08.09 Solar Systems

Overview

Renewable energies, i.e. primarily wind power, geothermal energy, biomass and solar energy, are inexhaustible sources of energy. They represent an important alternative or addition to fossil fuels in Berlin's energy supply. The expansion of solar energy use is emphasised as a particularly important building block in Berlin's climate protection strategy, since, with over 560,000 buildings in Berlin, there are rooftops and house façades aplenty, unlike suitable wind power sites. By 2050, the Berlin Senate aims to have achieved a climate-neutral energy supply of the city. The goal of increasing the generation and use of renewable energies on public buildings is established in Article 16 of the Berlin Energy Transition Act of March 22, 2016 (EWG Bln 2016). In addition, the expansion of renewable energies, in particular tapping into the potential of solar energy, was adopted by the Berlin Senate in the Berlin Energy and Climate Protection Programme 2030 (BEK 2030) (Abgeordnetenhaus Berlin 2016).

According to the BEK 2030, the "Masterplan Solarcity" (solar city master plan) forms an important stepping stone for overcoming existing obstacles and building on the currently rather limited development of solar energy. In September 2019, after an in-depth and hands-on process, the "Expertenempfehlung zum Masterplan Solarcity Berlin" (expert recommendations for the Berlin solar city master plan) was presented to the lead Senate Department for Economics, Energy and Public Enterprises. Combined with an extensive catalogue of measures, it forms the basis for the future expansion of solar energy in Berlin. The study confirms that Berlin has a potential solar power share of 25 %, provided that better framework conditions are put in place at federal level, creative approaches are taken on site and a variety of instruments is applied (Masterplan Solarcity, only in German).

Based on this, the Senate passed a comprehensive action plan to accelerate the development of solar energy in Berlin on 10 March 2020 (Senate Chancellery 2020). Since 2021, annual monitoring reports on the "Masterplan Solarcity" have been published (SenWEB 2021). The second report is currently available, the third is due to be published in November 2023 (SenWEB 2023).

The set of measures stipulated in the master plan is accompanied by the Berlin solar law. **Solar panels** have been **mandatory** since January 1, 2023. The installation and operation of photovoltaic systems have been mandatory since then for new and existing buildings under certain conditions (SenK 2021).

At the federal level, the Annual Tax Act 2022 (JStG 2022) reduced the VAT to zero percent for both the supply and the installation of solar modules, including the components required for operation and storage (JStG 2022, UStG Art. 12 Para. 3). This regulation applies to installations on residential buildings, public buildings and buildings used for activities in the public interest. The conditions for tax exemption apply if the system's capacity does not exceed 30kWp. The zero VAT rate has been in effect since January 1, 2023.

So far, solar power has accounted for less than one percent of the total generated power in Berlin (Berliner Morgenpost 2022). To start tapping more into the potential of solar energy, both in the private and the public sector, the SolarZentrum (solar centre) Berlin was opened in May 2019. It is a component of the "Masterplan Solarcity", which works as an independent advisory centre on the topic of solar energy (SolarZentrum Berlin, only in German). The centre is operated by the German Section of the International Solar Energy Society (DGS) and the Berlin Brandenburg regional association, supported by the Senate Department for Economics, Energy and Public Enterprises.

Previously, the use of energy-relevant data, such as solar data, and how it was presented on the map, was handled inconsistently using a variety of channels. In July 2018, the Energietlas Berlin (Energy Atlas, only in German) was created as a portal specialised in supporting the energy turnaround. For this purpose, it presents the most important data in a user-friendly and visually comprehensive way, which is updated regularly.

The Environmental Atlas contents regarding

- Photovoltaics (PV), i.e. the direct conversion of solar energy into electrical energy, and
- Solar-thermal energy (ST), i.e. the generation of heat from irradiation,

presented here refer to data published in the Energy Atlas on photovoltaic system locations (as of March 2, 2023) and those of solar thermal systems (as of December 31, 2015 and as of March 29, 2023 for aggregated BAFA data).

As part of updating Berlin's Energy Atlas, the frequency and quality of the data on solar systems, especially those with photovoltaics, will continually be optimised.

Since May 2022, a digital version of the solar calculator has also been available as one of the measures of the "Masterplan Solarcity" (SenWEB 2019). Homeowners and tenants, owners of commercial properties, housing associations and energy suppliers may use the map layers "Photovoltaic Potential" and "Solar Thermal Potential" to learn more about the options of using photovoltaics on roof areas and solar thermal energy on roofs. This measure is intended to further promote photovoltaic (PV) use in Berlin in particular (IP SYSCON 2022). The relevant map layers complement the three Environmental Atlas maps "Solar Systems – Photovoltaics (08.09.1)", "Solar Systems – Solar Thermal Energy (08.09.2)" and "Solar Systems – Irradiation" (see Map Description).

This information becomes even more important, as from January 1, 2023, solar systems have been mandatory for new buildings and existing buildings following substantial roof conversions (Solargesetz Berlin 2021 (Berlin Solar Act 2021), only in German). According to this, owners of buildings with a usable area of more than 50 m^2 are required to install and operate photovoltaic systems on their building. The law provides for exceptions, exemptions and alternative ways of compliance. Further information and a practical guide to the Solargesetz (Solar Act), in German, may be found here.

Map 08.09.1 Photovoltaics

Compared to solar thermal energy, there are far more photovoltaic systems registered in Berlin. As of July 7, 2023, 20,985 systems were in place, with a total installed capacity of around 230 MWp. The electricity that these generate per annum can only be estimated and is expected to amount to approx. 207 million kWh/a (minus 5 % for the generator output and an average electricity yield of 900 kWh/a per kW). Theoretically, this output could cover the supply of about 65,400 households with an assumed average electricity consumption of 3,000 kWh/a each.

Since the introduction of the Energy Atlas, the previous method of data recording used in the solar cadastre has been discontinued. The method switched to a combination of multiple sources (cf. Statistical Base) and ways of presenting analysis results. Figure 1 presents the range of development numbers by borough (Fig. 1a). Here, urban areas largely characterised by single and two-family homes account for the largest shares. In line with this, the lowest capacity class of up to 30 kWp (Fig. 1b), the preferred choice for smaller roofs, predominates with about 19,987 of the 20,985 systems. The amendment of the Renewable Energy Sources Act (EEG 2014) of August 1, 2014 affected these development figures negatively. The number of systems installed prior to the amendment had been considerably higher. About 88 % of the capacity recorded for the year had been installed by August 1. The negative change in framework conditions associated with the amendment, affecting particularly small and medium-sized systems, can thus be assumed to have caused the slump in PV expansion in Berlin also in the following year of 2015. With the amendment, the EEG surcharge was also introduced for using your own electricity. The contracting model used by housing associations in Berlin, for example, which supplied residents with their own PV electricity while the PV system remained the property of the investor, became much less attractive following this change. According to the Federal Network Agency, since the EEG amendment came into effect in August 2014, this trend has also been observed nationwide in the following two years, with only around 50,000 additional systems reported (Bundesnetzagentur 2020). In 2019, the annual growth for systems under the EEG exceeded 100,000 new installations for the first time. As of July 1, 2022, the EEG surcharge was set to zero and completely abolished with the EEG amendment in 2023. According to data from the Federal Network Agency, 2022 saw the largest increase to date with 386,719 new installations. This new record was already surpassed, however, in the first half of 2023 with 479,504 additional systems (Bundesnetzagentur 2023, as of June 2023).

In terms of area-related photovoltaic capacity, the State of Berlin, with 189.6 kWp/km^2 (kWp = kilowatt peak), just ranked above the national average of 188.5 kWp/km^2, significantly above the capacity of Hamburg, for example, as the second largest German city (94 kWp/km^2), but also considerably below some area states (Bavaria, Baden-Württemberg) (Renewable Energies Agency 2023). The existing data does not include off-grid systems, e.g. for self-supply and stand-alone power systems, such as PV modules on parking metres, on park lighting systems and in allotment gardens. These are estimated to amount to an extra 2,500 systems.

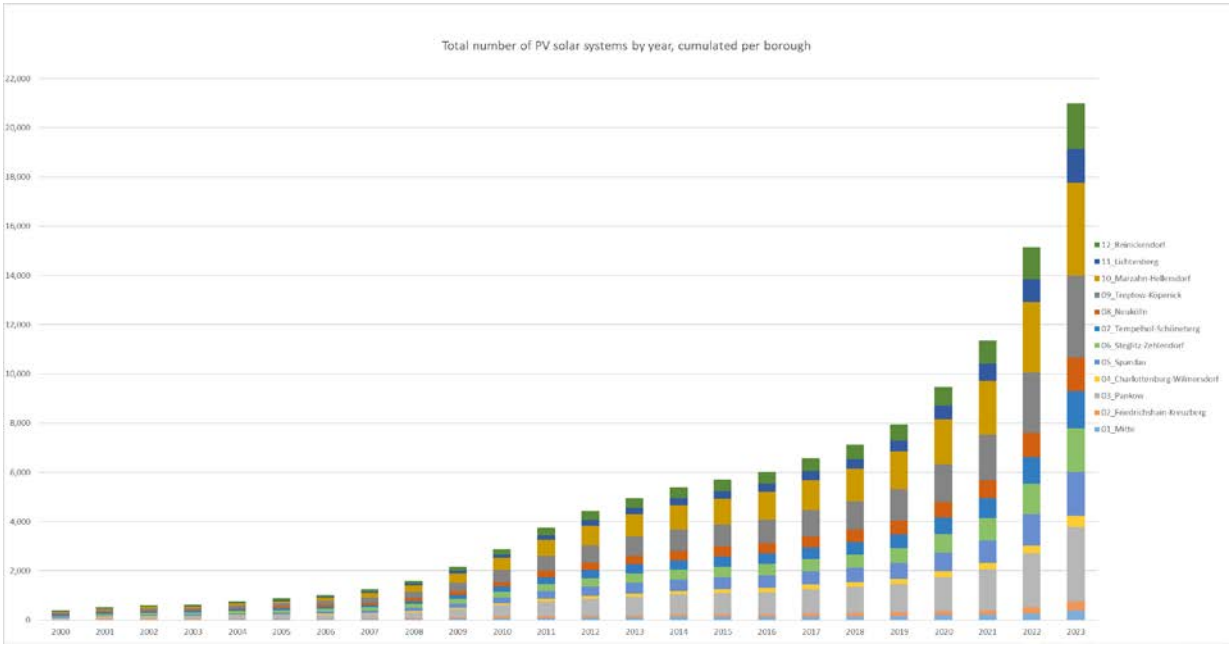

Fig. 1a: Development by borough (as of July 23, 2023)

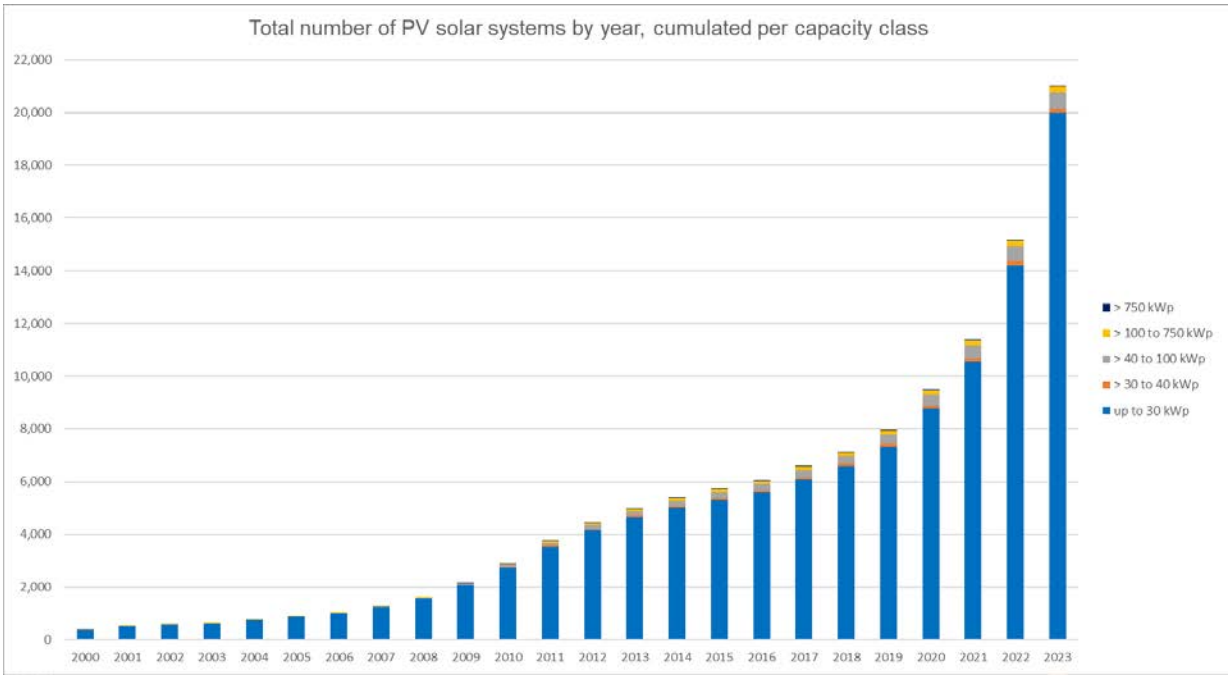

Fig. 1b: Development by capacity class (as of July 23, 2023)

Fig. 1: Development of photovoltaic systems in the State of Berlin, excluding off-grid systems, by borough and capacity class (cumulative per year, as of July 23, 2023)

The public sector plays an important role in setting an example for the expansion of photovoltaics. With the amendment of the Berlin Climate Protection and Energy Transition Act (EWG Bln) in 2021, the installation of solar systems on the entire technically usable roof area is mandatory for new buildings. Existing buildings must be retrofitted by December 31, 2024. Exceptions apply, for example, for roof areas that are unsuitable due to their location and orientation, or if public regulations prohibit the installation of PV systems. According to the master plan study for the “Masterplan Solarcity Berlin”, the

State of Berlin owns 5.4 % of Berlin's buildings. Their roof surfaces account for 8.3 % of the solar potential (SenWEB 2019).

On the public buildings in Berlin, there are 691 PV systems with a total installed capacity of 42.1 MWp (as of April 1, 2023). These figures include buildings owned by the Berlin boroughs, Berliner Immobilienmanagement GmbH (BIM), buildings of Berlin's public-law institutions, municipal housing associations, and certain state-owned enterprises. According to calculations by the Berliner Energieagentur (BEA) and IDU IT+Umwelt GmbH, based on the core energy market data register (MaStR) of the Federal Network Agency and data from the Official Real Estate Cadastre Information System (ALKIS), 5% of the systems and 16.4% of the installed capacity of PV systems in 2022 were located on public buildings in the State of Berlin (Fig. 2).

Most of the 20,985 PV systems in Berlin are located on privately owned buildings (84.7 %). It is important to note that while the buildings are owned by natural persons, the PV systems may not necessarily belong to them, as building owners can lease their roof space for use by third parties. A total of 9.5 % of the PV systems are installed on buildings owned by companies and housing associations. PV systems on private buildings account for 47.2 %, i.e. almost half of the total installed capacity. Another 34.8% is attributed to PV systems on buildings owned by companies and housing associations. These two groups together therefore account for the majority of the installed PV capacity.

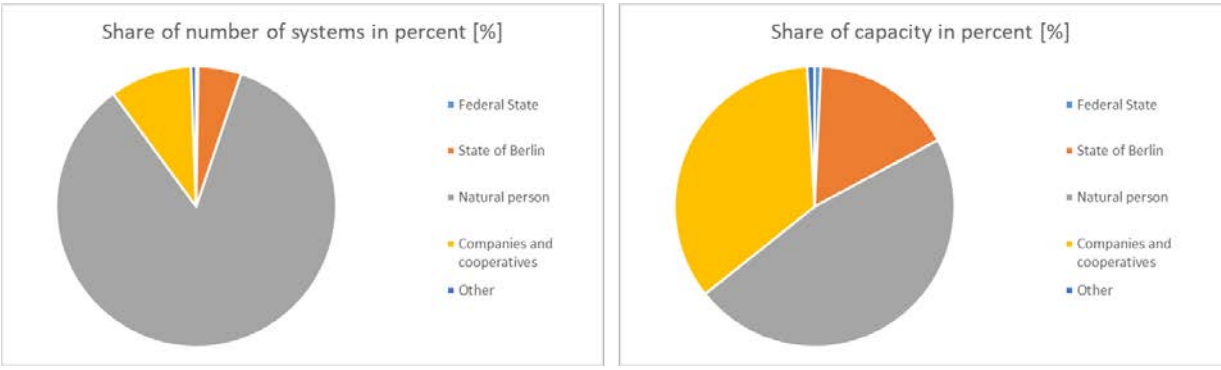

Fig. 2: Ownership structure as a percentage of the number of systems and installed capacity (Data as of March 2022, data source: Berliner Energieagentur (BEA) and IDU IT+Umwelt GmbH, based on the core energy market data register (MaStR) of the Federal Network Agency (BNetzA) and data from the Official Real Estate Cadastre Information System (ALKIS))

Map 08.09.2 Solar Thermal Energy

The previous method of data recording used in the solar cadastre was discontinued with the introduction of the Energy Atlas. The method switched to a combination of multiple sources (cf. Statistical Base) and ways of presenting analysis results.

As of March 29, 2023, there were about 8,250 solar thermal systems in the State of Berlin with an installed collector surface of more than 81,000 m² (last update as of December 31, 2015 for 7,733 systems, IP SYSCON 2016). Averaged over the years, the collector surface amounted to around 10 m² per system. As compared to the years prior to 2013, the following years saw a sharp decline in the growth of new installations, a development that is highlighted in Figure 3. Overall, a declining trend has been observed since then. In Berlin, solar thermal systems are mainly used for hot water supply and to supplement space heating. In addition, some larger solar systems are used for heating drinking water and swimming pool water; they are further used for solar air systems and air conditioning systems. Similar to the distribution of PV systems, solar thermal systems are clearly concentrated in the outer areas of the city, which are characterised by more rural types of settlements (cf. representation at postal code level in the Geoportal Berlin, map Solar Systems - Solar-Thermal (ST) Energy, "Number of Solar Thermal Systems by Postal Code" layer).

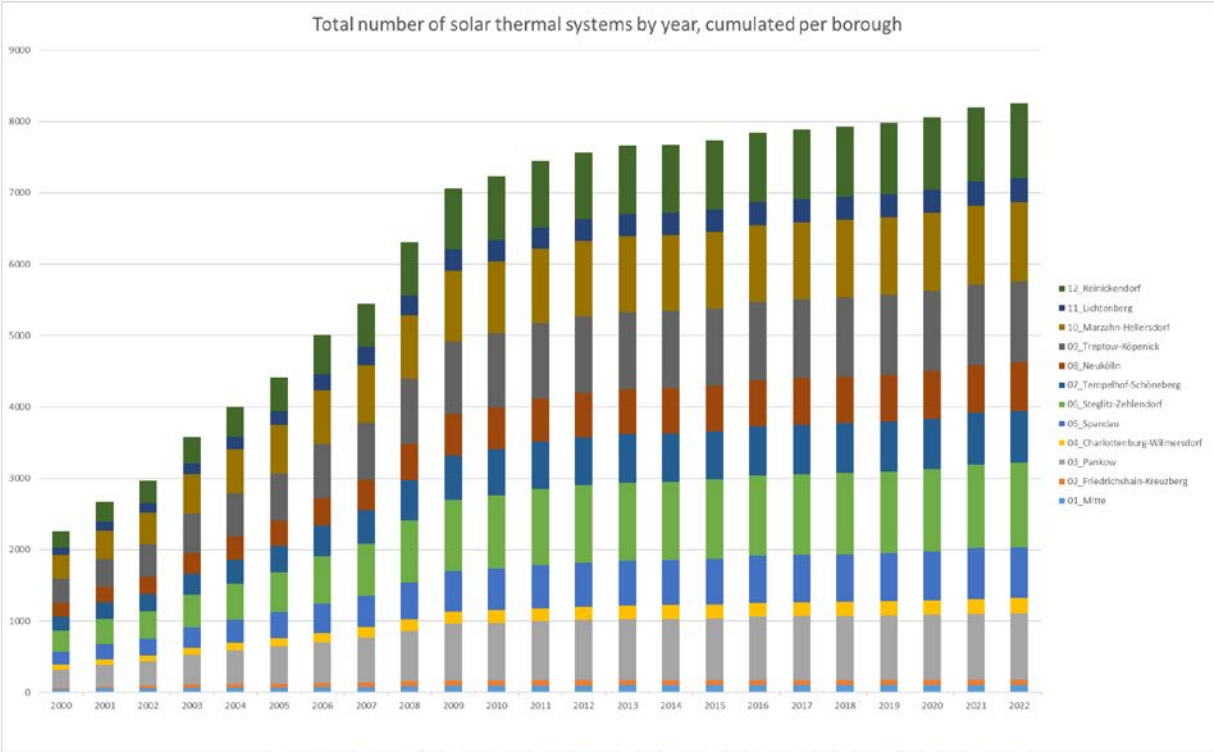

Fig. 3: Development of solar thermal systems in the State of Berlin in number of systems, by borough; (as of March 29, 2023)

Due to the incomplete recording of hot water supply systems, it may be assumed that the total number of solar thermal systems in Berlin is actually higher. Flat plate collectors were chosen for the largest number of installations. Table 1 shows which collector types were installed in 2014 and 2015.

Tab. 1: Type and number of collectors of the solar thermal systems installed in 2014 and 2015 (as of October 31, 2015, final available update for these categories)

Collector type	Number
Flat plate collector	80
Evacuated tube collector	52
Air collector	4
Not specified	9

Tab. 1: Type and number of collectors of the solar thermal systems installed in 2014 and 2015 (as of October 31, 2015, final available update for these categories, source: IP SYSCON 2016)

Most solar thermal systems in Berlin were mounted on single-family homes. Table 2 displays the number of systems per building type according to the utilisation details presented in the Property Map ALK (SenStadtUm 2016), which was still in use at the time.

Tab. 2: Number of installed solar thermal systems based on the building type according to ALK (as of December 31, 2015, final available update for these categories)

Building type	Number
Single-family home	4,895
Multi-family home	563
Other (non-residential)	66
Not specified	1,753

Tab. 2: Number of installed solar thermal systems based on the building type according to ALK (as of December 31, 2015), final available update for these categories, source: IP SYSCON 2016)

In Berlin, the number of new solar thermal systems has dropped dramatically since 2013 as compared to previous years and has continued to further decrease since then. The lowest increase in number and capacity of new systems since the year 2000 was recorded in 2014. In 2021, the growth compared to the previous year nearly doubled with 145 new installations, but in 2022, it significantly decreased again with only 57 new installations..

From 2015, the data for Berlin has been provided by the Federal Office for Economic Affairs and Export Control (BAFA), which is aggregated at a more general level and does not provide detailed information. Conclusions regarding collector types, building types or collector surfaces can therefore no longer be drawn.

Across Germany, the growth of new solar thermal collector surfaces has slowed since 2015, and by the end of 2021 it had dropped to a growth rate of below 600,000 m²/a. Generally, the curves for both growth (in area) and for the number of systems have flattened considerably in the last few years (German Solar Association 2023). The situation in Berlin therefore also reflects the national development (cf. Fig. 3).

Map 08.09.3 Irradiation

The comprehensive analysis of solar irradiation is used to calculate the usable radiation and is captured by an annual sum (IP SYSCON 2022). For the Berlin area, the Deutscher Wetterdienst (Germany's National Meteorological Service, (DWD)) provides an average annual sum of global radiation, which consists of varying proportions of direct and diffuse solar radiation. It is measured in relation to a horizontal plane and ranges between 1,081 and 1,100 kWh/m^2 for the current-long term observation period (1991-2020). The irradiation measured in the Berlin area is thus almost exactly in the middle of the range recorded throughout Germany (cf. Fig. 4). A comparison of the last two reference periods 1981-2010 and 1991-2020 reveals that the solar irradiation in Berlin and Brandenburg increased by 40-50 kWh/m² per year, i.e. about 5 %, as a result of climate change.

The irradiation on a horizontal plane is influenced by a variety of factors depending on the geographical position (cf. Methodology).

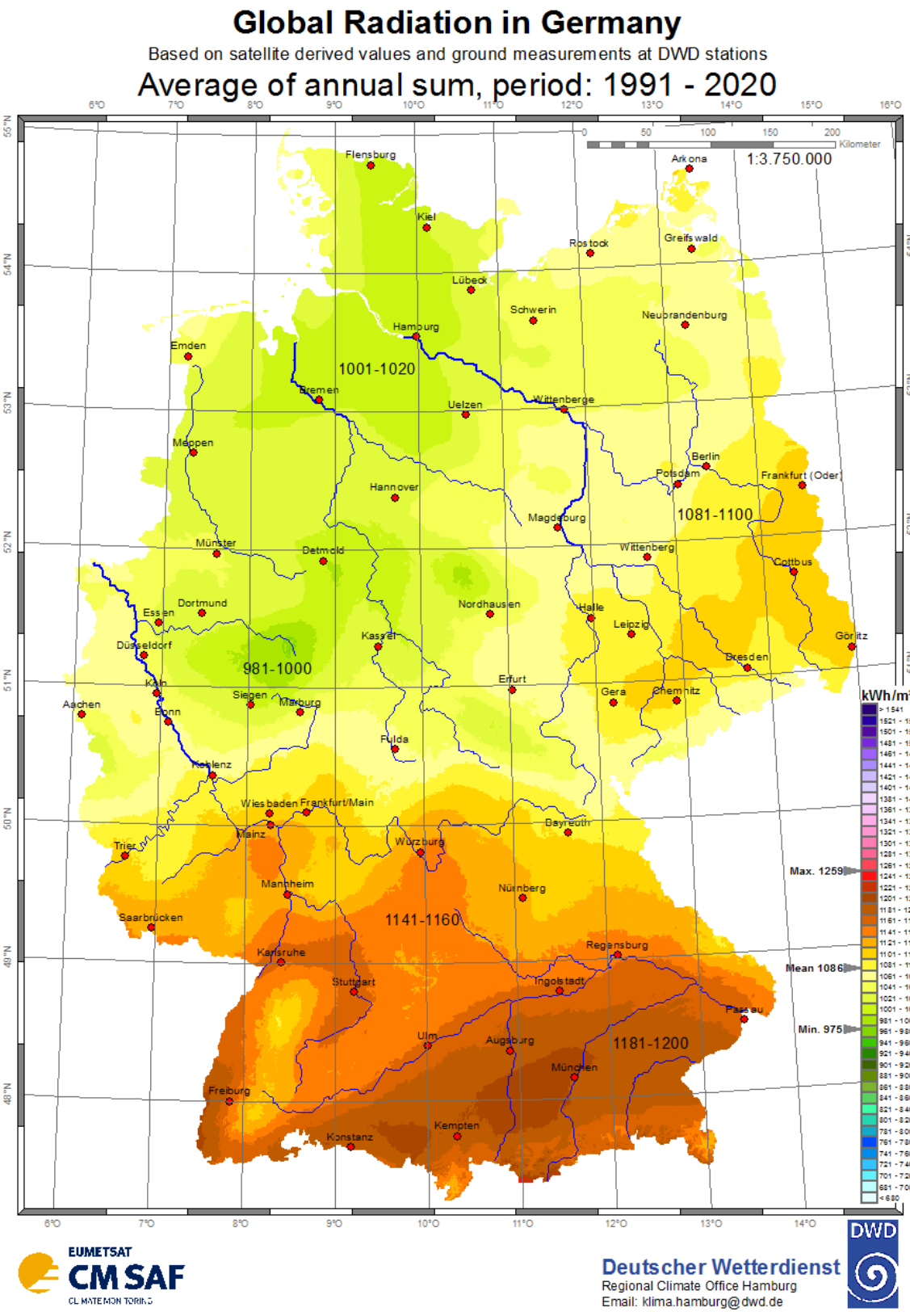

Fig. 4: Average annual sums of the global radiation in Germany for the period from 1991 to 2020 (unaltered reproduction; source: Deutscher Wetterdienst (DWD) 2022)

Statistical Base

As mentioned earlier, the previous method of data recording used in the solar cadastre was discontinued with the introduction of the Energy Atlas. The method switched to a combination of multiple sources and

ways of presenting analysis results. In the future, this responsibility will be transferred to the Energiedatenbank (Energy Database), which currently forms the basis for the Energy Atlas.

The individual data sources are listed below:

Photovoltaics:

- Energieatlas Berlin (Energy Atlas), Senate Department for Economics, Energy and Public Enterprises (SenWEB), online version as of August 2023
- PV locations: data provided by the Federal Network Agency (BNetzA) according to the Installation Register Ordinance (AnlRegV) and the core energy market data register (MaStR), as of July 23, 2023
- Data on the public sector: retrieved by Berliner Energieagentur GmbH from public institutions, as of March 31, 2023
- PV electricity feed-in: data provided by Stromnetz Berlin GmbH, as of December 31, 2018
- PV potential coverage rate: expert recommendation for the “Masterplan Solarcity Berlin”, Fraunhofer ISE (2019) commissioned by the State of Berlin, Senate Department for Economic Affairs, Energy and Public Enterprises (baseline scenario)
- PV potential: analysis of Berlin’s solar potential, IP SYSCON, commissioned by the SenWEB, as of December 8, 2021
- Postal code areas: data as of June 30, 2023.

Solar thermal energy:

- Energieatlas Berlin (Energy Atlas), Senate Department for Economics, Energy and Public Enterprises (SenWEB), online version as of August 2023
- ST locations: data provided by the solar cadastre Berlin, as of December 31, 2015
- Number of systems per borough or postal code: location data from December 31, 2015; supplemented by data from the Federal Office for Economic Affairs and Export Control for the years from 2016 to 2022, as of March 29, 2023
- ST system locations and number of ST systems per borough - public sector: retrieved by Berliner Energieagentur GmbH from public institutions, as of March 31, 2023
- ST potential: analysis of Berlin’s solar potential, IP SYSCON, commissioned by the SenWEB, as of December 8, 2021
- Postal code areas: data as of June 30, 2023

It may safely be assumed that not all solar systems installed in Berlin are known, also in relation to the respective year of recording. For example, photovoltaic systems that do not feed into the grid and use the electricity exclusively for self-supply are not included in the data collection and the presentations. This applies both to off-grid systems as well as stand-alone power systems, such as PV modules on parking meters, on park lighting systems and in allotment gardens.

Irradiation:

- Energieatlas Berlin (Energy Atlas), Senate Department for Economic Affairs, Energy and Public Enterprises (SenWEB), online version as of July 2022
- Analysis of Berlin’s solar potential, IP SYSCON, commissioned by the SenWEB, as of March 21, 2022.

Methodology

The three maps each contain several layers covering different topics and areas. This is due to data protection considerations and academic reasons. The layers are self-contained; i.e. combining several of the two-dimensional layers will not generate any additional information.

More specifically, the maps consist of the following specialised layers:

Map 08.09.1 Photovoltaics contains 12 layers:

- PV system locations for small systems up to 30 kWp (not true to location) and above 30 kWp
- PV system locations – public sector
- Installed capacity of the PV systems presented separately per borough and postal code area
- Installed capacity of the PV systems per borough – public sector
- PV electricity feed-in presented separately per borough and postal code area
- PV potential (theoretical) – building and

- PV potential (theoretical) – roof area
- Relative coverage rate presented separately per borough (ratio of the output that can be achieved theoretically to the already installed capacity).

Map 08.09.2 Solar Thermal Energy contains 7 layers:

- ST system locations (data protection reasons allowed only for a limited range of scales to be used for presentation)
- ST system locations – public sector
- Total number of ST systems presented separately per borough and postal code area
- Total number of ST systems presented separately per borough – public sector
- ST potential (theoretical) – building and
- ST potential (theoretical) – roof area.

Map 08.09.3 Solar Potential – Irradiation contains 1 layer

- "Irradiation".

Map 08.09.1 Photovoltaics

With the amendment of the Renewable Energy Sources Act (EEG) in August 2014, the responsibility for publishing PV system data was transferred to the Federal Network Agency (BNetzA) as a centralised institution with uniform standards across Germany. This is a distinctive feature of the current methodology. Previously, the responsibility for publishing PV system data was with the network operators, who would usually publish information on the address and generator output of all systems on their own websites. For data protection reasons, the Federal Network Agency only publishes the postal code for systems below 30 kWp; the exact address including street name and house number is only published for an output of 30 kWp or more.

Map layer **"PV system locations for small systems up to 30 kWp (not true to location) and above 30 kWp":**

The data set only includes systems that are subsidised according to the EEG. Systems that do not feed into the grid and use the electricity exclusively for self-supply are not included in the presentation. This applies for example to off-grid systems and stand-alone power systems, such as PV modules on parking meters, park lighting systems and in allotment gardens.

The location of systems above 30 kWp was determined based on the address details provided by the system data reported. It cannot be ruled out that these may deviate slightly from the actual system location in individual cases, as it was not always possible to match the system to its roof. Due to data protection regulations, systems of up to 30 kWp are not displayed at their exact location but are presented together in the centre of a specific postal code area.

The PV system data is based on preliminary reports from the core energy market data register of the Federal Network Agency. As data on existing systems is still being added, the figures are still incomplete. This data will be added successively as part of the updating process, however, i.e. the figures will be completed gradually.

Map layer **"PV system locations – public sector"**.

This map layer shows the locations of PV systems on public sector buildings. These include buildings owned by the boroughs, buildings of the Berliner Immobilienmanagement GmbH (BIM) and buildings of Berlin's public-law institutions. It also encompasses buildings owned by municipal housing associations and other affiliated companies of the State of Berlin. Not all companies and public-law institutions in which the State of Berlin has a stake have yet provided feedback on the expansion status of PV systems. The locations were identified by their exact address.

Map layers **"Installed capacity of the PV systems per borough and postal code area":**

The data set only includes systems that are subsidised according to the EEG. The Anlagenregisterverordnung (Installation Register Ordinance) (in force until August 2017) summarised all master and billing data for PV systems previously reported by the transmission system operators. This data is address-specific and was summed up per borough and postal code areas.

Map layer **"Installed capacity of the PV systems per borough – public sector"**

This map layer presents the number and installed capacity of PV systems on public buildings. The data was collected by exact address and aggregated at borough level.

Map layers **“PV electricity feed-in per borough and postal code area”:**

The electricity feed-in data presented includes the billed quantities determined by the Stromnetz Berlin GmbH, aggregated by borough and postal code area. For the electricity feed-in, the measured data and the data billed in accordance with the valid, defined market processes is available. The available annual values are not to be regarded as final; changes may still have occurred in individual cases, for example due to billing corrections.

Considerable annual fluctuations in electricity feed-ins may occur in individual areas. Specific reasons may include weather fluctuations, system extensions or operational failures. Based on the available data, however, it is not possible to identify the exact underlying reasons.

Map layer **“Theoretical PV potential per building”:**

The map layer shows the photovoltaic potential for the roof areas of Berlin’s buildings. In addition to the local global radiation, shading as well as the orientation and the angle of a roof area play a key role in the design of a photovoltaic system. Suitable roof areas were determined as part of an analysis of the potential. The irradiation conditions are illustrated by a colour scale on the map. These provide initial insight into the use of solar energy.

More detailed information for each building may be accessed using the factual data display. In addition to an assessment of how suitable a building is for the installation of a PV system, the installable capacity [kWp], the number of installable modules and the potential electricity yield per year [kWh/a] are listed. However, this information does not replace the expert assessment of the individual object that is still required in relation to other parameters, for example the statics of the roof, before a solar system may be planned in detail and eventually constructed. The technical suitability is therefore not guaranteed and needs to be determined for each individual case. Further information and advice (in German) are available from the SolarZentrum Berlin free of charge.

Existing data sources such as aerial photographs and ALKIS building floor plans, as well as a transparent calculation process, were used to determine the solar potential. More details may be found in the final documentation (IP SYSCON 2022, only in German). Only roof areas that have been found suitable are shown on the map. The suitability criteria selected included a “minimum available area of 7 m²” and the “achievement of a specific electricity yield of 650 kWh/kWp”. The map does not distinguish between roof areas that already have PV systems installed and those that do not, due to the data sources used. In addition, developments on buildings that were erected, modified, demolished or included in the Official Real Estate Cadastre Information System after the date of data collection (April 22, 2021) were not taken into account.

Map layers **“Relative coverage rate of the actual output compared to the theoretical PV output that can be achieved by borough”:**

The theoretically achievable PV potential for Berlin’s rooftops was calculated in 2019 as part of the master plan study for the “Masterplan Solarcity Berlin” by the Fraunhofer Institute for Solar Energy Systems. The results were aggregated at borough level, and the relative coverage rates were determined from the ratio between the actually installed and the potential PV capacity.

At first glance, the coverage rates appear to be relatively low for the boroughs. However, the reasons for this lie in the deviation between theoretically calculated and technically achievable potential. This would have to be confirmed by further investigations and calculations in order to obtain an accurate picture.

Map 08.09.2 Solar Thermal Energy

At this point, it is helpful to remember that not every installed system could be recorded in the solar cadastre in its final version as of December 31, 2015. Six years and 468 new systems separate the location data of the cadastre and the updated and aggregated version from late 2021.

Map layer **“ST system locations”**

Due to data protection regulations, the presentation of system locations (as of December 31, 2015) is only permissible for certain scale ranges. The solar thermal systems are therefore presented only at a scale of 1:15,000 and larger.

Map layer **“ST system locations – public sector”**

This map layer shows the locations of ST systems on public sector buildings (as of March 31, 2023). These include buildings owned by the boroughs, buildings of the Berliner Immobilienmanagement

GmbH (BIM) and buildings of Berlin's public-law institutions. It also encompasses buildings owned by municipal housing associations and other affiliated companies of the State of Berlin. Not all companies and public-law institutions in which the State of Berlin has a stake have yet provided feedback on the expansion status of ST systems. The locations were identified by their exact address.

Map layers **"Total number of ST systems presented separately per borough and postal code area"**

The data presented also includes updates for the years between 2016 and 2022, i.e. additions based on information provided by the Federal Office of Economic Affairs and Export Control (BAFA). The data is only available at postal code level, which forms the most detailed level here. It was therefore possible to adjust the total number summed up at postal code and borough level. The location of individual systems, however, could not be identified.

Map layer **"Total number of ST systems presented separately per borough – public sector"**

This map layer presents the number and installed capacity of PV systems on public buildings as of March 31, 2023. The data was collected by exact address and aggregated at borough level. For comparison, the total number of solar thermal systems on public buildings is also indicated for the entire city of Berlin.

Map layer **"Theoretical ST potential at building level"**

The map layer shows the solar thermal potential for the roof areas of Berlin's buildings. In addition to the local global radiation, shading as well as the orientation and the angle of a roof area play a key role in the design of a solar thermal system. Suitable roof areas were determined as part of an analysis of the potential. The irradiation conditions are illustrated by a colour scale on the map. These provide you with initial insight into the use of solar energy.

More detailed information for each building may be accessed using the factual data display. In addition to an assessment of how suitable a building is for the installation of a solar thermal system, the potential heat generation per year [kWh/a] is also indicated. However, this information does not replace the expert assessment of the individual object that is still required in relation to other parameters, for example the statics of the roof or required heat, before a solar system may be planned in detail and eventually constructed. The technical suitability is therefore not guaranteed and needs to be determined for each individual case. Further information and advice (in German) are available from the SolarZentrum Berlin free of charge.

Existing data sources such as aerial photographs and ALKIS building floor plans, as well as a transparent calculation process, were used to determine the solar potential. More details may be found in the final documentation (IP SYSCON 2022, only in German). Only roof areas that have been found suitable are shown on the map. The suitability criteria selected included a "minimum available area of 4 m²" and the "achievement of a potential heat generation of 350 kWh/kWp per m²". The map does not distinguish between roof areas that already have PV systems installed and those that do not, due to the data sources used. In addition, developments on buildings that were erected, modified, demolished or included in the Official Real Estate Cadastre Information System after the date of data collection (April 22, 2021) were not taken into account.

Map 08.09.3 Solar potential – Irradiation

Berlin's calculation of irradiation includes all surfaces that may be found in the city, not only those of buildings and structural elements. It is therefore also suitable for evaluation purposes other than those required in the solar potential analysis. The method for creating the high-resolution grid data is described in detail in the final report on the solar potential analysis (IP SYSCON 2022) and will only be touched upon here briefly.

The analysis was based on aerial photography flight data of the year 2020 (SenStadtWohn 2020). A 3D model was derived from this data, which enabled, first and foremost, a three-dimensional analysis. This analysis was able to take into account the influence of the shading effect of trees, building structures and different positions of the sun, which may have a major impact, depending on the season. The monthly means of the long-term mean global radiation provided by the Deutscher Wetterdienst (DWD), here the mean between 1991 and 2020 (cf. Fig. 4), formed the basis for calibrating the calculation method.

In addition to the annual sums presented here, irradiation was also determined for the heating period between October 1 and April 30 in order to calculate the possible support towards heating that solar thermal energy may provide.

Map Description

A total of 29,243 individual systems are presented in the two maps, of which 8,258 are solar thermal systems (as of March 29, 2023) and 20,985 photovoltaic systems (as of July 23, 2023). These only include systems that are known to the various funding bodies. However, it may be assumed that more than 90 % of all existing systems in Berlin were recorded for the different system types at their respective times of data collection.

The stand-alone photovoltaic systems, e.g. solar-powered parking meters or lighting systems and similar off-grid systems, form a separate data set that is not included here.

Map 08.09.1 Photovoltaics (PV)

As of July 23, 2023, 20,985 PV systems were registered in Berlin. The great majority of these are small systems below 30 kWp (19,987) while only 227 of them are larger systems (> 100 kWp). They have a total installed capacity of about 229,492 kWp. Of these, the above-mentioned larger systems account for about a third (approx. 54,222 kWp) of the total capacity in Berlin. The three boroughs of Marzahn-Hellersdorf, Treptow-Köpenick and Pankow have by far the largest number of systems and the highest total capacity with the number of systems ranging between 3,010 and 3,778. In terms of installed capacity, the borough of Lichtenberg also stands out with 21,59 MWp. Here, the considerably lower absolute number of systems is offset by individual systems that have a high installed capacity. Taking a closer look at postal code level reveals that most postal code areas with capacities exceeding 1,000 kWp fall into single family-home estates on the periphery with a high absolute number of systems.

As of April 1, 2023, a total of 691 PV systems with a capacity of 42.08 MWp were installed on buildings of the public sector. The borough of Lichtenberg has the highest number of PV systems on public buildings with 112 systems, followed by Pankow (91) and Marzahn-Hellersdorf (90). However, the borough of Pankow achieves the highest installed capacity with 5.46 MWp, closely followed by Charlottenburg-Wilmersdorf, Mitte, and Spandau. The public sector also maintains buildings outside of Berlin, where four PV systems are installed at three locations. These four PV systems, each with an average capacity of around 470 kWp, collectively reach a similar installed capacity as the 30 and 39 systems in the boroughs of Tempelhof-Schöneberg and Friedrichshain-Kreuzberg.

Tab. 3: Number of PV systems and their installed capacity in Berlin's boroughs (as of July 23, 2023)

Borough	Number	Total capacity [MWp]	Avg. capacity [kWp]	Electricity feed-in [MWh] (as of 2018)	Number of systems – public sector	Total capacity – public sector [MWp]	Avg. capacity – public sector [kWp]
Mitte	375	9.49	25.30	4,140.74	51	4.62	90.62
Friedrichshain-Kreuzberg	389	5.19	13.33	1,740.79	39	1.99	51.08
Pankow	3.010	26.40	8.77	7,911.88	91	3.30	36.25
Charlottenburg-Wilmersdorf	469	8.10	17.27	2,688.31	54	4.33	80.10
Spandau	1.775	19.60	11.04	5,666.21	42	3.18	75.60
Steglitz-Zehlendorf	1.764	14.88	8.43	3,525.17	33	3.02	91.63
Tempelhof-Schöneberg	1,512	21.38	14.14	5,438.05	30	1.84	61.32

Neukölln	1,382	13.39	9.69	4,385.34	39	1.71	43.82
Treptow-Köpenick	3,312	31.61	9.54	8,596.04	74	3.27	44.19
Marzahn-Hellersdorf	3,778	37.86	10.02	11,325.40	90	5.25	58.36
Lichtenberg	1,360	21.59	15.88	7,722.88	112	5.46	48.75
Reinickendorf	1,859	20.02	10.77	6,639.82	31	2.20	70.83
Outside Berlin	–	–	–	–	4	1.88	469.02
Total	**20,985**	**229.49**	**10.94**	**69,780.63**	**690**	**42.05**	**60.93**

Tab. 3: Number of PV systems and their installed capacity in Berlin's boroughs (as of July 23, 2023, electricity feed-in as of December 31, 2018, data on systems of the public sector, as of April 1, 2023)

Since the systems often produce more electricity than is needed for self-supply, the surplus electricity is fed into the grid. In Berlin, this accounted for about half of the PV electricity in 2018. Since 2012, the amount fed into the grid has risen steadily from around 43 GWh in 2012 to its peak value of 69.8 GWh in 2018 (see Fig. 5). In 2016, a slight decrease was observed for Berlin. Between 2012 and the end of 2018, the largest increases were recorded for the boroughs of Marzahn-Hellersdorf (+127 %), Reinickendorf (+120 %) and Mitte (+83 %). The highest absolute electricity feed-ins were recorded for the boroughs of Marzahn-Hellersdorf (11,325.4 MWh) and Treptow-Köpenick (8,596.04 MWh) according to the latest data (cf. Tab. 3). Electricity feed-ins are clearly concentrated in the northern and eastern boroughs. Friedrichshain-Kreuzberg feeds the least electricity into the grid. This is, however, also the borough with the fewest systems accounting for a low total capacity. The more centrally located area 10365, west of the Zentralfriedhof Friedrichsfelde (Friedrichsfelde Central Cemetery), however, was the postal code area with the highest electricity feed-in, which was around 3,063 MWh, according to the 2018 data collection. With 4,190 kWp, this area's installed capacity also ranks among the top of the PV capacity aggregated by Berlin's postal code areas.

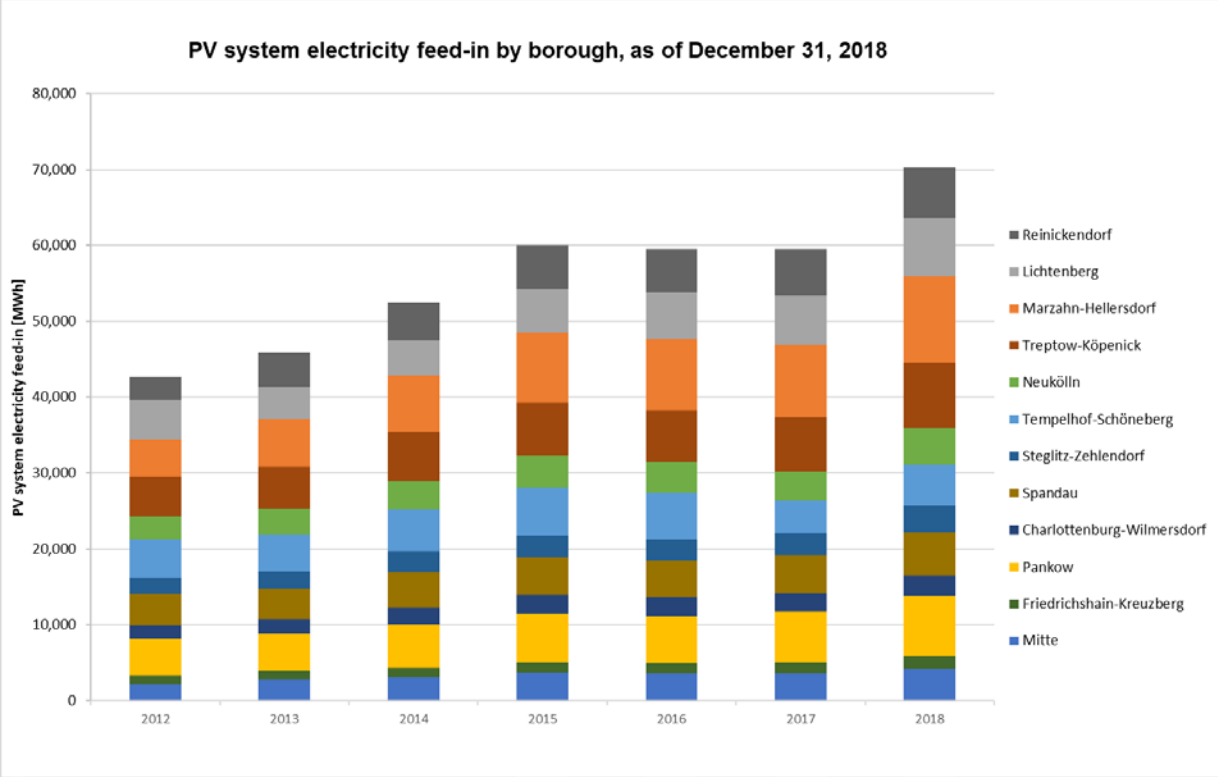

Fig. 5: Electricity feed-ins of PV systems at the level of Berlin's boroughs (as of December 31, 2018)

The relative coverage rates of photovoltaics vary across the boroughs, fluctuating between 1.58 % in Charlottenburg-Wilmersdorf and 7.63 % in Marzahn-Hellersdorf (cf. Tab. 4).

The determined relative coverage rates between potential and actual installations for the boroughs and postal code areas appear relatively low at first glance. However, the reasons for this lie in the deviation between theoretically calculated and technically achievable potential. This would have to be confirmed by further investigations and calculations in order to obtain an accurate picture.

Tab. 4: Relative PV capacity coverage rates in Berlin's boroughs (PV systems as of July 23, 2023)

Borough	Theoretically achievable output [kWp]	Actually installed capacity [kWp]	Relative coverage rate [%]
Mitte	532,000	9,485.97	1.78
Friedrichshain-Kreuzberg	285,000	5,187.29	1.82
Pankow	609,000	26,396.83	4.33
Charlottenburg-Wilmersdorf	512,000	8,098.51	1.58
Spandau	545,000	19,600.49	3.60
Steglitz-Zehlendorf	612,000	14,876.22	2.43
Tempelhof-Schöneberg	687,000	21,381.73	3.11
Neukölln	527,000	13,388.39	2.54
Treptow-Köpenick	604,000	31,610.17	5.23
Marzahn-Hellersdorf	496,000	37,857.41	7.63
Lichtenberg	465,000	21,594.14	4.64
Reinickendorf	562,000	20,015.29	3.56
Total	**6,436,000**	**229,492.43**	**3.57**

Tab. 4: Relative PV capacity coverage rates in Berlin's boroughs (PV systems as of July 23, 2023 (potential in relation to the installed capacity))

Results of the study on photovoltaic potential on roof areas

Of the nearly 536,000 buildings examined, some 421,000 buildings are suitable for solar PV use. If the theoretically suitable module area of 45.7 km² were utilised for electricity generation through PV with an efficiency of 19.5%, it could produce 7,929 GWh/year of electricity and save 4.3 million tons of CO_2.

Suitability	Solar module area in m²	kWp capacity	Electricity yield in GWh/a (with an efficiency of 19.5%)	CO_2 savings in t per year (with an efficiency of 19.5 %)
Suitable	45,679,550	8,894,703	7,929	4,313,594

Tab. 5: Results of the solar potential analysis for photovoltaics on roof areas in Berlin (flat roofs are taken into account with an elevated installation facing south) (IP SYSCON 2022)

Map 08.09.2 Solar Thermal Energy (ST)

The updated data based on additional information from the Federal Office of Economic Affairs and Export Control (BAFA) indicates that 8,258 solar thermal systems are installed on rooftops throughout the city.

It is evident, both at a smaller scale of individual systems and at scales aggregated by postal code and borough, that the largest number of systems are installed on the periphery of the city. At borough level, key areas emerge for the boroughs of Steglitz-Zehlendorf, Treptow-Köpenick and Marzahn-Hellersdorf with more than 1,100 systems each (cf. Table 6). Similar to the situation in the PV system sector, these are smaller systems (avg. 9-11 m²) installed on single-family and two-family homes for private use. They are primarily used to heat water (IP SYSCON 2016) and thus constitute an important contribution to the energy supply. A considerably lower number of systems is installed in the inner city area and more specifically in the boroughs of Friedrichshain-Kreuzberg (76 systems), Mitte (104 systems), Charlottenburg-Wilmersdorf (209 systems). These are also the boroughs, however, with systems featuring a large-scale potential for electrical output or heat generation (avg. collector surface of 15-37 m²). These are located on buildings with public or industrial/commercial use. It is also worth noting that (as of December 31, 2015) six of the ten largest solar thermal systems in Berlin are installed on multi-family homes, i.e. they support the energy supply in the residential sector.

Tab. 6: Number of solar thermal systems and number of solar thermal systems of the public sector in Berlin's boroughs (as of March 2023)

Borough	Number	Number of systems – public sector
Mitte	104	30
Friedrichshain-Kreuzberg	76	5
Pankow	930	11
Charlottenburg-Wilmersdorf	209	19
Spandau	719	2
Steglitz-Zehlendorf	1.182	8
Tempelhof-Schöneberg	729	21
Neukölln	677	11
Treptow-Köpenick	1.135	23
Marzahn-Hellersdorf	1.109	7
Lichtenberg	333	6
Reinickendorf	1.055	5
Total	**8.258**	**148**

Tab. 6: Number of solar thermal systems and number of solar thermal systems of the public sector in Berlin's boroughs (as of March 2023)

Results of the study on solar thermal potential

Of the almost 536,000 buildings examined, more than 464,000 buildings are suitable for solar thermal use with a total module area of 66.2 km².

Suitability	Solar module area in m²	No. of buildings	Potential heat in GWh/a
Suitable	66.264.578	464.826	40.553

Tab. 7: Results of the solar potential analysis for solar thermal energy for water heating on roof areas in Berlin (flat roofs are considered with an elevated installation facing south) (IP SYSCON 2022)

Map 08.09.3 Solar Potential – Irradiation

When taking into account all surfaces in the city, Berlin's calculated annual sums of global irradiation range between a maximum of about 1,220 kWh/(m²/a) and a minimum of about 246 kWh/(m²/a). The mean annual sum for Berlin set by the Deutscher Wetterdienst DWD is 1,032 kWh/(m²/a). Roof areas only record very low numbers when they are covered by trees or are shaded for other reasons (cf. Fig. 6).

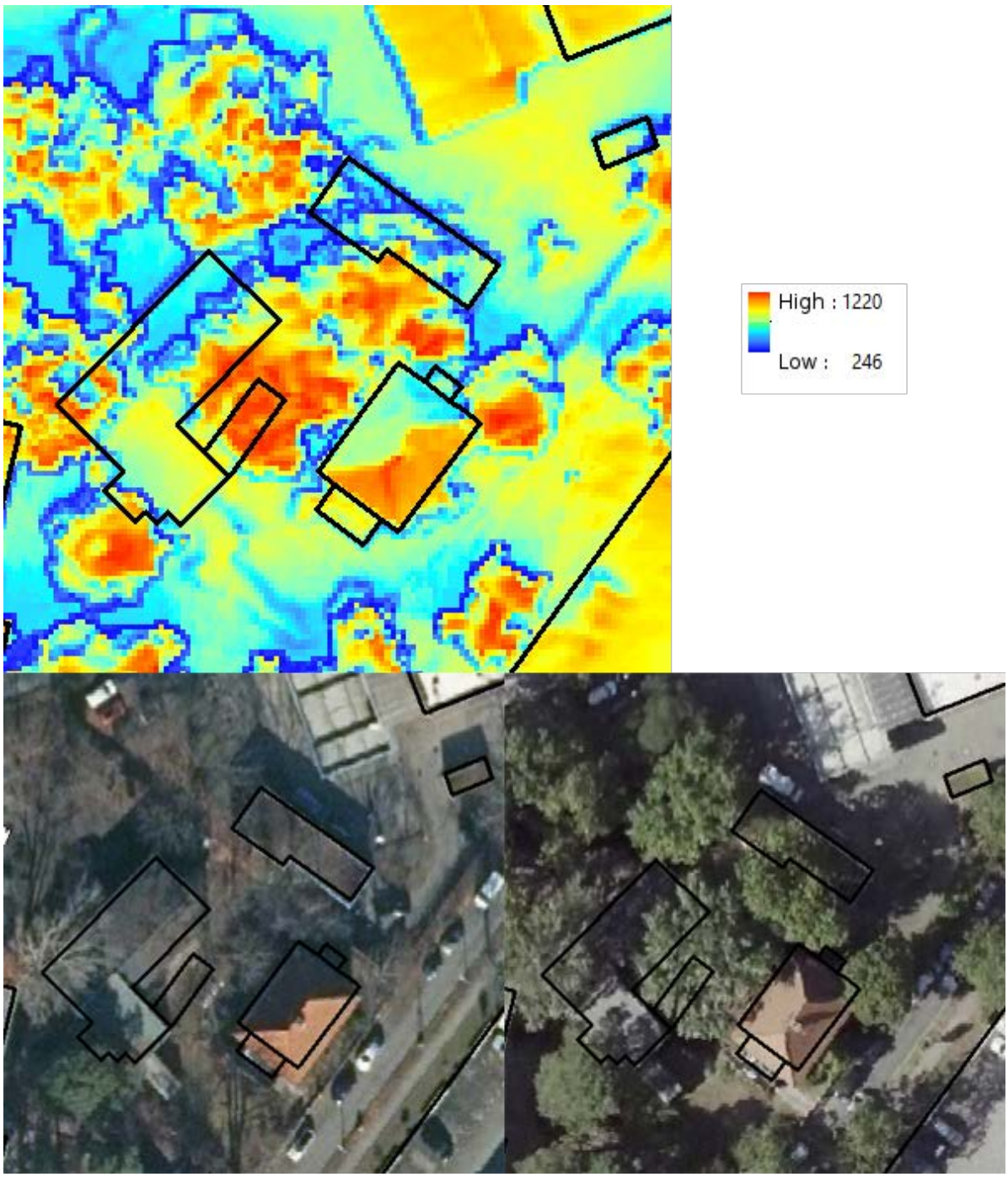

*Fig. 6: Influence of the covering effect of trees also due to roof orientation on the calculated solar irradiation of rooftops (mean annual sums in kWh/(m²/a)). Top: calculated irradiation of the surface grids at a resolution of 0.5 * 0.5 m², in black: building perimeters. Bottom: left: section of aerial photograph, February 2021, right: section of aerial photograph, August 2020.*

Images: aerial photographs: Geoportal Berlin, DOP20RGBI (bottom left); TrueDOP20RGB – summer aerial photography flight (bottom right).

In contrast, the highest numbers are measured on roof areas neither shaded nor covered that are facing south. Open and unshaded vegetated areas, such as the Tempelhofer Feld, also record high numbers around 1,000 kWh/(m²/a). Forest areas and tree-covered areas, however, reduce irradiation substantially, down to the lowest irradiation range of around 250-300 kWh/(m²/a) due to their structure and shading.

A direct relationship with urban climatic effects may be observed here, such as those modelled in the analysis maps of the climate model (cf. Environmental Atlas map "Climate Model Berlin: Radiation Temperature 2015" (04.10.3)). The "Solar Potential – Irradiation" (08.09.3) map therefore encompasses a wide range of potential uses.

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