05.09 Green Volume 2020

Introduction

Green volume is a **parameter used in landscape planning** denoted by the green volume number (GVZ). The GVZ was developed in Hamburg in the 1980s with the purpose of quantifying the required vegetation to be planted in binding numbers for landscape, green space and development planning (Schulze et al. 1984).

The GVZ measures the existence of three-dimensional vegetation bodies (trees, shrubs, grasses) present in one unit of area and is denoted in unit m³ per m². In Berlin, this refers to both blocks and block segment areas shown in map 1 : 5,000 (ISU5, Spatial Reference, 2020) as well as to road segments.

The **functions of vegetation** are manifold. The following applies to many of them: the larger the green volume, the more pronounced its impact. The following functions are particularly important in relation to urban and landscape planning:

- dust binding,
- increase of evaporation,
- decrease of temperature,
- increase of small-scale air circulation,
- shading,
- habitat and biotope function,
- noise reduction.

Furthermore, green volume plays an important role in recreation, cityscape and landscape.

Comprehensive green volume data has been collected in multiple cities to date, e.g. by means of laser scanner data and spatial deficits in the provision of green space have been identified. (Meinel 2022, Frick et al. 2020). In the Brandenburg State Capital of Potsdam, the green volume number, along with biotope type mapping and the degree of imperviousness, is an integral part of its environmental monitoring carried out in a six-year cycle (Brandenburg State Capital of Potsdam 2018). With the help of the impervious soil coverage and green volume parameters, the environmental status may serve as an indicator of quality of life and housing and the climatic burden on urban quarters (Arlt et al. 2005, State Capital of Potsdam 2010).

Due to the climate change and **climate adaptation in the cities**, the green volume has become more and more important in recent years (cf. Reusswig et al. 2016, SenStadtUm 2016a). The diverse beneficial effects vegetation has, e.g. on the local climate, have been proven in a range of studies (cf. Meinel et al. 2022). The shading effect of trees, among other things, was hence investigated. Using the example of three sites, an Oxford research project demonstrated that the surface temperature of lawns and paved areas in the shade of trees was greatly reduced (by up to 13 K), as compared to that of unshaded areas. Furthermore, the project found that green volume has a direct impact on surface temperature. By increasing the green volume by 10 %, it is possible to reduce the temperature by 2.2 K (1961-1990) and 2.5 K (scenario 2080) (Gill et al. 2007). Increasing the green volume therefore lowers the maximum surface temperature, thus mitigating the effects of climate change and the formation of urban heat islands.

For Potsdam, green volume and imperviousness were confirmed to be relevant in influencing the temperature development within the context of climate adaptation. Taking the example of a hot summer day with temperatures ranging from approx. 25 to 35 °C, it was demonstrated that each additional m³/m² of green volume reduces the temperatures by about 0.3 K, while 1% (1 m²/100 m²) of additional imperviousness causes the temperature to rise by about 0.03 K (Tervooren 2015).

The distribution of green volume also plays a role in this (Mathey et al. 2011). Large, connected open spaces and parks have a more pronounced internal climatic effect and a slightly greater cooling effect on their surroundings than many smaller, scattered open spaces. At the same time, a dense network of smaller open spaces allows for easier accessibility, compensating for the above advantages. These effects can be explained applying the indicators “Cold air affect range within settlement areas” and “Green spaces with high volume flow” (SenStadtUm 2016c) of the summary Climate Analysis Map of Berlin.

There is no doubt in the scientific community about the importance of the green volume indicator in determining the quality of residential areas (F+B 2020). Since 2019, it has been part of a list of 13 indicators used to determine the quality of residential locations for the Berlin rent index.

Statistical Base

The data of the Environmental Atlas Map “Vegetation Heights” (06.10.2 SenStadtWohn 2020) forms the basis for calculating the green volume number for all ISU5 block (segment) areas and road areas (Spatial Reference, Environmental Atlas 2020). It contains all vegetation objects in the State of Berlin indicating their mean vegetation height (cf. Figure 1). The process for determining vegetation heights is based on an elaborate workflow, which the associated project report discusses in detail (SenStadtWohn 2021, only in German).

Both digital colour infrared orthophotos obtained during an aerial photography flight in August 2020 and a variety of digital surface models (cf. SenStadtWohn 2021, Statistical Base) were used to analyse the green volume.

Rather than creating a 3D canopy model, a simple cylinder graph was employed (cf. Figure 1). As a result, the green volume of trees has generally been somewhat overestimated.

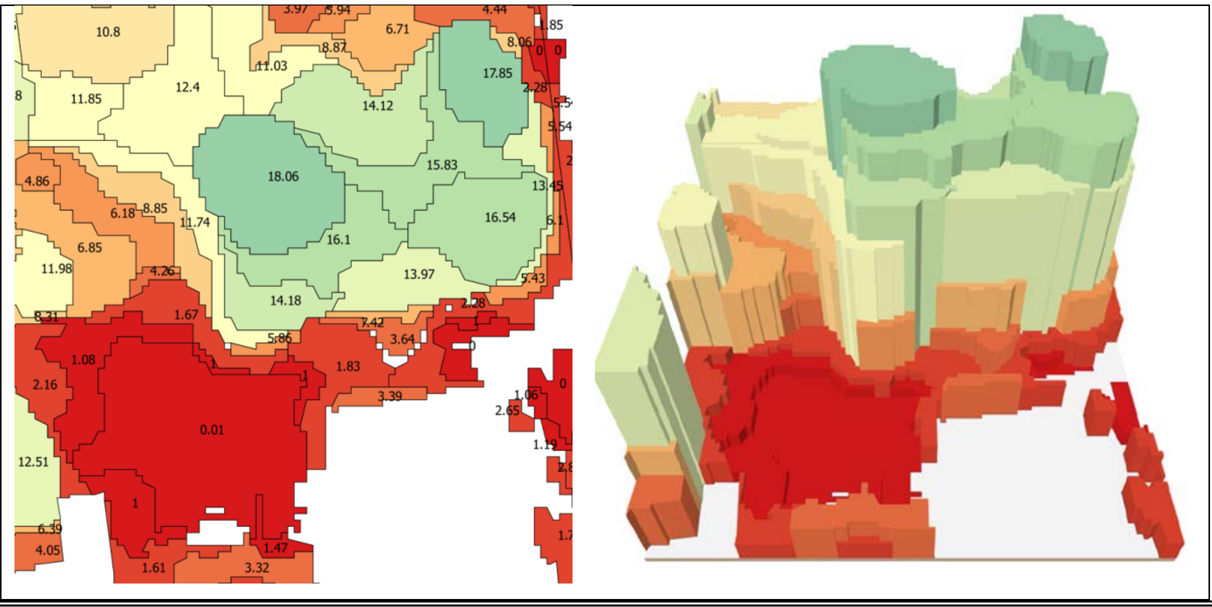

Fig. 1: Vegetation areas incl. height indicator (left) and 3D cylinder graph of vegetation (right)

Above-ground buildings of the Official Real Estate Cadastre Information System (ALKIS, as of September 2021, SenStadtWohn 2021) were also used in addition to the results of a building classification carried out by LUP GmbH, which was based on the 2020 true orthophotos (NOT-ALKIS-Buildings 2020), to determine the green volume of undeveloped block (segment) areas.

Methodology

To calculate the green volume, the data sets of vegetation heights were intersected with the ISU5 areas (block, block segment areas and road areas) (intersections formed, cf. Figure 2) and the vegetation data was transferred to the ISU5 areas.

Green volume of blocks, block segment areas and road areas

Each ISU5 area was used to trim each corresponding vegetation area. The area size of the trimmed vegetation area was then multiplied by its mean height (= green volume of a trimmed vegetation area) (cf. Figure 2).

The sum of these for each ISU5 area yields the green volume of all individual block, block segment and road areas (m³). Dividing the green volume by the area sizes (m²) then results in the respective green volume number for each area (m³/m²).

The green volume number also serves as the mean vegetation height (in m) relative to the entire block (segment) area or the non-built-up parts of the block (segment) or road area.

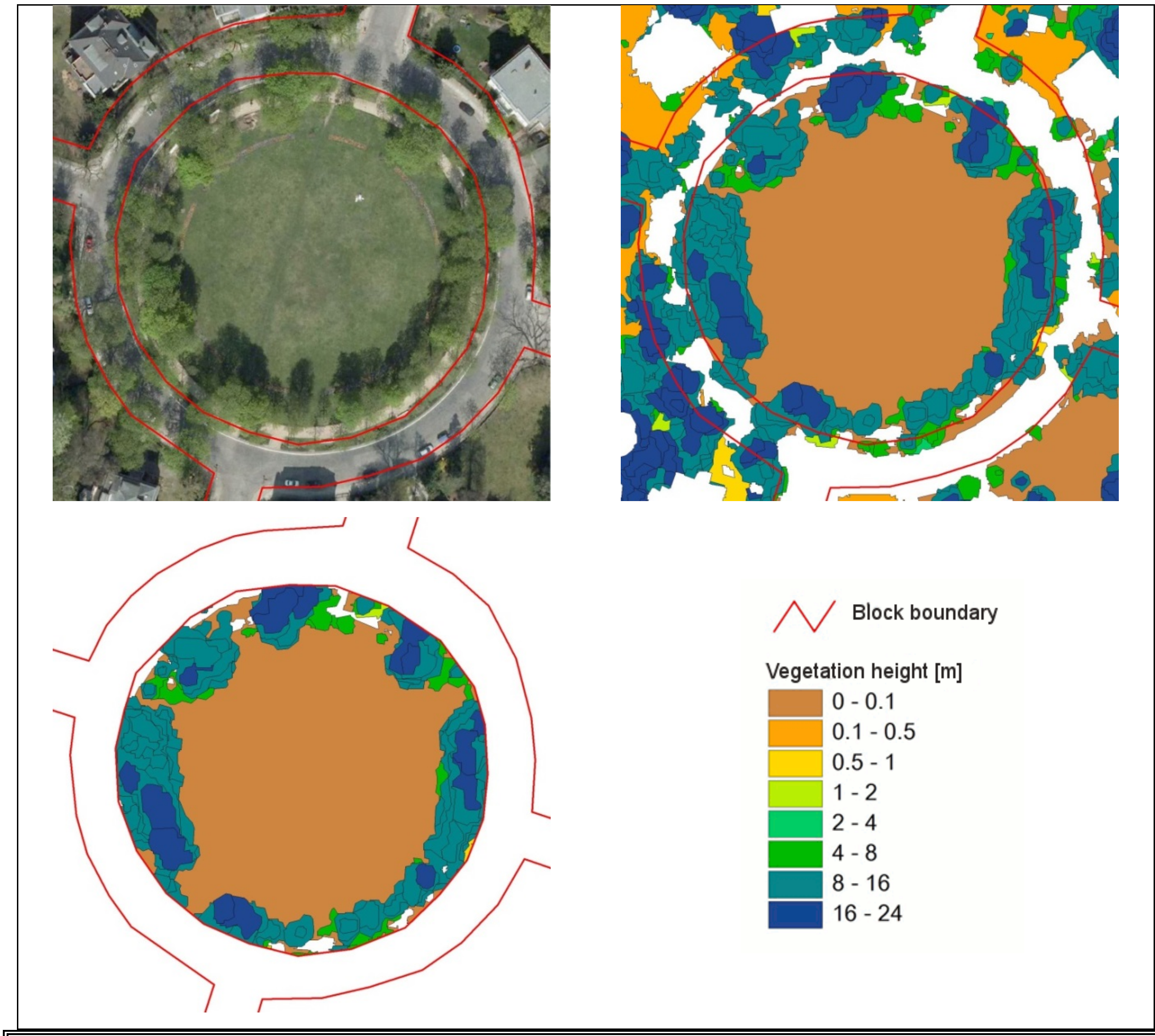

Fig. 2: Method for calculating the green volume of block (segment) areas (top left: orthophoto with block boundaries; top right: vegetation areas with block boundaries; bottom: trimmed vegetation areas and legend)

Green volume of non-built-up parts of block (segment) areas

To determine the green volume of non-built-up block (segment) areas, the buildings above ground were first assigned to their respective areas. These buildings were then used to trim the individual areas.

The stock of vegetation assigned to the areas extend beyond the non-built-up parts (vegetation in road areas, canopies above building level and green roofs).

Trimming the vegetation share based on the non-built-up areas yields the desired vegetation of the non-built-up block (segment) areas and road areas (Figure 3).

The green volume was calculated further according to the process described above.

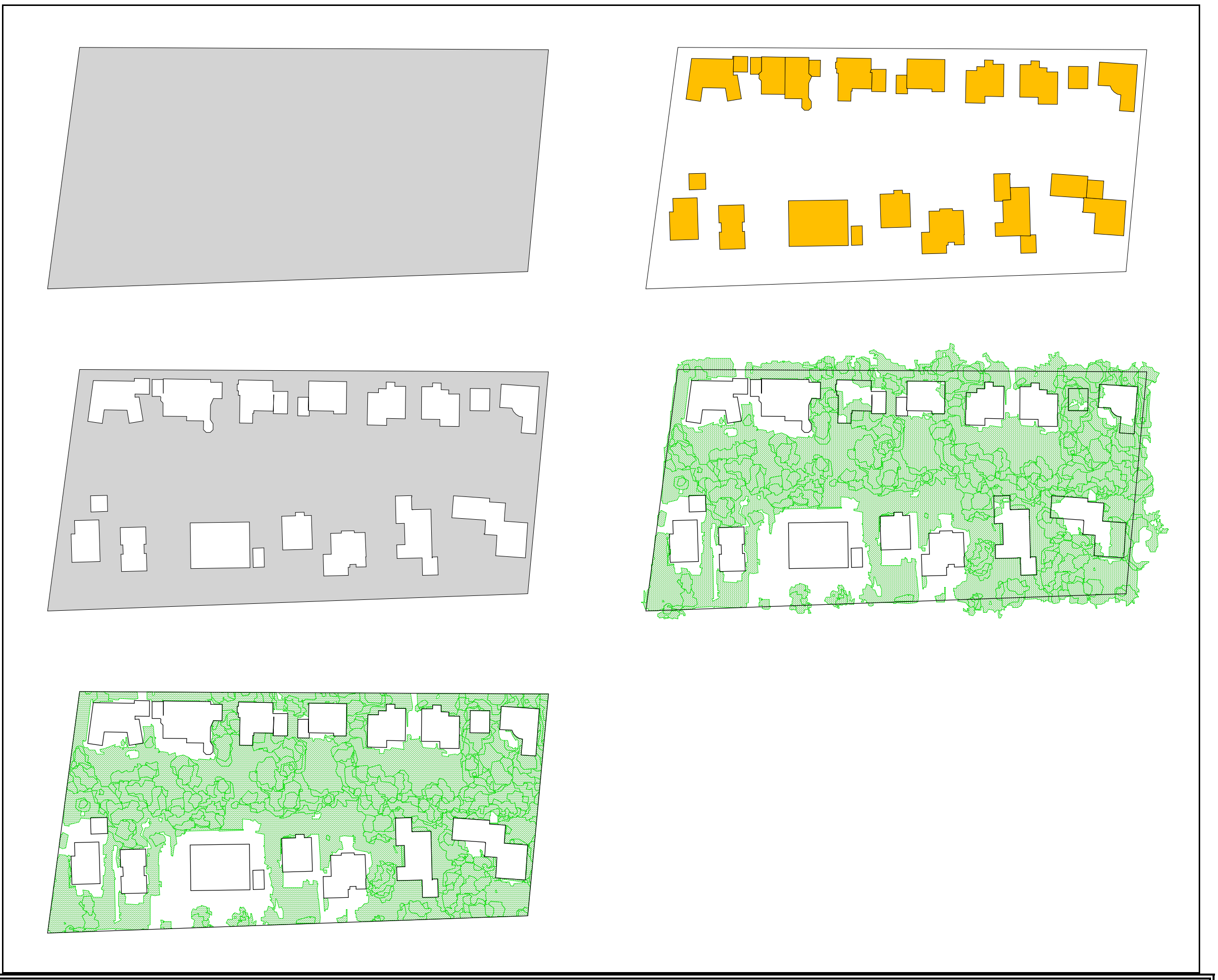

Fig. 3: Method to calculate the green volume of non-built-up block (segment) areas (top left: block area; top right: buildings above ground; centre left: non-built-up block area (grey share); centre right: vegetation cover; bottom: vegetation of the non-built-up block area)

Dataset from 2010: comparison of the old and new surveys

When updating the dataset to the version of 2020, the entire procedure of recording vegetation heights was switched from object-based sectioning (aerial photography flights in 2009/ 2010) to grid-based sectioning. Key advantages include the size and completeness of the dataset and therefore its suitability for further processing. Using this method, the 2010 dataset could also be reclassified and recalculated. The two periods could therefore be compared without methodological discrepancies while also minimising potential errors (cf. project report, only in German, SenStadtWohn 2021).

In the following, the two different datasets from 2010, from the old and new survey will be compared (cf. Table 1). First of all, it is clear that the old survey underestimated the green volume in all use groups. The largest discrepancy here occurs for the built-up area types. The new survey recorded an additional 148.3 km³ of green volume for these groups. This is due to the fact that the green structures in built-up areas are rather fragmented and were eliminated in the course of the segmentation process of the old mapping in which areas were combined. By switching to a grid-based segmentation for the new survey, these smaller green structure fragments could be recorded in more detail.

The old mapping of the forest areas also omits a green volume of 88.4 km³. For other green and open spaces and road areas, the green volume difference is smaller, amounting to about 21 km³.

Overall, the total green volume for 2010 that is recorded in the new mapping is therefore 5,157 km³, exceeding that of the old survey by 279.8 km³.

Tab. 1: Comparison of the old and new data surveys from 2010						
Use	**Green volume number, new, 2010 [m³/m²]**	**Green volume, new, 2010 [km³]**	**Share of green volume, new, 2010 [%]**	**Green volume number, old, 2010 [m³/m²]**	**Green volume, old, 2010 [km³]**	**Share of green volume, old, 2010 [%]**
Built-up area	2.9	1124.3	21.8	2.6	976.0	20.0
Forest	17.9	2871.8	55.7	17.3	2783.4	57.1
Other green or open space	4.3	841.2	16.3	4.0	820.0	16.8
Roads	3.3	319.7	6.2	3.1	298.0	6.1
Berlin without bodies of water and roads	**6.5**	**4,837**	**93.8**	**6.2**	**4,579**	**93.9**
Berlin without bodies of water	**6.2**	**5,157**	**100.0**	**5.8**	**4,877**	**100.0**

Based on their use, 1,926 areas are categorised as both built-up and non-built-up.

For this analysis, the "open space use" was considered for areas with dual use (green priority).

Tab. 1: Dataset from 2010: comparison of the old and new data surveys

Map Description

The map illustrates the green volume for block, block segment and road areas. As expected, the highest green volume numbers were recorded for Berlin's forest areas. The green volume also varied within residential areas, however, which are described in more detail below.

In total, Berlin has a green volume of 4.867 km³, excluding bodies of water. This corresponds to an average green volume number of 5.8 m³/m². The average green volume number of the entire urban area is therefore higher than that of Leipzig (2.4 m³/m²) or Potsdam (4.75 m³/m²), for example (cf. Frick et al. 2020). As expected, more than half of the green volume stems from forest areas (2.697 km³, 16.8 m³/m²). The built-up block (segment) areas house the least vegetation per area (2.6 m³/m²) as do the roads (3.1 m³/m²) (Table 2, cf. Map “Actual Use of Built-Up Areas” (06.01) and Map “Inventory of Green and Open Spaces” (06.02).

In relation to the green volume of road areas, it should be noted that it is mainly roadside trees and vegetation, e.g. tree crowns, protruding from block (segment) areas that influence green volume calculations. Due to the cylinder graph used (cf. Figure 1), the green volume is often overestimated here, compared to other areas.

Tab. 2: Green volume by use group incl. road areas						
Use	**Green volume number, 2020 [m³/m²]**	**Green volume, 2020 [km³]**	**Share of green volume, 2020 [%]**	**Green volume number, 2010 [m³/m²]**	**Green volume, 2010 [km³]**	**Share of green volume, 2010 [%]**
Built-up area	2.6	995.5	20.5	2.9	1124.3	21.8
Forest	16.8	2697.3	55.4	17.9	2871.8	55.7
Other green or open space	4.4	870.3	17.9	4.3	841.2	16.3
Roads	3.1	303.9	6.2	3.3	319.7	6.2
Berlin without bodies of water and roads	**6.2**	**4,563**	**93.8**	**6.5**	**4,837**	**93.8**
Berlin without bodies of water	**5.8**	**4,867**	**100.0**	**6.2**	**5,157**	**100.0**

Based on their use, 1,926 areas are categorised as both built-up and non-built-up.

For this analysis, the "open space use" was considered for areas with dual use (green priority).

Tab. 2: Green volume by use group incl. road areas, comparison of the 2020 and 2010 data surveys

Comparing the green volume numbers of 2010 and 2020 reveals an overall decrease of 290 km³ in the total green volume since 2010. A total loss of vegetation area of 2,648 ha was already described in the Map “Vegetation Heights” (06.10.2). Changes in the shares of green volume were inconsistent within the individual use groups. Forest areas recorded the largest loss of green volume with 174.5 km³. At the same time, the green volume number dropped from 17.9 m³/m² (2010) to 16.8 m³/m² (2020) in the forests. There does not seem to be a simple answer as to what caused this loss. Rather, it may be assumed that there were various influences at play at the same time. On the one hand, mature trees dying as a result of the dry summers may have been an influencing factor. On the other hand, consequences associated with human intervention, including the use of wood and the effects of the Mischwaldprogramm der Berliner Forsten (mixed forest programme of the Berlin Forests, only in German) to produce resistant forests with a large variety of species may have had a serious impact.

The built-up areas also displayed a substantial loss of green volume of 174.5 km³. This loss may be attributed to new construction activities and retrospective densification within built-up areas. These, in turn, lead to block (segment) areas with smaller shares of non-built-up, green spaces. Mature trees dying as a result of the dry summers and additional tree felling on private and public properties may also have contributed to this.

Similarly, “Road areas” suffered a loss of green volume of 16 km³. The reasons for this reduction lie both in a general decrease in the number of roadside trees (cf. SenUVK 2020) and in a serious deterioration in the condition of existing roadside trees due to pest infestation (cf. SenUVK 2021).

Conversely, “Other green and open spaces” recorded a slight increase in the green volume from 841.2 km³ to 870.3 km³. The reason behind this growth is spontaneous vegetation that has grown on fallow areas, increasing their green volume number from 3.9 m³/m² (2010) to 4.8 m³/m² (2020). All in all, however, this increase in green volume is mitigated by the loss of green volume of the “Cemetery areas”, which dropped from 10.4 m³/m² (2010, new) to 9.5 m³/m² (2020). This may also be attributed, in some parts, to a loss of mature trees in forest and park cemeteries caused by heat stress.

On closer inspection of the residential development at area type level, striking differences within the built-up area become evident. The green volume numbers of the total areas corresponding to residential block and block segment areas vary between 0.8 m³/m² for the area type “Core area” and up to 4.6 m³/m² for “Villas and town villas with park-like gardens” (cf. Table 3 and Figure 5).

Comparing the green volume numbers for non-built-up parts of residential block and block segment areas, however, the numbers for densely built-up area types also increase in some cases, which applies particularly to the following area types:

- “Dense block-edge development, closed rear courtyard, 5 - 6 storeys”,
- “Closed block development, rear courtyard (1870s-1918), 5-storeys”,
- “Closed and semi-open block development, decorative and garden courtyard (1870s-1918), 4-storeys” and
- “Block-edge development with large quadrangles (1920s-1940s), 2 - 5 storeys”.

the existing old tree stocks, which occupy a large volume on a relatively small area, play a key role here (cf. Figure 4).

Fig. 4: “Closed block development, rear courtyard (1870s-1918), 5-storeys” incl. old tree stocks (left: example from Gipsstraße to Sophienstraße; right: example east and west of Swinemünder Straße, Background: digital and coloured orthophotos from 2020 (TrueDOP20RGB)

For area types with a more balanced ratio between built-up and non-built-up parts, there is little difference between the green volume numbers of the total block area and the non-built-up part. Furthermore, the green volume numbers in these cases are generally lower than in densely built-up areas (cf. Table 3 and Figure 5). This is also related to greenery, which is often characterised by a high proportion of low-growing vegetation or lawns (“green fringes”) especially in multi-storey residential buildings. The following residential area types of private and rental housing construction illustrate these conditions:

- “Rental-flat buildings of the 1990s and later”,
- “Row houses and duplex with yards”,
- “Detached single-family homes with yards”.

Forest tree estates constitute a special case within the overall green volume picture. These are estates that were built on Berlin’s forest edges. Their gardens and open spaces are often still characterised by stocks of old pine, oak and birch trees. The Berlin Landscape Programme identifies areas of forest tree estates along the following areas: the Grunewald, the Spandauer Forst, in Gatow, in the Köpenicker Forst, in Hermsdorf, Frohnau and Waidmannslust (cf. SenStadtUm 2016b). In contrast to residential areas built on former farmland areas (e.g. the ground moraines of the Teltow and Barnim plateaus consisting of boulder clay and marl), the green volume is clearly higher in the forest tree estates.

Tab. 3: Green volume number by area type incl. roads

Area type		Green volume number, 2020 [m³/m²]	Green volume number, non-built-up, 2020 [m³/m²]
1	Dense block development, closed rear courtyard, 5 - 6 storeys	1,6	4,2
2	Closed block development, rear courtyard, 5-storeys	2,0	4,2
3	Closed and semi-open block development, decorative and garden courtyard, 4-storeys	2,6	4,4
6	Mixed development, semi-open and open shed courtyard, 2 - 4 storeys	2,2	3,3
10	Block-edge development with large quadrangles, 2 - 5 storeys	2,8	4,3
72	Parallel row buildings with architectural green strips, 2 - 5 storeys	3,7	5,0
8	Heterogeneous inner-city mixed development, post-war gap closure	2,2	3,6
7	De-cored block-edge development, post-war gap closure	2,6	4,4
73	Rental-flat buildings of the 1990s and later	1,7	2,5
9	Large estate with tower high-rise buildings, 4 - 11 storeys and more	3,4	4,3
11	Free row development, landscaped residential greenery, 2 - 6 storeys	3,8	4,8
25	Densification in single-family home area, mixed dev. with yard and semi-private greening	3,7	4,9
21	Village-like mixed development	2,3	2,9
24	Villas and town villas with park-like gardens	4,6	5,8
22	Row houses and duplex with yards	2,3	3,0
23	Detached single-family homes with yards	2,7	3,4
59	Weekend cottage and allotment-garden-type area	2,8	3,2
29	Core area	0,8	1,8
31	Commercial and industrial area, large-scale retail, dense development	0,6	1,2
38	Non-residential mixed use area, dense development	1,1	1,9
30	Commercial and industrial area, large-scale retail, sparse development	1,4	1,9
33	Non-residential mixed use area, sparse development	2,3	3,2
32	Utility area	3,0	3,5
92	Railway station and railway ground, without track area	2,3	2,7
99	Track area	2,7	2,7
91	Parking area	2,9	3,0
94	Other traffic area	4,7	4,8
93	Airport	0,7	0,8
43	Administrative	2,4	3,6
45	Culture	3,0	3,7
41	Security and order	5,1	6,0
12	Old school (built before 1945)	3,5	4,6
13	New school (built after 1945)	3,3	4,2
44	University and research	3,4	4,4
47	Children's day care centre	4,9	5,6
51	Other youth facility	9,0	9,8
58	Camping ground	9,7	9,8
60	Other and miscellaneous public facility / special use area	4,9	5,8

49	Church	4,8	5,7
46	Hospital	5,9	7,4
98	Construction site	0,7	0,7
54	City square / promenade	3,6	3,6
17	Sport facility, covered	3,7	4,7
16	Sport facility, uncovered	3,4	3,5
36	Tree nursery / horticulture	2,2	2,3
37	Allotment garden	2,0	2,2
53	Park / green space	5,7	5,7
27	Cemetery	9,5	9,6
57	Fallow area	4,8	4,8
56	Agriculture	0,9	0,9
55	Forest	16,7	16,7
	Roads	3,1	3,1

Tab. 3: Green volume number by area type

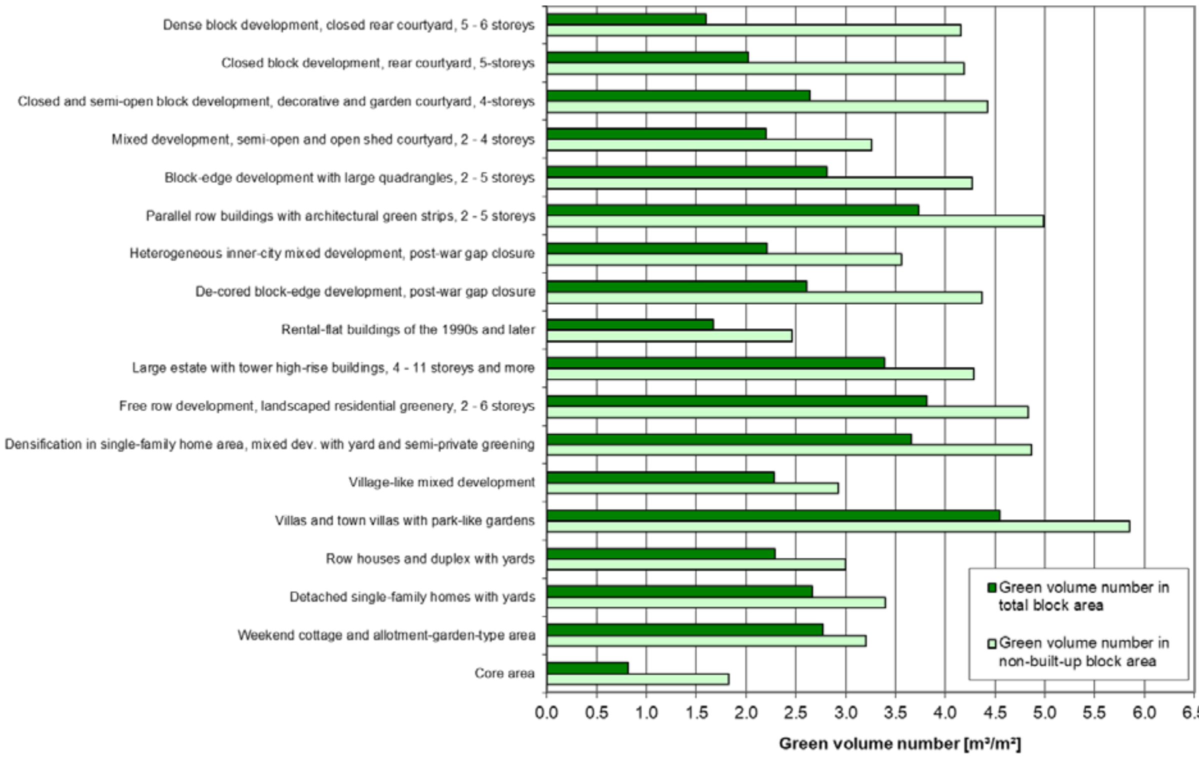

Fig. 5: Green volume number by residential area type

Figure 6 illustrates the distribution of uses at an aggregate level. The range of values for heterogeneous residential area types is discussed above. In this representation, the high values for non-built-up parts under “Cemetery” and “Public and special use” stand out in particular. Structurally, the cemeteries differ mainly in their tree population. Especially the forest and old park cemeteries influence the green volume number positively.

The “Public and special use” category displays the highest green volume number among the built-up uses. This is due to a large number of areas with a high proportion of greenery and trees, e.g. the Olympiapark and hospital locations with old tree stocks, which fall into this use type.

The relatively low green volume number of 1.5 m³/m² for allotments may be explained by the planting and management regulations, which prohibit the planting of large deciduous trees as well as decorative trees and shrubs. These management regulations do not apply to weekend cottage and allotment-garden-type uses, which display a green volume number that is higher by 2.8 m³/m² in comparison. Parks and green spaces are at least partially characterised by trees and shrubs, resulting in the third highest green volume numbers, following those of forest and cemetery areas.

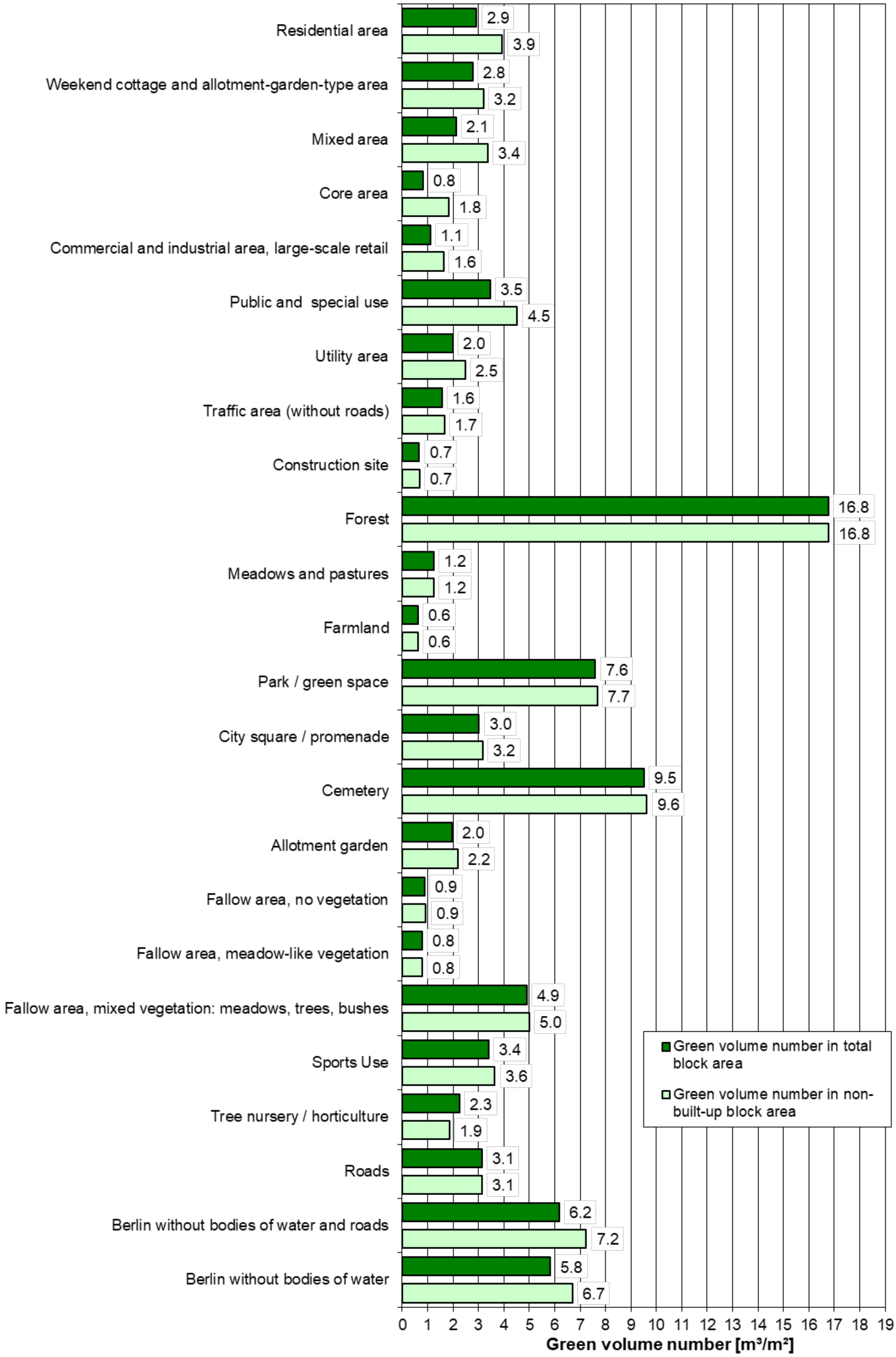

Fig. 6: Green volume number by use incl. roads

Comparing the vegetation volume across the twelve boroughs of Berlin, all boroughs containing extensive forest areas stand out immediately because of their substantial vegetation volume. These boroughs are characterised by their location on the outskirts of the city and a large total area. Treptow-Köpenick is the leading borough, accounting for almost 30 % of Berlin's total green volume as the most densely forested borough in Berlin. Other boroughs with large green volume numbers are Reinickendorf with the Tegeler Forst, Steglitz-Zehlendorf with the Grunewald, Spandau with the Spandauer Forst, Charlottenburg-Wilmersdorf also with the Grunewald and Pankow with the Bucher Forst (cf. Figure 7, the boroughs are sorted according to the numbering system of the Verwaltungsgliederung (administrative division) of Berlin).

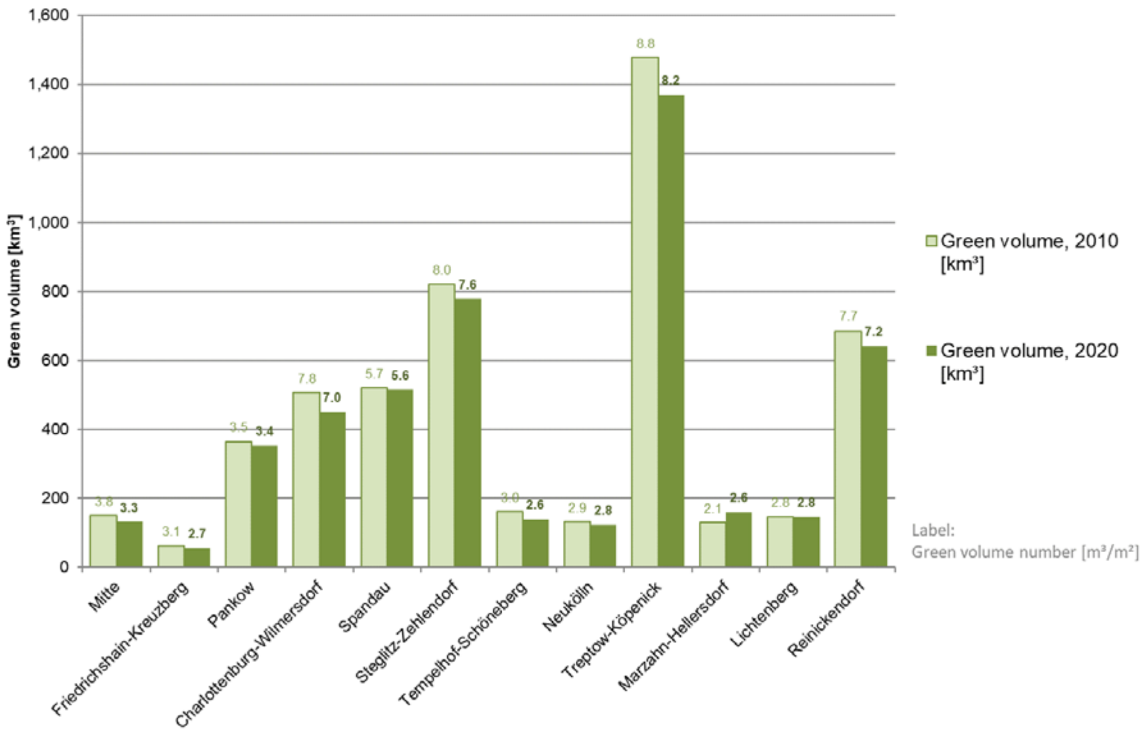

Fig. 7: Green volume and green volume number of Berlin's 12 boroughs in 2010 and 2020

The decrease in green volume numbers between 2010 and 2020 is most evident in the above mentioned boroughs, which contain large forest areas. The complex causes, especially with regard to the loss of green volume in Berlin's forest areas, have already been discussed.

Marzahn-Hellersdorf is the only borough that saw an increase in green volume. It is home to numerous fallow and park areas, the green volume of which has increased over the past decade. In addition, redevelopment measures were carried out with the aim of reducing the number of green fringes, located in non-built-up parts of large housing estates, that serve no other purpose.

Literature

[1] **Arlt, G., Hennersdorf, J., Lehmann, I. & Xuan Thinh, N. 2005:**
Auswirkungen städtischer Nutzungsstrukturen auf Grünflächen und Grünvolumen. IÖR Schriften. Nr. 47. Dresden. [Effects of urban use structures on green spaces and green volume]

[2] **Brandenburg State Capital Potsdam 2010:**
Gutachten zum Integrierten Klimaschutzkonzept 2010. [Assessment of the integrated climate protection concept]
Download:
https://www.potsdam.de/sites/default/files/documents/IntegriertesKlimaschutzkonzept2010.pdf

[only in German]
(Accessed on 7 April 2022).

[3] **Brandenburg State Capital Potsdam 2018:**
Umweltmonitoring Potsdam. Erhebung und Auswertung von Umweltindikatoren. Umwelt analysieren und verstehen. [Environmental Monitoring Potsdam. Collection and evaluation of environmental indicators. Analysing and understanding the environment.]
Download:
https://vv.potsdam.de/vv/Umweltmonitoring_-_Flyer_Dez2018.pdf [only in German]
(Accessed on 27 June 2017).

[4] **F+B Forschung und Beratung für Wohnen, Immobilien und Umwelt GmbH 2020:**
Berliner Mietspiegel 2019 - Grundlagendaten für den empirischen Mietspiegel und Aktualisierung des Wohnlagenverzeichnisses zum Berliner Mietspiegel 2019 – Methodenbericht [2019 Berlin rent index – core data for the empirical rent index and updated list of the residential locations of the 2019 Berlin rent index – report on methodology]; assessment commissioned by the Senate Department for Urban Development and Housing, Berlin.
Download:
https://www.stadtentwicklung.berlin.de/wohnen/mietspiegel/de/download/Mietspiegel2019_Berlin_Ergebnisbericht.pdf [only in German]
(Accessed on 24 May 2022)

[5] **Frick, A., Wagner, K., Kiefer, T. & S. Tervooren 2020:**
Wo fehlt Grün? – Defizitanalyse von Grünvolumen in Städten [Where do we lack greenery? – Analysis of green volume deficits in the cities]. In Meinel, G., Schumacher, U., Behnisch, M. & T. Krüger (ed.): Flächennutzungsmonitoring XII. IÖR Schriften. Band 78. Rhombos Verlag. Berlin.
Download (DOI):
https://doi.org/10.26084/12dfns-p023
(Accessed on 2 May 2022)

[6] **Gill, S. E., Handley, J. F., Ennos, A. R. & Pauleit, S. 2007:**
Adapting Cities for Climate Change: The Role of the Green Infrastructure. Built Environment, 33 (1), 115-133. doi:10.2148/benv.33.1.115.
Download:
https://www.researchgate.net/publication/253064021_Adapting_Cities_for_Climate_Change_The_Role_of_the_Green_Infrastructure
(Accessed on 2 May 2022)

[7] **Mathey, J., Rößler, S., Lehmann, I., Bräuer, A., Goldberg, V., Kurbjuhn, C. & Westbeld, A. 2011:**
Noch wärmer, noch trockener? Stadtnatur und Freiraumstrukturen im Klimawandel. Abschlussbericht zum F+E-Vorhaben "Noch wärmer, noch trockener? Stadtnatur und Freiraumstrukturen im Klimawandel". [Even warmer and drier? Urban nature and open spaces in climate change. Final report on the R&D project “Even warmer and drier? Urban nature and open spaces in climate change”] Bonn-Bad Godesberg: Federal Agency for Nature Conservation, Naturschutz und Biologische Vielfalt, No. 111.

[8] **Meinel, G., Krüger, T., Eichler, L., Wurm, M., Tenikl, J., Frick, A., Wagner, K., Fina, S. 2022:**
Wie grün sind deutsche Städte? – Fernerkundliche Erfassung und stadträumlich-funktionale Differenzierung der Grünausstattung von Städten in Deutschland (Erfassung der urbanen Grünausstattung). [How green are German cities? – Remote data collection and urban-functional differentiation of the green facilities of German cities (urban greenery survey)] BBSR online publication, edition: 03/2022.
Download:
https://www.bbsr.bund.de/BBSR/DE/veroeffentlichungen/bbsr-online/2022/bbsr-online-03-2022-dl.pdf?__blob=publicationFile&v=3
(Accessed on 7 April 2022).

[9] **Reusswig, F., Becker, C., Lass, W., Haag, L., Hirschfeld, J., Knorr, A., Lüdeke, M. K. B., Neuhaus, A., Pankoke, C., Rupp, J., Walther, C., Walz, S., Weyer, G., Wiesemann, E. 2016:**
Anpassung an die Folgen des Klimawandels in Berlin (AFOK). Klimaschutz Teilkonzept. Teil I. Hauptbericht; Teil II: Materialien. [Concept for adaptation to the impacts of climate change in Berlin (AFOK). Climate protection, partial concept. Part I: Main report; Part II: Materials. Potsdam, Berlin. July 2016.

Download:
https://www.berlin.de/sen/uvk/_assets/klimaschutz/anpassung-an-den-klimawandel/programm-zur-anpassung-an-die-folgen-des-klimawandels/afok_zusammenfassung.pdf [only in German]
(Accessed on 27 June 2017)

[10] **Schulze, H.-D., Pohl, W. & Großmann, M. 1984:**
Gutachten: Werte für die Landschafts- und Bauleitplanung: Bodenfunktionszahl, Grünvolumenzahl. – Schriftenreihe der Behörde für Bezirksangelegenheiten [Assessment: Values for landscape and urban development planning: soil function number, green volume number. – Series of publications of the Authority for District Affairs], Naturschutz und Umweltgestaltung Freie Hansestadt Hamburg, 9. 1. ed. Christians. Hamburg.

[11] **SenStadtUm (Senate Department for Urban Development and the Environment, Berlin) 2016a:**
Klimafolgenmonitoring des Landes Berlin [Monitoring Climate Impacts of the State of Berlin]. Sachstandsbericht 2016 [Status report 2016].
Download:
https://www.berlin.de/sen/uvk/_assets/klimaschutz/publikationen/klimafolgen-monitoringbericht2016_barrierefrei.pdf [only in German]
(Accessed on 2 May 2022)

[12] **SenStadtUm (Senate Department for Urban Development and the Environment, Berlin) 2016b:**
Landschaftsprogramm. Artenschutzprogramm. Begründung und Erläuterung 2016. [Landscape programme, protection of species programme. Explanation and commentary 2016]
Download:
https://www.berlin.de/sen/uvk/_assets/natur-gruen/landschaftsplanung/lapro_begruendung_2016.pdf [only in German]
(Accessed on 2 May 2017)

[13] **SenStadtWohn (Senate Department for Urban Development and Housing, Berlin) 2021:**
Vegetationshöhen – Weiterentwicklung und Anwendung des Bestimmungsverfahrens 2020. [Vegetation heights – further development and application of the 2020 measurement process]
Download:
https://www.berlin.de/umweltatlas/_assets/literatur/vegetationshoehen_2020.pdf
(Accessed on 17 June 2022)

[14] **SenUVK (Senate Department for the Environment, Transport and Climate Protection, Berlin) 2020:**
Antwort auf die schriftliche Anfrage Nr. 18/22191 vom 20. Januar 2020 über Förderprogramme Stadtbäume [Answer to written question No. 18/22191 of January 20, 2020 regarding support programmes for urban trees]. Berlin.
Download:
https://pardok.parlament-berlin.de/starweb/adis/citat/VT/18/SchrAnfr/s18-22191.pdf
(Accessed on 17 June 2022)

[15] **SenUVK (Senate Department for the Environment, Transport and Climate Protection, Berlin) 2021:**
Straßenbaum-Zustandsbericht Berliner Innenstadt 2020. Ergebnisse der Straßenbaum-Zustandserhebung aus CIR-Luftbildern. [Report on the condition of roadside trees in Berlin's inner city in 2020. Results of the survey assessing the condition of roadside trees based on CIR aerial photographs]. Berlin.
Download:
https://www.berlin.de/sen/uvk/_assets/natur-gruen/stadtgruen/stadtbaeume/strassen-und-parkbaeume/zustand-der-strassenbaeume/strb_zustandsbericht2020.pdf
(Accessed on 17 June 2022)

[16] **Tervooren, S. 2015:**
Potenziale von Grünvolumen und Entsiegelung zur Klimaanpassung am Beispiel der Landeshauptstadt Potsdam [Green volume potential and potential for the removal of impervious soil coverage for climate adaptation, using the example of the Brandenburg State Capital of Potsdam]. In: AGIT – Journal für Angewandte Geoinformatik, 1-2015. Herbert Wichmann Verlag, VDE VERLAG GMBH, Berlin/Offenbach. ISBN 978-3-87907-557-7, ISSN 2364-9283, doi:10.14627/537557037.

Download:
http://gispoint.de/fileadmin/user_upload/paper_gis_open/AGIT_2015/537557037.pdf [only in German]
(Accessed on 27 June 2017).

Maps

[17] **OSM (Open Street Map) 2021:**
Gebäudedaten. [Building data]
Internet:
https://download.geofabrik.de/europe/germany/berlin.html

[18] **SenStadtUm (Senate Department for Urban Development and the Environment) (ed.) 2016c:**
Environmental Atlas Berlin, Map 04.10.07 Climate Model Berlin – Climate Analysis, Urban Climate, Edition 2016, 1 : 50,000, Berlin.
Internet:
https://www.berlin.de/umweltatlas/en/climate/climate-analysis/2014/summary/

[19] **SenStadtWohn (Senate Department for Urban Development and Housing) (ed.) 2020:**
Environmental Atlas Berlin, Map 06.10.02 Vegetation Heights, as of 2020, Berlin.
Internet:
https://www.berlin.de/umweltatlas/en/biotopes/vegetation-heights/2020/summary/

[20] **SenStadtWohn (Senate Department for Urban Development and Housing Berlin) (ed.) 2021:**
ALKIS Berlin (Official Real Estate Cadastre Information System) (as of September 6, 2021).
Internet:
https://fbinter.stadt-berlin.de/fb/index.jsp?loginkey=showMap&mapId=wmsk_alkis@senstadt
[only in German]