# The potential for household photovoltaics in Germany

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To meet climate targets, Germany needs to accelerate the uptake of photovoltaics. Household rooftop photovoltaics, which accounted for more than half of all systems installed in Germany in 2023, play an important role here. But not all regions in Germany are equally suitable for their installation. The purpose of this study is to identify regions which still have a particularly high potential for new installations.

More and more households in Germany have already installed photovoltaics in recent years. By the end of 2023, one in eight residential buildings with one or two apartments had a photovoltaic system installed. Most installations are located in the south of Germany, where some regions already boast one in five dwellings with photovoltaics.

Global radiation as a measure of incident solar energy determines how much electricity a photovoltaic system can generate. Based on regional information on global radiation, we identify the expected diffusion of household photovoltaics and compare it with the observed diffusion on a district level in Germany.

In regions that have fewer household photovoltaic systems than expected, a further expansion is attractive as there are still likely to be many buildings without systems and a relatively good orientation. This is the case in Bremen, Hamburg, the Saarland, Mecklenburg-Western Pomerania, around Dresden and in Schleswig-Holstein, for example. With some minor exceptions, it also applies to the regions around Lüneburg and Trier as well as Upper Bavaria, Thuringia and southern Hessen.

The potential for further expanding photovoltaics uptake is generally greater in urban, densely populated regions and in those where the average age of inhabitants is high. Information offerings and advertising campaigns by suppliers of photovoltaics may be promising in these regions.

## Photovoltaics capacity expansion set to triple

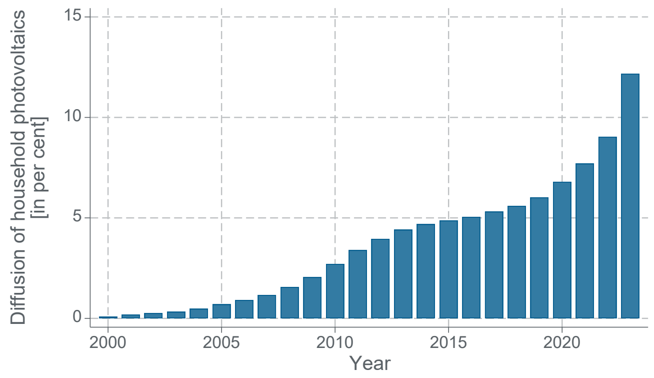
The German Federal Government wants to further increase the expansion of photovoltaics (PV). From the year 2026, new capacity installations are to triple from current levels.[1] In order to reach this goal, rooftop photovoltaics installed by private households play an important role, partly because these roofs would otherwise remain unused. Besides, the electricity is generated decentrally and often consumed locally, easing the load on the power grid. In 2023, such household systems made up at least half the newly installed photovoltaic systems registered in the core energy market data register.[2] That represents around one third of newly installed PV capacity.

Because of differences in incident solar radiation, Germany's regions are not equally well-suited for the installation of household PV. This study shows which regions have particularly high potential for further installations.

## Sharp increase in household installations

Figure 1 shows the diffusion of household PV systems over time. By the end of 2000, only 0.1% of residential buildings with one or two apartments were equipped with photovoltaics. At the end of 2010, that figure was already close to 3%, and at the end of 2023 it was around 12%.

Figure 1: Household photovoltaics over time




Note: We calculate the diffusion of household photovoltaic systems as the share of dwellings with household photovoltaics in all residential buildings with one or two apartments at the end of the respective year.

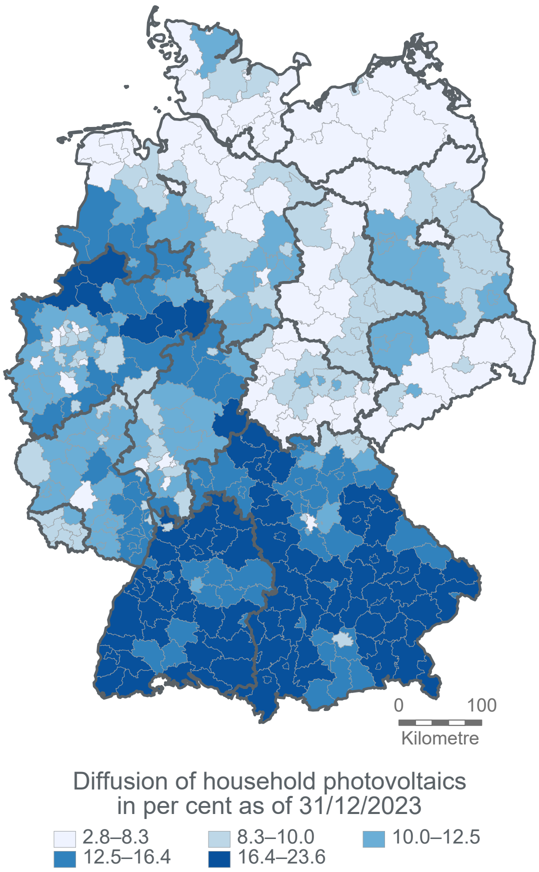
Source: Own calculations based on the core energy market data register and the German Federal Statistical Office.[3]

The evolution of the annual capacity increase allows us to understand the current trend. While the annual increase averaged 0.3 percentage points between 2013 and 2018, it rose to an average 1.5 percentage points in the years since 2020. In 2023 the increase even reached 3 percentage points. Higher electricity prices and lower material costs for PV may also lead to a relevant number of new installations in the future.

## Major regional differences

There are vast regional differences in the diffusion of photovoltaic systems. Figure 2 shows that in many districts in Baden-Württemberg and Bavaria, more than 16% of residential buildings with one or two apartments were already equipped with household PV at the end of 2023. By contrast, the diffusion rates in many districts of Mecklenburg-Western Pomerania and Schleswig-Holstein are below 8%. There are not only differences between the North and the South, the diffusion of household systems also tends to be broader in more sparsely populated rural areas.

Figure 2: Household photovoltaics across districts




Note: We calculate the regional diffusion of household photovoltaic systems as the share of dwellings with household photovoltaics in all residential buildings with one or two apartments.

Source: © GeoBasis-DE / BKG 2020. Data: Own calculations based on the core energy market data register and German Federal Statistical Office.

## Trends in federal states

Again, there are interesting trends here. Table 1 shows the average new household PV installations in percentage points per year for each federal state. Baden-Württemberg and North Rhine-Westphalia recently had the highest increases, at 2.7 and 2.5 percentage points. The city-states of Bremen and Hamburg, on the other hand, experienced the slowest increases of just 0.8 and 1.0 percentage points.

In some states, however, the average annual growth in installations paints a different picture. Table 1 reveals that in Bavaria and the Saarland, household PV have grown at a relatively slow rate of 20%. In Bremen, Hamburg and Mecklenburg-Western Pomerania, on the other hand, the expansion was a comparatively strong 50%. This shows that the increase is picking up steam in some regions where diffusion rates are currently low.

## Suitability for photovoltaics

The suitability of a building for PV is primarily determined by the orientation and pitch of the roof, potential shading and roof area. Without shading and with a sufficiently large area, maximum annual solar output is achieved in Germany if the roof has a southern orientation and a pitch of around 35 degrees. With an optimum pitch, a photovoltaic system with an easterly or westerly orientation delivers around one fifth less electricity than a system with southern orientation.

Table 1: New household PV installations by federal state

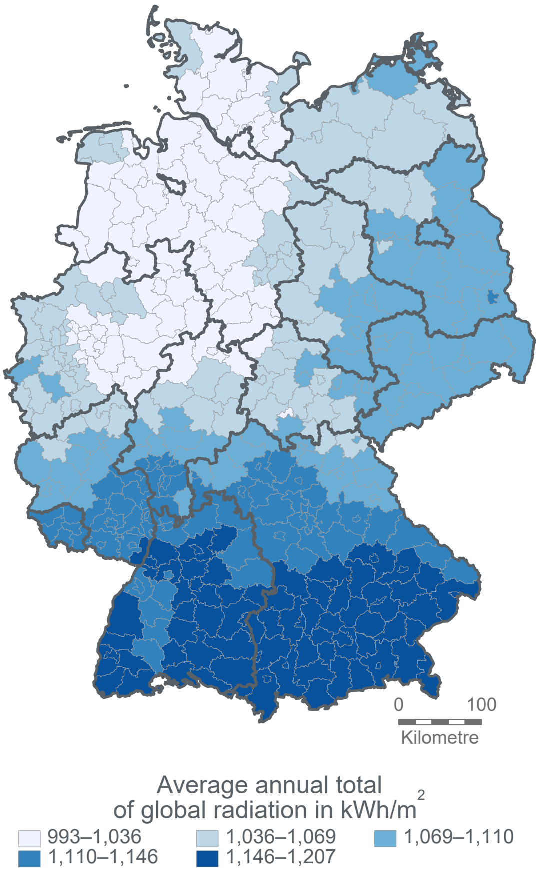
| Rank | Federal state | New installations per year (average in 2022 and 2023) | |
|---|---|---|---|
| | | in percentage points | Growth in per cent |
| 1 | Baden-Württemberg | 2.7 | 23% |
| 2 | North Rhine-Westphalia | 2.5 | 36% |
| 3 | Bavaria | 2.4 | 20% |
| 4 | Lower Saxony | 2.3 | 44% |
| 5 | Brandenburg | 2.1 | 39% |
| 6 | Rhineland-Palatinate | 2.0 | 27% |
| 7 | Saxony | 1.9 | 39% |
| 8 | Hessen | 1.9 | 26% |
| 9 | Saxony-Anhalt | 1.9 | 42% |
| 10 | Berlin | 1.9 | 45% |
| 11 | Schleswig-Holstein | 1.7 | 42% |
| 12 | Mecklenburg-Western Pomerania | 1.7 | 50% |
| 13 | Thuringia | 1.6 | 34% |
| 14 | Saarland | 1.4 | 21% |
| 15 | Hamburg | 1.0 | 50% |
| 16 | Bremen | 0.8 | 49% |

Source: Own calculations based on the core energy market data register and German Federal Statistical Office.

In addition, global radiation, a measure of incident solar energy, determines how much electricity a photovoltaic system can generate. Figure 3 shows the average annual total global radiation for the districts in Germany. In southern Germany, global radiation levels are up to 20% higher than in the North. All else being equal, a properly aligned roof in northern Germany can therefore deliver an electricity output similar to that of a less well-aligned roof in the south. In the transition, however, it is efficient to install photovoltaic systems on roofs with optimal orientation in regions with high global radiation.

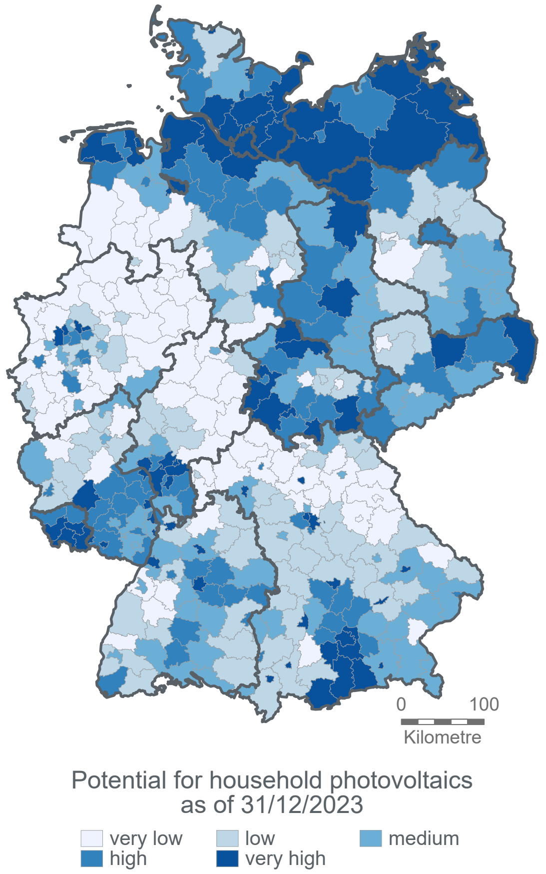
Based on the regional distribution of global radiation, we estimate a diffusion model for household PV on the district level in Germany. This allows us to identify the expected diffusion of household photovoltaics and compare it with their observed diffusion. The relative difference between these two variables expresses the photovoltaics potential as a measure of how far the districts are behind the relevant expected expansion. The box at the end of this study contains details of the calculation.

Figure 3: Regional global radiation




Source: © GeoBasis-DE / BKG 2020. Data: Own calculations based on the average annual total of global radiation on the horizontal plane as measured by the German Weather Service.

Figure 4: Potential for household photovoltaics across districts




Note: See box at the end of the study for calculation of the potential.

Source: © GeoBasis-DE / BKG 2020. Data: Own calculations based on the German Weather Service, core energy market data register and the German Federal Statistical Office.

## Photovoltaics potential high in some districts

Figure 4 shows the regional differences in PV potential for households at the end of the year 2023. High and very high potentials are particularly evident in Bremen, Hamburg, the Saarland, Mecklenburg-Western Pomerania, around Dresden and in Schleswig Holstein. With some minor exceptions, this is also true for the regions around Lüneburg and Trier as well as parts of Upper Bavaria, Thuringia and southern Hessen. These regions so far have fewer household photovoltaic systems than expected. Further expansion is attractive there. Considering global radiation, we expect enough unequipped buildings with well-aligned roofs in these regions.

Table 2 shows determinants of a high PV potential for household systems for the year 2023. The determinants are based on a simple linear regression at district level. The potential for household PV tends to be high in cities. Shading may play a role there more often. Furthermore, regions with higher PV potential for households tend to have a higher population density. The roofs available for PV in densely populated districts may often be too small so that an installation is less financially attractive. The inhabitants of regions with higher PV potential for households are also older on average. Older people may be more likely to shy away from installing a photovoltaic system because it takes several years for the investment to pay off.

Interestingly, there is no statistical association between the potential for household PV and household income per capita as a proxy for economic prosperity in the region.

Table 2: Determinants of potential for household photovoltaics

| Variable | Association |
|---|---|
| Urban | High potential |
| High population density | High potential |
| High average age | High potential |
| Share of university graduates | None |
| Household income per capita | None |
| Eastern German states | None |

Note: Simple linear regression of the potential for household photovoltaics on the specified variables (with a lag) for a cross-section of the districts for the year 2023. Log-transformed population density and per capita household income.

Source: Own calculations, see endnote for data 3.

## Conclusion

Household photovoltaic systems are a mainstay in achieving the German Federal Government's declared objective of significantly expanding photovoltaics. So far, only a small percentage of Germany's roof surfaces is equipped with photovoltaics. Recently, however, a significant increase in the installation of such systems has been observed. In 2023 alone, photovoltaic systems were installed on 3% of residential buildings with one or two apartments.

At the same time, in places such as Bremen, Hamburg, the Saarland, Mecklenburg-Western Pomerania, around Dresden, in Schleswig-Holstein, around Lüneburg and Trier as well as in parts of Upper Bavaria, Thuringia and southern Hessen, fewer household photovoltaic systems were installed than would be expected based on regional global radiation. A further expansion is attractive there because these locations can be expected to have many relatively well-suited residential buildings without photovoltaic systems.

Based on this study, we derive specific approaches for supporting the expansion of household photovoltaics:

– It may be helpful to provide information about the suitability of roofs or, where such information already exists, to make it more public in the identified regions. The photovoltaics potential of individual roofs is accessible online for Baden-Württemberg and Hessen, for example.[4]

– Installers of household photovoltaic systems could also advertise their services more in the regions mentioned.

– Finally, information about the regional distribution of photovoltaics potential could be considered in shaping investment incentives.

**Box: Estimating the potential for household PV**

We examine the share of dwellings with photovoltaics (systems with a capacity of at least 1 $kW_p$ and not more than 10 $kW_p$, see endnote 2) in all residential buildings with one or two apartments. The regional distribution of this variable, $F_{r,t}$, almost follows a logistical function over time.[5] We allow the logistical function to be exclusively influenced by one exogenous variable: the average annual total of global radiation ($GS_r$). We therefore estimate the diffusion of household photovoltaic systems for districts $r$ and the years $t$ as $F_{r,t} = (a_0 + a_1 GS_r + a_2 {GS_r}^2)/(e^{-(b_0+b_1 GS_r+b_2 {GS_r}^2)t-(c_0+c_1 GS_r+c_2 {GS_r}^2)})$.

The estimated coefficients $a_{0-2}$ influence the saturation level, $b_{0-2}$ the speed and $c_{0-2}$ the inflexion point of the diffusion. Figure 4 summarises five categories with the same number $r$ based on the relative measure for the year 2023 $(\hat{F}_{r,2023} - F_{r,2023})/F_{r,2023}$. In this, $\hat{F}_{r,t}$ is the predicted diffusion from the diffusion model. The category *very low* means up to 27% more than expected, *low* 27 to 16% more, *medium* 16 to 6% more, *high* 6% more to 11% less, and *very high* more than 11% less.

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[1] So läuft der Ausbau der Erneuerbaren Energien in Deutschland | Bundesregierung (*Update on the expansion of renewable energy in Germany | German Federal Government* – our title translation, in German) last accessed on 17 January 2024.

[2] We define household photovoltaic systems as systems with a net nominal capacity of at least 1 $kW_p$ and not more than 10 $kW_p$, which were installed at a location for the first time according to the core energy market data register, and which are declared for use in the *Household* (713) and as *Structural installations (house roof, building and facade)* (853). Furthermore, we use the date of commissioning to identify when they were installed and the municipality ID to allocate the systems to districts. According to the core energy market data register, just under one third of the photovoltaic systems newly installed in 2023 had a net nominal capacity of less than 1 $kW_p$ (capacity share 1.4 %). Microsystems with up to 0.6 $kW_p$ are often referred to as balcony systems or plug-and-play solar panels. These are subject to simplified legal regulations. It is safe to assume that a relevant number of such systems exists that are not captured in the core energy market data register. Therefore, we did not take them into account in this study.

[3] Data sources:

*Photovoltaic systems:* German core energy market data register, overall data excerpt of 21 January 2024, downloaded on 21 January 2024 from https://www.marktstammdatenregister.de/MaStR/Datendownload;

*Residential buildings:* German Federal Statistical Office, Table 3 31231-02-01-4, number of residential buildings and apartments in residential and non-residential buildings – as at 31 December – regional depth: Districts and cities with district status, downloaded on 29 November 2023 from https://www.regionalstatistik.de/; Table 31231-01-02-4, residential buildings and apartment stock – as of 31 December – regional depth: districts and cities with district status (until 2010), downloaded on 29 November 2023 from https://www.regionalstatistik.de/;

*Geodata (shapefiles):* German Federal Agency for Cartography and Geodesy, administrative areas, historic levels, date: 31/12/2020, downloaded on 29 November 2023 from https://daten.gdz.bkg.bund.de/produkte/vg/vg5000_1231/2020/;

*Global radiation:* Deutscher Wetterdienst (official German weather service), raster data of average multi-annual total of global radiation on the horizontal plane for Germany based on ground and satellite measurements, version V003, time covered 1 January 1981 – 31 December 2010, spatial resolution 1 km x 1 km, downloaded on 23 November 2023 from https://opendata.dwd.de/climate_environment/CDC/grids_germany/multi_annual/radiation_global/;

*Population:* German Federal Statistical Office, Table 12411-01-01-4: Population by gender – as at 31 December – regional depth: districts and cities with district status; downloaded on 29 November 2023 from https://www.regionalstatistik.de/;

*Ground area:* German Federal Institute for Research on Building, Urban Affairs and Spatial Development, Indicators and maps on spatial and urban development – INKAR, downloaded on 17 November 2023 from https://www.inkar.de/;

*Average age:* German Federal Statistical Office, Table 12411-07-01-4: Average age of the population – as at 31 December – regional depth: districts and cities with district status; downloaded on 29 November 2023 from https://www.regionalstatistik.de/;

*Share of university graduates:* German Federal Statistical Office, Table 13111-12-03-4: Employees subject to social security contributions at place of residence by gender, nationality and type of educational qualifications – as at 30 June – regional depth: districts and cities with district status; downloaded on 29 November 2023 from https://www.regionalstatistik.de/;

*Household income per capita:* German Federal Statistical Office, Table 13111-12-03-4: Disposable income of households including private non-profit-making organisations – annual total – regional depth: districts and cities with district status; downloaded on 25 January 2024 from https://www.regionalstatistik.de/;

[4] The photovoltaics potential of roof surfaces is accessible online in the Energieatlas Baden-Württemberg and in the Solarkataster Hessen, for example. Both websites were last accessed on 24 January 2024.

[5] For photovoltaic systems, this was shown by Comin, D. and Rode, J. (2023): Do Green Users Become Green Voters? NBER Working Paper 31324. National Bureau of Economic Research. This also applies to other technologies. For broadband Internet access, e.g. see Czernich, N. et al. (2011): Broadband Infrastructure and Economic Growth. *The Economic Journal* 121. 552, pp. 505–532.