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 Turnaround 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). The first monitoring report on the "Masterplan Solarcity" has been available since January 2021 (SenWEB 2021).

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

So far, solar power has accounted for less than 0.5 % of the total generated power (Berliner Morgenpost 2019). 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 16, 2022) and those of solar thermal systems (as of December 31, 2015 and as of December 31, 2021 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 2021). 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 two Environmental Atlas maps “Solar Systems – Photovoltaics (08.09.1)” and “Solar Systems – Solar Thermal Energy (08.09.2)” (see Map Description).

This information becomes even more important, as from January 1, 2023, solar systems shall be 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 March 16, 2022, 11,414 systems were in place, with a total installed capacity of around 160 MW. The electricity that these generate per annum can only be estimated and is expected to amount to approx. 144 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 34,200 households with an assumed average electricity consumption of 4,000 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 kW (Fig. 1b), the preferred choice for smaller roofs, predominates with about 9,875 of the 11,414 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 cooperatives 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 Bundesnetzagentur (Federal Network Agency 2020), this trend continued and was observed nationwide in the two years following the EEG amendment coming into force in August 2014, with only approximately 50,000 new installations. In the meantime (as of June 2020), the nationwide increase for systems according to the EEG has returned to between 80,000 and 100,000 systems.

In terms of area-related photovoltaic capacity, the State of Berlin, with 179.5 kWp/km² (kWp = kilowatt peak), ranked above the national average of 164.2 kWp/km² and significantly above the capacity of Hamburg, for example, as the second largest German city (91.4), but also considerably below some area states (Bavaria, Baden-Württemberg) (Renewable Energies Agency, 2022). 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.

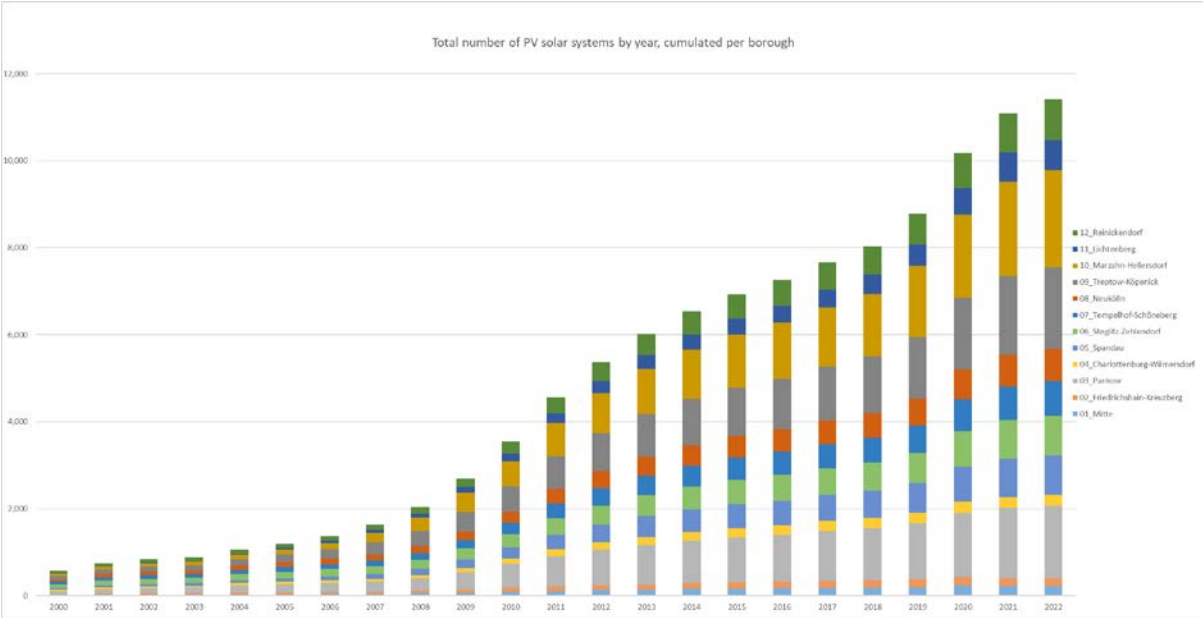

Fig. 1a: Development by borough

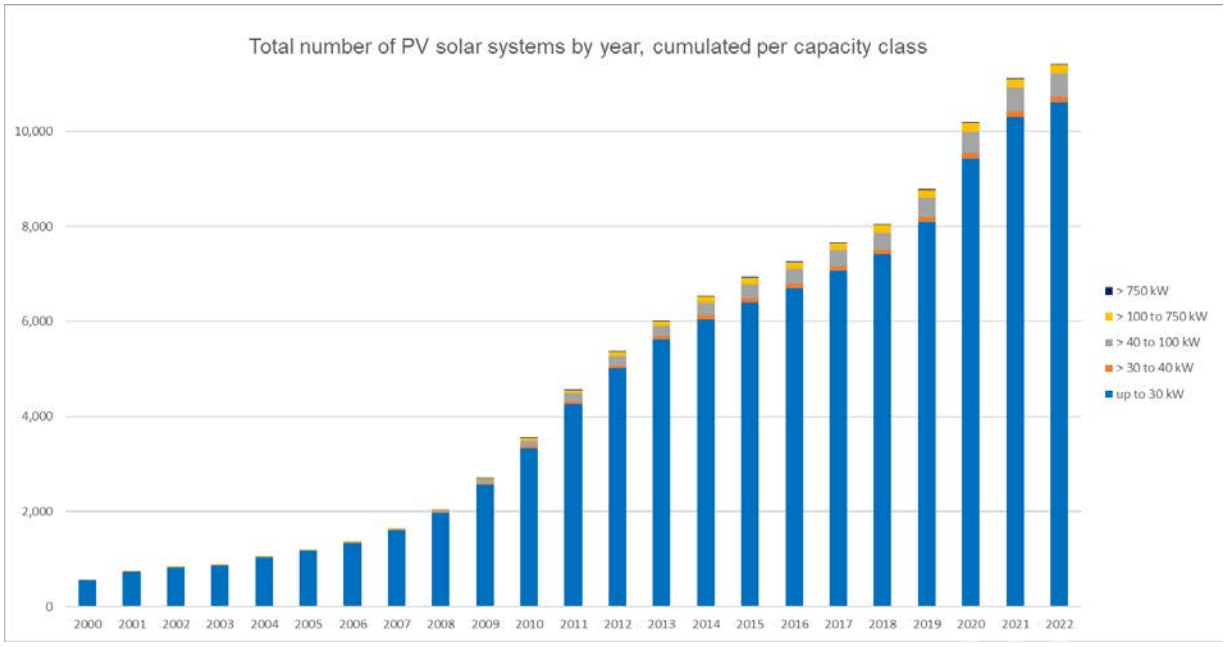

Fig. 1b: Development by capacity class

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 March 16, 2022)

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 December 31, 2021, there were about 8,200 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 2. 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).

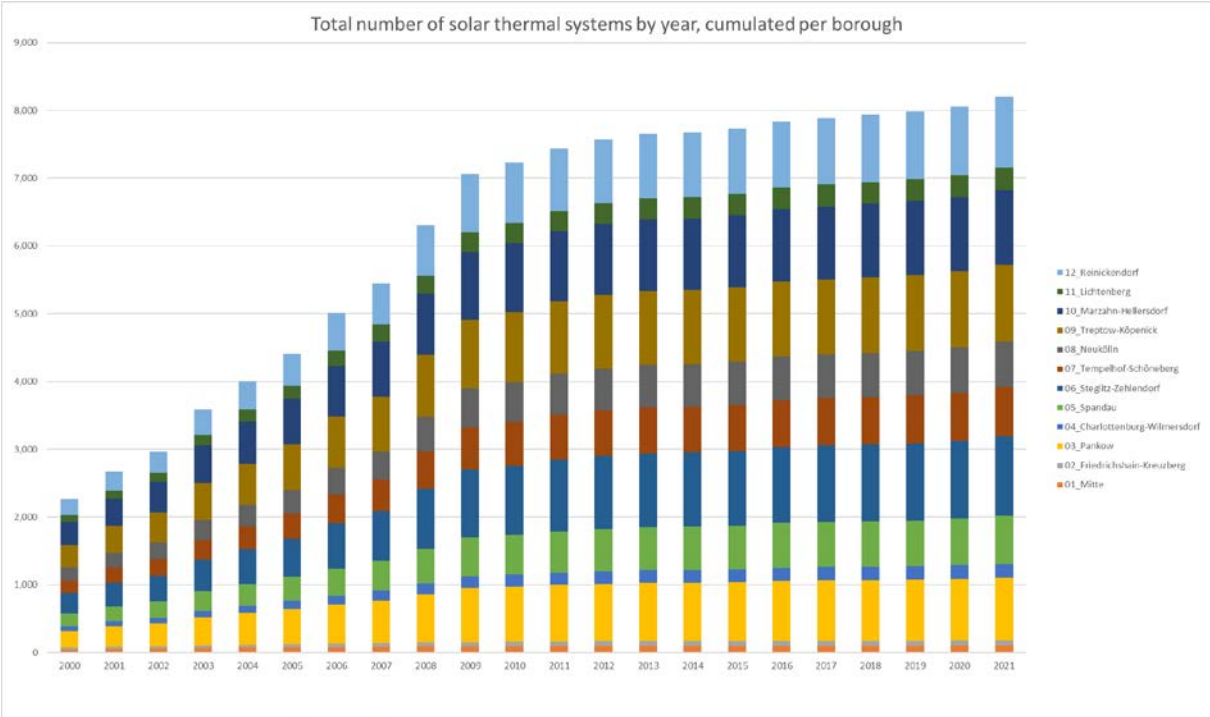

Fig. 2: Development of solar thermal systems in the State of Berlin in number of systems, by borough; (as of December 31, 2021)

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 installations since the year 2000 was recorded in 2014. In 2021, the increase nearly doubled from the previous year, with 145 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 2022). The situation in Berlin therefore also reflects the national development (cf. Fig. 2).

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. 3). 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).

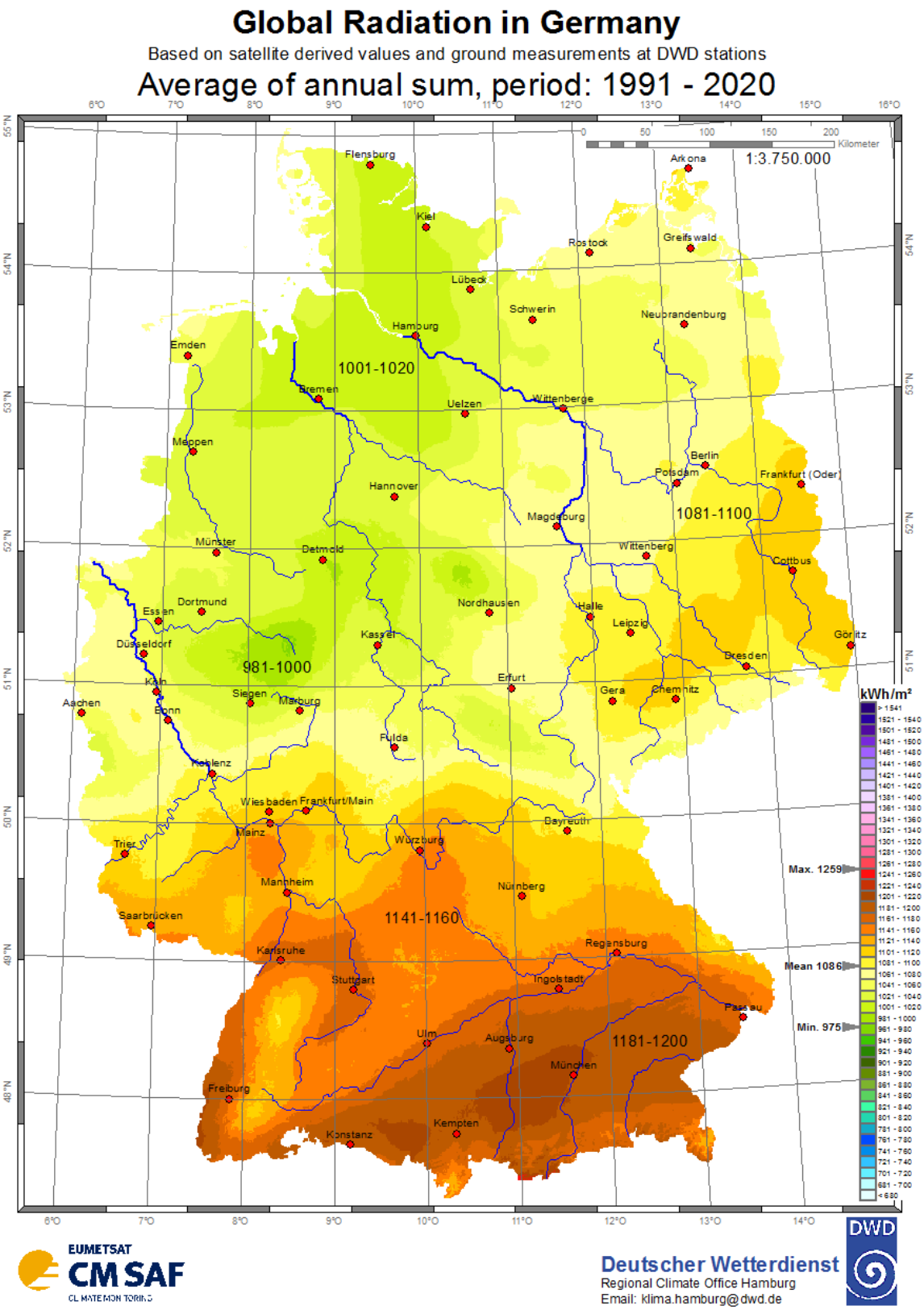

Fig. 3: Average annual sums of the global radiation in Germany for the period from 1991 to 2020 (unaltered reproduction; source: Deutscher Wetterdienst (DWD) 2022)

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 July 2022
- PV locations: data provided by the Bundesnetzagentur (Federal Network Agency) according to the Anlagenregisterverordnung (Installation Register Ordinance) and the core energy market data register (MaStR), as of March 16, 2022
- PV electricity feed-in: data provided by Stromnetz Berlin GmbH, as of December 31, 2018
- PV coverage rate: data provided by the Bundesnetzagentur (Federal Network Agency) according to the Anlagenregisterverordnung (Installation Register Ordinance) and the core energy market data register (MaStR), as of January 14, 2021
- PV potential: analysis of Berlin's solar potential, IP SYSCON, commissioned by the SenWEB, as of March 21, 2022
- Postal code areas: data as of March 3, 2016.

Solar thermal energy:

- Energieatlas Berlin (Energy Atlas), Senate Department for Economics, Energy and Public Enterprises (SenWEB), online version as of July 2022
- 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 2021, as of December 31, 2021
- ST potential: analysis of Berlin's solar potential, IP SYSCON, commissioned by the SenWEB, as of March 21, 2022
- Postal code areas: data as of March 3, 2016

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:

- Analysis of Berlin's solar potential, IP SYSCON, commissioned by the SenWEB, as of March 21, 2022.

Methodology

The two maps feature multiple layers that differ thematically and spatially. This is both for data protection considerations a well as academic reasons. The layers are self-contained; 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 10 layers:

- PV system locations for small systems up to 30 kW (not true to location) and above 30 kW
- Installed capacity of the PV systems presented separately per borough and postal code area
- 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 and postal code area (ratio of the output that can be achieved theoretically to the already installed capacity).

Map 08.09.2 Solar Thermal Energy contains 5 layers:

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

Map 08.09.3 Solar Potential – Irradiation only contains 1 layer, i.e. "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 Bundesnetzagentur (Federal Network Agency) 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 kW (not true to location) and above 30 kW":**

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 kW 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 kW are not displayed at their exact location but are presented together in the centre of a specific postal code area.

The PV system data for the period from 2017 to January 2021 is based on preliminary reports from the core energy market data register and the EEG installation 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 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 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 and postal code area":**

The theoretical PV potential for highly suitable rooftops was calculated as part of analysing the PV potential for the Solar Atlas Berlin (cf. previous section), which resulted in the present data. The latter was also based on information on existing stock supplied by the Installation Register Ordinance (in force until August 2017, cf. sections above), which provided the actually measured feed-ins.

At first glance, the relative coverage rates between the potential and existing stock calculated for the boroughs and postal code areas appear to be relatively low. This is, however, due to the difference between the theoretically calculated potential and the potential that is technically feasible. These would need to be confirmed individually by further investigations and calculations to facilitate reliable assessments.

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 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 2021, 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 **"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 1981 and 2020 (cf. Fig. 3), 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 19,615 individual systems are presented in the two maps, of which 8,201 are solar thermal systems (as of December 31, 2021) and 11,414 photovoltaic systems (as of March 3, 2022). 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 March 16, 2022, 11,414 PV systems were registered in Berlin. The great majority of these are small systems below 30 kW (10,606) while only 188 of them are larger systems (> 100 kW). They have a total installed capacity of about 160,700 kW. Of these, the above-mentioned larger systems account for about a third (approx. 49,700 kW) 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 1,668 and 2,213. In terms of installed capacity, the borough of Tempelhof-Schöneberg also stands out with 15.32 MW. 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 1000 kW fall into single family-home estates on the periphery with a high absolute number of systems.

Tab. 3: Number of PV systems and their installed capacity in Berlin's boroughs (as of March 16, 2022)

Borough	Number	Total capacity [MW]	Average capacity [kW]	Electricity feed-in [MWh]
Mitte	232	8.5	36.63	4,140.74
Friedrichshain-Kreuzberg	174	4.09	23.50	1,740.79

Pankow	1,668	17.92	10.74	7,911.88
Charlottenburg-Wilmersdorf	245	6.67	27.22	2,688.31
Spandau	906	12.83	14.16	5,666.21
Steglitz-Zehlendorf	917	9.65	10.52	3,525.17
Tempelhof-Schöneberg	792	15.51	19.58	5,438.05
Neukölln	745	9.15	12.28	4,385.34
Treptow-Köpenick	1,867	21.15	11.32	8,596.04
Marzahn-Hellersdorf	2,231	25.33	11.35	11,325.40
Lichtenberg	689	16.04	23.28	7,722.88
Reinickendorf	948	13.87	14.63	6,639.82
Total	**11,414**	**160.71**	**14.08**	**69,780.63**

Tab. 3: Number of PV systems and their installed capacity in Berlin's boroughs (as of March 16, 2022, electricity feed-in as of December 31, 2018)

Since the systems often produce more electricity than is needed for self-supply, the surplus electricity is fed into the grid. In Berlin, this accounts for about half of the PV electricity. 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. 3). 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 kW, this area's installed capacity also ranks among the top of the PV capacity aggregated by Berlin's postal code areas.

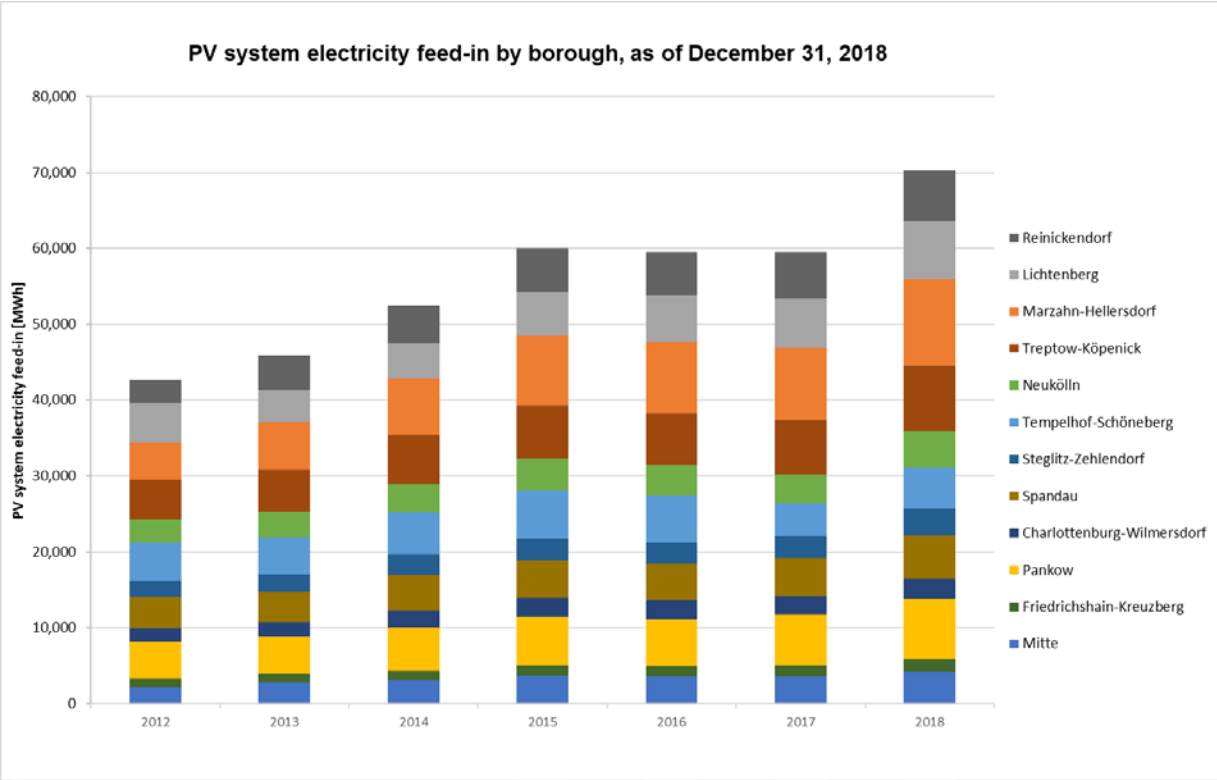

Fig. 4: Electricity feed-ins of PV systems at the level of Berlin's boroughs (as of December 31, 2018)

The relative coverage rates of photovoltaics vary across the boroughs, fluctuating between 3.82 % in Charlottenburg-Wilmersdorf and 15.79 % in Marzahn-Hellersdorf (cf. Tab.4).

At first glance, the relative coverage rates between the potential and existing stock calculated for the boroughs and postal code areas appear to be relatively low. This is, however, due to the difference between the theoretically calculated potential and the potential that is technically feasible. These would need to be confirmed individually by further investigations and calculations to facilitate reliable assessments.

At the smaller scale of postal code areas, much higher coverage rates (> 20 % in some cases) can be detected than at borough level. This is not only the case for postal code areas located in the two boroughs with the highest coverage rates (Marzahn-Hellersdorf and Treptow-Köpenick), but also areas in the boroughs of Reinickendorf, Pankow and Tempelhof-Schöneberg. At the same time, there are postal code areas with coverage rates below 1%, mainly in the inner city area. The underlying reasons in the two areas on the periphery lie in their respective development and therefore the system structure.

A high proportion of private single-family and two-family homes, which is much more common in the outer areas of the city than in the inner city, results in a higher density of smaller systems. As the roof area available per building is also smaller than, for example, that of flat roof areas of many a commercial area, however, this leads to higher coverage rates regarding the electricity generation numbers that PV systems could potentially achieve in single-family and two-family home developments.

Tab. 4: Relative PV capacity coverage rates in Berlin's boroughs (PV systems as of January 14, 2021)

Borough	Theoretically achievable output [kW]	Actually installed capacity [kW]	Relative coverage rate [%]
Mitte	176,976	8,241.85	4.66
Friedrichshain-Kreuzberg	102,814.67	4,279.19	4.16
Pankow	211,841.81	16,242.71	7.67

Charlottenburg-Wilmersdorf	186,551.89	7,129.19	3.82
Spandau	157,862.49	11,240.82	7.12
Steglitz-Zehlendorf	148,843.77	8,558.52	5.75
Tempelhof-Schöneberg	219,547.67	16,842.19	7.67
Neukölln	164,642.05	9,154.58	5.56
Treptow-Köpenick	172,219.62	19,035.98	11.05
Marzahn-Hellersdorf	151,318.02	23,892.77	15.79
Lichtenberg	160,709.96	17,338.58	10.79
Reinickendorf	164,752.05	13,302.29	8.07
Total	**2,018,080.72**	155,258.656	**7.69**

Tab. 4: Relative PV capacity coverage rates in Berlin's boroughs (PV systems as of January 14, 2021 (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. The area that is theoretically suitable for modules amounts to 45.7 km². If this area was used to generate electricity using PV, 7,929 GWh/a of electricity could be generated via PV systems with an efficiency of 19.5 %. This could save 4.3 million t of CO_2.

Tab. 5: Results of the solar potential analysis for photovoltaics on roof areas in Berlin (IP SYSCON 2022)	
Suitable solar module area:	45.679.550 m²
Capacity:	8.894.703 kWp
Electricity yield (with an efficiency of 19.5 %):	7.929 GWh/a
CO_2 savings in t per year (with an efficiency of 19.5 %)	4.313.594 t

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 some 8,200 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 5). 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 (207 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 (as of December 31, 2021), operator status and collector surface (as of December 31, 2015) of solar thermal systems in Berlin's boroughs

Borough	Number (December 31, 2021)	Operator status, if known (December 31, 2015)			Collector surface /average [m²] (data available for number of systems recorded on December 31, 2015)
		Public	Commercial	Private	
Mitte	104	13	12	32	5,144/51 (99)
Friedrichshain-Kreuzberg	76	13	3	25	2,470/33 (74)
Pankow	921	11	4	390	9,790/11 (876)
Charlottenburg-Wilmersdorf	207	10	8	85	2,74698/15 (188)
Spandau	713	7	1	273	5,6184.704/9 (653)
Steglitz-Zehlendorf	1,171	10	450	-	9,894/9 (1.124)
Tempelhof-Schöneberg	724	6	2	292	7,943/12 (686)
Neukölln	673	8	1	296	5,540/9 (638)
Treptow-Köpenick	1,131	12	8	518	10,845/10 (1,091)
Marzahn-Hellersdorf	1,106	1	2	569	8,533/8 (1,070)
Lichtenberg	332	10	1	140	4,133/13 (322)
Reinickendorf	1,043	2	2	382	8,856/9 (966)
Total	**8,201**	**103**	**44**	**3,452**	**81,512/10 (7,787)**

Tab. 6: Number (as of December 31, 2021), operator status and collector surface (both as of December 31, 2015) of solar thermal systems in Berlin's boroughs

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.

Tab. 7: Results of the solar potential analysis for solar thermal energy for water heating on roof areas in Berlin (IP SYSCON 2022)

Suitable solar module area	66,264,578 m²
No. of buildings	464,826
Potential heat	40,553 GWh/a

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. 5).

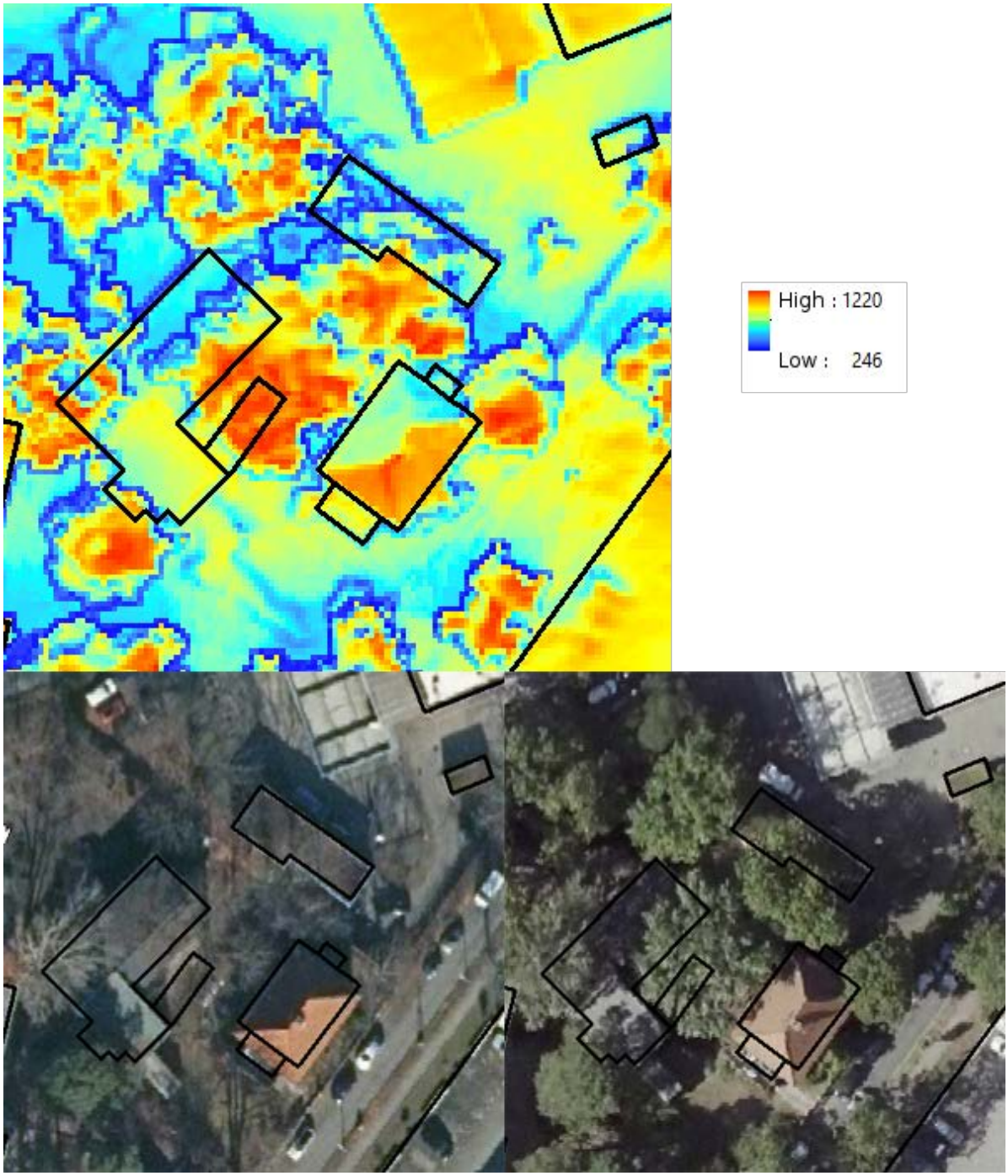

*Fig. 5: Influence of the covering effect of trees also due to roof orientation on the calculated solar irradiation of rooftops (mean annual sums in kWh/(m²/a)). Top: calculated irradiation of the surface grids at a resolution of 0.5 * 0.5 m², in black: building perimeters. Bottom: left: section of aerial 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. Areas not shaded but covered in vegetation, such as the Tempelhofer Feld, also record high

numbers around 1,000 kWh/(m²/a). Forest areas and tree-covered areas, on the other hand, reduce irradiation substantially, down to the lowest irradiation range of around 250-300 kWh/(m²/a) due to their structure and shading.

Here, it is apparent that there is a direct link to urban climatic effects, 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)). In this perspective, the "Solar Potential – Irradiation" (08.09.3) map may be used for a variety of purposes.

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