximately 1.1 billion euros in terms of grid expansion alone [IWES], [ECOFYS]. The equivalent annual costs of this grid expansion amount to roughly ten percent of the routine yearly expenditure for strengthening the grid. The studies took into account expanding the low-voltage grid using PV plants that provide ancillary services (e.g. voltage scheduling through reactive power compensation) and partially equipping local distribution transformers with regulating devices.

16.3.7 Switching consumers capable of storing power to electrically operated systems

Switching drive systems allows key groups of consumers to be supplied with electric power. Consumers capable of storing power are able to absorb PV and wind power according to how much is actually available to them. This means that temporary peaks in generation that are greater than the current electricity demand can be utilized, allowing PV plants and wind turbines to be expanded further and their ability to meet power consumption demands to increase.

While space and process water heating is often carried out by burning fossil fuel resources, heat pumps can also be used for this. The efficiency of heat pumps (electric energy to heat) is stated in terms of the seasonal energy efficiency ratio (SEER) and stands at around 300 percent. Once converted into heat, the former electrical energy can be stored efficiently and cost effectively.
For fluctuating energy sources, like wind and solar, without appreciable marginal costs, it is not economical to design the system to meet 100% of the demand at the highest efficiency. At rare times, periods of peak electricity generation must be handled with simple measures, for example, directly converting electricity into heat (albeit inefficient) or as a last case, shutting down the system. This so-called "capping" reduces the annual electricity production by only a few percent.
While motorized forms of transport burn fossil fuels at an extremely low efficiency, electric vehicles with regenerative braking systems significantly increase efficiency. Several vehicle manufacturers sell mass-produced hybrid electric vehicles, which are able to store solar power during the day especially during spring and summer and are capable of traveling for distances of between 10 and 50 kilometers using electricity alone. However, revolutionizing the way we fuel our personal means of transport has really taken off on two wheels: In comparison to around 50,000 hybrid vehicles and a few ten thousand vehicles driven using electricity alone, more than one million electric bikes have been sold in Germany.

16.3.8 Energy storage

Small, stationary batteries at home allow the on-site consumption of PV power to continue into the evening, increasing it significantly (Figure 55).

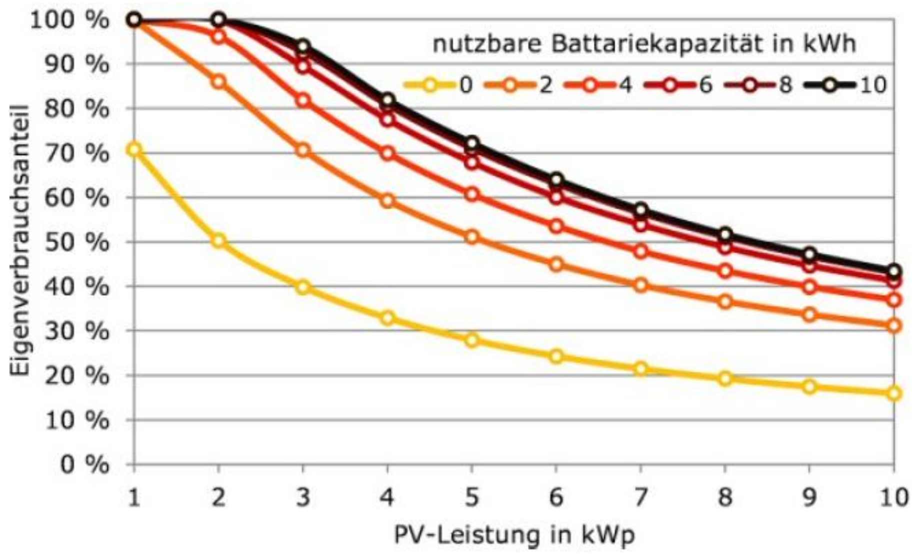


Figure 55: Percent of on-site consumption in dependence of the battery capacity and PV array power for a single-family home with an annual electricity consumption of 4,700 kWh. [Quasch]

A Fraunhofer ISE study showed that systems with a grid-optimized operation can reduce the load on the power grid by reducing both the feed-in to the grid at peak times as well as the electricity purchase in the evenings (Figure 56). Storage systems enable therefore more PV to be built. "Load flow calculations showed that a grid-optimized PV / battery operation reduces the feed-in peak of all systems by about 40%. Results indicate that 66 % more PV / battery could be installed as long as these systems also operate using a grid-optimized feed-in strategy." [ISE7]

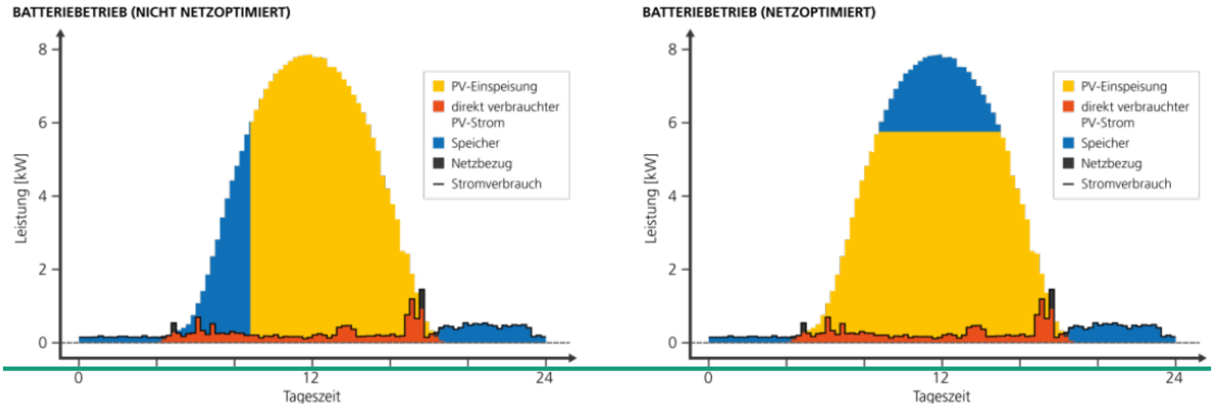


Figure 56: Comparison of the conventional and grid-optimized system operation [ISE7]

We have already made reference to heat pumps equipped with heat storage systems. Depending on the storage system's dimensions, PV power generated on site can assume a significant role in heating process water, and the same can be said of wind power's ability to cover heating requirements.

Centralized storage systems currently only exist in the form of pumped storage. The currently installed pumped storage capacity in the German power grid stands at almost 38 GWh, while rated power is approximately 6.4 GW and the average efficiency value is 70 percent (without taking transmission losses into account). As a comparison, the aforementioned storage capacity corresponds to the yield generated by German PV power plants in the space of fewer than two full-load hours. Around 10 GW of power shall be available by 2019 if only some of the projects currently in the planning stage are realized.

However, it must also be remembered that the German power grid is part of the European integrated power grid. Switzerland has a hydroelectric capacity of around 2 GW, while Austria boasts roughly 4 GW and France approximately 25 GW of hydroelectric power. "As of June 27, 2012, a total of 9,229 MW of pumped storage capacity was connected to the German power grid (net rated power in generator mode). This comprised 6,352 MW in Germany, 1,781 MW in Austria and 1,096 MW in Luxembourg. The capacity of Germany's pumped-storage power plants currently amounts to 37,713 MWh." [Bundesreg]

All neighboring countries have adjustable plants in their pool of fossil fuel power plants and experience high levels of demand during the core hours of the day. Strengthening

cross-border transmission lines allows the European electricity market to make a significant contribution towards evening out PV volatility.
Research is currently being conducted into storing electrical energy in adiabatic compressed air energy storage systems (CAES). The promising conversion and storage of solar and wind power in the form of hydrogen or, where appropriate, methane is currently being scaled and tested, but as of yet no noteworthy capacities exist. Meanwhile, the conversion of renewable power to gas will open up enormous storage possibilities that have already been put in place. The gas grid itself and underground and overground storage systems are able to accommodate more than 200 TWh of energy (equivalent to 720 petajoules).

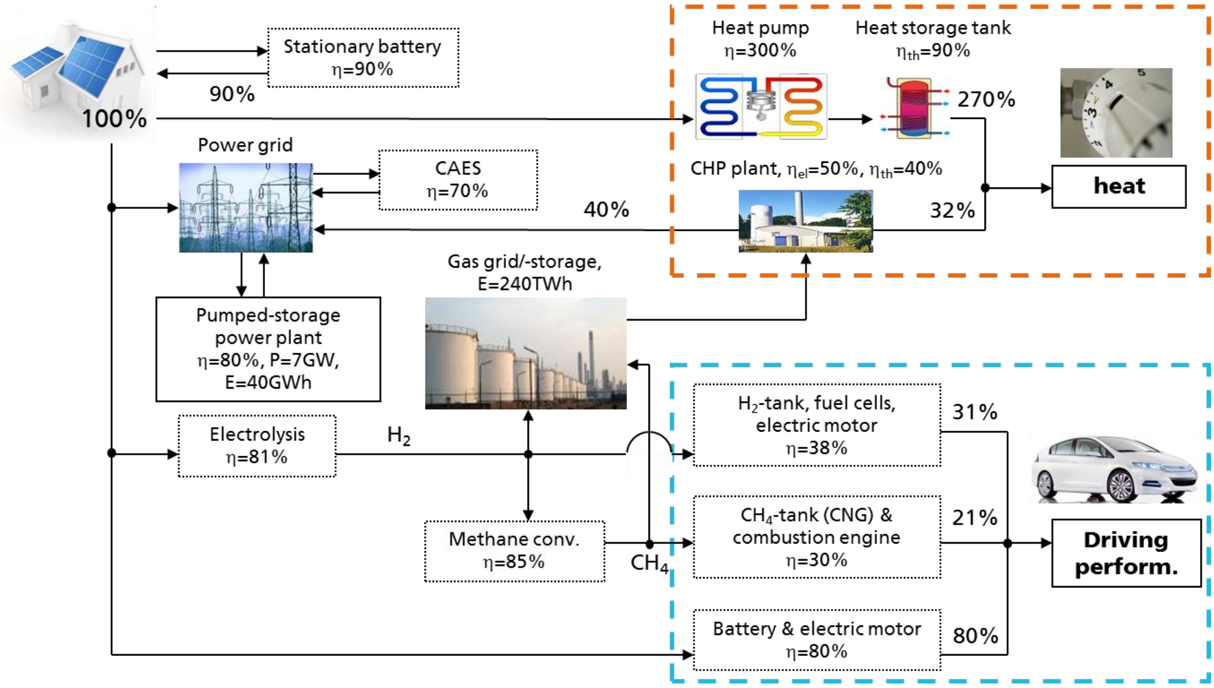


Figure 57: Possible ways of converting and storing PV power with indicative data on efficiency values.

The conversion of power into renewable gas also has the potential to replace fossil fuels in vehicles, albeit with a low level of efficiency. Figure 57 presents an overview of possible ways of converting and storing PV power.

17. Do PV modules contain toxic substances?

17.1 Wafer-based modules

The silicon wafer-based modules (approximately 88 percent of the market share in 2010) produced by many manufacturers often contain lead in the cell metallization layer (around 2 grams of lead per 60-cell module) and in the solder used (approximately 10 grams of lead per 60-cell module). In terms of technology, it is possible to completely substitute the lead for harmless materials at a low additional cost. Other than lead, wafer-based modules do not contain any known toxic substances.

17.2 Thin-film modules

Cadmium telluride (CdTe) thin-film modules (approximately eight percent of the market share in 2010) contain cadmium (Cd) and the technology behind this type of module does not allow for this material to be substituted. Alternative thin-film modules containing little or no Cd are based on amorphous silicon or copper indium selenide (CIS). CIS solar cells contain selenium, which is classified as toxic, and has a particularly poisonous effect when it is oxidized (e.g. following a fire).

17.3 Take-back schemes and recycling

PV producers set up a manufacturer-independent recycling system in June 2010 (PV Cycle), which currently has more than 300 members. The version of the European WEEE Directive (Waste Electrical and Electronic Equipment Directive) which came into force on August 13, 2012 must be implemented in all EU states by the end of February 2014. This directive makes it compulsory for manufacturers to take back and recycle at least 85% of their PV modules free of charge.

18. Are there enough raw materials available for PV production?

18.1 Wafer-based modules

Wafer-based modules do not require any raw materials which could become limited in the foreseeable future. The active cells are fundamentally composed of silicon, aluminum and silver. Silicon accounts for 26 percent of the mass of the earth's crust, meaning that it is virtually inexhaustible. While aluminum is also readily available, the use of silver poses the most problems. The PV industry currently uses approximately **1,500 metric tons** of silver annually [Photon Int. 2011-08], corresponding to almost **seven percent** of production in 2010. In the future, the silver in solar cells will be used more efficiently and replaced by copper as far as possible.

18.2 Thin-film modules

The availability of raw materials depends on the technology being used.

Contradictory statements have been made concerning the availability of tellurium and indium for CdTe and CIS modules respectively. No raw material shortages have been foreseen for thin-film modules made from silicon.

19. Do PV plants increase the risk of fire?

19.1 Can defective PV plants cause a fire to break out?

Yes, as is the case with all electric installations.
Certain faults in the components of PV plants that conduct electricity may cause electric arcs to form. If flammable material lies in close vicinity to these arcs, a fire may break out depending on how easily ignitable the material is. In comparison to alternating current installations, the power supply of solar cells may even stabilize any fault currents that occur. The current can only be stopped by disconnecting the circuit or preventing irradiation reaching any of the modules, meaning that PV plants must be constructed carefully.
With more than one million PV plants in Germany, the combination of all of these factors has been proven to have caused a fire to break out in just a few cases. The majority of the fires started as a result of faults in the cabling and connections.
"Using qualified skilled workers to ensure that existing regulations are adhered to is the best form of fire protection. To date, 0.006 percent of all PV plants have caused a fire resulting in serious damage. Over the past 20 years, 350 solar systems caught fire, with the PV system being at fault in 120 of these cases. In 75 cases, the damage was severe and in 10 cases, the entire building was burned to the ground.
The most important characteristic of PV systems is that they produce direct current. Since they continue to generate electricity for as long as light falls on their modules, they cannot simply be turned off at will. For example, if a low-quality or poorly installed module connector becomes loose, the current flow is not always interrupted immediately, potentially resulting in an electric arc, which, in the worst case scenario, may cause a fire to break out. Accordingly, investigations are being carried out on how to prohibit the occurrence of electric arcs. In addition, detectors are being developed that sound an alarm as soon as only a small electric arc occurs.
PV plants do not present a greater fire risk than other technical facilities. Sufficient regulations are in place that ensure the electrical safety of PV systems and it is imperative that these are followed. Fires often start when systems are fitted by inexperienced pieceworkers. Weak points are inevitable when solar module connectors are installed using combination pliers instead of tools designed especially for this purpose or when incompatible connectors are used, and system operators should not cut costs in the wrong places.
In addition to technical improvements, control regulations are therefore vital. At present, system installers themselves are permitted to confirm that their installations were carried out in compliance with regulations but experts now recommend that acceptance tests are performed by third parties. It has also been suggested that privately owned PV sys-

tems are subjected to a compulsory, regular safety test similar to that performed on commercial plants every four years." [ISE6]

19.2 Do PV plants pose a danger to firefighters?

Yes, as is also the case with many systems fitted with live cables.
Standing at least a few meters away from the fire when extinguishing a fire from outside of the building protects firefighters from electric shocks. This safe distance is normally given for all roof-mounted installations. The greatest risk for firefighters arises when extinguishing a fire from inside the building in areas where live, scorched cables connected to the PV plant come into contact with water or the firefighters themselves. To minimize this risk, the industry is developing emergency switches that use safety relays to separate the modules from their DC connection in close vicinity to the roof.
In Germany, no firefighter has to date been injured by PV power while putting out a fire. An incident widely reported in the press confused solar thermal collectors with PV modules and no PV plant was fitted to the house in question whatsoever.
"Comprehensive training courses for the fire brigade could eliminate any uncertainties firefighters may have. As with every electrical installation, depending on the type of electric arc it is also possible to extinguish a fire using water from a distance of one to five meters. Based on investigations to date, all of the claims stating that the fire brigade could not extinguish a house fire due to the PV system have been found to be false." [ISE6]

19.3 Do PV modules prevent firefighters from starting to extinguish fires externally from the roof?

Yes.
The second "roof covering" created by the PV modules hinders the ability to extinguish the fire, as the water simply drains away. According to the fire brigade, objects damaged by a fire that needs to be extinguished in this way can rarely be saved, i.e. the damage has to a large extent already been done and is irreversible before the PV plant impedes the firefighters' ability to put out the fire.

19.4 Are toxic emissions released when PV modules burn?

Modules containing cadmium are seen as being the most likely to present health risks. The Bavarian Environment Agency (Bayerisches Landesamt für Umwelt) has calculated that the dispersion of fumes following the burning of CdTe modules does not pose a serious risk for the surrounding area and general public [LFU].

20. Appendix: Specialist terminology

20.1 EEG levy

"The EEG levy (EEG-Umlage) is the portion of the electricity price that must be paid by the end user to support renewable energy. It results from the equalization scheme which is described in the Act on Granting Priority to Renewable Energy Sources (EEG). The EEG provides incentives for plants that generate power from renewable energy and which otherwise could not be commissioned as a result of the market situation. Hydroelectric power plants, landfill gas, sewage gas, mine gas, biomass, geothermal energy, wind energy and radiant energy from the sun are supported.
Several stages are used to determine how the costs of promoting electricity generated by renewable energy are allocated to power consumers. In the **first stage**, operators of plants generating power from renewable energy are guaranteed to receive a fixed tariff for all of the power they produce." [Bundestag]
This tariff is based on the levelized cost of electricity of the installed PV plant and is guaranteed for 20 years.

"Grid operators, who connect these plants to their grids and who have to reimburse the plant operators for the power that they have fed in, transmit the power to their appropriate transmission grid operators, who in turn reimburse them for the tariff paid to the plant operators (**second stage**). In the **third stage**, the renewable energy is distributed proportionally between Germany's four large transmission grid operators, compensating for regional differences in the generation of renewable energy.
The Equalization Scheme Ordinance (Ausgleichsmechanismusverordnung, AusglMechV) dated July 17, 2009 resulted in changes being made to the **fourth step** of the remuneration and reimbursement scheme for renewable energy. Until these amendments were brought in, the power generated from renewable energy was simply transmitted to the energy supply companies selling the power via the transmission grid operators at the same price as the applicable feed-in tariff. Transmission grid operators are now, however, being urged to put the power generated from renewable energy on the market via the energy exchange (spot market). This results in the energy supply companies, which ultimately transmit the power to customers, being able to obtain their power from the market regardless of how much renewable energy is fed into the grid, offering them greater planning security and allowing them to make savings. As a result, the costs of the EEG remain first and foremost with transmission grid operators.
These costs are calculated on the basis of the difference between the rate of return generated by the renewable power put on the market (energy exchange) and the feed-in tariffs that are initially paid to plant operators. (...)" [Bundestag]
The amount of money provided by the EEG is equal to the difference between the feed-in tariff and the price of power on the energy exchange. This amount is apportioned to all of the power consumed and this act forms the EEG levy, which is then handed over to consumers by the energy supply companies. "The Equalization Scheme Ordinance (AusglMechV) stipulates that transmission grid operators set the EEG levy on October 15

of each year for the following year. The calculation of the levy is subject to review by the German Federal Network Agency. (...) The EEG levy is limited to 0.05 Euro cents/kWh for energy-intensive companies." [Bundestag].
As a result, energy-intensive industrial enterprises which spend a high proportion of their costs on power are largely exempt from the EEG levy.

20.2 Module efficiency

Unless stated otherwise, module efficiency is given in terms of nominal efficiency. Under standard test conditions (STC), it is calculated in terms of the relationship between the amount of electricity generated and the level of irradiation on the module's total surface area. STC include in particular a module temperature of 25 °C, vertical irradiance of 1000 W/m^2 and a specific irradiance spectrum. During actual operation, conditions are normally so different from these standard conditions that efficiency varies.

20.3 Rated power of a PV power plant

The rated power of a power plant is the ideal DC output of the module array under STC, i.e. the product of the generator surface area, standard irradiance (1000 W/m^2) and nominal efficiency of the modules.

20.4 Specific yield

The specific yield [kWh/kWp] of a PV plant is the relationship between the useful yield (alternating current yield) over a certain period of time (often one year) and the installed (STC) module capacity. The useful yield is influenced by actual operating conditions, such as module temperature, solar radiation intensity, angle of light incidence, spectral deviation from the standard spectrum, shading, snow cover, transmission losses, conversion losses in the inverter and, where applicable, in the transformer, and operational failures.
Manufacturer data on module output under STC may vary from the actual value, making it imperative that information on tolerances are checked.
The specific yield is generally higher in sunny locations but it is not dependent on nominal module efficiency.

20.5 System efficiency

The system efficiency of a PV plant is the relationship between the useful yield (alternating current yield) and the total amount of irradiance on the generator surface area. The nominal module efficiency affects system efficiency.

20.6 Performance ratio

The performance ratio is often used to compare the efficiency of grid-connected PV plants at different locations with various module types.
Performance ratio comprises the relationship between a plant's useful yield (alternating current yield) and ideal yield (the product of the total amount of irradiance on the generator surface area and nominal module efficiency).
New, carefully planned plants achieve annual PR values of between 80 and 90 percent.

20.7 Base load, intermediate load, peak load, grid load and residual load

"Power demands fluctuate throughout the course of the day, generally peaking during the day and falling to a minimum at night between midnight and 6:00am. Power demand development is depicted as a load curve or load profile. In traditional energy technology, the load curve is divided into three sections as follows:

1. base load
2. intermediate load
3. peak load

Base load describes the load line that remains almost constant over a 24-hour period. It is covered by base-load power plants, such as nuclear power plants, brown coal-fired power plants and, for the time being, run-of-the-river power plants.
Intermediate load describes self-contained peaks in power demand which are easy to forecast and refers to the majority of power needed during the course of a day in addition to base load. Intermediate load is covered by intermediate-load plants, such as hard coal-fired power plants and combined cycle power plants powered by methane with oil-fired power plants being used now and again. Peak load refers to the remaining power demands, generally only coming into play during parts of the day when demand is at its highest. Peak load is handled by peak-load power plants, such as gas turbines and pumped-storage power plants. These can be switched to nominal output within an extremely short space of time, compensating for fluctuations and covering peaks in load." (…) "Grid load refers to the amount of electricity taken from the grid, while residual load is the grid load less the amount of renewable energy fed in." [ISET1]

20.8 Net and gross power consumption

Net power consumption is the amount of electrical energy (final energy) used by the end consumer. It does not take into account transmission losses or energy consumed by the power plants themselves. PV plants predominantly generate energy decentrally when electricity demand is at a peak and the amount of energy they use does not reduce the PV yield by a noteworthy amount. As opposed to following the custom of comparing

output with gross power consumption, it is therefore plausible to compare PV power production with net power consumption. Generating and distributing power using conventional fossil fuel and nuclear power plants results in a gross power consumption that is around 18 percent greater than net power consumption.
Gross power consumption is calculated as the sum of gross power generation and the balance of power exchanged with bordering countries.

20.9 External costs [DLR]

"In terms of technological external effects, external costs predominantly arise in relation to the damage inflicted on the environment, climate and human health as a result of pollutant and noise emissions caused by economic activities. These include:

- damage to flora and fauna, materials and human health caused by air pollution; the majority of damage caused by air pollution is attributable to converting and using energy (including transportation).
- emerging effects of climate change caused by the increasing accumulation of CO_2 and other greenhouse gases in the atmosphere and its consequences; in Germany, 85 percent of these gases are emitted by the energy sector.
- damage caused by pollution to bodies of water, soil contamination, waste and noise pollution. As this study concentrates solely on classic airborne pollutants and greenhouse gases generated as a result of converting energy, these are not dealt with further."

21. Appendix: Conversion tables [EEBW]

Vorsätze und Vorzeichen

k	Kilo	10^3	Tausend
M	Mega	10^6	Million (Mio.)
G	Giga	10^9	Milliarde (Mrd.)
T	Tera	10^{12}	Billion (Bill.)
P	Peta	10^{15}	Billiarde (Brd.)

Umrechnungen

		PJ	GWh	Mio. t SKE	Mio. t RÖE
1 PJ	Petajoule	1	277,78	0,034	0,024
1 GWh	Gigawattstunde	0,0036	1	0,00012	0,000086
1 Mio. t SKE	Mio. Tonnen Steinkohleeinheit	29,31	8.141	1	0,70
1 Mio. t RÖE	Mio. Tonnen Rohöleinheit	41,87	11.630	1,43	1

Typische Eigenschaften von Kraftstoffen

	Dichte [kg/l]	Heizwert [kWh/kg]	Heizwert [kWh/l]	Heizwert [MJ/kg]	Heizwert [MJ/l]
Biodiesel	0,88	10,3	9,1	37,1	32,6
Bioethanol	0,79	7,4	5,9	26,7	21,1
Rapsöl	0,92	10,4	9,6	37,6	34,6
Diesel	0,84	12,0	10,0	43,1	35,9
Benzin	0,76	12,2	9,0	43,9	32,5

Typische Eigenschaften von festen und gasförmigen Energieträgern

	Dichte [kg/l] bzw. [kg/m³]	Heizwert [kWh/kg]	Heizwert [kWh/l] bzw. [kWh/m³]	Heizwert [MJ/kg]	Heizwert [MJ/l] bzw. [MJ/m³]
Steinkohle	-	8,3 - 10,6	-	30,0 - 38,1	-
Braunkohle	-	2,6 - 6,2	-	9,2 - 22,2	-
Erdgas H (in m³)	0,76	11,6	8,8	41,7	31,7
Heizöl EL	0,86	11,9	10,2	42,8	36,8
Biogas (in m³)	1,20	4,2 - 6,3	5,0 - 7,5	15,0 - 22, 5	18,0 - 27,0
Holzpellets	0,65	4,9 - 5,4	3,2 - 3,5	17,5 - 19,5	11,4 - 12,7

22. Appendix: Abbreviations

CHP plant	Combined heat and power plant – a plant that uses combustion engines or gas turbines to generate electrical energy and heat
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BSW	German Solar Industry Association
CCS	Carbon dioxide capture and storage – segregation of CO_2 from power plant emissions and storage in geological formations
RE	Renewable energy
EEG	Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act, EEG)
ESC	Energy supply company
IEA	International Energy Agency
ICT	Information and communications technology
CHP	Combined heat and power – the principle of simultaneously generating mechanical energy (ultimately converted into electrical energy) and useful heat
PV	Photovoltaics
W_p	Watt peak – rated power of a PV module or array

23. Appendix: Sources

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24. Appendix: Figures