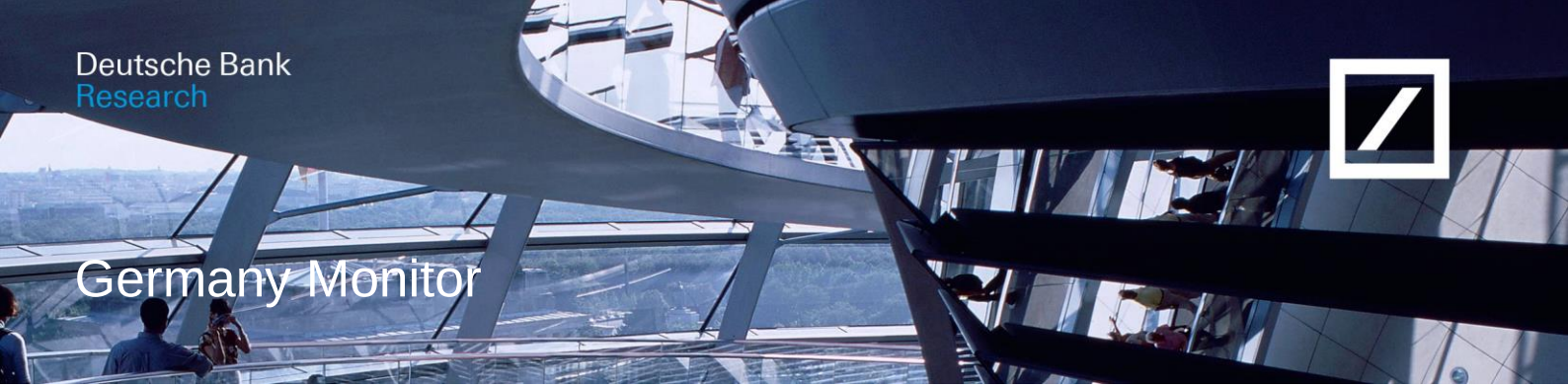

Costs of electricity generation: System costs matter

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Author
Eric Heymann
+49 69 910-31730
eric.heymann@db.com

Editor
Stefan Schneider

Deutsche Bank AG
Deutsche Bank Research
Frankfurt am Main
Germany
E-mail: marketing.dbr@db.com
Fax: +49 69 910-31877

www.dbresearch.com

DB Research Management
Stefan Schneider

Ahead of the phase-out of nuclear energy in Germany, the costs of electricity generation were debated again. Often, however, no distinction is made as to which specific costs are meant. There should be a distinction among (at least) three types of electricity generation costs: marginal costs, levelized costs of electricity, and system costs.

Marginal costs are the costs of an additional kilowatt-hour (kWh) of electricity from an existing traditional power plant or a renewable energy (RE) plant. Weather-dependent renewables are exceptionally cheap with marginal costs close to zero. Existing nuclear power plants usually have low marginal costs as well. Marginal costs of gas-fired power plants, however, increased dramatically last year due to the steep rise in gas prices.

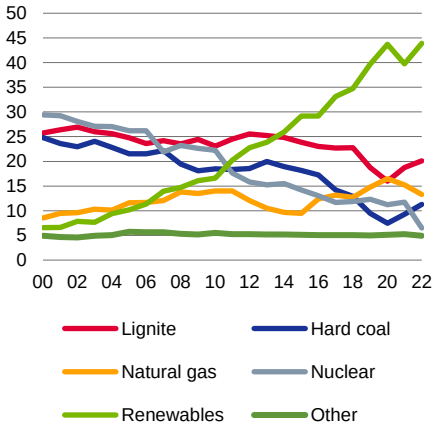
The levelized cost of electricity (LCOE) is the ratio of initial investment costs, fixed and variable operating costs, and capital costs over the lifetime of a planned plant to the amount of electricity generated over its lifetime. It is the business perspective of an investor or operator of a plant. The LCOE of weather-dependent renewable energies has fallen quite steadily in recent years. Their competitiveness against conventional power plants increased further last year due to higher prices for fossil fuels.

The public debate often neglects those costs that result from a high and increasing share of weather-dependent renewables in the electricity market. These system costs are the macro-economically relevant variable. They result, for example, from the provision of back-up power plants and the falling average capacity utilization of all existing power plants, the necessary grid expansion, grid congestion management measures, or the need to build power storage facilities. The statement that renewables are the most cost-effective form of power generation seems too general.

Costs of electricity generation: System costs matter

Renewables in the lead 1

Share of different energy sources in gross electricity production in Germany, %

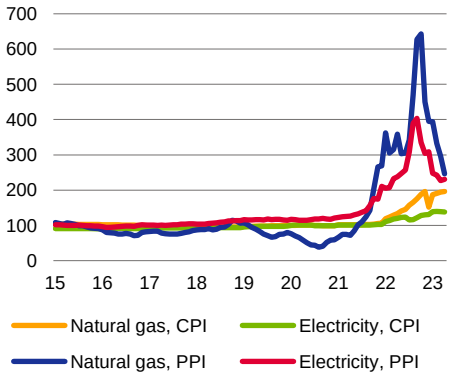


* January-July

Source: AG Energiebilanzen

Energy prices: Peak for consumer prices in sight 2

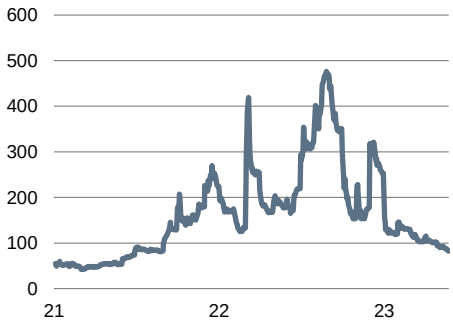
CPI and PPI for natural gas and electricity in Germany, 2015=100



Source: Federal Statistical Office

Electricity prices have come down significantly 3

Daily electricity price (industrials), baseload (1M future), EUR per MWh



Source: EEX

Before the last three nuclear power plants were taken off the grid in Germany in mid-April, there was once again an intense debate in politics and the media about the advantages and disadvantages of nuclear energy and whether a phase-out at this point would make sense. The costs of electricity generation were also a focus area. Proponents of a phase-out argued that nuclear power is one of the most expensive forms of electricity generation and that electricity from renewables is much cheaper. Supporters of a lifetime extension countered that keeping nuclear power plants on the grid (temporarily) would lower the cost of electricity generation in Germany. The positions could not have been more opposing.

The debate about the costs of generating electricity from different energy sources is not new. Often, however, no distinction is made as to which specific costs are meant. There should be a distinction among (at least) three types of electricity generation costs: marginal costs, levelized costs of electricity, and system costs.

Marginal costs: Weather-dependent renewables are extraordinarily cheap

Marginal costs are the costs of an additional kilowatt-hour (kWh) of electricity from an existing traditional power plant or a renewable energy (RE) plant. Weather-dependent renewables are incomparably cheap with marginal costs close to zero. In this case, it's true that the wind and the sun do not send a bill for an additional kilowatt-hour of electricity. In conventional power plants, on the other hand, energy sources (e.g., coal or natural gas) must be added to get an additional kilowatt-hour. Marginal costs also determine the order in which the various types of power plants feed electricity into the grid (merit order). Thanks to their low marginal costs, coupled with the feed-in priority guaranteed by the German Renewable Energy Law (EEG), weather-dependent renewables are always at the beginning of the merit order. Before nuclear power was phased out, nuclear power plants came after weather-dependent renewables, as they also had very low marginal costs. Among the thermal power plant types, lignite, hard coal, and gas-fired power plants usually followed in the merit order in Germany. The order depends, among other things, on the respective prices of the energy sources and the prices for CO_2 certificates in EU emissions trading, which are intended to internalize the external costs of fossil fuel consumption (climate change). For all thermal power plants, marginal costs in 2022 increased due to higher prices for energy raw materials and emission allowances, in some cases significantly.[1]

Due to high gas prices, the merit order effect became more widely known last year. Gas-fired power plants were very often the price-setting power plants. As a result, high gas prices had a knock-on effect on the price of electricity on the wholesale market.[2] For the time being, the phase-out of nuclear power means that the CO_2 intensity of base-load power supply in Germany is increasing. Because nuclear power plants have fallen out of the merit order curve, more expensive peak load power plants (e.g., based on natural gas) will be needed for sufficient power generation sooner than before. Ultimately, for the existing nuclear power plants in Germany, it was true to say that the (marginal) costs of electricity generation were very low.

[1] Cf. Forschungsstelle für Energiewirtschaft (2022). Veränderungen der Merit Order und deren Auswirkungen auf den Strompreis.
[2] Cf. EWI Köln (2022). Energiekrise 2022: Gaspreis treibt Strompreis auf Rekordwerte.

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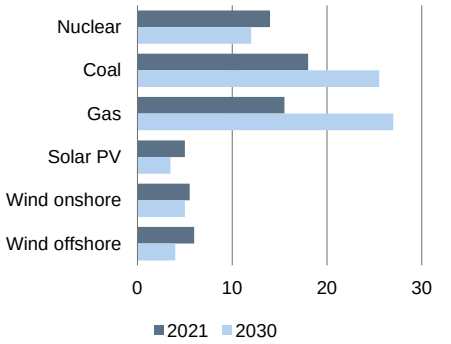
EU: LCOE for coal and gas-fired power plants to increase massively 4

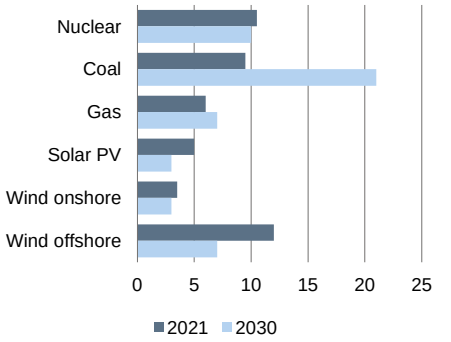
LCOE by energy source, US cent per kWh



Sources: IEA, IRENA

US: Falling LCOE for renewables and nuclear expected 5

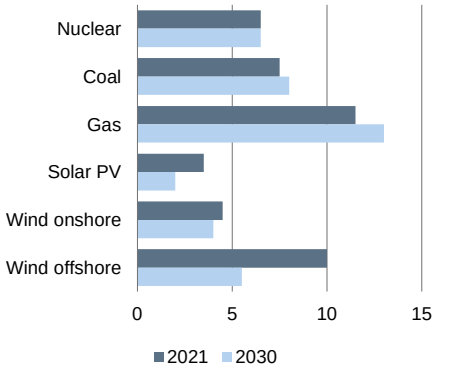
LCOE by energy source, US cent per kWh



Sources: IEA, IRENA

China: LCOE of nuclear power quite competitve 6

LCOE by energy source, US cent per kWh



Sources: IEA, IRENA

Levelized costs of electricity: Competitiveness of renewables steadily increasing

The levelized cost of electricity (LCOE) is the ratio of initial investment costs, fixed and variable operating costs, and capital costs over the lifetime of a planned plant to the amount of electricity generated over its lifetime. Therefore, it is the business perspective of an investor or operator of a plant before it is built (or when it is purchased). The LCOE of weather-dependent renewable energies has fallen quite steadily in recent years and was at least competitive with conventional power plants even before the energy crisis. The Fraunhofer ISE, for example, put the LCOE for onshore wind power (in Germany) in 2021 at about 4 to 8 cents per kWh, for photovoltaics (without batteries) at around 3 to 11 cents per kWh, and for offshore wind power at 7 to 12 cents per kWh. In 2021, this contrasted with a LCOE for gas and steam power plants of 8 to 13 cents per kWh and for hard coal power plants of 11 to 13 cents per kWh.[3] The BMWK recently stated that the LCOE of wind and solar power increased in 2022 for the first time in more than 20 years due to rising prices for input products and material bottlenecks, as well as higher capital costs.[4] However, the LCOE of thermal power plants is likely to have expanded even more strongly due to higher prices for fossil energy resources, which is why the competitiveness of renewables has increased.

The LCOE of RE plants or conventional power plants differs depending on the region or regulatory environment. In locations with a lot of wind, the LCOE is lower than in locations with little wind (e.g., northern Germany versus southern Germany). In countries where CO_2 emissions are priced, the LCOE of coal- or gas-fired power plants is higher than in countries without such regulation.

For nuclear power plants, different statements on the LCOE can be found in the existing literature. The U.S. investment bank Lazard estimates it at about 14 to 21 US cents per kWh for new nuclear power plants (in the US; for comparison, onshore wind power: 2.4 to 7.5 US cents per kWh).[5] The cost of treating radioactive waste is explicitly not included here. In its latest Word Energy Outlook, the International Energy Agency (IEA) put the LCOE for nuclear power plants in 2030 at 10 US cents per kWh in the US, 12 US cents per kWh in the EU, and 6.5 US cents per kWh in China. Wind and solar power are cheaper in all three countries/regions. For the Hinkley Point C nuclear power plant that is under construction in the UK, the operator has agreed a guaranteed power purchase price of 10.7 pence per kWh. The LCOE of investments in extending the operating lives of existing nuclear power plants is significantly lower than that for new nuclear power plants. According to an IEA study from 2020, they ranged from less than 3 to less than 5 US cents per kWh.[6]

The figures indicate that wind and solar power are more favorable than conventional thermal power plants in terms of levelized costs of electricity, and that new nuclear power plants are among the forms of electricity generation with very high levelized costs of electricity. If the prices for CO_2 certificates in EU emissions trading rise because of a continuous shortage in the future, this will lead to higher LCOE for coal-fired or gas-fired power plants.

[3] Cf. Fraunhofer ISE (2021). Stromgestehungskosten erneuerbare Energien.
[4] Cf. BMWK (2023). Wettbewerbsfähige Strompreise für die energieintensiven Unternehmen in Deutschland und Europa sicherstellen. Arbeitspapier des BMWK zum Industriestrompreis für das Treffen Bündnis Zukunft der Industrie.
[5] Cf. Lazard (2023). LCOE+.
[6] Cf. IEA (2020). Projected Costs of Generating Electricity.

System costs: Intermittency and seasonality of renewables drive costs

The public debate often neglects those costs that result from a high and increasing share of weather-dependent renewables in the electricity market. These system costs are the macro-economically relevant variable. The system costs arise, for example, from a decreasing average capacity utilization of all existing power plants. For example, installed capacity in the German electricity market has increased by about 40% to 238 gigawatts (GW) since the beginning of the last decade, primarily due to the addition of wind and solar power (net nominal capacity in mid-2022 according to the Federal Network Agency). By comparison, the peak load, the highest demand at a given time during the year, has a magnitude of 80 GW in Germany. Therefore, the installed capacity already exceeds the peak load by a factor of 3. However, total gross power generation fell by 6% in the same period (2022 vs. 2011 according to AG Energiebilanzen). On the one hand, this is due to the fact that weather-dependent renewable energies have a low capacity utilization per se. On the other hand, their low marginal costs force fossil power plants out of the market, which is desirable from a climate policy perspective. For coal-fired power plants, capacity utilization fell from about 50% in 2011 to just under 39% in 2022. For gas-fired power plants, it declined from 36% to just under 27% (in each case, it is the ratio of full-load hours to total annual hours). The decreasing utilization causes higher costs for the operators of conventional plants. The gap between installed capacity and peak load will likely continue to increase in the coming years with the further expansion of renewable energies, although the peak load is also likely to increase with greater electrification of the heating market, transport sector and industrial processes.

System costs also include the ramping up and down of thermal power plants in response to wind or solar radiation. Many traditional power plants are only partially designed for this. To address the problem of capacity utilization, it could be possible to reduce secured power generation capacity more quickly. However, a significantly higher rate is not possible for the time being, because there are still long phases in which wind and solar power contribute only little to total power generation (e.g. during inverted atmospheric conditions with stable high pressure in winter). At the same time, due to the higher degree of electrification (e-mobility, heat pumps, industrial processes), it is expected that not only the peak load but also the absolute electricity demand will rise from about 555 terawatt hours (TWh) in 2022 to 680 to 750 TWh in 2030 (an increase of at least one fifth). Especially during winter, photovoltaics will continue to contribute little to electricity generation.

Grid expansion is also of particular importance for system costs. This is triggered at least in part by the expansion of weather-dependent renewables. For example, the generation centres for wind power are in the north of Germany, but many large electricity consumers are in the south. A first-draft strategy of the transmission system operators published at the end of March 2023 shows that the investment required for the transmission network could amount to EUR 198 billion by 2037. The distribution grid will also need to be physically expanded and better controlled if both decentralized power generation from renewables and distributed power demand (e.g. heat pumps, charging stations) continue to increase. Without such measures, the distribution grid is likely to become a regional bottleneck for the electrification of the heating market and the transport sector. As early as 2021, the German Federal Network

Agency had estimated the need for investment in the electricity distribution network at EUR 47 billion by 2030. The figure is likely to have risen since then.[7]

With an increasing share of weather-dependent renewable energies, grid operators will also have to carry out grid and system security measures more frequently. According to the German Federal Network Agency, total grid congestion management measures stood at EUR 771 m in Q2 2023 alone (Q2 2022: EUR 389 m).[8] Finally, investments in electricity storage are also part of the system costs associated with the expansion of weather-dependent renewables, as they are supposed to mitigate the problem of the intermittency and seasonality of weather-dependent renewables.[9] This applies to batteries for smaller consumers as well as to electrolysers to produce (green) hydrogen or other power-to-X technologies.

It is not trivial to attempt to quantify the system costs exactly, though it is not possible to precisely separate each of the different costs. It is clear, however, that the statement that renewables are the most cost-effective form of power generation is too general. In any case, a balanced debate should consider all the consequential costs that arise from the expansion of weather-dependent renewable energies in the absence of cheap and large-scale power storage technologies. In the same way, it makes sense to consider the external costs of thermal power plants based on fossil fuels, which are not yet or insufficiently internalized by CO_2 prices or other instruments in many countries outside the EU. The consequential costs of using nuclear energy (e.g., radioactive waste, risk of accidents) are also part of the system costs. Their calculation is also not trivial, as the Scientific Service of the Bundestag has stated in a paper.[10] Even renewable energies are not entirely free of external costs. These include the impact on natural and cultural landscapes caused by the erection of wind turbines, or public protests against wind turbines and power grids.

Investments in renewables easier to realize than construction of new back-up power plants

Due to the low LCOE, investments in renewable energies are easier to realize than investments in new back-up power plants. In the future, direct contracts (Power Purchase Agreements, PPAs) between operators of RE plants and large electricity consumers will be more important. In this case, the customers guarantee to purchase the electricity at a predefined price. This helps to increase planning certainty for both sides.

The situation is more difficult for H2-ready gas-fired power plants, which the German government plans to build. They are intended to act as back-up power plants for times when there is little wind and/or sunshine and to enable the phase-out of coal-fired power generation (ideally by 2030). The LCOE of such power plants is likely to be at least as high as that of traditional gas-fired power plants. As renewables continue to expand, their market share of electricity generation will increase. Thus, the annual capacity utilization of back-up power plants is likely to decline further. However, this insufficient capacity utilization makes it difficult for investors to make a business case for new gas-fired power plants when revenues can only be generated through electricity sales. Therefore, the government could support the necessary investment by creating

[7] Cf. Handelsblatt (2023). Deutschlands Stromnetz kommt an seine Grenzen.
[8] Cf. Federal Network Agency (2022). Marktbeobachtung, Monitoring Elektrizität/Gas. Quartalsbericht. Netzengpassmanagement. Zweites Quartal 2022.
[9] Cf. Brand, James, and Olly Jeffery (2022). Decarbonising power & gas: the intermittency & seasonality challenges. Deutsche Bank Research.
[10] Cf. Wissenschaftliche Dienste des Deutschen Bundestags (2022). Ausarbeitung. Gestehungskosten im Vergleich.

a capacity market in which operators of back-up power plants are paid for providing secured capacity. Without sufficient additions of such (H2-ready) gas-fired power plants, some of the coal-fired power plants would probably have to run longer than 2030 or remain in a kind of safety reserve.

Eric Heymann (+49 69 910-31730, eric.heymann@db.com)