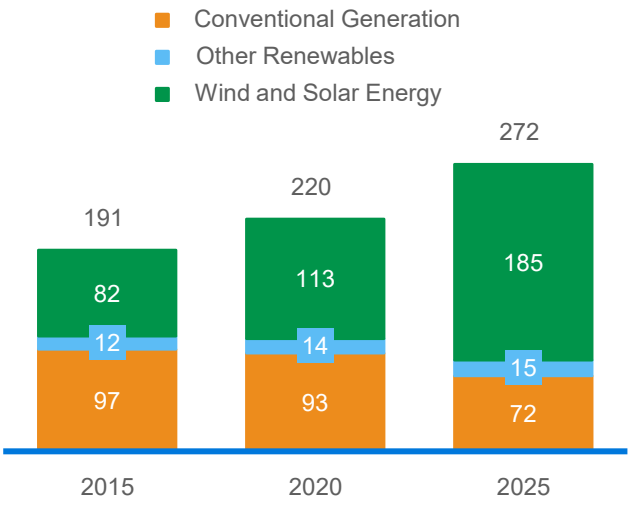
Dunkelflauten (Dark Doldrums): A structural component of the German electricity system

Duration and frequency of Dunkelflauten in Germany and implications for the electricity system – Time series analysis of wind and solar power generation (2016–2025)

The significant expansion of renewable capacities has fundamentally changed the nature of the German electricity system. In 2025, as much as 46% of public electricity generation came from wind and solar energy alone. These sources are highly weather-dependent, making generation much more volatile today than it was a decade ago (see Figure 1). This volatility increases the relevance of periods with very low generation from wind and solar energy—so-called Dunkelflauten.

Figure 1: Installed capacity in Germany in GW (2015–2025).



Source: Own representation based on Fraunhofer ISE, Energy-Charts.

Dunkelflauten occur regularly and often last longer than commonly assumed in public discourse. These events are not marginal phenomena but represent a structural pattern. Their frequency, duration, and intensity largely determine the future requirements for storage, flexibility, and dispatchable capacity.

This paper examines how often and for how long Dunkelflauten occurred between 2016 and 2025, identifies structural patterns, and derives implications for designing a reliable energy system.

Methodology

The analysis is based on generation data for wind and solar power over the past ten years. Since there is no uniform definition of Dunkelflauten, many existing studies define them as periods during which wind and solar generation falls below a certain threshold for a minimum number of consecutive hours. In such approaches, a Dunkelflaute is considered over as soon as generation exceeds the threshold for a single hour. From a system perspective, however, this method is insufficient: short-term peaks have no meaningful impact on security of supply, as they neither allow storage systems to be charged nor reliably stabilize the system. As a result, structural supply gaps tend to be underestimated.

To address this limitation, the present analysis evaluates each hour using a rolling 6-hour average in order to filter out short-term, systemically irrelevant fluctuations. This approach – referred to as Mean-Below-Threshold (MBT) in scientific literature – enables a more realistic identification of periods during which the electricity system depends on firm generation. A Dunkelflaute is defined as a period of at least 10 consecutive hours in which wind and solar generation falls below 10% of installed capacity.

Results

Over the past ten years, 1,435 Dunkelflauten lasting longer than 10 hours occurred (see Figure 2). On average, this means that a Dunkelflaute occurs every third day. Over the period 2016–2025, Dunkelflauten lasted an average of 12.9 hours, i.e. longer than half a day.

In addition to frequency and average duration, however, it is naturally the extremes that are of particular interest, as the electricity supply system ultimately has to be prepared for these. Longer-lasting events are less frequent but still occur regularly. A 24-hour Dunkelflaute occurs almost every

month, while three-day Dunkelflauten occur around twice per year. Extreme Dunkelflauten lasting more than five days are rare; nevertheless, security of supply must also be ensured during these periods. On average, such events occur every three and a half years.

In 2023, there was even a nearly week-long Dunkelflaute (161 hours). The results show: Dunkelflauten lasting at least 10 hours are a regularly recurring phenomenon.

Conclusions

The analysis confirms that periods of very low wind and solar generation are a structural feature of the German energy system. These events are neither exceptions nor random extremes but occur with high regularity. For security of supply, this means that Dunkelflauten must be treated as a standard case in planning future generation and storage infrastructure. Storage will play an important role in the energy transition. However, only conventional power plants are capable of generating electricity at any time, regardless of weather conditions or charging cycles. Therefore, firm and flexible generation capacities will remain indispensable in the long term to bridge prolonged Dunkelflauten.

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Figure 2: Number of Dunkelflaute events with a minimum duration of 10 hours.

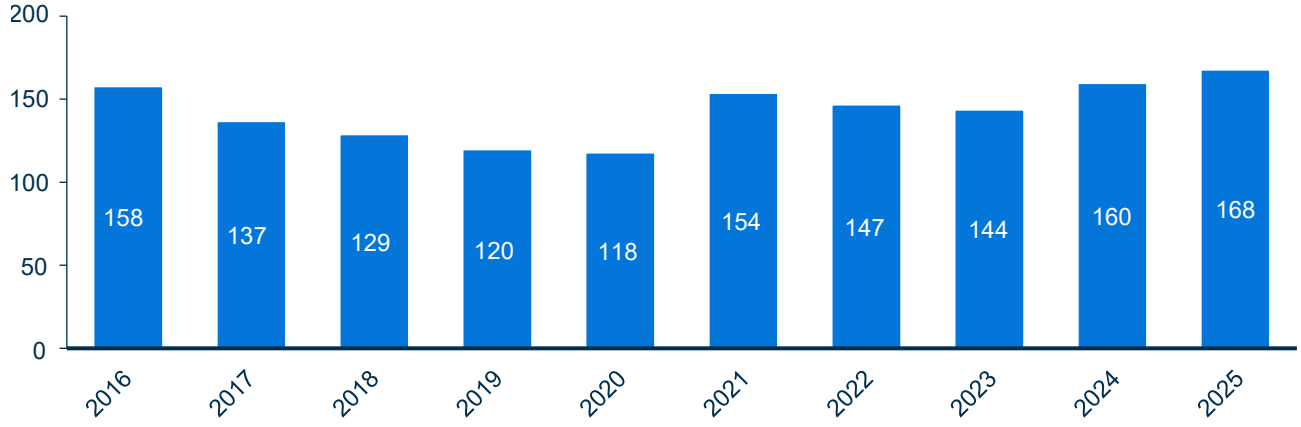
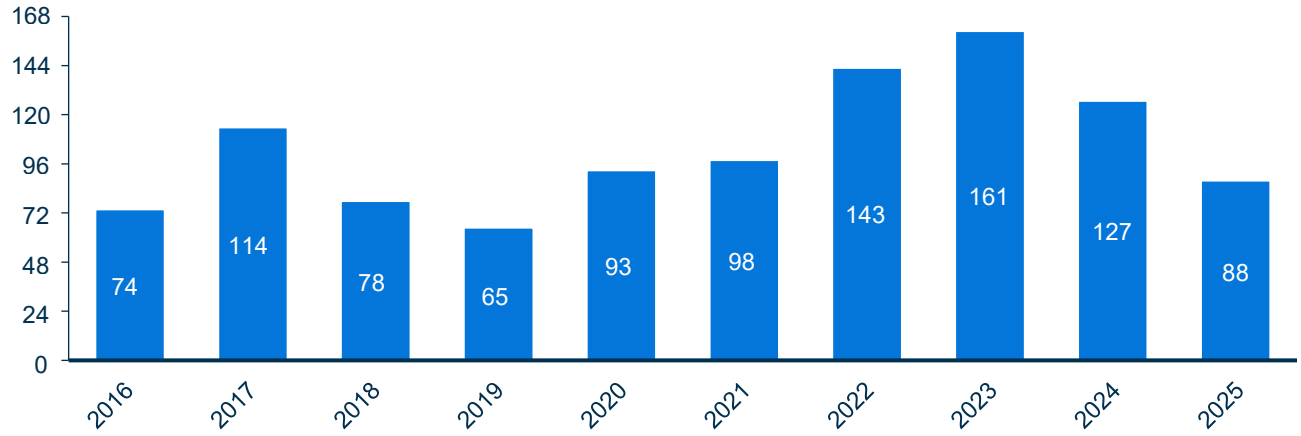


Figure 3: Longest Dunkelflaute (hours)





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