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Recent Facts about Photovoltaics in Germany

Last update: **January 3, 2018**

Compiled by
Dr. Harry Wirth
Division Director Photovoltaics
Modules and Power Plants
Fraunhofer ISE

Contact:
Karin Schneider
Press and Public Relations
Phone +49 761 4588-5147
Fraunhofer Institute for Solar Energy Systems ISE
Heidenhofstrasse 2
79110 Freiburg
Germany
info@ise.fraunhofer.de

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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 power production. This compilation of current facts, figures and findings is regularly updated. It aims to help in creating an overall assessment of PV growth in Germany.

2. Are we reaching our annual capacity target?

No.

In 2017, **2.1 GW** new PV capacity was installed in Germany [ISE4], which corresponds to about 2% of total new PV capacity worldwide. In the German Renewable Energy Act EEG 2014 and 2017, the federal government set down an annual target of 2.5 GW PV [EEG]. To meet most of or all of Germany's energy demand with renewables by 2050, ca. 150-200 GW PV installed capacity is required by 2050 [ISE5, IWES2]. This means that an average of **4-5 GW** PV must be installed annually up to 2050. With time, the older PV systems must be replaced. As of now, replacing installations have not played a large role. Once the targeted capacity of 200 GW PV has been reached and assuming an operating life of 30 years, estimates show that **6-7 GW** PV must be replaced each year.

3. Does PV contribute significantly to the power supply?

Yes.

According to estimates, PV-generated power amounted to **about 40 TWh** [BDEW5] and covered approximately **7.2 percent** of Germany's net electricity consumption including grid losses (final energy, see section 22.8) in 2017. Renewable energy as a whole (RE) accounted for ca. **39 percent** of net electricity consumption, while PV and total RE in accounted for ca. **6.7 percent** and **36 percent of** Germany's gross electricity consumption respectively**.** On sunny weekdays, PV power can cover 35 percent of the momentary electricity demand. On weekends and holidays the coverage rate of PV can reach 50 percent. At the end of 2017, the total nominal PV power installed in Germany was ca. **2.8** GW, distributed over **1.6 million** power plants.

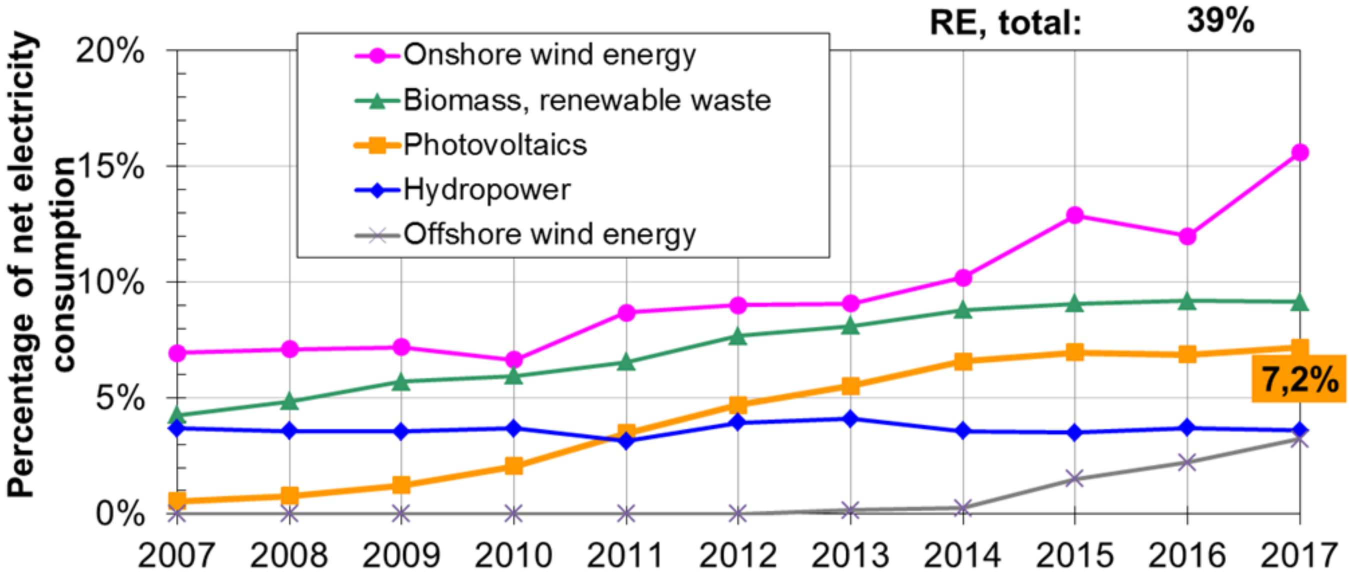


Figure 1 Percentage renewable energy in net electricity consumption (final energy) for Germany, data from [BMWi], [AGEB5]

4. Is PV power too expensive?

It depends on the benchmark used.

It is difficult to compare the costs of PV electricity with fossil and nuclear electricity since the external costs are ignored (see section 22.9, [DLR1], [FÖS1], [FÖS2]). The marginal costs for nuclear power are in the order of only 1 €-ct/kWh, for coal-fired power 3-7 €-cts/kWh, for gas-fired power 6-9 €-cts/kWh. The fixed costs of power generation (e.g. investments, capital) are added on top of this. The cost of the fuel is included in the marginal costs yet not the cost of treating the waste.

Although an emissions trading system has been implemented for the energy sector EU-wide to make CO_2 emissions more expensive and to internalize costs to some extent. Due to an overabundance of available certificates, however, the price collapsed in part because the expansion of renewable energy was not considered and also because of the drop in fuel costs. Estimates of the direct and indirect follow-up costs also facing Germany in the coming years due to global climate change are not yet known. Expenditures for dismantling the nuclear power plants which have been shut down are most probably not covered by the operator’s reserves. The creation and maintenance of permanent storage sites for nuclear waste in Germany will probably cost much more than the 23 billion euros given to the German states for storing Germany’s nuclear waste. Damages from nuclear accidents are covered up to 250 million euros by the insurance company and up to 2.5 billion euros by an operator pool. For amounts above this, the nuclear power plant operator is liable with its assets. [ATW1]. As a comparison, damage caused by the Fukishima nuclear disaster amounted to ca. 100 billion euros, a value which is many times higher than the company value of the German nuclear power plant operators. The uncovered risks are carried by the tax payers.

In new MW power plants, PV electricity is produced at costs starting at 4-5 €-cts/kWh, under the condition that the all of the produced electricity is directly fed into the grid. The power produced by the older, smaller power plants is much more expensive, due to the previously higher investment costs. In order to bring on the energy transformation and foster investments in PV systems of all sizes, the German Renewable Energy Sources Act RES (Erneuerbare Energien Gesetz EEG) was created in 2000. This instrument guarantees a fixed rate of purchase and enables plant operators to run their installations with an appropriate profit. The aim of the Renewable Energy Source Act is to effect a continual reduction in the cost of electricity generation from renewables by creating a market for RE systems. (See section 4.1).

Increasing PV capacity is only one of the costs in Germany's energy transformation. For a long time, the costs associated with PV expansion stood in the forefront of the discussions. Over the past few years, PV and wind have an established place in Germany's energy supply system, bringing new costs to the fore. Besides the costs for electricity generation, costs in the following areas are becoming increasingly significant:

- Expanding the north-south power lines for wind power
- Shutdown of nuclear power plants
- Dismantling and modification of fossil power plants to enable a more flexible operation during reduced utilization
- Build up storage and converter capacities i.e. for grid-stabilization (stationary batteries and electric mobility, pumped storage, heat pumps, heat storage, Power-to-X)

These costs are not caused by the increase in PV installations but rather, as with the expansion of PV itself, are associated with the normal progression of the energy transformation. All energy consumers for whom a long-term sustainable energy supply must be created are, in turn, responsible for the costs of its realization.

4.1 Levelized Cost of Energy

The levelized cost of energy (LCOE) for a PV power plant is the ratio between the total costs of the plant (€) and its total electricity production (kWh) over its economic lifetime. The LCOE for PV power plants [ISE1] is based primarily on:

1. purchase investments to construct and install the plant
2. financing conditions (return on investment, interest, plant lifetime)
3. operating costs over the lifetime of the plant (insurance, maintenance, repairs)
4. irradiance availability

5. lifetime and the annual degradation of the power plant

Thanks to technological progress, the learning curve and economies-of-scale, the investment costs for PV power plants, which make up the greatest outlay, have fallen an average of **13 percent** per year – in all, 75 % since 2006. Figure 2 shows the price development since 2006 for rooftop installations between 10 kW_p to 100 kW_p in Germany.

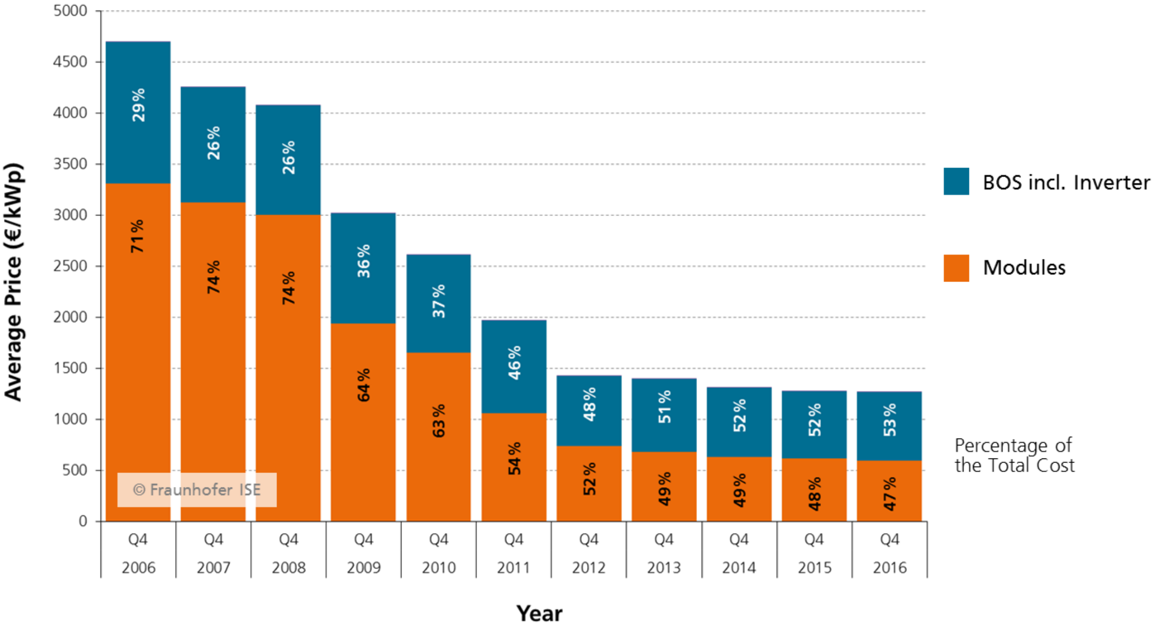


Figure 2: Average end customer price (net system price) for installed rooftop systems with rated nominal power from 10 - 100 kWp, data from BSW, plotted by PSE AG.

Module costs are responsible for almost fifty percent of the total investment costs of a PV power plant this size. This percentage increases for larger power plants. The price development of PV modules follows a so-called "price learning curve," in which doubling the total capacity installed causes prices to fall by a constant percentage. Figure 3 shows the global prices adjusted for inflation and calculated in euros. At the end of 2016, the cumulative installed PV capacity worldwide reached approximately **300 GW**. Provided that significant progress continues to be made in product development and manufacturing processes, prices are expected to keep dropping in accordance with this rule.

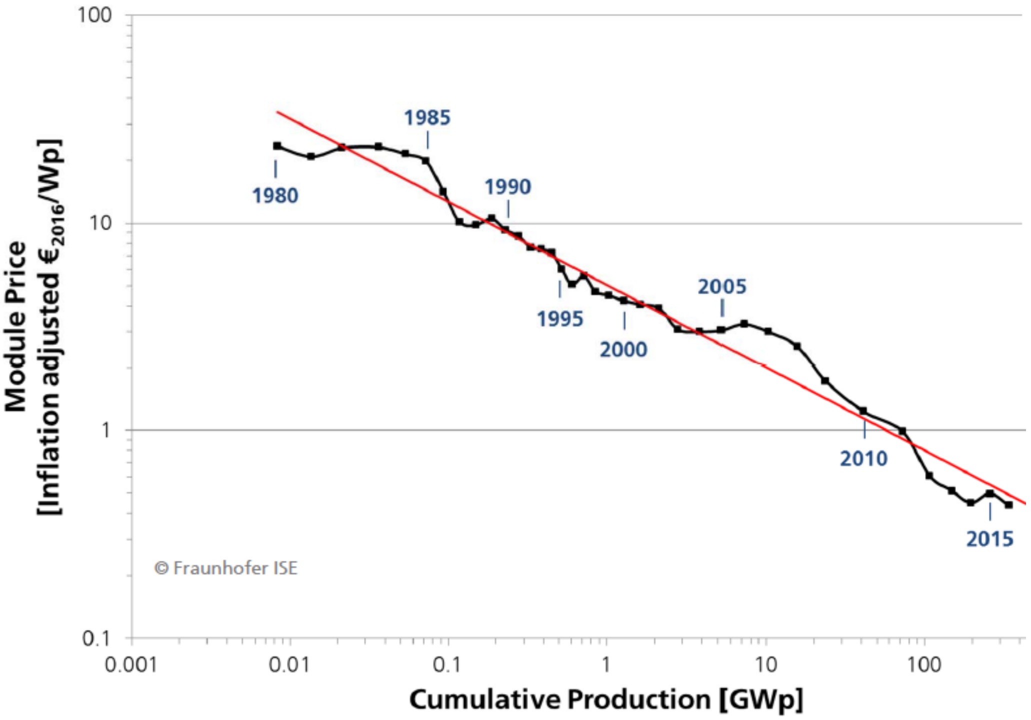


Figure 3: Historical price development of PV modules (PSE AG/Fraunhofer ISE, data from: Strategies Unlimited/Navigant Consulting/EuPD). The straight line shows the price development trend.

The average price shown includes all market-relevant technologies in the fields of crystalline silicon and thin-film technology. The trend indicates that doubling the cumulative installed PV capacity results in a price reduction of 24 percent. In Germany module prices lie about 10-20% higher than on world market, due to anti-dumping measures of the European Commission. The licensing round of the Federal Network Agency (see following section) gives a benchmark for the electricity generation costs for new open-field PV systems (< 10 MW).

4.2 Feed-in Tariff

The German energy transformation has required and will continue to require large investments in solar and wind capacity. In order to build a PV power plant today, an investor needs a purchasing guarantee that stipulates a fixed price over the economic life of the power plant. Otherwise, the investor may delay his investment based on trends that show PV power plant costs continue to decline (deflation). Since all the installed PV power plants produce electricity at the same time, the more expensive electricity from the older power plants becomes no longer competitive with time, if no price guarantee is in place.

To delay PV expansion in hopes of lower costs in the future would not only be a cynical reaction with respect to the progressing climate change but would also slow down the

dynamics of cost reductions. The first EEG in 2000 and the subsequent changes have shaped the growth of PV installments in Germany.
The EEG 2017 specifies a fixed expansion corridor for RE as a share of gross electricity consumption, attempting to both support and restrict the growth in PV capacity.

- For systems above a certain nominal power (ca. 10 kW), self-consumed PV energy is subjected to an EEG levy. (Section 4.7)
- New PV systems up to 100 kWp receive a fixed feed-in tariff
- New PV systems between 100 and 750 kWp must sell their energy by direct marketing.
- New PV systems over 750 kWp are required to partake in calls for tender and may not be used for self-production.
- Numerous other regulations exist regarding potential areas for installations, the capability of remote power control and power reduction, among others.

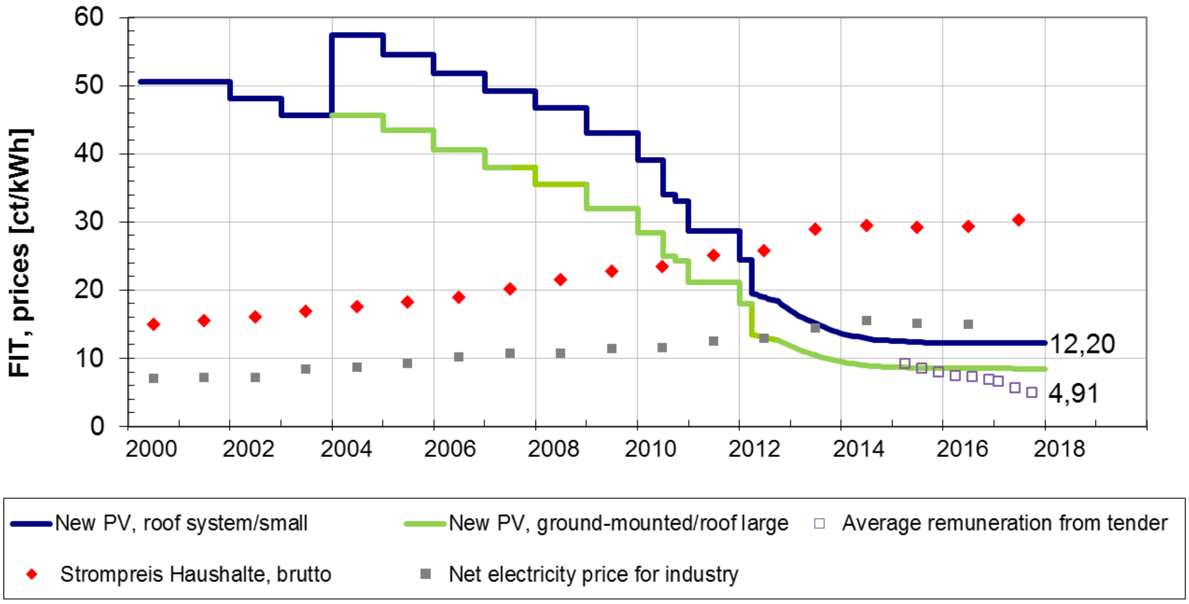


Figure 4: Feed-in tariff for PV power as a function of commissioning date, average remuneration of the bidding rounds of the Federal Network Agency, electricity prices from [BMWi1] up to 2016 and with estimates thereafter.

Depending on the system size, the feed-in tariff for small roof systems put into operation by January 2018 can be up to **12.20 €-cts/kWh** and is guaranteed to the operator over the next twenty years. For medium-size systems from 750 kW up to 10 MW, the feed-in tariff is set by the licensing agreement. The last licensing round of the Federal Network Agency in September 2017 set a mean value of 4.91 €-cts/kWh.

To compare: The second tender for electricity from onshore wind systems in 2017 brought an average price of 4.28 €-cts/kWh. On the global scale PV electricity prices in locations with high radiation levels has been offered at record low levels between 1.5 –

2.5 cts/kWh (e.g. in Saudia Arabia for a 300 MW plant). In constrast, the negotiated strike price for the planned nuclear plant Hinkley Point C in England translates essentially to a feed-in tariff of 12 €-cts/kWh plus inflationary adjustment for a period of 35 years. The plant is planned to start operation in 2025.

The EEG feed-in tariff for PV electricity is decreasing faster than for any other renewable energy technology. In 2011 newly installed, large-scale plants already achieved grid parity. Since then the feed-in tariff they receive lies appreciably below the (gross) value for household electricity. Since the beginning of 2012, newly installed, small rooftop installations have also reached grid parity.

Grid parity for these installations marks a crucial milestone that was almost utopian just ten years ago during the early phase of the EEG, but it should not suggest any comparison of the levelized cost of energy, or LCOE.

The user who consumes self-generated electricity can by no means consider the difference between the gross electricity price (electricity from the grid) and the EEG feed-in tariff (estimated value of the electricity generation costs) as profit. For one, self-consumption increases the fixed costs per kilowatt-hour withdrawn. Considering that the same connection costs are distributed over a smaller amount of withdrawn electricity, the electricity purchased per kWh becomes more expensive. Also, the electricity withdrawn from a PV system for self-consumption may be subject to extra taxes and charges. These can reach appreciable values, depending on the tax classification of the system [SFV]. Electricity produced by PV systems > 10 kWp which were put into operation after August 2014 are subjected to a portion of the EEG levy.

July 1, 2013 was an important date for grid parity. On this day, the remuneration for the electricity generated from newly installed free-standing PV systems reaches a level close to the estimated full costs for fossil and nuclear electricity [IFNE].

After 2020, the feed-in tariff will gradually expire for the oldest plants, as their 20-year payment period is reached. However, these plants will continue to supply power at levelized costs that undercut those of all other fossil fuel and renewable energy sources, due to low operating costs and zero fuel costs.

Due to the extreme drop in the feed-in tariff and the increasing amount of limitations on new installations, grid feed-in and self-consumption, the number of new PV installations in Germany has declined by over 80 % from 2013 to 2016. In the same period, however, new PV installations worldwide have more than doubled.

Up to April 2012, the value of the feed-in tariff given to plant operators for PV electricity decreased in irregular time steps, leading to unpredictable growth patterns in PV capacity. This problem was solved by implementing a monthly adjustment scheme.

4.3 Total Remunerations Paid

As stipulated in the EEG, the total costs for the remuneration of PV feed-in are determined each year by the transmission system operators (Figure 5). In 2015 the total costs amounted to 10.6 billion euros. The already radical reduction in feed-in rates and system size in addition to the phase out of the EEG feed-in tariff for new PV systems at a threshold of 52 GW capacity ensures that total remunerations paid for PV are limited to 10 -11 billion euros per year [ÜNB]. Further PV expansion within the existing EEG will only moderately increase total remunerations (Figure 5). Additional measures to throttle PV expansion will not lead to a decrease in the total remuneration. Such a measure-could, however, cause a slowdown in the construction of very inexpensive PV systems.

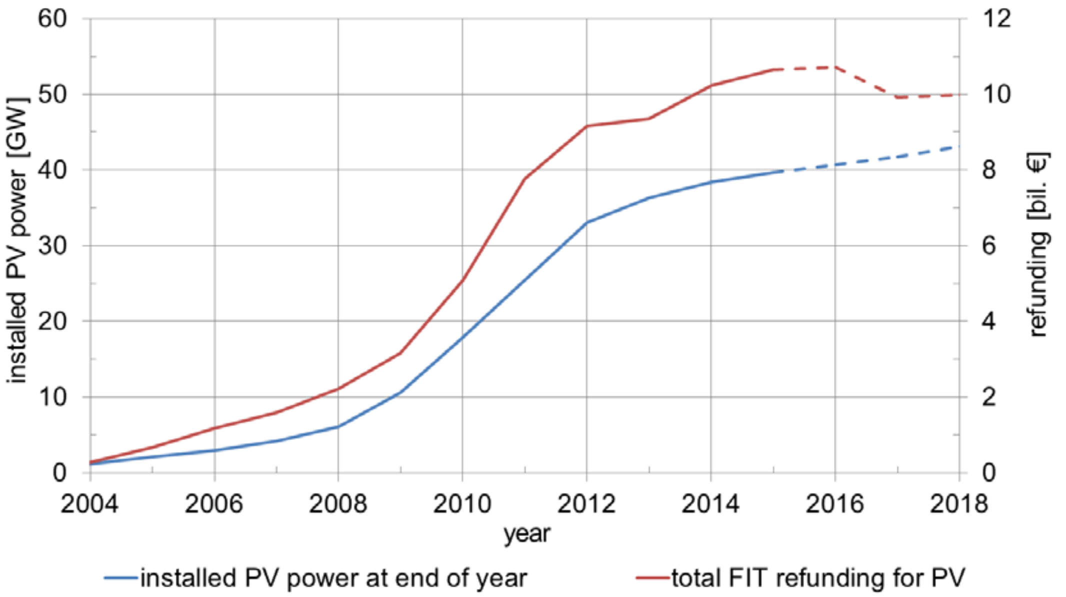


Figure 5: PV expansion and total feed-in tariff (Data from [BMWi1]), annual figures and prognosis of German grid operators [ÜNB].

4.4 Pricing on the energy exchange and the merit order effect

To estimate sales revenues from PV electricity, a mean electricity price is calculated based on the prices achieved on the European Energy Exchange. The running EEX price is determined by the merit order principle. Plant operators offer specific quantities of electricity, defined mostly by their marginal costs, and ranked in ascending order of price (Figure 6). 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 influences the profit margins of the cheaper suppliers.

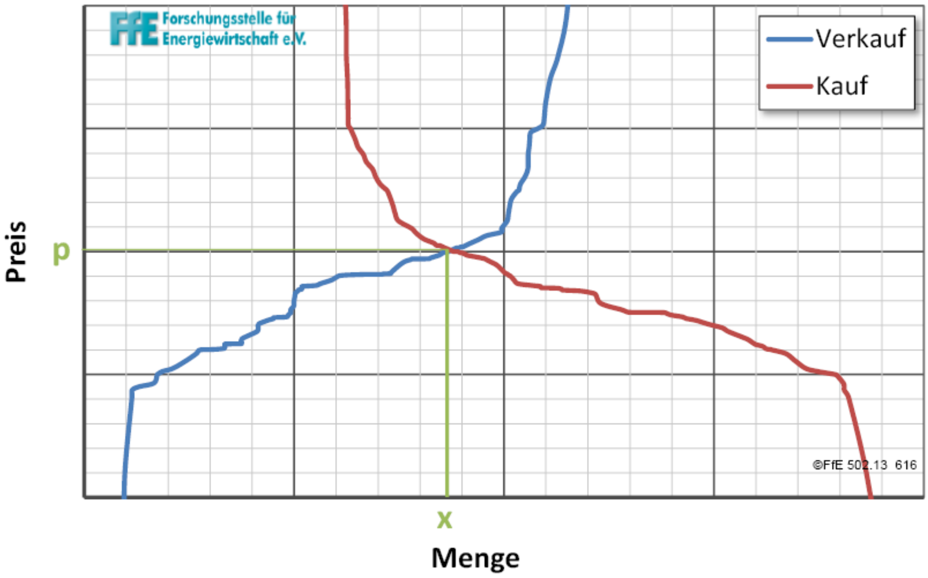


Figure 6: Pricing on the European Energy Exchange EEX [Roon].

PV power feed-in has legal priority, meaning that it is found at the start of the pricing scale due to the merit order effect. With fictitious marginal costs of zero, PV power is always sold when available. PV power is predominantly generated during the middle of the day when power consumption (and previously, but no longer, the electricity price) is at its midday peak. During these periods, PV power mainly displaces electricity from expensive peak-load power plants (especially gas-fired plants and pumped-storage). This displacement lowers the spot price of electricity on the market and leads to the merit order effect of PV feed-in (Figure 7). With sinking market prices, the profits of all conventional power plants (nuclear, coal, gas, hydro) also decrease. Further, solar PV electricity lowers the capacity utilization of the traditional peak-load power plants (gas and hydro in particular.)

In 2011, approximately one third of all the power generated in Germany was traded on the energy exchange [EEX]. It is, however, to be assumed that pricing on the energy exchange has a similar influence on over-the-counter prices on the futures market [IZES].

The increasing amount of renewable electricity being fed into the grid, lower coal prices and surplus of CO2 allowances have drastically depressed prices on the EEX (Figure 8).

On the electricity market, PV power had an average market price factor of 1 over the course of the year. This means that the revenue per kWh is equivalent to the average electricity price on the exchange. The market price factor for wind was about 0.9 [ÜNB]. With the futher expansion of volatile RE, the market price will decrease on the medium term because the electricity supplied increases with higher feed-in and the feed-in is controlled by the supply side.

With increasing feed-in of renewable electricity, the EEX becomes more and more a market for residual electricity, generating a price for the demand-related provision of renewable electricity and no longer reflecting the value of electricity.

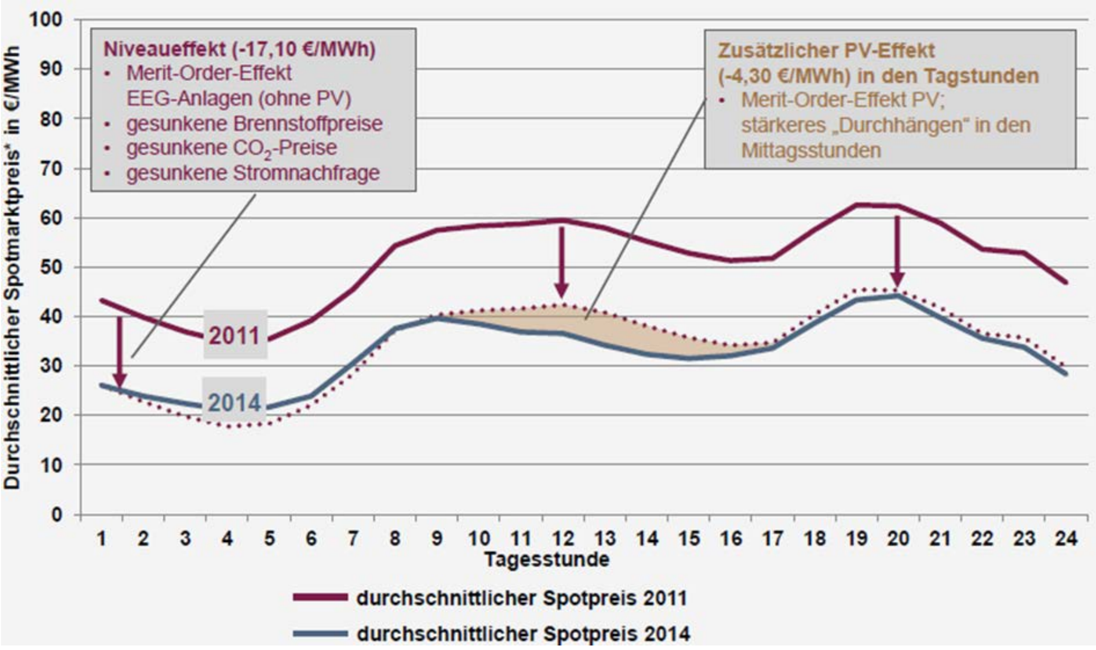


Figure 7: Influence of RE on the average spot price on the energy exchange (EEX) [BDEW2].

4.5 Determining the Differential Costs

The differential costs shall cover the gap between the remunerations paid out according to the EEG promotion and the sales revenue collected from PV electricity. Following a peak of almost 7 €-cts/kWh, the spot price of electricity, used to determine the differential costs, has since fallen to below 4 €-cts/kWh. The amount of electricity from PV and wind that is fed into the grid is increasing. This reduces the spot market price through the merit order effect and thereby, paradoxically increases the calculated differential costs. According to this method, the more PV installed, the more expensive the kWh price of PV appears to be. Price drops in coal and CO_2 allowances similarly reduce the spot price and thus increase the calculated differential costs.

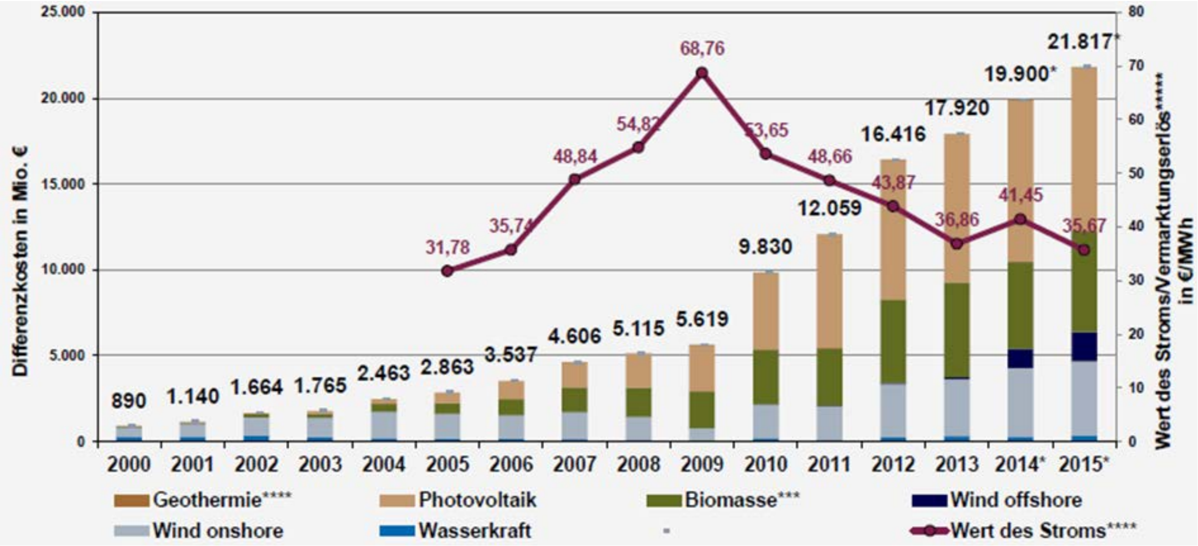


Figure 8: Development of the average spot electricity price and the calculated differential costs [BDEW2].

4.6 *Privileged Electricity Consumers*

Policy makers determine who shall finance the transformation to renewable energy [BAFA]. They decided that energy-intensive industries, i.e. those who spend a high proportion of their costs on electricity, are to be exempted from the EEG surcharge to a large extent. In 2015, industries were relieved of costs totaling ca. 4.8 billion euros. The total electricity of 107 TWh falling under this exemption amounts to almost one-fifth of Germany's entire power consumption. Figure 9 shows the estimated breakdown of the EEG surcharge paid by industry in 2015. This wide-scale exemption increases the burden on the other electricity customers, in particular, private households, who account for almost 30 percent of the total power consumed.

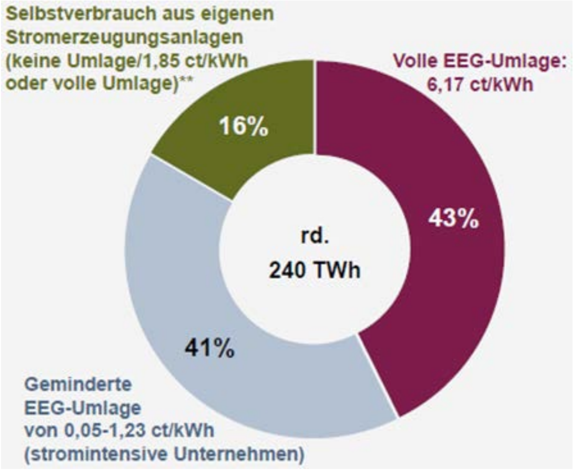


Figure 9: Electricity consumed and EEG surcharge for industry (estimated for 2015) [BDEW24]

The surcharge exemption for privileged customers as set down in the EEG has further increased the nominal EEG surcharge per kilowatt hour (see Section 5.5). At the same time, energy-intensive industries are benefiting from the lower spot prices on during peak-power times. It is evident that part of the surcharge indirectly ends up in the pockets of these energy-intensive industries: "Energy-intensive companies, which are either largely exempt from the EEG surcharge or pay a reduced rate of 0.05 €-cts/kWh, benefit the most from the merit order effect. For these companies, the lower prices brought about by the merit order effect overcompensates for the costs incurred as a result of the EEG surcharge by far." [IZES] Energy-intensive companies therefore benefit from the energy transformation without making a noteworthy contribution.

4.7 EEG Surcharge

The difference between the remunerations paid out and the sales revenues generated from renewable electricity (supplemented by other items) is compensated for by the EEG surcharge (Figure 10). The cost of the surcharge is borne by those power consumers, who do not fall under the exemption scheme. For 2018, the EEG surcharge is set at **6.792 €-cts/kWh**. End users must pay value added tax (19%) on this surcharge so that the costs imposed on private households increases to **8.08 €-cts/kWh**.

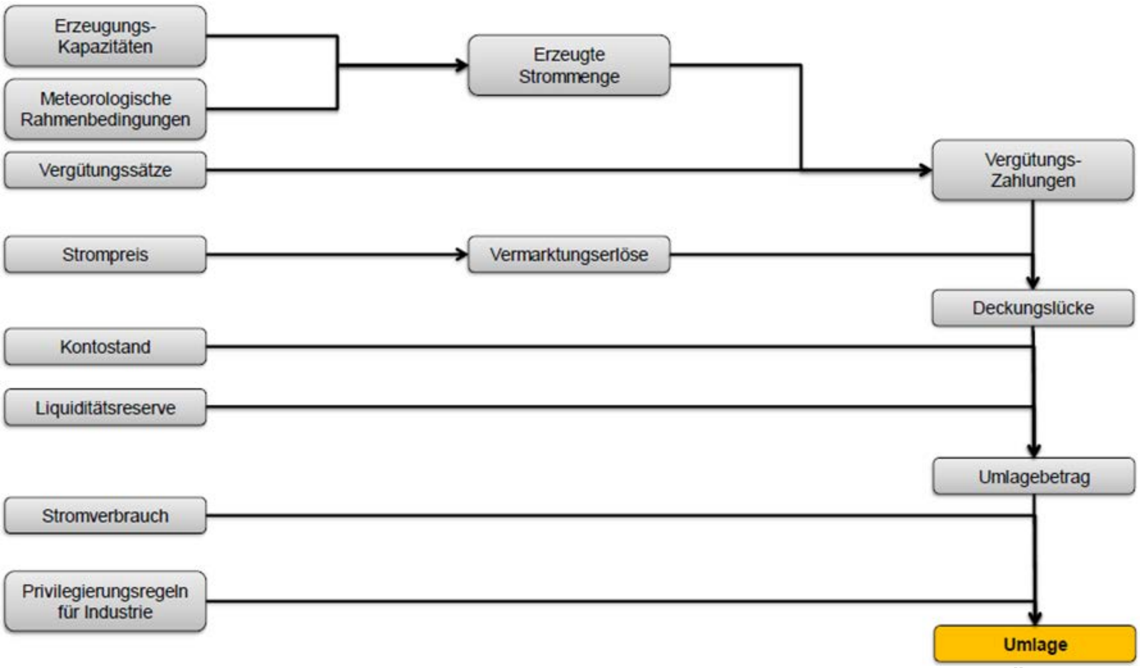


Figure 10: Influential parameters and calculating method for the EEG surcharge [ÖKO]

Figure 14 shows the EEG surcharge in cts/kWh and the sum paid out for installed systems. Since the measure basing the surcharge on the EEX spot market price was introduced in 2010, the surcharge and the feed-in tariff have been drifting apart. The increasing amount of privileged consumers in energy-intensive industry and other measures have also contributed to this drift.

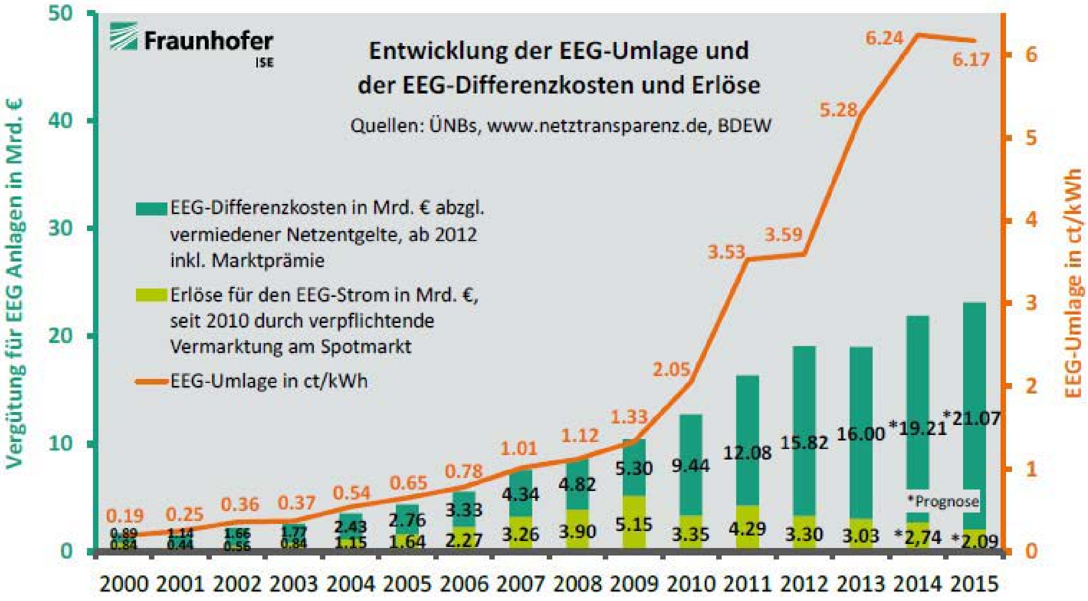


Figure 11: Development of the EEG surcharge and the EEG differential costs [ISE9]

Based on the way it´s defined, the EEG surcharge would increase for the following reasons:

1. increasing quantities of power used by "privileged" consumers
   Because energy-intensive industries are virtually exempt from contributing to the surcharge, smaller-sized consumers, such as private households, small industry and commercial consumers must bear additional costs amounting to billions of euros.
2. merit order effect and PV feed-in during daytime.
   PV power feed-in during, for example, midday when the EEX spot price formerly peaked reduced the electricity price very effectively, benefitting electricity customers. (See section 4.4). At the same time, however, the difference between the feed-in tariff and the market price, the basis of calculating the EEG surcharge, increased. This disadvantages smaller customers bound to pay the EEG levy.
3. Merit order effect and electricity surplus
   For many years, increasingly more power has been produced in Germany than effectively consumed, and namely power from fossil and nuclear power plants with low marginal costs being used as expensive peak load power plants. Due to the merit order effect, this surplus reduces the market price, pushing peak power plants out of the energy mix.

4. declining electricity consumption through efficiency measures

Initiatives supporting more efficient energy use (e.g. energy saving lamps) reduce the amount of electricity purchased, and thereby increase the surcharge per kWh consumed.

5. Additional expenditure from compulsory direct marketing
   The compulsory direct marketing creates additional administrative expense that power producers must compensate with a higher EEG remuneration.
6. Increasing production from RE power, without self-consumption
   The expansion of RE drives the levy up at least on the short term both directly (because more feed-in remuneration is paid out) as well as indirectly (due to the reduced price of emission certificates leading to a cheaper price for energy from fossil fuel plants.)

5. Subventions and Electricity Prices

5.1 Is PV power subsidized?

No. The support is provided through a surcharge, which applies also to self-produced and self-consumed PV electricity.
The investment incentives for PV power are not supported by public funds. While fragmentary reports often quote figures relating to past and future PV power feed-in tariff payments in the hundreds of billions and call these “subsidies”, a true subsidy is supported by public funds. The EEG, on the other hand, makes provisions for a surcharge in which energy consumers make a compulsory contribution towards the energy transformation, a necessary and agreed upon resolution. This interpretation is also supported by the European Commission. The EEG surcharge is not the total remuneration, but rather the differential costs, calculated as the difference between costs paid (remuneration) and revenues received (see section 4.5). The cumulative costs paid out for PV power fed into the grid up to and including **2016** amounted to ca. **70 billion euros**.

To calculate the EEG surcharge, the financial benefits of PV power are determined according to the market clearing price on the European Energy Exchange (EEX) in Leipzig. By this method, the benefits of PV power are underestimated systematically. For one, PV power has long been having the desired effect on this market price, namely that of driving it downwards (see section 4.4). Second, the market price leaves out the heavy external costs of fossil fuel and nuclear power production (section 5.2). Considering total costs of fossil fuel and nuclear power production of ca. 10 €-cts/kWh, the additional costs of the PV feed-in tariff decline so quickly that the first intersection point occurs already in 2013 (see Figure 4). 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 prospects for a secure energy supply in the future, 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.

What would be the price to pay if the German energy transformation fails? Without knowing this figure, it is difficult to make a statement as to the total costs required to transform our energy supply system.

5.2 Are fossil fuel and nuclear energy production subsidized?

Yes.

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 CO2 (carbon capture and storage, CCS), the taxation of nuclear power as well as insurance and safety requirements for nuclear power plants.

This means that policy makers decide to what extent today's energy consumers must bear responsibility for the elusive risks and burden of producing electricity from fossil fuel and nuclear sources. As these aspects are more rigorously priced, it is very likely that PV power will make the electricity mix less expensive. Until this happens, fossil fuel and nuclear power will be sold at prices that conceal their external costs (see section 22.9, [DLR1], [FÖS1]) and pass the burden on to future generations.

Contrary to initial plans, and with costs of 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. (See **Fehler! Verweisquelle konnte nicht gefunden werden.**) Compare with estimated realistic prices of 70 euros per metric ton [DLR], this equates to a subsidy of more than 20 billion euros per year for fossil fuel power plants.

Figure 12: Price of CO_2 allowances from 2008-2013 on the EEX spot market (http://www.finanzen.net/rohstoffe/co2-emissionsrechte/Chart)

It is currently impossible to pinpoint the actual costs and risks of generating power from fossil fuel and nuclear sources. 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. According to experts, the risks of nuclear power are so severe 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 accrued, 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 insurers. 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 as 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 544 billion dollars of subsidies worldwide in 2012 [IEA4]. According to a study by the International Monetary Fund, total subventions worldwide for coal, oil and natural gas in 2015 are estimated to be 5.1 billion US$ [IWF].

5.3 Do tenants subsidize well-positioned 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 industry, the costs of switching our energy system to RE are being borne by all consumers (including all households and thereby home owners and tenants) according to the cost-by-cause principle. In addition to PV, these costs also contribute funding to wind power and other renewables. All electricity customers can decrease their energy consumption by selecting and using energy efficient appliances. Many municipalities offer free consultations on energy saving advice and also 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 under 10 kWp. The systems within this power range make up less than 15% of the total installed PV power in Germany, while large systems above 500 kWp make up about 30 % (Figure 22). The larger systems are often financed with citizen participation or funds, in which tenants can also participate.

5.4 Does PV make electricity more expensive for householders?

Yes.

However, private households bear many additional charges within their electricity bill. The German legislature sets the principles for calculating and distributing the EEG surcharge, and other taxes and fees, the effects of which are currently detrimental to householders.

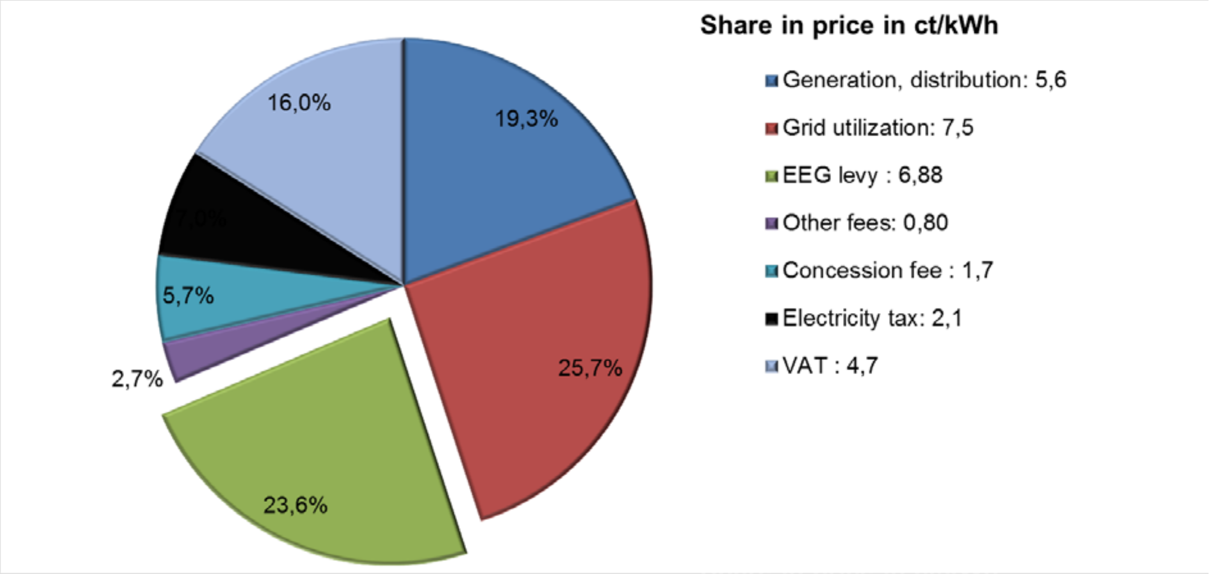


Figure 13: An example showing components making up the domestic electricity price of 29,2 €-cts/kWh in 2017 (CHP: German Combined Heat and Power Act); German Electricity Grid Access Ordinance (Strom-NEV): easing the burden on energy-intensive industries; concession fee: fee for using public land; offshore liability fee; AbLa: Levy on interruptible loads), Data from [BDEW3].

A typical household has an annual power consumption of 3,900 kWh paid roughly **29,32 €-cts/kWh** in 2016 [BMWi1]. Figure 13 shows a typical breakdown of this electricity price. The electricity levy was introduced in 1999. According to the law, the levy intends to make electricity more expensive; the proceeds go principally into the public pension fund. Private households must pay value added tax on the electricity levy and the EEG surcharge.

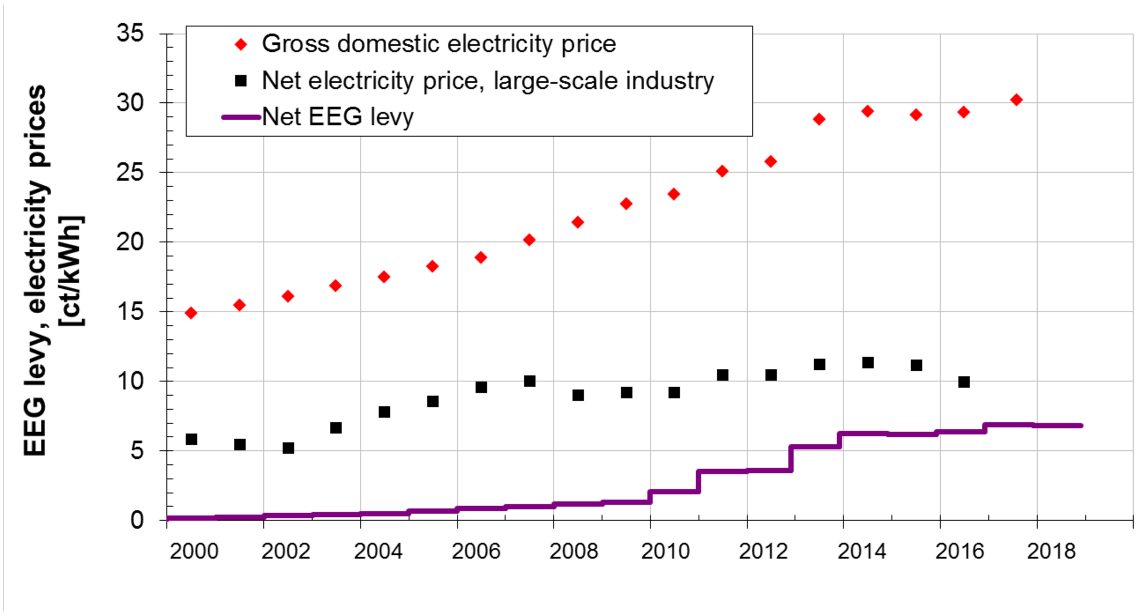
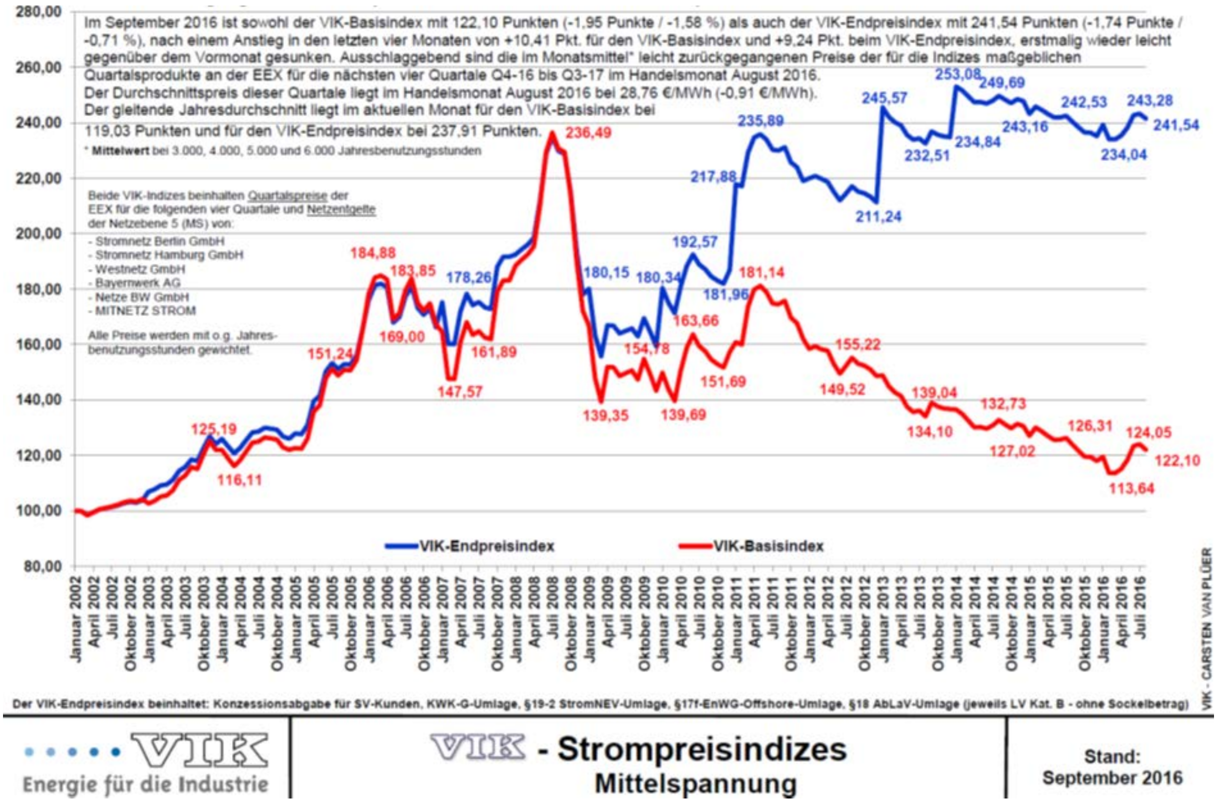


Figure 14: Development of gross domestic electricity prices (2017, estimated at 3% increase), net electricity prices for large-scale industrial consumers [BMWi1] and the EEG surcharge; about 55% of the gross domestic electricity price is made up of taxes and fees.

5.5 Does PV increase the electricity price for industry?

Yes and no. There are clear winners but also losers.

According to the German Industrial Energy and Power Federation (VIK), the electricity price is at a ten year low for medium voltage customers– provided that they are exempted from the EEG-surcharge. (See VIK base index, (Figure 15). Today the VIK final selling price index for non-privileged businesses is twice as high as the base index. This is mainly due to the EEG surcharge which makes up part of the final selling price.



Im September 2016 ist sowohl der VIK-Basisindex mit 122,10 Punkten (-1,95 Punkte / -1,58 %) als auch der VIK-Endpreisindex mit 241,54 Punkten (-1,74 Punkte / -0,71 %), nach einem Anstieg in den letzten vier Monaten von +10,41 Pkt. für den VIK-Basisindex und +9,24 Pkt. beim VIK-Endpreisindex, erstmalig wieder leicht gegenüber dem Vormonat gesunken. Ausschlaggebend sind die im Monatsmittel* leicht zurückgegangenen Preise der für die Indizes maßgeblichen Quartalsprodukte an der EEX für die nächsten vier Quartale Q4-16 bis Q3-17 im Handelsmonat August 2016.
Der Durchschnittspreis dieser Quartale liegt im Handelsmonat August 2016 bei 28,76 €/MWh (-0,91 €/MWh).
Der gleitende Jahresdurchschnitt liegt im aktuellen Monat für den VIK-Basisindex bei 119,03 Punkten und für den VIK-Endpreisindex bei 237,91 Punkten.

* **Mittelwert** bei 3.000, 4.000, 5.000 und 6.000 Jahresbenutzungsstunden

Beide VIK-Indizes beinhalten Quartalspreise der EEX für die folgenden vier Quartale und Netzentgelte der Netzebene 5 (MS) von:
- Stromnetz Berlin GmbH
- Stromnetz Hamburg GmbH
- Westnetz GmbH
- Bayernwerk AG
- Netze BW GmbH
- MITNETZ STROM

Alle Preise werden mit o.g. Jahresbenutzungsstunden gewichtet.

Der VIK-Endpreisindex beinhaltet: Konzessionsabgabe für SV-Kunden, KWK-G-Umlage, §19-2 StromNEV-Umlage, §17f-EnWG-Offshore-Umlage, §18 AbLaV-Umlage (jeweils LV Kat. B - ohne Sockelbetrag)

Figure 15: VIK electricity price index for medium-voltage customers [VIK]

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

No, the increased export surplus comes primarily from coal power plants.

"In 2016, Germany recorded an export surplus of ca. 50 TWh, approx. 2 TWh, or 4%, more than exports in 2015; setting once again an export record compared to the past record years of 2012, 2013, 2014 and 2015. The majority of electricity exports were sent to Holland where part of the electricity was sent on to Belgium and Great Britain [ISE4]."

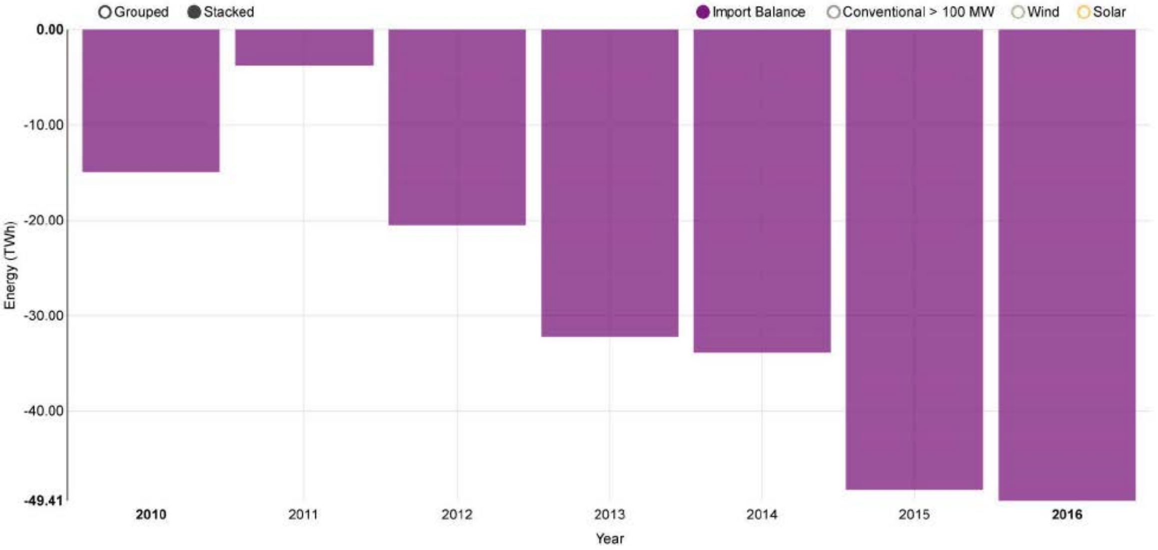


Figure 16 Electricity export/import balance for 2010-2016 [ISE4]

The monthly export surplus happened to be the largest in winter, i.e. in the months when the PV output was especially low. This finding contradicts the assumption that PV electricity is exported in massive amounts. Furthermore, the Energy Charts, a dynamic compilation of data on power in Germany (https://www.energy-charts.de/trade_de.htm) show that the mean price per kWh received for electricity exports was about the same as the mean import price.

7. Can new PV plants bring reasonable rates of return?

Yes, however, the massive slump in the annually installed new capacity (-57 % in 2013, -42% in 2014, ca. -30 % in 2015) confirms that this has become more difficult. In principle, new PV installations can bring profits through grid feed-in as well as self-consumption. The policy makers, however, are increasingly cutting into the profits in both business models by imposing new measures. (See section 4.7). On the other side, trade restrictions (minimum price, quantitative limitations and punitive tariffs for Chinese modules in place since 2013 by the European Union) drive up the module prices in Germany.

Self-consumption becomes more worthwhile, the greater the difference is between the cost of delivering PV electricity and the LCOE of the PV system. For systems without energy storage, the self-consumption is dependent on coinciding supply and demand profiles. Independent of the system size, households generally consume 20-40 % of their self-produced electricity [Quasch]. Larger systems increase the percentage of PV coverage for the total power, however, reduce the percentage of self-consumption. Commercial or industry consumers achieve an particularly high rate of self-consumption as long as their consumption profile doesn't collapse on the weekends (e.g. Refrigerated warehouses, hotels and restaurants, hospitals, server centers, retail). Storage and technologies for energy transformation offer a large potential for increasing the self-consumption (compare Section 17.3).

The PV system yield is higher in sunnier regions, however, regional irradiation differences do not transfer to specific yield in a one-to-one ratio (kWh/kWp). (See section 22.4.) Other parameters, such as the module operating temperature or the duration of snow cover, also affect the annual yield.

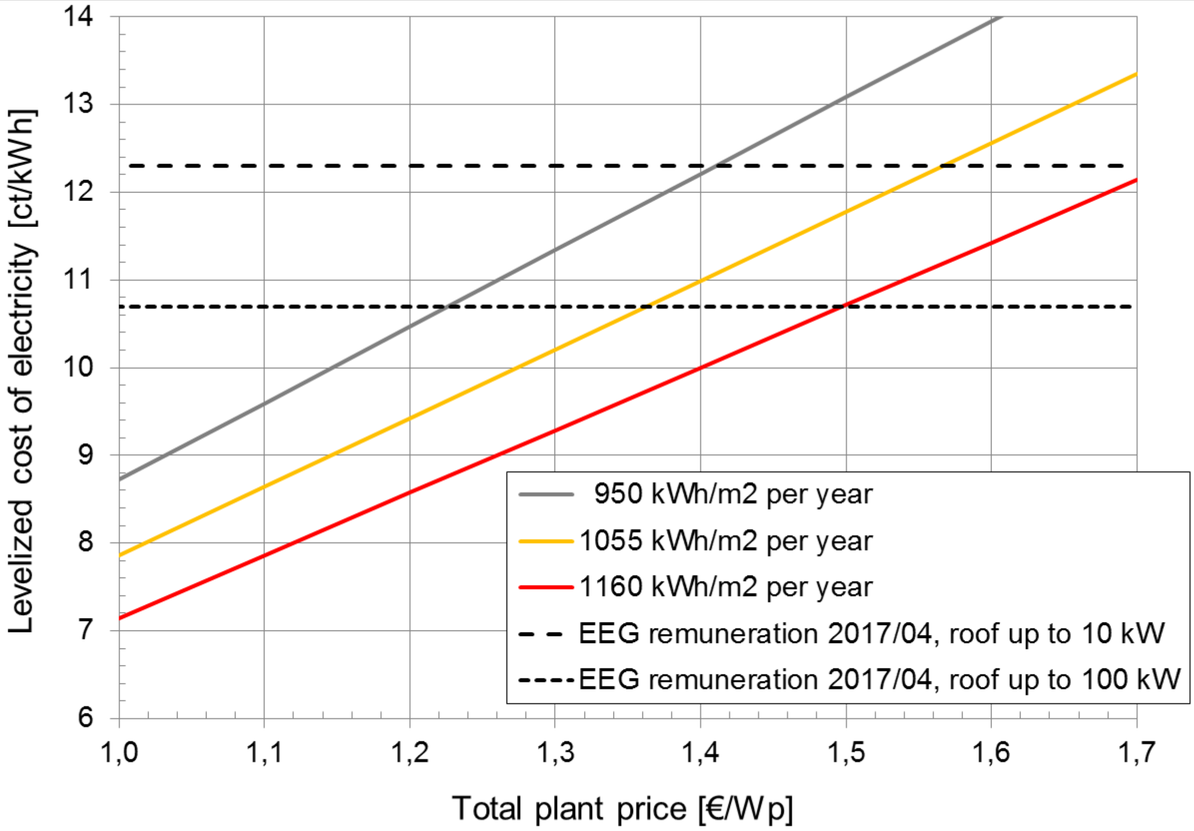


Figure 17: Rough estimate of levelized cost of electricity (LCOE) for PV power plants at different annual irradiances

To obtain a rough estimate of the discounted LCOE (not adjusted for inflation, see Figure 17), the following assumptions were used:

- optimal orientation of module (approximately 30° south)
- performance ratio (section 22.6) 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 0 percent

- nominal imputed interest rate of 5 percent (average of own and borrowed capital investments)

In Germany, the annual sum of average global irradiance on a horizontal surface is 1055 kWh/m^2 per year [DWD]. The levelized cost of energy (LCOE) is estimated using the net present value method, according to which, the running costs and LCOE are discounted by the interest rate given at the time the plant was commissioned. The LCOE values determined are not adjusted for inflation. This makes 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, the imputed interest is equal 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 [BNA1].

It is currently not possible to calculate the energy yield beyond the twenty-first operating year of a PV system. It is likely, however, that many plants will continue to generate significant quantities of electricity at marginal running costs. However, the guidelines governing self-consumption and the future pricing and remuneration concept of ESCs as well as any interventions from policy makers also affect yield calculations. There is no guarantee on the PV plant's rate of return during the EEG remuneration period. Neither the manufacturer's guarantee nor plant insurance policies are able to remove the risk to the investor entirely.

8. Does installing PV only create jobs in Asia?

No, however over the last few years Germany lost many jobs in the PV industry.
In 2015, the PV industry employed **30,000** people in Germany (Figure 17) and achieved an export quota of around **70 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 solar cells, modules, inverters, supporting structures, cables and coated glass
3. construction of manufacturing plants
4. installation (especially trade)

Many jobs were lost in Germany in the last few years as a result of company closures and insolvency, which affected cell and module manufacturers, the mechanical engineering industry and installers. In 2007, the plan that the combination of EEG, investment grants in the (new) eastern states of Germany and research support would help establish Germany as a worldwide leading production site for PV cells and modules appeared to work. A German company led the international rankings in production volume. Since then, however, the market share of German manufactures has decreased dramatically due to the industrial policy in Asia and the huge investments put into in production capacity 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. For 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 investments of 90 billion euros through to 2014 [DLR2]. In these countries, however, the economic-political framework is missing for generating investments in production capacity within a competitive format (e.g. on the gigawatt scale). 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.

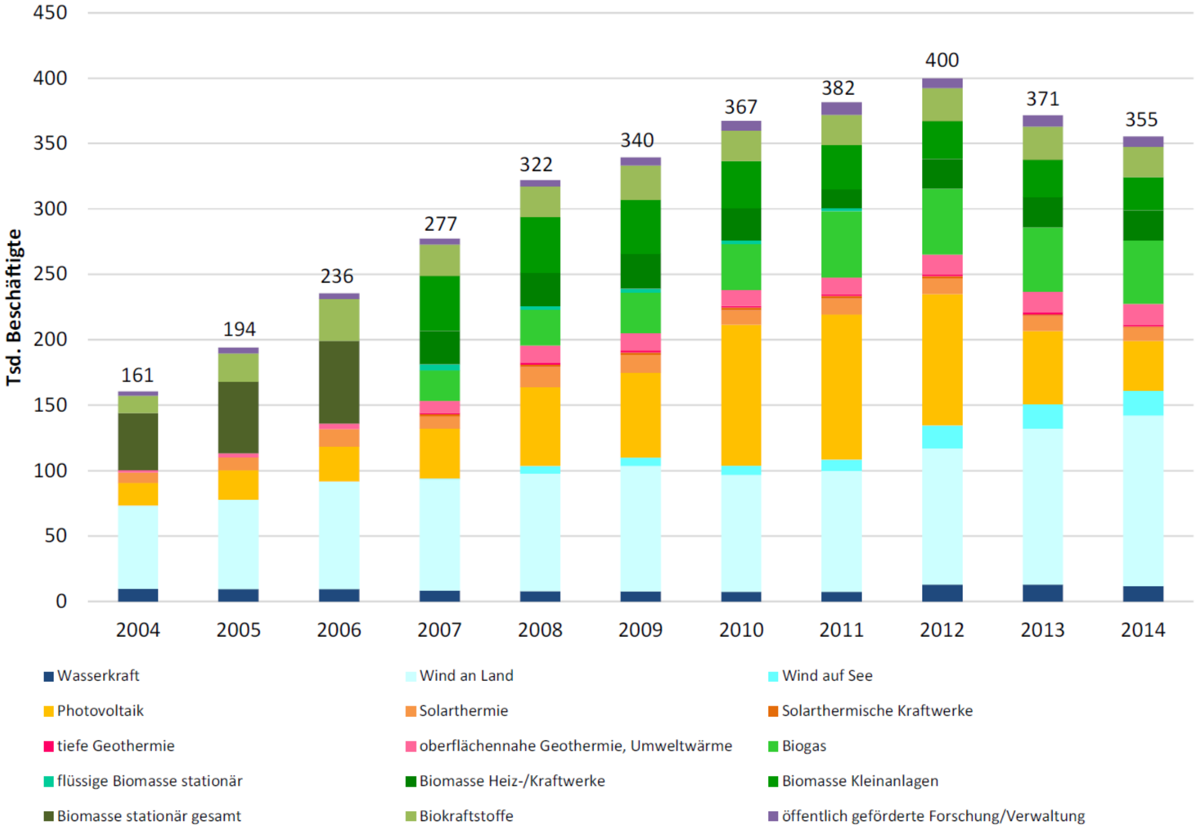


Figure 18: Employees in the RE sector in Germany [DLR2]

In spite of the high import quota of PV modules, a large part of the value chain for PV power plants remains within Germany. Assuming that around 80 percent of PV modules installed in Germany come from Asia, that these modules comprise roughly 60 percent of the total PV plant costs (other 40 percent predominantly from inverter and installation costs) and that initial plant costs make up around 60 percent of the levelized cost of electricity (remainder: capital costs), then nearly 30 percent of the feed-in tariff goes to Asia for imported modules. Also to consider is that a share of all Asian PV products are produced on manufacturing equipment made in Germany.

In the long term, the falling costs of PV module manufacturing coupled with increasing freight costs and long delivery times shall improve the competitive position of manufacturing companies in Germany.

9. Are large power plant operators interested in PV?

For a long time, large German power plant operators have shown little interest in PV power production.

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 four big power plant operators EnBW, Eon, RWE and Vattenfall (called "big four" in Figure 19) owned a mere 0.2 percent. Where does their aversion to PV power come from?

1. The electricity consumption in Germany is showing a declining tendency since 2007. The construction of new renewable power plants will force either a reduction in the utilization rate of existing power plant parks or an increase in electricity export.
2. Because PV electricity is generated primarily during periods of peak load, conventional peak load power plants are required less often. This reduces their utilization and profitability in particular. Paradoxically flexible power plants with fast response times are increasingly in demand.
3. PV power plants deliver power during the day at times when demand is at a peak (Figure 45). This lowers the market price of electricity on the EEX, which carries over to all plants presently producing electricity. (Section 4.4). Previously, the big power plant operators were able to sell inexpensive base load power at a lucrative price during midday. Since 2011, PV led to price reductions on the energy exchange and thus to dramatic slumps in profit.
4. Because PV power production fluctuates, the slow start-up and shut-down properties of nuclear of older coal-fired power plants cause difficulties with increasing PV expansion. One particularly striking example is negative electricity prices on the market. Coal is being burned and the consumers must pay for the electricity. This leads to system wear in places where controls are technically feasible but no provision in the necessary frequency exists.
5. Radically new business models are required for decentralized PV production as compared to largely centralized coal and nuclear power production. In the wind sector, especially offshore production, the transformation effect is less drastic.

While big power plant producers have shown little interest in PV up to now, large wind farms, especially offshore wind, fit much better into their business model. In an interview appearing on April 2, 2013 in the *Frankfurter Allgemeine Zeitung*, the EU commissioner Günther Oettinger gave his opinion on this issue: "The expansion of photovoltaic capacity 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 renewables until we have developed sufficient storage capacities and energy grids to intelligently distribute the electricity. (…) Actually, it is much more meaningful in the long term to install wind farms out on the open sea because there more many more wind-hours per year there.

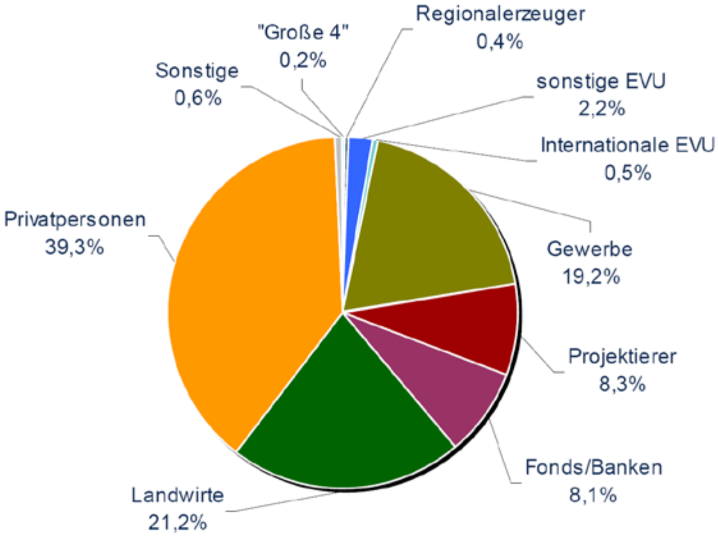


Figure 19: Division of ownership of the total installed capacity of PV plants at the end of 2010 [trend:research].

As the balance sheets of the "BIG 4" German power producers began to worsen dramatically, they began to react: RWE transferred two-thirds of its staff to its daughter innogy, which handles all business related to the energy transformation, including PV electricity. In its mid-year report for 2017, it states that Innogy operated less than 100 MW PV at the end of 2016. Similarly, E.ON SE has formed Uniper to handle its traditional gas and electricity and is now concentrating on renewable energy, including PV. In 2013, EnBW stated that it is redirecting its activities to focus on the energy transformation. As of September 2016, the company operates 50 PV plants. Vattenfall is selling its lignite sector and plans to concentrate on renewable electricity production, and since 2016 also PV.

Many of the approximately 1000 municipal electricity suppliers in Germany recognized the challenges facing the energy transformation early on and have reacted by offering new products and integral concepts, e.g. "virtual power plants" (Figure 20).

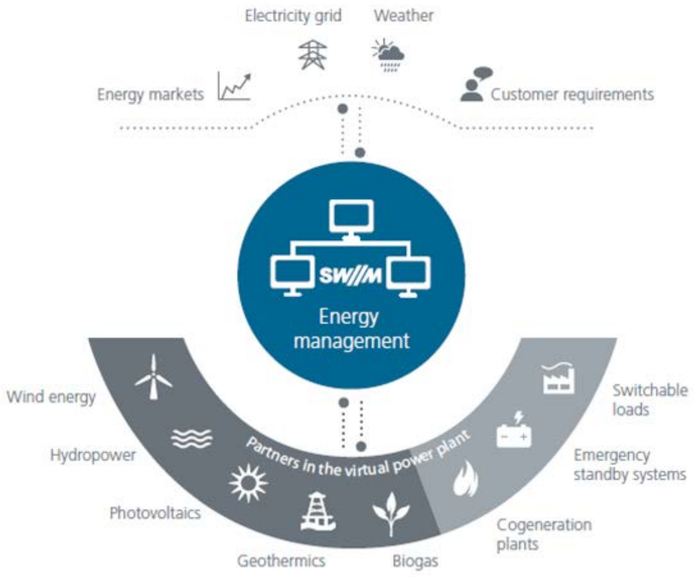


Figure 20: Concept for a virtual power plant of the Stadtwerke München (Munich municipal works) [SWM]

10. Is PV research taking up high levels of funding?

Looking back at previous numbers, Figure 21 shows that it took time for renewable energy and energy efficiency to become a focal point of energy research.
Figure 22 shows the funding granted for PV research by the federal ministries.

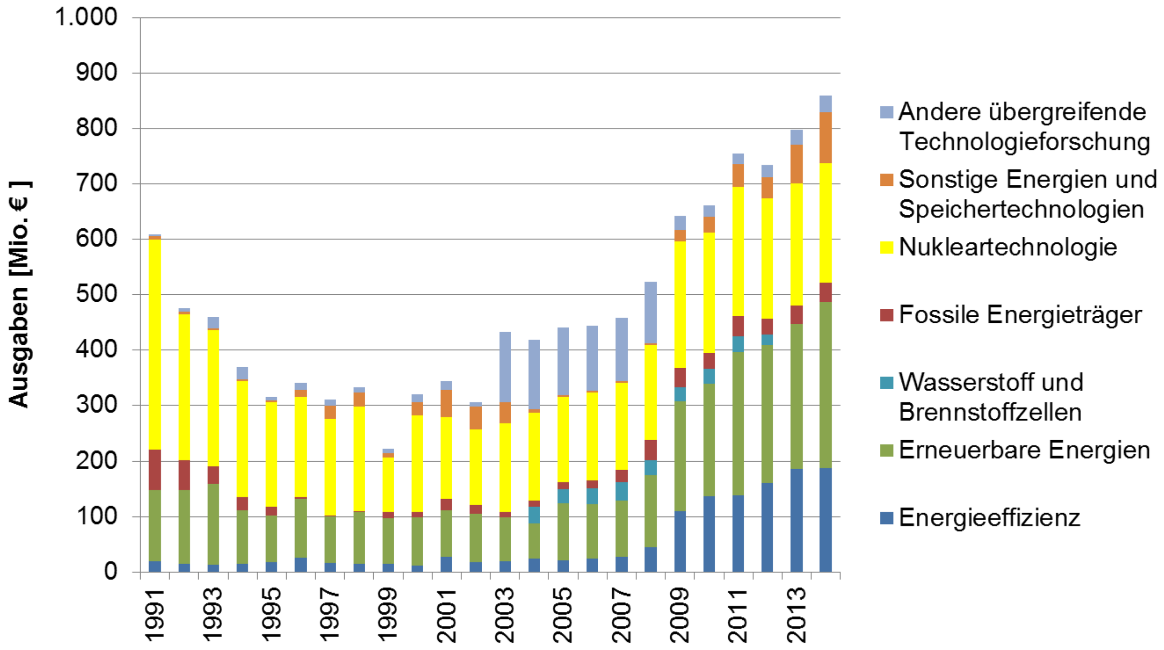


Figure 21: Germany's expenditure on energy research, Data from [BMWi1].

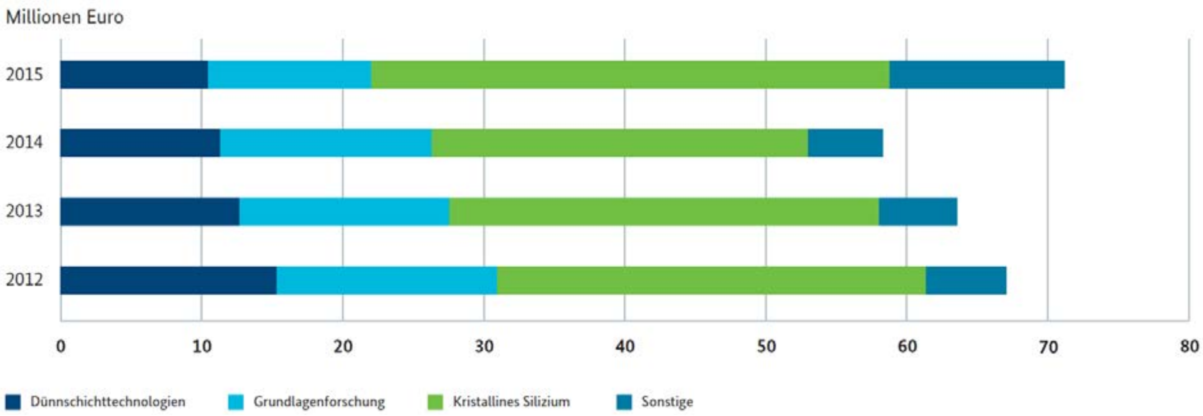


Figure 22: Funding for PV research categorized by technology [BMWi3].

11. Does PV power overload our present energy system?

11.1 Transmission and distribution

Over 98 percent of Germany's 1.5 million PV power plants are connected to the decentralized low-voltage grid and generate solar electricity in close proximity to consumers [BSW]. PV plants of over 1 MW installed capacity account for only 15 percent of the total PV capacity in Germany.

Thus, the feed-in of solar electricity takes place predominantly in a decentralized manner and hardly makes any demands on an expansion of the German national transmission network.

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. 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.

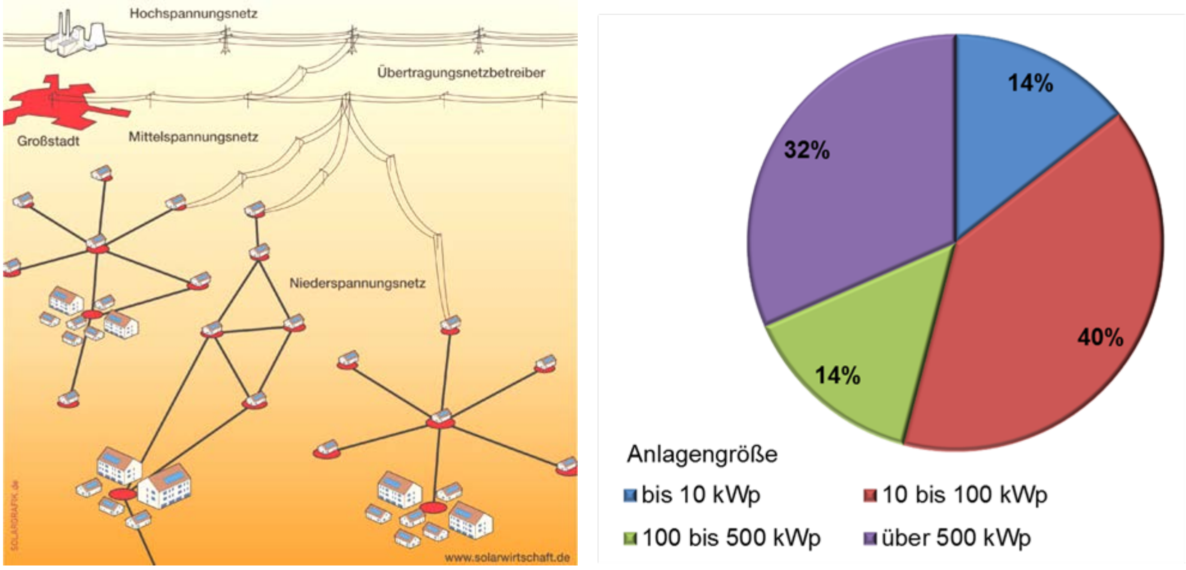


Figure 23: Left: Schema of PV power feed-in [BSW], Right: Installed PV power categorized by system size (as of Dec. 2015) (Data up to 2008 from transmission system operators (TSO), 2009: Bundesnetzagentur (German Federal Network Agency); Data compiled by PSE/Fraunhofer ISE.

PV power plants are decentralized and well distributed thereby accommodating the feed-in and distribution of the existing electricity grid. Large PV power plants or a local accumulation of smaller plants in sparsely populated regions require that the distribution network and the transformer stations are reinforced at certain sites. The further expansion of PV shall be carried out with more attention to supply, in order to simplify the distribution of solar electricity. The states of Bavaria and Brandenburg have three to four times more PV capacity installed per resident as compared to the states of Saarland, North Rhine-Westfalia, Saxony or Hessen.

Network congestion and bottleneck cost grid operators over 1 billion euros in 2015. Due to surplus wind power in Northern Germany, electricity deficits due to power plant shutdowns (nuclear in Southern Germany) and a sluggish grid expansion, grid bottlenecks often occurred in the German transmission grid. Because the grid expansion – a necessary step to alleviate the bottlenecks – will still take some time, redispatching measures will be increasingly required in the foreseeable future. Redispatching means that the transmission operators (TSO) intervene in the market-based operation schedule of the power plants (dispatch) to redistribute the electricity feed-in, prevent power surges in the grid (preventative redispatch) or to carry out fixes (curative redispatch). Before a bottleneck occurs, the energy feed-in is reduced (negative redispatch) and afterwards increased (positive redispatch) [BDEW4].

11.2 Volatility

11.2.1 Solar power production is predictable

Reliable national weather forecasts mean that the generation of solar power can now accurately be predicted (Figure 24). Because PV power generation is decentralized, regional changes in cloud cover do not lead to serious fluctuations in PV power production throughout Germany as a whole.

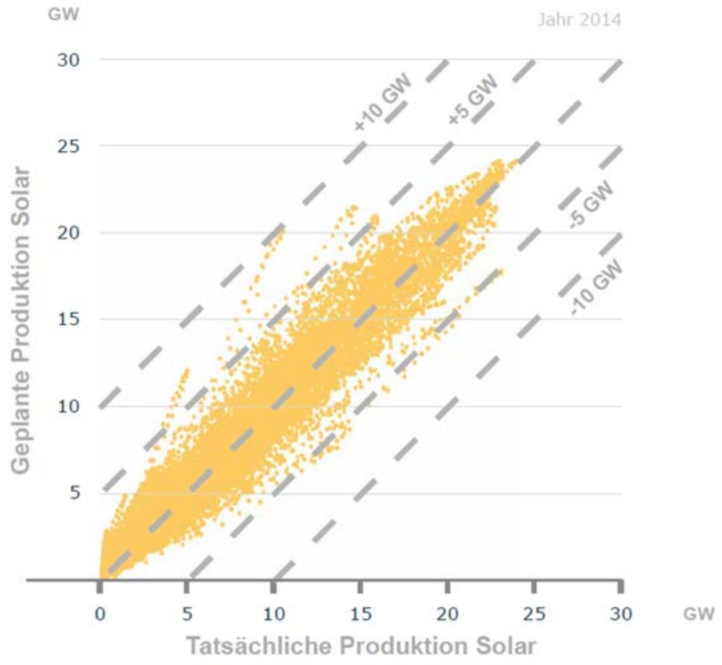


Figure 24: Actual and predicted hourly generation of power in 2014 [ISE4].

11.2.2 Peak production is significantly lower than installed capacity

For technical reasons (performance ratio (PR) <= 90 percent, see section 22.6) and due to variable weather conditions, the actual PV power generated will be above 70 percent of the total installed rated power (see section 3) across Germany on only a very 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.

11.2.3 Solar and wind energy complement each other

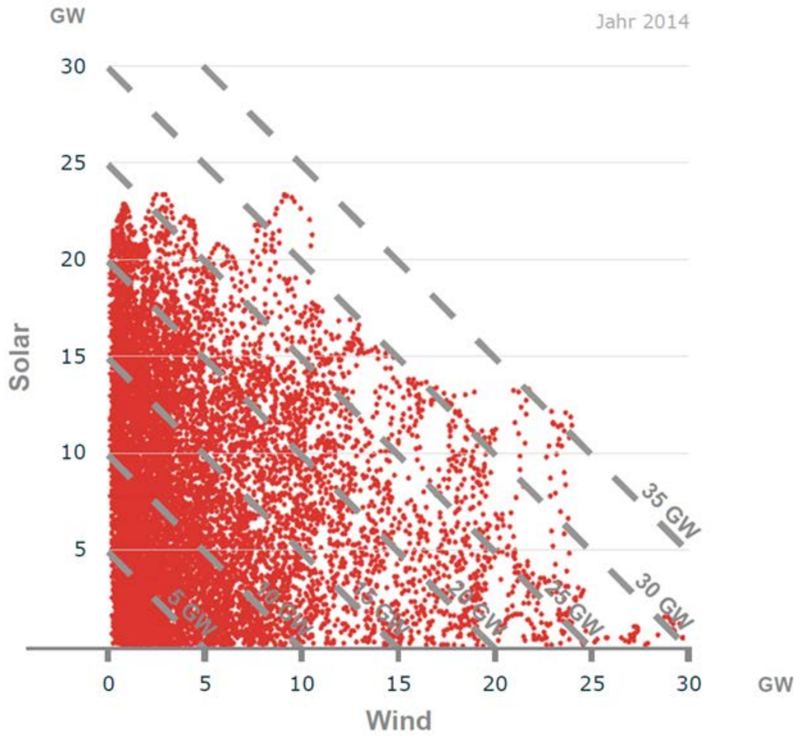


Figure 25: Average hourly amount of solar and wind energy fed into the grid in 2014 [ISE4].

Due to the particular climate in Germany, high solar irradiance is negatively correlated with high wind speeds. At the end of 2014, there was 38 GW PV and 36 GW wind installed in Germany. The total electricity from solar and wind power fed into the grid rarely exceeded the 30 GW mark (Figure 25:). 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 capacity 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).

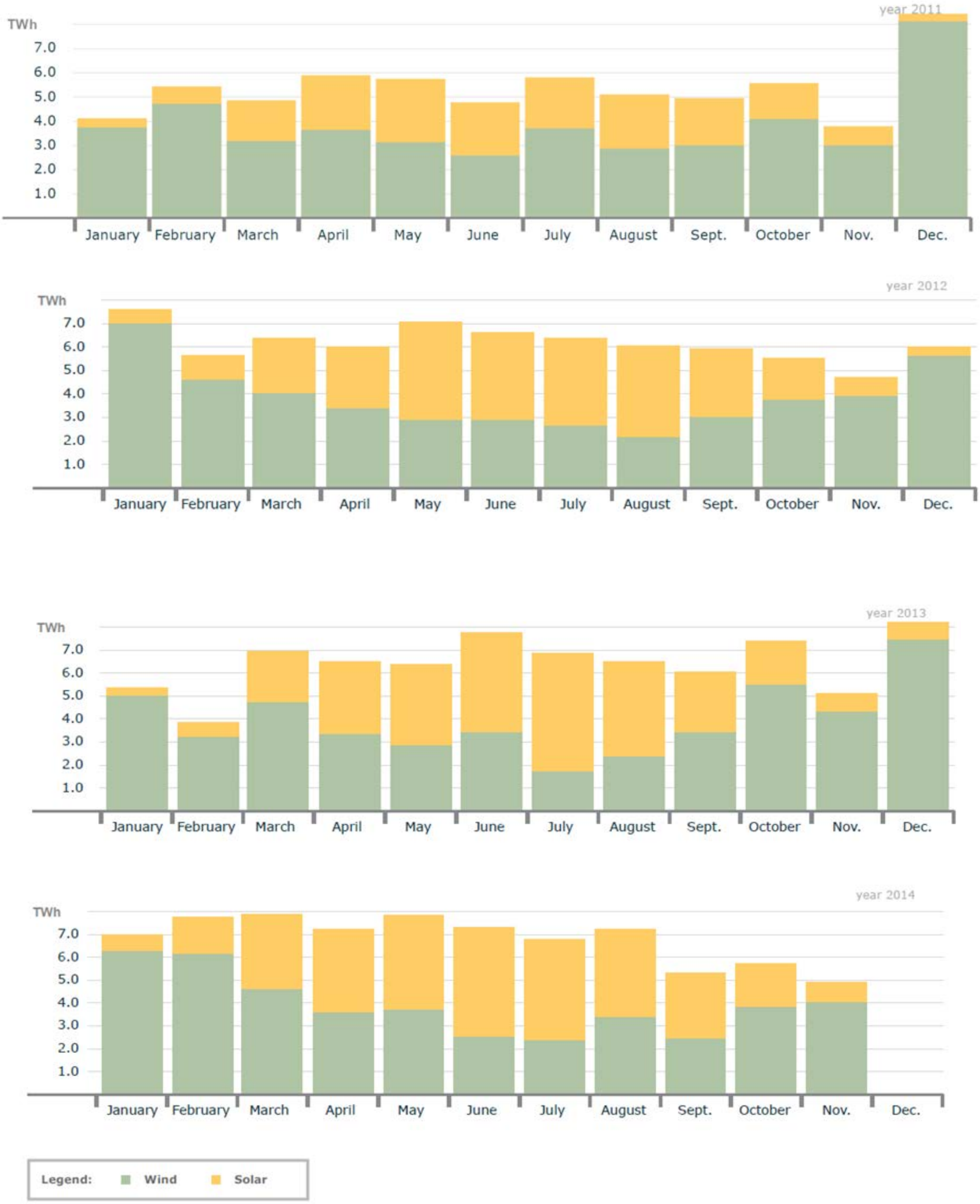


Figure 26: Monthly production of PV and wind power for 2011 - 2014 [ISE4].

11.3 Controllability

With its ever greater capacity, PV increasingly fulfills the 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]

11.4 Conflicts with slow-response fossil and nuclear power plants

The PV power generation profile fits so well to the power grid's load profile that at all times Germany's entire electricity demand, which ranges between 40–80 GW, shall exceed the PV electricity available, even if PV capacity continues to expand in the coming years. However, conflicts with slow plant start-up are increasing. Due to the present technical and economic constraints, these types of power plants react to fluctuating residual loads only to a very limited extent. Older power plants, especially lignite, can not provide balance energy economically. Nuclear power plants are technically able to run with a power gradient of up to 2 %/min. and a power increment from 50 % to 100 % [ATW2]. For economic reasons, the power production was seldom reduced in nuclear plants.

Essentially, priority must be given to power produced from intermittent energy sources due to their negligible marginal costs. This yet unsolved conflict can lead to short-term surpluses in production and large electricity exports at low, or even negative, trading prices, as shown in the example given in Figure 34.

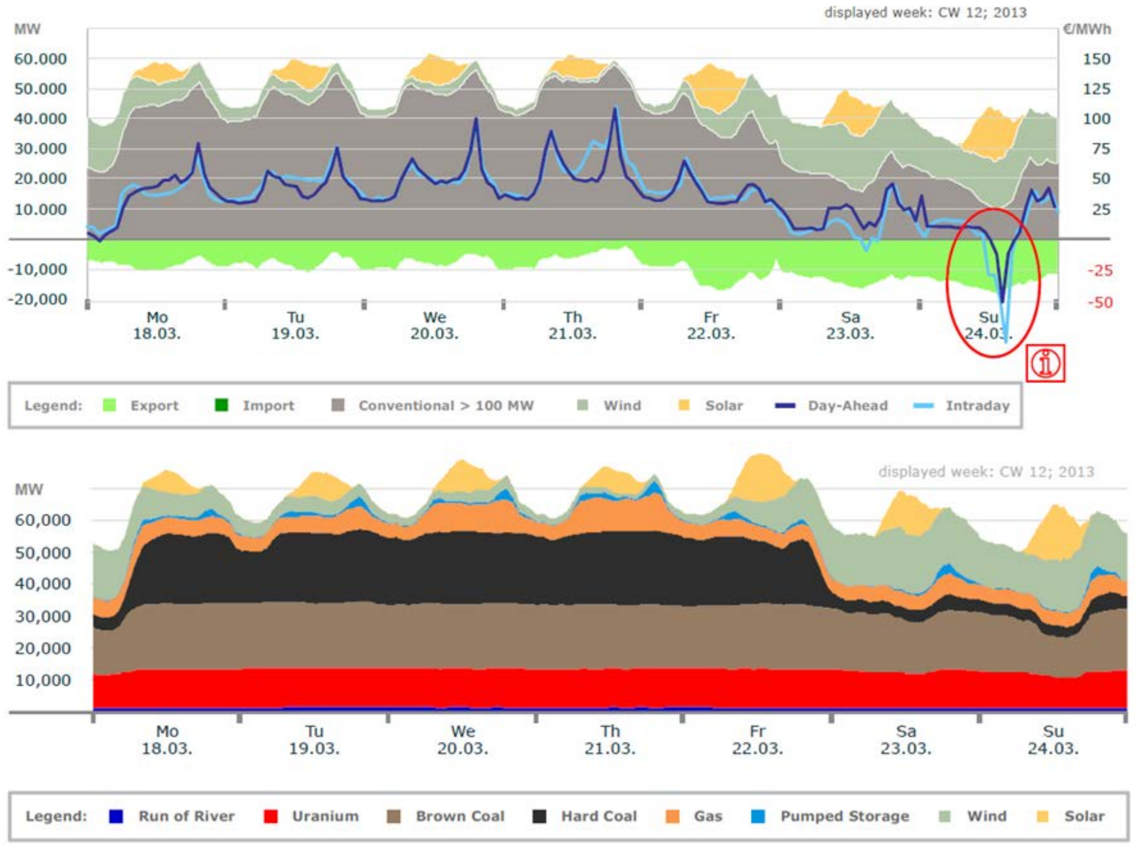


Figure 27: Example showing course of electricity trading price, conventional and renewable electricity in the 12th calendar week (March 2013)

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.

11.5 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 differences in the electricity price frequently occur, either on the electricity exchange market EEX or at the consumer level. Currently investments in storage, specifically pumped storage, are even being deferred because cost-effective operation is not possible.

A continued expansion of PV and wind will first cause prices on the electricity exchange EEX to sink more often and more drastically. On the other hand, a reduced amount of nuclear electricity caused by the planned phase out and more expensive electricity from coal-fired plants due to the imposed CO_2 allowances or taxes will result in price increases on the EEX. 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 electricity surpluses from renewable energy sources 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 by 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.

12. Does the manufacture of PV modules consume 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/m^2 , which is the mean value for 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, ever more efficient manufacturing processes mean that this value shall improve in the future. Wind power plants in Germany demonstrate even shorter energy pay back times ranging from 2-7 months.

13. Do PV Power Plants Require Excessive Amounts of Area?

13.1 Will Germany be completely covered with PV modules?

No.

The nominal power of all PV modules installed in Germany is presently ca. 40 GW. Assuming an average efficiency of 14 percent for all installations, this translates to a module area of approximately 300 km². Some of these modules are installed in open fields, and some are installed on rooftops.

Projections show that to achieve its target of a carbon neutral and sustainable energy supply system, Germany requires 200 GW of installed PV in total. This is five times the installed power existing in 2016. If one assumes a mean module efficiency of 19 percent, then the required PV module installations to meet this goal add up to about 1000 km². This module area is equivalent to about 2 percent of the total area of settlements and roads or 8 percent of the net land area used for residential purposes in Germany.

For modules installed on flat roofs and open spaces, the utilized area is actually about 2 to 2.5 times higher than the pure module area, due to the necessary spacing interval required between tilted modules mounted on horizontal planes.

13.2 Does new PV capacity compete with food production for land?

No.

The large-scale construction of PV systems on arable land has not been supported by the EEG since July 2010. As a result, the installation of such systems ground to a halt and new ground-mounted systems are only being constructed on specific redeveloped brownfield sites, low-quality sites or in the close vicinity of highways and railway lines.

Furthermore, expansion scenarios do not envisage a significant amount of PV installations being built on arable land. There are various methods under investigation in the area of Agro-PV that propose combined land use for both agricultural purposes and PV [Beck]. Reduced irradiance has not been found to stunt the growth of many crops; some crops even benefit from it.

14. Are PV plants in Germany efficient?

The nominal efficiency (see section 22.2) of commercial wafer-based PV modules (i.e. modules with silicon solar cells) in new production has risen in recent years by an annual rate of around 0.3 percentage points to an average of nearly **17 percent** and a peak performance of over **20 percent**. Each square-meter of module has a rated power of nearly 170 W, with premium modules reaching over 200 W. The nominal efficiency of thin-film modules lies between **12 and 14 percent**, with a peak performance of **16 percent**.

Since additional losses occur during operation, PV plants do not actually operate at nominal module efficiency. These effects are combined in the performance ratio (PR). A well-designed PV plant installed today achieves a PR of 80–90 percent throughout the year. This takes into account all losses incurred as a result of higher 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 alternating current (AC) for grid feed-in. The efficiency of new PV inverters currently stands close to 98 percent.

Depending on irradiance and performance ratio (PR), specific yields of around 900-950 kWh/kWp are typically generated in Germany and in the sunnier regions up to 1000 kWh/kWp. This corresponds to around 150 kWh per square-meter module and for premium modules around 180 kWh. An average 4-person household consumes around 4400 kWh electricity per year, corresponding to the annual yield generated by 30 m^2 of new modules with today's average market efficiency. Calculations show that a south-facing, tilted roof of a detached family home is typically expansive enough to accommodate about 20 PV modules. This would be sufficient to supply the equivalent of the family's annual electricity needs. To increase yield, PV modules are optimally tilted on flat roofs and open land to achieve the highest yield. Tilted south-facing modules, positioned at suitable distance from one another to prevent shading, require an area approximately 2 to 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 efficiency of combustion-based power plants is based on the chemical energy which already exists 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 28: compares the total driving distances of vehicles that burn various biofuels with that of an electric vehicle (plug-in hybrid drive), whose required drive energy is provided by a PV array covering an area equivalent to the energy crop acreage needed for the fuel.

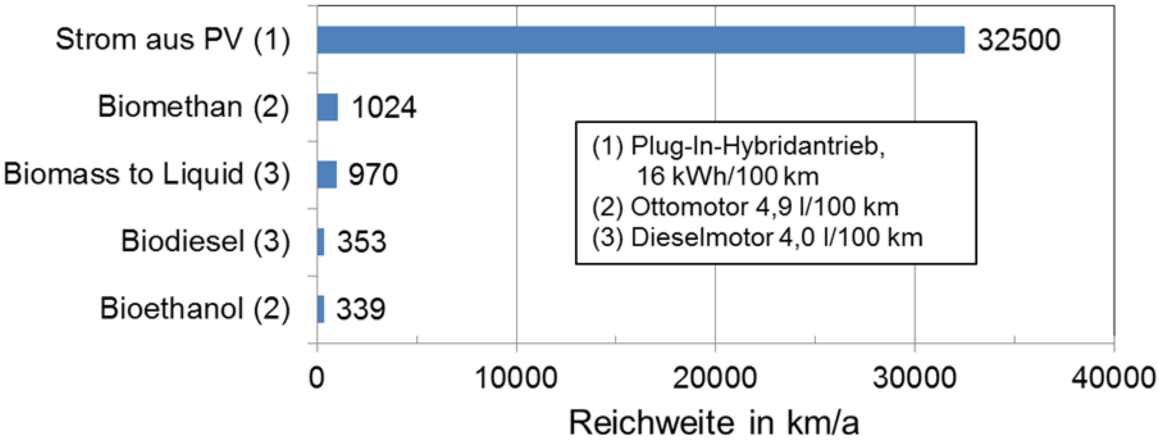


Figure 28: Vehicle range for an annual yield of 1 a = 100 m² of energy crops (2,3) or 40 m² of elevated PV modules constructed on 100 m² on flat, open ground, Sources: Photon, April 2007 (1) and Fachagentur Nachwachsende Rohstoffe (2), (3).

While southern Spain and North Africa are able to produce specific yields of up to 1600 kWh/kWp, the power transmission to Germany would result in 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.

14.1 Do PV plants degrade?

Yes, albeit very slowly.

Wafer-based PV modules age so slowly that detecting any output losses poses a challenge to scientists.
A study examining 14 plants in Germany fitted with multicrystalline 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. Typically the manufacturers guarantee holds for a period of 20 to 25 years and in some cases even 30 years, ensuring a maximal linear power loss of 20 % within this period.

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 types of thin-film modules. Depending on the type, degradation during the first few months of operation and seasonal fluctuations can be observed.

14.2 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, so that virtually no yield losses occur. Problems only arise in modules installed at extremely shallow angles or those located in the vicinity of deciduous trees or sources of dust.

14.3 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 22.3). Due to the fluctuating and cyclical solar irradiation patterns, PV plants actually operate for less than half of the 8760 total hours per year, and even when they are operating, the system generally operates at partial load. Based on a scenario giving expected trends for the years 2016–2020, the transmission system operators (TSOs) assume an average of 940 full load hours per annum for PV systems in Germany and 892 hours per annum for roof-mounted systems [ÜNB]. Figure 29 gives the forecasted full load hours per annum for different renewable energy systems in Germany, based on average values determined between 2012 and 2016.

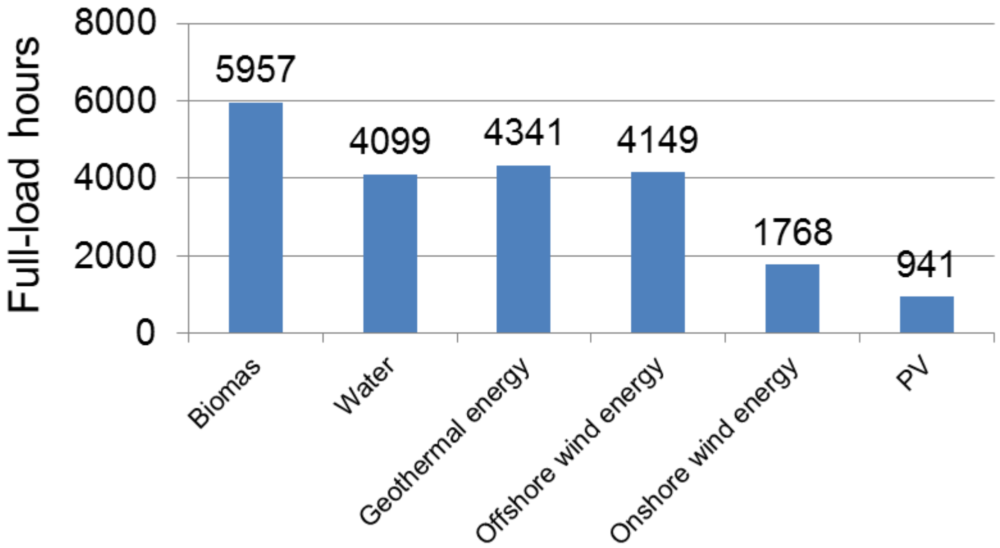


Figure 29 : Forecasted hours of full-load operation for renewable energy plants, mean values from 2012-2016

The average total horizontal irradiance for Germany between 1981 and 2010 was 1055 kWh/m^2 per year and fluctuates between approximately 950 and 1260 kWh/m^2 per year according to location [DWD]. Figure 30 shows the irradiance distribution across Germany. In order to maximize yields, PV modules are oriented facing south and are installed with a tilt angle 30–40° to the horizontal. Tilting the PV modules increases the total incident irradiance on the modules by around 15 percent compared to the horizontal surface. This increases the average incident irradiation to roughly 1200 kWh/m^2 per year throughout Germany.

A performance ratio PR (see section 22.6) of 85 percent and an ideal orientation would result in a geographical average across Germany of more than 1030 full-load hours. Since some roof-mounted systems are not ideally oriented and many still have a PR of less than 85 percent, the actual average number of full-load hours is somewhat lower. Technical improvements in the module and installation can increase the incident irradiation, the performance ratio PR, the yield and thus the number of full-load hours of a PV system. The improvements entail:

- Tracking (See Section 17.3.1)
- Bifacial PV technology
- Reducing losses caused by shading
- Reducing the temperature coefficient of the solar cells
- Reducing the operating temperature of the module by backside ventilation
- Increasing the module properties for weak light and askance light conditions
- Reducing module losses caused by snow cover and soiling
- Early detection and repair of reduced output
- Decrease degradation over the module lifetime

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], lignite-fired power plants reached 6640 full-load hours in 2007, while hard coal-fired power plants achieved 3550 hours.

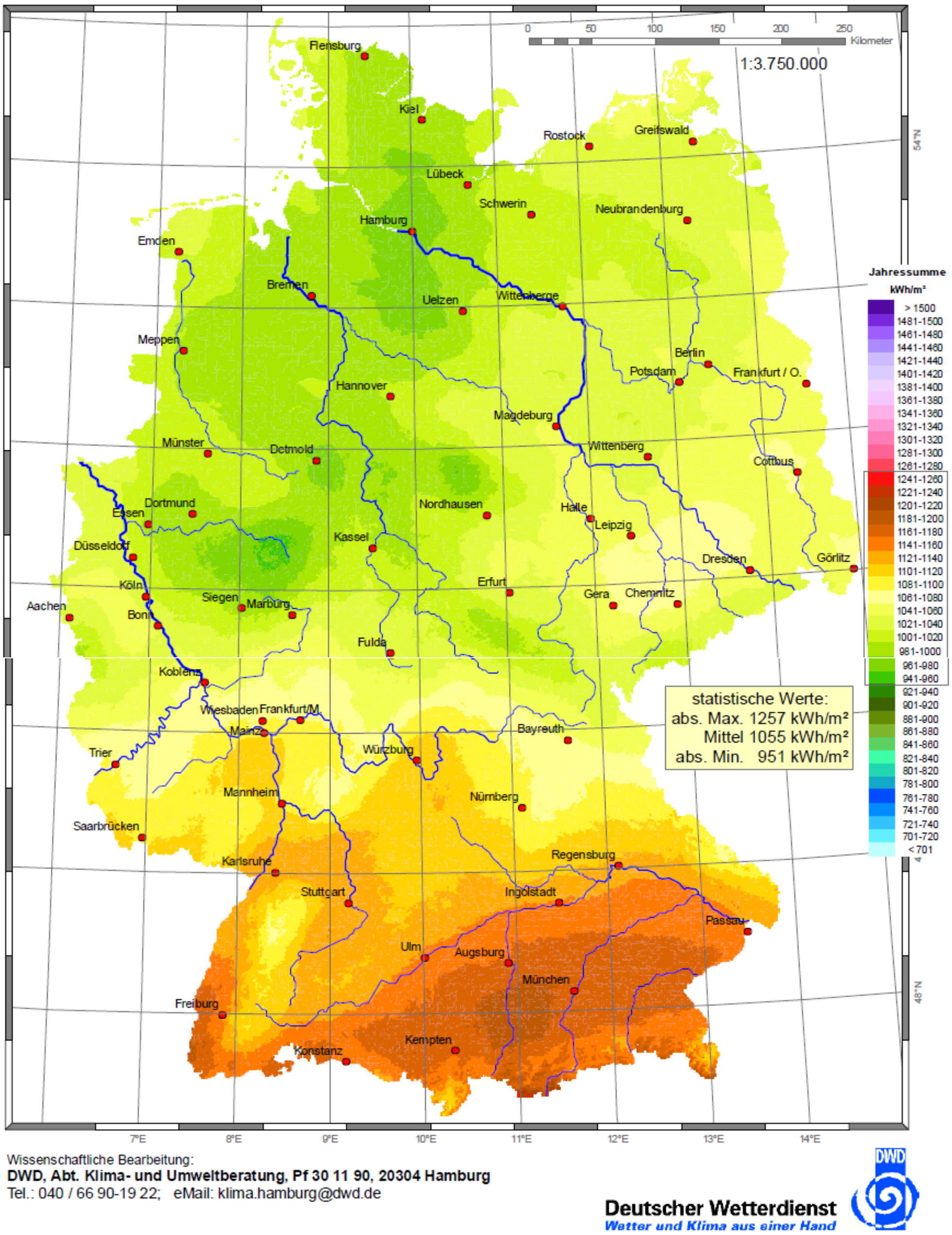


Figure 30: Horizontal annual global irradiation in Germany averaged over 1981-2010

15. Does PV make relevant contributions to climate protection?

15.1 Do anthropogenic CO_2 emissions danger the climate?

Yes. Most experts see a substantial risk.

It has been proven without a doubt that global warming is increasing [IPCC]. Compared to the preindustrial era, the mean global temperature has risen by 0.8 °C [IEA]. The majority of the scientific community assumes that that anthropogenic CO_2 and other greenhouse gas emissions are most likely the main cause for the rising concentration of greenhouse gases in the atmosphere as well as for the increase in the mean global temperature. In May 2013, the atmospheric CO_2 concentration reached 400 ppm for the first time in 800,000 years. Figure 31 and Figure 32 show the development through today of the atmospheric CO_2 concentration and the global, or rather Antarctic, temperature.

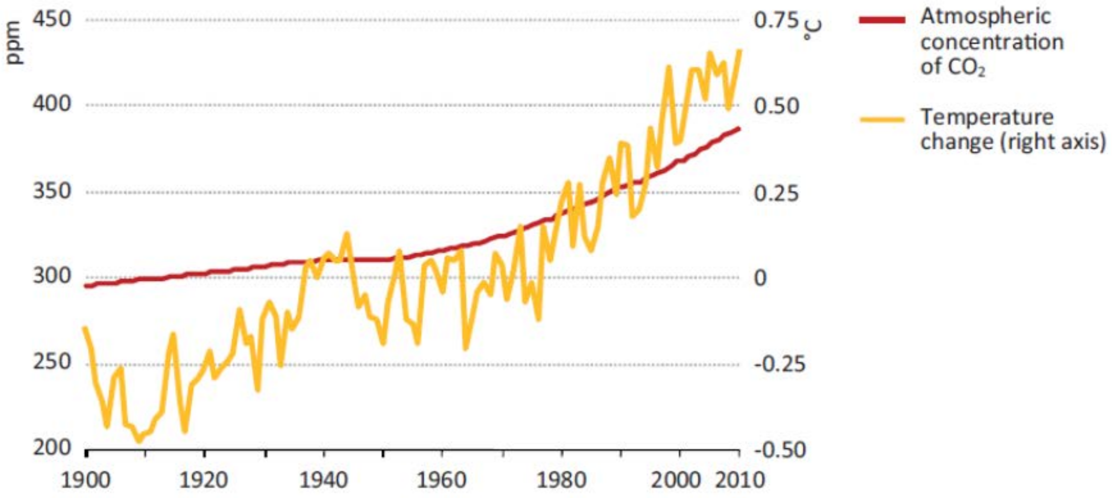


Figure 31: Development of the atmospheric CO_2 concentration and the mean global temperature change based on the NASA Global Land-Ocean Temperature Index [IEA2].

A more rapid increase in 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 numerous habitats.

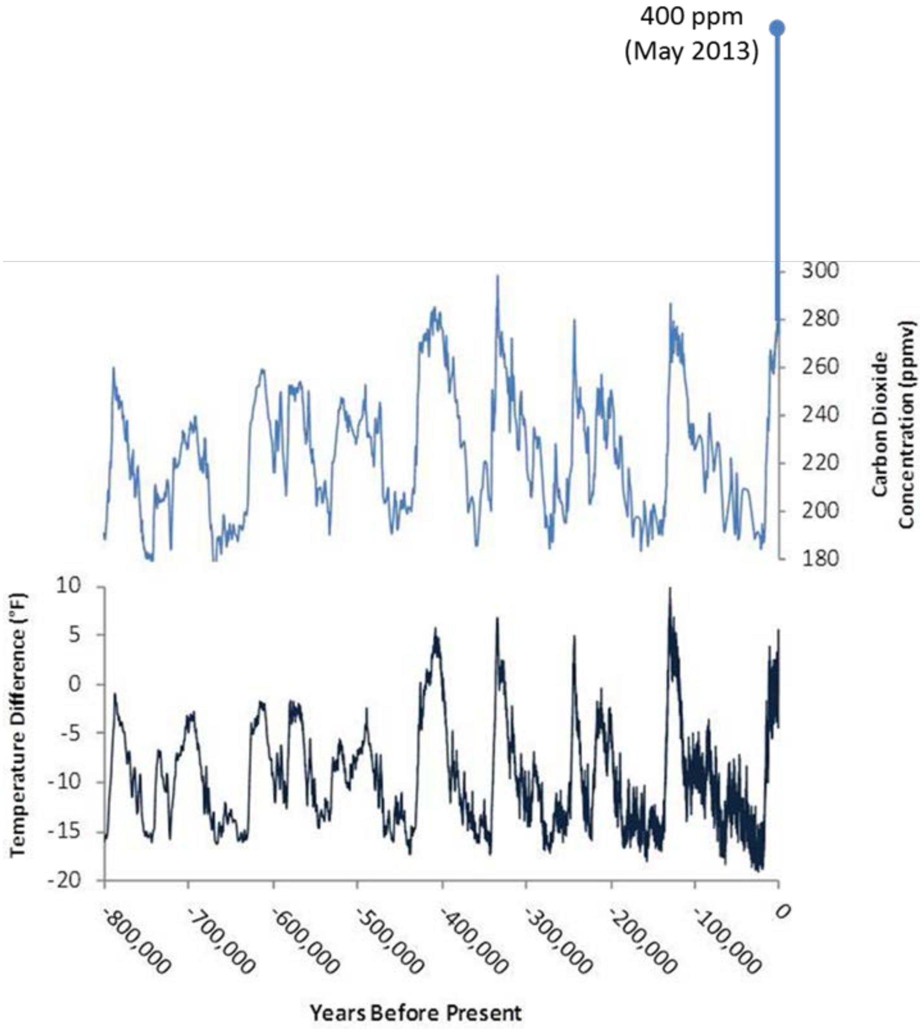
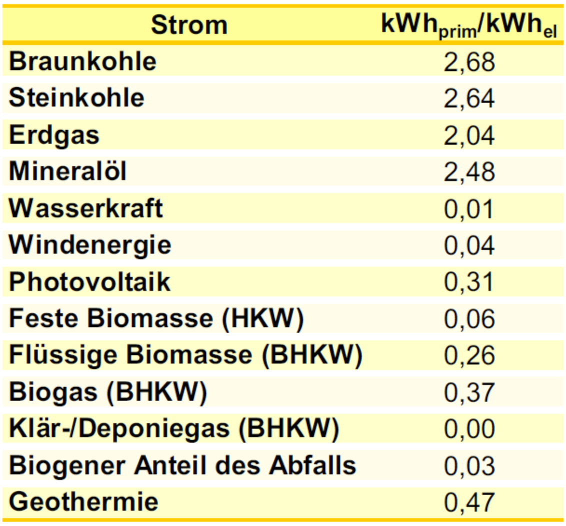


Figure 32: Estimate of the atmospheric CO_2 concentration and the temperature in Antarctica based on ice core data [EPA], CO_2 concentration for 2013 is included

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

Yes.

Presently PV is replacing electricity generated from natural gas and hard coal power plants on the market. Based on data from 2013 giving the proportional amount of power generated from each energy source and the primary energy factors, each kWh of PV-generated electricity saved about 2.2 kWh of primary energy. In 2013, total primary energy savings amounted to 65 TWh. The actual influence of PV electricity on the power plant operations in general is difficult to determine.



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 33: Primary energy required to generate power from various energy sources [EEBW].

In 2011, the level of emissions avoided by installing PV power was 664 g CO_2-equivalents/kWh [BMU1]. This factor is calculated as the quotient of the emissions avoided and the amount of electricity generated and takes into account both greenhouse gases and other air pollutants. It varies depending on the structure of the power plant park. A total consumption of **28 TWh** PV electricity in 2012 led to avoided greenhouse gas emissions on the order of **18.6 million tons** of CO_2 equivalent. 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.
New large PV power plant parks have an electricity generation cost of 5-6 €-cts/kWh with abatement costs of 10-12 euro-cts per kg CO_2-equivalent.
Germany's energy policy has influence on a global scale. Although only three percent of the global electricity consumption was due to Germany in 2008 (with consumption showing a downward trend), German policy makers are leading the way in terms of developing incentive programs for RE. The EEG is the best example of this. The EEG and its effect have been and continue to be closely observed around the world. It has been used by many countries (presently about 30) as a model for similar regulations. Meanwhile, China is leading in expanding its PV capacity and has surpassed Germany in annual installed power many times over (by a factor of 3.6 in 2013).

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. An additional five European countries also have decided to phase out nuclear energy (Belgium, Switzerland, Spain) while other countries have already completed the phase-out (Italy, Lithuania).

In terms of avoiding CO_2 emissions, the EEG achieved the highest impact due to a side effect: The creation of the largest and most secure sales market for PV, which lasted many years and decidedly accelerated global expansion, technology development and price reduction. Worldwide PV is reducing the use of fossil fuels for electricity production.

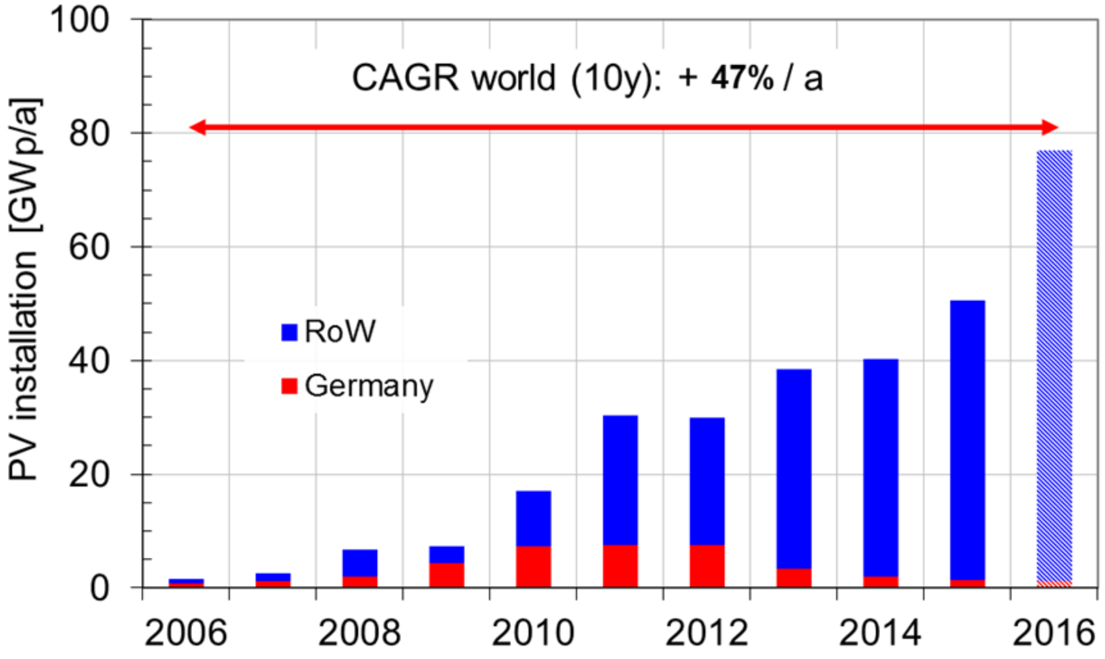


Figure 34: Development of annually installed PV capacity for Germany and globally, or Rest of World, (RoW), (2016 estimated) CAGR stands for the compound annual growth rate.

The German EEG has made PV power affordable faster, also extending out to 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," says Bodo Hombach in the "Handelsblatt" newspaper on January 11, 2013, and also helps developing countries to save significant amounts of CO_2.

15.3 In addition to CO_2 are there other 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 (NF_3) is still used, in part, to clean the coating systems. Residues of this gas can thereby escape into the atmosphere. NF_3 is more than 17,000 times as harmful to the environment as carbon dioxide. Current emission quantities are not known. As of 2013, however, NF_3 emissions are to be determined in 37 countries according to the revised Kyoto Protocol.

15.4 Do dark PV modules warm up the Earth through their absorption?

Solar radiation plays an important role in the Earth's energy balance. Light-colored surfaces reflect a larger amount of incident solar radiation into the atmosphere, while dark surfaces absorb more sunlight causing the Earth to heat up.

PV module installation alters the degree of reflection (albedo) of the ground on which the system is mounted. For example, the total thermal output of a PV module with 17 percent efficiency emits as much heat (locally) as an area with an albedo of ca. 20 percent. (To compare, asphalt has an albedo of 15 percent, grass 20 percent, and the desert ca. 30 percent.) In the desert, PV modules are often covered with a layer of dust, which increases the reflectance and reduces the energy yield. In consideration of the relatively low amount of area required by PV modules (Section 13.1), the albedo effect is marginal. Furthermore, PV electricity use replaces the power from fossil fuel plants, reduces carbon emissions and thus slows down the greenhouse effect.

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

No, 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 electricity or hydroelectric storage facilities are available in the grid, they are not capable of replacing the capacities generated by fossil fuel and nuclear power plants. Calm, dull winter days, when power consumption is at a maximum and no solar or wind power is available, present the most critical test.
Despite this, PV and wind power are increasingly colliding with conventional power plants with slow start-up and shut-down processes (nuclear, old lignite power plants). 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 multifunctional electrically powered CHP plants fitted with thermal storage systems (section 17.3.2).

17. Are we capable of covering a significant proportion of our energy demand with PV power?

Yes, depending on the extent to which we are able to adapt our energy system and the structure of our energy economy to meet the new requirements [FVEE2]. The following steps provide a brief overview of what Germany needs to do to achieve this aim, based on the situation today. More detailed explanations can be found in the following sections of this chapter.

Time frame: up to 2025. Focus on **"Creating flexibility"**

1. The energy efficiency of electricity consumers will be increased across all sectors.
2. The installed PV capacity will be increased to 70-80 GW for local use, to stabilize the production also in the east/west orientation or with tracking, with inverters for grid-support, for a production of ca. 60-70 TWh/a electricity at peak powers of ca. 50-55 GW. Wind power will be expanded by a similar amount.
3. Part of the electricity consumption from households, industry and electric vehicles will be demand controlled (daytime power supply, control signals from local PV systems or grid, different tariff structures) and matched to the availability of PV (and wind) power. Storage will be implemented for the cold supply.
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 will be increased.
5. PV systems need to be equipped with grid-connected battery systems.
6. For the feed-in of energy during the (seldom occurring) RE peaks, less efficient yet cost-effective (€/W) electrothermal heat generators with thermal storage feed-in (heat stab) will be constructed on the central to decentralized scale.
7. For the feed-in of (more frequent) surplus RE electricity, flexible capacities of electric heat pumps with thermal storage feed-in (heat,cold) will be set up, also on the central to dencentralized scale.
8. To cover the (seldom occurring) residual load peaks, less efficient yet cost-effective (€/W) gas turbines will be implemented (e.g. recycling of airplane turbines).
9. To cover (more frequent) gaps in the residual load efficient G&D/CHP power plants with thermal storage feed-in will be constructed, CHP also decentral.
10. Existing coal-fired plants need to be optimized to enable flexible operation, otherwise progressively decommissioned.
11. 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 number of CO_2 allowances or imposing a CO_2 tax on the national level.

Time frame: up to 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/ 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

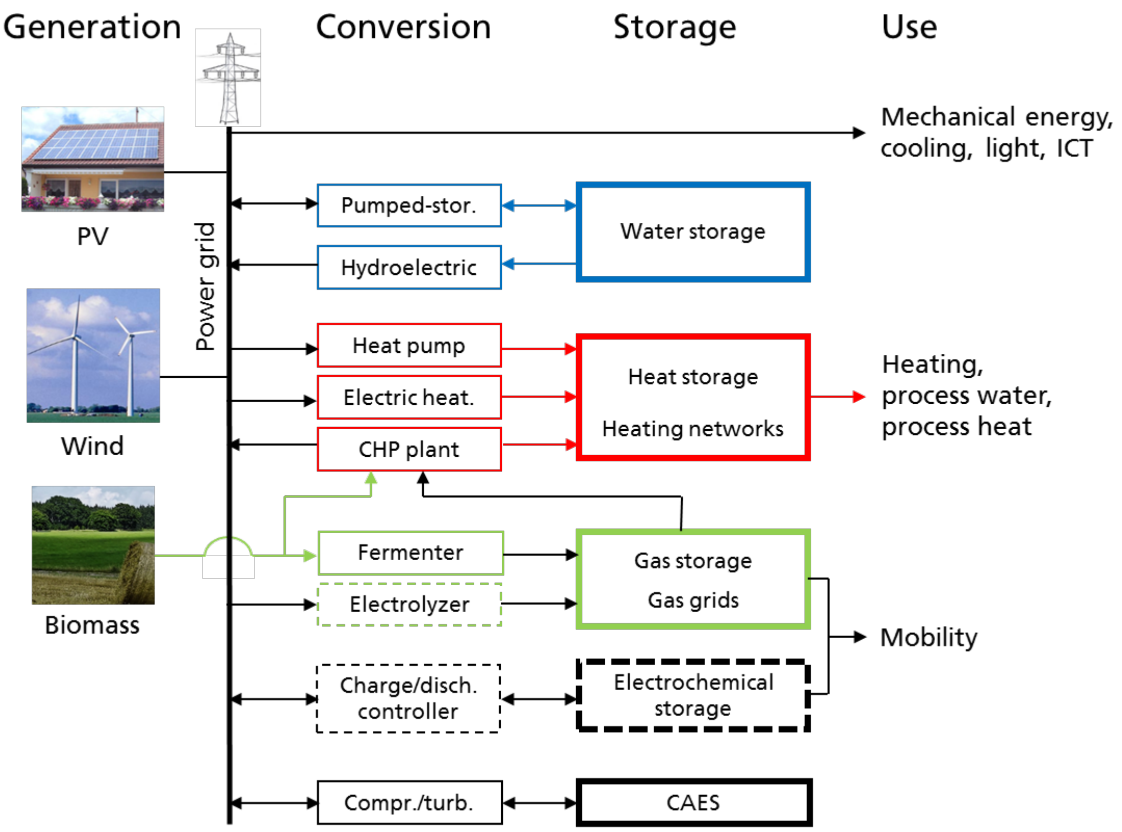


Figure 35: Simplified diagram of a renewable energy system with the most important grid-connected components for production, conversion, storage and consumption; ICT: information and communications technology; dotted lines: very low outputs/capacities currently available.

It is already possible to envisage the technical and economic aspects of an energy system based on 100 percent RE. Figure 35 shows the most important grid-connected elements ranging from power production to energy consumption.

17.1 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.

A study commissioned by the Federal Environment Agency has concluded that it is 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 be reached first with an installed capacity of 275 GW. Figure 36 outlines a conversion and storage concept for the power and heating sector.

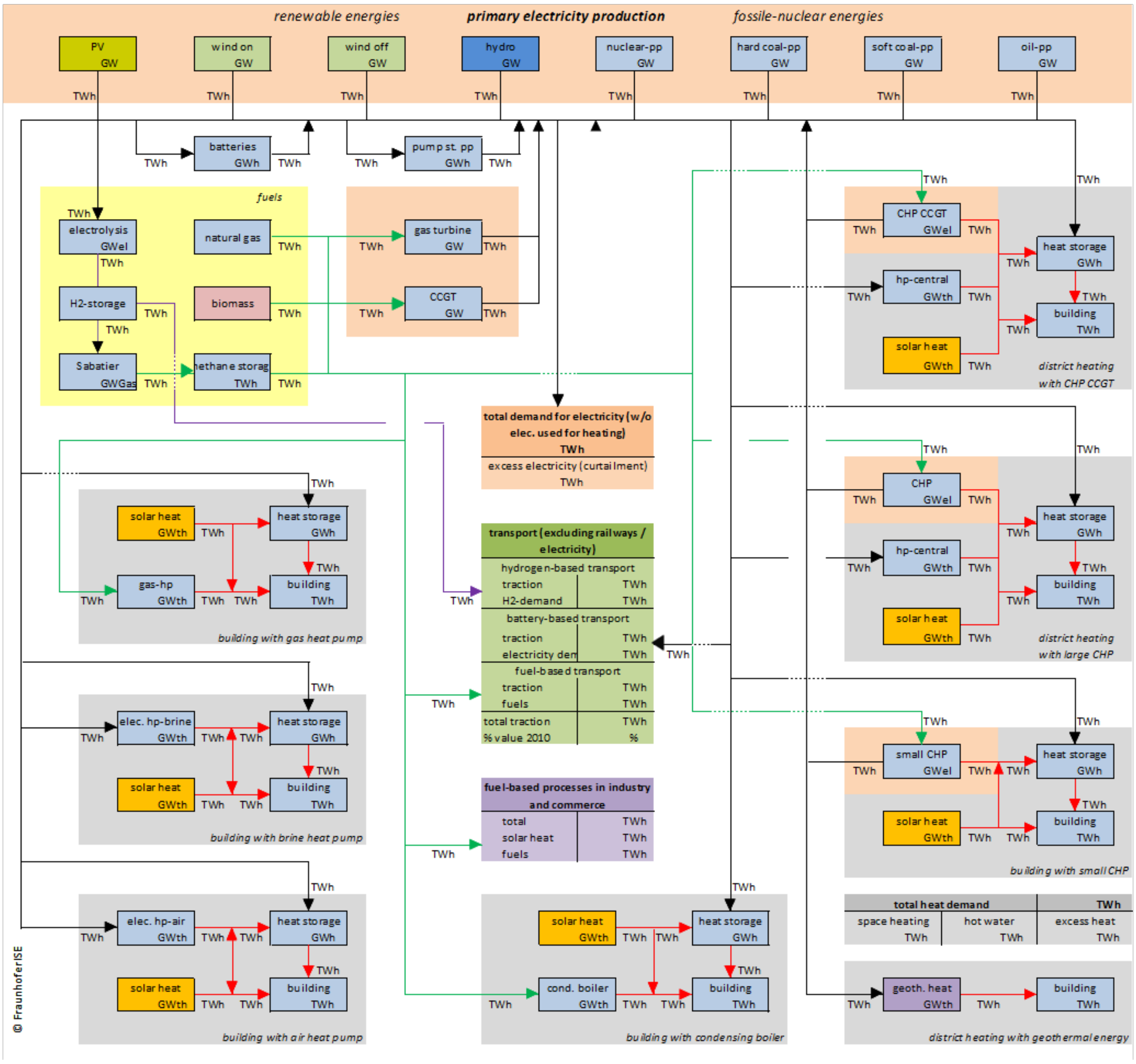
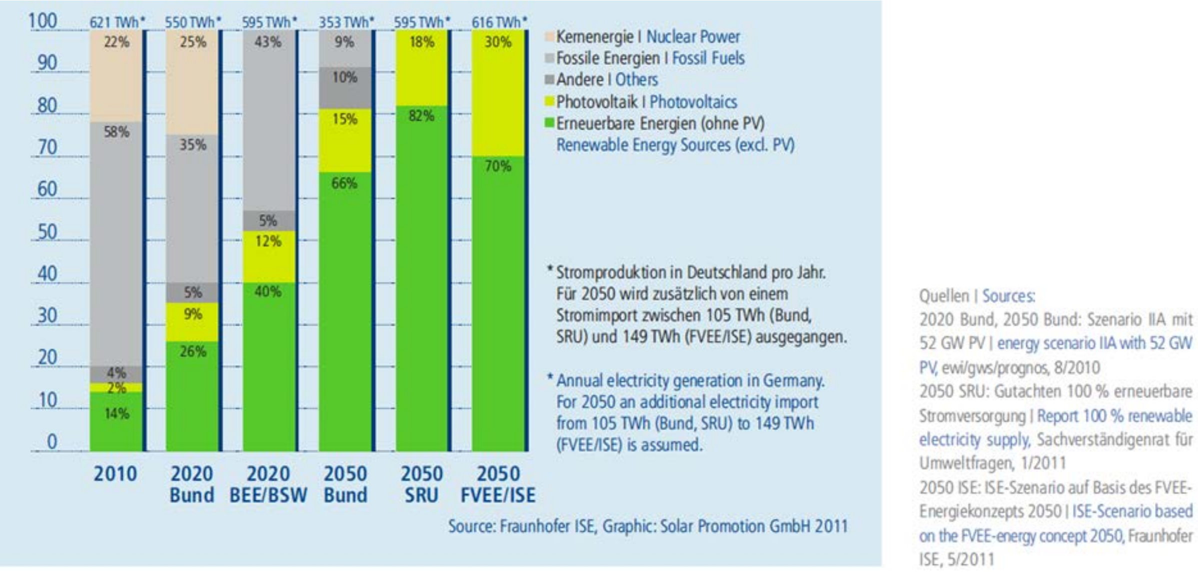


Figure 36: Scenario for Germany’s energy system, diagram of the system’s structure [ISE5].

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 37 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].



* Stromproduktion in Deutschland pro Jahr. Für 2050 wird zusätzlich von einem Stromimport zwischen 105 TWh (Bund, SRU) und 149 TWh (FVEE/ISE) ausgegangen.

* Annual electricity generation in Germany. For 2050 an additional electricity import from 105 TWh (Bund, SRU) to 149 TWh (FVEE/ISE) is assumed.

Source: Fraunhofer ISE, Graphic: Solar Promotion GmbH 2011

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

Figure 37: 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 38). 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].

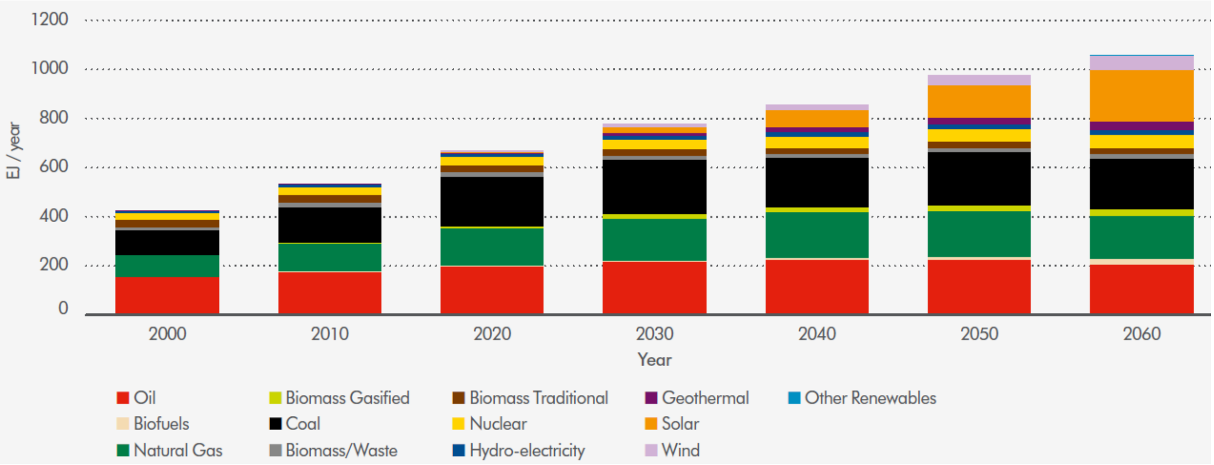


Figure 38: Primary energy consumption of various sources of power [Shell].

17.2 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 39 shows how heavily Germany depends on energy imports.

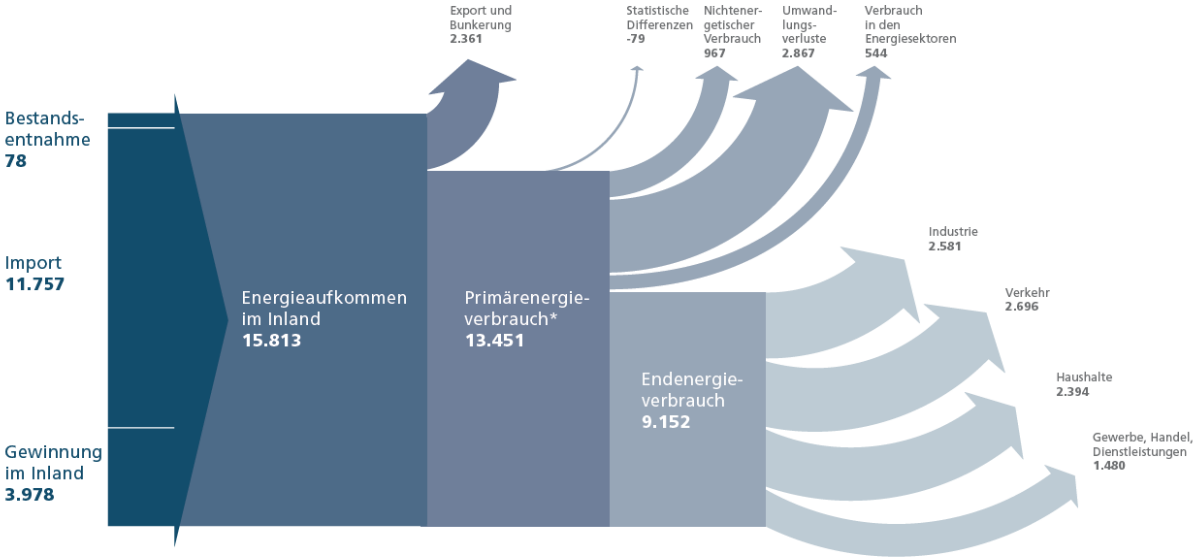
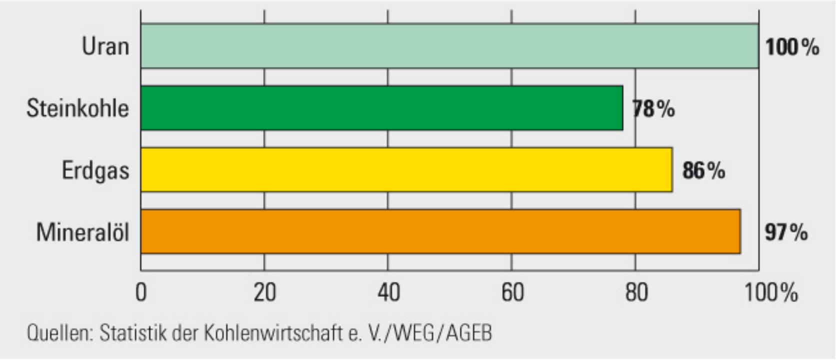


Figure 39: Energy flow diagram for Germany 2016 in petajoules (preliminary values) [AGEB2].

In energy conversion and consumption, large inefficiencies exist. 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 reduce their consumption by half through the introduction of 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.



Quellen: Statistik der Kohlenwirtschaft e. V./WEG/AGEB

Figure 40: Germany’s dependence on the import of raw energy materials 2011

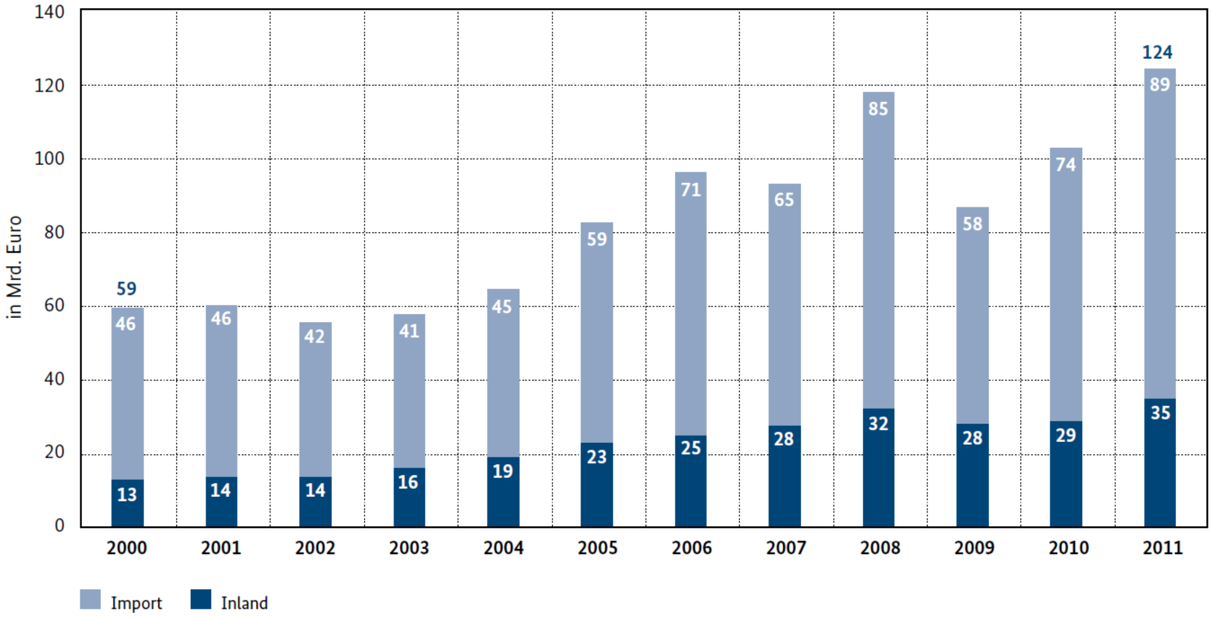


Figure 41: Cost development for the provision of primary energy in Germany [BMWi2]

Figure 41 shows the costs of energy imports, which reached 100 billion euros in 2012.

Figure 42 shows the different proportion of the various energy sources making up Germany's primary energy consumption. The severe lack of efficiency in electricity production using fossil and nuclear power plants results in primary energy losses between 50 and 75 percent. The inefficiency is one reason for the significant contribution of these energy sources 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.

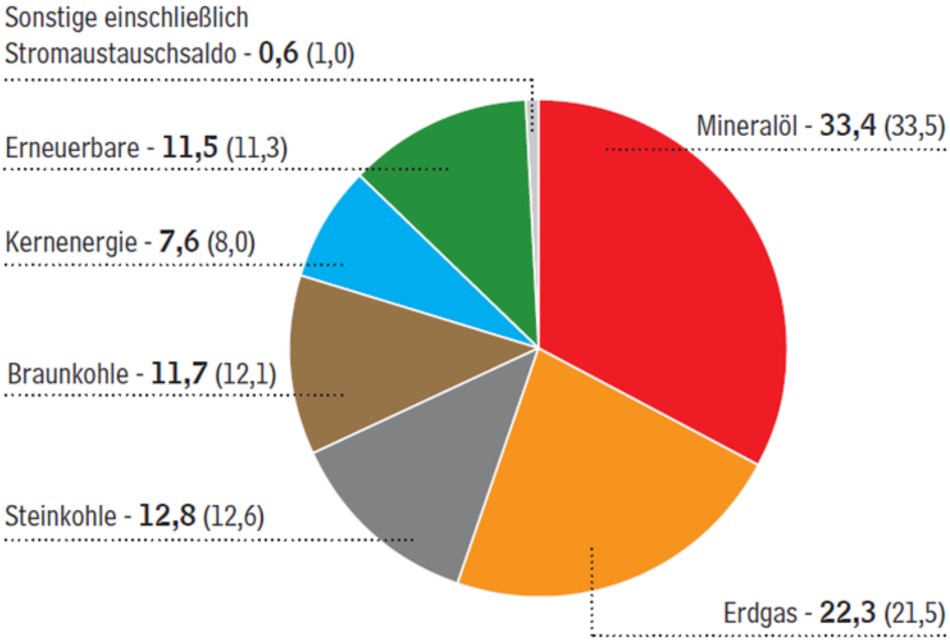


Figure 42: Composition of primary energy consumption in Germany 2013, figures given as percentages (data for previous year in brackets) and are preliminary estimates totaling 13,908 petajoules [AGEB3].

The majority of final energy (36 percent) is used to generate mechanical energy (force) for vehicles and stationary engines (Figure 43), whereby the combustion engines used in road vehicles evidence 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 insulation. Cooling is also generated indirectly via mechanical energy. Electric heat pumps are being used more and more to provide hot water and space heating. If, however, largely dimensioned thermal storage is lacking, then the thermal sensitivity of the electric load increases. Due to the absence of significant electric-electric storage capacity in the grid, large power reserves of fossil and nuclear power plants must be made available.

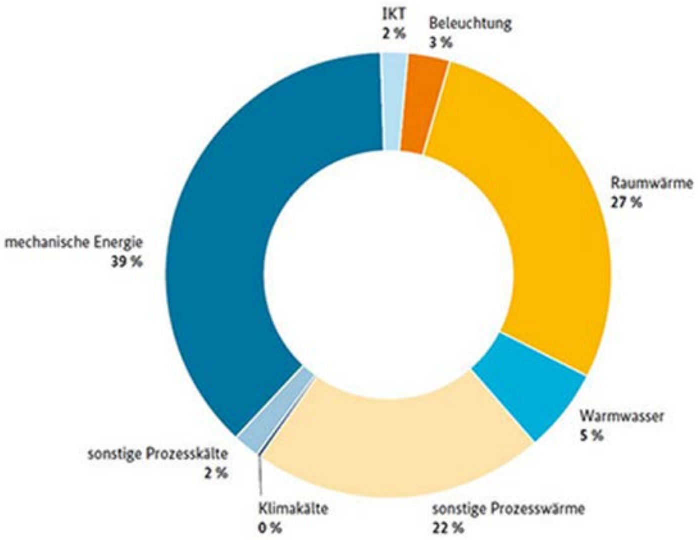


Figure 43: Share of final energy in Germany, categorized by utilization 2014 [BMWi4].

Figure 44 provides an example of how energy demand is distributed throughout the course of the year. The energy consumption in road transportation is characterized by base load. The total electricity consumption and the energy needed for hot water drop only slightly in summer. The heating demand correlates 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 44 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 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.

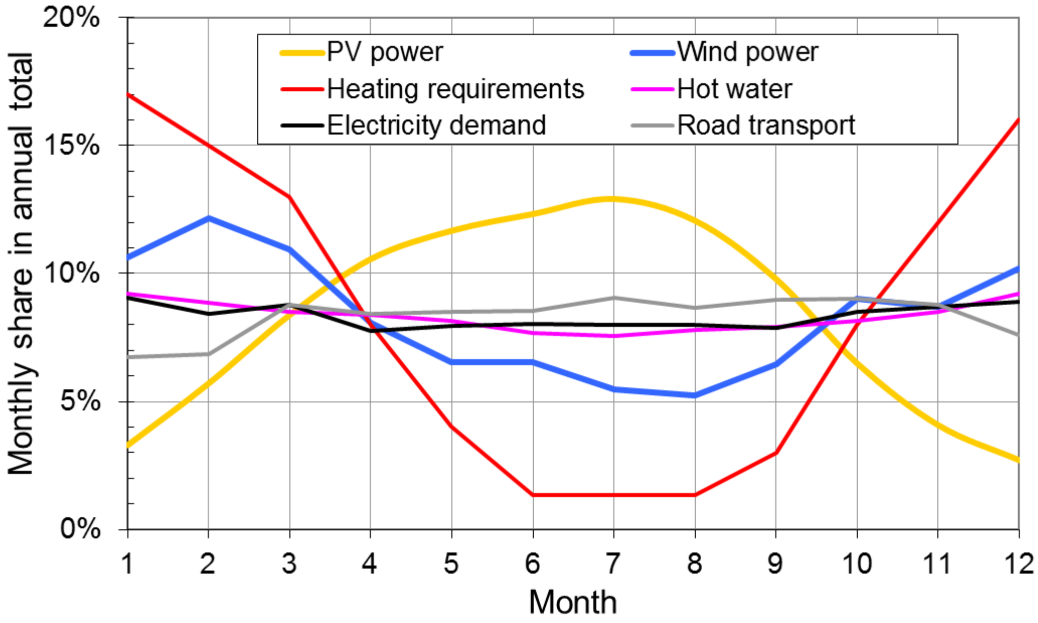
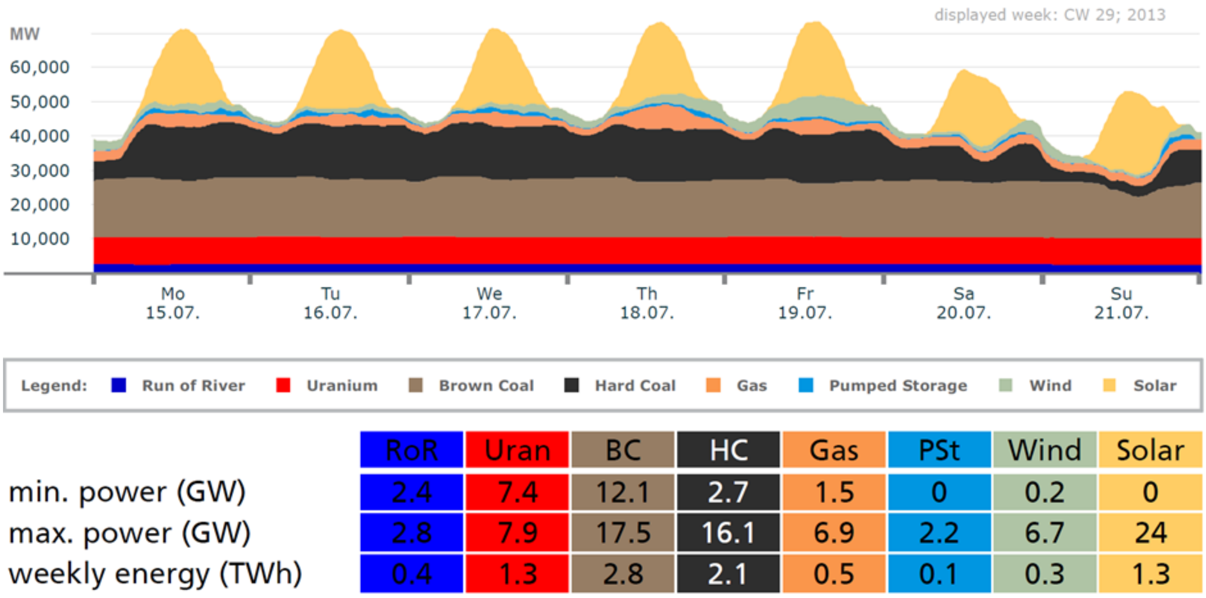


Figure 44: Rough estimate of the monthly distribution (annual total = 100 percent) of solar power calculated for Freiburg [PVGIS], wind power [DEWI], heating requirements based on the heating degree days (VDI Guideline 2067 and DIN 4713), energy requirements for domestic hot water production, electricity demand [AGEB1] and fuel requirements [MWV].

On the other hand, the energy load also fluctuates during the course of the day. More energy is required during the day than at night, and more on working days than over the weekend or on holidays. When considering load profiles, utilities distinguish between base, intermediate or peak load demands (see section 22.7). 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 mostly in a periodic manner, while peak load comprises sudden, highly changeable spikes in demand that are greater than the base and intermediate loads.

On sunny days, 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 the load 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. The further expansion of PV capacity leads to the midday peak load being covered even on less sunny days, while the midday electricity production on sunny days will cover even part of the base load requirements (see Figure 45), especially on the weekend.



	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 45 : 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 will not lead to a power surplus, provided that other energy sources are not increased at the same time.

Figure 47 shows what a power generation 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 22.7) only comes into play in the afternoon, with peak load occurring in the evening. With increasing expansion of RE, the residual base load disappears.

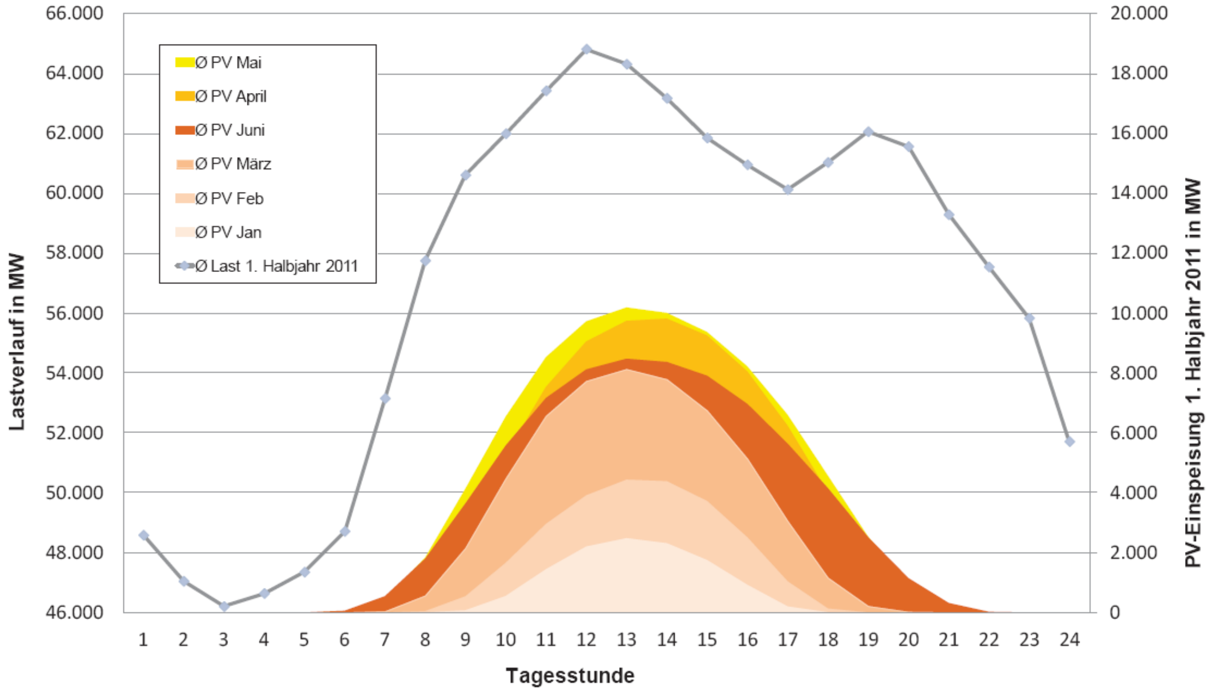


Figure 46: Average load profile and average monthly PV feed-in profiles in the first half of 2011 [IZES].

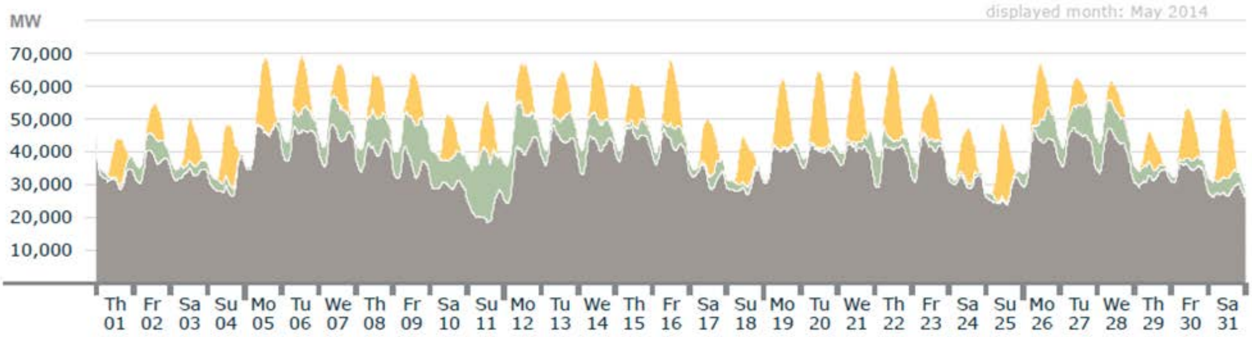


Figure 47: Simulated load profile and power generation based on weather data for a sunny week in May for installed capacities of 50 GW PV and 40 GW wind. Peak powers of 35 GW PV and 21 GW wind are generated respectively. (B. Burger, Fraunhofer ISE)

17.3 Compensatory measures

Despite there being no hard and fast rules for integrating intermittent 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.

17.3.1 Keeping PV power production 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, the availability of PV feed-in across Germany increases, meaning that complementary power plants do not need to be used until the late afternoon (compare Figure 47). Even more effective in achieving this aim are single and dual-axis tracking systems, which in addition to making power production more constant throughout the day, can increase the annual yield by between around 15-35 percent. Compared to non-tracking systems, these PV systems can reduce yield losses that occur due to higher operating temperatures or snow cover.

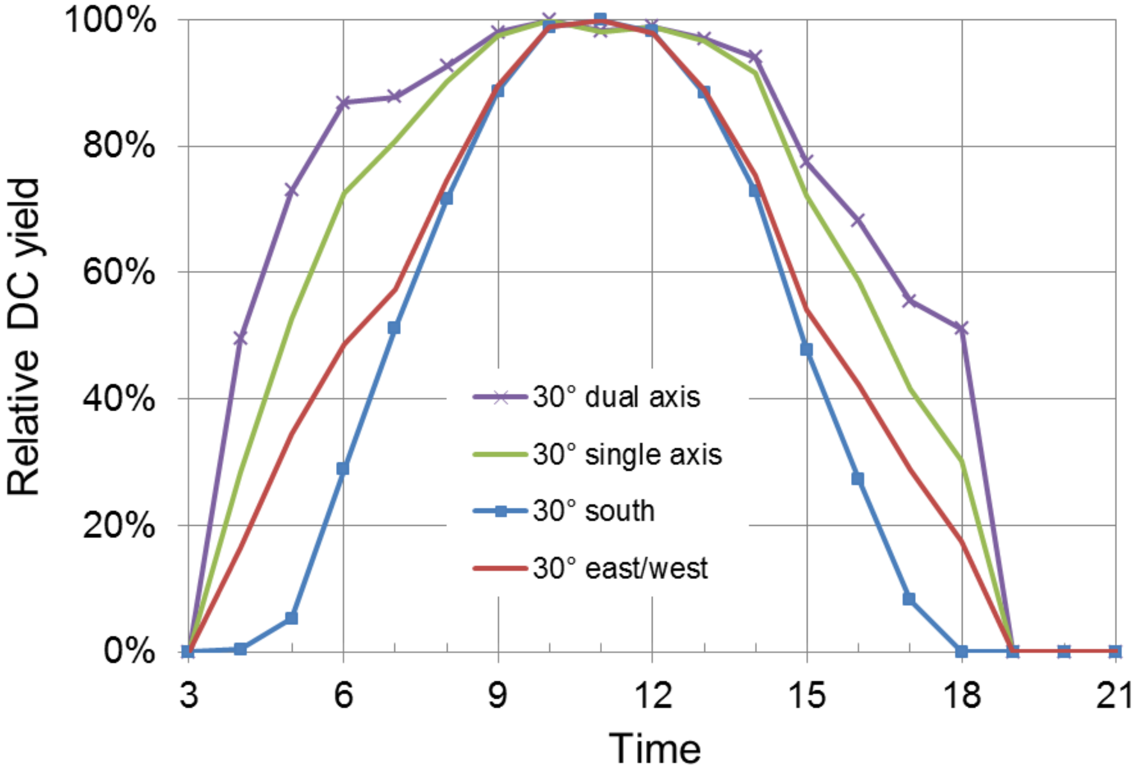


Figure 48: Yield development throughout the course of a day of PV plants installed in a variety of different ways, calculated using the software PVsol on a predominantly clear July day in Freiburg.

Increased on-site consumption and the associated savings due to less purchased electricity mean that the somewhat higher costs of electricity production due to more elaborate systems pays off already, especially for commercial consumers. Also the measures given in section 14.3 to increase the number of full-load hours contribute to the stability of the PV electricity supply.

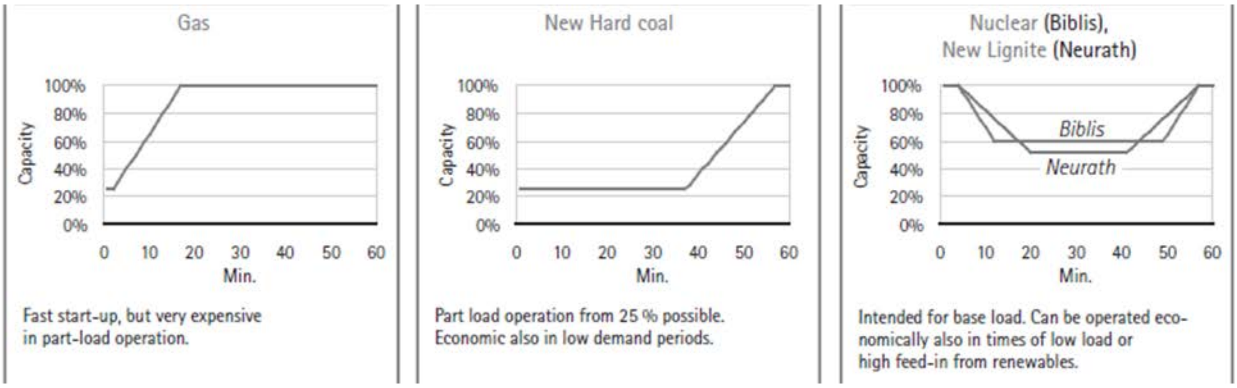
17.3.2 Complementary operation of adjustable power plants

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 49).

Partial load operation and any associated retrofitting increases the power production costs. Gas-fired power plants, in particular, are highly suitable for fluctuating loads. In combination with combined heat and power systems (CHP), natural gas power plants have a very high efficiency of 80-90 %. Gas power plants based on gas motors have only a fraction of the investment costs (€/kW) of combined cycle (gas and steam) power plants (CCPP).

However, since PV is already noticeably reducing the midday electricity demand and the associated price peak on the energy exchange, gas-fired plants do not currently constitute a worthwhile investment. Most of the natural gas must be imported. In 2013, the gas import quota was 90%, of which 38% was imported from Russia [AGEB6].

Nuclear and older lignite coal-fired power plants have the most difficulty with flexible operation. The expansion of RE capacity means that these type of plants will be pushed out in the long term. The sooner they make way for more flexible power plants, the faster the transformation to PV and wind power shall succeed.



Fast start-up, but very expensive in part-load operation.

Part load operation from 25 % possible. Economic also in low demand periods.

Intended for base load. Can be operated economically also in times of low load or high feed-in from renewables.

Figure 49: Power plant availability [VGB].

Existing hydroelectric power plants (see section 17.3.8 for information on pumped storage) may make contributions to the controllability of 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.

Provided their operators provide the required storage systems and are ready to accept a lower utilization rate, biomass power plants (5.9 GW of installed capacity at the end of 2013 [BMWi1]) 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. About 20 GW of CHP capacity 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 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 operate according to electricity demand, such systems 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.

17.3.3 Decreasing energy consumption

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, which is equipped solely 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 night, solar electricity is available only through storage systems which are, in comparison, costly and less efficient than direct use.

17.3.4 Adapting consumption habits

Raising consumer awareness, the use of timers and, in the future, control signals from the provider (grid or one’s own roof) indicating favorable times of use for household appliances as well as cooling devices with increased thermal mass will help change power consumption patterns of household appliances so that they are better correlated to PV (and wind by grid control) production (Figure 50). Washing machines, dryers and cooling devices with storage can be of service to the grid and – in the case of one’s own PV array – optimized for self-consumption. Some of the electric appliances must be able to communicate with the PV array on the roof or the electricity supplier. This communication port can increase the self-consumption of commercial businesses by a large amount.

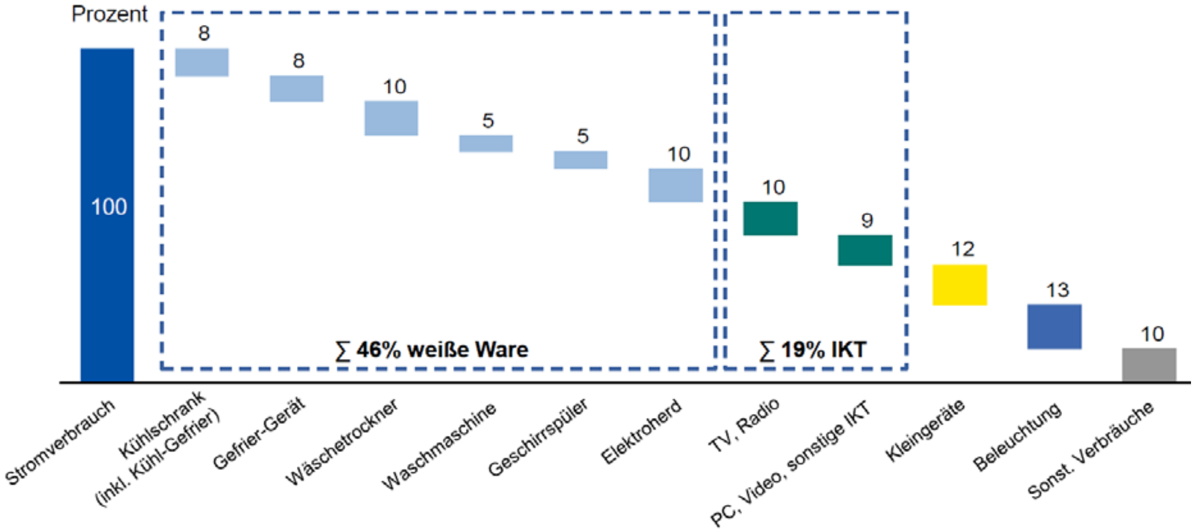


Figure 50: Energy consumption of an average household not including hot water production [RWE].

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 rate" 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.

There are also opportunities to adapt the consumption habits of energy-intensive industrial enterprises. These will only be introduced, once the cheaper daytime power is more frequently 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 storage.

The same applies to cold stores, grocery stores and air-conditioning units that are already equipped with a certain level of thermal storage capacity so that the addition of 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.

17.3.5 Balanced expansion of PV and wind power capacities

In Germany, weather patterns show a negative correlation between the PV and onshore wind power generated on both the hourly and monthly scales (Figure 25 and Figure 26). In terms of hourly fluctuations, the total amount of electricity generated from PV and onshore wind rarely exceeds 50 percent of the total rated power, while in terms of

monthly changes, the total electricity generated by both sources is distributed more evenly than the individual amounts generated by each source.
Storage demands will drop if the capacity of installed PV and onshore wind power continue to remain about equal.

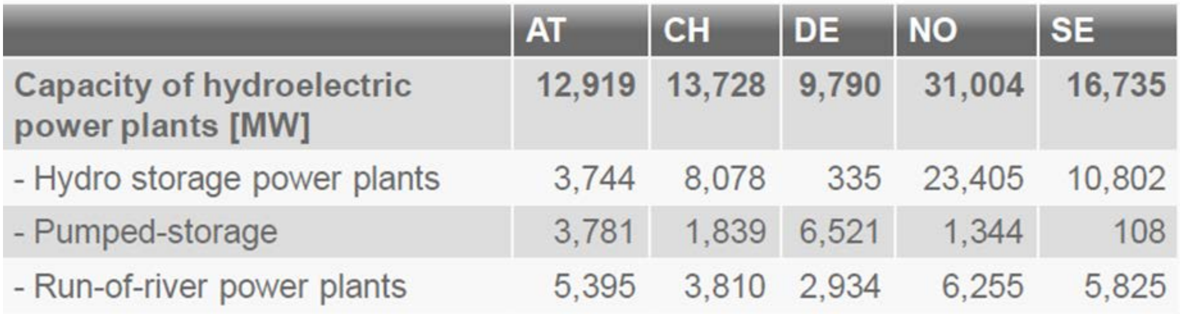
17.3.6 Grid expansion

17.3.6.1 National 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 make up roughly ten percent of the routine yearly expenditure for grid strengthening. 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.

17.3.6.2 Strengthening the European grid

The German electricity grid is part of the larger European grid. All neighboring countries have some controllable power plants in their fleet and also experience high levels of demand during peak hours, e.g. midday. Strengthening cross-border interconnection capacity (presently ca. 20 GW) and thus European electricity trade will contribute significantly to smoothing out the fluctuations in PV production.
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]
Norway has about 30 GW hydroelectricity [Prognos] with potential for expansion. By 2018, an underwater cable with a length of 600 km and a transmission power of 1.4 GW will be installed to create a direct connection to the German electricity grid. The installed capacity of the hydroelectric power in Switzerland and Austria are 12 GW and 9 GW respectively.



	AT	CH	DE	NO	SE
Capacity of hydroelectric power plants [MW]	**12,919**	**13,728**	**9,790**	**31,004**	**16,735**
- Hydro storage power plants	3,744	8,078	335	23,405	10,802
- Pumped-storage	3,781	1,839	6,521	1,344	108
- Run-of-river power plants	5,395	3,810	2,934	6,255	5,825

Figure 51 : Total power of hydroelectric stations in selected countries, status in 2010 [Prognos]. The capacity given for each of type of power plant differs according to the data source

17.3.7 Switching consumers with electric storage to electrically operable systems

Through the conversion of drive systems, key groups of consumers can be supplied with electric power. With storage facilities, consumers are able to accept electricity from intermittent PV and wind power as it is generated. This means that all of the power produced, even during times of temporary peaks greater than the momentary demand, can be utilized. This allows for the further expansion of PV and wind, leading to higher coverage rates from these energy sources in the energy supply.

17.3.7.1 Heat sector

While space and water heating is still carried out today primarily by burning fossil fuels, electric heat pumps with thermal storage can also be used for this purpose. Heat pump efficiency (electric energy to heat) is given by the seasonal energy efficiency ratio (SEER) and stands, independent of technology and load, at around 300 percent. Once converted into heat, the energy can be stored efficiently and cost effectively.

The provision of hot water with a combination of heat pumps, thermal storage and photovoltaics can achieve attractive utilization ratios for PV systems in Germany, especially when the PV system is mounted on steep south-facing roofs or facades. Space heating with PV is more difficult due to the weak correlation between the annual supply and demand. Large seasonal thermal storage is required in order to use a majority of the PV electricity for this purpose. Due to the seasonal availability, it makes more sense to cover the heating demand with wind and suitably sized thermal storage. Phase change materials offer much higher storage capacities than sensible heat storage.

For fluctuating energy sources without appreciable marginal costs, like wind and solar, it is not economical to design the system to meet 100 percent 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 using heating rods (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 and is therefore not systematically important.

17.3.7.2 Mobility

Motorized road transport burns fossil fuels at an extremely low efficiency with respect to the transport performance. Most of the energy consumed disappears as waste heat in the motor and in the brake system. Electric vehicles use highly efficient motors (efficiency > 90 %) and the mechanical energy generated can be used to a large extent (recuperation brake). In particular, the batteries can assist in stabilizing the grid through a controllable charging/discharging. For example, charging stations at work enable employees to charge their cars during peak PV production at midday.

Plug-in hybrids have an electric driving range of ca. 80 km (Opel Ampera).

Purely electric vehicles with driving ranges up to 300 km (e.g.BMW i3) are on the market and provide a realistic option for commuters. The federal government plans to have one million electric vehicles on the road in Germany by 2020. With a charging capacity of ca. 40 kW per vehicle (chargers presently in development), 25,000 vehicles plugged into the electricity grid would provide one gigawatt of controllable consumption. However, revolutionizing our personal means of transport has really taken off on two wheels: More than 2.5 million electric bikes were sold in Germany by the end of 2015. To compare, the number of plug-in hybrids and purely electric cars on German roads by mid-2016 totaled 60,000.

17.3.8 Energy storage

17.3.8.1 Distributed Storage

Small, stationary batteries at home allow the on-site consumption of PV power to continue into the evening, increasing it significantly (Figure 52).

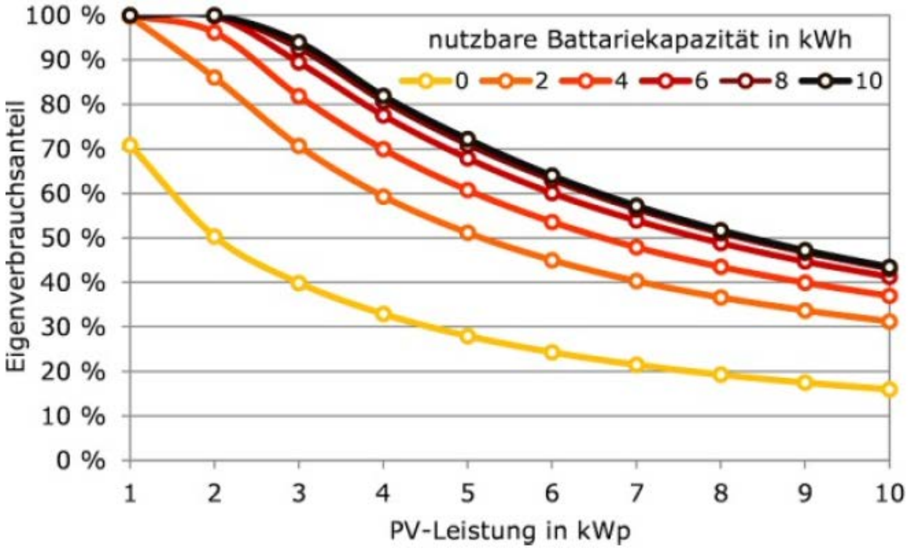


Figure 52: Percent of on-site consumption in dependence of the battery capacity and PV array power for a single-family home with an annual electricity consumption of 4,700 kWh. [Quasch]

A study from Fraunhofer ISE shows that systems with grid-optimized operation can reduce the grid load by decreasing the grid feed-in at peak times as well as the electricity purchased in the evenings (Figure 53). With the use of storage systems, more PV can be installed. "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]

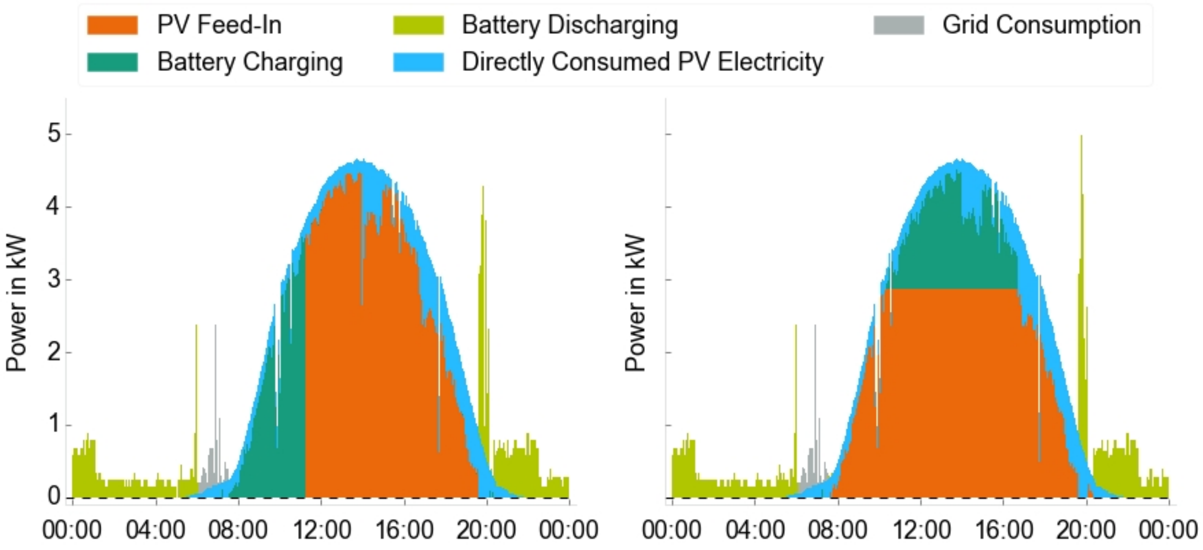


Figure 53: Comparison of the conventional and grid-optimized system operation [ISE7]

Electric vehicles, which are connected to the grid and must not be immediately available to drive, can also serve as electricity/electricity storage. The heat pump with thermal storage was already mentioned (See 17.3.7).

17.3.8.2 Centralized Storage

Centralized storage systems exist only in the form of pumped storage at present. The currently installed pumped storage capacity in the German grid stands at almost 38 GWh, while rated power is approximately 6.4 GW and the average efficiency value is 70 percent (without transmission losses). 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.

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 over-ground storage systems are able to accommodate more than 200 TWh of energy (equivalent to 720 petajoules).

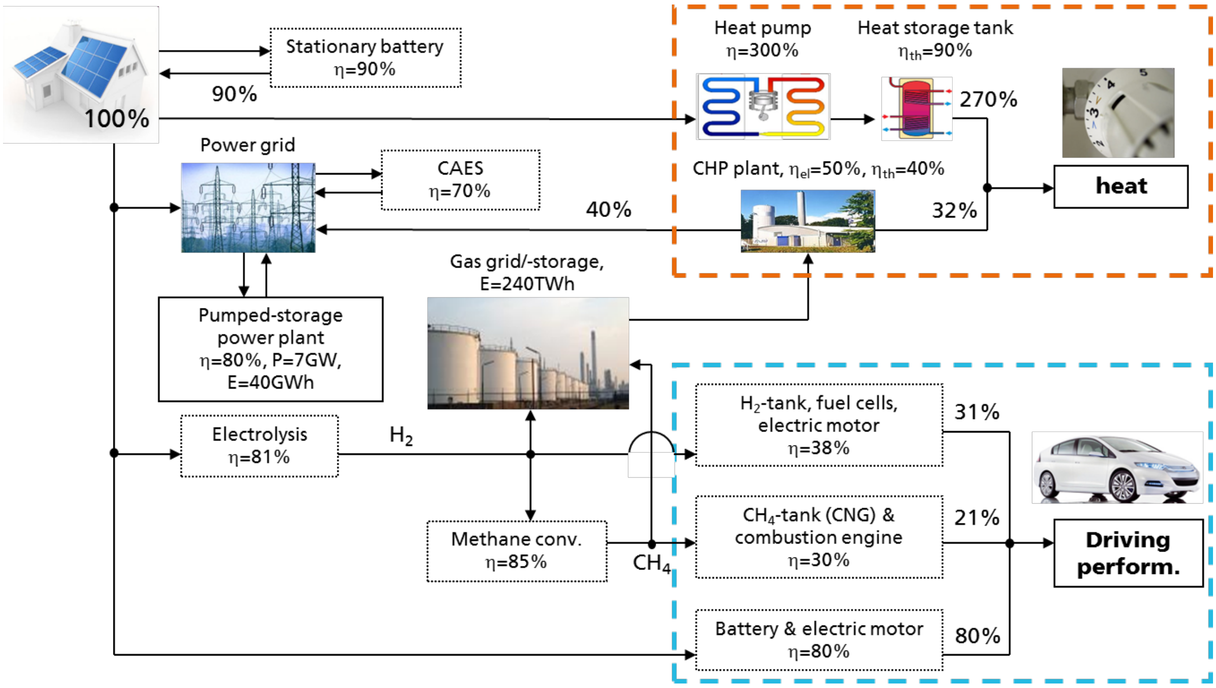


Figure 54: Possible ways of converting and storing PV power with indicative data on efficiency values.

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 54 presents an overview of possible ways of converting and storing PV power.

18. Do we need PV production in Germany?

Yes, if we want to avoid new dependencies in energy supply.
As the energy transformation progresses, Germany will leave behind the "fossil fuel" century, in which we spent 90 billion euros for oil and gas imports annually and thus financed authoritarian governments. The energy transformation offers the chance to escape from this dependency. Not only does the sun also shine in Germany but Germany has also made decisive contributions to technology development in the solar sector. In spite of the enormous slump in Germany's solar market, the German PV sector with its material manufacturers, engineers, PV producers, R&D institutes and training facilities has held onto its leading position worldwide.

A future energy system based on renewable energy sources with ca. 200 GW installed PV: For the construction and increasingly the up-keep of these power stations, annual installations of 6-7 GW are required. This corresponds to about 20 million PV modules at a cost of several billion euros. A PV production within Germany offers long-term security of supply at high ecological standards and quality.

19. Do PV modules contain toxic substances?

That depends on the technology and materials used.

19.1 Wafer-based modules

The silicon wafer-based modules (approximately 90 percent of the market share) 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). It is possible to completely substitute lead, a poisonous heavy metal, for harmless materials at a low additional cost. Other than lead, wafer-based modules do not usually contain any known toxic substances.

19.2 Thin-film modules

Cadmium telluride (CdTe) thin-film modules (approximately five percent of market share) contain cadmium (Cd) in salt form. The technology behind this type of module does not allow this material to be substituted. Metallic cadmium and cadmium oxide are classified as toxic; CdTe as harmful to health. 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 can be toxic when oxidized (e.g. after a fire) independent of the amount. Many manufacturers declare the conformity of their CIS modules with the RoHS chemical regulation (Restriction of certain hazardous substances) and the EU chemicals ordinance REACH (Registration, Evaluation, Authorization and Restriction of chemicals). For a differentiated evaluation, reference is made to independent investigations of each module type.

19.3 Solar glass

All conventional solar modules require a front cover made of glass. The glass shall have a very low absorption in the spectral range between 380 and 1100 nm, conform to solar glass quality. Many glass manufactures increase the transmission by adding antimony (Sb) to the glass melt. If this glass is disposed of in waste dumps, antimony can seep into the ground water. Studies indicate that antimony compounds have a similar effect as arsenic compounds.

19.4 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. In October 2015, the electric and electronic device law came into effect. It classified PV modules as household devices and set down provisions for take-back obligations as well as financing.

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

20.1 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 **1,400 metric tonnes** of silver annually, corresponding to almost five percent of production in 2015. In the future, the silver in solar cells will be used more efficiently and replaced by copper as much as possible.

20.2 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.

21. Do PV plants increase the risk of fire?

21.1 Can defective PV plants cause a fire?

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, like roofing material or wood, lies in close vicinity to these arcs, then a fire may break out depending on how easily the material ignites. In comparison to AC installations, the DC power of solar cells may even serve as a stabilizing factor for 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 1.4 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 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 be performed by third parties. It has also been suggested that privately owned PV systems are subjected to a compulsory, regular safety test similar to that performed on commercial plants every four years." [ISE6]

21.2 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]

21.3 Do PV modules prevent firefighters from extinguishing 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.

21.4 Are toxic emissions released when PV modules burn?

The Bavarian Environment Agency (Bayerisches Landesamt für Umwelt) has calculated that the dispersion of fumes following a fire involving CdTe modules does not pose a serious risk for the surrounding area and general public [LFU].For CIS modules, independent investigations for the different module types are referenced.

For wafer-based modules, the rear side foils can contain fluoropolymers, which themselves are not poisonous. In a fire at high temperatures, however, they can decompose. Upon examination, the Bavarian Environment Agency came to the conclusion that during a fire, conflagration gases other than fluoropolymers play a more critical role in defining the potential danger.

22. Appendix: Terminology

22.1 EEG surcharge

"The EEG surcharge (EEG-Umlage in German) 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 for renewable energy sources, which is described in the Renewable Energy Act (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 power and solar power are supported.

Several stages are used to determine how the costs associated with promoting renewable electricity are allocated to the end users. In the **first stage**, plant operators, who generate power from renewable energy, are guaranteed a fixed feed-in tariff for all power produced by their plant." [Bundestag]

The level of this feed-in tariff is based on the levelized cost of electricity (LCOE) for PV plants installed at that time and is guaranteed for 20 years.

"The grid operators, who connect these renewable plants to their grids and who also reimburse the plant operators for the fed-in power, transmit the power to the responsible transmission system operator (TSO), who reimburse them in turn (**second stage**). In the **third stage**, the renewable energy is distributed proportionally between Germany's four transmission system operators (TSO), compensating regional differences in renewable energy generation.

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 adopted, the renewable power generated was simply transmitted (via the TSOs) at the price of the feed-in tariff to the energy supply companies, who sell the power. Now, however, TSOs are required to put the power generated from renewables onto the EEX (spot market). The energy supply companies, which ultimately transmit the power to the end customers, can obtain power from the market regardless of how much renewable energy is fed into the grid. This gives them greater planning security and also allows them to save costs. As a result, the costs of the EEG promotions remain first and foremost with the TSOs.

The costs related to the EEG promotion is calculated based on the difference between the rate of return generated by the renewable power put on the market (EEX) and the feed-in tariffs paid to plant operators. (...)" [Bundestag]

These costs are then distributed over the total energy consumption – the so-called EEG surcharge, which is apportioned to the end consumers by the electricity supply companies. "The Equalization Scheme Ordinance (AusglMechV) stipulates that the TSOs set the level of the EEG surcharge on October 15 of each year for the following year. The calculation of the surcharge is subject to review by the German Federal Network Agency. (...) The EEG surcharge is limited to 0.05 €-cts/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 surcharge.

22.2 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 conditions imply a module temperature of 25 °C, vertical irradiance of 1000 W/m^2 and a standard solar irradiance spectrum. During actual operation, conditions are normally so different from these standard conditions that efficiency varies.

22.3 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.

22.4 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 solar 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 values. Therefore, it is 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.

22.5 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 surface area of the PV modules. The nominal module efficiency affects system efficiency.

22.6 Performance ratio

The performance ratio (PR) is often used to compare the efficiency of grid-connected PV plants at different locations with various module types.

Performance ratio is defined as 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.

22.7 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, lignite 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 coming into play when demand is at its very 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]

22.8 Gross and nets power consumption

The gross power consumption is calculated as the sum of the national electricity production and the balance of power exchanged between bordering countries. It includes the self-consumption from power plants, storage losses, grid losses and unknowns. In 2013, the sum of all losses amounted to 12% of the gross power consumption [AGEB6], whereby only the storage losses were listed at 1.3%.

Net power consumption is the amount of electrical energy (final energy) used by the end consumer. PV plants predominantly generate energy decentrally when electricity demand is at a peak and the PV plant's self-consumption does not reduce the PV yield by a noteworthy amount. Instead of following the usual method of comparing output with gross power consumption, it is plausible for PV to compare power output with net power consumption.

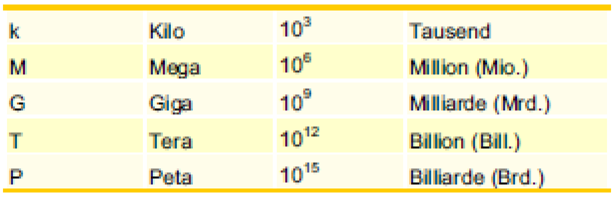
22.9 External costs [DLR1]

"External costs, as defined within the context of the technological external effects, arise as a result of damage inflicted on the environment, climate and human health due to pollutants 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."

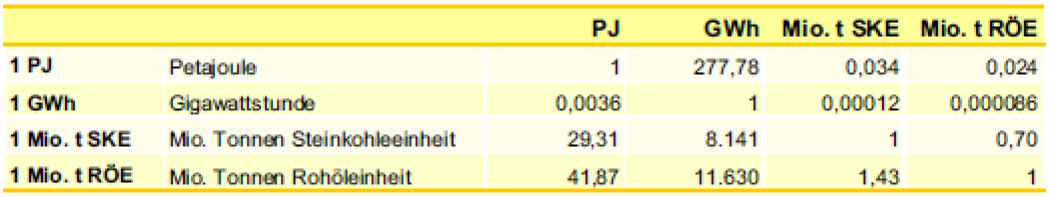
23. Appendix: Conversion tables [EEBW]

Vorsätze und Vorzeichen



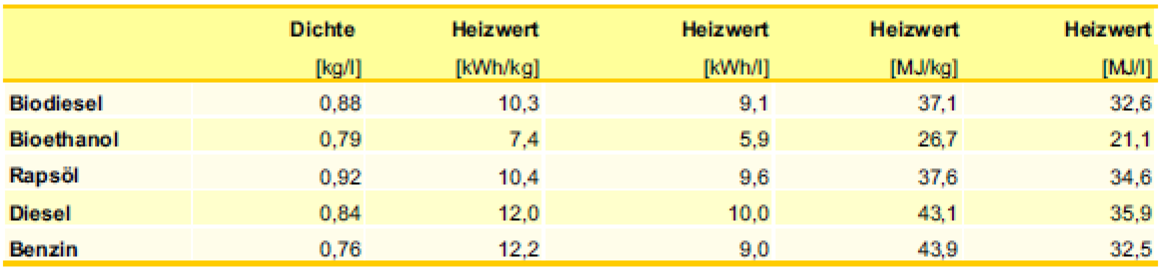
k	Kilo	10^{3}	Tausend
M	Mega	10^{6}	Million (Mio.)
G	Giga	10^{9}	Milliarde (Mrd.)
T	Tera	10^{12}	Billion (Bill.)
P	Peta	10^{15}	Billiarde (Brd.)

Umrechnungen



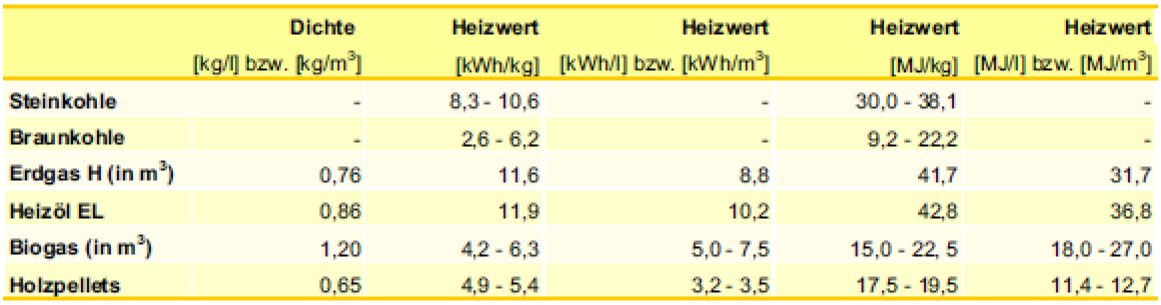
		PJ	GWh	Mio. t SKE	Mio. t RÖE
1 PJ	Petajoule	1	277,78	0,034	0,024
1 GWh	Gigawattstunde	0,0036	1	0,00012	0,000086
1 Mio. t SKE	Mio. Tonnen Steinkohleeinheit	29,31	8.141	1	0,70
1 Mio. t RÖE	Mio. Tonnen Rohöleinheit	41,87	11.630	1,43	1

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/m^3]	Heizwert [kWh/kg]	Heizwert [kWh/l] bzw. [kWh/m^3]	Heizwert [MJ/kg]	Heizwert [MJ/l] bzw. [MJ/m^3]
Steinkohle	-	8,3 - 10,6	-	30,0 - 38,1	-
Braunkohle	-	2,6 - 6,2	-	9,2 - 22,2	-
Erdgas H (in m^3)	0,76	11,6	8,8	41,7	31,7
Heizöl EL	0,86	11,9	10,2	42,8	36,8
Biogas (in m^3)	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

24. Appendix: Abbreviations

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
CHP	Combined heat and power – the principle of simultaneously generating mechanical energy (ultimately converted into electrical energy) and useful heat
CHP plant	Combined heat and power plant – a plant that uses combustion engines or gas turbines to generate electrical energy and heat
EEG	Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act, EEG)
ESC	Energy supply company
ICT	Information and communications technology
IEA	International Energy Agency
PV	Photovoltaics
RE	Renewable energy
W_p	Watt peak – rated power of a PV module or array

25. Appendix: Sources

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AGEB2	Energieflussbild 2016 für die Bundesrepublik Deutschland in Petajoule, AGEB
AGEB5	Bruttostromerzeugung in Deutschland von 1990 bis 2015 nach Energieträgern, AGEB, http://www.ag-energiebilanzen.de/, 28 January 2016
AGEB6	Energieverbrauch in Deutschland in Jahr 2013, AGEB, März 2014
AGEB7	Witterung treibt Energieverbrauch, AGEB, Pressedienst 3/2014
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BDEW3	BDEW-Strompreisanalyse Juni 2014, Haushalte und Industrie, Berlin, 20. Juni 2014
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BMU3	Forschungsjahrbuch Erneuerbare Energien 2011, German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), July 2012
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DEWI	Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020, Studie im Auftrag der Deutschen Energie-Agentur GmbH (dena), February 2005

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IFNE	Langfristszenarien und Strategien für den Ausbau der Erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global, study commissioned by BMU as of March 2012
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26. Appendix: Figures