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Urban heat islands vulnerability and risk assessment

SOFIA MUNICIPALITY

Specific objective 1	Provide evaluation tools for cities to better understand the causes and effects of the UHI
Activity 1.3:	Testing the methodology and tools in the partner cities: conducting UHI vulnerability risk assessments
Result 1.3.1	City UHI risk assessment reports
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List of abbreviations

SDA	Sofia Development Association
BCC	Bulgarian Red Cross
RES	Renewable energy sources
GIS	Geographical Information System
GRAO	Directorate General for Civil Registration and Administrative Services
UHI	Urban Heat Island
DCC	Diagnostic and Consultative Centre
EC	European Commission
EU	European Union
EEA	Executive Environment Agency
BCF	Building coverage factor
NASCRGF	National Automated System for Continuous Monitoring of the Gamma Radiation Background
NSI	National Statistical Institute
OP	Municipal Enterprise
FAR	Floor area ratio
SM	Sofia Municipality
SMC	Sofia Municipal Council
WMO	World Meteorological Organization
GT	Ground temperature

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1. Introduction

ABOUT THE PROJECT

Urban heat islands (UHIs) are a common challenge that 19 partners (including 9 associate partners) from 12 countries are seeking to address to strengthen societal preparedness and adaptive capacity, tackle the impacts of climate change and promote resilience at the city level. The approach used in this project will allow partners to undertake targeted, small-scale, context-based measures to address UHI in critical urban areas. Urban pilot projects will test solutions in three areas: 'green acupuncture' (vegetation-based interventions); 'white acupuncture' (based on innovative surfaces and materials); and 'blue acupuncture' (new use of water resources). The approach of co-developing, testing and evaluating solutions contributes to the most effective use of shared experiences to better understand the effects of UHIs and build institutional capacity at local/regional level to develop policies and practical interventions.

ABOUT THE REPORT

This report aims to test the assessment methodology, which includes 4 elements of vulnerability (Figure 1): exposure, sensitivity, preparedness and adaptive capacity, and groups at risk. The report is the result of activity 1.1.1. Shared methodology and tools for vulnerability and risk assessment of UHIs.

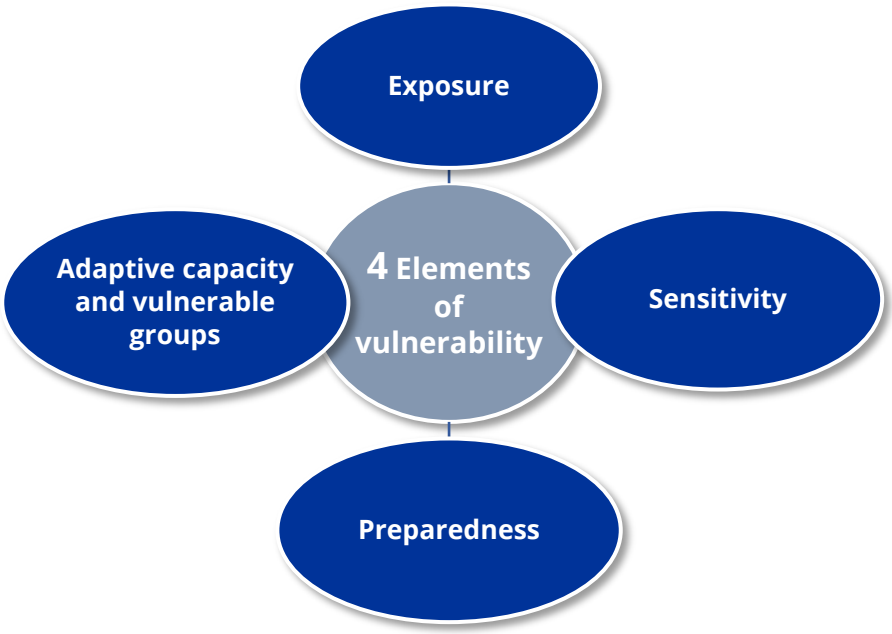

Figure 1: Four Elements of Vulnerability to UHI

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AREAS OF ASSESSMENT AND INTERVENTION

Territorial context

City of Sofia

Sofia Municipality

Bulgaria

Note: All data in the assessment and indicators cover the territory of Sofia Municipality, not only the city of Sofia, as the strategic policies and actions reflect the entire municipality, which includes 38 settlements - Sofia, three other cities and 34 villages.

Statistics [1]

Area: 1344.9 sq. km

Population: 1 224 175 according to the data as of 31.12.2023

Density: 908 in/sq.km

GDP per capita (€): 27 480

Minimum wage (€/2024): 550,66

About Sofia

Sofia is the capital of Bulgaria. With 1,224,175 permanent residents (17.5% of Bulgaria's population), it is the largest city in the country and the 15th largest city in the European Union.

Sofia is located in the Sofia Valley at an altitude of about 550 meters on an area of 1,311 square kilometres, of which the settlements and urbanized areas occupy 245.5 square kilometres, the agricultural areas are 509 square kilometres, the forest areas - 466.5 square kilometres, the areas for extraction of minerals - 40.5 square kilometres, the areas for transport and infrastructure - 20.6 square kilometres and watercourses and water areas - about 40 square kilometres.

The Sofia field contains iron ore, building materials (sand, gravel, rubble, limestone and clays), and lignite.

The area is rich in mineral waters.

Several low-water rivers flow through Sofia. Their beds within the city limits have been corrected. The larger ones are Iskar, Vladaiska, Perlovska, Sukhodolska, Slatinska, Boyanska, Bistrishka, Bankyanska. The main drainage artery is the meridian valley of the Iskar River. The hydromineral resources on the territory of Sofia occupy a significant share of those of the country (15 deposits with a total consumption of mineral water - 130 l/s).

Sofia is located in the central part of the Balkan Peninsula, in the Sofia Basin, surrounded by several mountains, which is the largest and one of the highest fields in the Sub-Balkan region. The city of Sofia is situated in the largest of the Trans-Balkan valleys, the Sofia Valley, at the foot of the Vitosha Mountain, in the western part of the country. It is surrounded by several other mountains - Stara Planina to the north and Viskjar Mountain to the northeast, Lyulin Mountain to the southwest,

[1] Source: National Statistical Institute

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Lozenska Mountain to the south, and Vakarel Mountain and the Belitsa Ridge to the southeast. The city of Sofia and the Sofia region are located in the Southwestern region of Bulgaria. The region has more than 1/5 of the country's river and groundwater (groundwater that lies above the top impermeable soil layer). Almost 40% of the region is covered by forests. About 1/3 of the country's coniferous forests and about 1/2 of its grasslands are located here. Wood reserves are not large. Some of the most famous national parks and reserves are in the region.

Figure 2 shows the location of the city in regional and national plan.

Figure 2: Location of Sofia at national and regional level

The geographical boundaries of Sofia cover the territory of Sofia Municipality as an administrative unit, which is one of the 27 districts on the territory of Bulgaria. Sofia Municipality includes the city of Sofia, the towns of Bankya, Bukhovo and Novi Iskar and 34 villages. It covers an area of 1344.9 sq.km, of which about 256 sq.km are urban areas, about 89 sq.km are transport areas, about 464 sq.km are agricultural areas, about 442 sq.km are forests, about 52 sq.km are water and water basins, about 14 sq.km are protected areas and about 20 sq.km are disturbed areas. The shares of the areas distributed by land use are shown in Figure 3.

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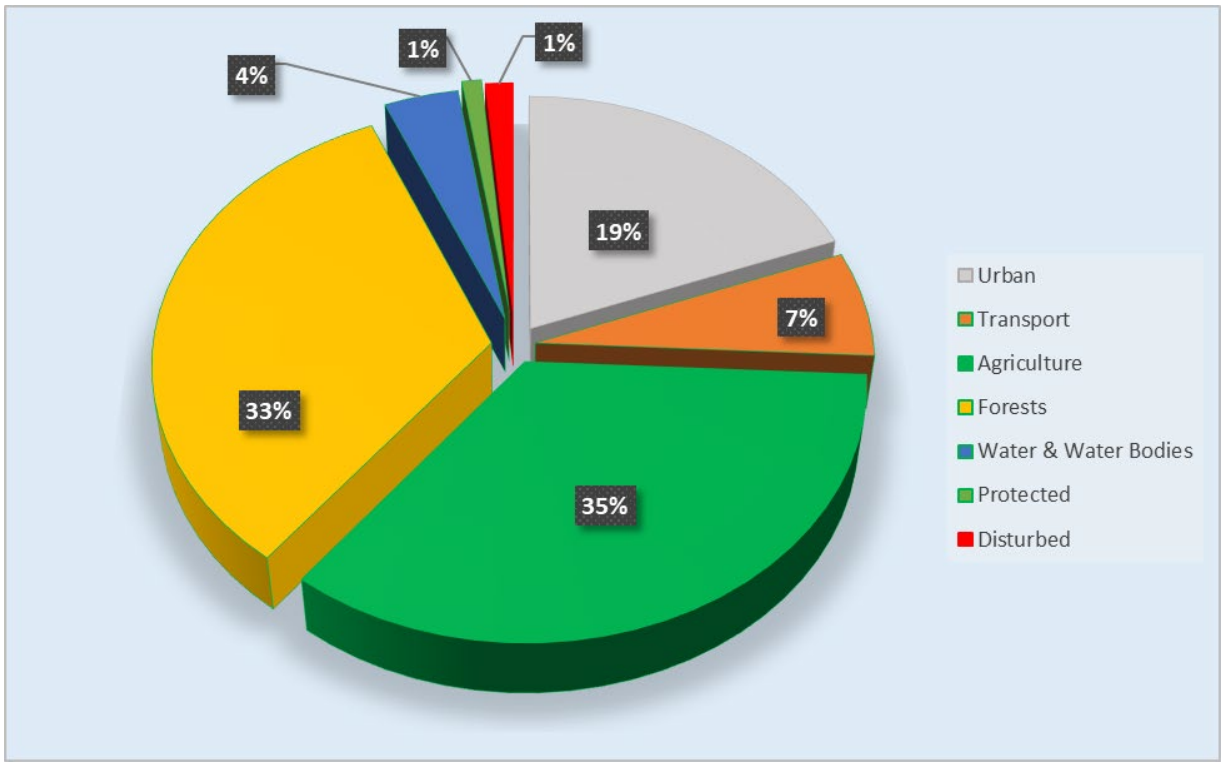

Figure 3: Territorial structure of Sofia Municipality by land use

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2. Methodology of the process

SUMMARY OF THE UHI VULNERABILITY ASSESSMENT PROCESS

The UHI risk assessment in Sofia is a preparatory activity for the implementation of the pilot projects to co-create, test and validate jointly developed solutions to mitigate the effects of UHI. The assessment is based on historical data and statistics as well as other information and data from various sources. The risk assessment was conducted with the support of a local coalition of stakeholders and citizens, enabling community engagement and raising citywide awareness of the project goals and expected outcomes. The development of the city report was also supported by the Be Ready project's research partners.

PREPARATORY PHASE

In the initial phase, a review of all available sources of information was carried out, along with the identification of local stakeholders and their input, as well as ways to involve civil society in the process. Missing data were identified, as well as methods to collect the necessary data through citizen participation. Areas where Sofia Municipality needs to increase its risk assessment capacity were also identified, as well as ways to address the issues.

ACTIVITIES

Several events/activities were organised to aid the assessment:

- A focus group with representatives of Sofia Municipality, relevant municipal enterprises, NGOs, businesses and universities to contribute to the assessment of Tool 4: Adaptive capacity of municipalities to cope with and mitigate climate risks.

- Online survey with 50 respondents: 28% representatives of Sofia Municipality, 22% NGOs, 18% municipal enterprises, 15% universities and 16% business and business support organizations. The purpose of the survey was to contribute to Tool 3: Vulnerable Groups and Tool 4: Adaptive Capacity of Sofia Municipality.

- An online workshop with the participation of Sofia and the City of Vienna aimed at enhancing the capacity of Sofia to address UHI with policies and practices based on the experience of Vienna and its UHI mitigation strategy and initiatives such as "Cool Streets".

TIMELINE OF THE PROCESS

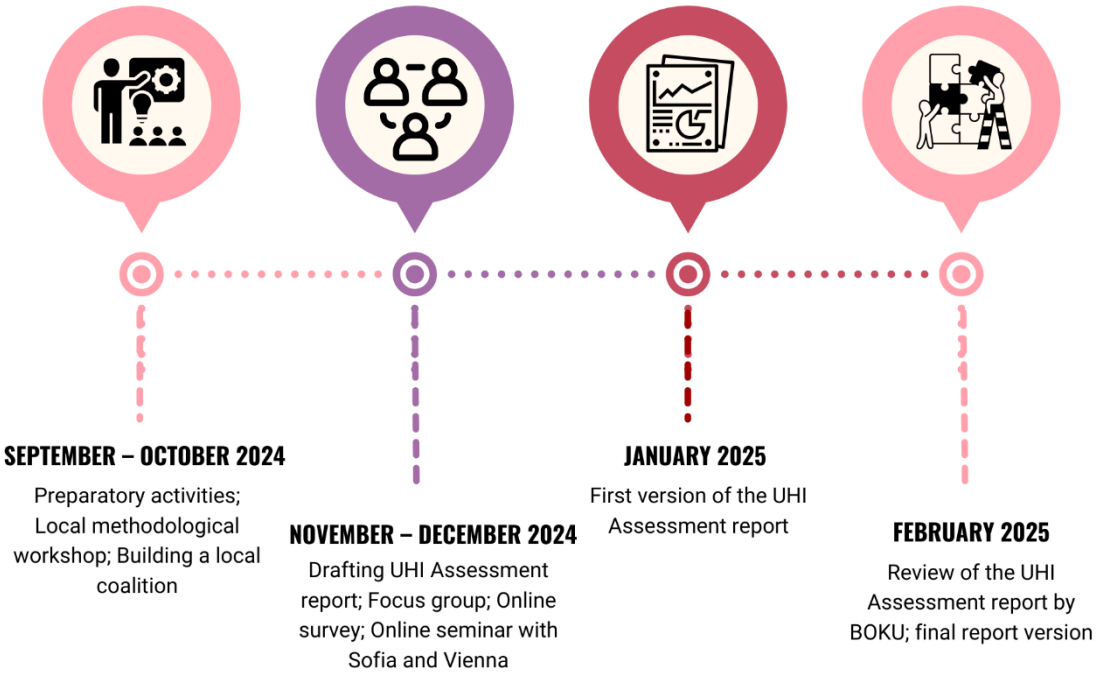

Figure 4: Timeline of the UHI vulnerability assessment process

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3. Urban climate

GENERAL INFORMATION AND URBAN CLIMATE TRENDS

The climate in Sofia - including historical data, status and trends (modelling) until 2099 are presented in the context of climate change in the whole country. Historical data as well as data from testing of predictive models by different research teams show that a steady and gradual increase in temperature is observed in all seasons both for the whole country and specifically for the city of Sofia.

This trend has been analyzed and proven in studies by the National Institute of Meteorology and Hydrology and by various research teams of Sofia University and that of Ekipat na Sofia.

The report "The Changing Climate of Bulgaria - Data and Analyses" of the National Institute of Meteorology and Hydrology (2023) refers to most recent research by WMO (WMO, 2021; 2022) which indicates that 2016, 2019 and 2020 were the three warmest years for the entire period of meteorological observations. The decade 2011-2020 is the warmest globally, with each successive decade since the 1980s being warmer than the previous decade. In 2022, the planet was 1.15 ± 0.13 °C warmer than the preindustrial period, ranking it among the 6 warmest years since 1850 (Fig. 4 (II.1-2)).

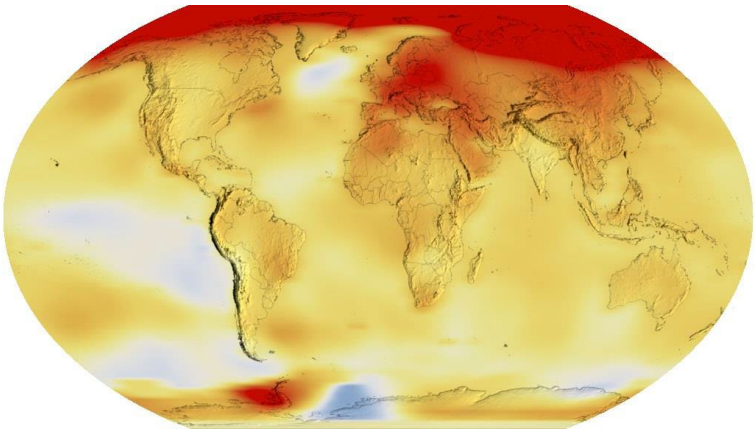

Figure 5: Map of the mean annual temperature anomaly for the 5-year period 2018-2022 against temperature norms calculated for the 30-year NASA 1951-1980 baseline period. Source: NASA's Scientific Visualization Studio [2]

As the report states, "the fluctuations of the annual mean air temperature in Bulgaria in the period 1931-2020 compared to the climate norm 1961-1990 show an increasing, statistically significant trend of 0.14 °C/10 years. Up to the mid-1980s, deviations from the norm ranged from -1.6 °C (1942) to +1.0 °C (1934), with alternating periods of cooling and warming, while since the beginning of the present century there have been virtually no negative deviations from the norm (except in 2005) and none since 2011 of less than 1 °C." The 2019 temperature anomaly of +2 °C is a record for the 90-year period under consideration', exemplified in Figure 5 below.

[2] https://svs.gsfc.nasa.gov/5060

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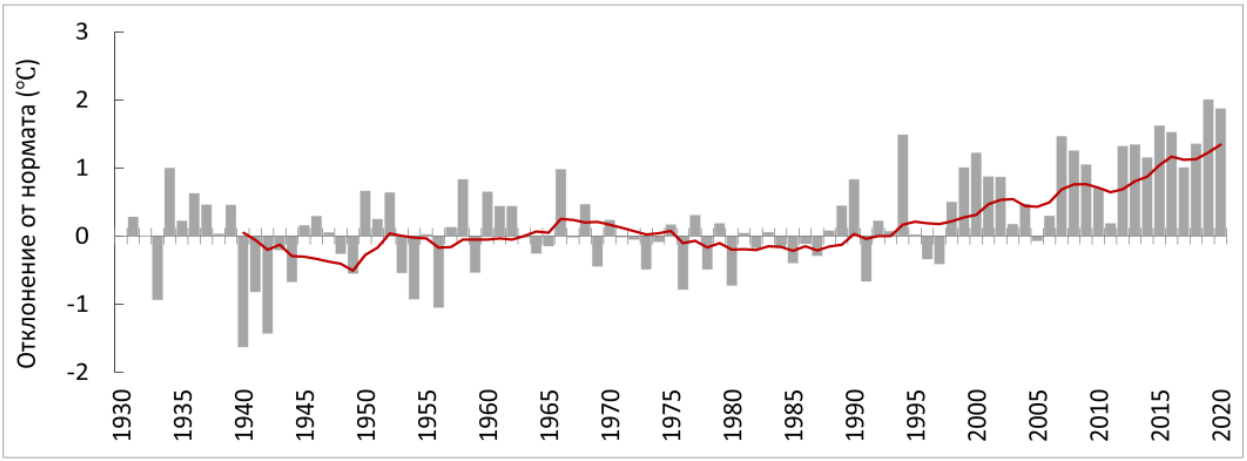

Figure 6: Fluctuations of the annual mean temperature in the period 1931-2020 compared to the norm for the period 1961-1990. The red line shows the 10-year moving average. Source: National Institute of Meteorology and Hydrology

In addition, the same report states that "[t]he statistically significant positive trends in January and February mean temperatures (+0.25 °C/10 yr) chart a well-defined upward trend in winter temperatures of +0.19 °C/10 yr. Spring also shows a warming trend of around +0.17 °C/10, but of the spring months only March shows a statistically significant warming trend (+0.30 °C/10). The increase in summer temperatures of +0.16 °C/10 is driven by a statistically significant warming trend in June, July and August (+0.15, +0.12 and +0.18 °C/10, respectively). Autumn temperatures did not follow a clear trend over the period under consideration, but they have also been increasing since the turn of the century."

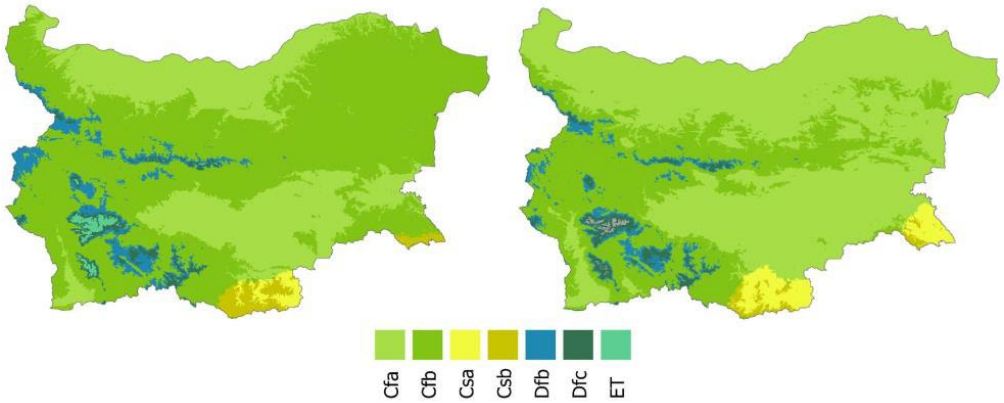

Figure 7: Köppen-Geiger climate classification for the periods 1961-1990 (left) and 1991-2020 (right). Horizontal resolution: 30 arcsec. Source: National Institute of Meteorology and Hydrology

According to the Köppen-Geiger climate classification, “there are three main climate types in Bulgaria - Fig. 6 (II.2)..1-2): 1) *temperate* (C, temperate), which can have a dry summer season (Mediterranean type) - hot (Csa) or warm (Csb), or without a dry summer - hot (Cfa) and warm (Cfb); 2) *boreal* (D, boreal), continental type - with warm summer (Dfb) or cool summer (Dfc); 3) *polar* (E, polar) - alpine tundra type (ET).”

The predominant climate type during 1961-1990 was Cfb (61%), followed by Cfa (28.7%). Overall, about 93% of the country falls into the temperate climate group.

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Between 1991 and 2020, significant changes occurred in the distribution of the major subtypes. According to research (Malcheva & Bocheva, 2023), "the shift from colder to warmer and/or drier climates has affected about 36% of the country's territory, and the relative change in mountain climate subtypes shows a significant reduction (by 60-70%) of areas with alpine climates."

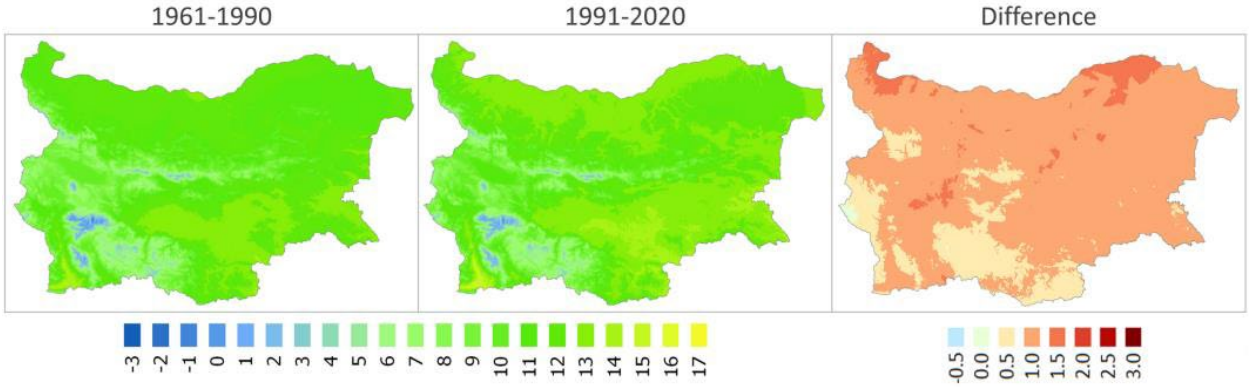

Figure 8: Spatial distribution of mean annual temperature for the periods 1961-1990 and 1991-2020 and the absolute difference between the latter and former periods (°C). Source: National Institute of Meteorology and Hydrology

Maximum temperatures above 42-43 °C are a relatively rare but possible temperature extremes. Consistent with the resulting statistical estimates of high temperatures characteristic of the lowland climate during the warm half of the year, hot waves can be defined as periods with maximum air temperatures ≥ 32, 34, 36, 38 and 40 °C with corresponding durations of at least 6, 5, 4, 3 and 2 consecutive days. This climatic indicator describes well the severity of heatwaves in a country as a combined assessment of their intensity and duration (Malcheva et al., 2021).

There is a clear trend of increasing frequency of hot waves in recent decades, illustrated in Figure 8 (II.2.5-5). All the extremely hot periods with maximum temperatures ≥ 38 °C and ≥ 40 °C and about 90% of the hot periods with threshold values of 32, 34 and 36 °C occurred after the mid-1980s. In some years, extreme heat events with temperatures ≥ 40 °C on 6-8 consecutive days are observed.

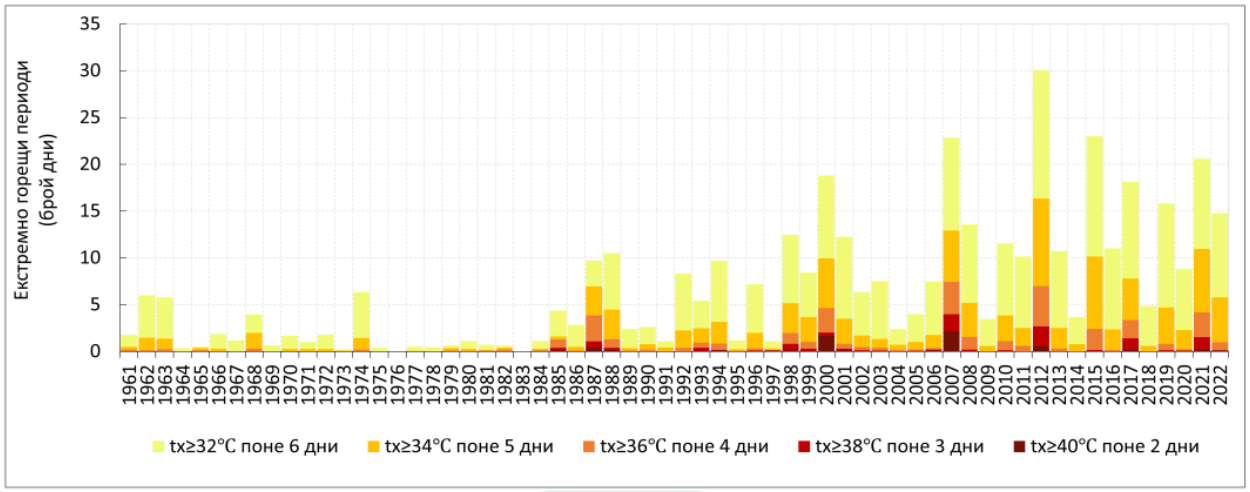

Figure 9: Multi-year variation of the national average summed duration of recorded hot spells at different threshold values (1961-2022). Source: National Institute of Meteorology and Hydrology

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Table 1 (III.1-1) summarizes the results of the analysis of the expected changes in temperature and precipitation according to the "two scenarios for the near (2021-2050) and far (2070-2099) future (Bocheva et al., 2023). Seven ETCCDI indices calculated on an annual basis were analysed along with the annual mean values of minimum, daily mean and maximum temperature (denoted as TN, TG and TX): absolute maximum temperature (TXx), absolute minimum temperature (TNn), maximum number of consecutive frost days (CFD), maximum number of consecutive summer days (CSU), rainfall sum (RR), number of days with heavy rainfall (RR10 mm) and maximum number of consecutive dry days (CDD)."

Table 1: Climate indices change according to RCP4.5 and RCP8.5 scenarios for near (2021-2050) and far (2070-2099) future. Source: National Institute of Meteorology and Hydrology

Период	Сценарий	TN, °C	TG, °C	TX, °C	TNn, °C	TXx, °C	CFD, дни	CSU, дни	RR, %	RR10mm, дни	CDD, дни
2021-2050	RCP4.5	+ 1–2	+ 1–3	+ 1–4	+ 2–3	< +2	- 7–14	+ 14–21	- 5–8	- 1–2	+ 4–6
	RCP8.5	+ 1–2	+ 1–3	+ 1–3	+ 3–4	+ 2–3	- 7–14	> + 21	- 5–8	- 2–3	+ 6–7
2070-2099	RCP4.5	+ 2–3	+ 3–4	+ 3–4	+ 3–5	+ 1–3	- 18–30	+ 42–54	- 10–15	- 2–5	+ 10–15
	RCP8.5	+ 4–5	+ 5–6	> + 6	+ 7–9	+ 5–7	- 18–30	> + 54	< -20%	- 4–8	> +15

The results confirm that warming will continue in all seasons, and especially in summer. According to the RCP4.5 scenario, the average annual temperature in Bulgaria is expected to increase by 1.8-2.1℃ in the period 2021-2050 and by 2.9-3.2℃ in the period 2071-2099. In the period 2021-2050, the greatest warming can be expected in summer (3-3.2 °C). In the other seasons, the temperature increase is less, 1.6-2.4 °C. In the period 2071-2099, seasonal temperatures are expected to increase by 3.5-4.5 °C, except in summer, the temperature increase could reach 6℃.

According to a report (November 2019)[3] by experts from Sofia University, "for the region of the Sofia Basin under the RCP4.5 scenario, the average annual temperature in the future period is expected to reach 8.0°C, and under the RCP8.5 scenario 8.6°C." This means that under the "moderate" scenario the expected temperature increase is 1.1°C, and under the "pessimistic" scenario 1.7°C. For the Sofia region, the same two scenarios predict the annual mean surface temperature to "increase compared to the reference period by 1.2°C and 1.8°C, respectively. Expected mean temperatures by season also increase under both scenarios, as can be seen in Figure 9 (5.4) for the Sofia Basin and Figure 5.5 for Sofia. Depending on the scenario, the expected increase in the Sofia Basin is 1.2-1.3°C in spring, 1.7-2.2° C in summer, 1.0-1.8°C in autumn, and 0.7-3.1° C in winter. In Sofia, the temperature increase is expected to be: in spring by 1.2-1.3° C, in summer by 1.9-2.6°C, in autumn by 0.9-1.8° C, and in winter by 0.7-1.5°C (also depending on the scenario)."

[3] Popov., A. et al., PROUCVANE_NA_DOBRI_PRAKTIKI_ZA_TOPLINNITE_OSTROVI_NA_TERITORIATA_NA_STOLICNA_OBSINA_IZSLEDVANE_I_KARTOGRAFIRANE_NA_EFEKTA_NA_GRADSKIA_TOPLINEN_OSTROV_NA_TERITORIATA_NA_SOFIA_I_PROUCVANE_NA_DOBRI_PRAKTIKI [Good practices of UHI Study in Sofia Municipality. Study and Mapping of the UHI Effects on the Territory of Sofia and Good Practices for UHI Mitigation.] DOI:10.13140/RG.2.2.15518.48969 (hereafter referred to as Good Practices Report). Accessed 27 December 2024.

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	пролет	лято	есен	зима
Tmean(1976-2005)	5,3	16,9	7,6	-2,2
RCP4.5_Tmean(2021-2050)	6,5	18,6	8,6	-1,5
RCP8.5_Tmean(2021-2050)	6,6	19,1	9,4	0,9

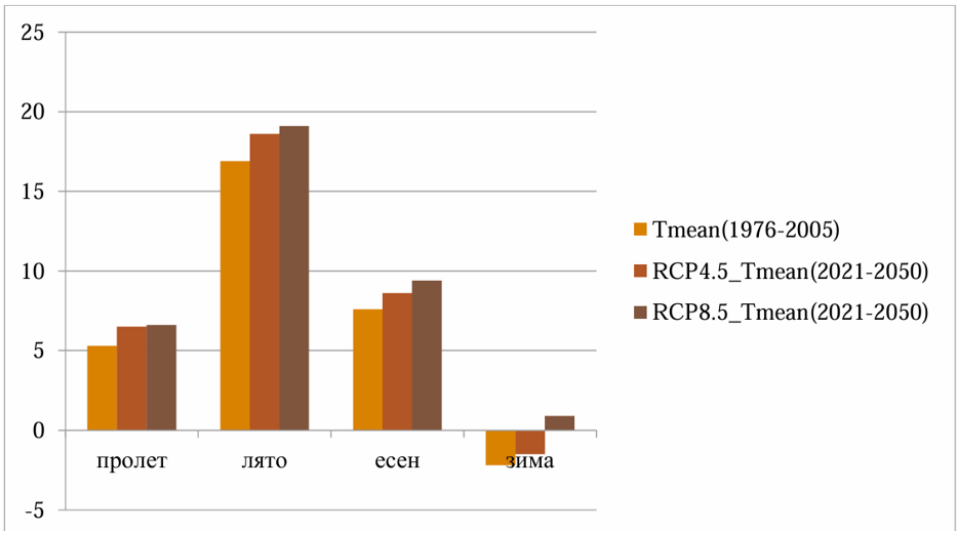

Figure 10: Estimated changes in the mean land surface temperatures by season in the Sofia Basin (C). Source: Good Practices Report

	пролет	лято	есен	зима
Tmean(1976-2005)	6,2	18	8,3	-1,9
RCP4.5_Tmean(2021-2050)	7,4	19,9	9,2	-1,2
RCP8.5_Tmean(2021-2050)	7,5	20,5	10,1	-0,4

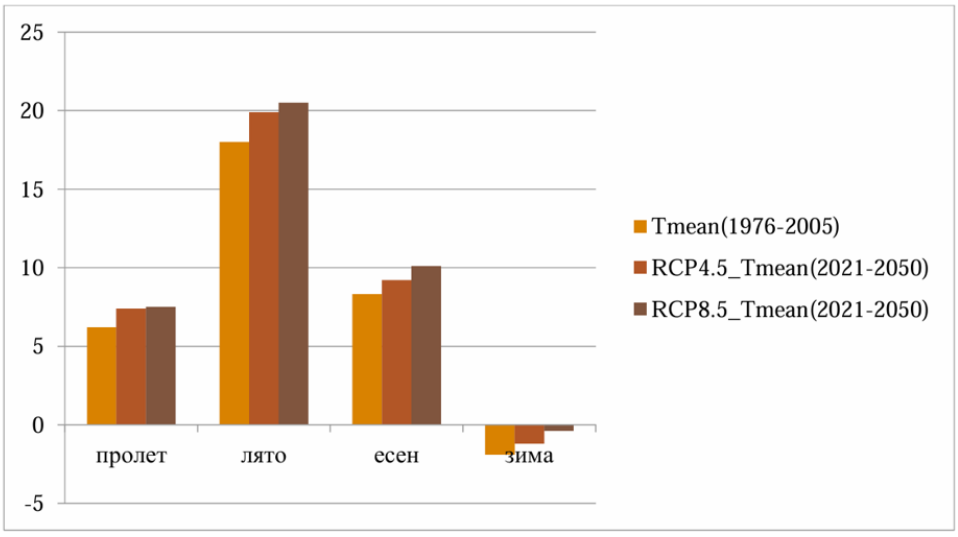

Figure 11: Expected changes in mean surface temperatures by season in Sofia (C). Source: Good Practices Report [4]

[4] Ibid.

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Both scenarios for the future period 2021-2050 are expected for the Sofia Basin and the city of Sofia. Sofia will experience an increase in monthly mean temperatures (Fig. 11(5.6), Fig. 12 (5.7). Under both future scenarios, the largest increase is expected to be in August, and the significant increase of 2.3-2.4° C in January is also noteworthy.

	1976-2005	RCP4.5	RCP8.5
I	-3,0	-2,1	-0,7
II	-1,7	-1,0	-0,7
III	1,0	2,1	1,7
IV	4,9	6,2	6,5
V	10,0	11,1	11,5
VI	14,9	16,2	16,4
VII	17,9	19,4	20,0
VIII	17,8	20,3	21,0
IX	13,4	15,1	15,5
X	8,0	8,5	9,5
XI	1,6	2,1	3,2
XII	-2,1	-1,5	-1,2
Год.	**6,9**	**8,0**	**8,6**

Figure 12: Mean monthly land surface temperatures during the control period and the future period under the two scenarios (C). Source: Good Practices Report

	RCP4.5	RCP8.5
I	0,9	2,3
II	0,7	1
III	1,1	0,7
IV	1,3	1,6
V	1,1	1,5
VI	1,3	1,5
VII	1,5	2,1
VIII	1,5	3,2
IX	1,7	2,1
X	0,5	1,5
XI	1,1	1,6
XII	0,6	0,9
Год.	**1,1**	**1,7**

Figure 13: Estimated temperature differences between the control and future period (monthly values with an increase greater than 1.5 degrees C are marked in red). Source: Good Practices Report

Figure 14 summarises the expected changes for the period 2021-2050.

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София	1976-2005		RCP4.5		RCP8.5	
	Ср. мин.	Ср. макс.	Ср. мин.	Ср. макс.	Ср. мин.	Ср. макс.
I	-5,9	-0,5	-6,9	1,6	-3,0	3,5
II	-4,18	1,38	-4,24	1,55	-2,97	3,54
III	-1,3	3,9	-0,1	5,4	-0,5	5,7
IV	2,3	8,5	3,5	10,4	5,0	9,9
V	8,0	13,9	10,3	14,9	9,9	15,7
VI	13,7	20,3	14,3	21,4	14,5	20,5
VII	16,2	23,4	17,3	25,0	18,0	27,8
VIII	15,7	22,9	17,4	25,4	17,5	27,1
IX	11,3	18,6	12,6	19,3	11,8	19,9
X	5,9	11,7	6,5	12,7	6,1	14,4
XI	-2,6	5,2	-0,9	7,0	-0,4	6,2
XII	-4,6	1,0	-4,6	2,5	-4,5	2,0
Год.	**4,6**	**10,9**	**5,4**	**12,3**	**6,0**	**13,0**

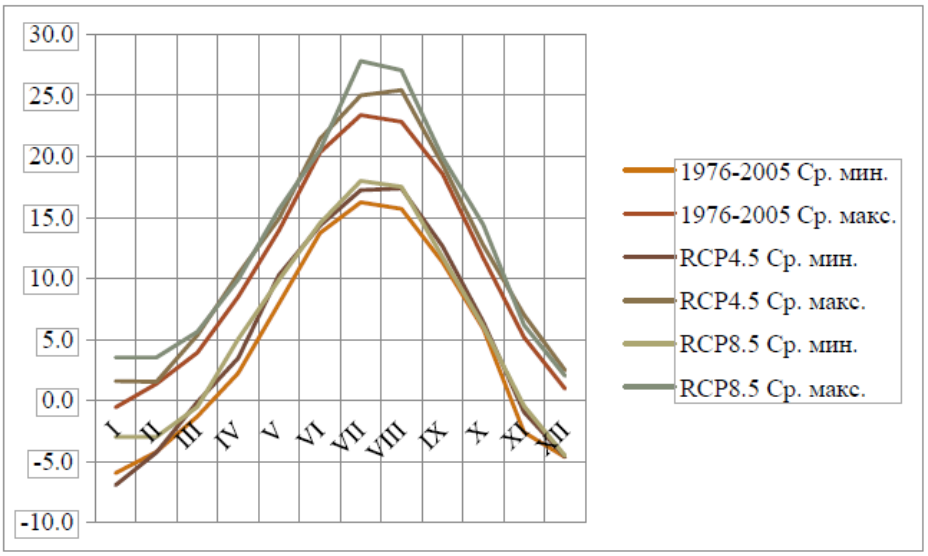

Figure 14: Expected changes over the period 2021-2050 of the average monthly minimum and maximum temperatures (C) of the land surface in Sofia under the climate scenarios RCP4.5 and RCP8.5 compared to the reference period 1976-2005 Source: Good Practices Report

The report "Study of Good Practices for UHI on the Territory of Sofia Municipality. Study and Mapping of the UHI Effect in Sofia" presents in a synthesized form the authors' conclusions on the results of the analysis of the expected climate changes.

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Table 2: Summary of expected climate change. Source: Good Practices Report

LINK	TREND	CLIMATE CHANGE (EXPECTED CHANGES)	DEGREE OF CONFIDENCE
Temperature	↑	Increase in all seasons and months; Greatest increase in summer; Increase in temperature amplitudes; Increase in length of growing season.	High
Precipitation	↑ ↓	Relatively small increase in average annual precipitation; decrease in summer precipitation and increase in late autumn and spring.	Moderate
Snow cover	↓	Reduction in the thickness and extent of snow cover and shortening of the duration of the period with snow cover; Significant reduction in the proportion of water equivalent snowfall and increase in the proportion of rainfall.	High
Water temperature	↑	Increase in temperature of smaller rivers and shallower reservoirs.	High
Water quality	↓	Deterioration, especially in summer and early autumn; Flooding caused by heavy rainfall combined with anthropogenic pollution and increased temperatures could exacerbate the problem.	Moderate
Soil moisture	↑ ↓	Decrease in soil moisture in summer and early autumn, increase in late autumn, winter and spring.	Moderate

Another factor to consider in relation to the sustained trend of increasing air and land surface temperatures is solar radiation. Bulgaria receives a huge amount of solar energy due to its southern location and relatively low cloud cover. In Bulgaria, the average annual sunshine period is about 2 100 hours, and in some areas, it can reach up to 2 500 hours.

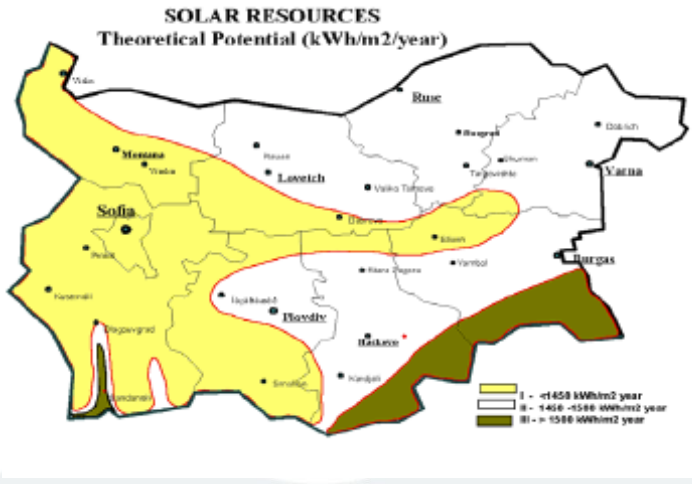

Figure 15: Annual solar resources in Bulgaria.

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The table below from the Meteo online platform provides aggregated data from 2018 onwards on solar resources in the country.

Table 3: Aggregated data on solar resources in the country from 2018 onwards. Source: Meteo.chavo.biz[5]

	Avg	Min	Max	Range
2018	193.9	0	1294	1294
2019	167.4	0	1214	1214
2020	152.5	0	1095	1095
2021	148.8	0	1070	1070
2022	151.5	0	1138	1138
2023	134.0	0	1029	1029
2024	145.3	0	1071	1071
2025	35.5	0	412	412

The natural gamma radiation background is a physical characteristic of the environment and represents the gamma-ray field in which all living organisms on Earth 219 220 are located. The measured quantity is the power of the ambient equivalent dose, H*(10) of gamma radiation and is specific to each point, area, region. Figure 16 presents the annual average gamma radiation background values for the period 2020-2022 at all 26 local monitoring stations in the country.

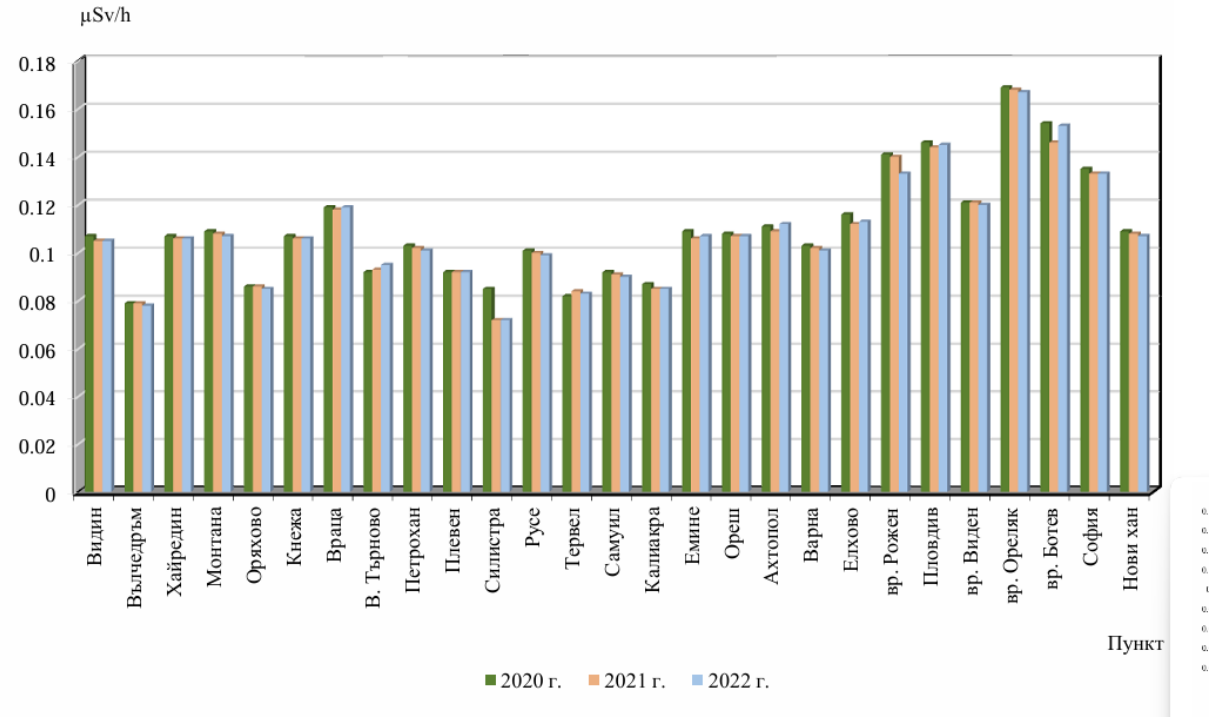

Figure 16: Annual average values of the gamma background radiation in Bulgaria, 2020-2022, µSv/h. Source: Executive Environmental Agency.[6]

[5] https://meteo.chavo.biz/pages/station/climate.php?var=S
[6] https://eea.government.bg/bg/soer/2017/radiation/radiatsionno-sastoyanie-na-okolnata-sreda

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4. Assessing the city against 4 elements of vulnerability: exposure, sensitivity, preparedness and adaptability

4.1. EXPOSURE OF BUILDINGS AND SURROUNDINGS

Urban morphology

The territory of Sofia Municipality is located at 4204' N and 2309' E, falling entirely within the temperate-continental climatic region of the country. Within this area, the municipality is in the climatic region Sofia Valley, occupying a position in the south-western part of the region, close to the border of the second main climatic region of the country - the Transition Continental (according to data with medium-high spatial resolution satellite imagery from the Landsat platform.)

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The urban area influences most climatic elements and processes. This is due to several main effects related to the artificial ground surface (urban substrate, roofing materials), urban morphology, polluted urban air. Urban morphology affects the duration of sunshine, wind flows, temperature amplitudes between central urban areas and peripheral areas.

Exposure to climate hazards, in particular heat islands, is determined for different sectors relative to the average multi-year norm of the respective hazard (according to Sofia Municipality Sustainable Energy and Climate Action Plan, Annex 2). In the Plan, exposure to climate hazards is defined as the degree of exposure of entities and sites to the adverse effects of these hazards.

The *Good Practices* report measures the surface temperature of the city of Sofia. Sofia and adjacent areas, finding that "there is a temperature difference of over 26°C between the most and least heated surfaces."

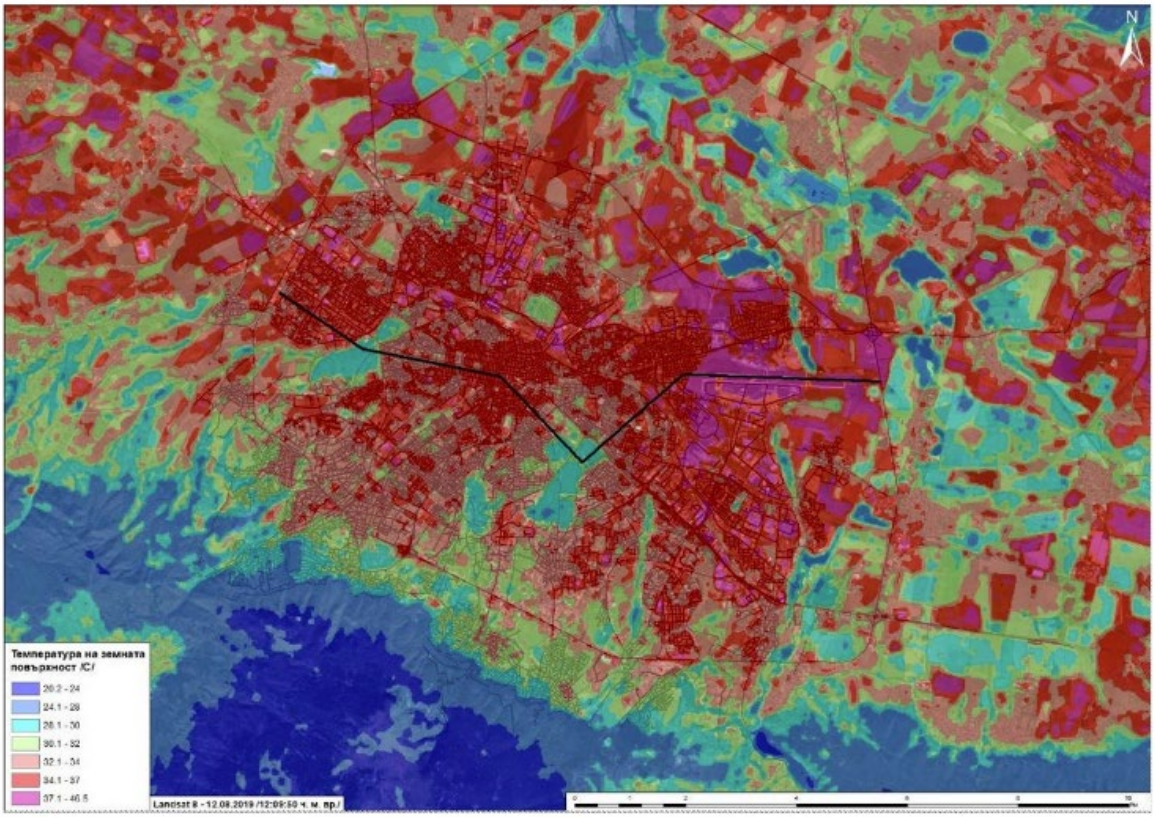

Figure 17: Land surface temperature profile line between the western and eastern parts of the city. Source. Good Practices Report[7]

[7] Ibid., *supra* note 4.

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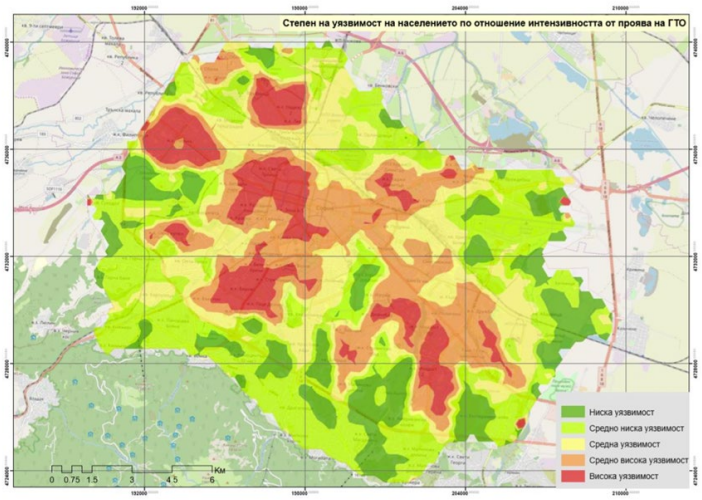

Accordingly, the lowest surface temperatures relate to water bodies and areas of natural vegetation, including green spaces, forest parks and urban gardens, while the highest temperatures relate to impervious surfaces with different types of industrial, residential and transport land use. Temperatures are particularly high in the eastern parts of the city, in central areas, and in residential areas, due to dense development, narrow streets, and lack of sufficient green spaces.

Figure 18: Land surface temperature profile. Source: Good Practices Report [8]

To validate the results described, the study *Good Practices* constructs a west to east temperature profile - Figure 15 (4.4) - that tracks changes in land surface temperature for different land cover types within the city. The temperature profile values clearly show the significantly higher temperature values for areas with sealed spaces and those with dense construction of tall buildings. The cooling effect of parklands and natural landscapes on adjacent urban areas is also clearly visible. The profile also highlights the maximum TOD values that are noticeable in the airport area - Figure 16 (4.5).

According to the studies, the complexes in the eastern (Mladost) and western (Lyulin and Nadezhda) parts of the city have the highest average measured surface temperature. In the central part, a significant heat island has also formed between the main parks and areas of the city.

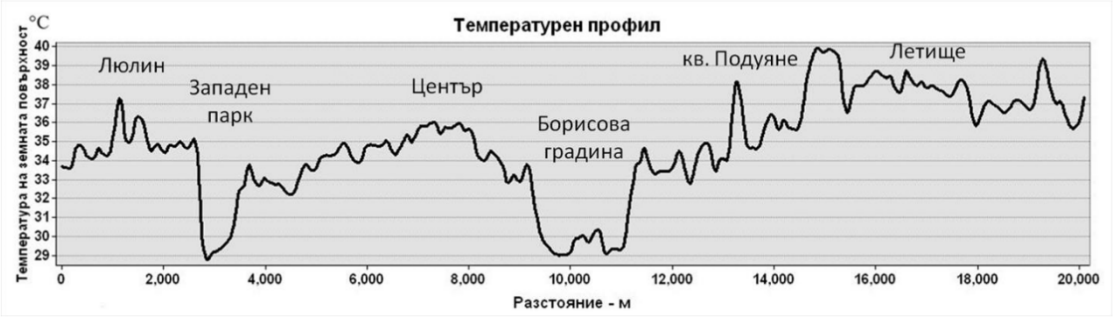

Figure 19: Classification of the territory of Sofia by degree of vulnerability to the UHI effect. Source. ResearchGate[9]

Over the last 20 years, Sofia has experienced 2.3 cases of heat waves lasting 9 days - i.e. about 20 days on average per summer with heat waves. In the summer of 2012 - the hottest summer since regular meteorological observations began in the city - there were about 20 hot spells. In Sofia (for a period of 125 years) there were 5 heat waves, and their total duration was 65 days (i.e. 2/3 of the days of the season were extremely hot).[10]

[8] https://www.researchgate.net/profile/Stelian-Dimitrov/publication/337830859_PROUCVANE_NA_DOBRI_PRAKTIKI_ZA_TOPLINNITE_OSTROVI_NA_TERITORIATA_NA_STOLICNA_OBSINA_IZSLEDVANE_I_KARTOGRAFIRANE_NA_EFEKTA_NA_GRADSKIA_TOPLINEN_OSTROV_NA_TERITORIATA_NA_SOFIA_I_PROUCVANE_NA_DOBRI_PRAKT/links/5dede70d299bf10bc34c5eea/PROUCVANE-NA-DOBRI-PRAKTIKI-ZA-TOPLINNITE-OSTROVI-NA-TERITORIATA-NA-STOLICNA-OBSINA-IZSLEDVANE-I-KARTOGRAFIRANE-NA-EFEKTA-NA-GRADSKIA-TOPLINEN-OSTROV-NA-TERITORIATA-NA-SOFIA-I-PROUCVANE-NA-DOBRI-PRAK.pdf

[9] Ibid.

[10] Velev St., "The hottest Sofia summer", in *Problems of Geography*, 2012, vol. 3-4, pp. 160-164).

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Building coverage ratio, floor area ratio, street canyon ratio

The central areas have the highest density of development as a share of the district the area, and the areas along Bulgaria, Cherni Vrah, Simeonovsko Shose and Tsarigradsko Shose Boulevards have a high density of development in absolute terms *(Municipal Action Plan for Sustainable Energy and Climate, Annex 6, 473*).

This aspect includes the indicators of (a) the cumulative floor area of buildings to urban units; (b) the absolute value of the cumulative floor area.

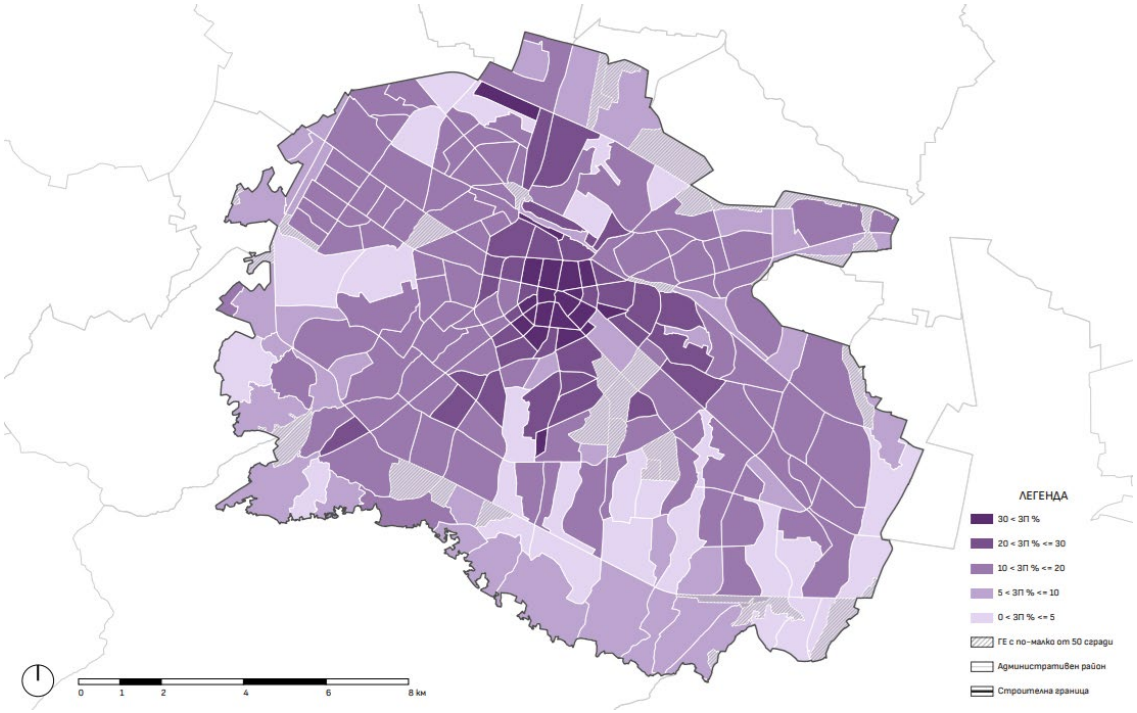

Figure 20: Morphology of the city. Source: Vision for Sofia[11]

Unfortunately, data regarding street canyons in Sofia is not available. There are some research papers addressing the issues, however, they use modeling and are not map-based.

[11] https://vizia.sofia.bg/wp-content/uploads/2019/02/Morfologiya.pdf

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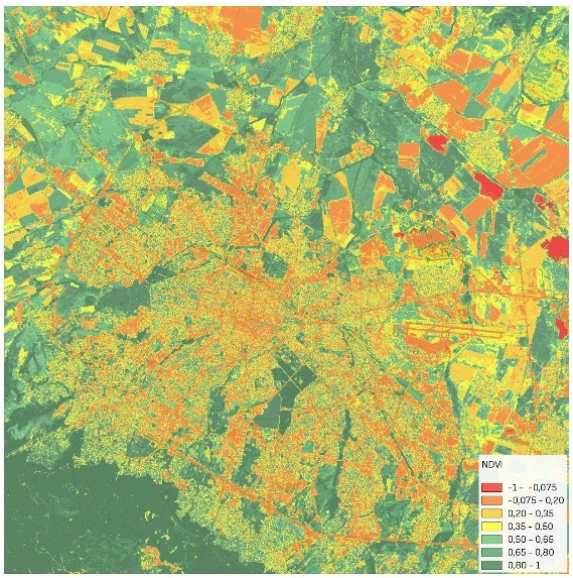
Green urban spaces and vegetation



Sofia's green system is characterized by "strong fragmentation" and imbalance in terms of green spaces in urban areas: on the map, the areas in red are without vegetation or the existing vegetation is in a very poor state of health.

Figure 21: Map of green surfaces in the city. Source: Copernicus Database[12]

	Дял на зелените площи (% от общата площ)	Дистрибуция на зелените площи (метра на хектар)
София	62%	18.74
Букурещ	28.10%	13.56
Будапеща	35.00%	17.55
Братислава	67.40%	11.16
Виена	49.50%	32.43
Любляна	72.50%	26.43
Рим	68.30%	16.34
Париж	21.50%	23.96
Лондон	33.50%	17.92
Дъблин	23.20%	29.44
Брюксел	33.00%	35.59
Амстердам	28.70%	7.84
Берлин	39.70%	28.03
Копенхаген	22.20%	18.82
Стокхолм	56.40%	50.93
Хелзинки	53.00%	48.13
Талин	36.70%	22.39
Рига	41.00%	20.57
Вилнюс	65.20%	17.15
Варшава	46%	23.14
Прага	55.30%	22.76
Мадрид	57.70%	44.77
Лисабон	24.10%	8.52
Люксембург	54.90%	32.12

Европейска агенция за околната среда

Дял и дистрибуция на зелените площи в 24 европейски столици по данни на Европейската агенция по околната среда.

According to data from the European Environment Agency, published in Sega Newspaper in 2019, Sofia ranks 5th in the share of green areas as a % of the total area. That is 62% of the total area of the city has green space.

The distribution of green areas in Sofia is 18.74 square meters per hectare of the total urban area.

Figure 22: Proportion and distribution of green space in 24 European capitals according to the European Environment Agency. Source: SEGA Newspaper[13]

[12] https://browser.dataspace.copernicus.eu/?zoom=5&lat=50.16282&lng=20.78613&themeId=DEFAULT-THEME&visualizationUrl=U2FsdGVkX1%2Fee%2BzY7qGRz2XaJrBHTN5qAmtrJ7BOWp0xEwgMjkzUybHjIcnKJg%2Bc2DAtxDH0ZER7WhoLz3XdmXeCM9MlCeXHb8EdyDSh5ye13sCtv4sGnZ3sUaSzULYN&datasetId=S2_L2A_CDAS&demSource3D=%22MAPZEN%22&cloudCoverage=30&dateMode=SINGLE

[13] "Зелените площи в София - хем много, хем зле поддържани." [Zelenite plosti na Sofia – hem mnogo, hem zle poddarzhani]. *Сега*, 18 Sept. 2019, Accessed 27 Dec. 2024.

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Green coverage ratio

The "Environment" section of the document "Vision for Sofia" provides summary information on the total area of parks, gardens, street and boulevard landscaping of 22,252 acres. According to the data of OP Sofproekt (now OP Sofiaplan) in the city of Sofia there are 22,250 parks and gardens. Sofia has 138 urban gardens and parks, and their area distribution shows that over 70% are less than 50 acres in size.

Table 4: Number and area of green parks in Sofia. Source: Vision for Sofia, Annex 6.

Разпределение по площ	Брой	Обща площ, дка
Под 10 дка	58	299,08
От 10 до 50 дка	42	912,36
От 50 до 100 дка	14	1009,58
От 100 до 1000 дка	20	5602,38
Над 1000 дка	4	10280,13
Обща площ		**18103,53**

On the territory of the SO the street landscaping, with few exceptions, is well implemented.

Figure 23: Landscaping by spatial zones, Source: ***Sofiaplan***[14]

[14] https://ekipnasofia.bg/solutions/water/

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Water Coverage

Most of the drinking water in Sofia (80%) is supplied from Iskar reservoir, which is close to the city and has sufficient capacity and very good quality. The challenge is that this is the only source of drinking water and there is no alternative.

The city is also rich in mineral water springs.

Sofia rivers are small. They have been turned into concrete canals in the past and parts of them were tunneled underground. They are still considered part of the city engineering infrastructure, and Sofia does not use their full potential.

Figure 24: Map of rivers in Sofia, Source: ***Sofiaplan***[15]

According to the European Environment Agency Bulgaria – and Sofia – are at risk of drought. Around 2030 the water shortage is expected to hit the capital city.

Tree Coverage

According to Sofiaplan's research, there are over 5.5 million trees in Sofia Municipality, and over 640,000 are in Sofia.

From 2000 to 2020, Sofia gained 9.74 kha of tree cover region-wide equal to 9.2% of all tree cover gain in Bulgaria, while the city lost 6.74 kha (1.6%) in tree cover.

As of 2000, 50% of Sofia land cover was tree cover with >30%canopy density.

[15] https://ekipnasofia.bg/solutions/water/

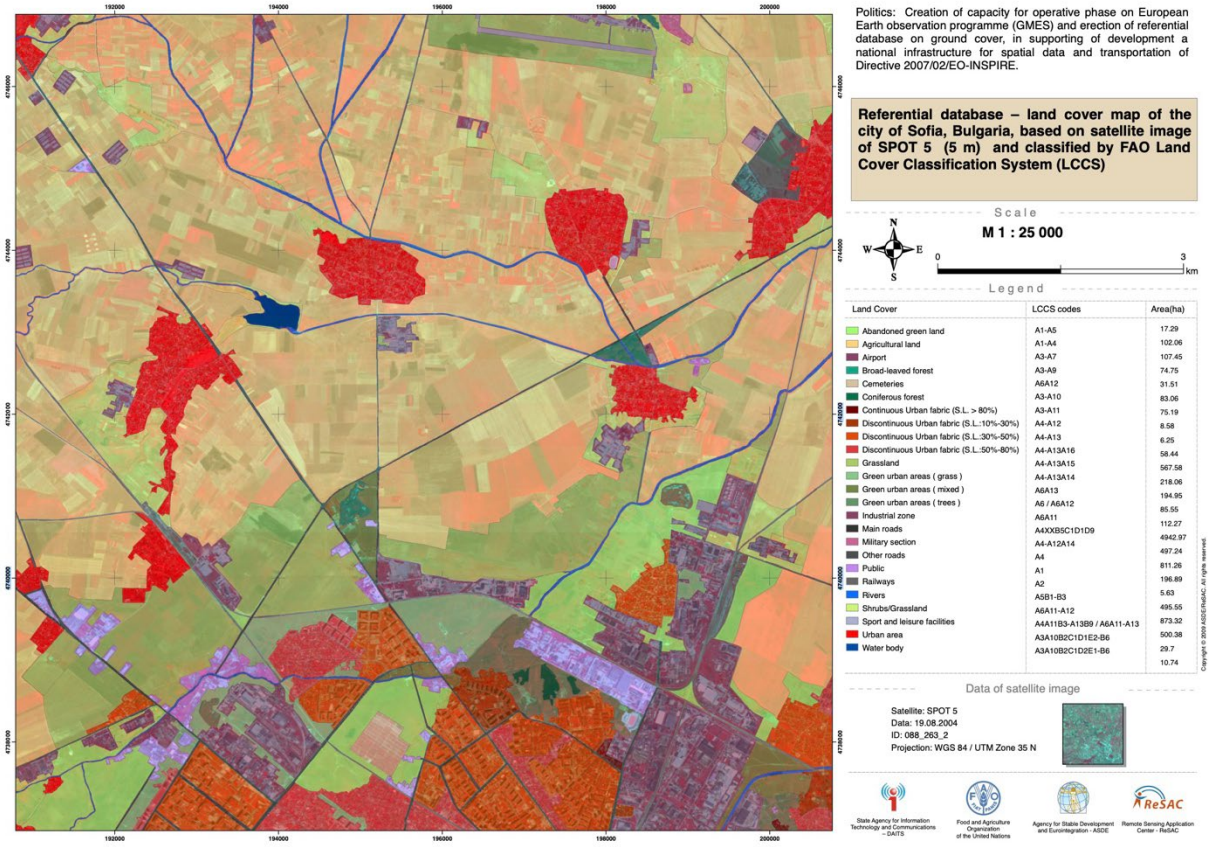

Figure 25: Land cover map of Sofia, Source: ***Bulgarian Infrastructure for Spatial Data***[16]

Permeability of surfaces

The properties of urban materials, particularly their reflectivity, thermal emissivity and heat capacity have a significant effect on the formation and manifestation of UHI. They determine the formation of specific thermal regimes in different parts of urban spaces depending on their ability to radiate and absorb thermal energy (Good Practices Report, 2019).

[16] https://bsdi.asde-bg.org/data/Lccs/pdf/lccs_sofia_spot5_en.pdf

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Proportion of permeable surfaces to impermeable surfaces

According to 2018 data, 84% of the area in Sofia Municipality is unsealed soil, and 16% of the area is fully or partially sealed.

Figure 26: Example of classified land cover types in the spatial areas (Sealed surfaces - grey, buildings - yellow, vegetation - green). Source: Good Practices Report

Human activities

The average population density in Sofia Municipality is 7052 people per square kilometre, for Sofia this indicator is 1,348 people, according to the National Statistical Institute for 2023. The territory of Sofia Municipality is divided into 24 administrative districts. There are 13 districts (every second district) with a population of more than 50 thousand people in whivh 73.8% of the population of Sofia Municipality lives.

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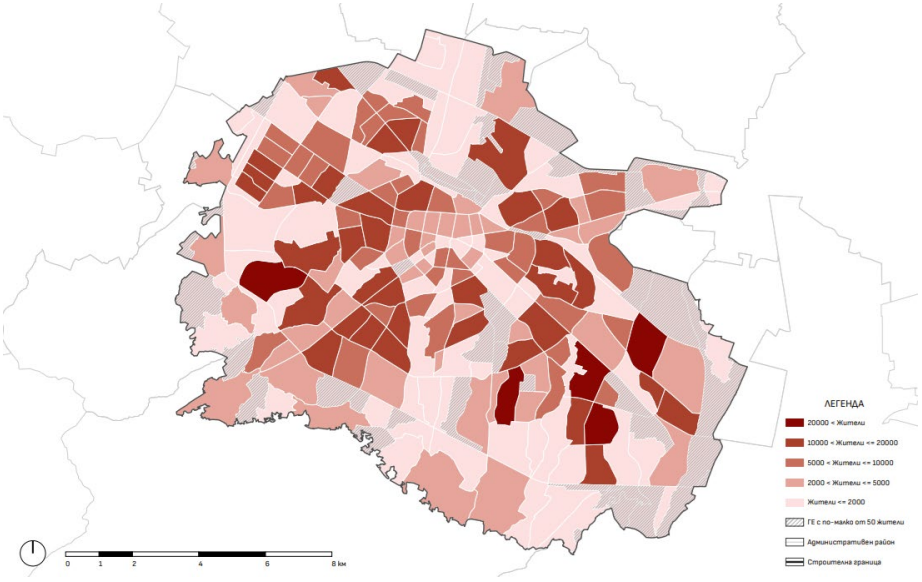

Figure 27: Population density map (absolute number of inhabitants). Source: Vision for Sofia[17]

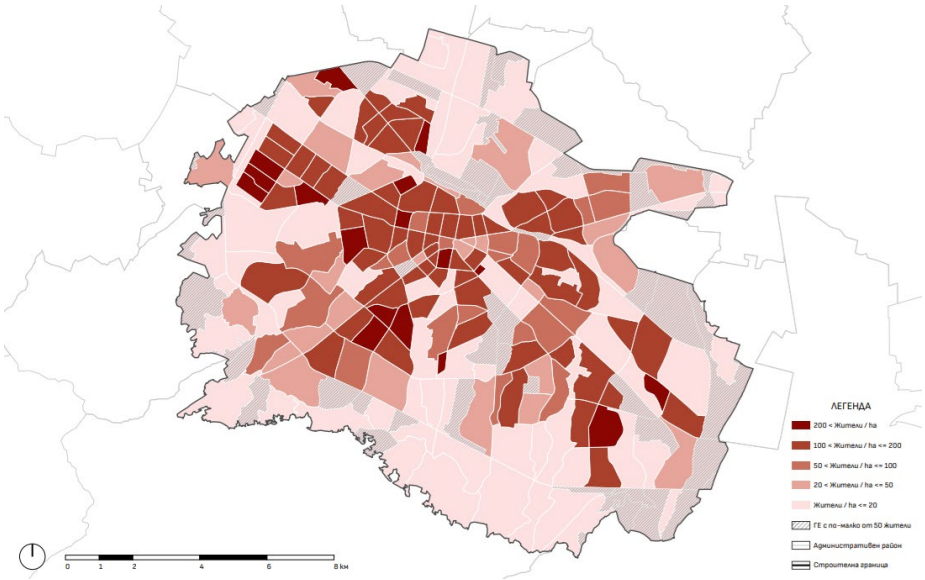

Figure 28: Population concentration map (inhabitants/area). Source: Vision for Sofia[18]

[17] https://vizia.sofia.bg/wp-content/uploads/2019/02/Morfologiya.pdf
[18] https://vizia.sofia.bg/wp-content/uploads/2019/02/Morfologiya.pdf

Population density

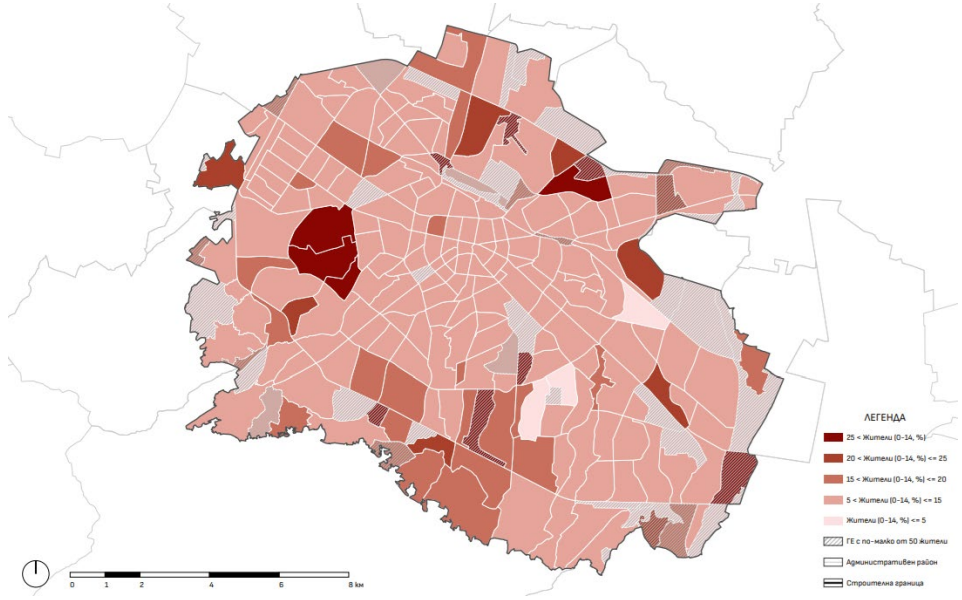

Figure 29: Map of the concentration of inhabitants aged 0-14 years. Source: Vision for Sofia[19]

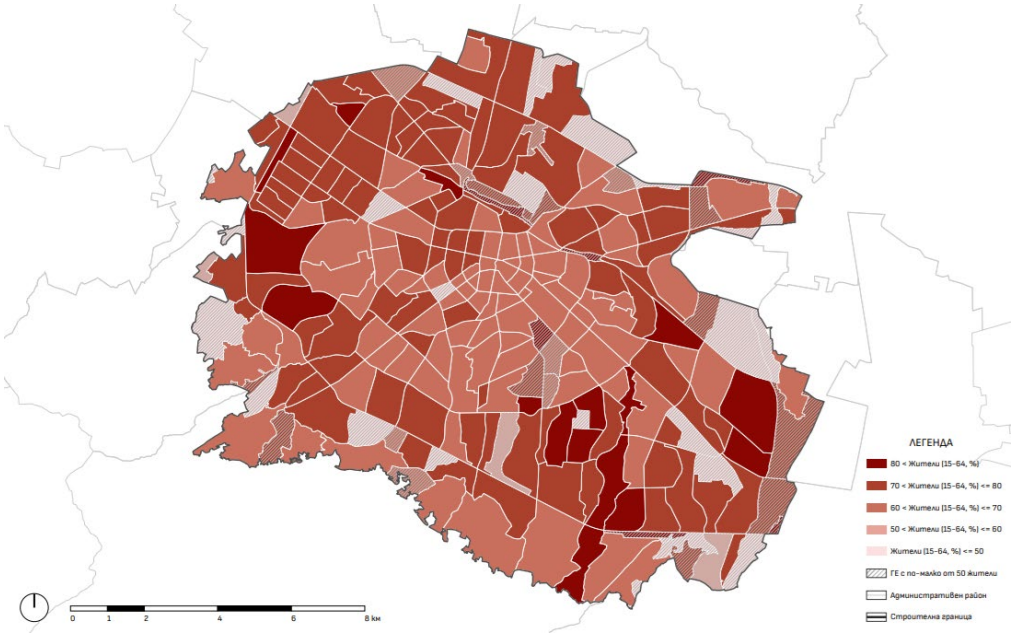

Figure 30: Map of the concentration of inhabitants aged 15-64 years. Source: Vision for Sofia[20]

[19] https://vizia.sofia.bg/wp-content/uploads/2019/02/Morfologiya.pdf
[20] https://vizia.sofia.bg/wp-content/uploads/2019/02/Morfologiya.pdf

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Land Use

Sofia has about 9000 ha of undeveloped land in the urban part of the city, of which 1200 ha are in large and accessible open spaces (public parks, forests and gardens). An additional 1700 ha are in residential areas (inter-block spaces). The inter-block spaces in the city total 1,700 ha.[21]

Energy consumption of buildings

The Green City Action Plan of Sofia Municipality indicates that renewable energy installations in the municipality include less than 2 MW of solar PV capacity (installed on public buildings) and 4 MW of other renewable energy sources.

According to the first energy atlas of Sofia, created by the GATE Institute, several main conclusions have implications with regard to reducing the UHI effects:
1) there is a "clear contrast in energy consumption between buildings in highly urbanised areas compared to those in the suburbs";
2) "buildings with high energy consumption belong to areas where commercial, industrial and sports buildings are located and already built";
3) The purpose and function of buildings is an effective predictor of the range of energy consumption.

According to the study, there are high and low energy consumption scenarios for buildings. The total amount of energy consumed per apartment decreased significantly by year from 8.3 to 6.35 MWh/ap/year, i.e. by 0.208 MWh/ap/year or an average of 2.4% per year based on 2008. In the last 10 years, the consumption of heat for heating and DHW has decreased by 24%.

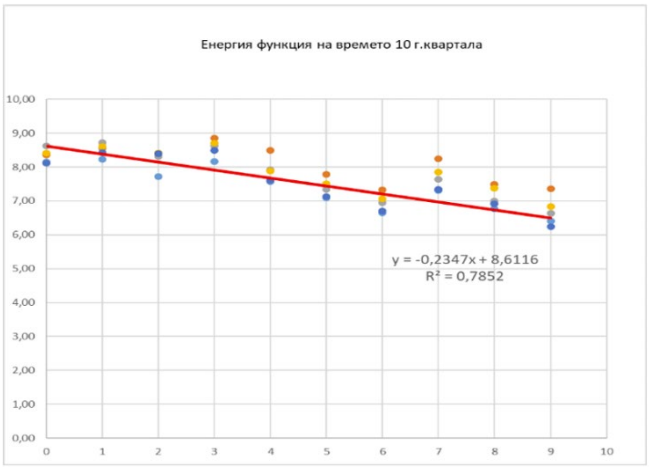

Figure 31: Variation of the consumed heat energy by neighbourhood and year in the city of Sofia. Heat consumption in Sofia. Source: Sofiaplan[22]

According to the report, the annual consumption of heat for heating and DHW for residential buildings decreased from 4 058 100 MWh to 3 074 539 MWh, i.e. 22%, while that for non-residential buildings increased by 1.3%.

[21] Vatseva et al. 2016. *Mapping Urban Green Spaces Based on Remote Sensing Data.*

[22] https://sofiaplan.bg/wp-content/uploads/2021/10/I.5.3_%D0%95%D0%BD%D0%B5%D1%80%D0%B3%D0%B8%D1%8F_%D0%9F%D1%80%D0%B8%D0%BB%D0%BE%D0%B6%D0%B5%D0%BD%D0%B8%D0%B5_%D0%9A%D0%B0%D1%80%D1%82%D0%B8.pdf

Energy intensity of transport

Public transport in Sofia Municipality is one of the largest electricity consumers in Bulgaria.

Urban transport in Sofia Municipality includes metro, tram, trolleybus and bus transport. There are three municipal transport operators operating in Sofia - Metropolitan EAD, Stolichen Elektrotransport EAD and Stolichen Autotransport, as well as two private transport operators.

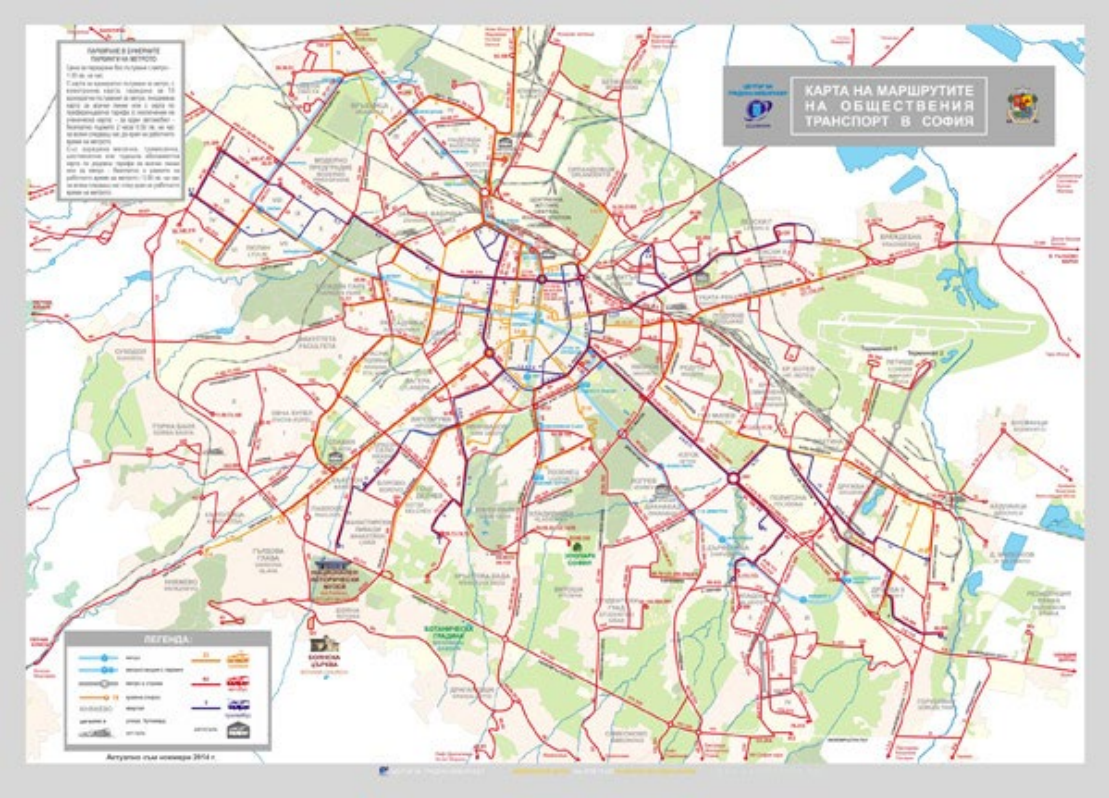

Figure 32: Sofia public transport map. Source: ***Sofia Municipality***

The busiest intersections emitting the highest level of heat, are Orlov Most, Lavov Most and Stochna Gara:

Figure 33: The busiest intersections emitting the highest level of heat

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4.2. SENSITIVITY OF EQUIPMENT AND MATERIALS

Albedo factor and emissivity

Albedo and emissivity are key factors in shaping UHI, the quality of the environment and life in the city. These are key indicators of the microclimatic characteristics of the urban ecosystem and provide an explanation for the formation of heat islands in the city. The higher the reflectivity (albedo) and emissivity of a material, the less likely it is to store heat and radiate it back.

Table 5: Albedo of different surface types. Source: Nachbarschaftsverband Stuttgart (1992)

SURFACE TYPES	REFLECTANCE/ALBEDO (%)
Dark soil, dry	14
Dark soil, moist	8
Light sand	30-40
Snow, clean	99
Surface water	5-15
Green grass	26
Concrete	14-22
Walls, white	65-50
Walls, yellow	65-50
Walls, grey	20-45
Asphalt	12-25
Gravel	5-10

Table 6: Albedo and emissivity of different materials

MATERIAL	EMISSION FACTOR	ALBEDO
Polished aluminium	0.1	0.9
Concrete	0.9	0.2
Dark tree	0.95	0.15
Red bricks	0.9	0.3
Honey	0.4	0.4
White marble	0.9	0.6
White facade paint	0.9	0.8
Gypsum	0.9	0.9

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The albedo coefficient in Sofia was analyzed by Vision for Sofia, using satellite image data from Urban Atlas, the European land monitoring program Copernicus.

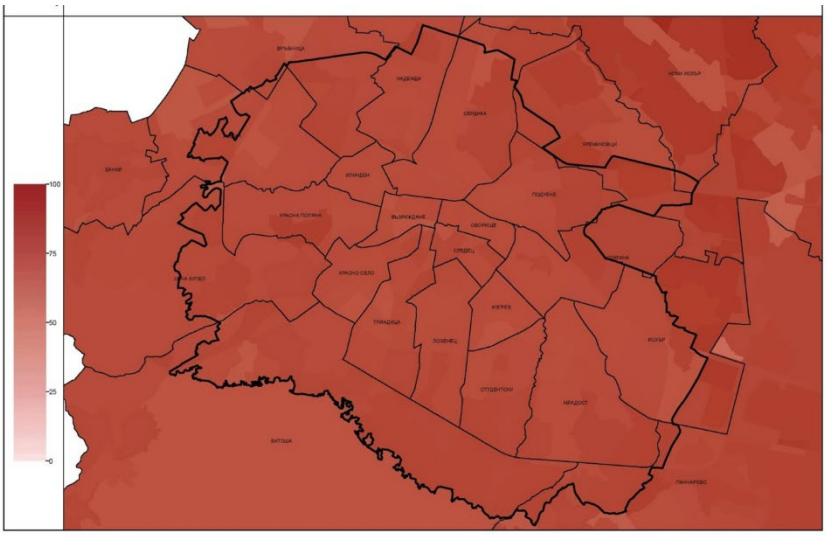
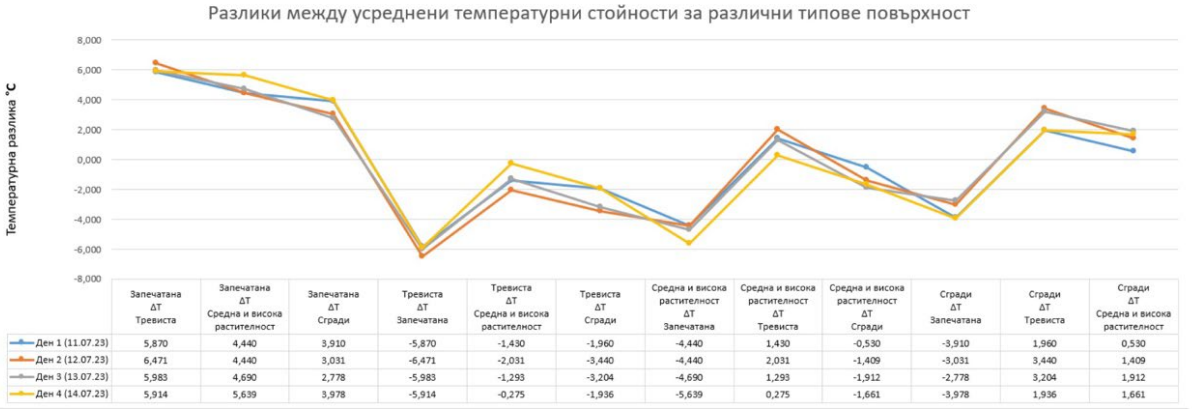


Figure 34: Map of the albedo coefficient in Sofia. Source: Sofiaplan[23]

Thermal conductivity and heat capacity

The thermal characteristics of all major land cover types were determined from a study by the National Center for Geospatial Research and Technology at Sofia University (according to the Local Plan for Climate Adaptation of Lyulin residential area through digital twin, Sofia, 2023).

Table 7: Difference between average temperature values for different surface types. Source: Lylin Digital Twin data[24]



	Запечатана ΔT Тревиста	Запечатана ΔT Средна и висока растителност	Запечатана ΔT Сгради	Тревиста ΔT Запечатана	Тревиста ΔT Средна и висока растителност	Тревиста ΔT Сгради	Средна и висока растителност ΔT Запечатана	Средна и висока растителност ΔT Тревиста	Средна и висока растителност ΔT Сгради	Сгради ΔT Запечатана	Сгради ΔT Тревиста	Сгради ΔT Средна и висока растителност
Ден 1 (11.07.23)	5,870	4,440	3,910	-5,870	-1,430	-1,960	-4,440	1,430	-0,530	-3,910	1,960	0,530
Ден 2 (12.07.23)	6,471	4,440	3,031	-6,471	-2,031	-3,440	-4,440	2,031	-1,409	-3,031	3,440	1,409
Ден 3 (13.07.23)	5,983	4,690	2,778	-5,983	-1,293	-3,204	-4,690	1,293	-1,912	-2,778	3,204	1,912
Ден 4 (14.07.23)	5,914	5,639	3,978	-5,914	-0,275	-1,936	-5,639	0,275	-1,661	-3,978	1,936	1,661

[23] https://vizia.sofia.bg/2019/04/25/environment_factors_components/
[24] https://www.sofia.bg/documents/d/guest/2024-04-26-lokalen-plan-za-klimaticna-adaptacia

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Surface temperature and emissivity

The complexes in the eastern (Mladost) and western (Lyulin and Nadezhda) parts of Sofia have the highest average measured surface temperature.

The following map shows the spatial distribution of measured surface temperature values in Sofia in August 2019 (in the time interval 20:00-22:00), based on Landsat 8 imagery.

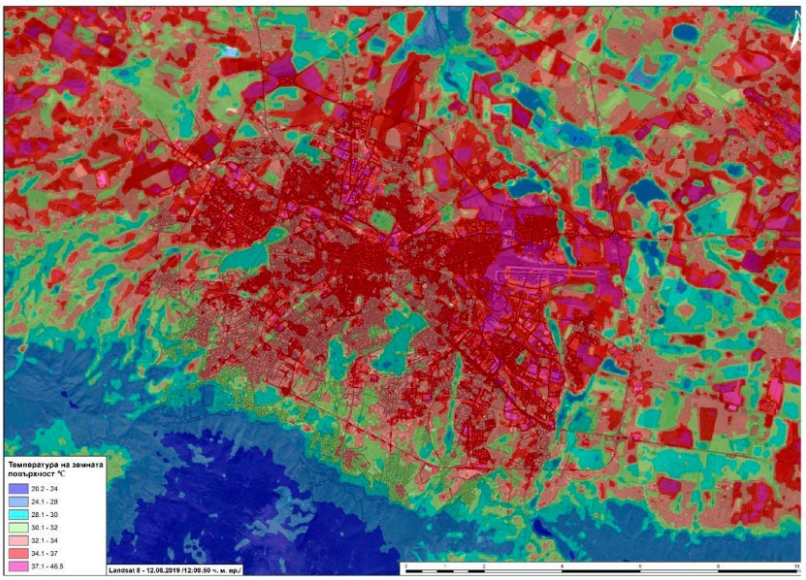

Figure 35: Map of the spatial distribution of measured surface temperature values in Sofia. Source: Lylin Digital Twin data[25]

Condition of materials

The total length of Sofia's street network of about 3 500 km. The condition of pavements is unsatisfactory, especially outside the central parts of the city. In 2024, Sofia Municipality and district administrations have renovated nearly 133 000 m^2 of pavements in the city.

Seventy percent of the buildings in Sofia are multi-family, built before 2000. Less than 10% of the buildings in Bulgaria have technical passports, so there is no data on the condition of the materials of the building stock. A study by the European Commission's Joint Research Centre (JRC) on the impact of climate change on the corrosion of Europe's reinforced concrete building stock predicts for Bulgaria that under a severe climate change scenario with a projected warming of 3 degrees Celsius by 2100, the country could face total repair costs due to corrosion of €11 **billion.** This would mean the need to repair 99 percent of the approximately 383,174 buildings surveyed in the country.

In a large number of residential buildings (single-family and multi-family), as a result of lack of maintenance and regular repairs, the building elements and common areas are depreciated and in poor condition, and as a result the plaster is falling off, they are not energy efficient, and face other technical problems as well.

[25] https://www.sofia.bg/documents/d/guest/2024-04-26-lokalen-plan-za-klimaticna-adaptacia

Sealed surfaces

According to data from 2018 cited by Sofiaplan, 84% of the territory of the municipality has surfaces of unsealed soil, and 16% of the territory is fully or partially sealed.

The use of permeable surfaces can mitigate the impact of soil sealing to some extent. By being able to infiltrate more stormwater, groundwater recharge is aided as well as lowering flood risks and water treatment costs. An important factor in urban cooling is evapotranspiration, which is allowed by permeable surfaces and in turn reduces air temperature and the energy required for cooling.

Figure 36: Map of pavement streets in Sofia. Source: Sofia GIS Plan.[26]

In the urban sections, the proportion of soil sealing is high. Oborishte is the area with the highest percentage - 71.27%, which is due to the very small surface area and the negligible amount of green spots. The situation is similar in the Vazrazhdane and Krasno Selo districts.

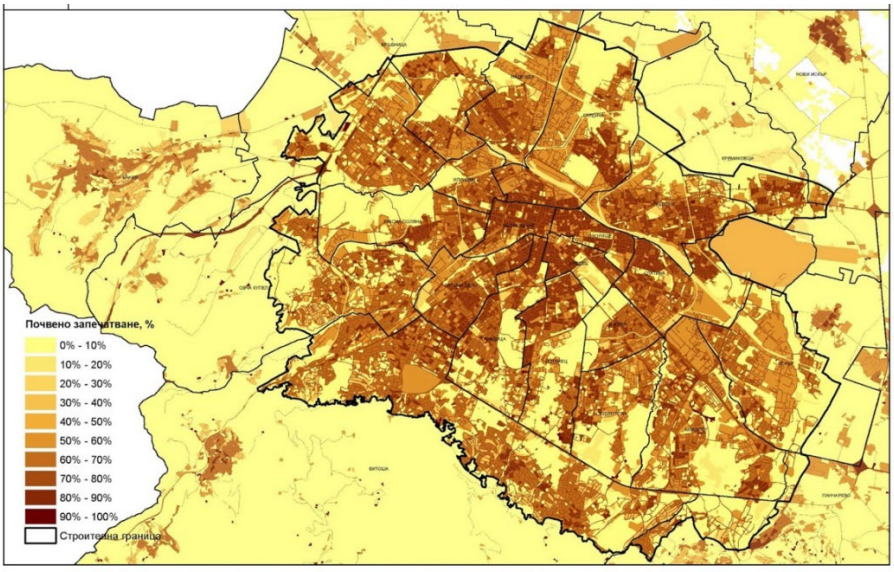

Figure 37: Soil sealing map. Source: Vision for Sofia[27]

[26] https://gis.sofiaplan.bg:3344/webappbuilder/apps/7/
[27] https://vizia.sofia.bg/2019/04/25/environment_factors_components/

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In 2020 Sofia Municipality adopted an Urban Environment Ordinance, which also contains a standard for pavements in pedestrian spaces. The table below indicates the main requirements for surface coverage.

Table 8: Standard for pedestrian spaces in Sofia. Source: Urban Environment Ordinance, Sofia Municipality

	Pavers and stone slabs	Concrete slabs and pavement with stone aggregate	Concrete slabs and pavement	Cast concrete	Asphalt pavement with stone fill	Asphalt paving
Zone 1: historic centre						
Zone 2: wide centre						
Zone 3: wide centre						
Zone 4: peripheral areas						
Zone 5: peripheral areas						
Zone 6: peripheral areas						
Zone 7: industrial areas						

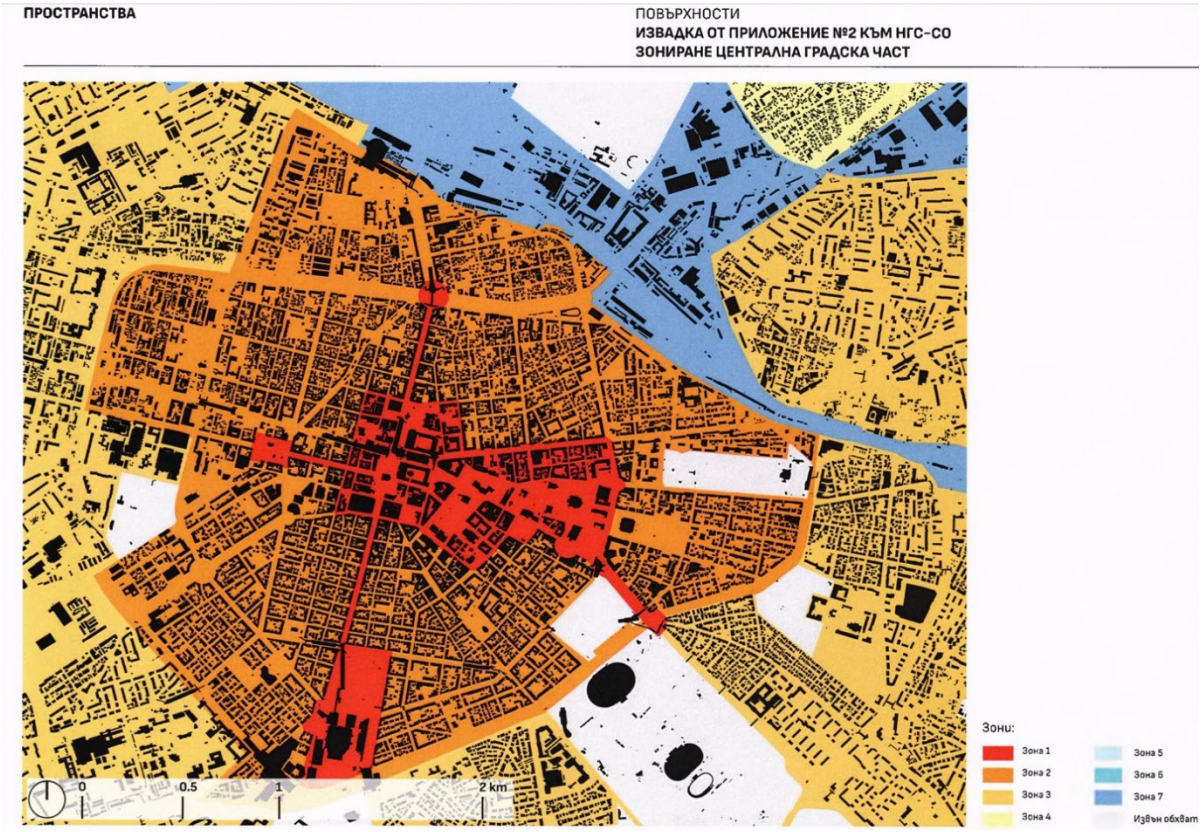

Figure 38: Zoning of a central urban area. Source: Sofia Municipality Ordinance[28]

[28] https://council.sofia.bg/documents/20182/1147995/R.537_PR.1_P.2.pdf/10d9701c-95d5-4be4-ba47-e16220c78ed4

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Green coverage

Forty-seven percent of the city's area is covered by parks, gardens and forests according to Sofiaplan. According to data from the European Environment Agency, published in "Sega" newspaper in 2019 (*see supra* footnote 13), Sofia ranks 5th for the share of green spaces as a percentage of the total city area among 28 European cities. The data notes that 62% of the city's total area is covered by green space.

Most of the landscaping was done between the 1950s and 1980s. During the 1990s, maintenance of the major parks and gardens in Sofia declined significantly and iconic sites of garden and park art were retired. Combined with climate change, this has led to the deterioration of more demanding species of long-lived woody vegetation, with some failing to adapt and decaying.

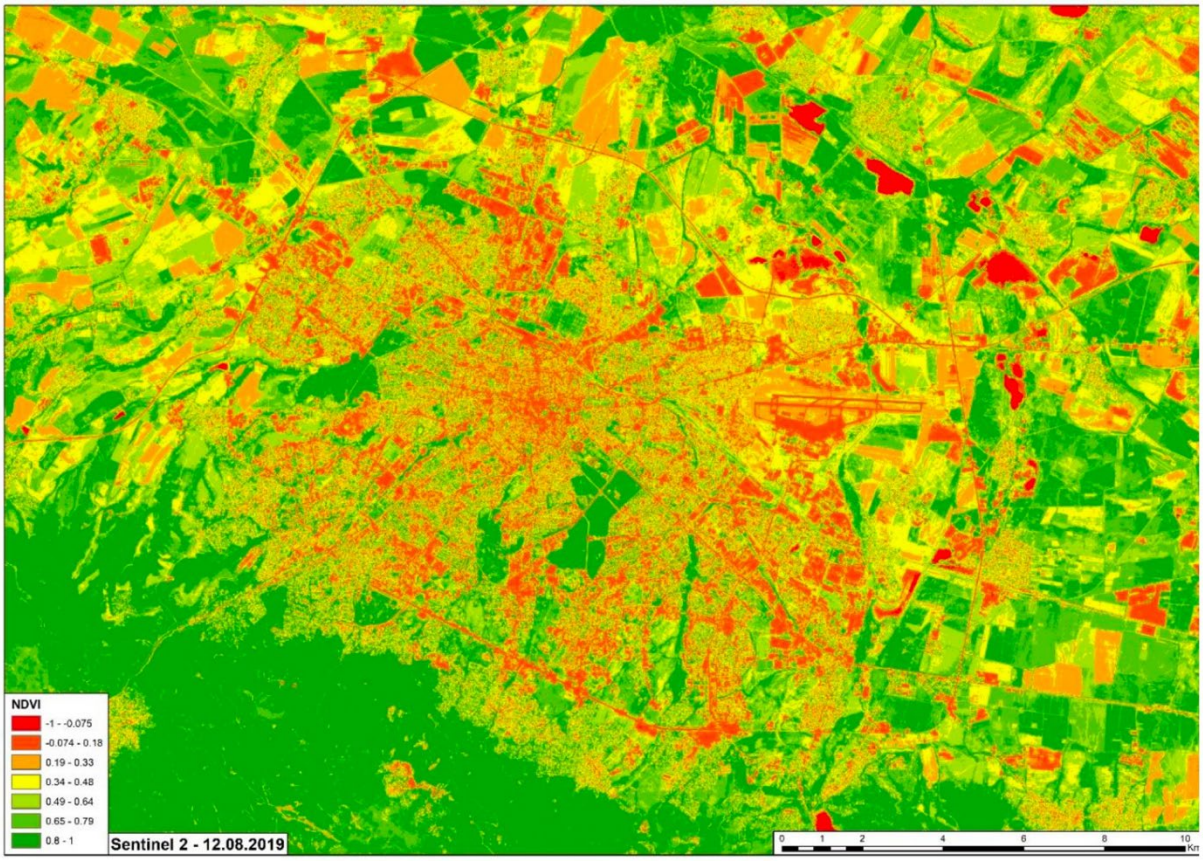

Figure 39: Land cover biomass and vegetation assessment index based on satellite data from Sentinel 2, as of 12 August 2019. Source: Good Practices Report.

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4.3. VULNERABLE GROUPS

Socio-economic indicators

Young people

Children are among the most vulnerable to urban heat due to physical and physiological differences compared to adults.

Sofia's population under 14 years is 185 107 and is distributed as follows (NSI data, 2020):

- 0 - 4 years – 61,940;
- 5 - 14 years -123,167.

Most young people live in fast-growing southern areas with active housing development.

Older people

The general trends of population ageing are also valid for Sofia, albeit in a milder version than the national average. According to NSI data for 2020, the population of Sofia is 1,221,785. The median age of the population is 40.4 years. The number of people over 64 (retirement age) is 213,058, of which 88,427 are over 75 years old. They predominate in the central areas of Sofia, where there is no major new construction, as well as in the outskirts of the city, in the neighbourhoods beyond the ring road.

Poverty level

In Sofia Municipality the relative share of the poor is 6.6%[29]. However, in 4 of the 24 districts this figure is higher, with the highest share in the Studentski district.

According to "Vision for Sofia", the analysis of the economic development and poverty levels by district[30] show that "Mladost stands out as the district with the highest economic importance with a share of 13% of the municipality's revenues and a growth of 82% for the period 2010-2016. The construction of new office buildings and the renewal and expansion of infrastructure in the area are attracting businesses and have a positive economic impact, bringing with them a population with significantly higher personal incomes. At the other end of the spectrum is Lyulin residential district, which generates only 2% of the revenues of companies in the capital and recorded a 27% decline compared to 2010, ranking among the last places in personal income levels."

[29] https://www.nsi.bg/sites/default/files/files/publications/povmap.pdf
[30] https://vizia.sofia.bg/2019/03/14/economic-profiles-sofia-districts/

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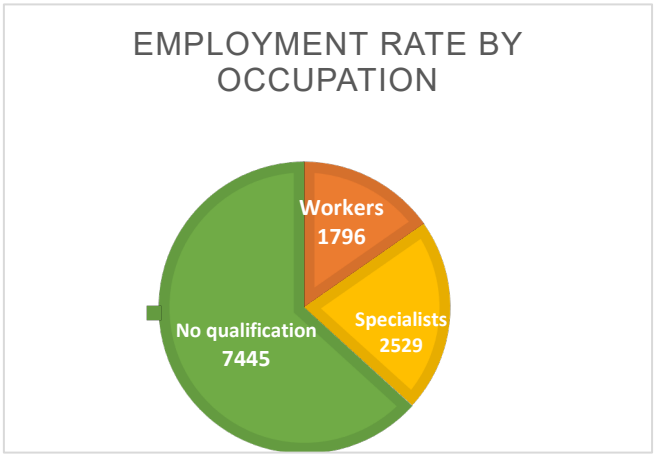
Unemployment

The unemployment rate of the population aged 15-64 (annual average) (2023) is 4.9%. The employment rate of the population aged 15-64 (annual average) (2023) is 78.4%. The number of unemployed people in Sofia in 2020, according to NSI data, is 13,057, of which 7 193 are men and 5,864 are women. The unemployment rate is 1.8% according to the Employment Agency - the lowest of all municipalities in the country and one of the lowest in Europe. As of the end of 2019, the number of people with more than 1 year of registration in the labour offices was just over 200 (0.003% of economically active citizens). The employment rate reached 77.9%.



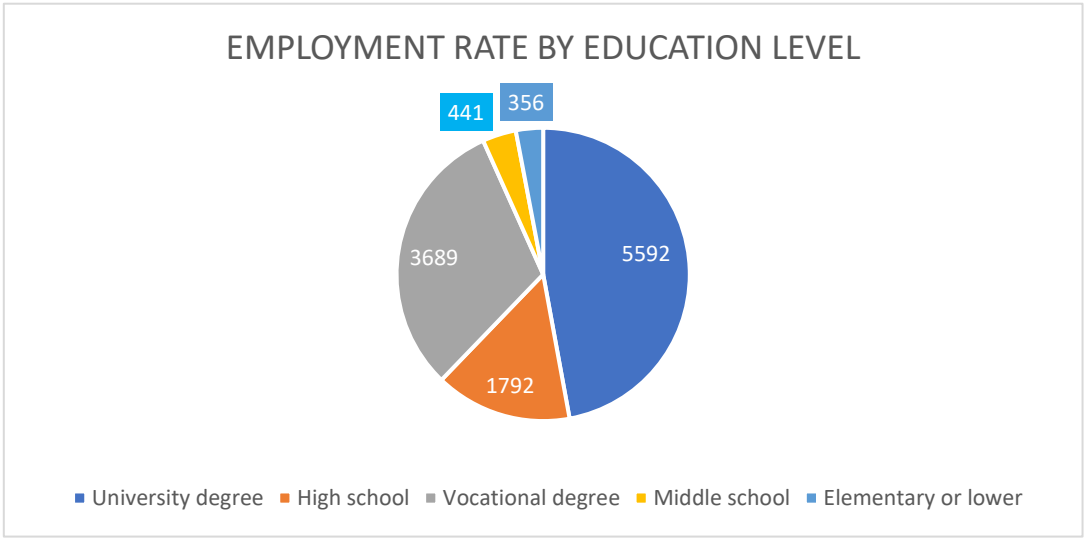


Figure 40: Structure of unemployed persons in Sofia by occupational qualification and education, 2019 Source: InvestSofia [31]

[31] https://investsofia.com/wp-content/uploads/2020/11/Sofia-Economic-Profile-Part-2-Labour-Force-2020.pdf

Population ratio by gender

There are slightly more women than men: 637 279 (52.5%) women compared to 584 506 (47.5%) men (NSI, 2020). The number of men is greater than the number of women up to the age of 44, after this age the proportion of women increases in direct proportion.

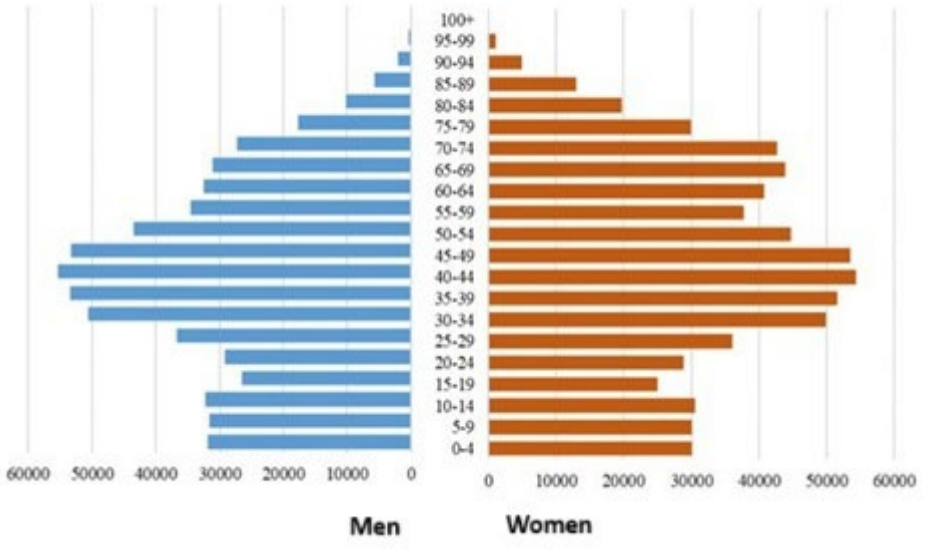


Figure 41: Age structure of the population as of 7 September 2021. Source: InvestSofia[32]

Migrants

Of the total population of 1,221,785 (NSI, 2020), 1,190,443 are people with Bulgarian citizenship.

As of September 7, 2021, 98.5% of the population of the municipality are Bulgarian citizens; 0.9% have dual citizenship.

Sofia is home to 30,405 non-EU citizens (2.3%), 57,000 foreign-born (4.4%) according to Urban Audit. The main migrant groups are refugees from Ukraine, Geneva Convention refugees from Syria and Afghanistan and economic migrants arriving through bilateral agreements.

Statistics on third-country nationals by city/municipality are not collected. The available data is the result of specific projects and initiatives. Within Sofia, observations suggest that the neighbourhoods around the Mosque and the Women's Market are the most preferred by migrants.

There are three registration and reception centres for asylum seekers in Sofia - in the districts of Ovcha Kupel, Vrazhdebna and Voenna Rampa. There are several integration centres for refugees and migrants supported by the Bulgarian Red Cross, Caritas and other organisations. There is also a closed detention centre for migrants in the Busmanci district and several accommodation centres for unaccompanied minors.

[32] https://investsofia.com/wp-content/uploads/2020/11/Sofia-Economic-Profile-Part-2-Labour-Force-2020.pdf

Low skilled jobs

The share of the population aged 25-64 years with higher education is 57.6% (compared to 29.8% in the country), while the share of the population with primary education and below is 4.0% (compared to 16.0% in the country).

In 2020, according to the NSI, there were 45,439 people aged between 25 and 64 with primary education or less. While this figure is declining, at 58,405 in 2019 there remains a high proportion of people with no or low education and skills, which is consistent with low-skilled employment.

Population density and territorial distribution

According to the data of the GRDA, the territories that attract the most population are the southern districts of Sofia, which are also experiencing a large residential construction. The districts with the largest populations are Studentski (43 000 people) and Mladost 3 (30 000).

The highest population density - between 350 and 600 inhabitants per hectare - is observed in the areas between Tsar Boris III, Bulgaria and Okolovrastno Shose boulevards and in their immediate vicinity.

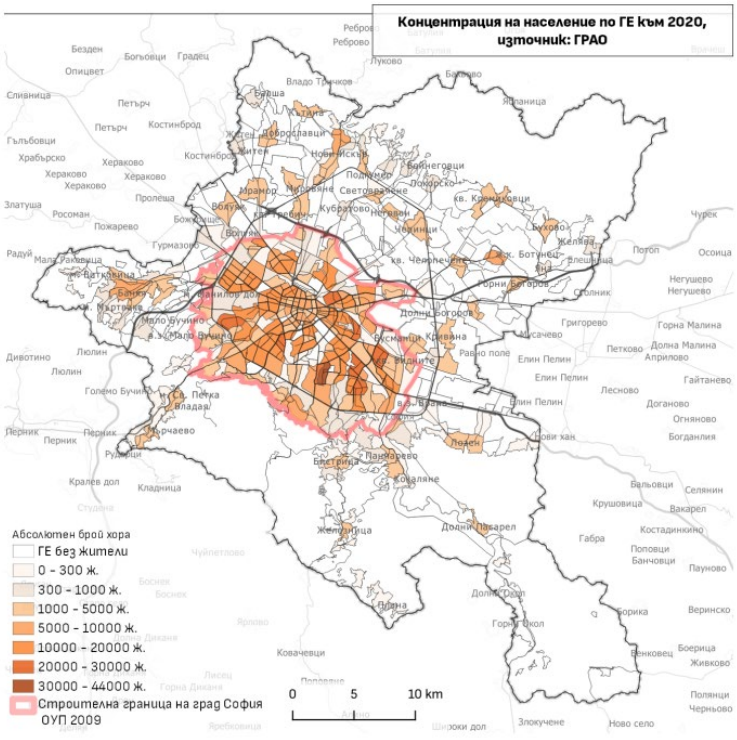


Figure 42: Population concentration by geographic unit in 2020. Source: Sofiaplan

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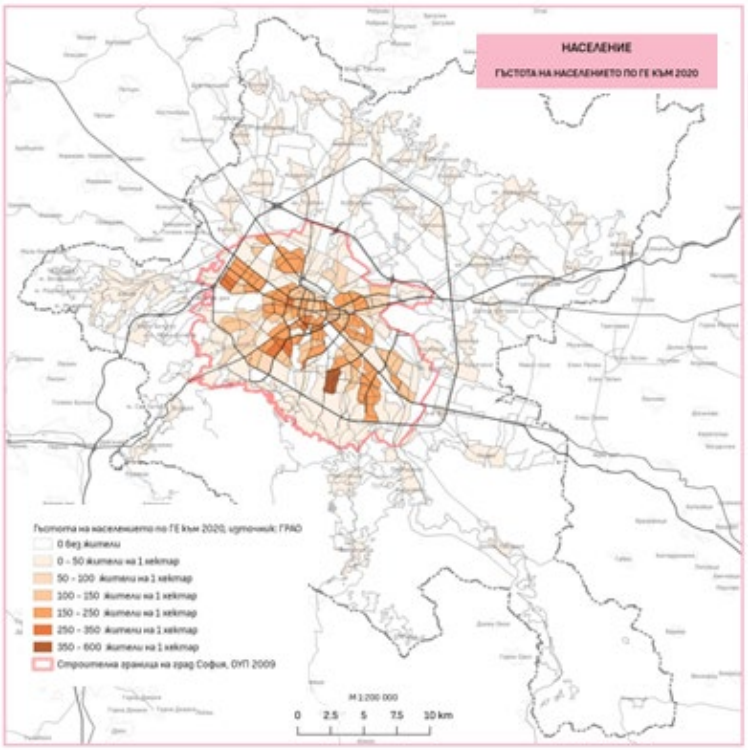

Figure 43: Population density by geographic unit by 2020 Source: SofiaPlan

Health condition

People with diseases

Sofia is the city with the highest concentration of population, medical facilities and access to health care. However, the overall health status of the metropolitan population, including children and adolescents, is unsatisfactory.

The total life expectancy at birth has temporarily decreased by 1.5 years in 2020 compared to 2019, due to deaths due to the COVID-19 pandemic. Stroke, ischaemic heart disease and lung cancer for the leading causes of death and accounted for a third of all deaths in 2018.[33]

There are several risk factors that contribute to poor health status - smoking, unhealthy diet, alcohol use, low physical activity. Certain environmental factors, especially air pollution, also influence disease and mortality. In contrast to these factors, adult obesity is below the European average.

People with disabilities

According to data on the health status of the population from the last census in September, 2021, people with disabilities in Bulgaria are nearly 10%[34] and the percentage in Sofia is similar.

[33] https://health.ec.europa.eu/system/files/2022-01/2021_chp_bulgaria_bulgarian.pdf
[34] https://nsi.bg/bg/content/19944/прессъобщение/здравен-статус-на-населението-към-7-септември-2021-година

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The proportion of people aged 16 and over with a disability over 50% is 9.2%, lower than the national average.

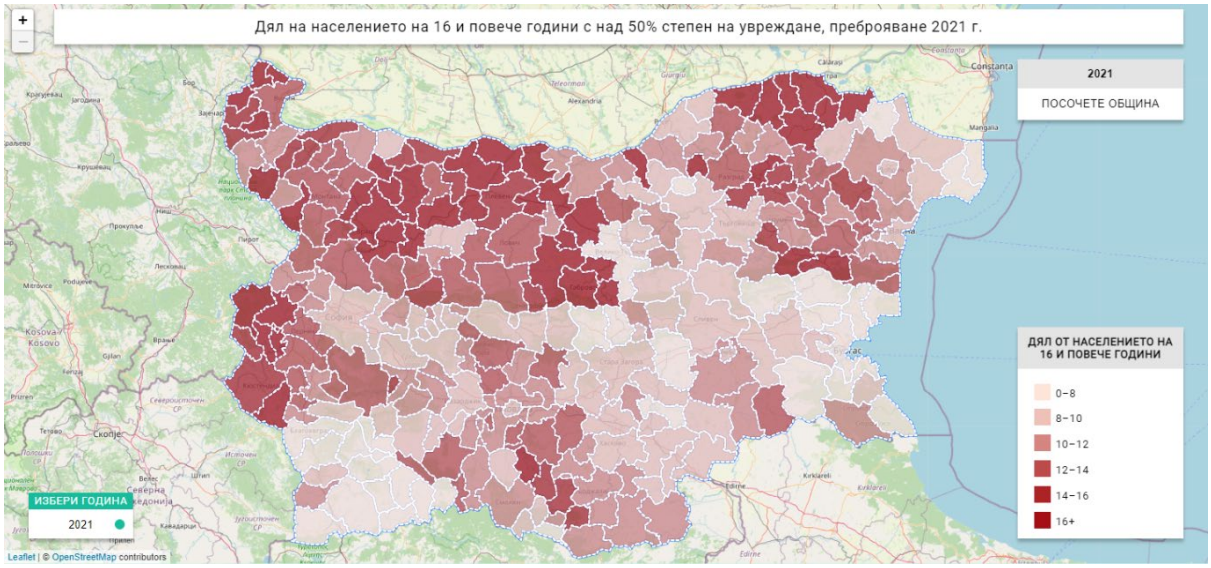

Figure 44: Proportion of population aged 16 and over with more than 50% disability, Census 2021. Source: Institute for Market Economics[35]

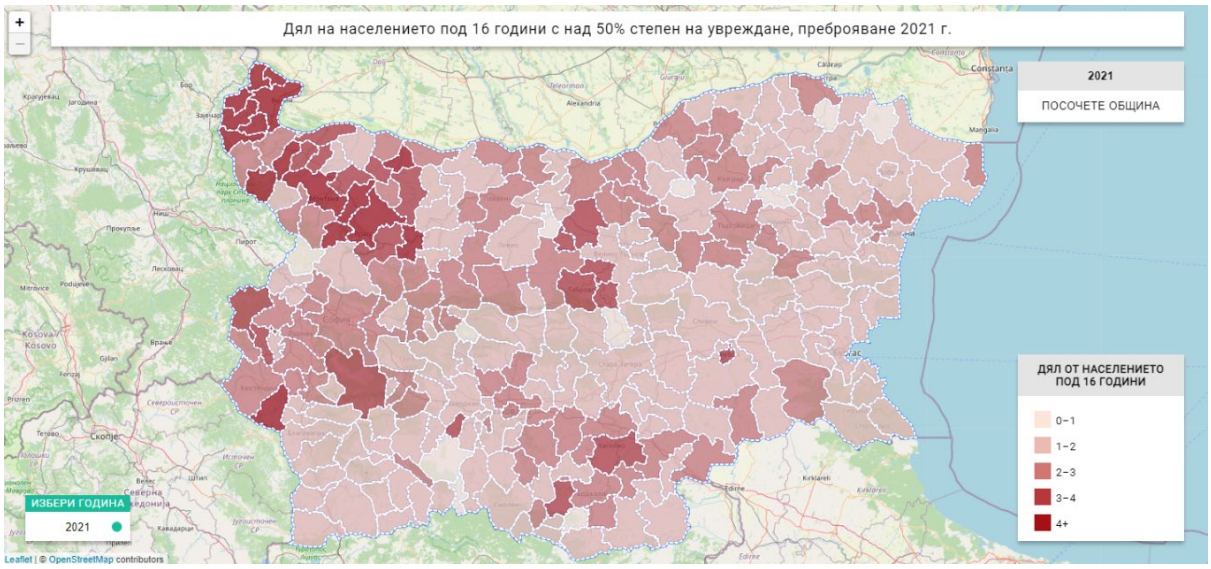

Figure 45: Proportion of population aged under 16 with more than 50% disability, Census 2021. Source: Institute for Market Economics[36]

[35] https://ime.bg/articles/karti-horata-s-uvrejdaniya-v-bylgariya-spored-prebroyavane21-1/
[36] https://ime.bg/articles/karti-horata-s-uvrejdaniya-v-bylgariya-spored-prebroyavane21-1/

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Mentally ill people

A sociological survey of mental health in Sofia Municipality shows that one in six Sofia residents knows someone suffering from a mental disorder or disability, and another 29% have experiences of such cases. Only a quarter have not encountered such a problem[37]. At the same time, respondents believe that people with mental disabilities are the most neglected by both institutions and society compared to people with other types of disabilities.

There are state, municipal and university facilities in Sofia where mental health care can be obtained. There are also private psychiatric practices. There are six sheltered housing facilities for persons with mental retardation and mental disorders, which are insufficient for the needs of the municipality.

Usually, older people with mental disorders also have comorbidities - diabetes, hypertension, neurological diseases, etc. In addition, there is a large gap between the health and social systems, which place emphasis on resocialization and social integration into the community. These deficits affect most severely people without relatives to care for them and they are at risk of marginalisation.

Mortality

The overall mortality rate among the population is lower than the national average. According to Sofiaplan[38], between 2001 and 2005 the value was around 12.6 - 12.7%. For the subsequent ten-year period, the mortality rate ranged between 11.6 and 11.9%, with a national average of 15.5%. In the Covid-19 setting, the mortality rate reached 16.8%. In 2020, 16,277 people have died.

Infrastructure

Capacity of hospitals

According to the NSI[39], there are 67 hospital care facilities in Sofia (of which 38 are specialised and the remaining 28 are multi-profile) with a total of 11,040 beds. There are 344 outpatient medical facilities (diagnostic and consultative centres, medical centres, dental centres, etc.). The total number of health institutions is 612. There are 51.2 doctors per 10 000 inhabitants in Sofia (National Centre for Public Health, 2020).

Sofia Municipality manages 38 health care facilities, making it a very large health care provider. These are 21 diagnostic and consultative centres, 2 dental centres, 2 medical centres, 1 mental health centre, 1 centre for skin and venereal diseases, 7 specialised and 4 multi-profile hospitals.

[37] http://psihichnozdrave.com/wp-content/uploads/2011/05/Analysis_Health_Social_System-final.pdf
[38] https://sofiaplan.bg/wp-content/uploads/2021/10/I.2_Население_Приложение_Карти.pdf
[39] https://www.nsi.bg/bg/content/3312/лечебни-и-здравни-заведения-на-3112-по-статистически-райони-и-области

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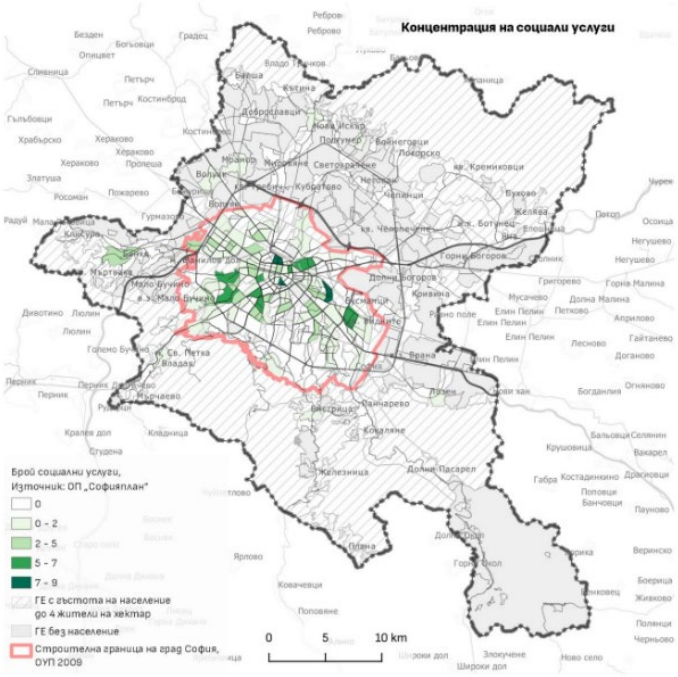
Social services for the elderly in the community

There are 43 pensioners' clubs in Sofia - at least one in each of the 24 Sofia districts, except for Serdika and Vitosha.

On the territory of Sofia Municipality there are:

- 8 homes for the elderly with a total capacity of 1001 places (the ratio of people accommodated in them is 37 per 100 000 inhabitants);
- 3 temporary accommodation centres for adults with a total capacity of 510 places;
- 2 accommodation centres for homeless people with a total capacity of 170 places;
- 14 centres for social rehabilitation and integration of people with a total capacity of 670 places;
- 7 community support centres with a total capacity of 530 places;
- 10 social canteens served by the municipal enterprise "Social Patronage"[40].



Around 1 600 people use the service of OP "Social Patronage" for food delivery - the highest share of them live in "Lozenets", "Sredets", "Krasno Selo", "Vitosha" and "Novi Iskar".

Figure 46: Territorial coverage of social services. Source: SofiaPlan [41]

Vulnerability index

Data related to population health is particularly protected due to the possibility of personal data being disclosed. They are therefore not geographically localised by region. In addition, the decentralisation of health and social services leads to an influx of clients from other parts of the country. For this reason, the vulnerability index was tested for only three areas of Sofia, with only public data available. The source of the data below is the National Statistical Institute and reports of "Vision for Sofia."

[40] https://sofiaplan.bg/wp-content/uploads/2021/10/I.7.3_Социални-услуги_Приложение_Карти.pdf
[41] https://sofiaplan.bg/wp-content/uploads/2021/10/I.7.3_%D0%A1%D0%BE%D1%86%D0%B8%D0%B0%D0%BB%D0%BD%D0%B8-%D1%83%D1%81%D0%BB%D1%83%D0%B3%D0%B8_%D0%9F%D1%80%D0%B8%D0%BB%D0%BE%D0%B6%D0%B5%D0%BD%D0%B8%D0%B5_%D0%9A%D0%B0%D1%80%D1%82%D0%B8.pdf

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Table 9: Vulnerability index for three areas in Sofia

	Krasna Polyana	Kremikovtzi	Nadezhda
Population	**53 000**	**22 500**	**65 000**
Men/women (%)	**48% / 52%**	**49% / 51%**	**47% / 53%**
Children 0-14 years (%)	**17,10%**	**15,3%**	**13%**
Adults 65+ (%)	**21,5%**	**21,1%**	**22.8%**
Income compared to the average for Sofia (%)	**-20% (1048 BGN)**	**-25% (990 BGN)**	**-31% (903 BGN)**
People with primary and lower education (%)	**23%**	**30%**	**18%**
Population density (inhabitants/hectare)	**190**	**50**	**200**
Medical facilities	**2**	**1**	**2**
Pensioner clubs	**3**	**4**	**3**
Vulnerability index	**0.43**	**0.29**	**0.41**

The vulnerability index above was calculated based on a methodology developed by the Be Ready project's science partners. The calculation of the vulnerability index involves determining the weight of each indicator involved in the study. The weighting of indicators according to the methodology is carried out by working groups of stakeholders in each project partner city. Following the methodology, SDA organized an expert workshop (see focus group report in Annex 2 below) where a maximum and minimum value for each indicator were defined. The maximum and minimum values are real values from other Sofia districts. Example: Population - data for the region with the least numerous population and the region with the highest population. Similarly for the other indicators. The indicator weight is shown in the table below. According to the methodology, the above indicator values are correlated to the lowest and the highest indicator values among the district administrations of Sofia Municipality and are calculated according to a formula specified in the methodology.

Table 10: Calculation of the vulnerability index by indicator weight

Indicator	Indicator Weight (1 is the least weighted - 10 is the most weighted)	Minimum value	Maximum value
Population	**8**	12747	106112
Men/women (%)	**5**	49%	54%
Children 0-14 years (%)	**9**	9.60%	17.40%
Adults 65+ (%)	**10**	18.80%	31.80%

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Income compared to the average for Sofia (%)	**4**	5	226
People with primary and lower education (%)	**6**	2%	30%
Medical facilities	**7**	1	4
Pensioner clubs	**3**	0	5

The vulnerability index application was the first activity of this kind for Sofia. Although the experience – as a pilot – raised a bit of scepticism and resulted in some uncertainty, the team was content with the outcome and the opportunity to quantify the vulnerability and therefore add objective indicators to it.

Data gaps and community engagement

To validate the available data, address the lack of publicly available data and engage potentially vulnerable communities, several methods of quantitative and qualitative data collection were used: an online survey, meetings at SDA office for collaborative mapping, a focus group. These methods contributed to clarifying socioeconomic and health categories and personal experiences with urban heat and ways of coping.

Based on these methods, the following three infographics were developed for three groups of vulnerable citizens, presented below.

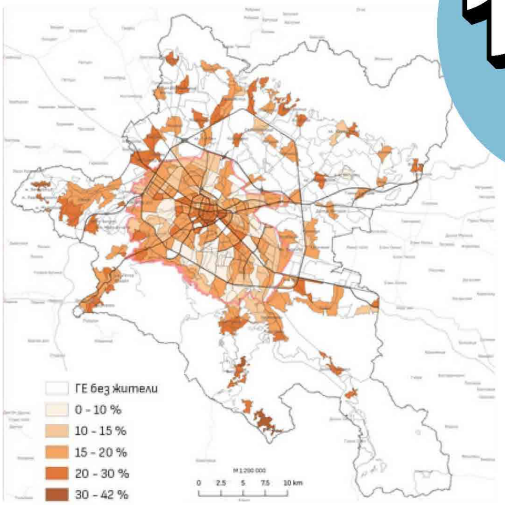
ELDERLY PEOPLE

1 ★ POPULATION AGED 65 AND OVER

Population aged 65-74: **124 631**

Population aged - 75: **88 427**

★2020, National Statistical Institute



Concentration of population over 65 years of age by GE by 2020 in the city of Sofia, source: GRAO, Sofiaplan.

2 HOW DO URBAN HEAT ISLANDS AFFECT THE ELDERLY?

- Dehydration, dizziness, weakness, severe thirst and headache.
- For people with cardiovascular diseases - drop in blood pressure.
- In case of an increase in internal body temperature (heat stroke) - organ failure.
- Possible complications and life-threatening conditions related to kidney diseases, stroke, heart attack, migraine, mental illness.

3 THE DEGREE OF DANGER IS DETERMINED BY:

AGE: the ability to regulate body temperature decreases with age.

PHYSICAL AND MENTAL HEALTH: chronic problems often occur, and especially in cardiovascular, respiratory and endocrine diseases.

ECONOMIC AND SOCIAL CONDITIONS: if they cannot afford to have air conditioning at home or to use it in the summer, they do not have the option of temperature comfort and cooling; or if they have to go outside because of commitments or a feeling of social isolation.

RISK-INDUCING BEHAVIORS: direct sun exposure or physical activity at peak heat hours; switching abruptly from cool indoor conditions to hot outdoor environments, with a temperature difference of over 10 degrees and no time to adapt; wearing dark, thick clothing made of artificial fabrics and not wearing a hat; insufficient water intake.

4 HOW THE ELDERLY PREFER TO COPE WITH EXTREME HEAT:

- If their homes have cooling - air conditioning or ventilation - older people prefer to stay at home during heatwaves.
- If their homes lack cooling, the elderly prefer to go to a park with tree cover for shade and water facilities; with drinking water, toilets, benches and places to rest, but without factors causing social stress: too much noise and crowds.
- Going outside is often about having company–those living in social isolation may not consider seeking a cool place outdoors as an option.
- Many elderly people still do not recognize the harmful effects of heat, as for most of their lives, the problem has been the opposite: staying warm.

Sources: NSI; CRAS; Sofiaplan; own research

Figure 47: Infographic for elderly people

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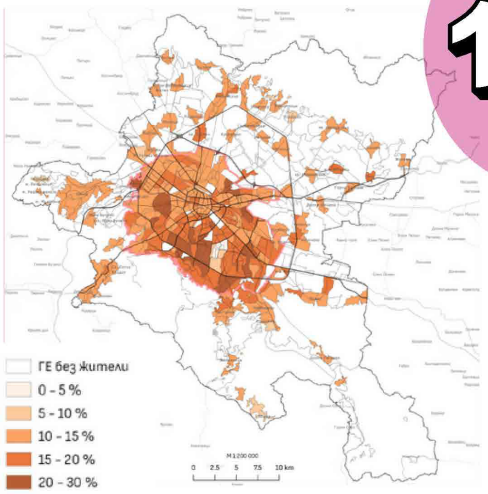
CHILDREN

1 ★ POPULATION AGED 0 TO 14 YEARS

Children aged 0-4 years: **61 940**

Children aged 5-14 years: **123 167**

★ 2020, National Statistical Institute



Concentration of population aged 0 - 14 years. by GE by 2020 in Sofia, source: GRAO, Sofiaplan.

2 HOW DO URBAN HEAT ISLANDS AFFECT CHILDREN?

- Children have physical and physiological differences compared to adults: a higher surface-to-mass ratio, a less developed body and immune system, a lower sweating rate due to smaller sweat glands, and a different ability to perceive the thermal environment.
- Young children exposed to high temperatures are more likely to develop jaundice and neurological dysfunction, and dehydration can affect their nutritional status. They may experience heat exhaustion and muscle cramps, and heat strokes can damage their brain, heart, kidneys, and muscles.
- Extreme heat causes sleep problems during the day and night.
- Many children become lethargic, lose the desire to play (fundamental for their development), and do not have the opportunity to spend time outside, which can lead to nutritional problems and depression.
- Their concentration and focus deteriorate, and their school performance declines.

Sources: National Statistical Institute, GRAO, Sofiaplan, own research

3 THE DEGREE OF DANGER IS DETERMINED BY:

AGE: particularly dangerous is extreme heat for infants from 0 to 4 years.

ADAPTABILITY: children may not notice signs of heat stress, they adapt more slowly to changes in temperature.

FLUID INTAKE: if not carefully monitored, children may not take in enough fluids.

SOCIAL AND ECONOMIC CONDITIONS: if they live in a home without cooling and ventilation or spend a lot of time outside directly exposed to the sun.

4 HOW TO PROTECT CHILDREN FROM THE INFLUENCE OF HEAT ISLANDS:

- Children cannot cope or decide for themselves, as adults do. That's why adults should be extra attentive.
- Outdoor public spaces intended to be used or visited by children such as playgrounds, spaces between residential buildings, public transportation stops, etc., shall be screened and adapted to protect from heat with appropriate landscaping, access to potable water, and shade.
- Going outdoors should be done during suitable hours when temperatures are lower, and with appropriate clothing.
- Places visited by children - schools, kindergartens and nurseries, health centers, child care centers, etc. should also be equipped to deal with the heat, with adequate cooling, shade in courtyards, and potable water, especially in neighborhoods with low-income families.

Figure 48: Infographic for children

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PEOPLE WITH DISABILITIES

1 PEOPLE WITH DISABILITIES

The City of Sofia does not have accurate statistics on the number of people with disabilities. Available data is from the 2021 census self-reported health status.

The proportion of people aged **16** and over with a disability level of over **50%** is **9.2%**, which is lower than the national average.

2 HOW DO URBAN HEAT ISLANDS AFFECT THE DISABLED AND CHRONICALLY ILL (E.G. DIABETES, CARDIOVASCULAR DISEASES, SENSORY IMPAIRMENTS, MENTAL ILLNESS, ETC.)?

- In addition to the problems caused by heat that affect everyone, such as insomnia, dehydration, brain fog, etc., people with disabilities may experience additional difficulties (depending on the type of disability. For some disabilities, there are physical limitations in coping with heat, such as the inability to sweat (which helps minimize overheating). If people with mental illnesses are left to cope with the heat on their own, it can worsen their condition. Some of the medications taken by people with disabilities also interfere with the body's cooling mechanisms. Prolonged exposure to extreme heat, due to some people's limited mobility, also increases discomfort and sensitivity to pain.
- Particularly vulnerable are people with spinal injuries and people with mental illness.
- For those who rely on assistive devices or equipment, such as wheelchairs or orthotics, the heat generated by these devices increases discomfort in hot weather.
- Social aspects - people with disabilities have more difficulty accessing transportation and public parks suitable for cooling; limited to stay at home, they are more likely to experience social isolation, especially during heatwaves.
- Economic aspects: people with disabilities and chronic illnesses often have lower incomes, and have a harder time maintaining a comfortable living environment.

3 HOW TO PROTECT PEOPLE WITH DISABILITIES FROM THE IMPACT OF HEAT ISLANDS:

- Check their homes for medication storage conditions and create a "cool place" with temperatures below 26 C in the summer.
- A plan for personal assistants, social and health workers, and volunteers (when appropriate) on how to care for people with disabilities during heat waves.
- Create accessible channels for climate and heat emergency information for people with disabilities.
- Fostering networks of acquaintances, relatives, neighbors, and friends to maintain contact with people with disabilities during heatwaves.

Sources: Institute for Market Economy, own research

Figure 49: Infographic for people with disabilities

4.4. READINESS AND ADAPTATION CAPACITY OF SOFIA MUNICIPALITY

Institutional factors

Management structures

The organization and activity of the Sofia Municipal Administration is regulated by the existing laws and regulations. In accordance with the competence conferred, the Sofia Municipality ensures the performance of its functions through the following organogram (updated 12.01.2023, Sofia Municipality website)[42].

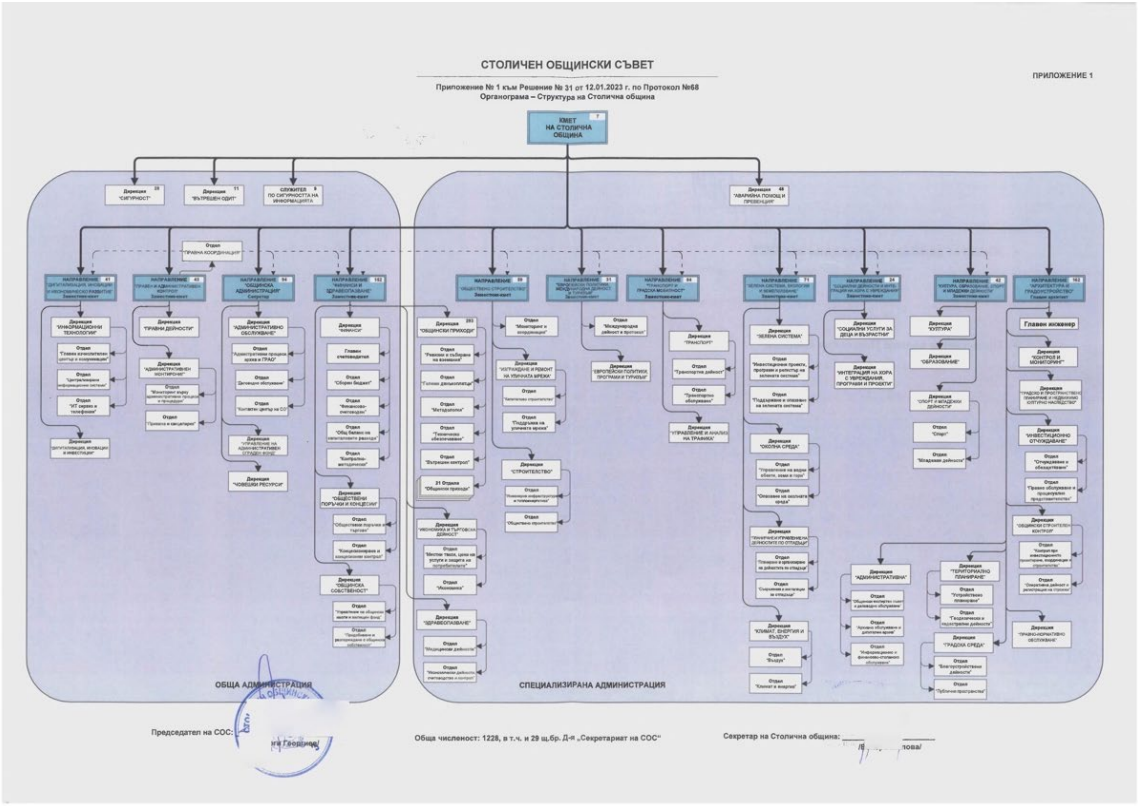

Figure 50: Organogram of Sofia Municipal Administration

The Green System, Ecology and Land Use Department is headed by a Deputy Mayor and comprises 4 directorates: the Green System; Environment; Waste Planning and Management; and Climate, Energy and Air.

Activities and policies related to climate change and urban heat islands are mainly within the scope of the latter directorate, although they also affect the activities of the others.

[42] https://www.sofia.bg/web/mayor-of-sofia/structure-of-administration

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According to several respondents to the Be Ready survey, the relationship between the Climate and Energy Directorate and the rest of Sofia Municipality is not clear and effective. Climate change concerns health, economy, tourism, transport, security, construction. A more efficient allocation of portfolios and human resources is widely recommended, with a Deputy Mayor for Climate and Energy as the head.

"There is an organisational structure - a directorate - that is supposed to coordinate climate and energy policies, but unfortunately it does not seem to be fully effective, probably due to a lack of understanding by other strands why climate action and policies need to be integrated. There is probably also a need for increased expertise and capacity in terms of the number of staff dealing with the topic, and why not a structural change that at a purely hierarchical level would pick up the topic.[43]

"I don't think the structure of the municipal council and the municipal administration reflects the importance of the climate change issue either."

"The lack of horizontal understanding of the topic is very strongly felt and experts from different units of the municipality are not familiar with the need for a comprehensive understanding and implementation of the measures. Experts remain only in their respective areas and the understanding and implementation of the measures is not holistic. Example: people working on spatial planning policies, implementation of infrastructure projects, maintenance and operation of different systems, etc. do not understand, are not required to and respectively do not implement actions related to adaptation to climate change or reducing the effects of heat islands."

"I find the main challenge to be the lack of organisational and management capacity, as there are many opportunities, but no clear and consistent sense of moving towards addressing the climate challenge."

Legislative and regulatory regimes

Bulgaria's legal framework and policies at national level for climate change adaptation should be understood as implementing its commitments under international conventions and EU legislation. Several key strategies and programmes provide a good basis in this respect - such as the Third National Action Plan on Climate Change, the Climate Change Mitigation Act, the National Strategy for Adaptation to Climate Change 2030 and Action Plan, the Environmental Protection Act, the Biodiversity Act, the Spatial Planning Act, etc.

However, there are gaps and barriers. The biggest barrier cited by respondents is that climate change is not a priority of either local or national policy. The line ministry is the Ministry of Environment and Water, and climate is not even in its title. The next most frequently cited barriers are lack of institutional capacity and insufficient policy coherence and implementation coordination.

Besides, in the last two and a half years Bulgaria has been in a continuous political crisis. The lack of a regular national government, the poor absorption of EU funds, especially for reconstruction and development, is also not conducive to Sofia's adaptation to climate change. There is a lack of a targeted policy to inform citizens about the seriousness of climate change problems.

[43] All quotes are from the Be Ready project's own research.

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"Economic incentives for traditional energy sources and limited access to long-term financing are hindering Sofia's progress."

"In any case, the Bulgarian legislation is riddled with conceptual puns and inter-legal contradictions, especially regarding the green system of settlements. Economic policy and politics in general nowadays do not focus on climate or better urban greening and this, combined with increased investment pressure from the construction business, leads to excessive building and, in general, to a further deterioration of climatic conditions and quality of life in the municipality."

Policies, strategies and plans

Sofia has been a member of the Covenant of Mayors since 2011.

Sofia is one of the 100 Climate-Neutral and Smart Cities by 2030 - the European Commission's mission.

In the current mandate, Sofia has a representative in the European Committee of the Regions, in the Committee on Environment, Climate Change and Energy.

Sofia Municipality currently has the following strategic documents that address the topic of climate change and adaptation, which it is implementing:

- Ambient Air Quality Programme 2021-2026
- Climate Neutrality Treaty signed for CO
- Sofia Municipality's Sustainable Energy and Climate Action Plan 2021-2030, including an Energy Efficiency Programme and a Long-Term Programme to Promote the Use of Renewable Energy and Biofuels
- Climate Change Adaptation Plan 2019-2025
- Green City Action Plan
- Climate Change Adaptation Plan for the Lyulin Region based on a digital twin and nature-based solutions
- Climate Neutrality Treaty of Sofia as one of the 100 Climate Neutral and Smart Cities
- Vision for Sofia 2050
- A strategic model for reducing the urban heat island effect and a master plan for planting and protecting street trees
- Sofia Municipality Integrated Development Plan
- Urban Environment Ordinance - standard for pavements in pedestrian spaces.

According to the legal requirements, all documents are agreed and subject to public hearings and adopted at meetings of the Sofia municipal council which are open to citizens.

The municipality has not implemented requirements for facade materials and colors, no climate oases/climate refuges have been built, no platform to provide traceable and timely climate information to stakeholders, no early warning system in case of climate disasters. Moreover, there is no practice to effectively implement some measures provided in the laws such as control of landscaping within 5 years after completion of construction as provided in the Land Use Planning Act.

In the questionnaire, which was conducted among 50 respondents from Sofia, most of these documents are known to those who are interested and know where on the website of the municipality to find them. However, the prevailing opinion is that the documents are available

mainly because they are required by European projects or international agreements and memberships, but this does not mean that the municipality has the capacity to fully implement them, at least in terms of performance monitoring, public reporting/disclosure of results, and systematic data collection, tracking and reporting.

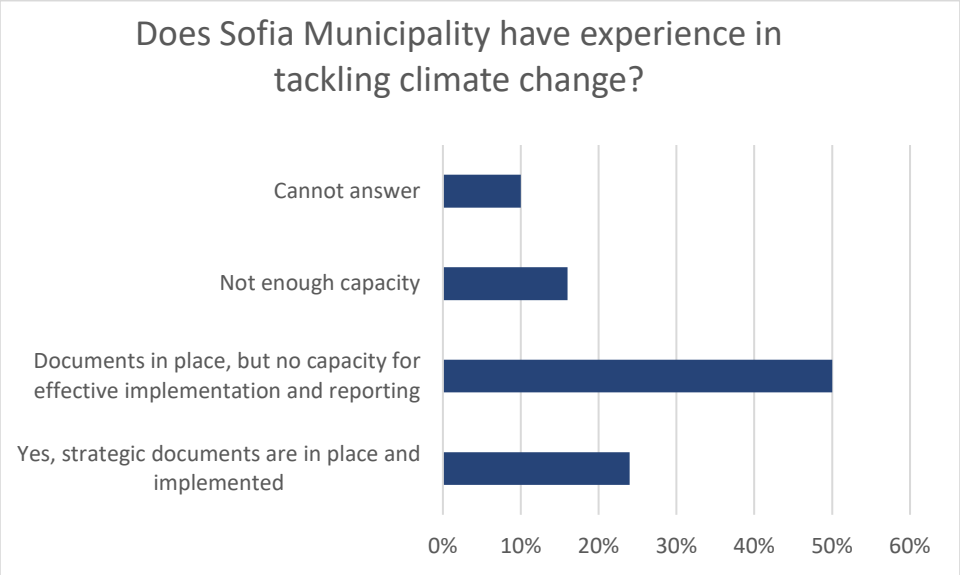

Figure 51: Sofia Municipality experience in tackling climate change. Source: SDA's own survey

Social factors

Social connectivity

Sofia Municipality has a permanent "Climate Neutrality Transition Unit", which includes representatives of stakeholders who have signed the Climate Neutrality Treaty. The Unit meets at least once every three months to monitor the implementation of the Treaty.

Since the previous mandate of the local government, there is a Scientific Council on Climate and Climate Change with the participation of representatives of the Bulgarian Academy of Sciences, Forestry University, University of Chemical Technology and Metallurgy, Higher School of Transport, Sofia University, Technical University, Deputy Mayor for Environment, Chief Architect of Sofia Municipality and representatives of the municipal enterprise "Sofiaplan".

The Climate Neutrality Contract was signed in September 2024 by the Bulgarian Council for Sustainable Development, the Bulgarian Chamber of Builders, SOF Connect JSC - operator of Sofia Airport, Veolia/Sofiyska Voda JSC, the Association of Owners of Business Buildings and Cleantech Bulgaria. On the part of the scientific community, the commitment was made by the Rectors of the University of Architecture, Civil Engineering and Geodesy, the University of National and World Economy, the Forestry University and the Todor Kableshkov University of Transport.

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Social cohesion and the capacity of communities to organise

According to the results of the focus group and the stakeholder survey, participation in the established ecosystem of Sofia Municipality is mainly driven by businesses, whose participation is largely determined by their corporate social responsibility and ESG, and by research organisations and universities. As evidenced by both the supporters of the Net Zero Cities Climate Treaty and the members of the Science Council, the participation of NGOs is more problematic because they express more diverse positions and are often in direct conflict with the Sofia Municipality.

"In principle there is an ecosystem, but de facto I see only politicisation, not compact working in symbiosis for the good of the common goal."

"The NGO sector works independently of the administration and although the latter could benefit from their experience, the impression remains that this is not happening."

Available skills and knowledge

Both as a participant in the EC's 100 Climate Neutral and Smart Cities Mission, as a capital city with more than 40 higher education institutions, and as a participant in European projects and networks, Sofia has access to the necessary financial, technological and scientific resources, knowledge, skills and networks to help tackle climate change and urban heat islands.

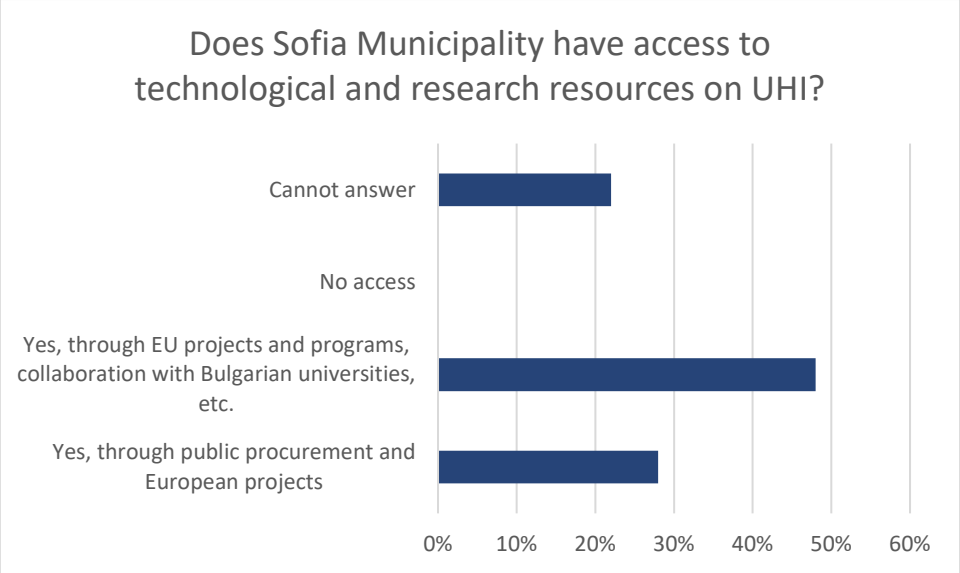

Figure 52: Sofia Municipality access to technological and scientific resources. Source: SDA's own survey

What is more problematic is not access but the institutionalisation of knowledge and skills. Most of the respondents to the survey were not aware that the Sofia Municipality had a policy on staff capacity development and retention. The small number of staff in the Climate and Energy Directorate and their heavy workload is also problematic, as is the lack of mechanisms for interaction between the different directorates.

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"I don't think there is a systematic policy in this direction. It relies to some extent on participation in projects. I don't know of any initiatives being supported such as skills audits, planning etc."

"Sofia Municipality has policies and mechanisms for the development and qualification of staff in the field of climate change and policies, but they are not formalized in a separate training program. Instead, initiatives are integrated into strategic documents and projects aimed at increasing expert capacity and effective implementation of climate action."

"I am not aware of one, but I am under the impression that municipal capacity in this regard is very low. There is a lack of capacity to attract quality experts to the municipality and as a result the results of climate action are not good. Outsourcing is often done with laconic assignments that in no way guarantee the quality of the final product."

Economic factors

Public financial resources

The capital city is the district with the highest share of own revenues in total revenues, as well as the highest coverage of municipal expenditures with local revenues. Foreign direct investment inflows are also considerably higher than the Bulgarian average, reaching EUR 11.2 thousand per capita (vs. EUR 4.1 thousand per capita nationally). The implementation of the municipal budget for 2023 amounts to BGN 956.9 million (101%) (SO, Budget 2024). The 2024 Budget of the Municipality foresees funds of BGN 2,577,149,857 as follows:

- Budget appropriations BGN 2,464,715,657
- 112,434,200 BGN from European programmes

Sofia has access to significant financial resources for adaptation and climate change activities. But there are also competing priorities - climate change is often put on the back burner for projects that bring greater short-term benefits. As of 30 June 2023, the capital is again the first city with the highest absorption rate of EU funds. The value of funds disbursed under operational programmes is BGN 4 264 per capita (compared to BGN 2 836 nationally).

There is a high dependence on EU funding, especially for large investment projects. The National Recovery and Sustainability Plan is currently leading the way. Sofia does not have specific strategies and measures for public-private partnerships to address urban heat, financial incentives, regulations, etc. for green roofs and facades to attract private investment.

According to experts, the municipality does not have sufficient resources to control the requirements in the Spatial Planning Act.

"There are countless programmes (European and others) for funding both specific projects and for skills and capacity building, but there is a lack of organisational and managerial capacity to participate and effectively benefit from the relevant instruments and funds. At the same time, the municipality does not seem to perceive the need to allocate its own budget to such capacity building or to optimise investments in different areas so that they have an impact in terms of addressing climate change."

"There is a lack of staff and a lack of a dedicated budget for climate issues. Research data is missing. Even adopted policies are not followed. The municipality does not know how to communicate with citizens and engage businesses. PPP in this area is critical to transition to clean manufacturing and a clean energy sector."

"Sofia Municipality has significant potential, supported by strategic documents and international projects, but additional efforts are needed to strengthen expert capacity, increase the internal budget and improve inter-agency coordination. These steps would help to address climate challenges more effectively."

"The bulk of the climate budget is spent on measures and activities indirectly, rather than directly, related to improving quality of life and tackling the negative effects of climate change."

Income per household

In 2022 in the capital, the annual total income per person per household is BGN 11,237 and increases by 17.7% compared to 2021, according to the latest NSI data. The minimum wage in 2024 is BGN 933 and from January 2025 - BGN 1,077.

It is clear from the NSI data that the differences in household wealth across income groups is significant, over 8 times. The difference is due to many factors such as education, employment, etc., but perhaps the most important factor is the number of household members. The richest 10% live in households with an average of 1.95 persons and the poorest 10% live in households with 3.5 persons, i.e. poor households are more numerous.

The NSI defines the poverty line for Sofia in 2023 according to Eurostat methodology in relation to the total disposable net income of 990 BGN per person. 22.2% of the population fall below this line - 18.7% men and 25.4% women.

The risks associated with urban heat are greatest for poor households and people living in low-standard housing.

Access to financial resources

The Social Assistance Agency provides monthly financial assistance for heating for the months of November through March for socially disadvantaged citizens. There is no similar facility for cooling and ventilation during the summer months.

There are opportunities for households to reduce energy consumption for heating and cooling through changes in domestic sector buildings, especially renovation and energy saving measures for existing housing stock, introduction of renewable energy in households supported by EU funds through operational programmes. Sofia Municipality also has a programme, supported by EU project funding, to replace appliances in households. Households heated by wood and coal can replace them without paying for air conditioning, gas heating/cooling or pellets. By the end of 2023, 13,038 eco-friendly appliances have been installed.

Technological factors and scientific knowledge

Availability of technological, social, institutional, environmental and other innovations

The European Commission's Regional Innovation Scoreboard 2023 identifies the South-West region, of which Sofia Municipality is a part, as an emerging innovator +, ranking 195th among European regions, with the region's performance improving by over 8 points.

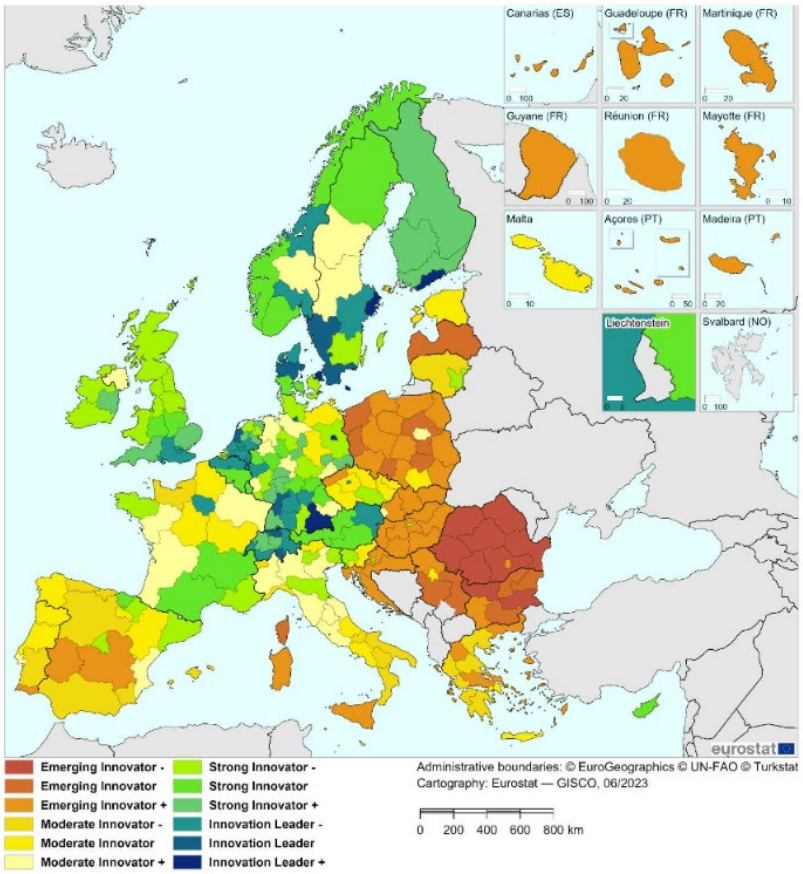


Figure 53: EC Regional Innovation Scoreboard Index 2023. Source: ***OP Europa***[44]

This positive result is mainly due to the capital city, as Sofia is not an independent region. R&D expenditures in the capital are the highest in Bulgaria - BGN 618 per person.

Ability to use innovation

Sofia has introduced and managed several innovations such as artificial intelligence for the analysis and management of urban transport and traffic through traffic lights, for municipal payments, for street lighting, for monitoring and tracking the state of the green system, etc. Almost all municipal services have been digitised.

[44] https://op.europa.eu/en/publication-detail/-/publication/c849333f-25db-11ee-a2d3-01aa75ed71a1/language-en

This policy is led by a dedicated Digitalisation, Innovation and Economic Development Unit, headed by a Deputy Mayor.

In 2025, Sofia Municipality is investing in a smart system to monitor and manage garbage collection. It will provide route data, task completion times and recognition when an unidentified container is attempted to be picked up.

Since 2020, the Sandbox for Innovative Solutions has been operating in Sofia Municipality; BGN 500,000 have been allocated for this activity in the budget for 2024. The Sandbox is a controlled environment where companies can safely experiment and test new products, services or business models in real conditions before their full implementation and scaling. The aim is to improve the quality of public services and life in Sofia, and to turn the capital into a test bed for technology solutions developed by local companies.

Other Sofia activities that both promote innovation and enhance the administration's ability to work with innovative solutions include the Sofia Social Innovation Funding Program, fostering innovation through competitions and hackathons, etc.

Availability of information on adaptation to climate change

The issue of climate-related data collection and provision has been the subject of most criticism and concern. While most respondents believe that Sofia Municipality collects data for climate tracking, analysis, forecasting and modelling, the process is not systematic, ubiquitous and methodical.

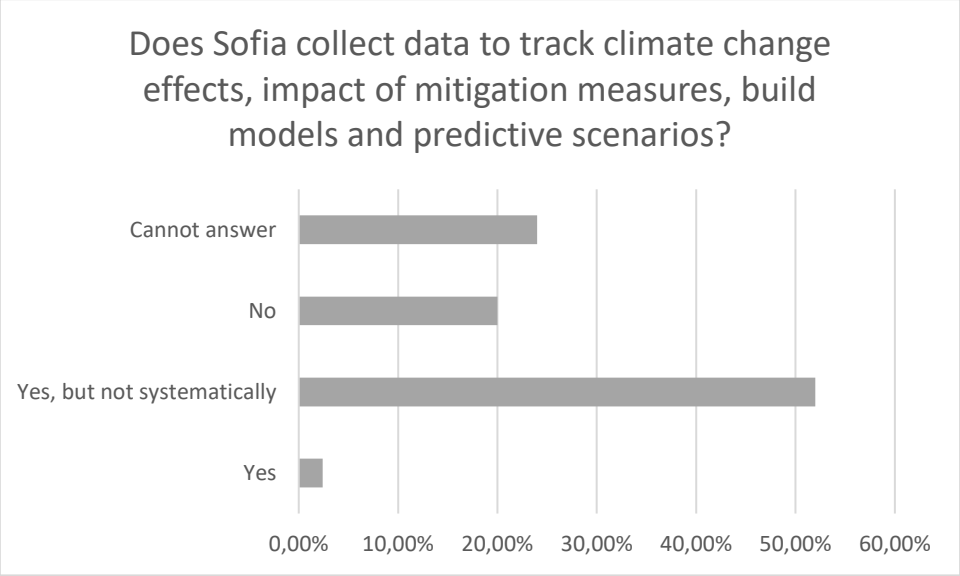


Figure 54: Climate change data collection in Sofia Municipality. Source: SDA's own survey

"Currently, Sofia Municipality does not explicitly collect climate or heat island data. All developments on the topic are thanks to remote methods and open data, but they are not generated by the Metropolitan Municipality."

"Sofia Municipality collects data that is needed to monitor the effects of climate change and to assess the effectiveness of adaptation and mitigation measures. This data is collected and analysed through a variety of mechanisms, including dedicated monitoring programmes, climate inventories and modelling. I believe that resource information is not available to all experts for a variety of reasons, and unfortunately the experts involved are too few relative to the needs of the Climate and Energy Division."

"The data available to monitor the effects of climate change and the implementation of coping and adaptation measures are insufficient in quantity and quality. To collect such data, two basic conditions are needed: technical (equipment - standardised measuring instruments) and technological (methodology according to which the collected data should be systematised, processed and stored). There is much to be done on both. Accordingly, there can be no quality modelling and forecasting."

"To unsystematic I would add insufficient. 1. The official network of ambient air quality monitoring stations is woefully inadequate to create a dataset that can serve as a basis for even basic digital simulations; 2. GIS-Sofia performs periodic sweeps of the municipal territory, but the product is limited (orthophoto images), the sweep period is not standardized, and the sweep timing is often not consistent with best practices; 3. In my observation, Sofia Municipality does not make the most of even the generally available data and products of the Copernicus programme, which are insufficient for detailed and qualitative monitoring, but are better than the data currently used; 4. It lacks a rudimentary digital counterpart of the Metropolitan Municipality in the form of a point cloud... Something that is available even for the smallest European municipalities and cities."

"Data on the city, annual temperature, materials used in construction, energy consumption, etc., are available but scattered across different units - municipal and national."

5. Conclusions

The UHI Risk and Vulnerability Assessment Report shows a clear picture of vulnerability in more densely populated urban areas, with less green space, massive development, underserved by public transport.

Although Sofia has already implemented several initiatives for field research, modelling and mapping of the UHI, a holistic approach, map and action plan have not yet been developed. Urban heat prevention, although mentioned in several municipal strategies, is not yet a priority in local policies and practices. Except for the municipal Urban Environment Ordinance, a standard for sidewalks in pedestrian spaces, there are no ordinances aimed at preventing UHIs.

There is a great need for data. Although a variety of data sources were used for this report, the process revealed that data related to UHI was not being collected and analyzed consistently. The available data is primarily at the city level and not geolocated, making it difficult to assess risk for neighborhoods and specific locations. An automated data collection process is recommended. Where possible, a consistent and free source of information should be used. Citizen science should also be encouraged. More effort is needed in the areas of building municipal adaptive capacity, defining and addressing vulnerable groups of UHI, communication and early warning systems and channels. Sofia is mitigating UHI mainly with green measures and to some extent with blue measures. Pilots using blue infrastructure measures are needed to demonstrate their effectiveness in real settings and to raise awareness of this approach.

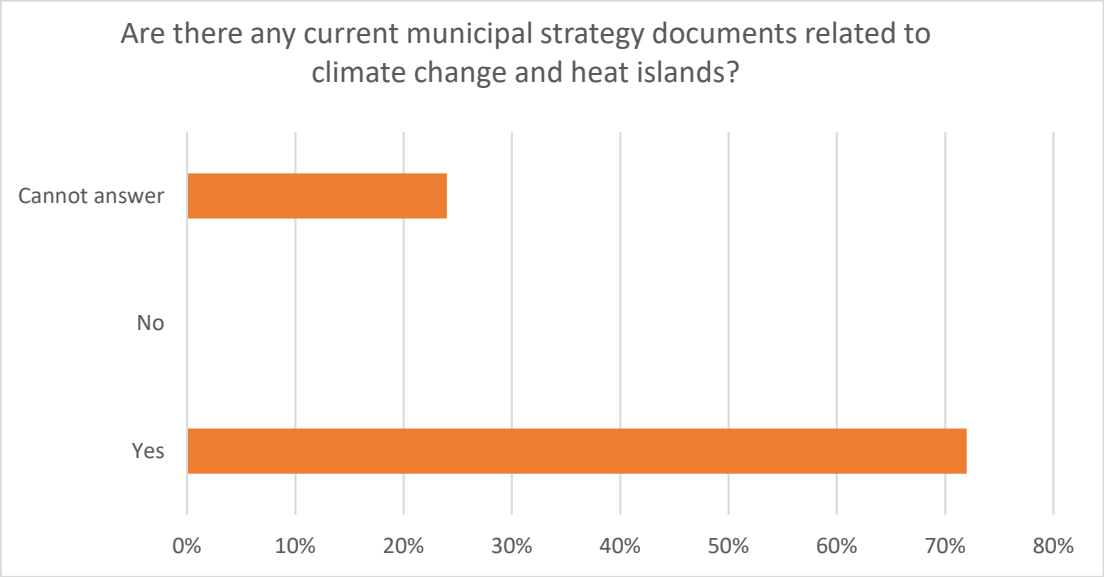
Be Ready activities in 2025 and 2026 will aim to address some of these findings.

Annex 1

SUMMARY OF A SURVEY ASSESSING THE ADAPTATION CAPACITY OF SOFIA MUNICIPALITY TO CLIMATE CHANGE

The research was conducted via an online survey form in the period October-November 2024. The received responses were 50. The summary results are presented below.

1. Are there any current municipal strategy documents related to climate change and heat islands?



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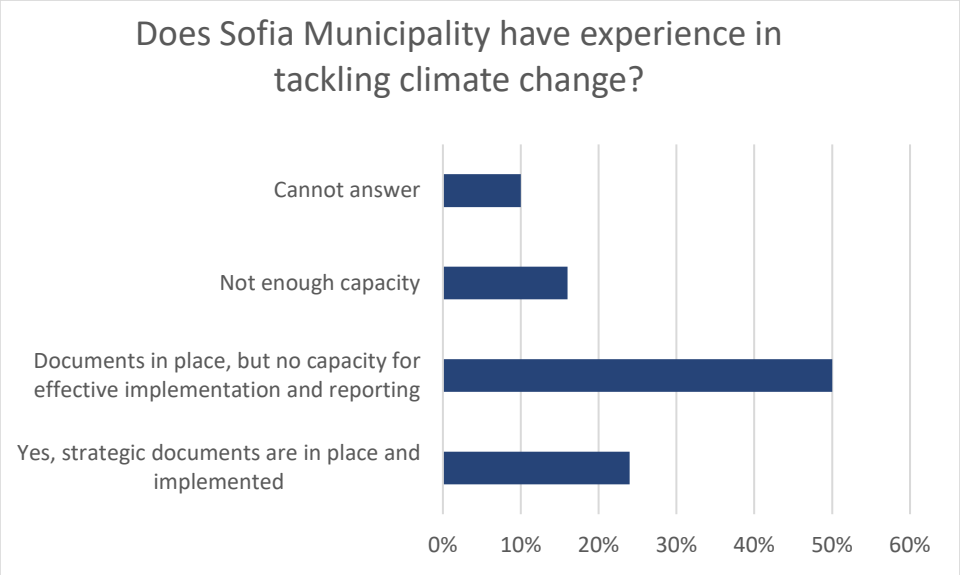
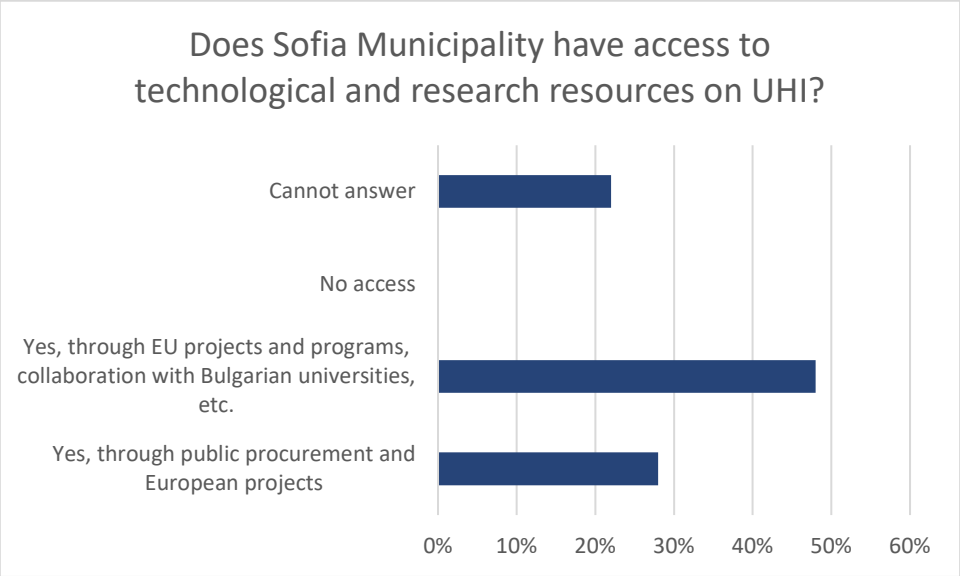
2. Does Sofia Municipality have experience in the field of climate change and addressing it?



3. Does Sofia Municipality have access to technological and scientific resources and knowledge on the subject?



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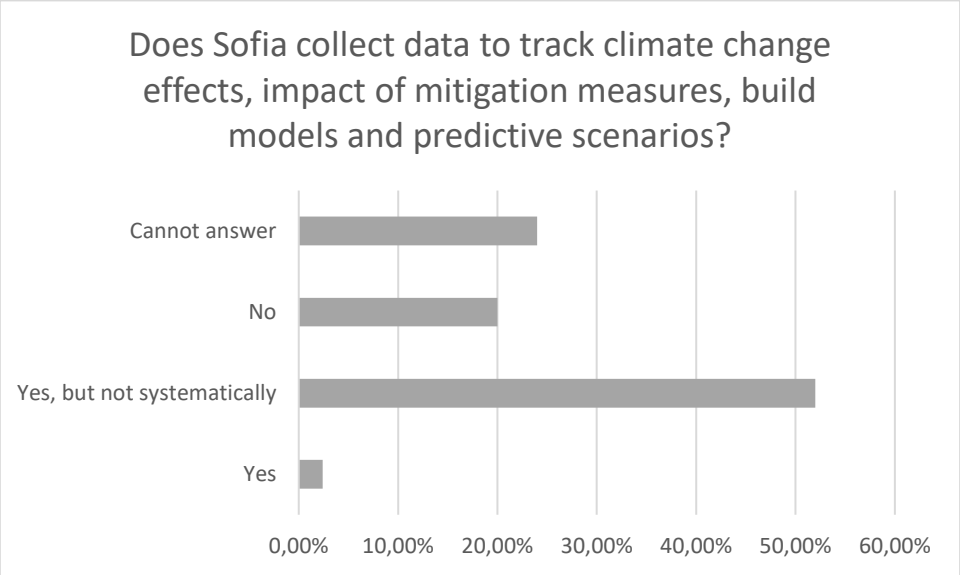
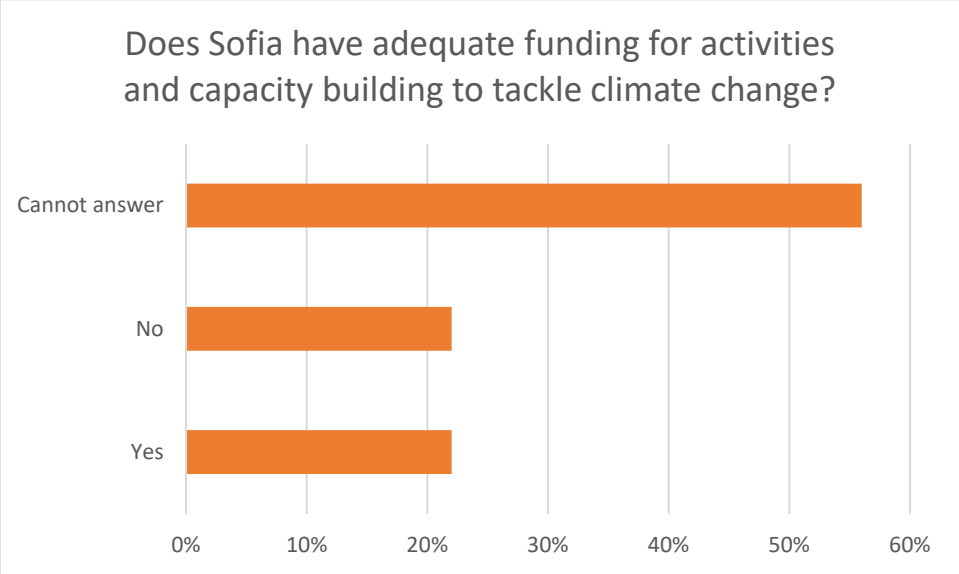
4. Is Sofia Municipality collecting the necessary data to monitor the effects of climate change, the effects of coping and adaptation measures, modelling and forecasting?



5. Does Sofia Municipality have/allocate adequate funding for activities and capacity building to address climate change?



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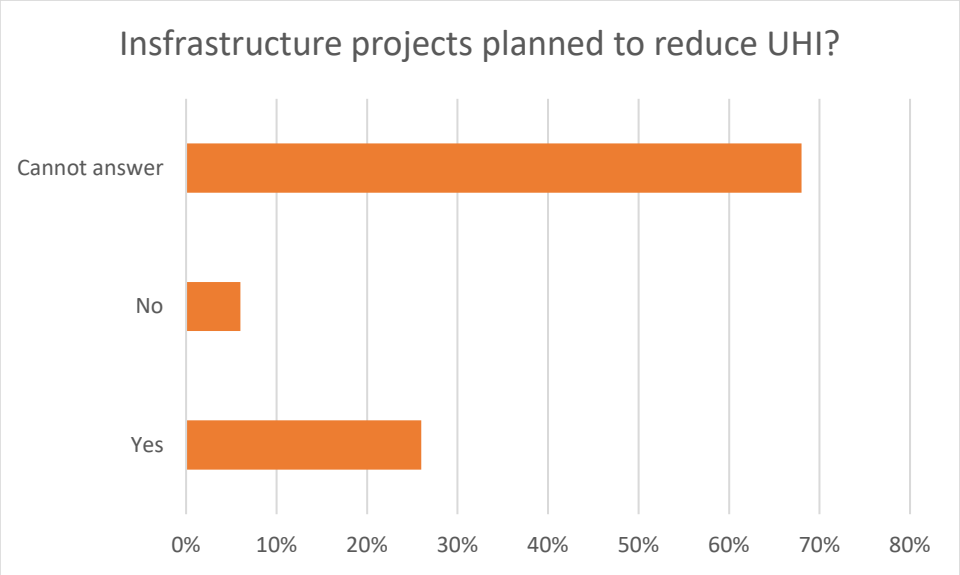
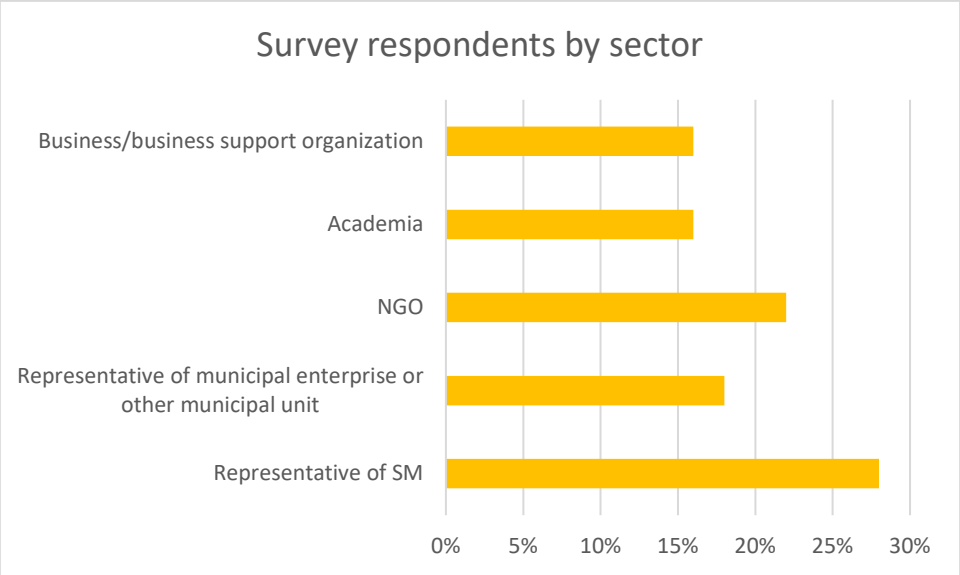
6. Are there any infrastructure projects planned related to reducing heat island effects?



7. You are (type of respondent)



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Annex 2

Report of the Focus Group on Preparedness and Adaptive Capacity of Sofia Municipality (SM) for Coping with Climate Change

1. Report of the Focus Group on Preparedness and Adaptive Capacity of Sofia Municipality (SM) for Coping with Climate Change

Date: 18 November 2024

Location: SofiaLab

Participants (from the quadruple helix):

- Representatives of Sofia Municipality - 2
- Representative of SDA - 1
- Representative of BISI - 1
- Representatives of other NGOs - 2
- Representatives of universities - 2
- Business representatives - 2.

Moderator: Teodora Gandova

The focus group was based on a scenario prepared in advance by the moderator. Participants shared knowledge and views on the following topics.

2. Sofia Municipality strategic documents on climate change mentioned by respondents (in descending order by number of references):

- Sofia Municipality's Sustainable Energy and Climate Action Plan 2021-2030, including an Energy Efficiency Programme and a Long-Term Programme to Promote the Use of Renewable Energy and Biofuels
- Climate Change Adaptation Strategy for Sofia Municipality;
- A climate change adaptation plan for the Lyulin region based on digital twin and nature-based solutions;

- Local Climate Adaptation Plan for the residential area of the city "Lyulin" through a digital double
- Climate Change Adaptation Plan for Sofia Municipality 2019 - 2025;
- Sofia Green City Action Plan (under the EBRD Green Cities Framework Programme);
- Climate Neutrality Treaty for the City of Sofia (to the European Union's Mission "100 Climate Neutral and Smart Cities of the Future by 2030").

It should be borne in mind that not all participants are aware of the existence of these documents - business and university representatives are the least aware. Even in the cases where they are aware of the strategies, participants have no idea whether the implementation is accounted for and what follows.

3. Sofia Municipality's experience in climate change

As with the previous question, the capacity of Sofia Municipality is rated highest in developing strategies and plans. The explanation for this is that strategies and plans are usually required for projects, city applications and others, and the most technical assistance is provided for their preparation - an example is the Green City initiative of the European Bank for Reconstruction and Development. The climate change adaptation plan for the Lyulin district is cited as a rare example of a document based on site-specific data rather than general principles.

The implementation and public reporting of strategic documents and action plans is assessed as a weaker area. According to the participants, it is primarily activities that are reported, not results. There is no consistent and/or easy to find information on progress on indicators, no open data, no campaigns to raise awareness of effects and results. Recent renovation activities, where trees are being cut down, lead to the perception that Sofia Municipality is contradicting its own strategies by its actions. Forecasting and acting on climate emergencies, notification systems are also judged to be inadequate.

Sofia Municipality has access to scientific resources mostly through the Sofia-based universities, but also through European projects. The mapping of heat islands, for example, is done by the Geology and Geography Faculty of Sofia University, the GATE Institute works with a digital double of Sofia Municipality. Problematically, these partnerships are predominantly project-based or directly commissioned by the municipality and therefore one-off/unsustainable.

Sofia Municipality does not have and/or does not allocate sufficient financial resources to address climate change, or at least this is not evident in the municipal budget.

According to the participants, the municipality also lacks an appropriate staffing and organizational structure to adequately proactively address climate change, train and enhance staff capacity, etc.

Sofia Municipality has some completed infrastructure projects related to reducing the effects of heat islands - the amphitheatre in West Park, a steam-cooled fountain in the city garden. There is no information on planned sites, nor how areas are identified for interventions. This leaves the impression of working piecemeal and on vague grounds.

4. An ecosystem of stakeholders working together with the municipality on climate change

The topic of climate change and sustainable development is popular and attracts a huge number of stakeholders. Sofia Municipality has a good partnership with several of them - as an example, the Climate Treaty this year was signed by the Bulgarian Council for Sustainable Development, the Chamber of Builders in Bulgaria, SOF Connect AD - operator of Sofia Airport, Veolia/Sofiyska Voda AD, the Association of Owners of Business Buildings and Cleantech Bulgaria.

NGOs are often very critical of Sofia Municipality, including some that have filed lawsuits against it. This makes it impossible to bring everyone together - although the goals are common, the ideas of how to achieve them differ substantially. Climate change and measures to tackle it are a dividing line in Sofia society. It is also an external barrier that is not specific to Sofia.

5. Vulnerable groups

Participants were not aware whether the municipality has defined vulnerable groups in terms of urban heat. They are also not aware of any specific policy or awareness or prevention measures targeting them. An external barrier is the collection of data related to the impact of heat on health because of the ethical issues involved. To the extent that data is available, it has not been geolocated within the municipality.

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